Data Collation Report

Teesdale Flood Risk Identification Study

Golden Plains Shire

16 May 2023

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Project Details

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Cover Image: Native Hut Creek at Stones Road/Tolson Road

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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.

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

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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

2.2 Flood Information

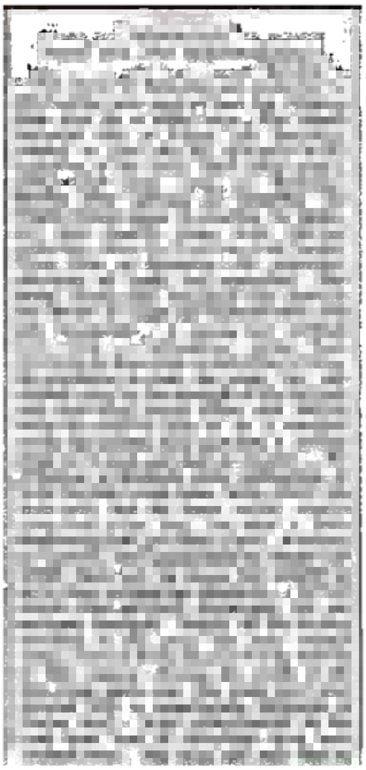
2.2.1 Historical Flood Records

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).



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.

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

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.

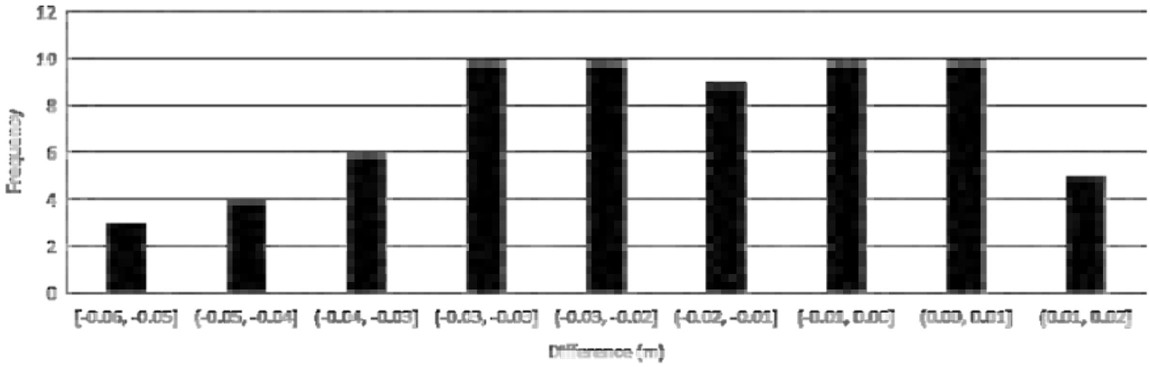

Figure 2-7 Distribution of survey and LiDAR comparison

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

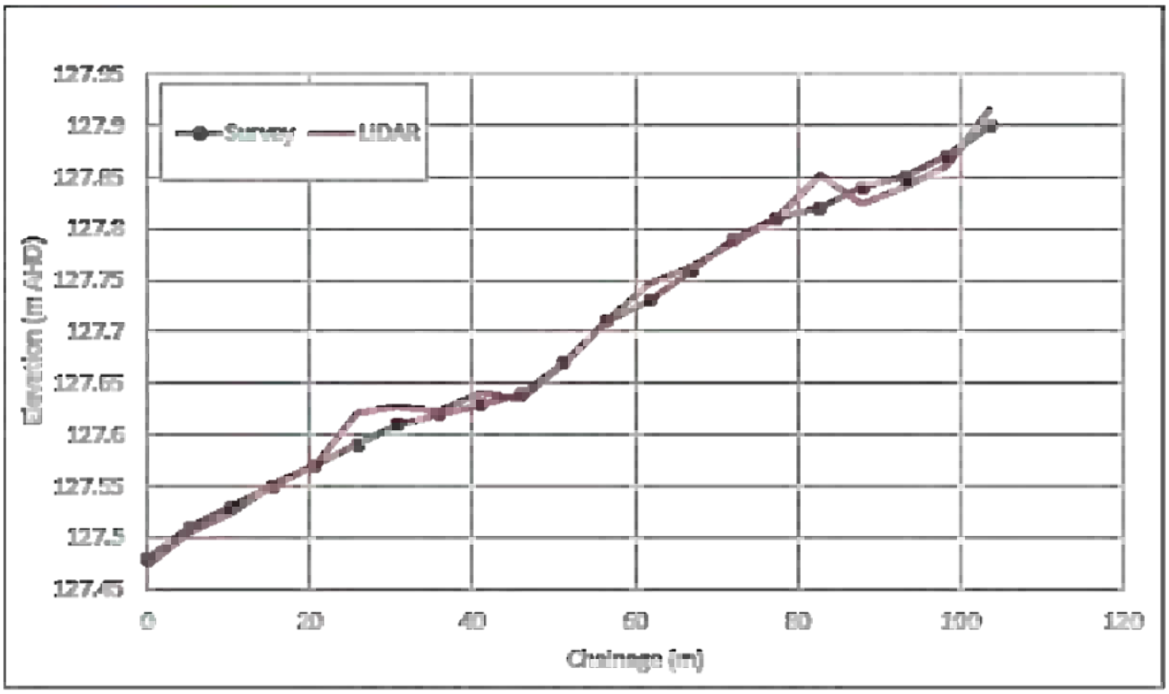

Figure 2-8 Rocklea Road – LiDAR verification

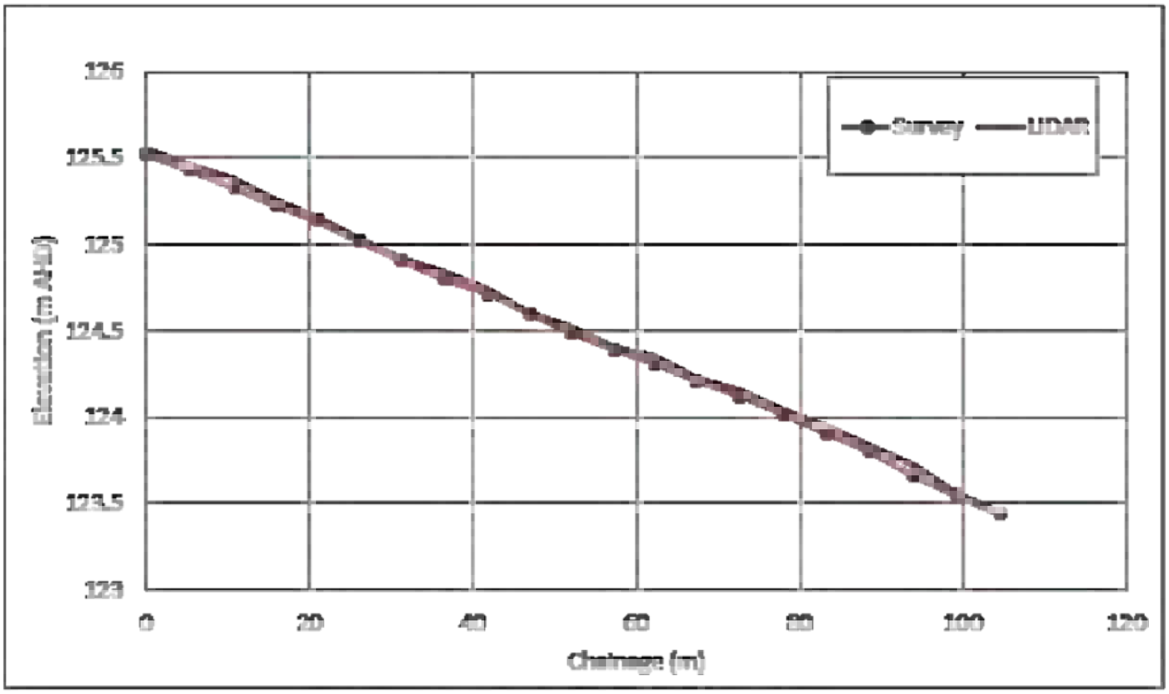

Figure 2-9 Jollys Road – LiDAR verification

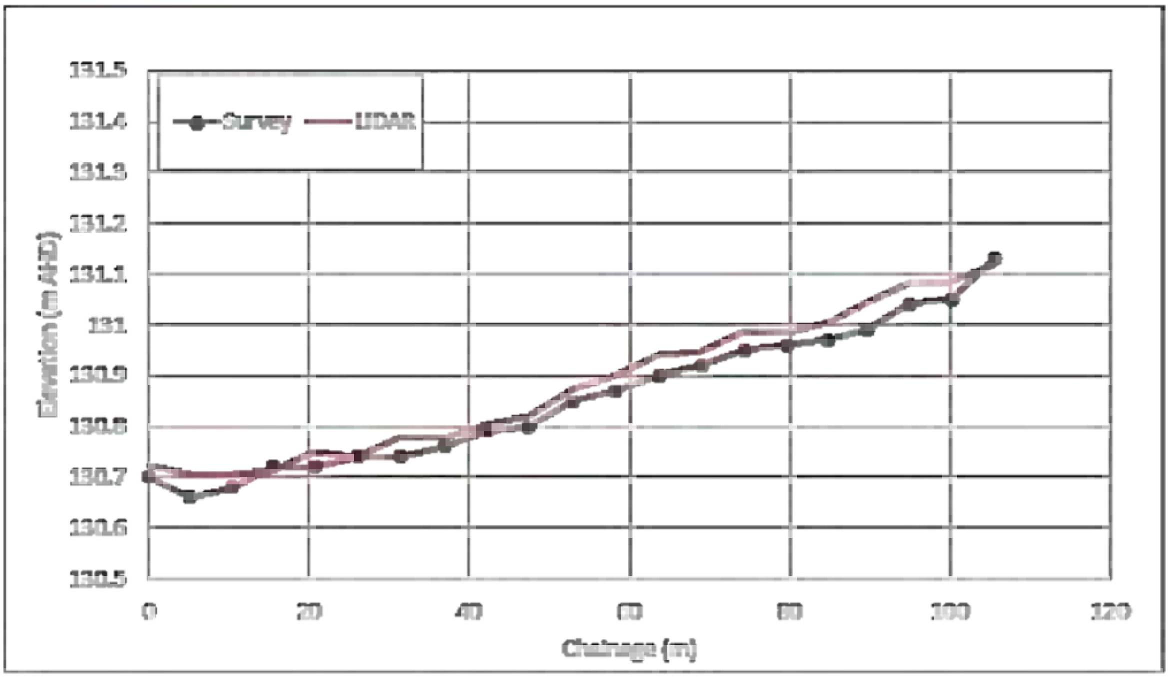

Figure 2-10 Sutherlands Road – LiDAR verification

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.

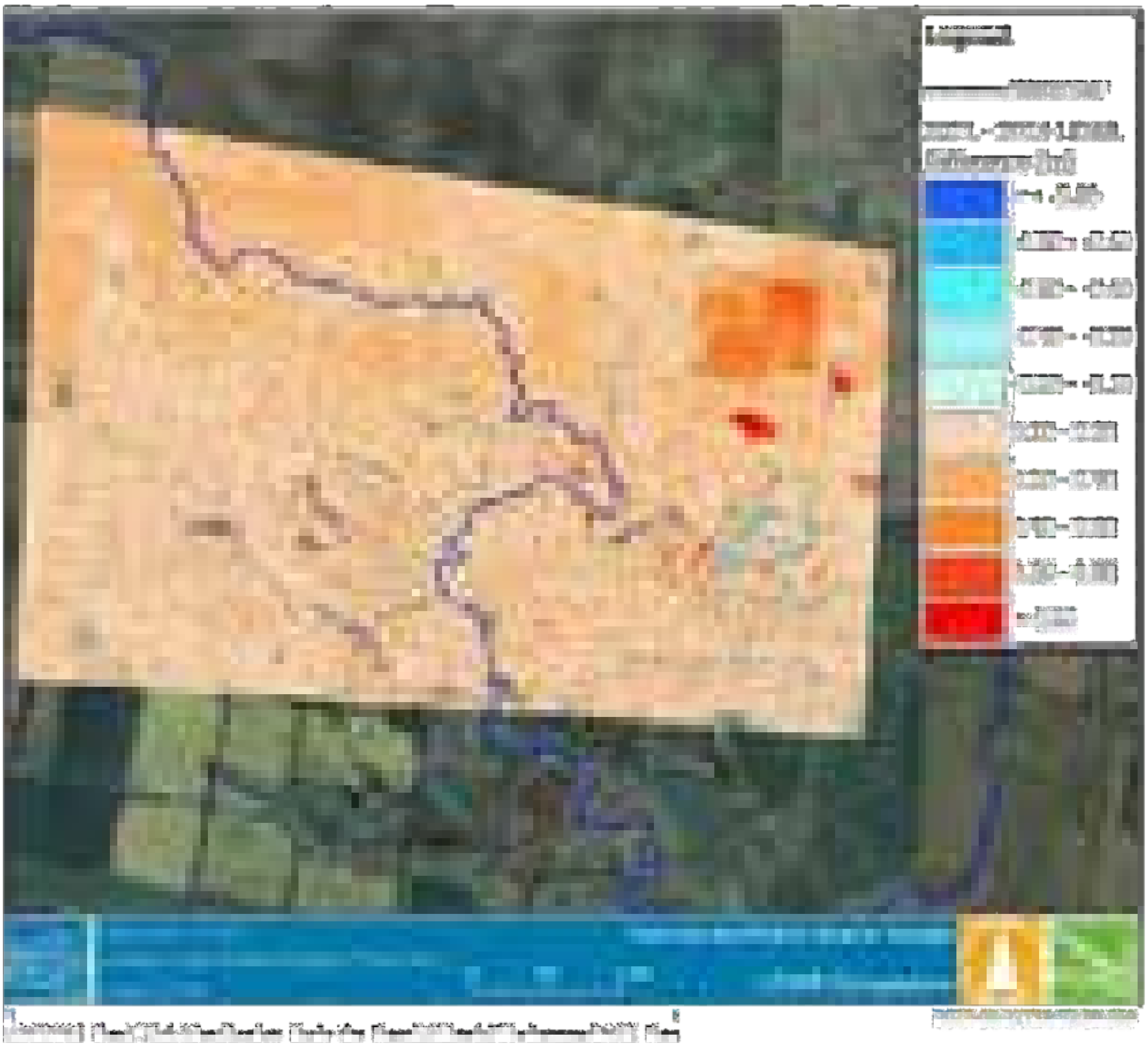

Figure 2-11 Comparison Between 2021 and 2014 LIDAR Datasets (± 0.1m not shown)

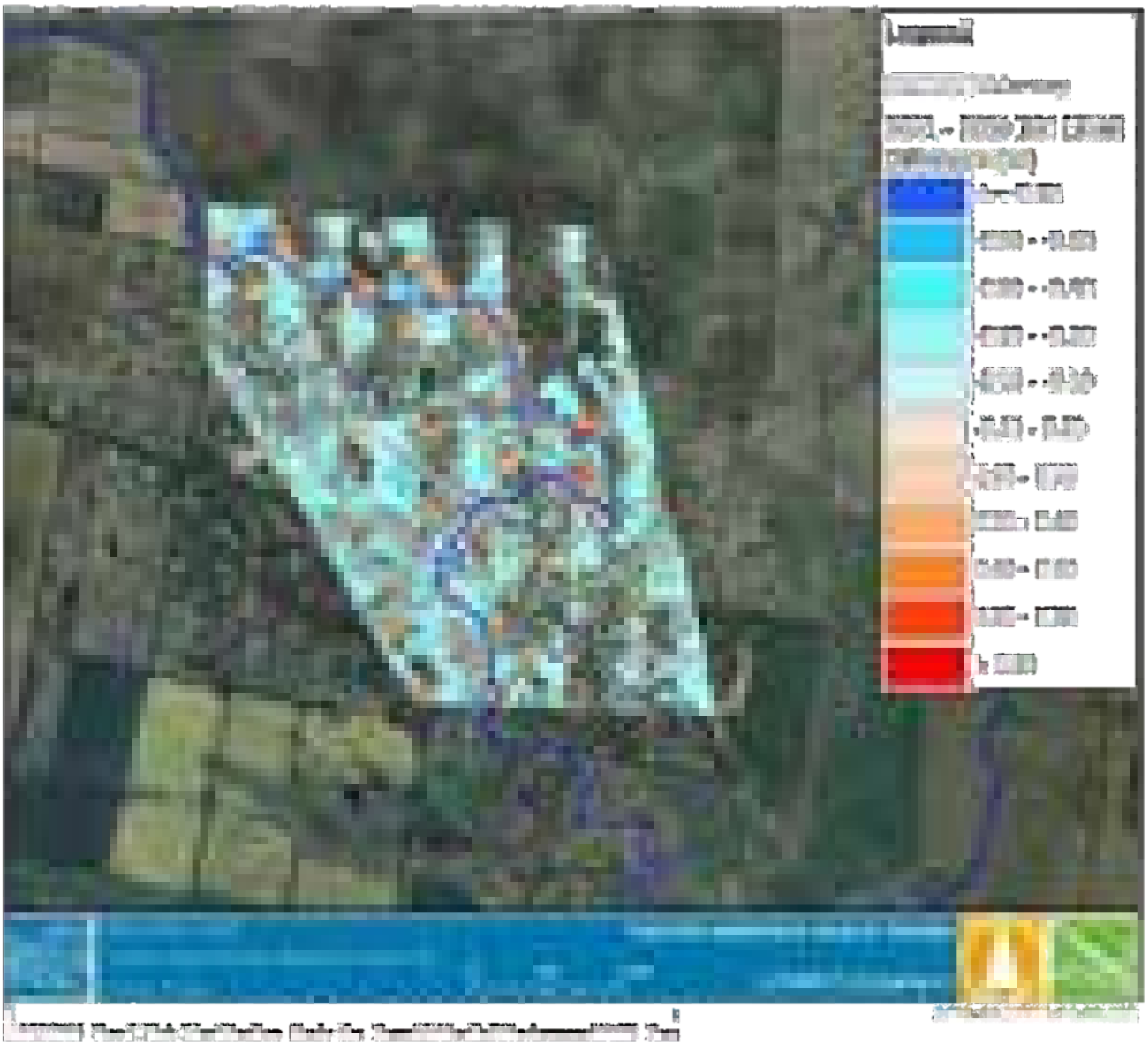

Figure 2-12 Comparison Between 2021 and 2010 LIDAR Datasets

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.

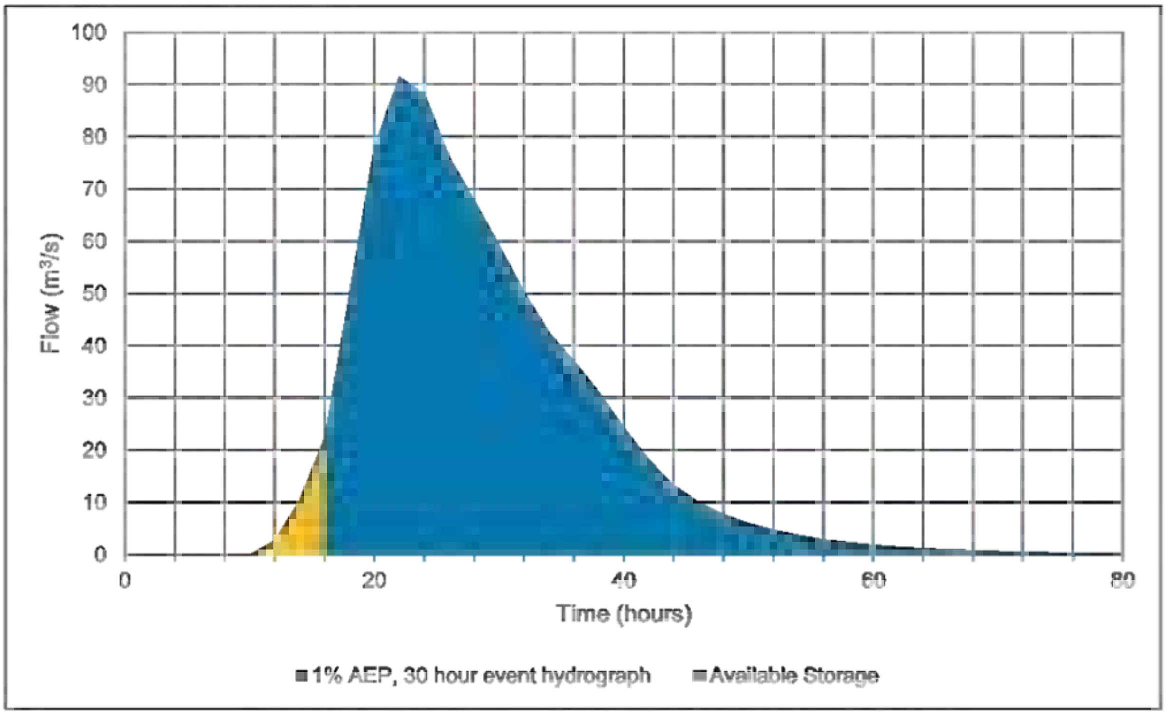

Figure 4-1: Example storage vs hydrograph volume comparison

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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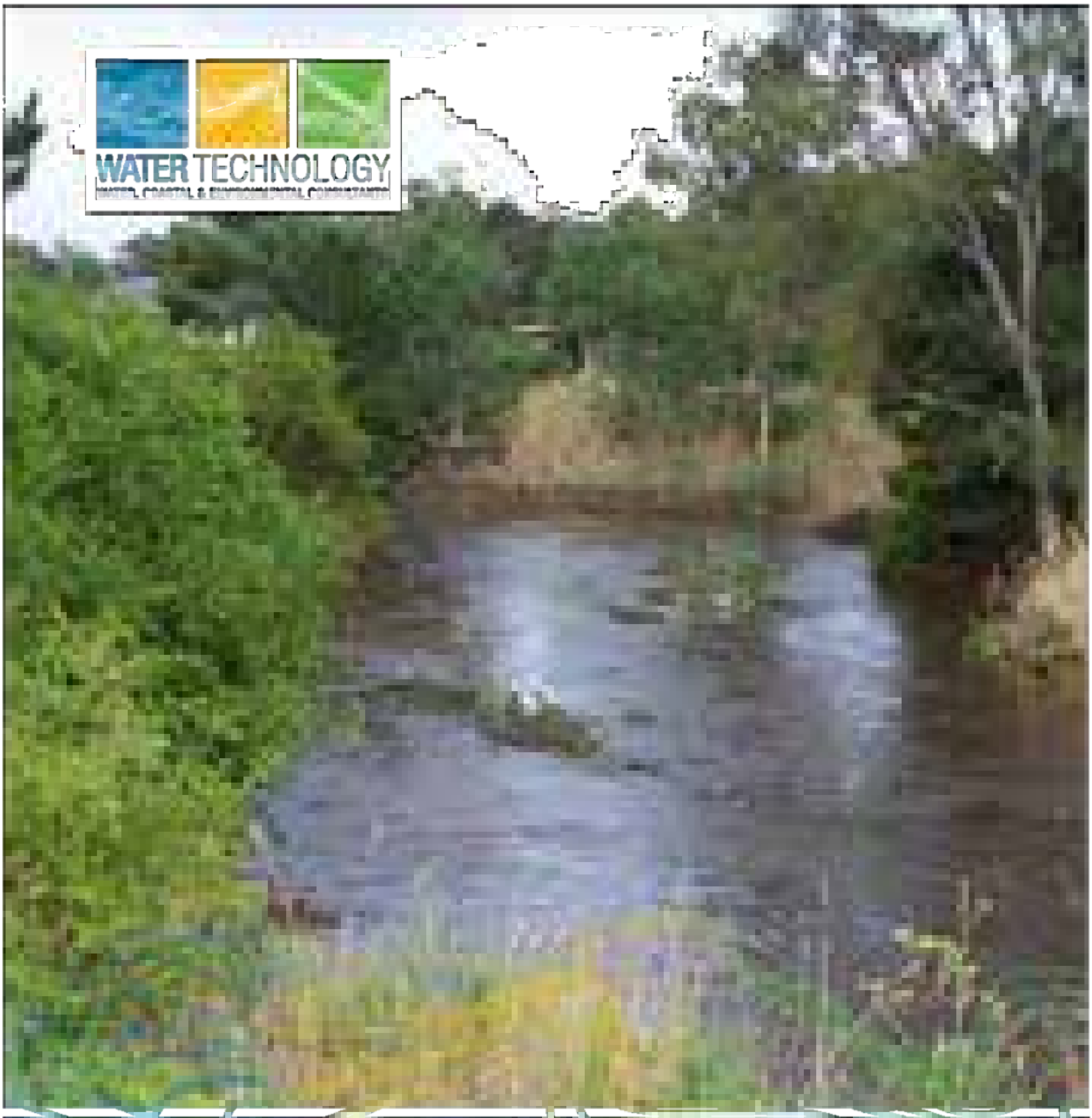

Joint Validation Modelling Report

Teesdale Flood Risk Identification Study

Golden Plains Shire

12 April 2023

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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.

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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 modeling, 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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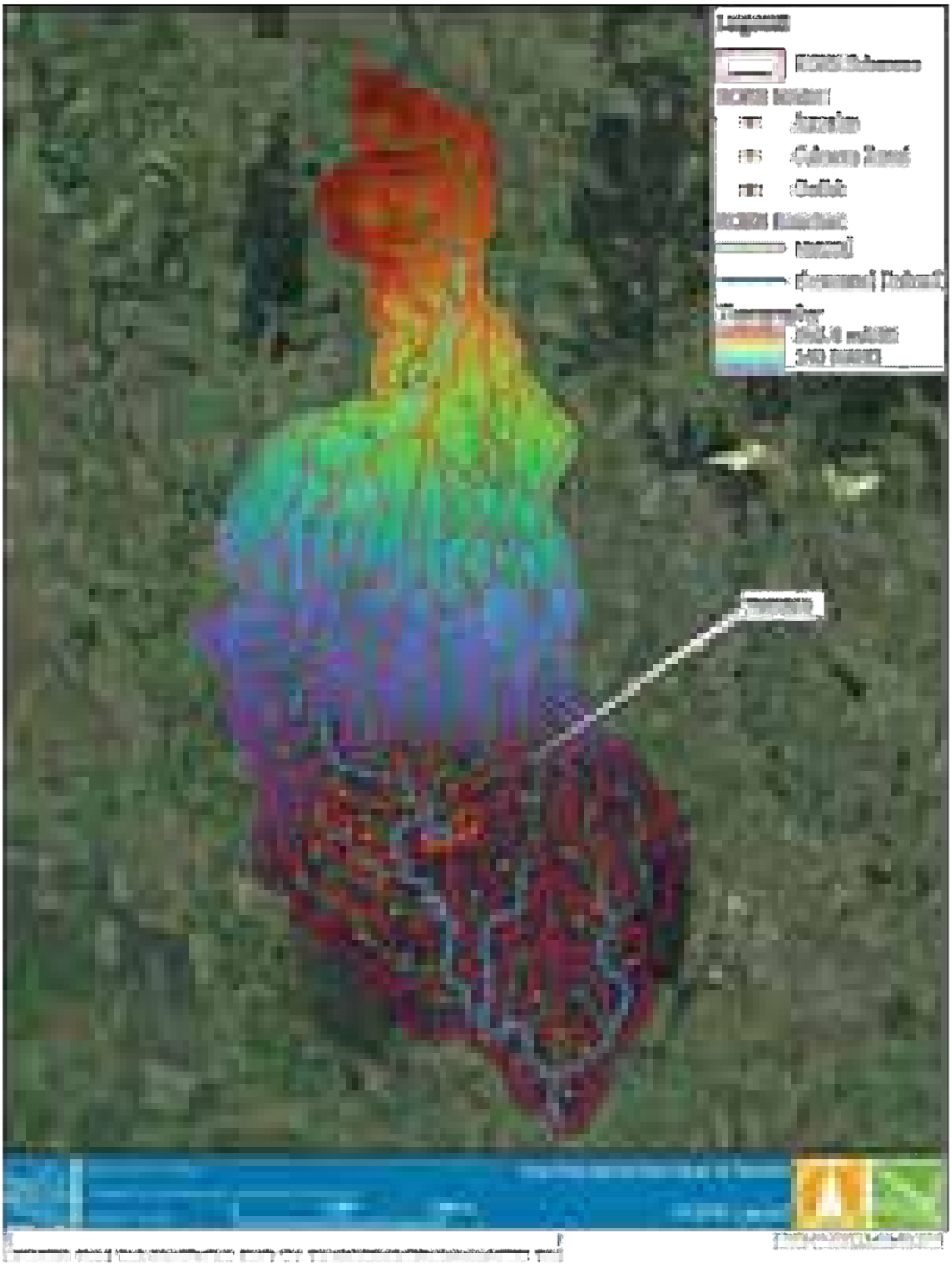

Figure 3-1 RORB model layout

Figure 3-2 RORB Interstation Areas

3.1.2.2 Fraction Impervious

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

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

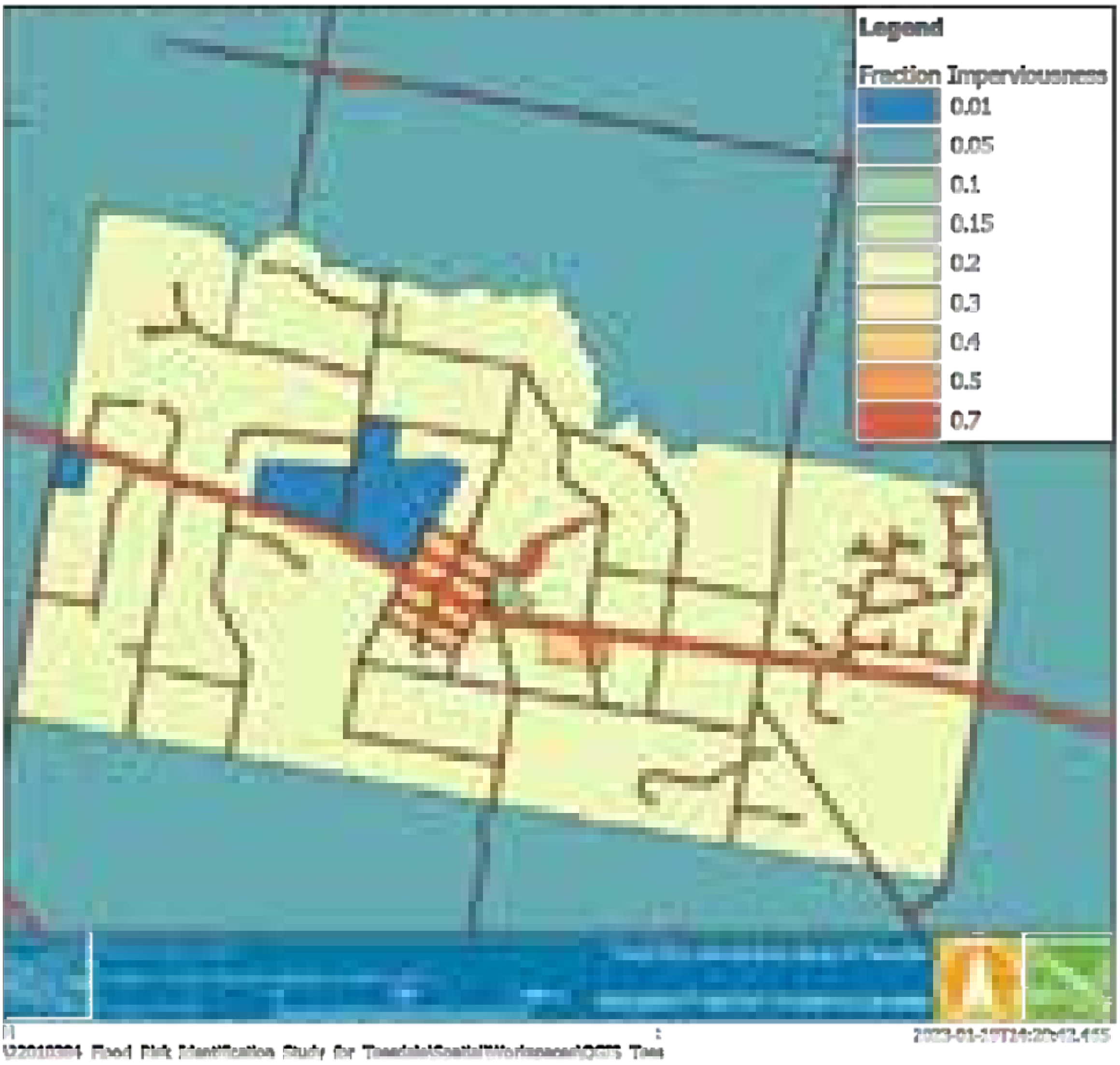

Figure 3-3 Adopted Fraction Imperviousness – Township

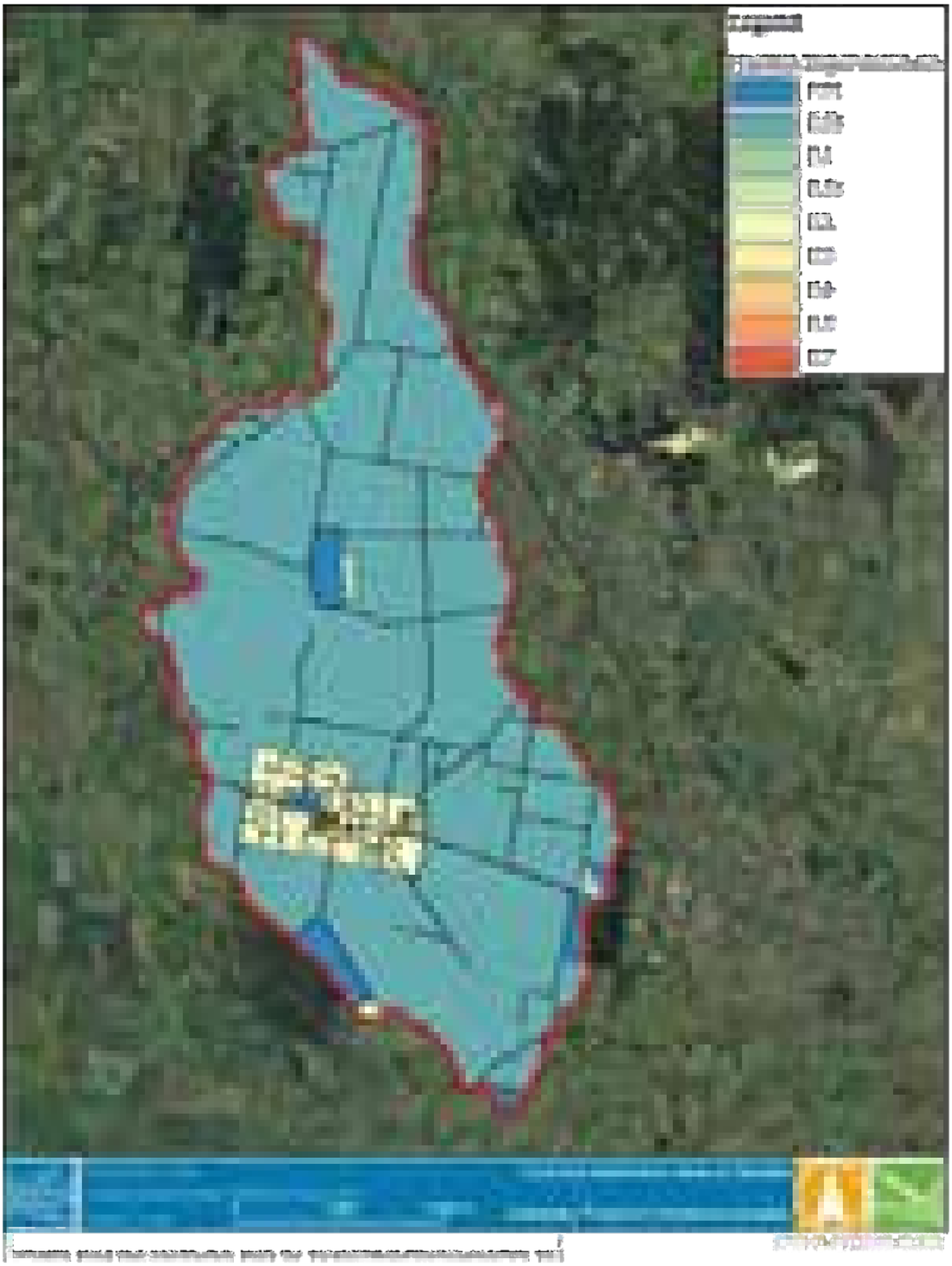

Figure 3-4 Adopted Fraction Imperviousness – RORB Extent

3.1.3 Rainfall

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

Figure 3-5 Utilised Daily Rainfall Stations

Table 3-1 Daily Rainfall Stations

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

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

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

Design Rainfall

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

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

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

The ARF was calculated with an area of 110.14 km², 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 km².

3.1.4 Spatial Variation of Design Rainfall

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

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

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

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

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

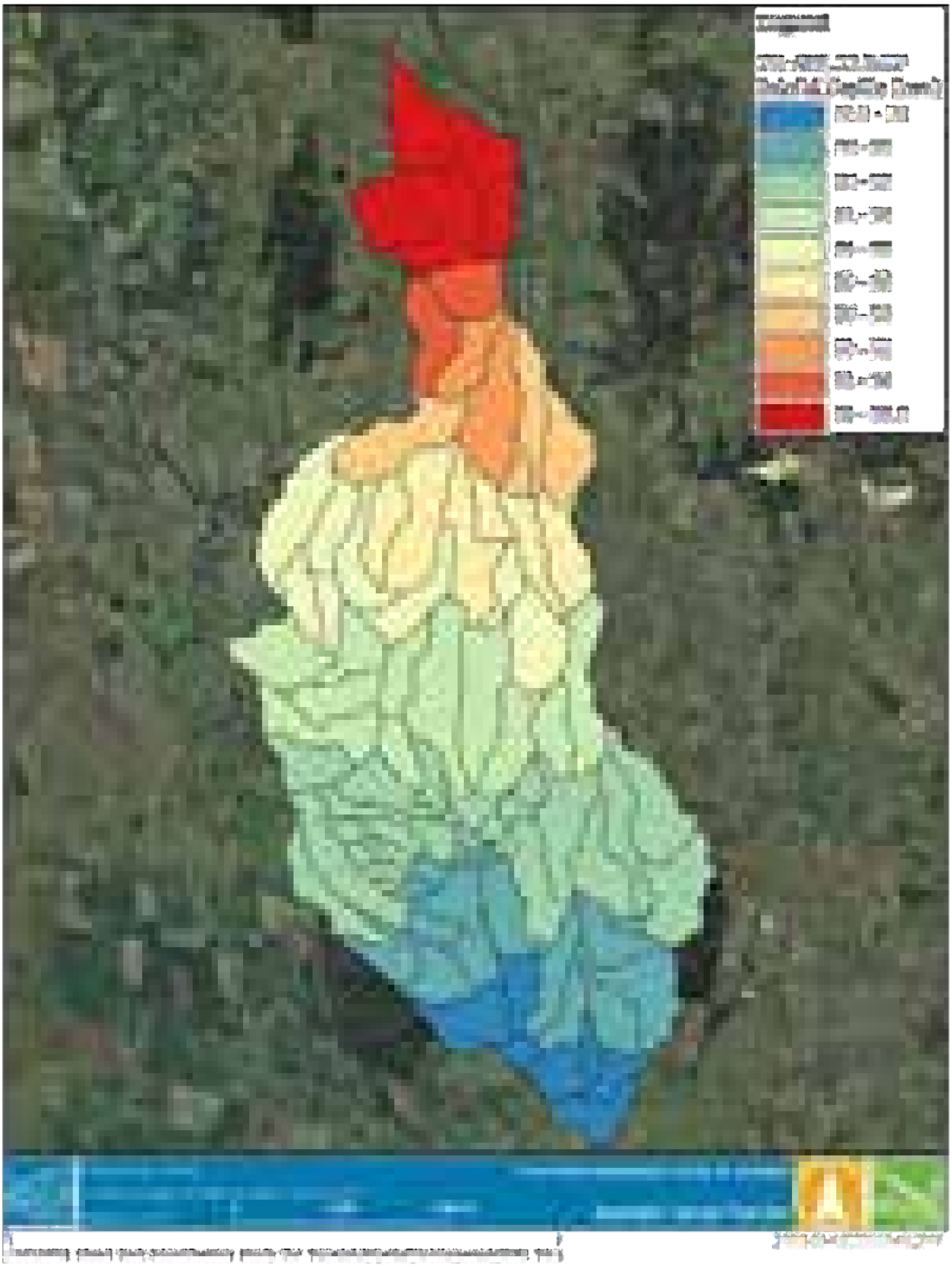

Figure 3-6 Example of Spatially Varied Rainfall, 1% AEP 12 Hour Event

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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:

$$IL_b = IL_s - \text{pre-burst depth}$$

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.

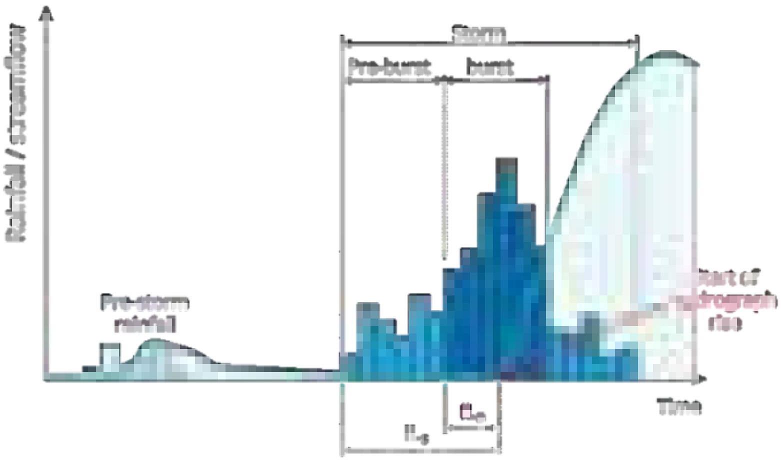

Figure 3-7 Conceptualisation of storm vs burst rainfall and its interaction with Initial Loss[3]

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

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3.1.5 Losses

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

Table 3-4 Adopted and comparative losses

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

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

3.1.6 RORB Parameters

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

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

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

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

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

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

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

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

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

Table 3-6 Adopted K_c values at each interstation area

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

4 HYDRAULICS

4.1 TUFLOW

4.1.1 Overview

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

Table 4-1 Key TUFLOW Parameters

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

4.1.2 Model Boundaries and Extent

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

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

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Figure 4-1 TUFLOW Extent and Model Boundaries

4.1.3 Model Topography

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

Alterations to the LiDAR DEM were made as follows:

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

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

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

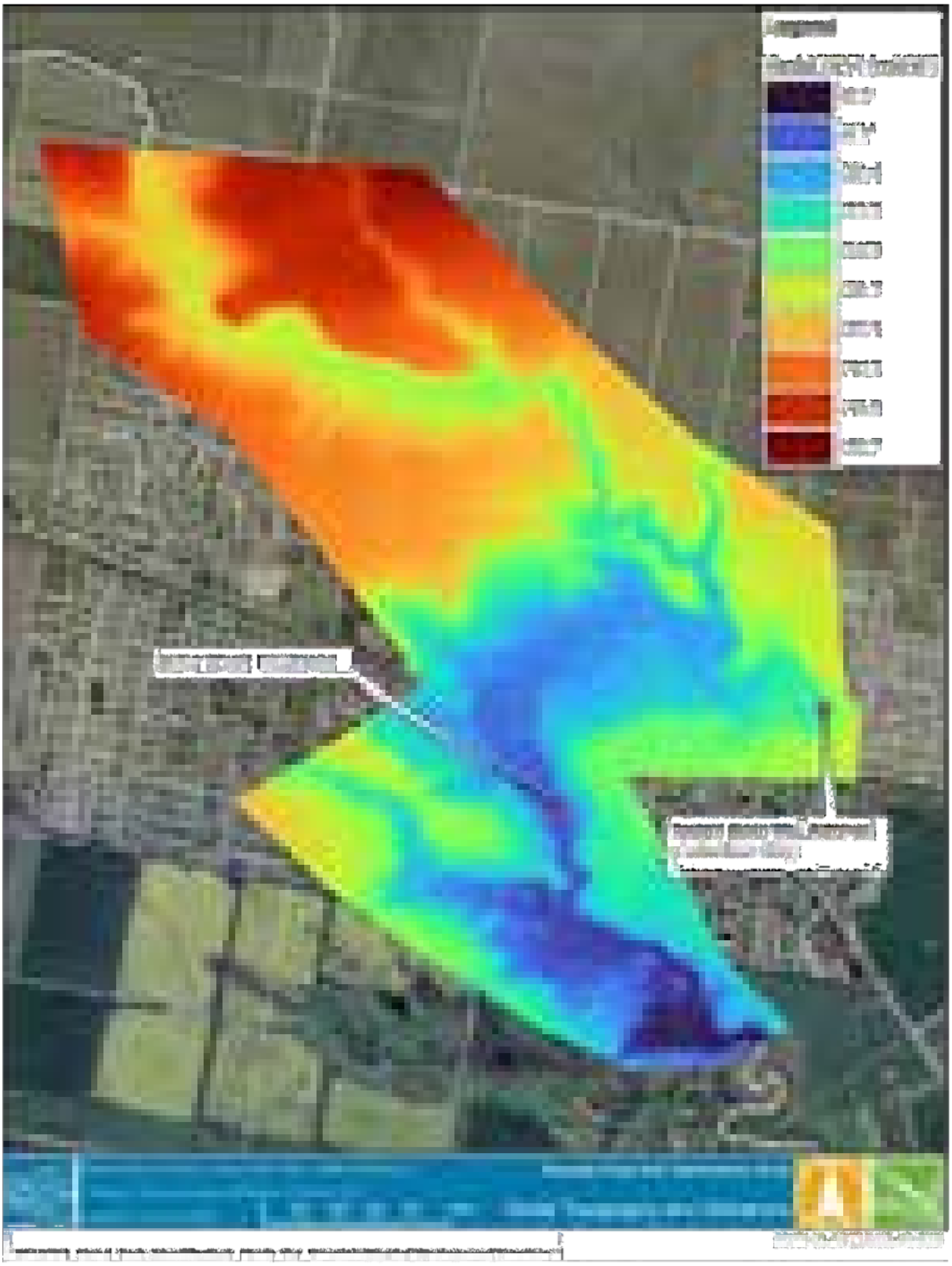

Figure 4-2 Model Topography

4.1.4 Hydraulic Roughness

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

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

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

Table 4-2 Hydraulic Roughness

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

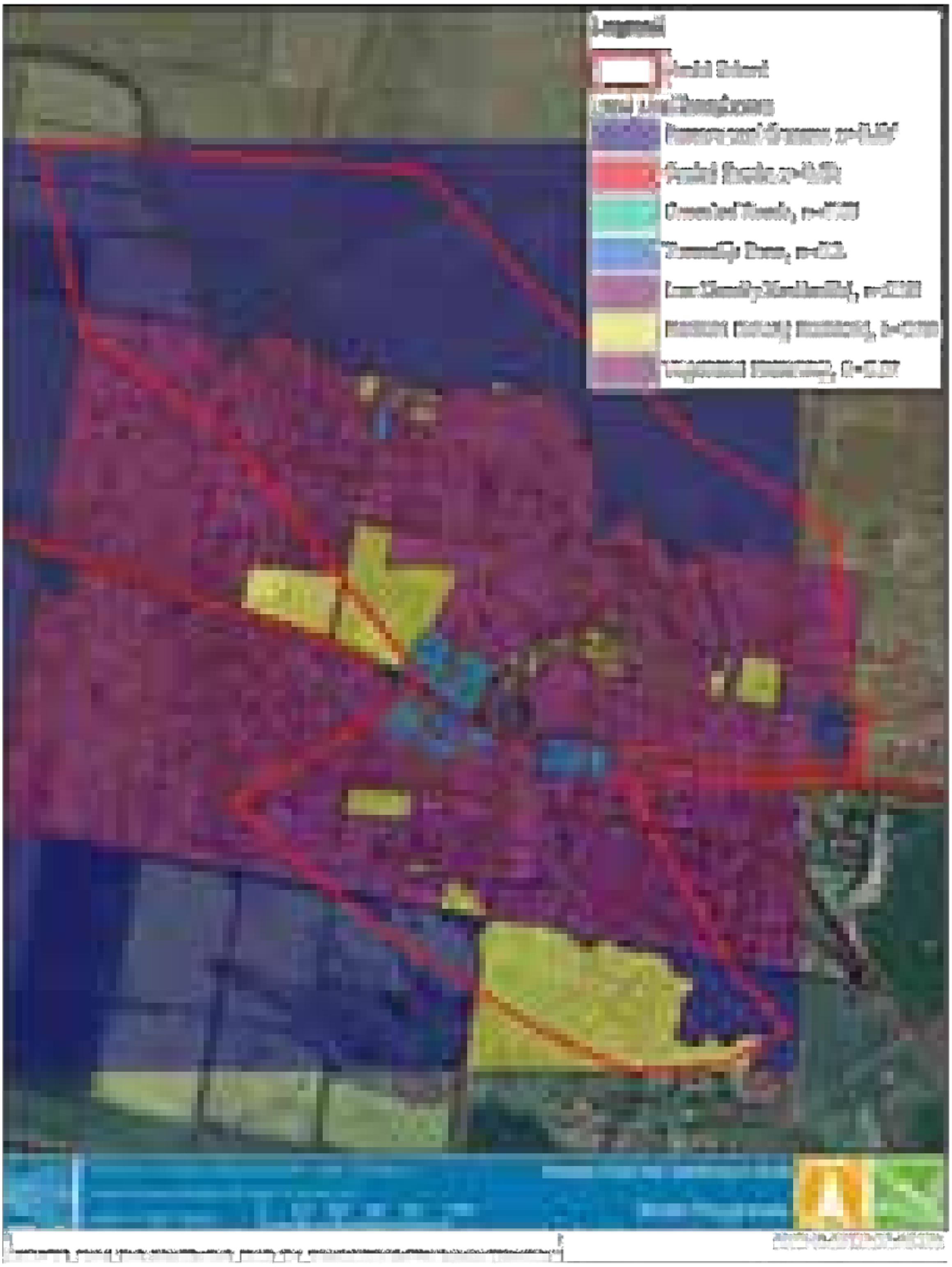

Figure 4-3 Hydraulic model roughness

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.

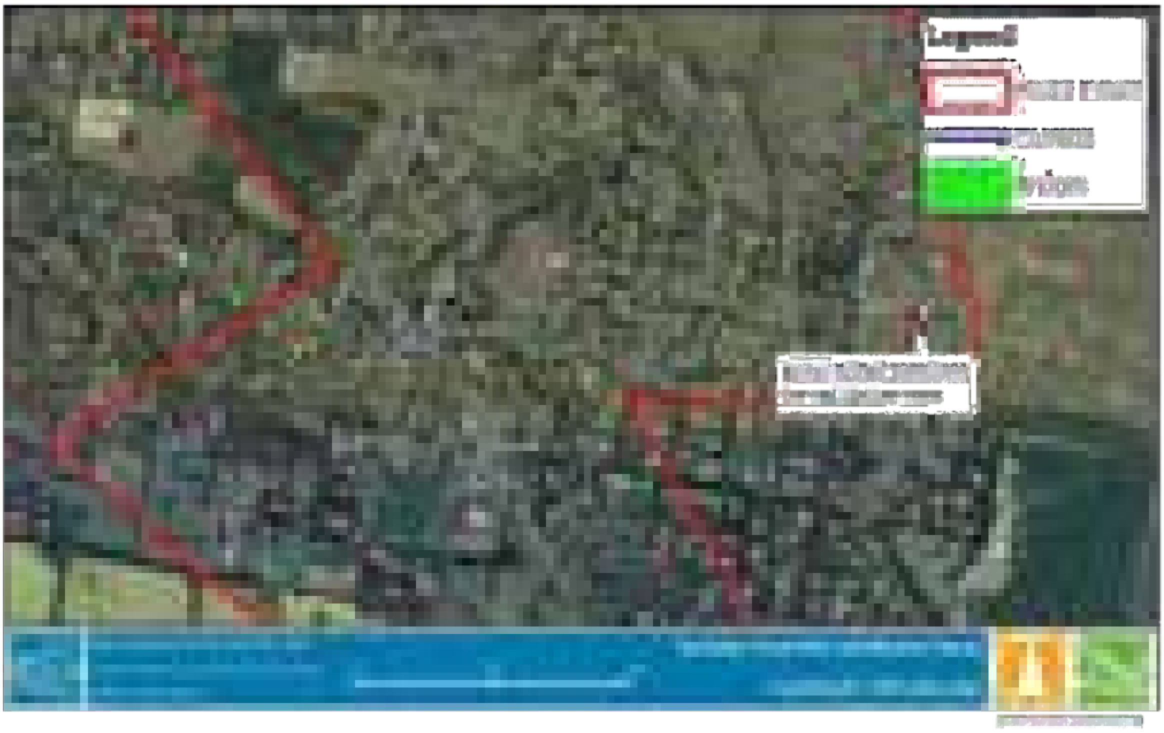

Figure 4-4 Hydraulic structures

[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.

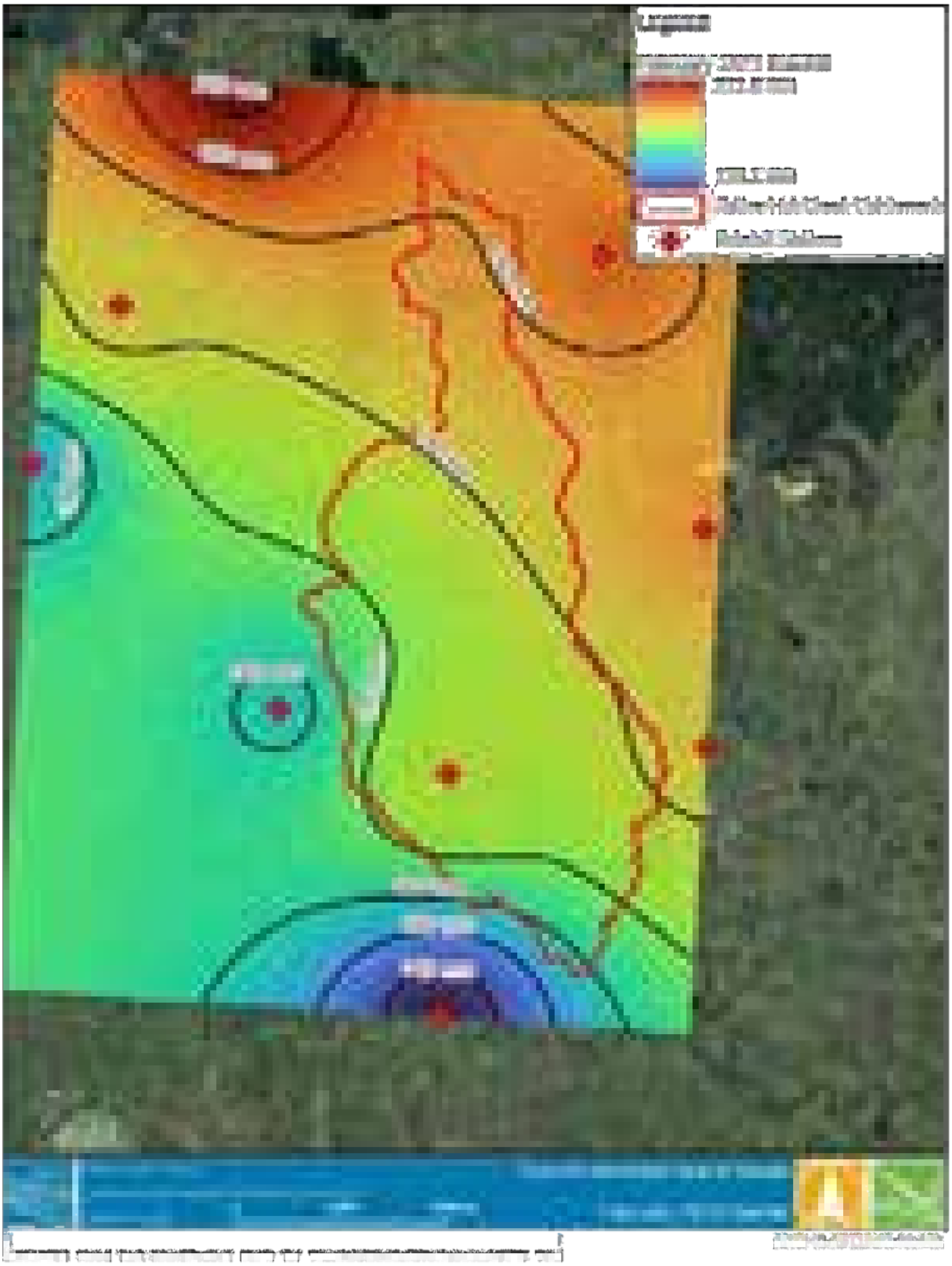

Figure 5-1 Rainfall Distribution and Isopleths for February 1973

5.1.1.2 Streamflow

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

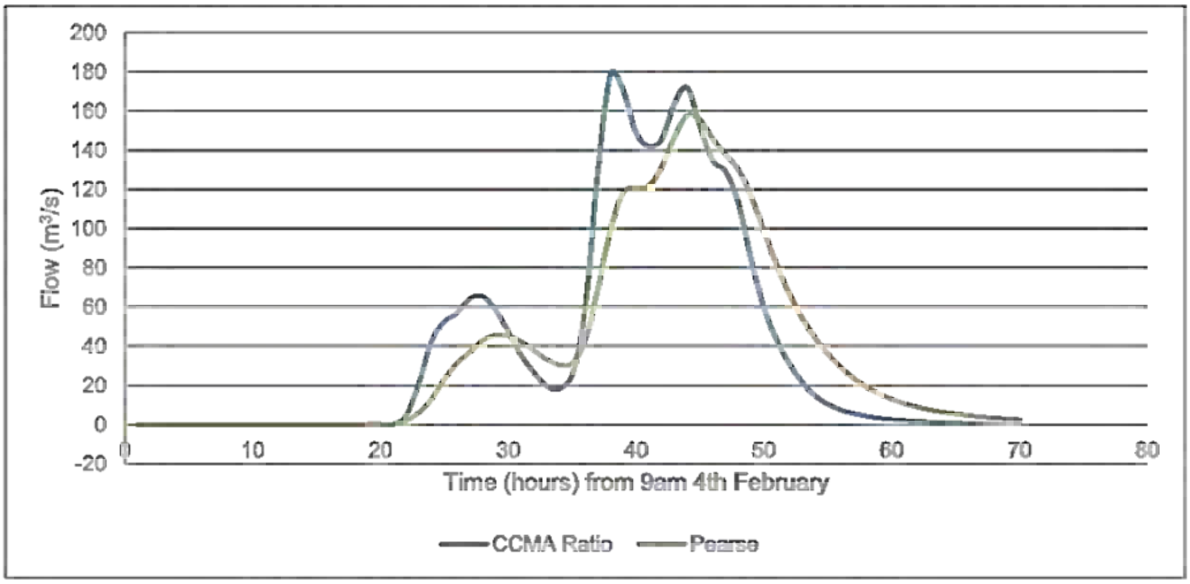

Figure 5-2 February 1973 modelled streamflow at Teesdale Bridge

5.1.1.3 Flood Behaviour

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

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

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

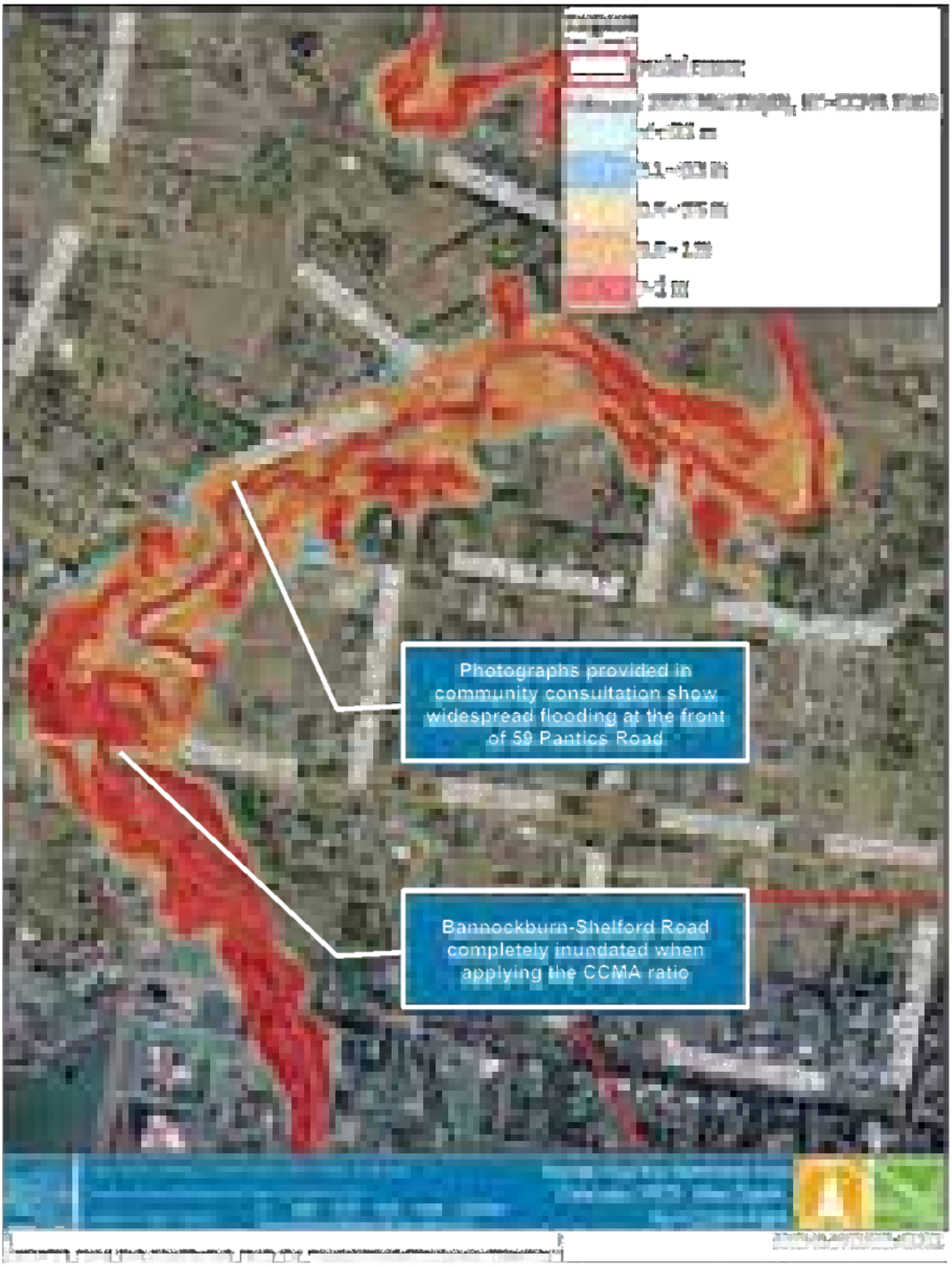

Figure 5-3 February 1973 Flood Depths, K_c=CCMA Ratio (Township)

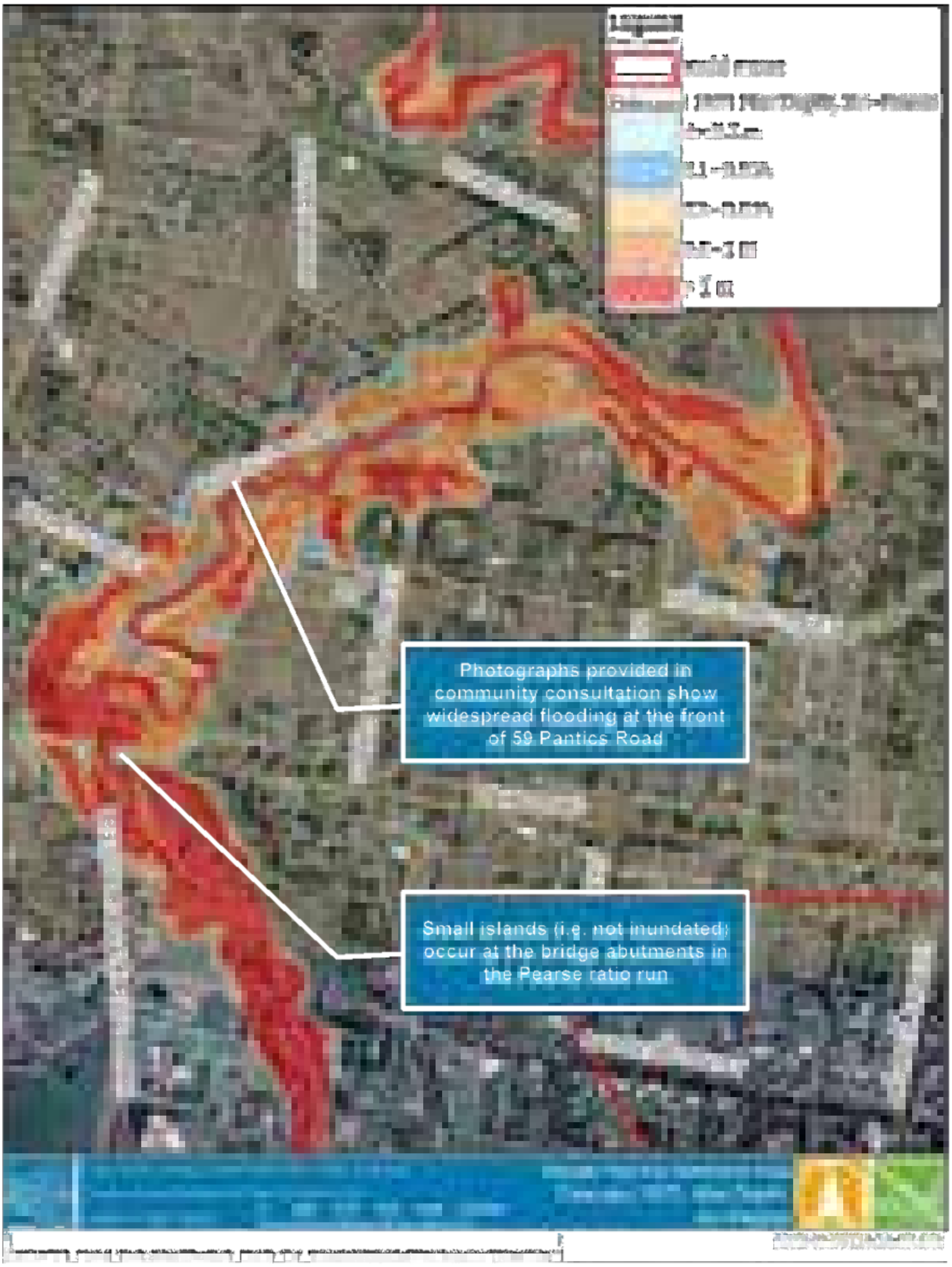

Figure 5-4 February 1973 Flood Depths, K_c=Pearse (Township)

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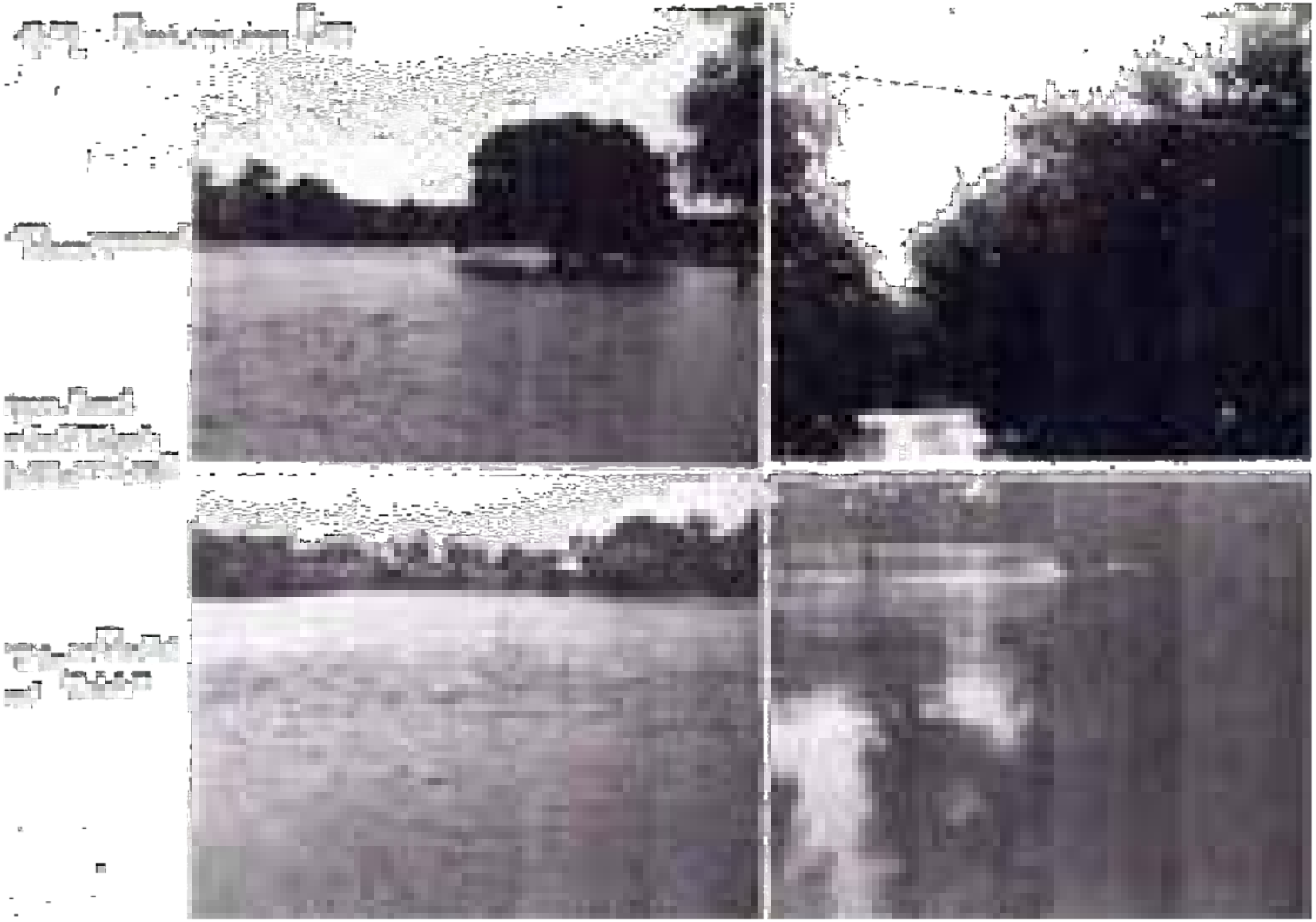

Figure 5-5 Photographs of 1973 flood event provided by the resident of 59 Pantics Road

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**

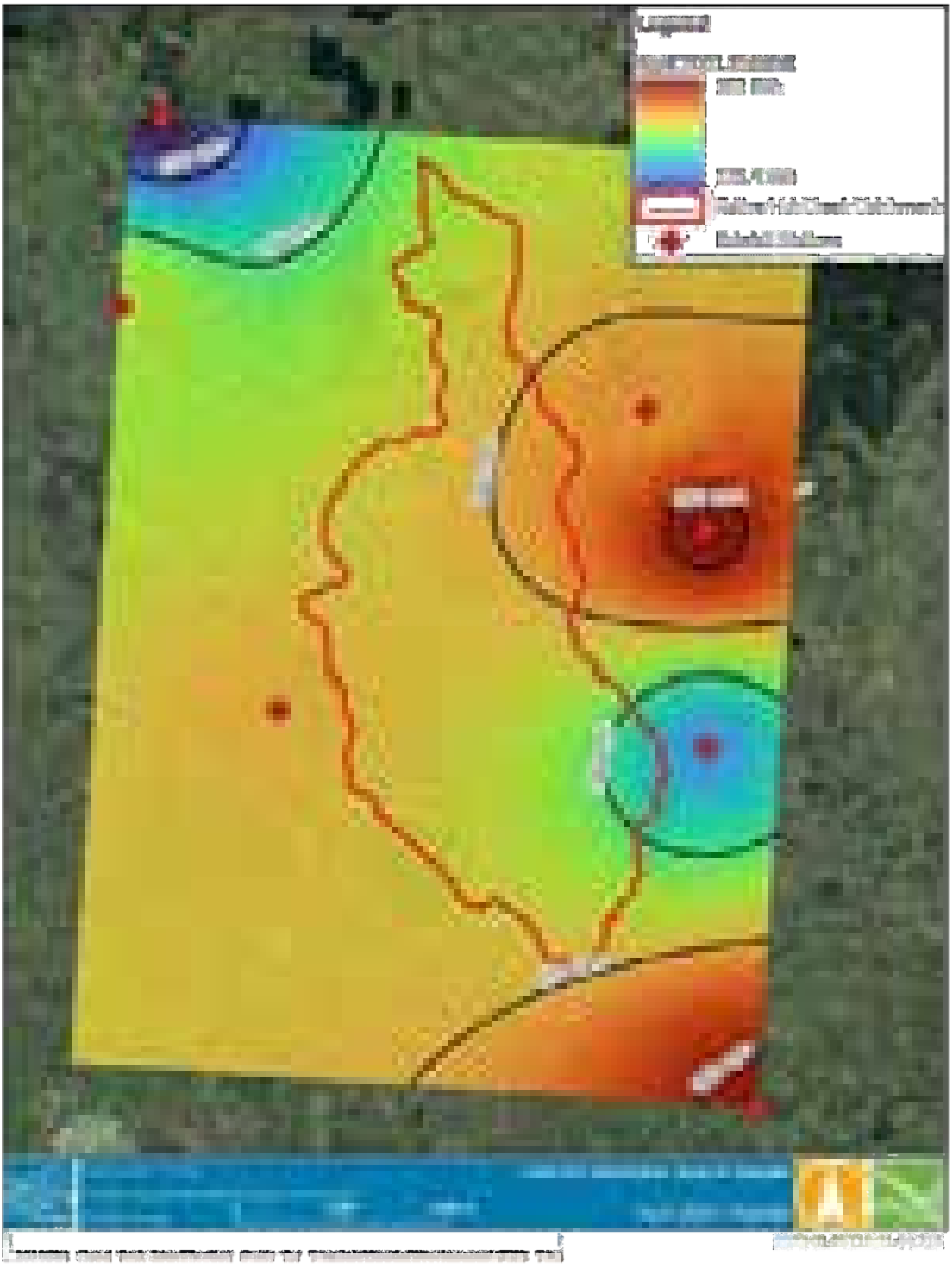

Figure 5-6 Rainfall Distribution and Isopleths for April 2001

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5.1.2.2 Streamflow

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

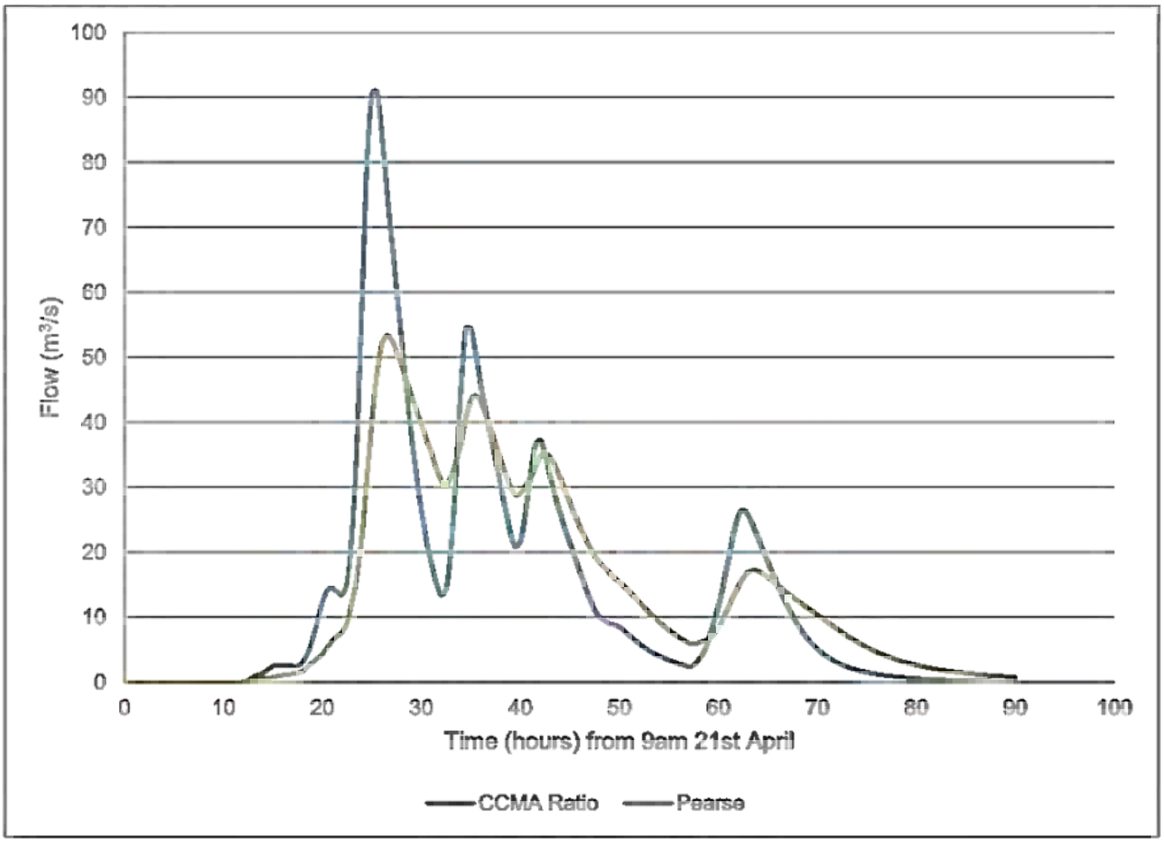

Figure 5-7 April 2001 modelled streamflow at Teesdale Bridge

5.1.2.3 Flood Behaviour

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

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

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

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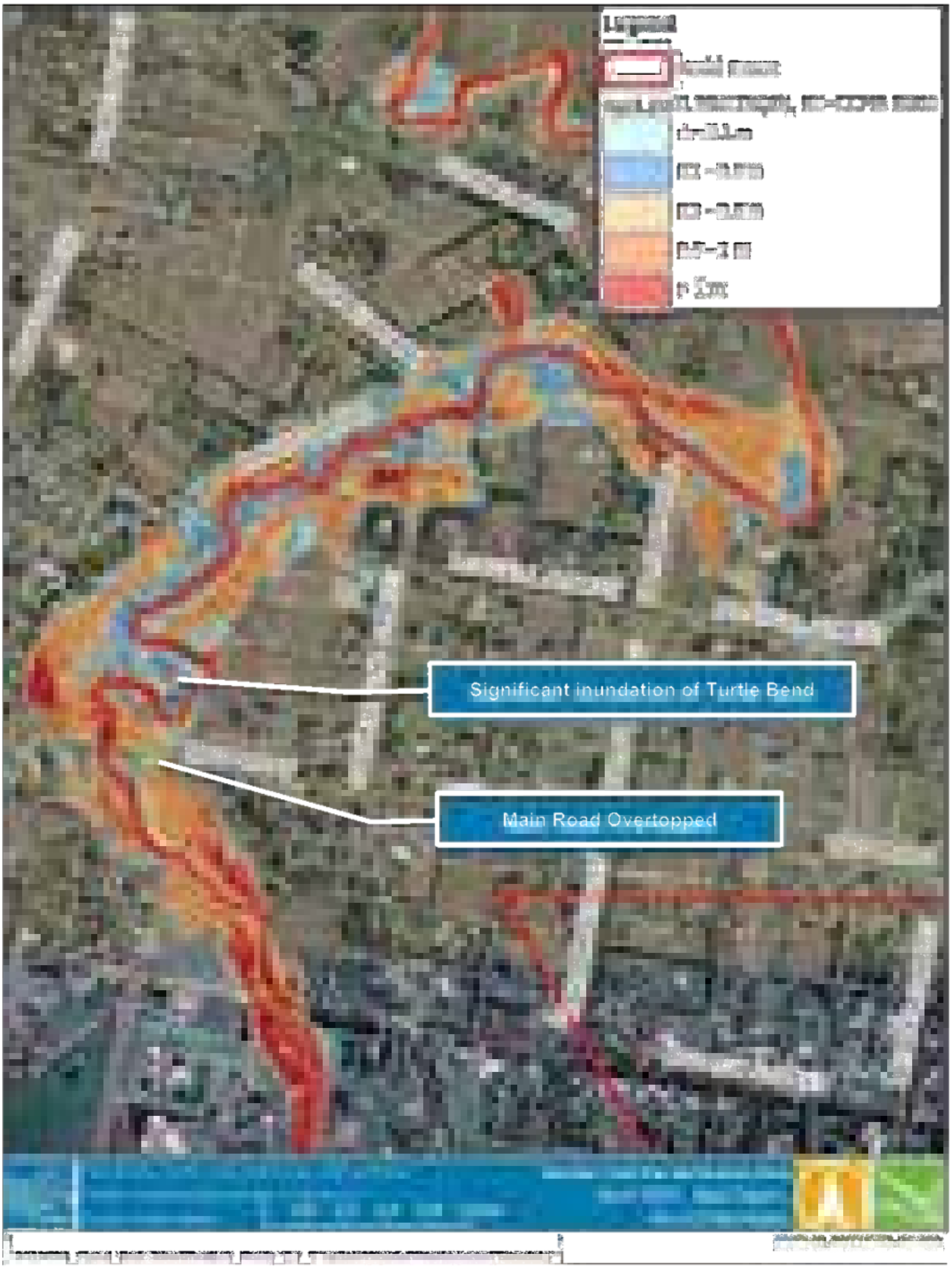

Figure 5-8 April 2001 Flood Depths, K_c=CCMA Ratio (Township)

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

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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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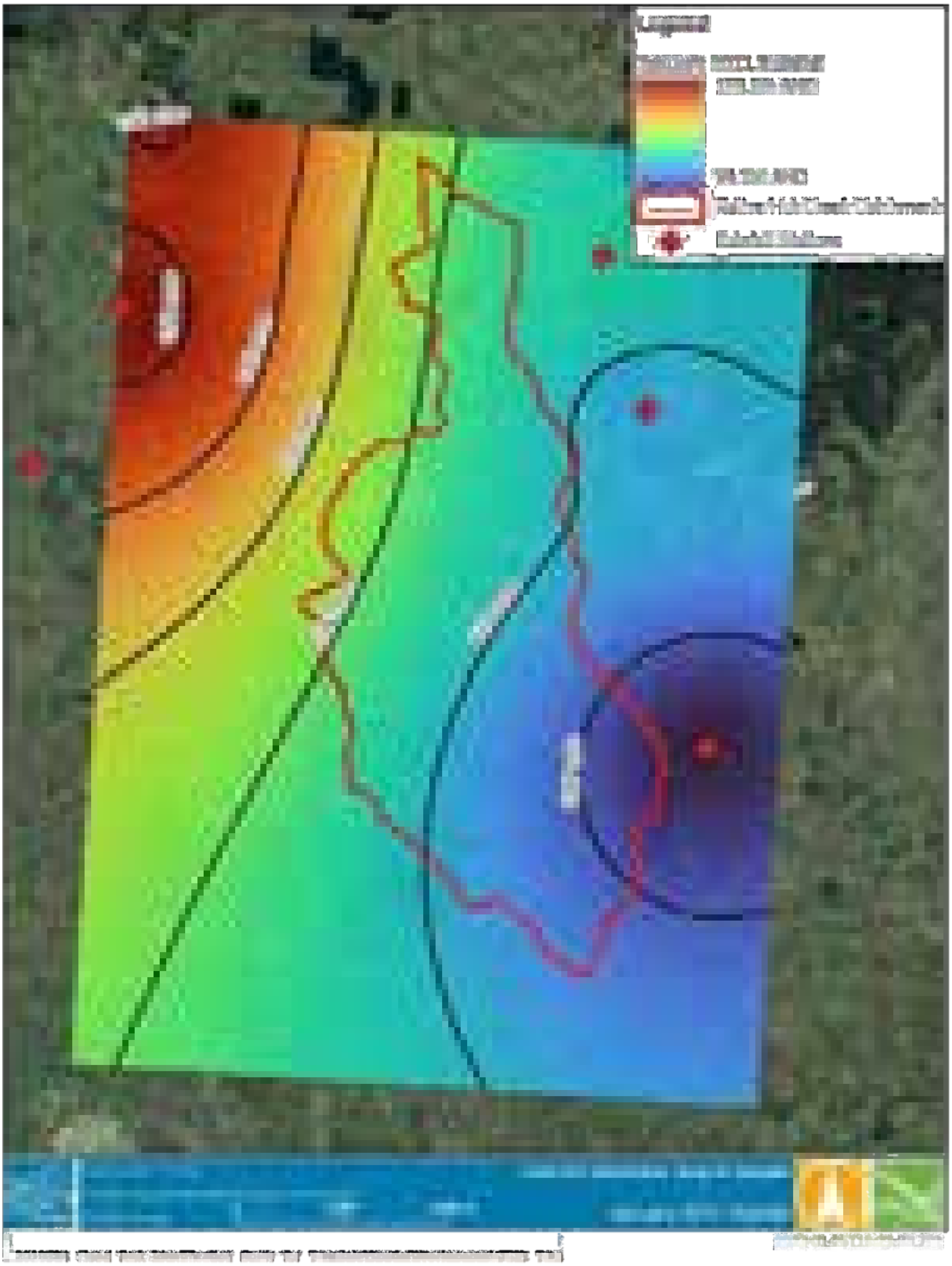

Figure 5-10 Rainfall Distribution and Isopleths for January 2011

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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 m³/s (CCMA) and 24 m³/s (Pearse). Lower values of K_c produce a hydrograph with significantly varying peaks and troughs, while higher values of K_c produce a more smoothed hydrograph.

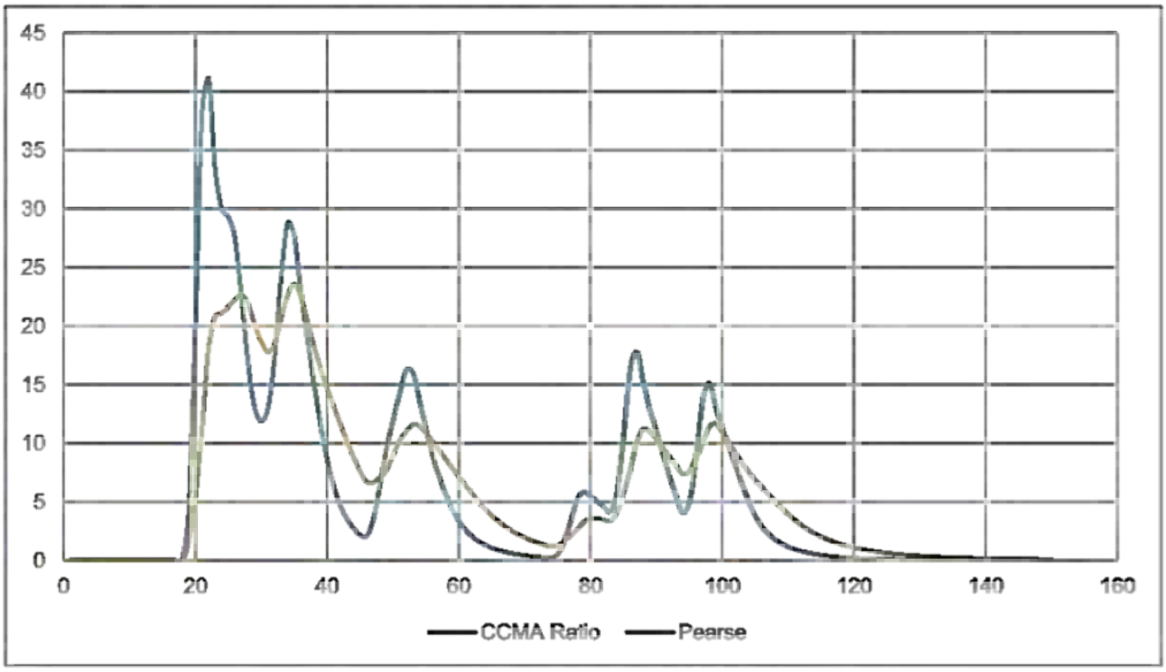

Figure 5-11 January 2011 modelled streamflow at Teesdale Bridge

5.1.3.3 Flood Behaviour

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

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

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

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

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

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

5.2 Validation Results Discussion

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

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

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

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

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

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

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

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

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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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Design Modelling Report

Teesdale Flood Risk Identification Study

Golden Plains Shire

21 April 2023

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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.

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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. 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
- **R03 – Design Hydrology and Hydraulic Modelling Report - This 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 and Context

This report follows report R02 – **Joint Validation Modelling Report**. The Joint Validation Modelling Report details the hydrologic and hydraulic model builds and modelling completed for three historic flood events:

- February 1973 – largest recent flood (anecdotally)
- April 2001 – significant event causing overbank flooding of Native Hut Creek within Teesdale
- January 2011 – a very recent, less severe event selected for validation due to the availability of anecdotal community evidence

The Joint Validation Modelling Report and model results produced were used to finalise the design model parameters, which are detailed herein. The models achieved good agreement with community observations of the January 2011 event, which was largely contained within the bed and banks of Native Hut Creek. Observations from the 1973 event were sparse given the time passed since that event however a photograph confirmed widespread flooding in the area of Pantics Road which was reflected in the modelling. The April 2001 event again had few available observations. Two observations from the 2001 event were conflicting, however based on the available evidence the modelling is considered to represent that event well.

This report should be read in conjunction with the Joint Validation Modelling Report. Key model parameters are repeated herein however the full details of the model builds are contained within the previous report.

2 METHODOLOGY

2.1 Overview

The Teesdale Flood Risk Identification Study has adopted a hydrologic/hydraulic modelling approach with the hydrology modelling completed using RORB software and hydraulic calculations completed within TUFLOW. Hydrologic model parameters were sourced from recent studies in the area and the ARR datahub, and validated against community observations in a joint model validation approach. Joint model validation consisted of producing streamflow hydrographs in RORB, running the TUFLOW model with the hydrographs as inflow boundaries and comparing the results to community observations. After some iteration, a good agreement between the model results and community observations was achieved and those model parameters were adopted for design modelling.

2.2 Hydrologic Model Parameters

The design hydrologic model (RORB) parameters are summarised in Table 1 below. The Joint Validation Modelling Report details the model build and parameter selection in more detail.

Table 1 RORB Model Parameters Summary

Parameter/Input	Value/Description
Kc/Dav Ratio	1.25
Kc – Tawarri area	2.55
Kc – Learmonth Street area	3.11
Kc – Main Native Hut Creek catchment	32.90
m	0.8
Burst Rainfall	Intensity-Frequency-Duration (IFD) information obtained from the Bureau of Meteorology, spatially compiled to produce a Native Hut Creek IFD table applied in conjunction with subarea weighting to account for spatial variation.
Pre-Burst Rainfall	Initial losses adjusted to account for pre-burst rainfall by subtracting the median pre-burst depth from the storm initial loss.
Initial Loss (storm)	17 mm
Continuing Loss	3.2 mm/hr
Reach Types	Type 1 (Natural) where no clear waterway present Type 2 (Excavated, unlined) where a waterway is clearly present
Storages	N/A
I/O Reaches	N/A

2.3 TUFLOW Model Summary

Table 2 summarises the key model parameters/inputs adopted for the TULFLOW modelling. Further details on the TUFLOW model inputs are described in detail in Section 4 of the Joint Validation Modelling Report.

Table 2 Key TUFLOW Parameters Summary

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 – Comparison with Classic to be completed
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

3 RESULTS

3.1 Design Hydrology

The RORB model was ran for the 50%, 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP and PMF events. Flows for the design events (excluding PMF) have been extracted from the model at the Bannockburn-Shelford bridge and are presented in Figure 1 below.

Native Hut Creek flows applied to the TUFLOW model were extracted from the RORB model at a print location upstream of Teesdale and at other print locations throughout the study area as required. This enables the model to account for local inflows while avoiding duplicate routing of flows in both the hydrologic and hydraulic models.

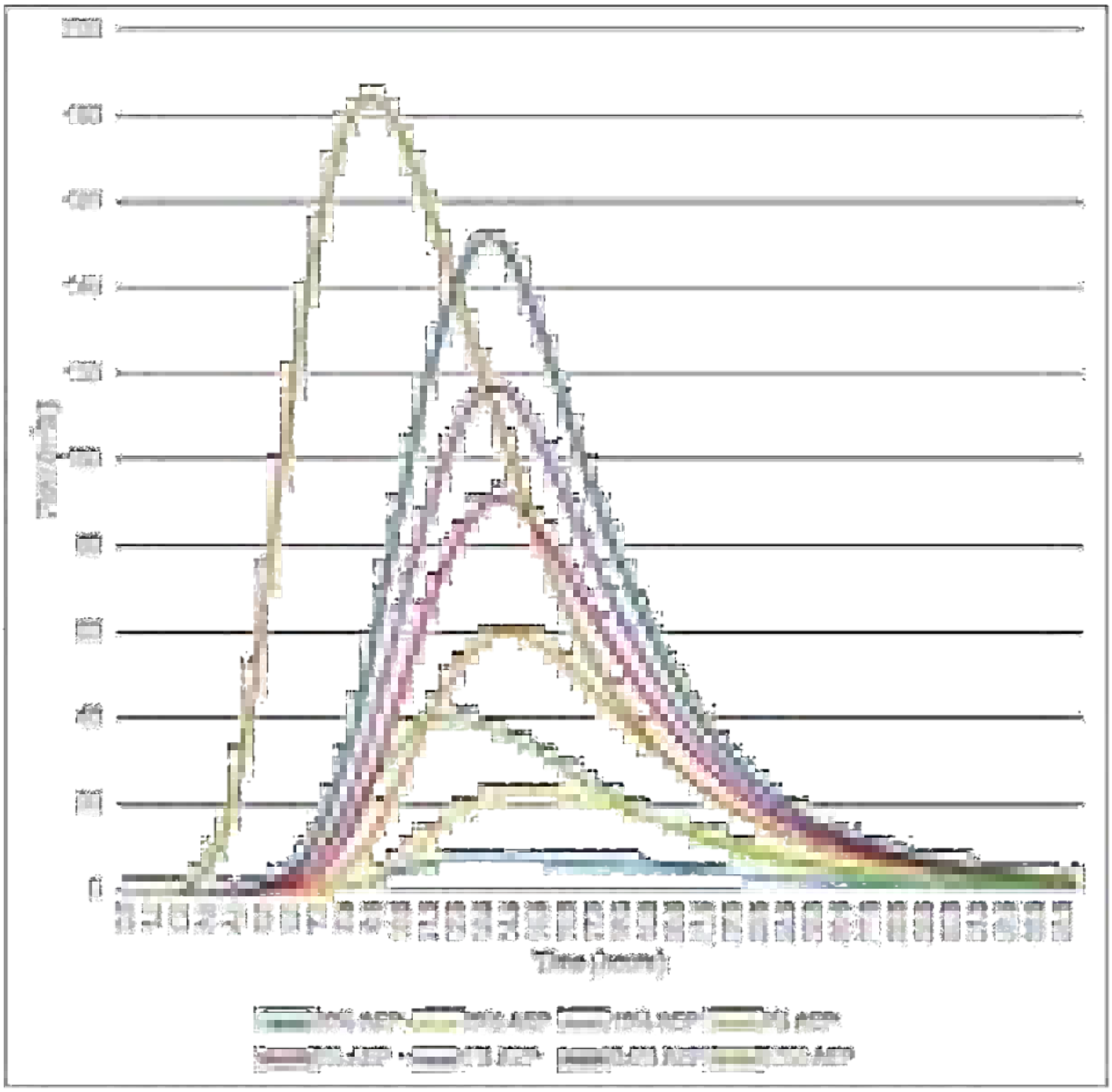

Figure 1 Design hydrographs, Native Hut Creek at Bannockburn-Shelford bridge

Critical Events and Temporal Patterns

As discussed in the Joint Validation Modelling Report, temporal patterns were selected from the "Southern Slopes (Vic) region". Given the size of the catchment and in line with the recommendations of ARR2019, areal temporal patterns were adopted in the first instance. Areal temporal patterns are only available for durations 12 hours and longer. As the 12-hour duration event was shown to be critical for most design event magnitudes, point temporal patterns were also run to ensure that the critical event had been captured. In two cases, the point temporal pattern produced a critical flow for the 9-hour event. In both cases the point temporal pattern was adopted as the design event.

The critical event durations, temporal patterns, source of pattern and peak flow rate at the bridge are shown in Table 3 below.

Table 3 Critical durations, temporal patterns and sources, and peak flows for modelled events

AEP	Duration	Temporal Pattern	Temporal Pattern Source	Peak Flow at Bridge (m^3/s)
50%	9 Hours	4	Point	7.4
20%	12 Hours	4	Areal	22.8
10%	9 Hours	7	Point	40.6
5%	12 Hours	4	Areal	60.6
2%	12 Hours	4	Areal	92.0
1%	12 Hours	4	Areal	117.7
0.5%	12 Hours	4	Areal	152.2
0.2%	12 Hours	5	Areal	184.9

3.2 Climate Change Assessment

The 10% and 1% AEP events were modelled with increases in rainfall intensity associated with climate change. Modelling considered Representative Concentration Pathways (RCP) 4.5 and 8.5 under projections to the years 2050 and 2100 in line with the ARR guidelines with rainfall scaling factors obtained from the ARR datahub. The resultant rainfall depths and resultant peak flows at the Bannockburn-Shelford Road bridge modelled are shown in Table 4 below.

The model results shown in Table 4 indicate that climate change scenarios cause an increase in flow at the Shelford-Bannockburn Road bridge. 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.

The increased rainfall depths were applied to the RORB model and the produced hydrographs which were applied to the TUFLOW model as inflow boundaries. TUFLOW results for the RCP8.5, 2100 1% AEP event are shown in Section 4 below.

As expected, the increased rainfall intensity RCP8.5, 2100 scenario produces an increase in flood levels across the study area. In the township, 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. Flood level increase mapping is shown in Figure 5 below.

Table 4 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

3.3 Probable Maximum Flood

The Probable Maximum Flood (PMF) rainfall depth was interpolated between depths estimated by the Generalised Short Duration Method (GDSM) and the Generalised Southeast Australia Method (GSAM). The rainfall depths were modelled utilising the 'rare' temporal patterns obtained from the ARR datahub and distributed spatially in line with the 0.2% AEP event. An initial loss of 0mm and a continuing loss of 1mm/hr was applied. All ten temporal patterns were simulated in the ensemble for the PMF. The maximum flow from the ensemble, (9 hour duration, temporal pattern 9) was selected as the design PMF event.

4 FLOOD MAPPING

The peak modelled flood depth in a 1% AEP event and climate change (2100 under an RCP8.5 scenario) are shown in Figure 3 and Figure 4 below. Detailed mapping of all modelled events is provided in PDF form as an appendix and GIS deliverables (grids and extents) will be provided to Council and CCMA.

Flood hazard mapping has been prepared in line with ARR2019 and the Australian Disaster Resilience Guideline 7-3 *Flood Hazard* (AIDR 2017). The hazard classifications are based on the peak depth, velocity and product of depth and velocity. The classifications are shown in Figure 2 below.

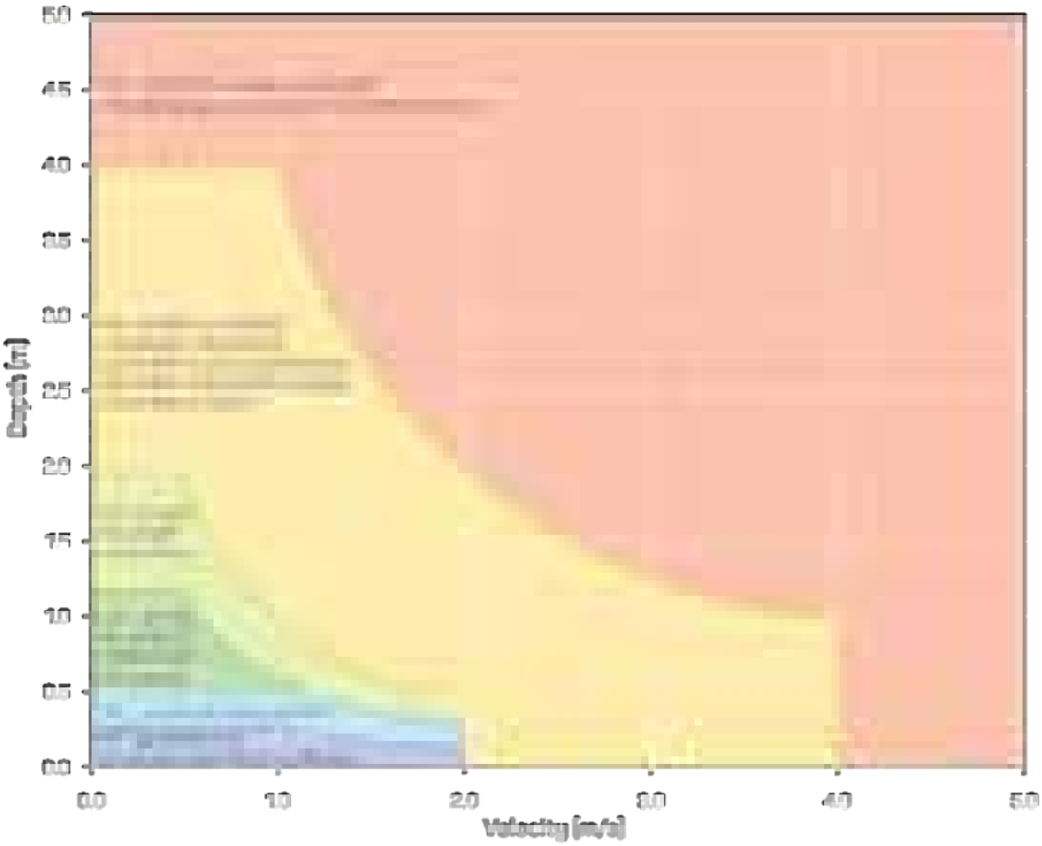

Figure 2 Hazard classifications (AIDR 2017)

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Figure 3 1% AEP Flood Depths in Teesdale (Existing Conditions)

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

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

5 SENSITIVITY TESTING

Sensitivity testing of flood models consists of altering an input or parameter and comparing results to the base case, revealing the sensitivity of the model results to that input or parameter. Sensitivity testing of the models have been undertaken for a range of parameters and inputs as described below. Sensitivity testing of the models was completed for the 1% AEP event only.

Afflux mapping of the sensitivity tests compared to the design mapping is shown for each sensitivity test was undertaken in the hydraulic model.

5.1 Losses

Loss parameters were tested in the hydrologic (RORB) model as detailed in Table 5 below.

Table 5 Hydrologic loss sensitivity test scenarios

Losses	Design	Initial Loss Test	Continuing Loss Test
Initial Loss (mm)	17	0	17
Continuing Loss (mm/hr)	3.3	3.3	1

The resultant peak flows at the Bannockburn-Shelford Road bridge are shown in Table 6. Lowering the continuing loss value from 3.2 mm/hr to 1 mm/hr had a significant impact on the modelled peak flow rates due to the critical storm duration of 12 hours resulting in a large proportion of the previously lost rainfall excess now forming runoff.

Table 6 Losses sensitivity testing results

Scenario	Peak Flow at Bridge (m³/s)	% Increase in Flow
Design	117.7 m³/s	0
Initial Loss Test	125.7 m³/s	6.8%
Continuing Loss Test	165.1 m³/s	40.3%

5.2 Hydraulic Roughness

Sensitivity to adopted roughness within the hydraulic model was tested by both lowering and raising the Mannings 'n' roughness. The roughness values in the model were multiplied by 0.75 and 1.5 for the low and high tests respectively.

Flood levels across the floodplain changed significantly, indicating the hydraulic model is sensitive to the selection of this parameter. The area upstream of the Bannockburn-Shelford Road bridge appears to be the least sensitive area in the model, 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 raised 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.

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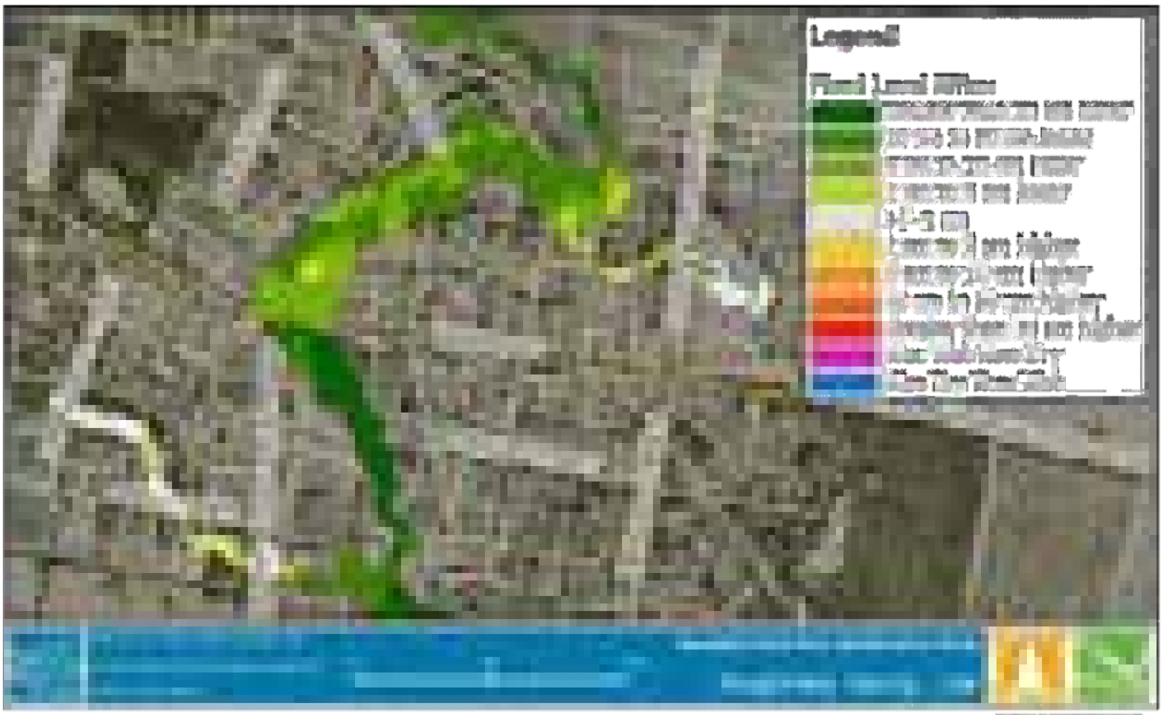

Figure 6 Low roughness sensitivity testing afflux mapping

Figure 7 High roughness sensitivity testing afflux mapping

5.3 Structure Blockage

Blockage factors were applied to the two bridges in town as follows:

- 20% blockage applied to the bridge opening (i.e. underneath the deck); and
- 100% blockage applied to the bridge railing.

The results show very minor impacts localised to the immediate area of the bridges. Both bridges show a slight raising of flood levels on the upstream side of the bridge. The Bannockburn-Shelford Road bridge also shows minor afflux with increases of up to 0.04 metres on the downstream western side of the bridge adjacent to the kindergarten. This is a result of the blockage causing additional overtopping of the road on that side. The kindergarten buildings remain out of the flood extent.

Figure 8 Blockage sensitivity testing afflux mapping

5.4 Boundary Conditions

The model has a single outflow boundary, which adopted a slope of 0.3% based on the slope of Native Hut Creek at the boundary location. Changing the downstream boundary slope to 5% lowers flood levels in the vicinity of the boundary. Flood levels in Teesdale are unaffected by the change, confirming the boundary was set a sufficient distance from the township. Flood levels at the boundary were lowered by 1.3 metres, quickly tapering to less than 10cm ~150 metres upstream of the boundary, and less than 1cm approximately 600 metres upstream of the boundary.

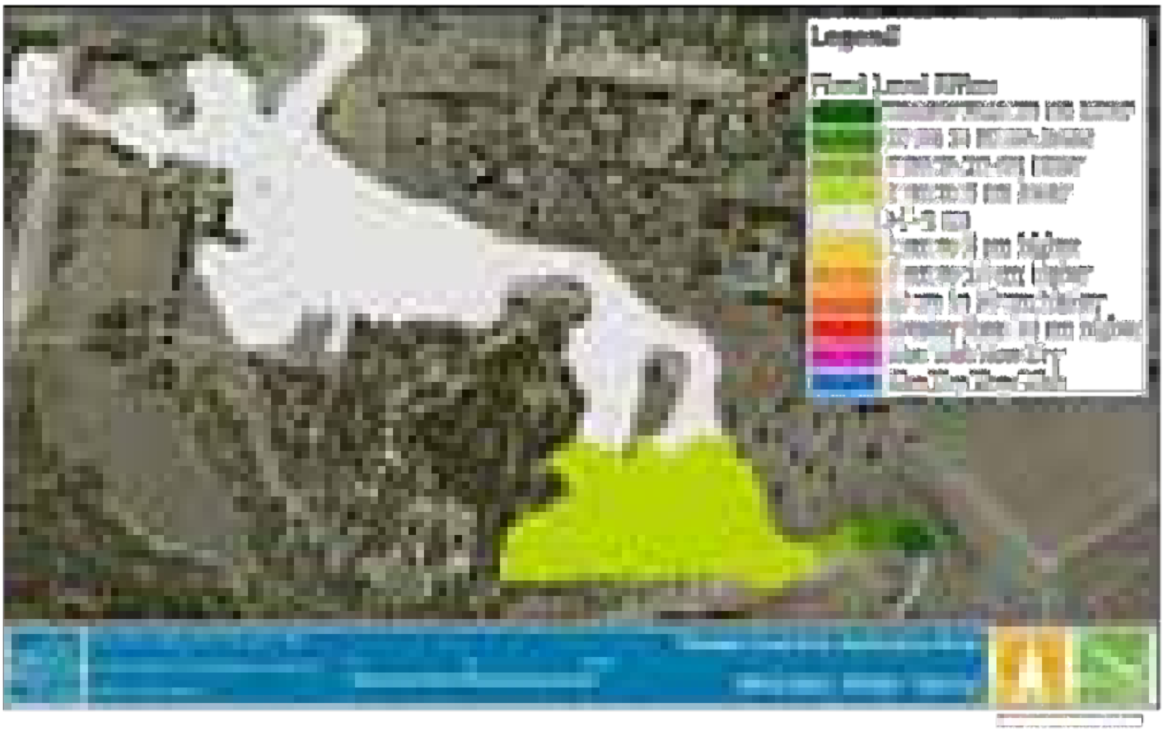

Figure 9 Boundary slope sensitivity testing afflux mapping

6 SUMMARY

Design modelling and sensitivity testing of the hydrologic and hydraulic models built as part of the Teesdale Flood Risk Identification Study has been completed and detailed in this report. Design flood mapping is provided as a separate appendix to this report.

The models have been simulated for the 50%, 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% and PMF events. The 10% and 1% were simulated with projected climate change increased rainfall intensity under RCP4.5 and RCP8.5 for the years 2050 and 2100.

Flood mapping has been produced in line with industry standards and the current Australian Rainfall and Runoff guidelines. The mapping is fit for the purposes of informing land use planning in Teesdale. The mapping will be used to assess average annual flood damages for the township and the models utilised to assess potential structural mitigation options. Flood intelligence products will be developed to inform emergency management planning and response.

Sensitivity testing shows the models are particularly sensitive to continuing loss in the hydrology and hydraulic roughness in the hydraulic model. For the 1% AEP event, structure blockage and boundary conditions were shown to be uninfluential on results in the township.

The flood mapping produced will inform draft planning scheme amendment mapping to update the planning scheme in line with the new intelligence.

APPENDIX A
FLOOD MAP PDFS

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Flood Intelligence and Warning

Teesdale Flood Risk Identification Study

Golden Plains Shire

5 May 2023

WATER TECHNOLOGY
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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. 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 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
- R03 – Design Hydrology and Hydraulic Modelling Report
- **R04 – Flood Intelligence and Flood Warning Report – This 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 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 report R03 – Design Modelling Report. R03 detailed the design event modelling for the range of modelled events (50% AEP to PMF). The previous report also detailed climate change modelling under a range of scenarios in addition to model sensitivity testing.

This report discusses the Flood Intelligence products developed as part of the study. It also provides an assessment of the Total Flood Warning System components currently in place for Teesdale, with recommendations for further improvement to the flood warning system.

2 BACKGROUND: TOTAL FLOOD WARNING SYSTEM

The Total Flood Warning System (TFWS) is intended to encompass all of the elements required to produce an appropriate timely response to flooding. The elements of the core TFWS are shown in Figure 2-1 below.

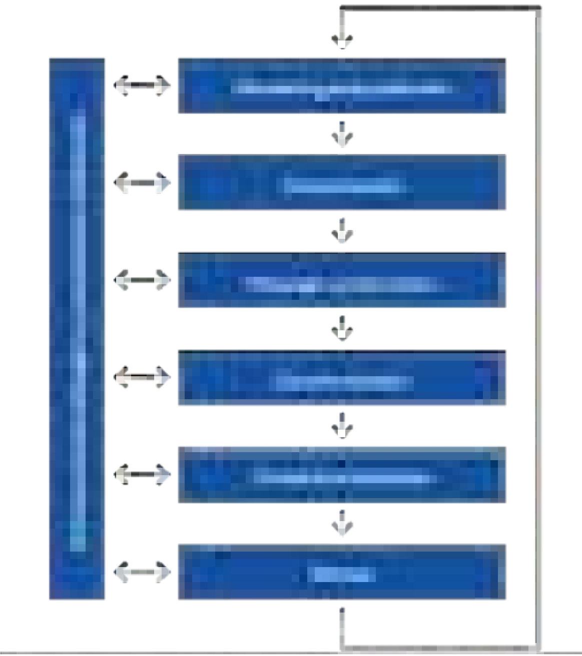

Figure 2-1 Total Flood Warning System elements[1]

The information produced by a flood investigation generally relates to the "monitoring and prediction" and "interpretation" elements. Flood mapping, damages and intelligence produced by the study will be valuable in interpreting incoming data. Some of the elements of the study (for example the "Flood/No Flood" tool produced in the Municipal Flood Emergency Plan) can aid with prediction.

Message construction, communication, and protective behaviour are outside the scope of a flood investigation however would generally be completed from within an Incident Control Centre (if one has been set up) and the applicable Incident Management Team controlling the incident. Formal flood warning messages in Victoria fall within the remit of the Bureau of Meteorology and fall within two classes: Flood Watches and Flood Warnings.

Flood Watches are general warnings covering a large area and are not specific to particular waterways or townships. They can be delivered well before flooding is expected to arise and are often based on forecast rainfalls.

Flood Warnings, on the other hand, are specific to a location and will predict how high the water will peak at that location. Flood Warnings are often related to Flood Class Levels (see Section 8 below).

Review of the available information should take place after any event, or any other discovery of new flood information as appropriate. Historic events should be added to the available information, particularly the MFEP, as they occur.

Monitoring, in the context of flooding, generally refers to monitoring rainfall and stream levels but may include other aspects such as storage levels and catchment conditions to name a few. Locations to monitor will depend on the available data sources and the catchment of interest.

The following sections will discuss the current and ideal monitoring capability for Native Hut Creek; a draft rating curve of Native Hut Creek at Teesdale to assist in future data collection and prediction where possible; flood behaviour and impacts at the modelled AEPs; flood travel times; and flood classification levels for Teesdale.

3 RATING CURVE DEVELOPMENT

A rating curve has been extracted from the TUFLOW hydraulic model at the Bannockburn-Shelford Road bridge. This location represents the most appropriate location for a gauge on Native Hut Creek due to the confined nature of the waterway corridor at this location, with flow contained in most events. In events larger than around a 2% AEP event, flows will overtop the road. Gauge boards on the upstream side of the road placed at the low point where overtopping commences along with a location further from the bridge would ensure gauge readings could be undertaken during large events, however the model indicates readings at this location may be slightly higher than those taken upstream of the bridge opening. Manual gauge readings may therefore overestimate the flow in Native Hut Creek at high flow rates.

The rating curve has been developed utilising a least squares polynomial fit across the model results for flow and height at the upstream side of the bridge. Model results for the 10%, 5%, and 0.5% AEP events informed the curve. A clear inflexion point can be seen just above 30 m^3/s, where the floodplain upstream of the bridge is engaged and small increases in water level correspond to significant increases in flow.

The curve is shown in Figure 3-1 and Figure 3-2 below. Also plotted are the flows and heights extracted from the model for all modelled events except the PMF. An example rating table, in the same format as that currently used by the Department of Energy, Environment and Climate Action, is provided in Appendix A. The example table is based on a gauge zero of 99.037 mAHD, which was taken from the TUFLOW model. Should the gauge site be developed, a gauge zero will be required and the stage heights can be linked using mAHD as a datum.

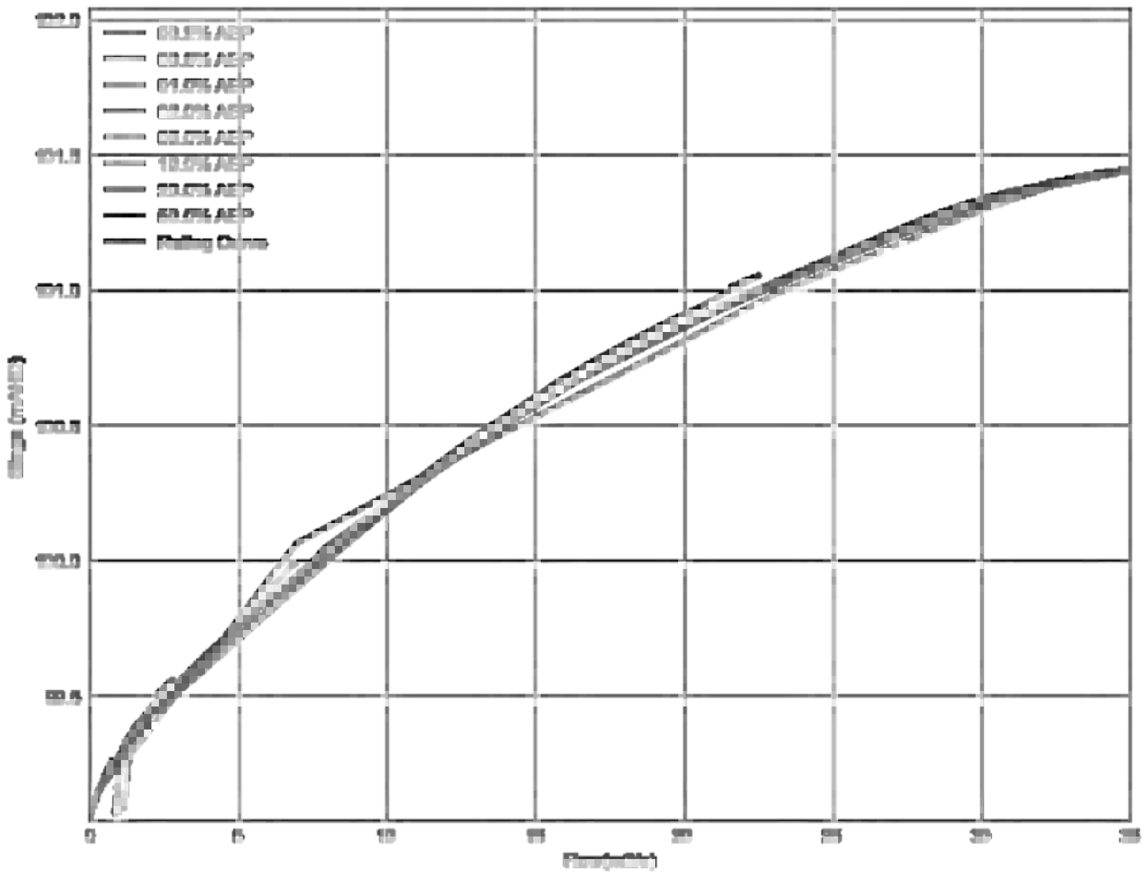

Figure 3-1 Native Hut Creek at Bannockburn-Shelford Road bridge, low flows

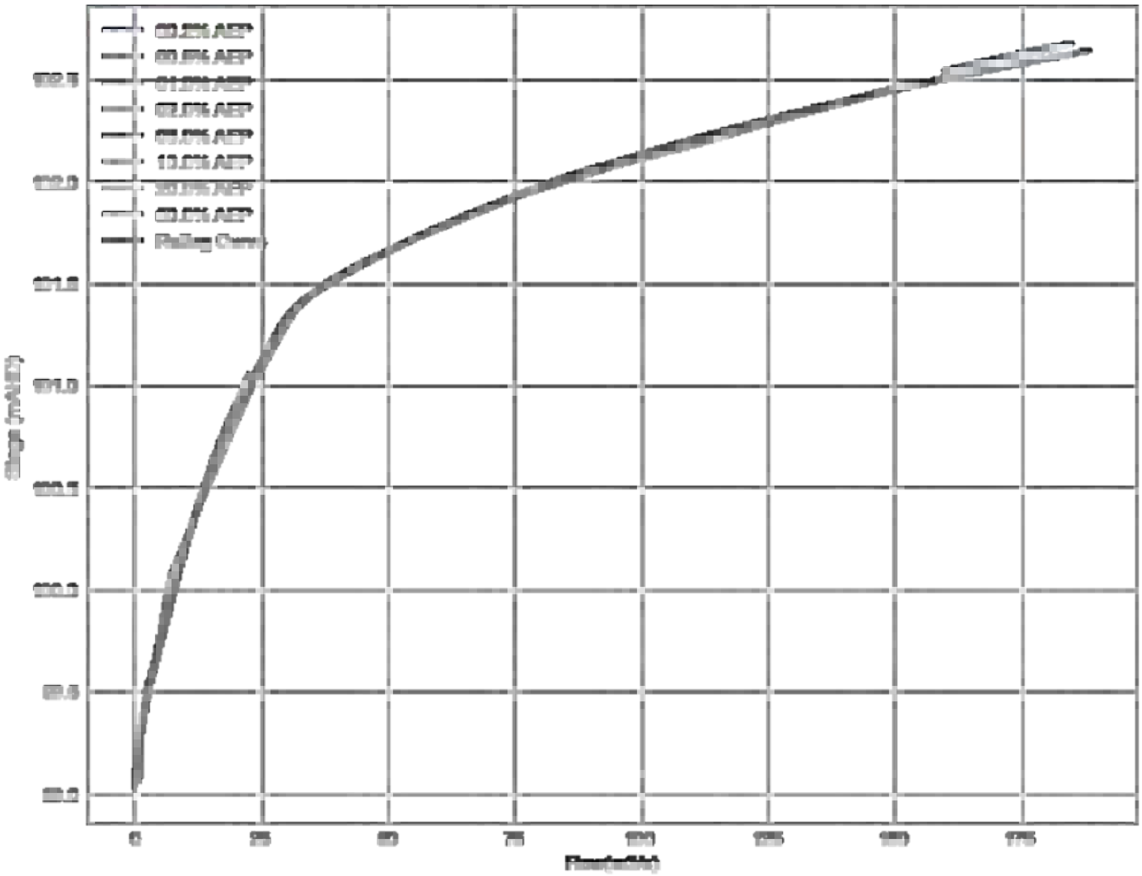

Figure 3-2 Native Hut Creek at Bannockburn-Shelford Road bridge, high flows

4 FLOOD BEHAVIOUR AND IMPACTS

4.1 Overview

When Native Hut Creek flows, water first breaks the banks at 4 Stones Road, flowing towards the west and over Stones Road before re-joining the creek upstream of Squires Road/Sutherland Street. Model results indicate this occurs at relatively low flow rates in the creek of around 10m³/s (~50% AEP). Barker Street overtops shortly after, with the minor culvert's capacity overcome in minor events. At higher flowrates of around 40m³/s (10% AEP), flows break out near the Stones Road/Tolsons Road bridge on the south side of the creek, flowing through residential properties and over Sutherland Street, re-joining the waterway approximately 200m north of the Bannockburn-Shelford Road bridge.

The elevated Bannockburn-Shelford Road overtops at around 90m³/s (~2% AEP), with overtopping commencing at a low point on the road 90 metres east of the bridge. As flows increase, another low point approximately 90 metres to the west begins to overtop. The depression on the west side of Teesdale-Inverleigh Road fills and the road is overtopped. The floodplain downstream of the bridge narrows towards Barker Street and remains relatively confined until the confluence with the Learmonth Street tributary, downstream of which numerous breakouts occur as the creek flows away from Teesdale.

4.2 Flood Impacts Summary

Table 4-1 provides a summary of key flood behaviour and impacts with a summary of roads inundated. Behaviours and impacts are shown in the likely order of inundation, i.e. from more frequent, lower magnitude events to less frequent larger flood events.

Note the table below refers to Stones Road, however it should be noted that this is also Tolsons Road. The inundation of Stones Road joins Tolsons Road at approximately 10% AEP and there are no properties or otherwise between the two inundation points, thus they have been combined.

Table 4-1 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)

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Flood Event	Characteristics – Flood Behaviour	Roadways Inundated
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)
5% AEP ~5,200 ML/d ~60.5 m³/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 m³/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 m³/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 m³/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 m³/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)

5 FLOOD PEAK TRAVEL TIME

With no active or historic gauges on Native Hut Creek, flood peak travel times have been extracted from the RORB model built for the study. The model is sensitive to selection of the K_c routing parameter with respect to flood timing. Flood timing is also expected to be influenced by antecedent catchment conditions. Given no gauge monitoring is possible, flood peak timing at Teesdale has been estimated from the start of significant rainfall.

The modelled hydrographs for the 10% AEP and 1% AEP rainfall events are shown in Figure 5-1 and Figure 5-2. The below graphs show all modelled events for the AEP between 3 hours and 72 hours in duration for all ten temporal patterns. A total of 100 hydrographs were produced for each AEP. Also shown on the graphs is the critical peak flow, selected in accordance with the recommendations of ARR.

The graphs show the significant range in peak flows and timing produced by rainfall depths of a certain AEP when that rain falls over different durations and patterns within the duration. This illustrates the difficulty in accurately predicting flood peaks and timing from rainfall alone.

The graphs show that flood peaks can manifest around 7 hours from the start of intense rainfall, with the majority of events peaking between 7 hours and ~30 hours from the start of the rainfall burst. Some events peak beyond 30 hours from the start of rainfall however these become rarer and may contain "embedded bursts" where rainfall intensity within the burst increases for a period of time.

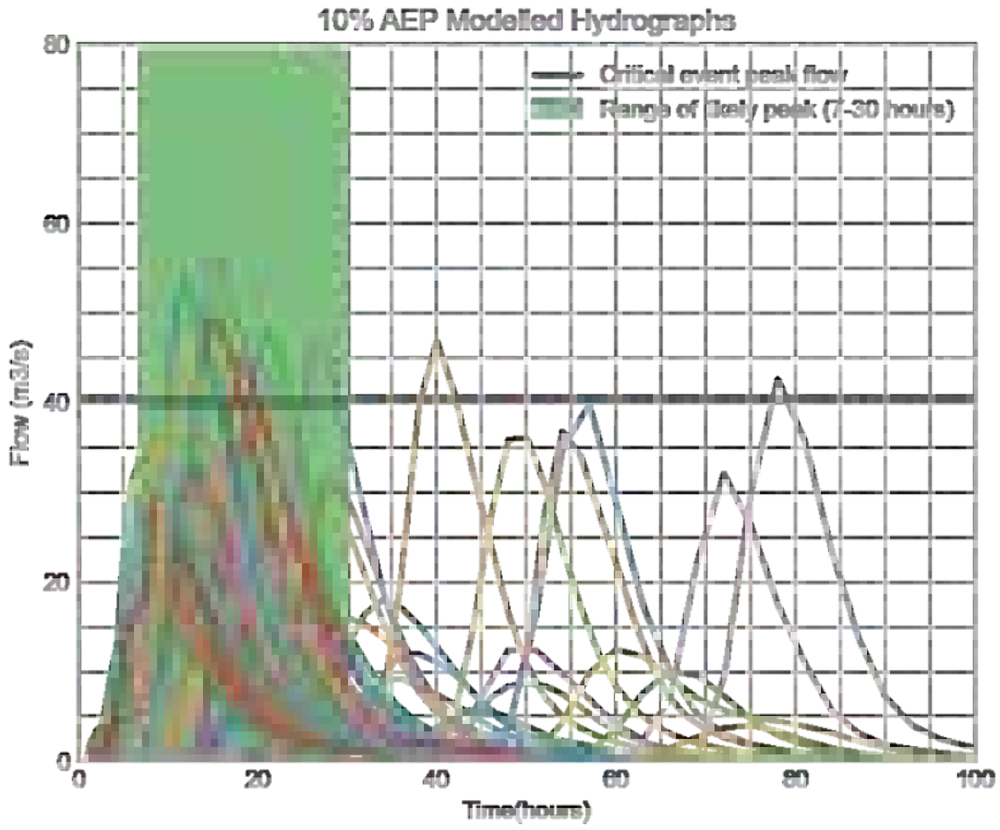

Figure 5-1 10% AEP hydrographs from all 100 modelled rainfall events

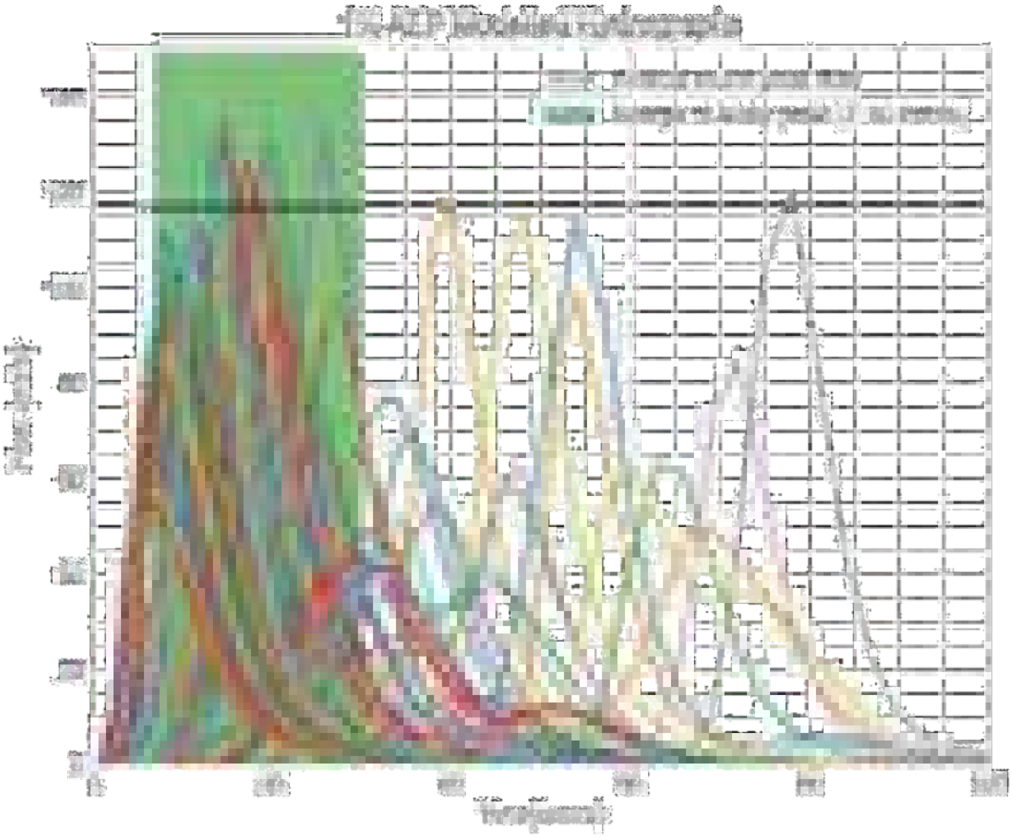

Figure 5-2 1% AEP hydrographs from all 100 modelled rainfall events

Similar graphs for the remaining AEPs modelled were used to develop Table 5-1 below of expected rises and peak times in the Native Hut Creek at Teesdale from the start of rainfall.

Table 5-1 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	

6 FLOOD/NO FLOOD TOOL

In the absence of a warning system, an estimate of the magnitude of flooding in Native Hut Creek at Teesdale may be obtained by monitoring the depth of rainfall in a given event, taken from the start of the event.

The Flood/No Flood tool in Figure 6-1 below provides a graphical representation of the Intensity-Frequency-Duration relationships for various AEP events as presented in R03 – Design Modelling.

To use the table, plot the total rainfall depth obtained against elapsed time since the start of the event. Exclude very light rain or drizzle when determining the event start point. Plotting of rainfall data should occur periodically as the event progresses. The likelihood and potential severity of flooding can be estimated by checking the rainfall and adopting the nearest curve AEP event as being likely.

It may be appropriate to step up or down a level depending on catchment antecedent conditions, for example if the rainfall for a 12 hour duration indicates a 5% AEP event will occur, but the catchment is dry with most farm dams empty, it may be appropriate to "step down" to a 10% AEP event or even lower. Similarly a very wet catchment will produce a greater response and may justify a "step up" in estimated AEP for response purposes.

The tool can provide a quick estimate as to whether there will be a flood and how severe that flood may be, however it must be stressed that the tool cannot provide accurate flood predictions and should not be relied upon entirely. Should life or property be in danger a cautious approach should be taken.

WATER TECHNOLOGY

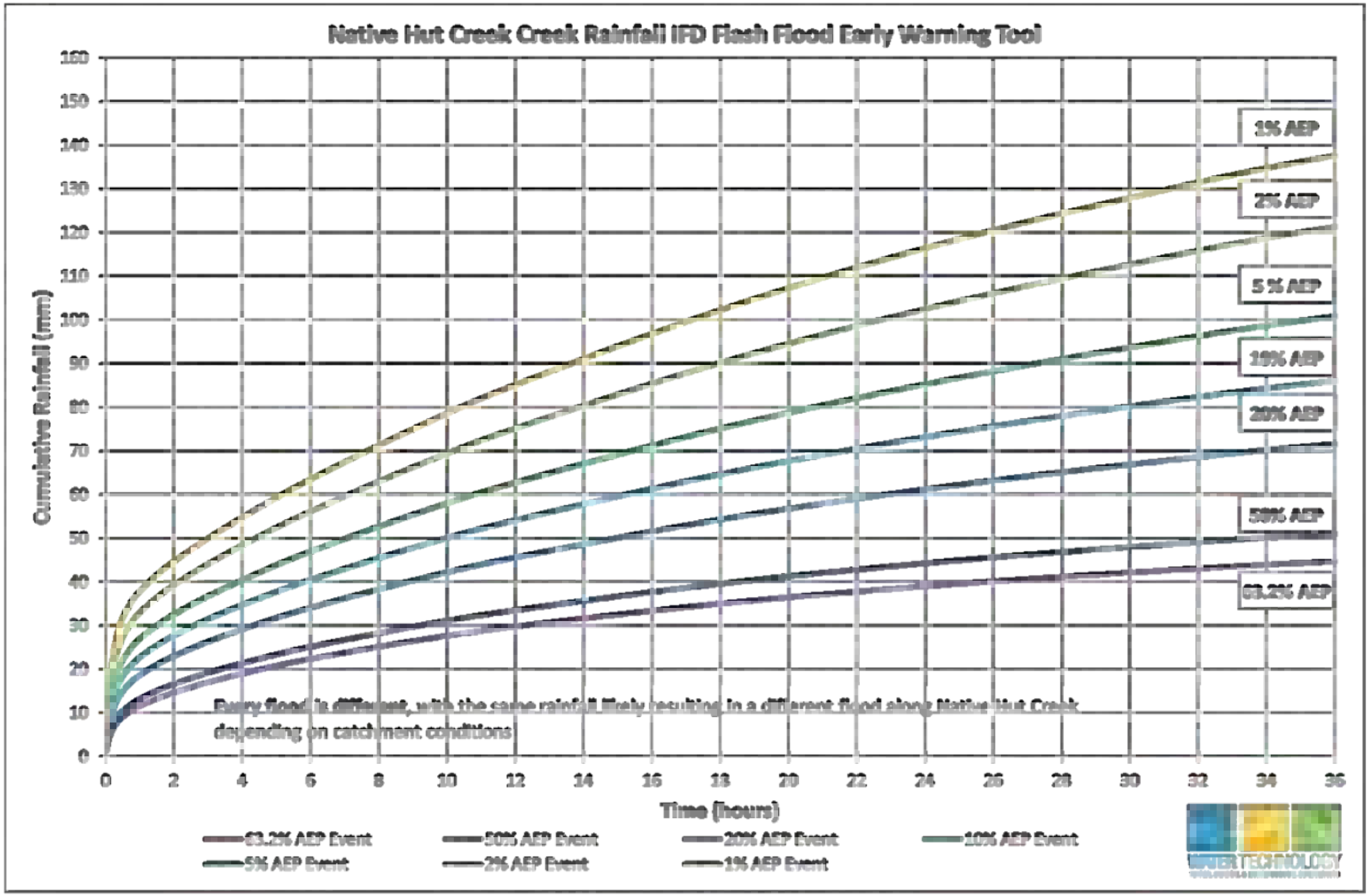

Figure 6-1 Teesdale Flood/No Flood Tool

7 FLOOD CLASSIFICATION LEVELS

While no gauge exists at Teesdale, recommended Flood Classification Levels (FCLs) have been developed utilising the theoretical gauging site and rating curve developed for the Bannockburn-Shelford Road bridge and the Bureau of Meteorology's definitions of FCLs. The bureau defines FCLs as per the below[1]:

Minor flooding

If the water level reaches the minor flood level, it causes inconvenience. Low-lying areas next to water courses are inundated. Minor roads may be closed and low-level bridges submerged. In urban areas flooding may affect some backyards and buildings below floor level as well as bicycle and pedestrian paths. In rural areas removal of livestock and equipment may be required.

Moderate flooding

If the water level reaches the moderate flood level, the area of inundation is larger. Main traffic routes may be affected. Some buildings may be affected above floor level. Evacuation may be required. In rural areas removal of livestock is necessary.

Major flooding

If the water level reaches the major flood level large areas are inundated. Many buildings may be affected above floor level. Properties and towns are likely to be isolated and major rail and traffic routes closed. Evacuation may be required. Utility services may be affected.

The results of the modelling have been assessed against the above criteria and flood class levels have been set for the proposed gauge location at the Bannockburn-Shelford Road bridge. The proposed flood class levels are detailed in Table 7-1 below.

Table 7-1 Proposed Flood Class Levels for Teesdale

Flood Class	Level at Bridge	Description
Minor	101.05 mAHD	The 20% AEP event matches the above minor flooding definition quite well, as Stones Road requires closure and low-lying areas next to Native Hut Creek are inundated.
Moderate	101.53 m AHD	The 10% AEP event floods Pantics Road to potentially hazardous levels and may require evacuation of vulnerable residents on that road. The area of inundation is significant. No buildings are flooded above floor level in this event.
Major	102.25 mAHD	The 1% AEP flood level is likely to require closure of the Bannockburn-Shelford Road bridge, potentially isolating parts of the town. Detours are likely to require careful management. Flooding of this magnitude is likely to be accompanied by flooding in neighbouring catchments.

[1] http://www.bom.gov.au/australia/flood/knowledge-centre/about-warning-service.shtml

8 MONITORING CAPABILITY FOR NATIVE HUT CREEK

8.1 Existing Capability

Currently, there is no formal flood warning system in place for the Native Hut Creek catchment. Additionally, there are no streamflow or rainfall gauges within the catchment. Due to this, official flood warning capability for the catchment and township is limited to the issue of a Flood Watch for the Barwon, Leigh and Moorabool Rivers area. Note a flood watch is not necessarily guaranteed to be issued prior to flooding.

The closest rain gauges that record sub-daily rainfalls and report to the Bureau of Meteorology's website are detailed in Table 8-1 below, with the distance measured from the Bannockburn-Shelford Road bridge.

Table 8-1 Nearby hourly rain gauges (Bureau of Meteorology)

Site Number	Name	Distance from Teesdale
87168	She Oaks AWS	15.2 km North-East
89104	Mt Mercer	25.6 km North
90167	Winchelsea	24.4 km South

8.2 Ideal (Potential) Capability

Flood data monitoring for Native Hut Creek would benefit from the placement of a rain gauge and stream gauge within the catchment. Rainfall in the north of the catchment is expected to be captured quite well by the Sheoaks gauge, however Teesdale itself lies between a number of gauges which may not reflect rainfall in the immediate vicinity of the township.

A sub-daily rain gauge within Teesdale would therefore improve the monitoring capability for the township and lower areas of the catchment. A Teesdale rain gauge would provide the additional benefit of allowing for monitoring of flash flooding conditions within the township, which is known to have caused issues recently, based on feedback received during community consultation sessions for this project.

In addition to a rain gauge within the township, a stream gauge on Native Hut Creek immediately upstream of the Bannockburn-Shelford Road bridge would greatly improve monitoring and data gathering for the township. Outputs from this Flood Risk Identification Study have been linked, where possible, to a gauge height at this proposed location. A stream gauge here would also gather stream height data in future flood events, allowing more detailed catchment analysis and calibration of models to improve confidence in the flood intelligence products.

Stream gauging in the catchment upstream is not expected to provide significant benefit to Teesdale. This is due to the following factors:

- The catchment shape and size already produce fast response times. Upper or mid catchment gauging may not provide sufficient lead time in an event to enable suitable response actions to be implemented.
- There is a significant tributary which enters Native Hut Creek immediately upstream of the Stones Road/Tolsons Road bridge. Any mid/upper catchment gauging would not be able to take account of this tributary and could therefore underestimate peak flows at Teesdale should the tributary influence flooding in a particular event.

In summary, a rain gauge at Teesdale and a stream gauge at the Bannockburn-Shelford Road bridge would improve flood monitoring and data gathering capabilities in Teesdale significantly. The rain gauge would play a direct role in warning of impending floods while the stream gauge would provide invaluable data to benchmark other monitoring information against.

In heavy rainfall events where Native Hut Creek rises quickly, a stream gauge may only provide warning time sufficient to enact response actions other than evacuation. A more cost effective option may therefore be to install a gauge without telemetry, or to have the site ready for deployment of a Portable Automatic Logging System (PALS) to monitor levels in Native Hut Creek during expected flow events. One potential issue with the PALS option is the demand for PALS units during events for which heavy rainfall is forecast. PALS ownership and deployment arrangements should therefore be confirmed prior to pursuing this option.

9 SUMMARY

Preferred monitoring capability and infrastructure to support a Total Flood Warning System for Teesdale has been discussed, with a sub-daily rain gauge and stream gauge suggested. Both the rain gauge and stream gauge are proposed within Teesdale itself and would improve the monitoring and data gathering capability for flood conditions in the town. A rating curve has been developed for Native Hut Creek at the Bannockburn-Shelford Road bridge, which can act as a starting rating table should the site be adopted until gauging can occur.

A number of flood intelligence products have been developed to improve flood response capability for the town, including a flood impact summary table, flood peak timing estimates and the development of a quick "flood/no flood" tool designed to estimate the magnitude of flooding based on observed rainfall.

Flood Class Levels have been recommended based off the Bureau of Meteorology's definitions and flood mapping completed for Teesdale. The Flood Class Levels utilise the proposed stream gauge site as their basis.

Much of the flood intelligence information contained in this report will be included in a draft revision of the Golden Plains Municipal Flood Emergency Plan (MFEP) for SES and Council approval.

APPENDIX A
RATING TABLE

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Table A-1 Rating Table for Native Hut Creek at Bannockburn-Shelford Road bridge in ML/d

mLGH	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	0.00	0.89	2.43	4.36	6.62	9.14	11.9	14.9	18.0	21.4
0.1	24.9	28.6	32.5	36.4	40.6	44.8	49.2	53.7	58.4	63.1
0.2	68.0	72.9	78.0	83.2	88.5	93.9	99.4	105	111	116
0.3	122	128	134	134	140	153	159	166	172	179
0.4	185	192	199	206	213	220	227	234	241	249
0.5	256	263	271	279	286	294	302	310	317	325
0.6	333	341	350	358	366	374	374	383	391	408
0.7	417	425	434	443	452	460	469	478	478	487
0.8	506	515	524	533	543	552	561	571	580	590
0.9	599	609	619	629	638	648	658	668	678	688
1	698	708	719	729	739	749	760	770	781	791
1.1	802	812	823	833	844	855	866	876	887	898
1.2	909	920	931	942	953	964	976	987	998	1010
1.3	1020	1030	1040	1060	1070	1080	1090	1100	1110	1120
1.4	1140	1150	1160	1170	1180	1200	1210	1220	1230	1240
1.5	1260	1270	1280	1290	1300	1320	1330	1340	1350	1370
1.6	1380	1390	1400	1420	1430	1440	1450	1470	1480	1500
1.7	1520	1530	1550	1560	1580	1600	1610	1630	1650	1660
1.8	1680	1700	1710	1730	1750	1770	1780	1800	1820	1840
1.9	1850	1870	1890	1910	1920	1940	1960	1980	2000	2010
2	2030	2050	2070	2090	2110	2130	2140	2160	2180	2200
2.1	2220	2240	2260	2280	2300	2320	2340	2360	2380	2390
2.2	2410	2430	2450	2470	2490	2510	2530	2560	2580	2600
2.3	2620	2620	2660	2660	2700	2700	2800	2800	2900	2900
2.4	3010	3010	3110	3110	3220	3220	3330	3330	3450	3450
2.5	3560	3620	3680	3740	3810	3870	3930	4000	4060	4130
2.6	4190	4260	4330	4400	4470	4540	4610	4690	4760	4830
2.7	4910	4980	5060	5140	5220	5300	5380	5460	5540	5630
2.8	5710	5710	5880	5880	6060	6060	6240	6240	6420	6420
2.9	6610	6610	6800	6800	7000	7000	7200	7200	7400	7400
3	7610	7720	7830	7940	8050	8160	8270	8380	8500	8610
3.1	8730	8850	8960	9090	9210	9330	9450	9580	9710	9830
3.2	9960	10100	10200	10400	10500	10600	10800	10900	11000	11200
3.3	11300	11300	11600	11600	11900	11900	12200	12200	12500	12500
3.4	12800	12800	13100	13100	13500	13500	13800	13800	14100	14100
3.5	14500	14600	14800	15000	15200	15400	15500	15700	15900	16100
3.6	16300	16500	16700	16800	17000	17200	17400	17600	17800	18000

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Flood Damages and Mitigation Assessment

Teesdale Flood Risk Identification Study

Golden Plains Shire

5 May 2023

WATER TECHNOLOGY
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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.
Averange Annual Damages (AAD)	A measure of average flood damages expressed as a dollar cost per year. Takes into account the expected damages of each event along with the event's probability of occurring in any year.
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.

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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. 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 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
- R03 – Design Hydrology and Hydraulic Modelling Report
- R04 – Flood Intelligence and Flood Warning Report – This Report
- **R05 – Flood Damages and Mitigation Assessment Report – This 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 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 report R04 – Flood Intelligence and Warning. The previous report presented the flood intelligence products developed for Teesdale informed by the modelling and analysis undertaken earlier in the project.

This report presents the results of the flood damages assessment for Teesdale, presenting the estimated average annual cost of flooding for the township. Mitigation options are also considered with the aim to reduce current and future flood risk and damages.

2 FLOOD BEHAVIOUR

2.1 Overview

Flooding in Teesdale occurs as a result of both local rainfall (i.e. overland/stormwater inundation) and riverine flooding when Native Hut Creek breaks its banks. The Teesdale Flood Risk Identification Study considers the impacts and behaviour of *riverine* flooding only (in accordance with project scope). A separate drainage investigation is also underway which will investigate inundation from local runoff in the town.

Native Hut Creek enters Teesdale at the northwest corner of the town, near the ends of River Drive and Eagle Court. The floodplain in this area is reasonably narrow and contained, although the northern portions of properties along Eagle Drive and Squires Road become inundated in large events of around a 5% to 2% AEP. East of the Squires Road/Bruce Street intersection the floodplain again becomes narrow, with the majority of flow contained within the waterway. Approximately 200m upstream of the Stones Road/Tolson Road bridge flows break out of the waterway corridor in even low magnitude (frequent) events.

The floodplain from the Stones Road/Tolson Road breakout through town is generally wide spread, with deep, high hazard flows observed in the floodplain in events greater (rarer) than a 10% AEP (rarer).

2.2 Roads

Inundation of roads presents a risk to pedestrians and vehicles safety, as the safe limits of depth and velocity are often exceeded and extremely difficult to observe or measure during an event. Isolation of community members also creates a need or desire to use inundated roads. Community and emergency services members may therefore inadvertently traverse roads which are extremely unsafe and should not be attempted.

The results of the flood modelling and mapping show a number of roads within Teesdale are overtopped in floods of varying magnitude. Table 2-1 shows the roads impacted by flooding and the lowest magnitude (i.e. most frequent) event at which the road is impacted within Teesdale.

Table 2-1 Roads Overtopped within Teesdale

Road	Design Event Overtopped
Barker Street	50% AEP
Stones Road/Tolson Road	50% AEP
Russell Street	50% AEP
Learmonth Street	50% AEP
Pantics Road/Squires Road	20% AEP
Mercer Terrace	10% AEP
Sutherland Street	10% AEP
Teesdale-Inverleigh Road	5% AEP
Bannockburn-Shelford Road	2% AEP
Jollys Road	2% AEP
Teesdale-Lethbridge Road	0.5% AEP
Bruce Street	PMF

Road inundation mapping for the 1% AEP event is shown in Figure 2-1 below. Mapping for all events has been supplied to Council and Corangamite CMA with the project deliverables and has been included in a draft update to the Golden Plains Municipal Flood Emergency Plan.

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Figure 2-1 1% AEP Road Inundation and Depths

2.3 Properties

Properties bordering Native Hut Creek are generally large lots. The majority of lots bordering the creek prior to the Stones Road/Tolson Road breakout are long lots with the dwellings positioned away from the creek. Throughout town the lot shapes and orientations have more variety however most lots are large enough to have some flood free land in even very rare events.

Historical development of the town has largely avoided the placement of dwellings within the floodplain. In the 0.2% (1 in 500) AEP event, only two dwellings in town are flooded above floor. One dwelling, located at 87 Pantics Road, is inundated above floor in a 10% AEP event or larger. Another dwelling located at 844 Teesdale Inverleigh Road is inundated above floor in a 2% AEP event or larger. This is likely a combination of low historical development pressure in the town combined with some large flood events in the past.

Table 2-2 summarises property inundation in Teesdale under various modelled design events. It should be noted that Table 2-2 does not include above floor flooding of sheds, agricultural structures etc. in the above floor flooding figures. A number of these structures are within the flood extent and may be subject to above floor inundation as these buildings often have their floor level at or close to ground level.

In accordance with the above section 2.2, a number of properties which are not necessarily directly impacted by flooding (at the dwelling) are liable to be isolated during large events in Native Hut Creek. The majority of properties liable to be isolated are on Pantics Road.

Table 2-2 Summary of properties flooded in Teesdale

Design Event (AEP)	Dwellings Flooded Above Floor	Properties Impacted by Floodwater
50%	0	63
20%	0	73
10%	1	90
5%	1	93
2%	2	102
1%	2	108
0.5%	2	111
0.2%	2	112

The two dwellings impacted by above floor flooding are shown in Figure 2-2 below.

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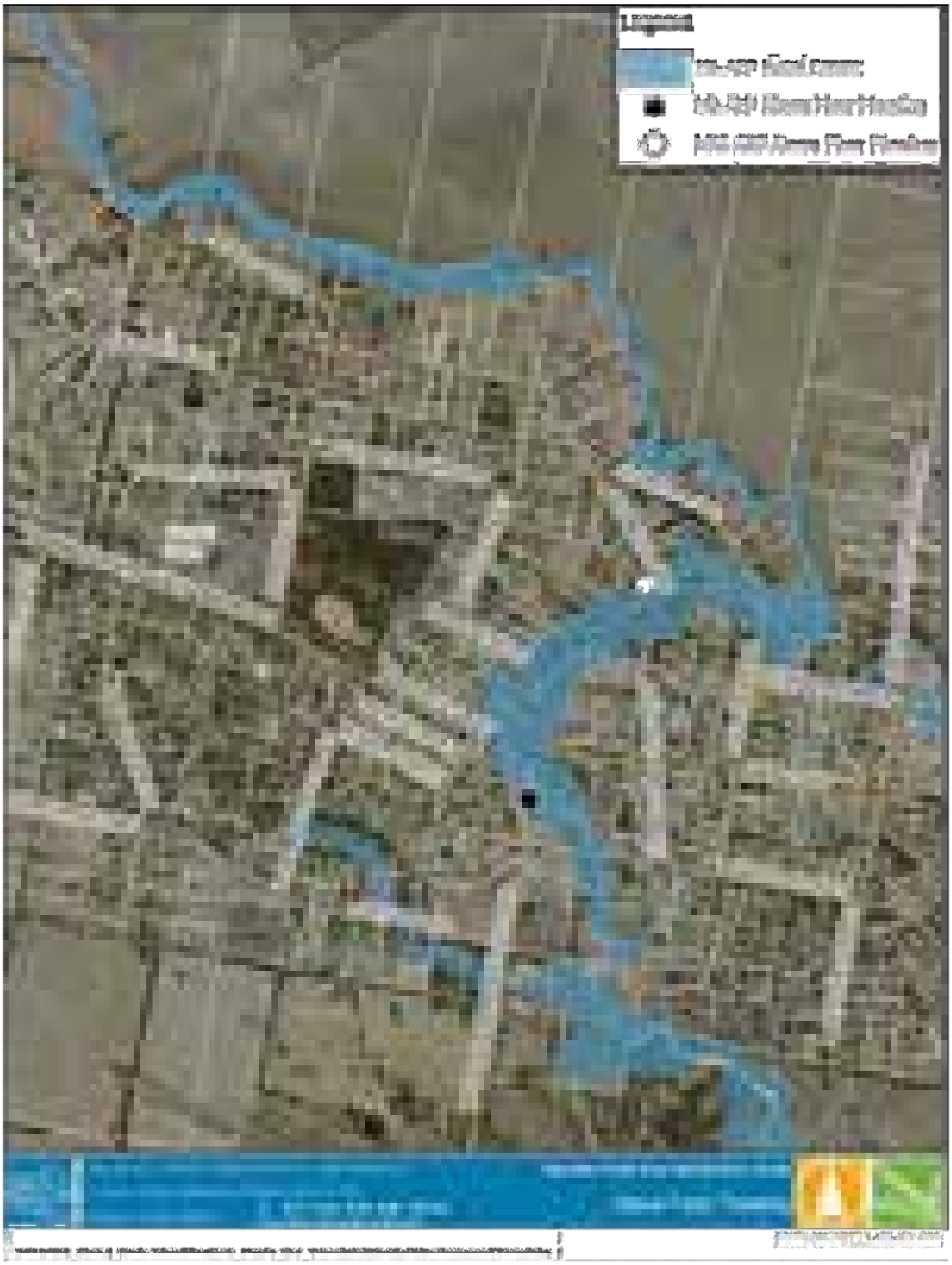

Figure 2-2 Dwellings impacted by above floor flooding

3 DAMAGES ASSESSMENT

A flood damage assessment was undertaken for the study area under existing conditions. The flood damage assessment determined the monetary flood damage for the range of modelled design events (i.e. 20%, 10%, 5%, 2% 1%, 0.5%, 0.2% AEP and PMF floods).

Model results for all mapped flood events were processed to calculate the number and the locations of properties and roads affected. These included properties inundated above floor, properties inundated below floor, properties which were not impacted but the grounds of the property were, and the lengths of flood affected roads. It should be noted that only sealed roads were assessed due to the availability of associated costs for flood damages.

Flood damages were calculated and summed for each property and road utilising the damage curves in Table 3-1 below.

Table 3-1 Damage Curves Utilised in Assessment

Damage Category	Damage vs Depth Curve
Residential	Stage damage curves based on NSW Office of Environment and Heritage 2007 methodology[1] (factored up to 2022 CPI)
Commercial	Stage damage curves based on ANUFLOOD 1992 methodology (increased by 60% as per RAM 2000 methodology[2], and factored up to 2022 CPI)
External Below Floor	Damage curve from NSW DPIE 1992 methodology (factored up to 2022 CPI)

A summary of the flood damage assessment is shown below in Figure 3-1. The assessment reveals an AAD for Teesdale of **$113,366 per year**. The AAD value for Teesdale is quite low given the small population of the town and the central presence of Native Hut Creek. This is reflective of the fact that few dwellings have been placed within the floodplain.

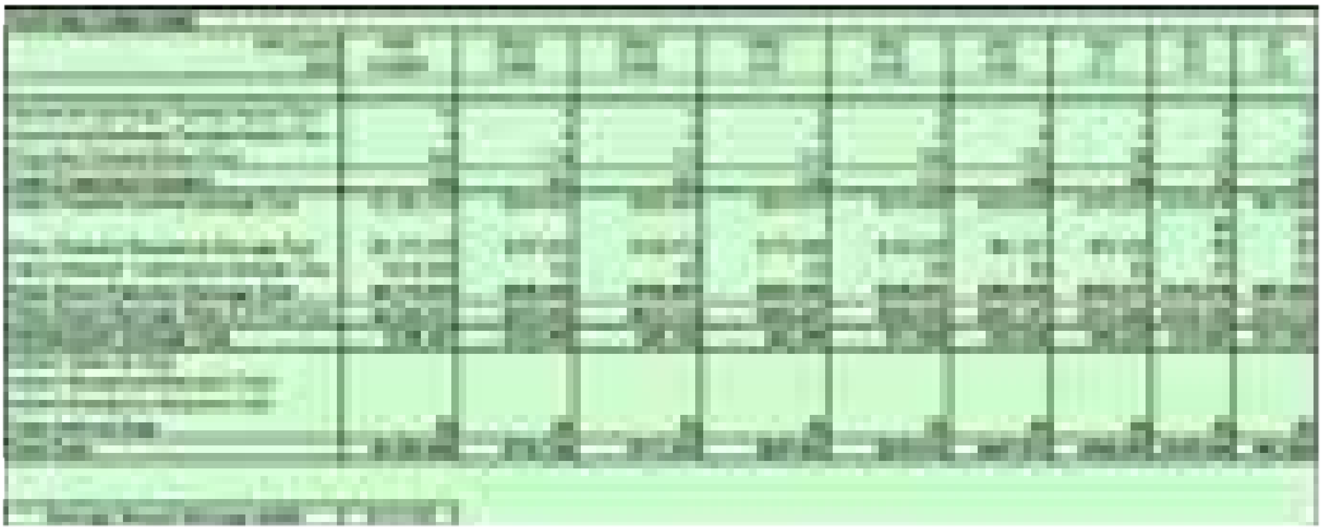

Figure 3-1 Existing Conditions Average Annual Damages (AAD)

[1] NSW Office of Environment and Heritage (2007) Floodplain Risk Management Guidelines: Residential Flood Damages
[2] Rapid appraisal method (RAM) for floodplain management, Victorian Department of Natural Resources and Environment, 2000

4 STRUCTURAL MITIGATION ASSESSMENT

4.1 Overview

Three potential structural mitigation options were tested in the hydraulic model for all design events. The three options considered were 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.

The results of the modelling were then processed to determine the AAD for each mitigation option to enable a comparison with the existing conditions. High level cost estimates for each option were developed and utilised to prepare a cost-benefit assessment. For each cost-benefit analysis, a 30-year project timeline was adopted with a discount rate of 6%.

The three options, their respective model results and cost benefit analyses are described in detail below. Cost estimates for the works have been based on Water Technology's experience of works on waterways and developments with supplementation from Rawlinsons Construction Cost Guide 2023 and Rawlinsons Australian Construction Handbook 2021 where required. Estimates from the 2021 edition have been increased by 20% due to the significant rises in construction costs (labour and materials) since then. A 30% contingency has been included in the total cost estimates for each option to account for administration, project management and unforeseen contingencies.

Each option has had its cost/benefit assessed in terms of the net present value of the option over a 30 year timeframe. The net present value of each option was assessed according to the below equation.

$$NPV = \sum \frac{R - M}{(1 + i)^n} - C$$

Where:

R = Reduction in AAD ($)

M = Annual Maintenance Cost ($)

i = Discount/Interest Date

C = Capital Cost ($)

n = Year (from 1 to 30)

4.2 Option 1: Raising of Pantics Road

This option, shown in Figure 4-1, involves raising Pantics Road to approximately 300mm above the 1% AEP flood level. This, combined with the upgrade of culverts under the road to include backflow prevention valves, aims to protect properties on the west side of the road along with the road itself.

WATER TECHNOLOGY

Figure 4-1 Mitigation Option 1: Raising of Pantics Road

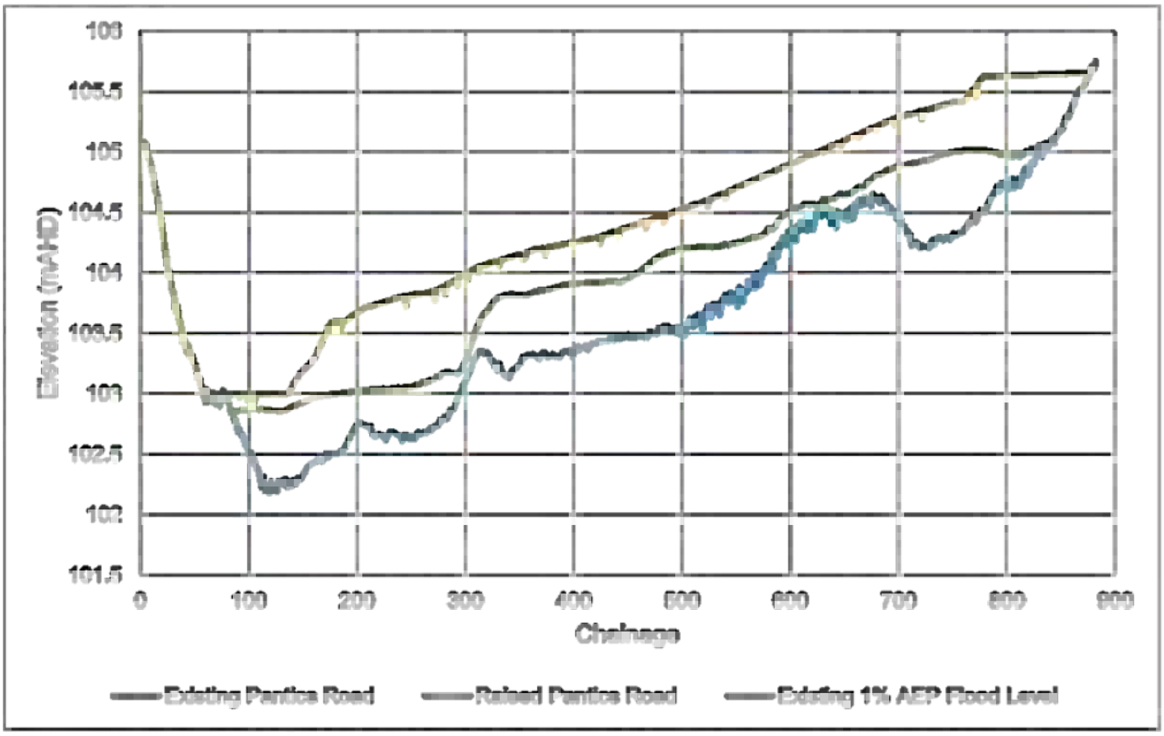

Figure 4-2 Existing and Proposed Pantics Road Long Section

4.2.1 Option 1 Flood Impact

The levee/road prevents inundation of the Pantics Road and properties on its western side in modelled events up to a 0.5% AEP event. The 0.2% AEP event overtops the conceptual levee, however depths are not as high in this scenario as the existing conditions. A flood level difference map for the 1% AEP event are presented in Figure 4-3 below, comparing the mitigation option to the existing conditions.

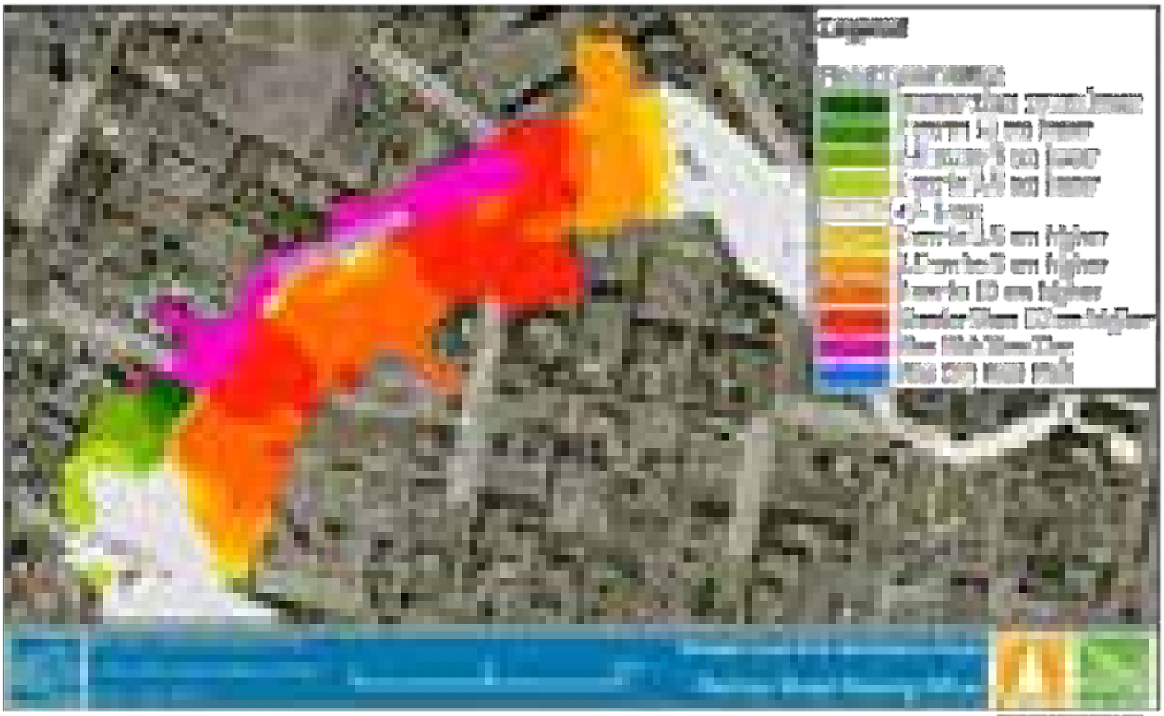

Figure 4-3 1% AEP Flood Level Afflux – Raising of Pantics Road

The levee has the following impact in events where it doesn't overtop (i.e. events lower in magnitude than the 0.5% AEP):

- Pantics Road is flood free, providing an access/egress route to many properties
- Properties west of Pantics Road are flood free, including 87 Pantics Road which has a building flooded over floor in a 10% AEP event
- Flood levels and extents to the east and north of Pantics Road are increased by varying amounts, with the worst increases being around Sutherland Street (~0.16m) and Squires Road (up to 0.25m)
  - The dwelling at 169 Squires Road becomes inundated above floor in a 0.2% AEP event – a change from the existing conditions where this dwelling was not inundated in any events other than the PMF

As can be seen from the mapping, the levee results in significant raising of flood levels in adjacent areas. This combined with the impact at 169 Squires Road means the proposal is unlikely to gain support from the community or approval authorities given more properties are negatively impacted than benefiting from the proposal. In general, flood mitigation proposals must demonstrate no negative impacts to gain support and funding from government.

4.2.2 Option 1 Cost/Benefit Assessment

Costs associated with levee construction are generally driven by the required levee dimensions, primarily height and width which in turn drive the total materials, machinery and labour required to construct the levee. In the case of the proposed Pantics Road raising, the levee is intended to also function as a road, resulting in a surfaced, wide top levee. Culverts will also be required to allow local drainage, although culvert sizing has not been undertaken.

On average, the levee requires raising of ground levels by 0.784 metres to reach the heights shown in Figure 4-1. The levee/road is a total of 882 metres long. Lane widths have been assumed to be 3 metres thus to total assumed width is 6 metres. Slopes of verges have been assumed at 1V:5H to allow mowing. The total volume of fill required is therefore estimated to be 6,900 m^3.

An estimated cost has been prepared based on the quantities shown in Table 4-1 below. The total preliminary cost estimate for the works is $905,556. No ongoing maintenance has been included as it is assumed that such work would form part of council's ongoing capital works regime and should be similar to the existing allocation, however this assumption should be confirmed as part of detailed cost estimation should the option be further progressed.

Table 4-1 Option 1 Cost Estimate

Item	Quantity	Units	$/Unit	Subtotal ($)
Removal of existing road surface	5,280	m2	$3.80	$20,064.00
Fill – compacted material suitable for levee and roadbase	6,900	m3	$40.00	$276,000.00
Crushed rock/metal base course including grading, rolling and consolidating to receive paving 150 mm thick	5,280	m2	$12.95	$68,376.00
Prime and two coats sprayed bitumen seal	5,280	m2	$11.20	$59,136.00
Hot Bituminous Concrete 25 mm thick	5,280	m2	$22.30	$117,744.00
Supply and install 450 RCP with anti backflow valves	48	m	$258.00	$12,384.00
Driveway crossovers	10	each	$5,000.00	$50,000.00
Design and Labour				$120,740.80
Contingency				$181,111.20
Total				**$905,556.00**

The model results were processed to assess the new AAD for Teesdale under the mitigated scenario. The resultant AAD 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 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.

4.2.3 Option 1 Discussion and Recommendation

While the conceptual levee does provide a significant benefit to properties on the west side of Pantics Road, adverse flood impacts caused by the levee cannot be ignored and are very difficult to justify. The savings afforded by this option are offset somewhat by additional flooding on properties on the flood side of the levee.

One factor that has not been considered in this assessment is the impact that the raised road may have on local runoff. While the cost estimate has included culverts with backflow valves, a detailed assessment of the upstream catchments and required capacity of those culverts has not been undertaken. It may be that the option worsens inundation from local runoff in such a way that the riverine benefits are lost completely.

The option has a significant cost associated with it and does not reduce flood damages sufficiently to offset this cost, leaving the project over half a million dollars in deficit after the 30 year test period. Further analysis indicates that with the saving of $12,547 in AAD, the total project cost would need to be reduced to $172,707.34 to achieve an even cost/benefit ratio, i.e. NPV = 0.

The financial analysis here does not account for isolation of properties during floods. In existing conditions, Pantics Road floods to depths beyond the limits of safety for most vehicles. Raising the road increases its flood immunity and therefore increases safety for residents of the road.

Further analysis and testing of various flood immunity levels for the road may provide a more favourable option, although it is noted that any reduction in road flood immunity is likely to reduce the savings in AAD. It is unlikely that any road height will produce a favourable benefit/cost ratio. Due to this further investigation of raising Pantics Road is not recommended. Future development in the area should consider the construction of a new road that does not traverse the floodplain, ensuring (rear) access to the properties along Pantics Road.

4.3 Option 2: Additional culverts under Bannockburn-Shelford Road

The Bannockburn-Shelford Road bridge lacks sufficient capacity to pass 2% AEP flows without overtopping the road. The existing bridge is approximately 18m wide with the soffit approximately 3.5 above the invert of the waterway. In a 1% AEP event there is a 0.6m drop in water level (head) across the road, indicating a large amount of energy is being lost as water passes over the road. Given the significant head drop across the road, adding additional flow capacity may prevent overtopping of the road in a 1% AEP event. This option was pursued iteratively, with the final run including 20 box culverts of dimension 2.1 x 0.9 metres on the east side of the bridge.

The final iteration of 20 x 2.1m x 0.9m culverts was arrived at after previous attempts to alleviate flooding of the road in a 1% AEP were unsuccessful. Previous runs had included 10 x 2.1m x 0.6m culverts and 20 x 2.1m x 0.6m culverts. The project team decided to have a final attempt at mitigating flooding with 20 culverts, despite the significant capital cost associated with such works.

In addition to the culverts themselves, this option requires excavation on the upstream side of the new culvert crossing to allow water to reach the proposed culverts at the nominated invert.

4.3.1 Option 2 Flood Impact

Modelling results indicate that the addition of 37.8m^2 of flow area was not enough to alleviate inundation of the road in a 1% AEP event. The option did have some benefit to the area upstream of the road with minimal impacts downstream. Flood levels were reduced by 0.33m immediately upstream of the culvert, tapering quickly to less than 0.15m. At a distance of around 250m from the culverts, the impact is negligible.

Downstream of the culverts, increased flood levels are localised to within 40m of the culvert outlet and are generally less than 0.1m. It is noted, however, that this occurs on private land and a shed does exist in the flow path. Negotiations with the impacted landholder would have to occur prior to further consideration of this option.

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The resultant change to flood levels in a 1% AEP event is shown in Figure 4-4 below.

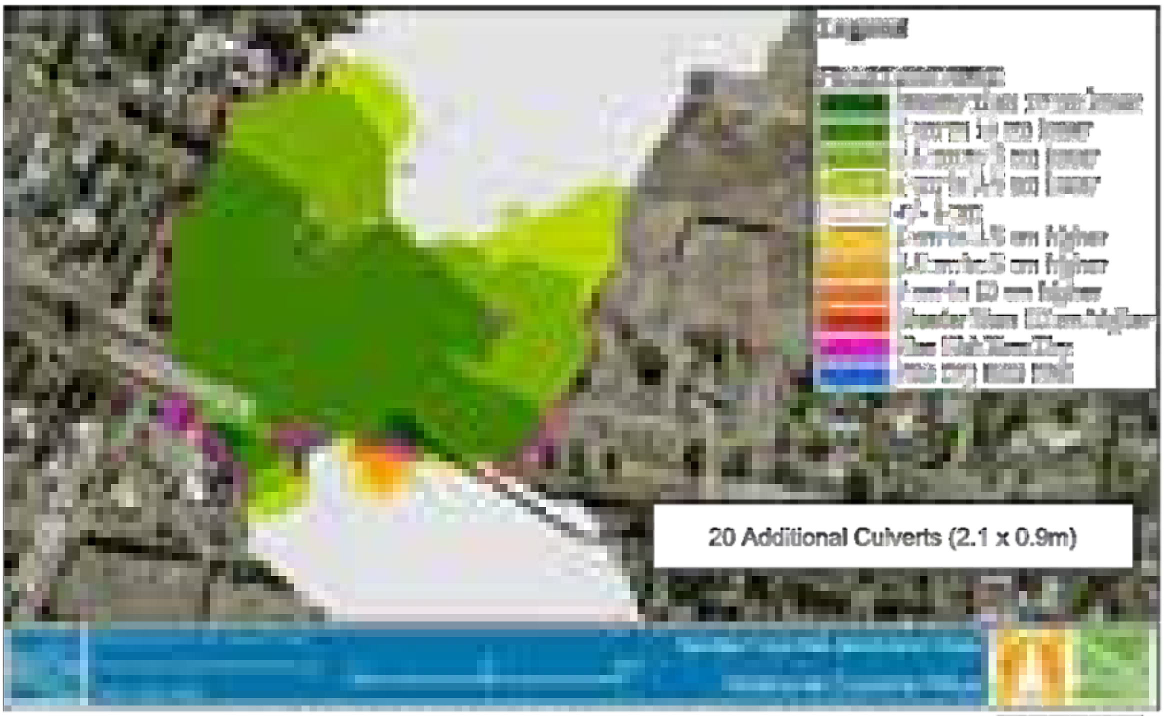

Figure 4-4 1% AEP Flood Level Afflux – Additional Culverts

4.3.2 Option 2 Cost/Benefit Assessment

The assessed reduction in AAD associated with Option 2 is $538 per year. This reduction is a result of the modest reductions in flood depths upstream of the crossing. Given no significant change to road inundation was achieved the minor change in AAD is not surprising.

The capital cost of implementing the option is shown in Table 4-2 below, with a total estimated cost of $478,712.50. No ongoing estimated costs have been assumed; however it is noted that at some point in time the culverts will require replacement which will be a significant renewal cost.

Table 4-2 Option 2 Cost Estimate

Item	Quantity	Units	$/Unit	Subtotal ($)
Remove road surface	450	m2	$3.80	$1,710.00
Excavate road and approaches for culverts	1000	m3	$20.70	$20,700.00
Supply and install 2.1 x 0.9 RCBC	270	metres	$1,080.00	$291,600.00
Supply and install headwall suitable for above	2	units	$40,000.00	$80,000.00
Supply and install road barriers at headwalls	100	m	$395.00	$39,500.00

Item	Quantity	Units	$/Unit	Subtotal ($)
Backfill and resurface road	450	m2	$46.45	$20,902.50
Design and Labour				$90,882.50
Contingency				$136,323.75
Total				**$681,618.75**

Given the insignificant reduction in AAD achieved, it is not surprising that the option results in a significant financial deficit. 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.

4.3.3 Option 2 Discussion and Recommendation

While some additional benefit may be realised by adding more culverts, increasing their size and/or lowering their invert levels, the cost/benefit ratio is unlikely to reach a level where the proposal becomes viable economically. Furthermore, by increasing the flow conveyance to the point where overtopping of the Bannockburn-Shelford Road is prevented, impacts downstream in the form of increased flood levels and potentially newly impacted properties become more and more likely.

Based on the cost/benefit ratio above, this option is not financially viable. In addition to the significant estimated cost for the works, the area of works is within an area of cultural heritage sensitivity and appears to require excavation in previously undisturbed areas. A Cultural Heritage Management Plan (CHMP) is likely to be required. The cost of developing and endorsing a CHMP has not been included in the above estimates. The cost/benefit ratio is therefore likely to be even worse than that stated.

Water Technology recommends that this option is not pursued or investigated further.

4.4 Option 3: Waterway Vegetation Clearing

There is a common perception in flood affected communities that waterway vegetation contributes to flooding by resisting flow of water. While this was not raised in the community consultation sessions held for the study, discussions with the Corangamite CMA suggested a mitigation analysis of waterway clearing may be warranted.

Clearing of the waterway was tested by lowering its roughness in the hydraulic model, representing smoother post clearing conditions. The model topography was not altered, i.e. a constructed channel was not considered. The modelling assumes the clearing will be maintained in perpetuity, i.e. that the works will be repeated as necessary to maintain the low roughness but not so regularly as to keep the waterway completely bare of vegetation and weeds.

The modelling adopted a manning's roughness value of 0.045 within the waterway. Design modelling had adopted to the value of 0.07 adopted for design and validation modelling. The value of 0.045 corresponds to a waterway with winding banks, some pools, shoals, weeds and stones. The waterway throughout the model extent had its roughness lowered, being approximately 11 linear kilometres of waterway.

4.4.1 Option 3 Flood Impact

As seen in the sensitivity analysis undertaken and detailed in R03 Design Modelling Report, the hydraulic model is highly sensitive to selection of the roughness parameters. It is therefore unsurprising that lowering the roughness of the waterway has a significant impact on flood levels through 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 it is 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 4-5 below.

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Figure 4-5 1% AEP Flood Level Afflux – Clearing of Native Hut Creek

4.4.2 Option 3 Cost/Benefit Assessment

Many assumptions are required to estimate the cost of Option 3. Waterway works, based on clearing works completed by contractors working closely with Water Technology recently, are estimated to cost around $35,000 per kilometre of waterway to be cleared. To clear the entire 11km of modelled waterway would cost around $385,000 based on this estimate.

The modelling involved clearing a 20 wide buffer along the waterway for 11km, resulting in a total of 22 hectares of vegetation "cleared" in the model. A detailed site assessment would be required to determine how much of the land to be cleared is native vegetation. Also required would be a tree assessment to determine how many large trees are to be cleared and any threatened fauna that may be living in the area.

In order to produce an estimate of costs, it has been assumed that 50% of the land to be cleared contains native vegetation and requires offsetting. An estimated 50 large trees have also been assumed. While pricing for native vegetation offsets is not standardised and can be difficult to budget for without quotes, the Melbourne Strategic Assessment (Environmental Mitigation Levee) Act 2020 provides a levy with standard pricing in lieu of developers in those areas purchasing offsets directly. Taking costs from the current MSA Levee[3] pricing as a guide, the estimates in Table 4-3 below were produced.

Table 4-3 does not address potential fencing replacement requirements, as these are impossible to predict without detailed planning. Any costs associated with fencing or other unforeseen issues are intended to be captured in the contingency.

Table 4-3 Option 3 Cost Estimate

Item	Quantity	Units	$/Unit	Subtotal ($)
Clear Waterway	11	km	$35,000.00	$385,000.00
Native Vegetation Offsets	11	ha	$166,874.00	$1,835,614.00
Large Trees	50	No.	$23,195.00	$1,159,750.00
Contingency				$1,014,109.20
Total				**$4,394,473.20**

In addition to the above capital costs, maintenance is estimated to cost approximately $3,500 per km per year being 10% of the capital clearing cost. Total maintenance therefore equals $38,500 per year.

The cleared scenario produces a resultant AAD of $96,003 per year, corresponding to a reduction of $17,363 per year. Given the reduction in AAD is less than the estimated maintenance, it can already be seen that the project will not achieve net savings.

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.

4.4.3 Option 3 Discussion and Recommendation

Modelling limitations

While the cost/benefit analysis above has attempted to quantify the significant costs associated with clearing of Native Hut Creek, there is no guarantee that the proposal could be approved. There are a number of significant approval hurdles associated with Option 3. These include, but aren't necessarily limited to:

[3] Melbourne Strategic Assessment (Environmental Mitigation Levy) Act 2020, current pricing accessed on 9/5/2023 from https://www.msa.vic.gov.au/regulatory-requirements/habitat-compensation

- Granting of a Planning Permit
- Cultural Heritage Management Plan endorsement
- Achievability of native vegetation offset requirements
- Potential triggering of other environmental legislation such as the Flora and Fauna Guarantee Act 1988, Environmental Protection and Biodiversity Conservation Act 1999 or others.

All of the above have costs associated with their application, investigation, assessment etc. that have not been directly accounted for in the above cost estimate, noting however that the 30% contingency is a significant figure and may account for some or all of these costs.

Even if all of the above challenges were surmountable, the option is financially irrational in addition to being ecologically damaging. Clearing waterways of vegetation degrades and destroys habitat and increases the risk of erosion. Waterway erosion creates the need for significant investment to protect assets threatened by the shifting banks. Eroded material is transported as sediment and deposited downstream, smothering downstream habitats and further degrading the habitat quality of the system.

Further analysis indicates that with the saving of $17,363 in AAD, the total project cost would need to be reduced to $238,998.76 to achieve an even cost/benefit ratio, i.e. NPV = 0, with no ongoing maintenance costs. This is an unachievable budget to undertake the works and approvals required.

Water Technology recommends that this option is not pursued or investigated further.

4.5 Cost-Benefit Summary

Table 4-4 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 4-4 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 4-4 clearly demonstrates that none of the mitigation methods investigated achieve favourable financial outcomes. None of the options are recommended for further investigation.

5 NON-STRUCTURAL MITIGATION

5.1 Planning Controls

Mitigation of potential future flood impacts can be achieved by updating the local planning scheme to reflect the flood intelligence produced by the Teesdale Flood Risk Identification Study (this study). Updating the planning scheme mapping allows development applications within the floodplain to be assessed in line with current national, state, regional and local policies. The ultimate effect of this will be to ensure inappropriate development within the floodplain does not occur, reducing the number of future buildings and occupants exposed to flood risk. As seen by the damages assessment above, there are few dwellings within the Native Hut Creek floodplain. By implementing planning controls this can be maintained and flood average annual damages for Teesdale can remain low, avoiding significant natural disaster impacts in the future.

Draft planning scheme mapping has been developed in line with the project brief and as discussed in a project meeting on the 4th April 2023. The mapping has not considered the use of the Urban Floodway Zone given the lack of urbanisation in Teesdale, in addition to the highly restrictive nature of that zoning.

The draft flood related overlays have been developed based on the 1% AEP behaviour for the year 2100, as projected under Representative Concentration Pathway RCP8.5. Flood modelling of the scenario was undertaken in line with Australian Rainfall and Runoff 2019 and is detailed in R04 – Design Modelling Report. The Land Subject to Inundation Overlay (LSIO) has adopted the projected flood extent while the Floodway Overlay (FO) has been applied to those areas where any of the following are exceeded:

- 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 above FO threshold aligns with the "H2" hazard classification threshold as detailed in the Australian Disaster Resilience Guideline 7-3 *Flood Hazard* (AIDR 2017). It is also the Corangamite Catchment Management Authority's threshold of choice for delineating the high hazard portion of the floodplain.

The resultant draft planning scheme mapping is shown in Figure 5-1 below.

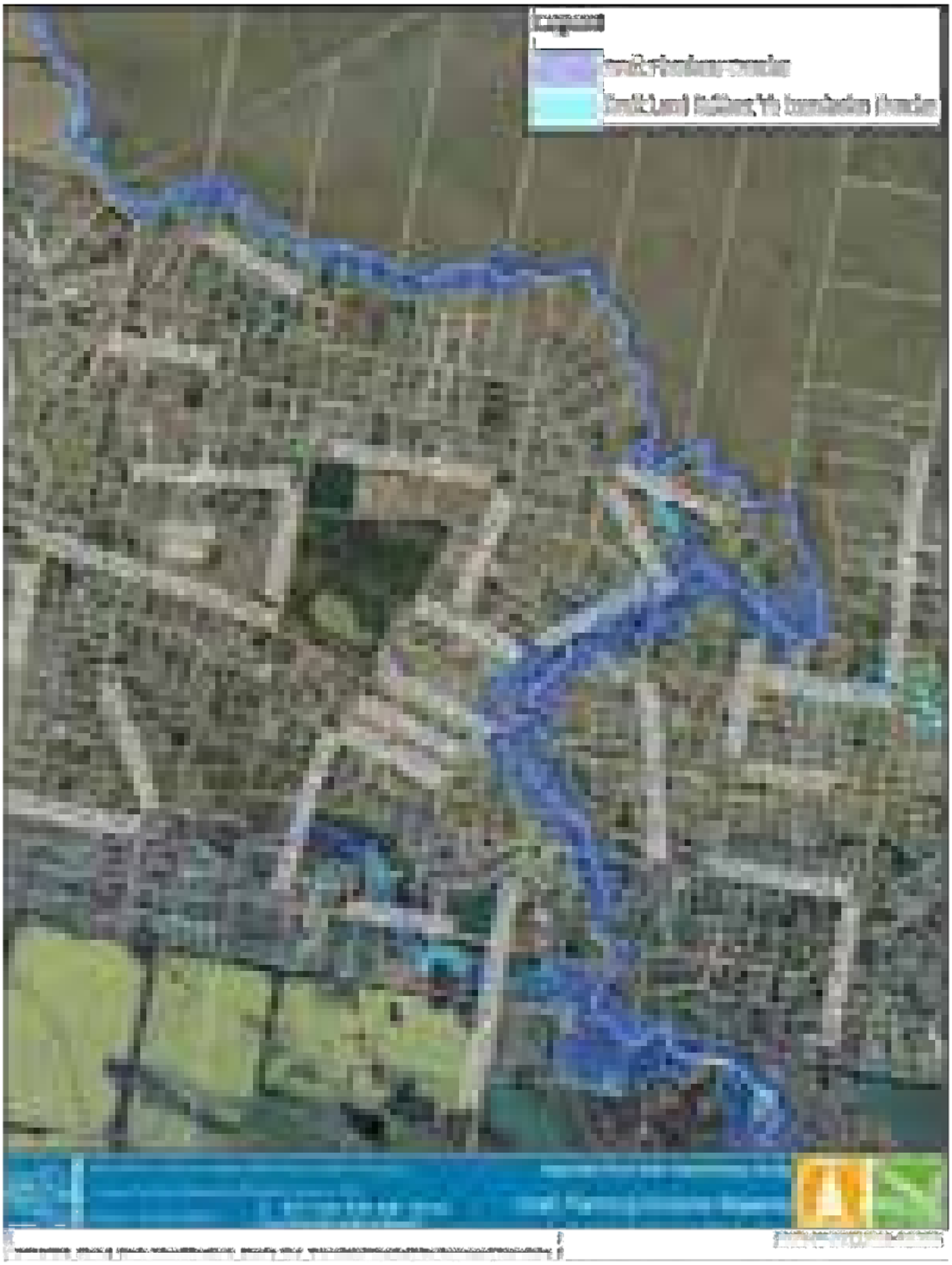

Figure 5-1 Draft Planning Scheme Mapping

5.2 Discussion – Adoption of Increased Rainfall Intensity

5.2.1 Policy Context

As discussed above, the draft planning mapping has been developed based on modelling which accounted for projected increased rainfall intensity to 2100 under RCP8.5. Clause 13.01 of the Victorian Planning Provisions is specific when dealing with sea level rise. The clause includes the strategy to plan for sea level rise of not less than 0.8 metres by 2100 and allow for the combined effects of tides, storm surges, coastal processes and local conditions such as topography and geology when assessing risks and coastal impacts associated with climate change. The Planning Provisions are not so specific when dealing with riverine flood risk, with Clause 13.03-1S including a strategy to identify the 1% AEP floodplain in planning schemes.

Notwithstanding the above, Clause 13.01 of the Provisions deals with climate change and includes the strategies to *respond to the risks associated with climate change in planning and management decision making processes* and to *identify at risk areas using the best available data and climate change science*. Thus the Provisions have established the following:

- The 1% AEP flood is the Design Flood Event against which planning decisions should be made and should be identified in the planning scheme;
- Areas at risk from climate change should be identified using the best available science; and
- A planning horizon to the year 2100 is appropriate in the context of coastal inundation.

It follows that a planning horizon to the year 2100 should therefore be appropriate for riverine inundation. Areas projected to be subject to riverine inundation in 2100, as identified using the best available science, should be identified. The Planning Scheme is the most appropriate means by which to identify these areas, as has recently been done using Schedules to the Land Subject to Inundation Overlay to identify coastal areas subject to inundation in a 1% AEP storm surge event with 0.8 metres of sea level rise[4].

5.2.2 Effect of Increased Rainfall Intensity

To understand the implications of adopting this scenario for the planning mapping, a comparison of draft planning scheme mapping has been undertaken for the increased intensity scenario compared to the present day 1% AEP event.

By delineating the flood related planning scheme overlays based on the projected scenarios, a cautious approach is adopted. The actual impact of this approach, however, is minimal. Table 5-1 shows the number of properties impacted by flood related overlays in the present day 1% compared to the climate change scenario. The figures in Table 5-1 exclude public reserves such as Turtle Bend and the waterway parcels.

Table 5-1 Properties impacted by flood related overlays, present day vs 2100 RCP8.5

	Present Day 1% AEP	2100 1% AEP under RCP8.5
Total Parcels Affected	136	139
Parcels Intersecting LSIO	136	136
Parcels Intersecting FO	125	130

The most significant difference in the mapping is an additional breakout which occurs in the increased rainfall scenario but not in the present day scenario. The breakout crosses Stones Road and flows through two parcels not impacted by flooding in the present day scenario and can be seen in Figure 5-2 below.

[4] Greater Geelong Planning Scheme Amendment C394ggee

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Figure 5-2 Comparison of the 1% AEP flood extents under present day and 2100, RCP8.5 conditions

Inclusion of the 2100 mapping in the Planning Scheme does not imply that results from the 2100 RCP8.5 modelling will be used to inform all responses to development within the Teesdale floodplain. Inclusion of the mapping instead triggers a permit application referral and gives the Corangamite CMA the opportunity to *respond to the risks associated with climate change in planning and management decision making processes* as required by the Scheme. If the Scheme mapping were not based on the 2100 RCP8.5 1% AEP extent, that opportunity may be missed.

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6 SUMMARY

Flood damages, in the form of Average Annual Damages (AAD), have been assessed for the township of Teesdale based on flood modelling of Native Hut Creek undertaken as part of the Teesdale Flood Risk Identification Study. The average annual cost in Teesdale as a result of flooding from Native Hut Creek equates to $113,366 per year. In the 1% AEP flood event, two dwellings are inundated above floor and 114 properties are impacted by floodwaters.

Three structural mitigation options were tested to reduce flood impacts and associated damage costs within the town. The options were:

- Raising Pantics Road to form a levee,
- Placement of additional culverts under Bannockburn-Shelford Road bridge, and
- Clearing the waterway.

Each option was tested in the hydraulic model, with the model results processed and an updated AAD calculated for the mitigation option. Cost estimates of each option were assessed against the option's reduction in AAD from the existing case to inform net present value analysis.

Based on the above assessment methodology, none of the options tested were shown to be financially viable. In addition to not being financially viable, clearing of Native Hut Creek was identified as having numerous legal approvals that are highly unlikely to be obtained regardless of investment. Raising of Pantics Road was found to have potential issues with local stormwater however this was not investigated as the financial viability does not invite further investigation. It is important to consider that future infrustructure upgrades to road and drainage may present an opportunity for improved drainage and flood resilience within the township. While this may not meaningfully reduce damages in measurable financial terms it may support improved resilience and safe access in minor events.

Non-structural mitigation in the form of town planning controls have also been presented. The Planning Scheme mapping has been based on model results with increased rainfall intensity under projected RCP8.5 to the year 2100. A comparison of the resultant maps to those that would have resulted from the "present day" modelling results was presented, with the increased rainfall scenario impacting three additional properties in total. The mapping has delineated the floodway overlay based on the Corangamite Catchment Management Authority's preferred delineation criteria.

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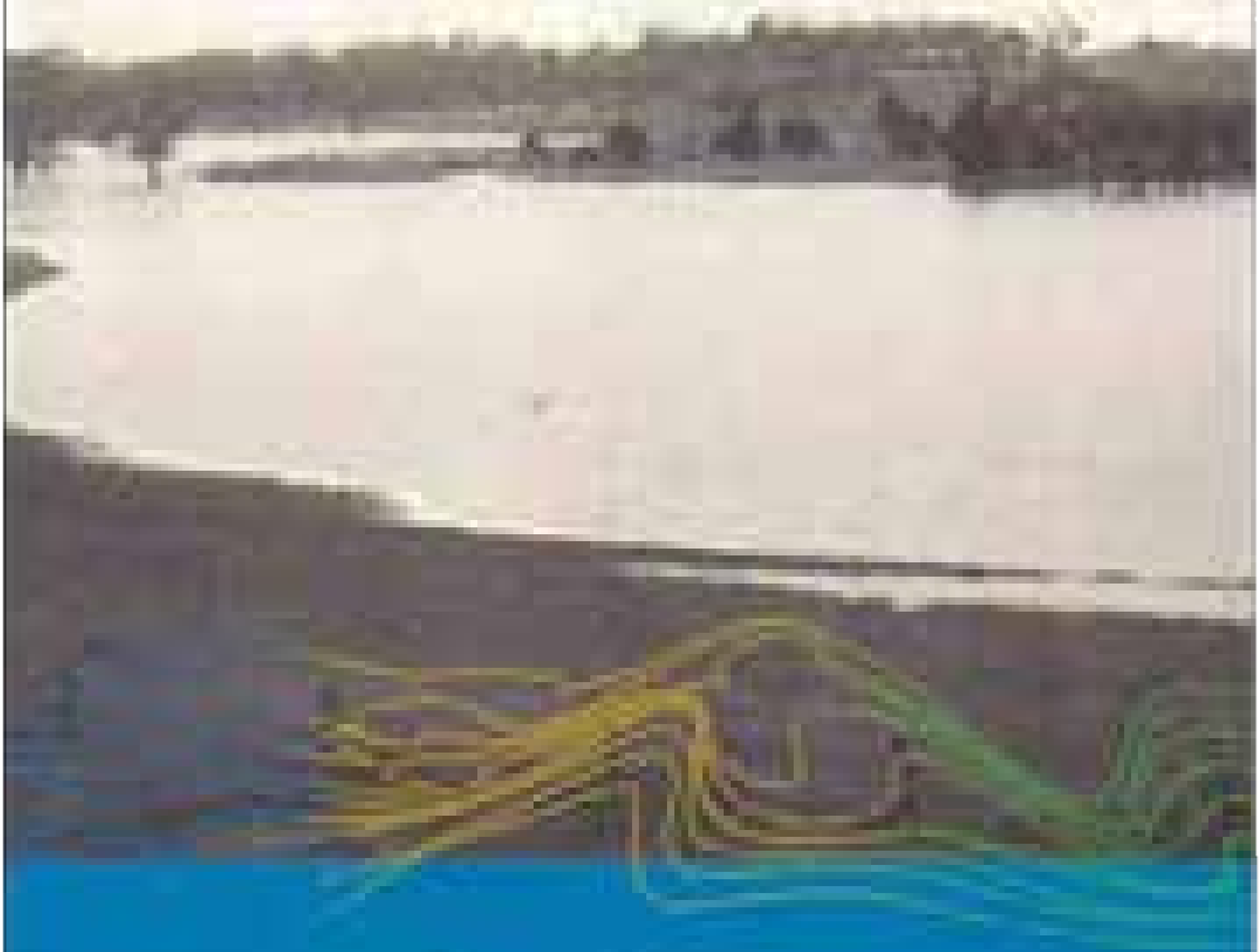

Summary Report

Teesdale Flood Risk Identification Study

Golden Plains Shire

12 May 2023

Document Status

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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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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.

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

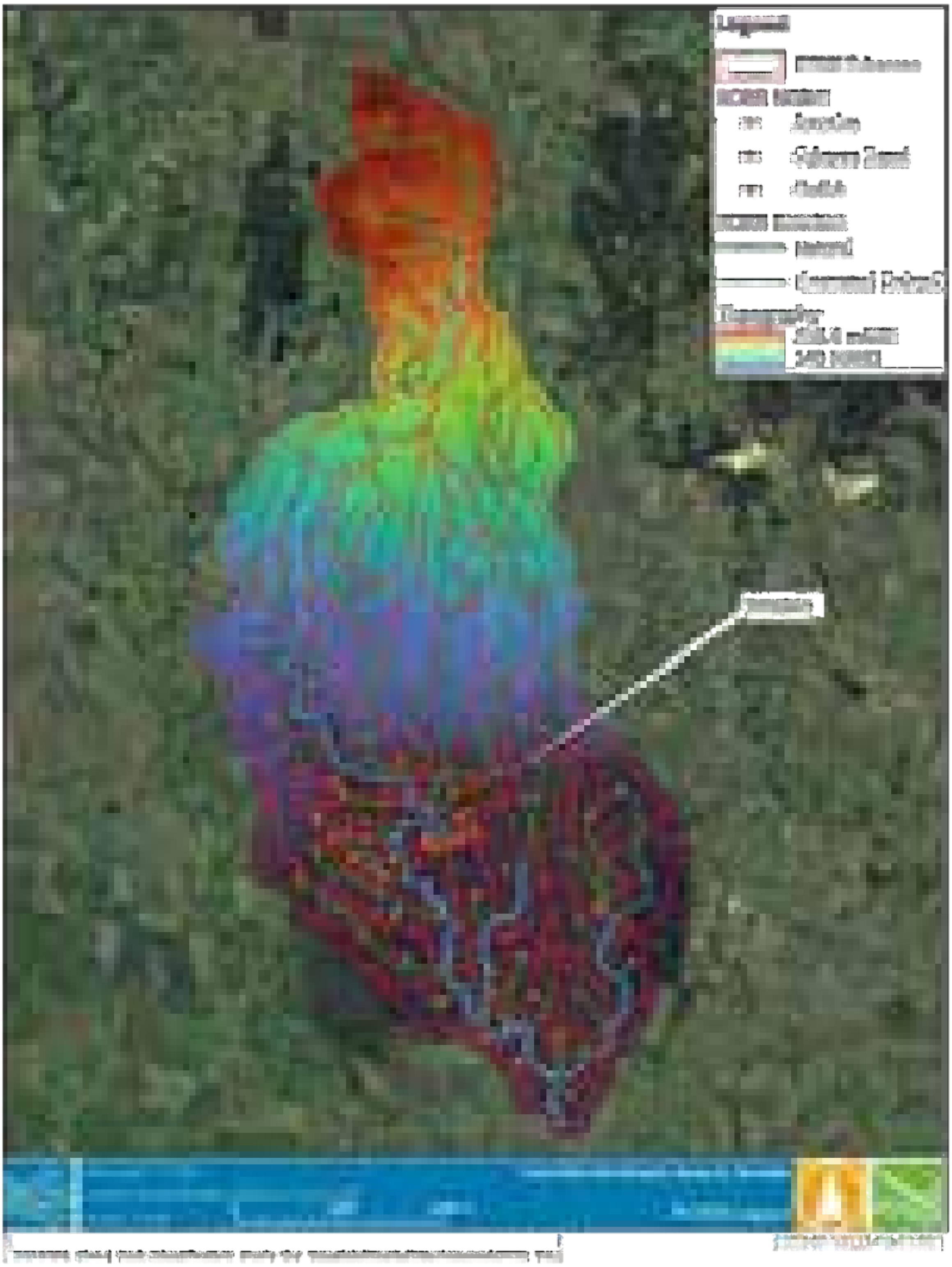

Figure 3-1 RORB model layout

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

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.

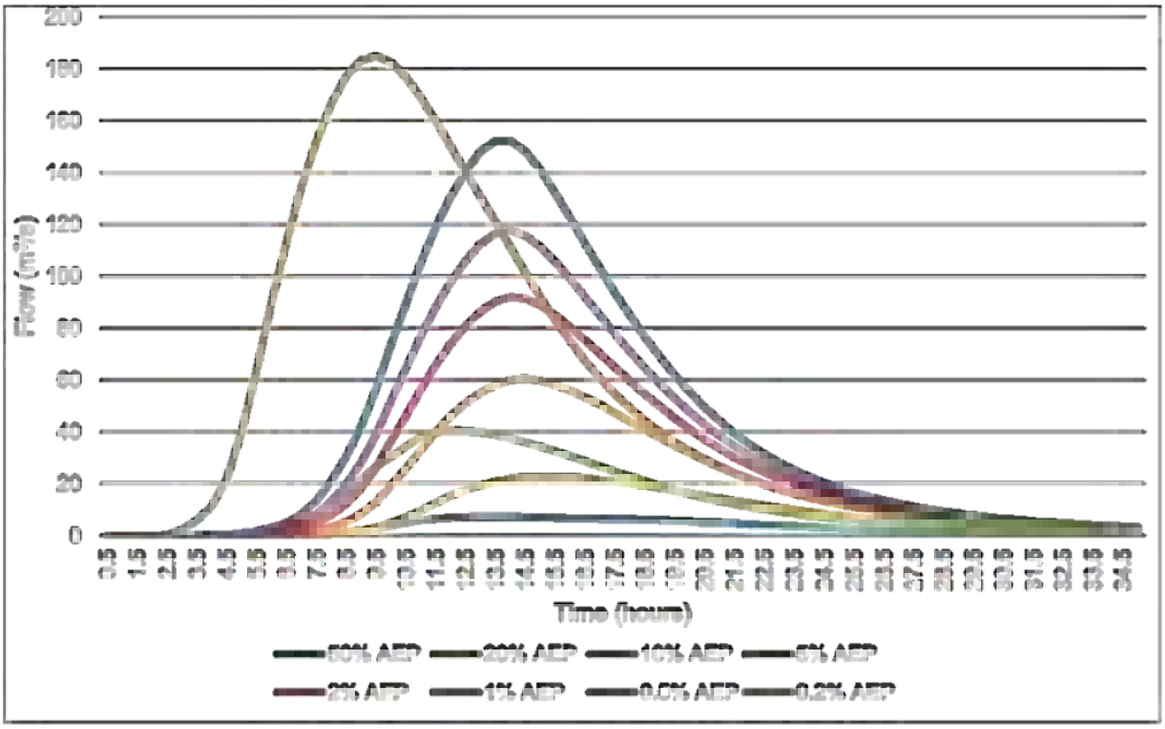

Figure 4-1 Design hydrographs, Native Hut Creek at Bannockburn-Shelford bridge

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)

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

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.

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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 m^3/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 m^3/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 m^3/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 m³/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 m³/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 m³/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 m³/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 m³/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	

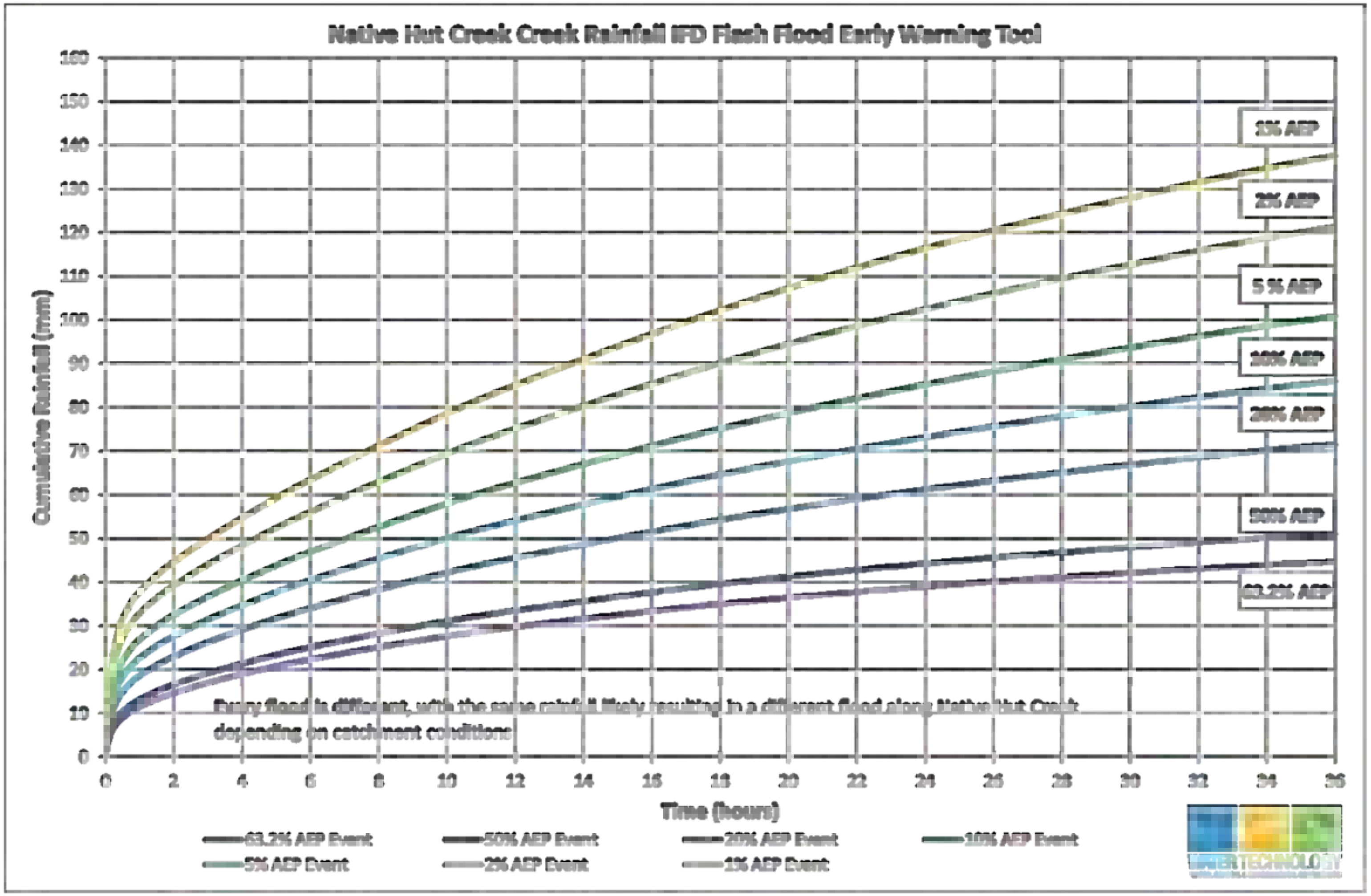

Figure 5-1 Teesdale Flood/No Flood Tool

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.

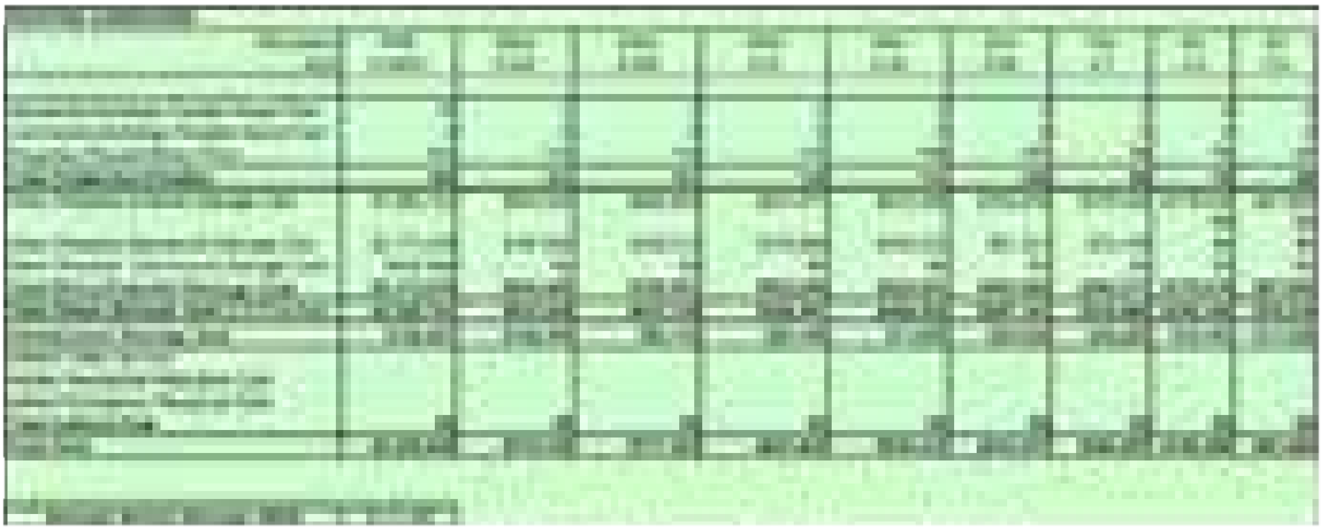

Figure 6-1 Existing Conditions Average Annual Damages (AAD)

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.

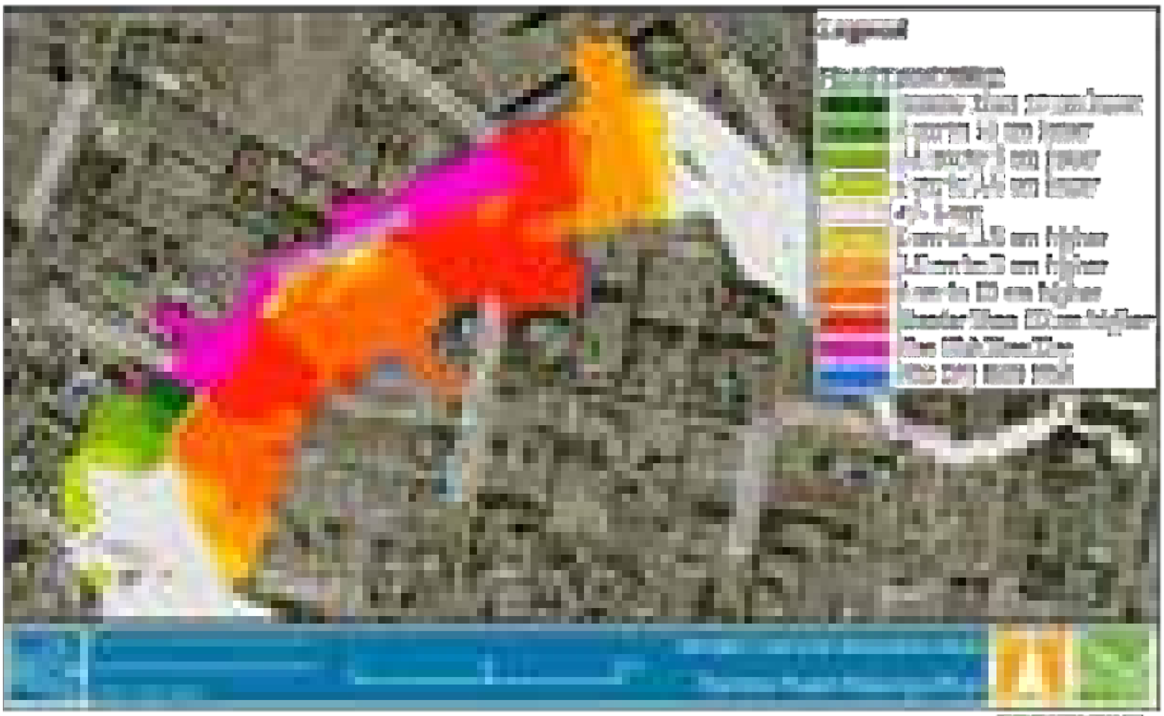

Figure 6-2 1% AEP Flood Level Afflux – Raising of Pantics Road

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.

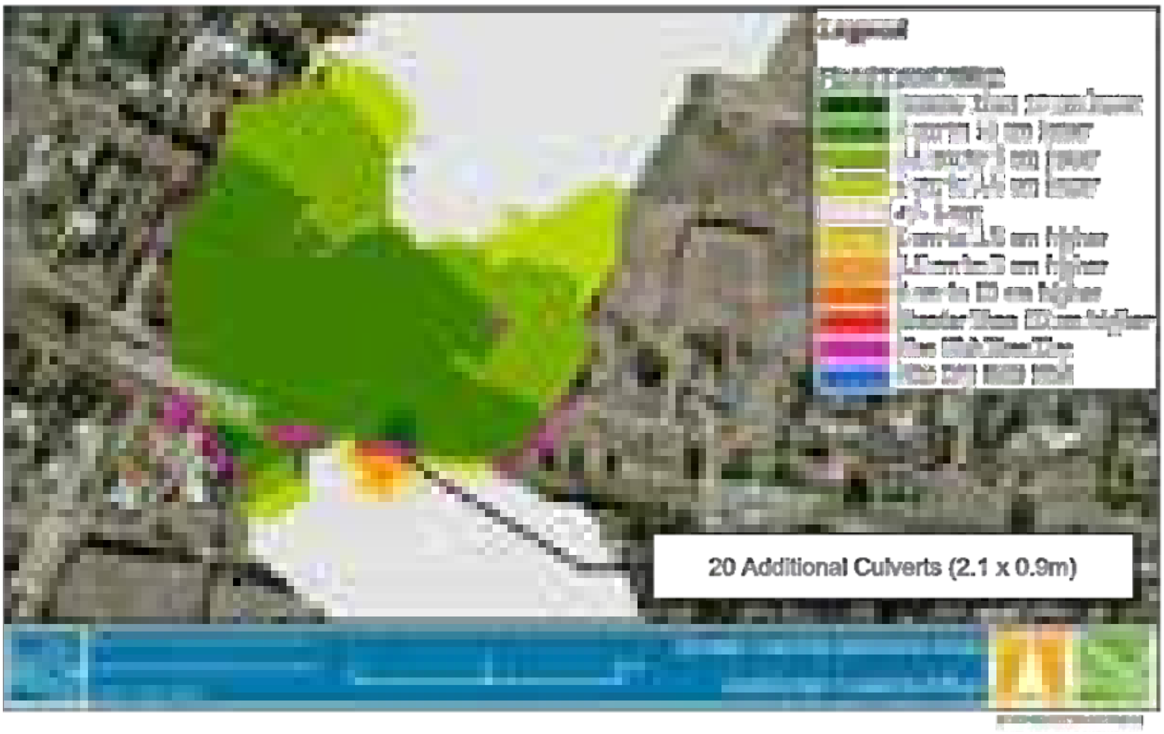

Figure 6-3 1% AEP Flood Level Afflux – Additional Culverts

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.

Figure 6-5 Draft Planning Scheme Mapping

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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watertech.com.au

Planning and Environment Act 1987

Golden Plains Planning Scheme

Amendment C104GPLA

Explanatory Report

Overview

The amendment implements the *Teesdale Flood Risk Identification Study* (Water Technology Pty Ltd, 2023), the 'Study', by applying new flood mapping to land identified as flood prone in the township of Teesdale by inserting a new Schedule 2 to the Floodway Overlay (FO2) and Schedule 2 to the Land Subject to Inundation Overlay (LSIO2).

The amendment also corrects a past error by providing Schedule 2 for existing FO and LSIO land across the municipality, except for land in Inverleigh whose flood controls are already in Schedule 1; LSIO1 and FO1. Existing LSIO and FO mapped areas will be correctly identified as FO2 and LSIO2. The schedules for these areas were inadvertently removed from the Golden Plains Planning Scheme when Amendment C80gpla was gazetted on 5 September 2019.

Where you may inspect this amendment

The amendment can be inspected free of charge at the Golden Plains Shire Council website at https://www.goldenplains.vic.gov.au/resident/planning/strategic-planning-projects

And/or

The amendment is available for public inspection, free of charge, during office hours at the following places:

Bannockburn Customer Service Centre	The Well
2 Pope Street	19 Heales Street
Bannockburn VIC 3331	Smythesdale VIC 3351

The amendment can also be inspected free of charge at the Department of Transport and Planning website at http://www.planning.vic.gov.au/public-inspection or by contacting the office on 1800 789 386 to arrange a time to view the amendment documentation.

Submissions

Any person may make a submission to the planning authority about the amendment. Submissions about the amendment must be received by 10 March 2025.

A submission must be sent to:

Golden Plains Shire Council

PO Box 111

BANNOCKBURN VIC 3331

Panel hearing dates

In accordance with clause 4(2) of Ministerial Direction No.15 the following panel hearing dates have been set for this amendment:

- directions hearing: 2 June 2025
- panel hearing: 30 June 2025

Details of the amendment

Who is the planning authority?

The amendment has been prepared by the Golden Plains Shire Council which is the planning authority for this amendment.

The amendment has been made at the request of the Council and the Corangamite Catchment Management Authority (CMA).

Land affected by the amendment

Teesdale

The amendment applies to land in the township of Teesdale, which is situated on the banks of the Native Hut Creek, as shown in figures 1-3.

The amendment applies to land in Teesdale projected to be affected by floodwater during a 1% Annual Exceedance Probability (AEP) flood event, incorporating 2100 climate change projections, as identified in the Study. These areas will be shown on LSIO-FO combined planning scheme maps as FO2 and LSIO2.

Other areas

The amendment also applies to all other areas in the municipality currently affected by the FO and LSIO maps but, which do not have an associated overlay schedule. These areas will be renamed to FO2 and LSIO2. The effect of this change will be that the extent, or coverage, of the existing FO and LSIO maps will not change and that the new schedules will provide planning permit exemptions which will be a benefit for landowners.

Areas of FO1 and LSIO1 that apply in Inverleigh are unaffected by this amendment.

A mapping reference table is found at the end of this document, at Attachment 1.

Figure 1: Teesdale amendment overlay areas showing the extents of the proposed FO2 and LSIO2. Note the overlay extents that are outside the study area remain unchanged.

Figure 2: Teesdale amendment overlay areas showing the extent of the current FO compared to the proposed FO2. A small section of the FO is shown as removed from the south east extent of the flood study boundary. Note the overlay extents outside the study area remain unchanged.

Figure 3: Teesdale amendment overlay areas showing the extent of the current LSIO compared to the proposed LSIO2. Note that the missing gap between them indicates the new extent of the proposed FO2 not shown on this map. Note the overlay extents outside the study area remain unchanged.

What the amendment does

The amendment implements the findings of the Study which was adopted by the Council at its ordinary meeting on 24 October 2023. It is also correcting an error by updating LSIO-FO maps across the Shire to LSIO2 and FO2.

Specifically, the amendment seeks to:

Overlays maps

- Amend maps 24 LSIO-FO and 26 LSIO-FO to apply new flood mapping in Teesdale, as shown in figure 1 and in the attached planning scheme maps.
- Amend maps throughout Golden Plains Shire 01 LSIO-FO, 02 LSIO-FO, 03 LSIO-FO, 04 LSIO-FO, 05 LSIO-FO, 06 LSIO-FO, 07 LSIO-FO, 08 LSIO-FO, 10 LSIO-FO, 11 LSIO-FO, 12 LSIO-FO, 13 LSIO-FO, 15 LSIO-FO, 16 LSIO-FO, 17 LSIO-FO, 18 LSIO-FO, 19 LSIO-FO, 20 LSIO-FO, 21 LSIO-FO, 22 LSIO-FO, 23 LSIO-FO, 24 LSIO-FO, 25 LSIO-FO, 26 LSIO-FO, 28 LSIO-FO, and 29 LSIO-FO to update the reference number in the maps from FO to FO2 and LSIO to LSIO2 as shown in the attached maps.

Planning scheme ordinance

- Insert a new Schedule 2 to Clause 44.03 Flood Overlay as shown in the attached document.
- Insert a new Schedule 2 to Clause 44.04 Land Subject to Inundation as shown in the attached document.
- Replacing the Schedule to Clause 72.08 (Background Documents) with a new Schedule to include the Teesdale Flood Risk Identification Study (Water Technology 2023).

Strategic assessment of the amendment

Why is the amendment required?

The amendment is required to implement the findings of the Study to update riverine flood mapping for Teesdale, and to insert new schedules FO2 and LSIO2 that include planning permit exemptions for minor developments and works to reduce permit burdens on landowners. The new FO2 and LSIO2 schedules at Clauses 44.03 and 44.04 will also be used for existing FO and LSIO to reintroduce and update flood overlay local schedules that were inadvertently removed upon the gazettal of Amendment C80gla in 2019.

Teesdale

In response to significant flood events across Victoria, the Council, with the support of the Corangamite CMA, commissioned a flood investigation to understand, and respond to, flood risk throughout the township of Teesdale. The Study was undertaken by Water Technology on behalf of the Council.

The Study provides the most recent information on flooding in Teesdale. The inclusion of the updated mapping into the Golden Plains Planning Scheme will ensure the scheme is current and contains the most accurate information available.

The amendment identifies land that is likely to be within the 1% Annual Exceedance Probability flood extent with a climate change projected rainfall intensity increase of 18.4%, to 2100. The flood lines used for the overlays are based on a flood event that has a 1 percent chance of occurring in any given year. The time horizon of 2100 has been chosen because typically most built form such as housing will still be in use by that time period. A high emission scenario has been chosen to allow for climate change uncertainty. This is the standard practice when planning for flood events with respect to climate change.

The Study provides recommendations for making changes to the existing planning scheme in areas identified as being at risk of flooding. A key implementation task from the Study is to update flood controls and mapping in the Golden Plains Planning Scheme.

The amendment applies a combination of updated FO and LSIO controls. The application of these planning controls allows some development to occur within floodwaters which are deemed low risk but is more restrictive for development in high-risk areas.

The changes to the proposed FO2 and LSIO2 maps in Teesdale will increase the area covered by the controls to include an additional 38 properties. The extent of the changes to the proposed overlays, can be seen in figures 1-3.

While engineering mitigation works and emergency response plans play a very important role in alleviating the impacts of flooding, in the long term, one of the most effective means of reducing the impact of flooding on communities is the establishment of appropriate planning scheme controls. The overlays have been used in this case to ensure appropriate development in areas affected by flooding.

Other areas

In September 2019, Amendment C80gpla introduced flood controls (FO1 and LSIO1) to Inverleigh. When C80gpla was approved and published in the Victoria Government Gazette an administrative error occurred that inadvertently removed the FO and LSIO schedules that had corresponded to the existing FO and LSIO mapping throughout the shire. No schedules have applied to these overlays since this time.

This amendment will correct this error by applying the Teesdale schedules to the existing FO and LSIO mapping which are proposed to be renamed FO2 and LSIO2.

Since 2019, most buildings and works within the existing FO/LSIO areas have required a planning permit. The effect of the local schedules is to provide exemptions where appropriate to exempt certain low risk buildings and works from the need for a planning permit.

The proposed new schedules are based on the content from the removed schedules but have been updated in accordance with the requirements of the Corangamite CMA and to align with the Victoria Planning Provisions and the form and content requirements of the Ministerial Direction s7(5). They are appropriate for the areas within the existing mapping and also for the new areas in Teesdale.

How does the amendment implement the objectives of planning in Victoria?

The amendment implements the objectives of planning in Victoria as outlined in section 4(1) of the *Planning and Environment Act 1987* as follows:

a) *Provide for the fair, orderly, economic and sustainable use, and development of land.*

The amendment will result in the fair, orderly, economic and sustainable use and development of land by implementing a well-planned, holistic approach to addressing flooding impacts in the existing and future community of Teesdale and the broader Golden Plains Shire community. The amendment will regulate development in hazardous areas.

This amendment will assist landowners and occupiers to understand the potential flood risk and provide more certainty to the community. It will assist the Council and the Corangamite CMA in making more informed and effective decisions on development of land affected by flooding.

b) *Provide for the protection of natural and man-made resources and the maintenance of ecological processes and genetic diversity.*

The amendment identifies and protects local environmental features by applying flood controls to protect the natural functions of floodplains from unsuitable development. The amendment will ensure that new development is appropriately designed and located for flood risk in a manner that maintains the free passage and temporary storage of floodwaters, and that future development does not compromise natural systems.

c) *Secure a pleasant, efficient and safe working, living and recreational environment for all Victorians and visitors to Victoria.*

The amendment more accurately identifies areas prone to flooding in Teesdale and appropriately reintroduces missing flood overlay schedules throughout the Golden Plains Shire. This will ensure development is managed safely in and around the floodplains which will assist in creating townships where communities can live, work and play safely and provide for a more efficient recovery from future flooding events.

f) *Facilitate development in accordance with the objectives.*

The amendment achieves the objectives of planning in Victoria by introducing a suite of planning scheme provisions to guide development for the benefit of the Golden Plains Shire, consistent with state, regional and local planning policy.

g) *Balance the present and future interests of all Victorians.*

The amendment supports this objective by identifying flood prone land based on a climate change high emission scenario for 2100 in the township of Teesdale. Development that is built for the long term will assist with intergenerational equality, while at the same time, alleviate the more immediate impacts that flooding can have on communities. The overlay schedules have been drafted to ensure development occurs in a logical manner consistent with the objectives of planning in Victoria.

How does the amendment address any environmental, social and economic effects?

Environmental effects

The amendment identifies flood-prone areas. Areas of environmental significance, such as swamps, billabongs and wetlands have an important role to play in supporting biodiversity, recycling nutrients and maintaining water quality. Through this amendment, these areas can be protected from inappropriate development that may pose a threat to water quality and flora and fauna communities The identification of flood-prone areas will ensure that development is compatible with local environmental conditions including flood hazards and drainage conditions.

The application of the FO2 and LSIO2 in Teesdale, which is underpinned by the Study, will ensure future development is managed in areas subject to flooding. The amendment will prevent development from occurring in areas that are subject to flooding that could reduce the capacity of the floodplain to store and convey water, and consequently will help protect the creek environs.

The appropriate location of development will reduce the impact that floating debris and sewage can cause to vegetation throughout floodplains during and after flooding events.

Social effects

This amendment aims to facilitate the orderly growth and development in relation to flooding impacts within the Golden Plains Shire.

The amendment applies restrictions on the development of land with the application of the flood overlays. This will minimise the effect of development on flood processes.

In the Teesdale township, these overlays could impact landowners by restricting what they can do with their land or requiring conditions for how to develop on some properties which were previously not covered by the current flood overlays. However, the overlays will ensure that development is undertaken in a safe manner. While in the case of reintroducing the mistakenly removed schedules, this will have the opposite effect, by providing exemptions to planning permit triggers for minor developments such as open type rural fencing. Overall, the amendment provides a community benefit by protecting important assets and protecting life and property.

Flooding can have significant consequences for individuals and for local communities. The impacts can include loss of life, loss of property and temporary or permanent displacement. Flooding may affect people and communities differently. Health, mental health and social vulnerability may be exacerbated for people living in exposed communities and can make normally resilient people vulnerable.

Specific groups within communities exposed to flooding may be further disadvantaged. For example, people with disability may be more disadvantaged than people without disability in responding to a flood event. This may be because people with disability may face barriers to receiving or understanding emergency warnings. Ensuring appropriate development occurs reduces the chance of socially vulnerable people living in flood prone areas.

Over the long term, applying appropriate planning controls will reduce the compounding impacts of social vulnerability.

Economic effects

The amendment is expected to have positive economic effects for the municipality. The identification of flood risk through planning scheme mapping will provide increased certainty to the community and reduce future economic loss from flooding. Flooding carries significant costs for the community, individual landowners and occupiers and the state.

Flood damage can disrupt communities and in extreme cases, cause extensive and costly damage to public and private assets, cause agricultural and industry losses, personal hardship and loss of life. By careful planning of new development, having regard to flood risk, future economic impacts of flooding can be reduced.

The publicly available flood risk information will assist current and future landowners make informed choices prior to purchasing and developing land. This information will assist in establishing future industries, tourism and community facilities in appropriate locations. Additionally, minor buildings and works are exempt under the proposed schedules to avoid unnecessary planning regulation.

Does the amendment address relevant bushfire risk?

The amendment does not increase the risk to life, property, community infrastructure or the natural environment from bushfire, as it identifies flood risk but does not facilitate strategic planning in identifying new locations for intensifying development.

The amendment meets bushfire policy in Clause 13.02 of the Planning Scheme. Much of the land affected by this amendment is unlikely to be intensified for urban purposes without subsequent planning approval, and further consideration and assessment against the purpose and decision guidelines of the Bushfire Management Overlay, where applicable.

Does the amendment comply with the requirements of any Minister's Direction applicable to the amendment?

The amendment complies with Minister Direction No. 11, *Strategic Assessment of Amendments*, under section 12 of the *Planning and Environment Act 1987* (P&E Act). The amendment is consistent with this direction which ensures a comprehensive strategic evaluation of a planning scheme amendment and the outcomes it produces. This explanatory report provides a comprehensive strategic evaluation of the amendment and the outcomes it produces.

It also complies with the form and content requirements of the Ministerial Direction *The Form and Content of Plannings Schemes,* section 7(5) of the P&E Act.

How does the amendment support or implement the Planning Policy Framework and any adopted State policy?

The amendment is consistent with the following clauses of the Planning Policy Framework and will assist in achieving objectives of the clauses:

Clause 11 – Settlement

The amendment is consistent with identifying that planning for settlements must have regard to *"health, wellbeing and safety"* and supports *"…anticipate and respond to the needs of existing and future communities…"*. The amendment supports this principle by documenting the extent of flooding now and into the future (for Teesdale) and the degree of risk from its impacts.

Clause 11.01-1S – Settlement

The amendment is consistent with the objective *"to facilitate the sustainable growth and development of Victoria and deliver choice and opportunity for all Victorians through a network of settlements"* by updating the extent of flooding in the Teesdale township and reintroducing mistakenly removed schedules. Applying the FO2 and LSIO2 for the degree of risk from flooding impacts will ensure that development within flood prone areas is regulated to prevent impacts to human life and property. The FO2 applies to areas that are at risk of faster flood flows and depths and the LSIO2 where the flood risk is lower.

This amendment is also consistent with *"minimising exposure to natural hazards, including increased risks due to climate change"* and *"support metropolitan and regional climate change adaption and mitigation measures"* by identifying land in the township of Teesdale that is likely to be within the 1% Annual Exceedance Probability flood extent under an climate change high emission scenario projected to 2100.

Clause 12.03-1S – River and riparian corridors, waterways, lakes, wetlands and billabongs

The amendment is consistent with the objective "*to protect and enhance waterway systems including river and riparian corridors, waterways, lakes, wetlands and billabongs*". It implements the following strategies: "*address the impacts of use and development on drought and flooding events at a catchment and site scale to protect the health and natural function of waterway systems and their surrounding landscape and environment*"; and "*design and site development to maintain and enhance the natural environment of waterway systems by: avoiding impeding the natural flow of waterways and future flood events*".

Clause 13 – Environmental risks and amenity

The amendment is consistent with strengthening the resilience and safety of communities by adopting a best practice environmental management and risk management approach. It assists in identifying, preventing and minimising the risk of harm to the environment, human health and amenity though development compatibility and effective controls to reduce significant impacts. Along with ensuring development and risk mitigation does not detrimentally interfere with important natural processes. In the township of Teesdale, the amendment prepares for and responds to the impacts of climate change.

Clause 13.01-1S – Natural hazards and climate change

The amendment is consistent with the objective *"to minimise the impacts of natural hazards and adapt to the impacts of climate change through risk-based planning"* by implementing the following strategies: *"identify at risk areas using the best available data and climate change science"*; *"direct population growth and development to low risk locations"*; *"site and design development to minimise risk to life, health, property, the natural environment and community infrastructure from natural hazards"*.

It assists with climate change adaptation responses in the township of Teesdale through implementing overlays based on climate change which will guide planning and management decision making processes such as where intensification of development is appropriate. The Teesdale overlays were prepared in line with the *Australian Rainfall and Runoff 2019* methodology which was the recommended approach at the time the Study was undertaken, and therefore represents the best available data at the time.

Clause 13.03-1S – Floodplain Management and Clause 13.03-1L Floodplain Management – Golden Plains Shire

The amendment is consistent with the objective in assisting with the protection of the following: *"life, property and community infrastructure from flood hazard, including coastal inundation, riverine and overland flows"*; *"the natural flood carrying capacity of rivers, streams and floodways"*; *"the flood storage function of floodplains and waterways"*, and the *"floodplain areas of environmental significance or of importance to river, wetland or coastal health"*.

Clause 19.03-3S – Integrated water management

The amendment is consistent with the strategies to: *"Take into account the catchment context; Protect downstream environments, waterways and bays; Minimise flood risks; Provide urban environments that are more resilient to the effects of climate change."*

The amendment assists with integrated water management responses through implementing overlays which will guide planning and management decision making and help inform a holistic approach to water management.

The amendment supports the above mentioned clauses by replacing the FO and LSIO overlays with updated mapping identified in the Study. The controls are being applied in order to protect life and property from future flood impacts and to ensure that the natural flood storage capacity of waterways remain relatively unencumbered.

How does the amendment support or implement the Municipal Planning Strategy?

The amendment is consistent with the following clauses of the Municipal Planning Strategy and will assist in achieving objectives of the clauses as follows:

MPS Clause 02.02 – Vision

The amendment is consistent with the vision *"Council's vision is to sustainably manage land use and development within the Shire, including: The natural* *environment will be protected and enhanced; The local economy will grow, particularly in township development and rural based and farming industries."* The amendment supports this vision by providing the community with up-to-date planning controls for flood risk which will assist in reducing the impacts on the local environment and the local economy. The amendment with provide the local community and businesses with more certainty on flooding information which can inform their decision making.

Clause 02.03-3 – Environmental risks and amenity

The amendment implements the strategic directions for environmental risks and amenity through applying flood controls, with the following strategic directions:

"The catchments of the various rivers and streams within Golden Plains Shire include areas of flood prone land where flooding has historically caused substantial damage to the natural and built environment. The town of Inverleigh is most affected by flooding due to the confluence of the Leigh and Barwon Rivers. The Woady Yaloak River is another key floodplain affecting the north of the Shire. Natural flooding, long term productivity of flood prone land, river and wetland health are all closely linked. Inappropriate development on the floodplain can lead to the deterioration of environmental values and reduced agricultural production.

The impact of floods is increasing due to land use and vegetation changes. In particular, urban expansion, raised earthworks and the clearing of land for rural and urban development have all contributed to the increase in the instances of flooding.

Council seeks to mitigate flood risk by:

- *Discouraging the intensification of land use and development in floodplains.*
- *Ensuring the future use and development of land prone to flooding minimises the consequences of inundation on life and property.*
- *Protecting floodways for their role in conveying floodwater."*

Does the amendment make proper use of the Victoria Planning Provisions?

The amendment utilises the most effective controls available from the Victoria Planning Provisions. Consideration was given to the level of flood risk, depth and velocity of flood waters in choosing planning scheme tools. The amendment is consistent with *Planning Practice Note 12: Applying the Flood Provisions in Planning Schemes*.

The Corangamite Catchment Management Authority supports the application of the Floodway Overlay and the Land Subject to Inundation Overlay.

The FO2 is applied to areas which flood frequently from riverine flooding, at high depth and/or velocity and for which the impacts of flooding are moderate to high, and in urban areas where development is anticipated.

The LSIO2 is applied to areas of lesser depth and velocity from riverine flooding in both rural and urban areas, or where development is anticipated. It is also applied to rural zoned land which is subject to higher flood frequency, depth and velocity but where less development is planned.

The planning permit exemptions set out in the FO2 and LSIO2 schedules correspond to the level of flooding risk for the locations.

How does the amendment address the views of any relevant agency?

The amendment has been prepared in consultation with the Corangamite CMA which is the relevant floodplain manager and recommending referral authority under Clause 66.03 of the planning scheme. The extent and configuration of the mapping for the overlays, along with the application of the schedules, has been prepared in consultation with the Corangamite CMA. Other agencies will be consulted via the exhibition process of this amendment.

Does the amendment address relevant requirements of the *Transport Integration Act 2010*?

The amendment is consistent with the objectives and decision-making principles in the *Transport Integration Act 2010*. Specifically:

- The amendment supports social inclusion and economic prosperity with respect to *"minimising barriers to access so that so far as is possible the transport system is available to as many persons as wish to use it"* and *"enabling efficient and effective access for persons and goods to places of employment, markets and services"*. It achieves this through providing information on flood risk which can be used to assist in future management and design of the transport system.

This amendment is unlikely to have a significant impact on the transport system as it is not significantly increasing intensification of flood risk areas.

Resource and administrative costs

What impact will the new planning provisions have on the resource and administrative costs of the responsible authority?

The amendment will improve the application and administration of the Golden Plains Planning Scheme, by providing greater certainty for the Council, Corangamite CMA, landowners and the community.

The introduction and reintroduction of schedules and therefore planning permit exemptions across the municipality will result in a decrease in the volume of permit applications relating to FO2 and LSIO2. This will ease burden on planners and reduce administrative costs for both council and the community.

Any costs from increased permit activity meets the test for net community benefit when compared with the benefits associated with ensuring development responds to flooding and the reduced demands on the Council's emergency management response and recovery resources from flooding events.

ATTACHMENT 1 - Mapping reference table

Location	Land /Area Affected	Mapping Reference	Address	Proposed changes		
				Zone	Overlay	Deletion
Golden Plains Shire	Land specified as FO and LSIO	01 LSIO-FO, 02 LSIO-FO, 03 LSIO-FO, 04 LSIO-FO, 05 LSIO-FO, 06 LSIO-FO, 07 LSIO-FO, 08 LSIO-FO, 10 LSIO-FO, 11 LSIO-FO, 12 LSIO-FO, 13 LSIO-FO, 15 LSIO-FO, 16 LSIO-FO, 17 LSIO-FO, 18 LSIO-FO, 19 LSIO-FO, 20 LSIO-FO, 21 LSIO-FO, 22 LSIO-FO, 23 LSIO-FO, 24 LSIO-FO, 25 LSIO-FO, 26 LSIO-FO, 28 LSIO-FO, 29 LSIO-FO			LSIO2 FO2	D-LSIO D-FO

Teesdale	Land in Teesdale affected by the 1% Annual Exceedance Probability flood extent as identified in the Teesdale Flood Risk Identification Study (Water Technology Pty Ltd, 2023).	24 LSIO-FO, 26 LSIO-FO			LSIO2 FO2	D-LSIO D-FO

Location	Planning Scheme Mapping Reference	Proposed Overlay changes
Teesdale (surrounds)	Map No 24 LSIO-FO	Inserts new flood mapping (FO2 and LSIO2)
Teesdale township	Map No 26 LSIO-FO	Inserts new flood mapping (FO2 and LSIO2)

Planning and Environment Act 1987

GOLDEN PLAINS PLANNING SCHEME

AMENDMENT C104gpla

INSTRUCTION SHEET

The planning authority for this amendment is the Golden Plains Shire Council.

The Golden Plains Planning Scheme is amended as follows:

Planning Scheme Maps

The Planning Scheme Maps are amended by a total of 52 attached maps.

Overlay Maps

1. Amend Planning Scheme Map No. 01 LSIO-FO in the manner shown on the 2 attached maps marked "Golden Plains Planning Scheme, Amendment C104gpla".

2. Amend Planning Scheme Map No. 02 LSIO-FO in the manner shown on the 2 attached maps marked "Golden Plains Planning Scheme, Amendment C104gpla".

3. Amend Planning Scheme Map No. 03 LSIO-FO in the manner shown on the 2 attached maps marked "Golden Plains Planning Scheme, Amendment C104gpla".

4. Amend Planning Scheme Map No. 04 LSIO-FO in the manner shown on the 2 attached maps marked "Golden Plains Planning Scheme, Amendment C104gpla".

5. Amend Planning Scheme Map No. 05 LSIO-FO in the manner shown on the 2 attached maps marked "Golden Plains Planning Scheme, Amendment C104gpla".

6. Amend Planning Scheme Map No. 06 LSIO-FO in the manner shown on the 2 attached maps marked "Golden Plains Planning Scheme, Amendment C104gpla".

7. Amend Planning Scheme Map No. 07 LSIO-FO in the manner shown on the 2 attached maps marked "Golden Plains Planning Scheme, Amendment C104gpla".

8. Amend Planning Scheme Map No. 08 LSIO-FO in the manner shown on the 2 attached maps marked "Golden Plains Planning Scheme, Amendment C104gpla".

9. Amend Planning Scheme Map No. 10 LSIO-FO in the manner shown on the 2 attached maps marked "Golden Plains Planning Scheme, Amendment C104gpla".

10. Amend Planning Scheme Map No. 11 LSIO-FO in the manner shown on the 2 attached maps marked "Golden Plains Planning Scheme, Amendment C104gpla".

11. Amend Planning Scheme Map No. 12 LSIO-FO in the manner shown on the 2 attached maps marked "Golden Plains Planning Scheme, Amendment C104gpla".

12. Amend Planning Scheme Map No. 13 LSIO-FO in the manner shown on the 2 attached maps marked "Golden Plains Planning Scheme, Amendment C104gpla".

13. Amend Planning Scheme Maps No. 15 LSIO-FO in the manner shown on the 2 attached maps marked "Golden Plains Planning Scheme, Amendment C104gpla".

14. Amend Planning Scheme Maps No. 16 LSIO-FO in the manner shown on the 2 attached maps marked "Golden Plains Planning Scheme, Amendment C104gpla".

15. Amend Planning Scheme Maps No. 17 LSIO-FO in the manner shown on the 2 attached maps marked "Golden Plains Planning Scheme, Amendment C104gpla".

16. Amend Planning Scheme Map No. 18 LSIO-FO in the manner shown on the 2 attached maps marked "Golden Plains Planning Scheme, Amendment C104gpla".

17. Amend Planning Scheme Map No. 19 LSIO-FO in the manner shown on the 2 attached maps marked "Golden Plains Planning Scheme, Amendment C104gpla".

18. Amend Planning Scheme Map No. 20 LSIO-FO in the manner shown on the 2 attached maps marked "Golden Plains Planning Scheme, Amendment C104gpla".

19. Amend Planning Scheme Map No. 21 LSIO-FO in the manner shown on the 2 attached maps marked "Golden Plains Planning Scheme, Amendment C104gpla".

20. Amend Planning Scheme Map No. 22 LSIO-FO in the manner shown on the 2 attached maps marked "Golden Plains Planning Scheme, Amendment C104gpla".

21. Amend Planning Scheme Map No. 23 LSIO-FO in the manner shown on the 2 attached maps marked "Golden Plains Planning Scheme, Amendment C104gpla".

22. Amend Planning Scheme Map No. 24 LSIO-FO in the manner shown on the 2 attached maps marked "Golden Plains Planning Scheme, Amendment C104gpla".

23. Amend Planning Scheme Map No. 25 LSIO-FO in the manner shown on the 2 attached maps marked "Golden Plains Planning Scheme, Amendment C104gpla".

24. Amend Planning Scheme Map No. 26 LSIO-FO in the manner shown on the 2 attached maps marked "Golden Plains Planning Scheme, Amendment C104gpla".

25. Amend Planning Scheme Map No. 28 LSIO-FO in the manner shown on the 2 attached maps marked "Golden Plains Planning Scheme, Amendment C104gpla".

26. Amend Planning Scheme Map No. 29 LSIO-FO in the manner shown on the 2 attached maps marked "Golden Plains Planning Scheme, Amendment C104gpla".

Planning Scheme Ordinance

The Planning Scheme Ordinance is amended as follows:

1. In Overlays – Clause 44.03, insert a new Schedule 2 in the form of the attached document.

2. In Overlays – Clause 44.04, insert a new Schedule 2 in the form of the attached document.

3. In Operational Provisions – Clause 72.08, replace the Schedule with a new Schedule in the form of the attached document.

End of document

--/--/----
Proposed C104gpla

SCHEDULE 2 TO CLAUSE 44.03 FLOODWAY OVERLAY

Shown on the planning scheme map as **FO2**.

RIVERINE FLOODING

1.0 Floodway objectives to be achieved

--/--/----
Proposed C104gpla

To identify riverine flood prone land only.

2.0 Statement of risk

--/--/----
Proposed C104gpla

None specified.

3.0 Permit requirement

--/--/----
Proposed C104gpla

A permit is not required to construct and carry out the following:

- Works associated with watering systems.
- Bicycle or pedestrian paths where there is no increase in the ground level.

4.0 Application requirements

--/--/----
Proposed C104gpla

None specified.

5.0 Decision guidelines

--/--/----
Proposed C104gpla

None specified.

--/--/----
Proposed C104gpla

SCHEDULE 2 TO CLAUSE 44.04 LAND SUBJECT TO INUNDATION OVERLAY

Shown on the planning scheme map as **LSIO2**.

RIVERINE FLOODING

1.0 Land subject to inundation objectives to be achieved

--/--/----
Proposed C104gpla

None specified.

2.0 Statement of risk

--/--/----
Proposed C104gpla

None specified.

3.0 Permit requirement

--/--/----
Proposed C104gpla

A permit is not required to construct and carry out the following:

- An extension to a non-habitable building (other than industrial and commercial), provided that the total ground floor areas of the building is less than 250 square meters.
- A non-habitable building (including a shed), including replacement of an existing non-habitable building provided:
  - The floor area is less than 20 square meters; and
  - The floor level is at least 150 milimeters above the 1% AEP flood level.
- A building which is open on all sides including a pergola, carport, domestic shed, animal enclosure, outbuilding, stockyard, or agricultural shed with unenclosed foundations.
- A verandah or decking area with a floor raised on stumps or piers and with unenclosed foundations on at least three sides.
- Post and wire and post and rail fencing.
- An outdoor recreation facility, excluding works that alter the ground level of the land
- Open sports ground with no grandstands or raised viewing areas, playgrounds, picnic shelters and barbeques.
- Road works or works to any other accessway (public or private), including construction of driveways, vehicle crossovers, footpaths, or bicycle paths if there is no change to existing surface levels or if the relevant floodplain management authority has advised in writing that it supports the proposed works.
- Bicycle or pedestrian paths where there is no increase in the ground level.

4.0 Application requirements

--/--/----
Proposed C104gpla

None specified.

5.0 Decision guidelines

--/--/----
Proposed C104gpla

None specified.

GOLDEN PLAINS PLANNING SCHEME

31/07/2018
VC148

SCHEDULE TO CLAUSE 72.08 BACKGROUND DOCUMENTS

1.0
--/--/----
Proposed C104gpla

Background documents

[illegible]	[illegible]
Bannockburn Town Centre Investment Strategy (Connell Wagner, 2008)	C46 Clauses 02 and 11
Bannockburn Growth Plan (Victorian Planning Authority, May 2021)	C94gpla Clauses 02 and 11
Bruce's Creek Master Plan (Land Design Partnership, 2009)	C59 Clauses 02 and 11
Corangamite Catchment Management Authority Floodplain Management Strategy (Corangamite Catchment Management Authority, April 2002)	Clauses 02, 12, 13 and 19
Corangamite Regional Catchment Strategy 2021-2027 (Corangamite Catchment Management Authority, 2021)	Clauses 02, 12, 13 and 19
Corangamite Waterway Strategy (Corangamite Catchment Management Authority, 2014)	Clauses 02, 12, 13 and 19
Gheringhap Structure Plan (Parsons Brinckerhoff, December 2012)	C62 Clauses 02 and 11
Golden Plains Heritage Study Stage 1 (Lorraine Huddle, 2004)	C55 Clauses 02 and 15
Golden Plains Heritage Study Stage 2 (Heritage Matters, 2009)	C55 Clauses 02 and 15
Golden Plains Rural Land Use Strategy (Parsons Brinckerhoff, 2008)	C40 Clauses 02 and 14
Infrastructure Design Manual (Local Government Infrastructure Design Association, 2022)	Clauses 02 and 19
Inverleigh Structure Plan (Golden Plains Shire, 2019)	C87gpla Clauses 02 and 11
Northern Settlement Strategy (Golden Plains Shire, 2019)	C85gpla Clauses 02 and 11
Review of south east area Golden Plains Shire (Parsons Brinckerhoff, 2007)	C45 Clauses 02 and 11
Smythesdale Urban Design Framework (Michael Smith and Associates, March 2006)	C36 Clauses 02 and 11
Strategic Bushfire Risk Assessment for the Bannockburn Growth Plan Investigation Area (Ecology and Heritage Partners Pty Ltd, August 2020)	C94gpla Clause 11
Teesdale Flood Risk Identification Study(Water Technology, 2023)	C104gpla
Teesdale Structure Plan (Golden Plains Shire, October 2021)	C92gpla Clause 02 and 11

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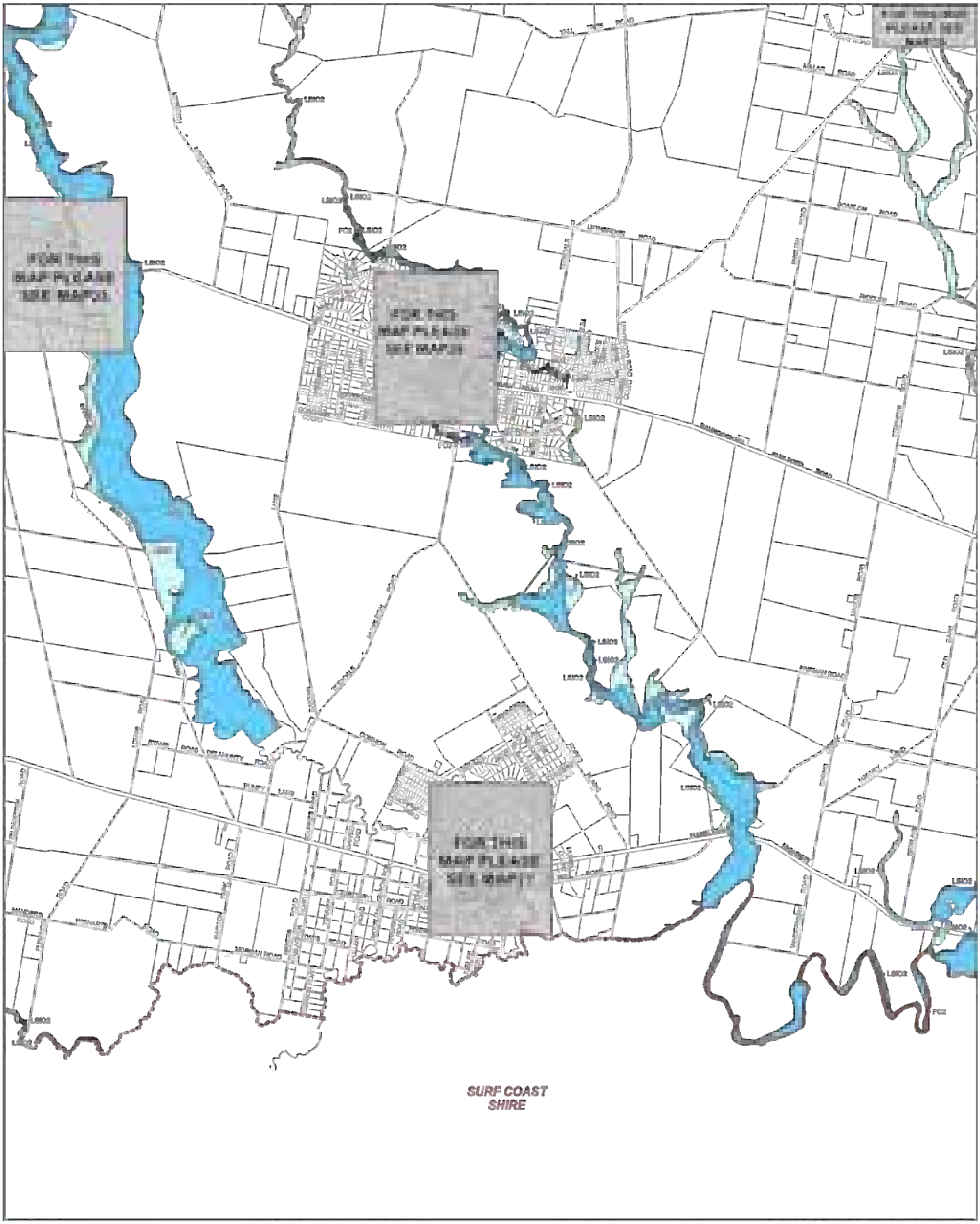
GOLDEN PLAINS PLANNING SCHEME - LOCAL PROVISION

AMENDMENT C104gpla



LEGEND

- FO2 - Floodway Overlay - Schedule 2
- LSIO2 - Land Subject to Inundation Overlay - Schedule 2
- Municipal Boundary

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0 1,750 3,500
Metres

Australian Map Grid Zone 54

Planning Group
Print Date: 11/03/2024
Amendment Version: 2

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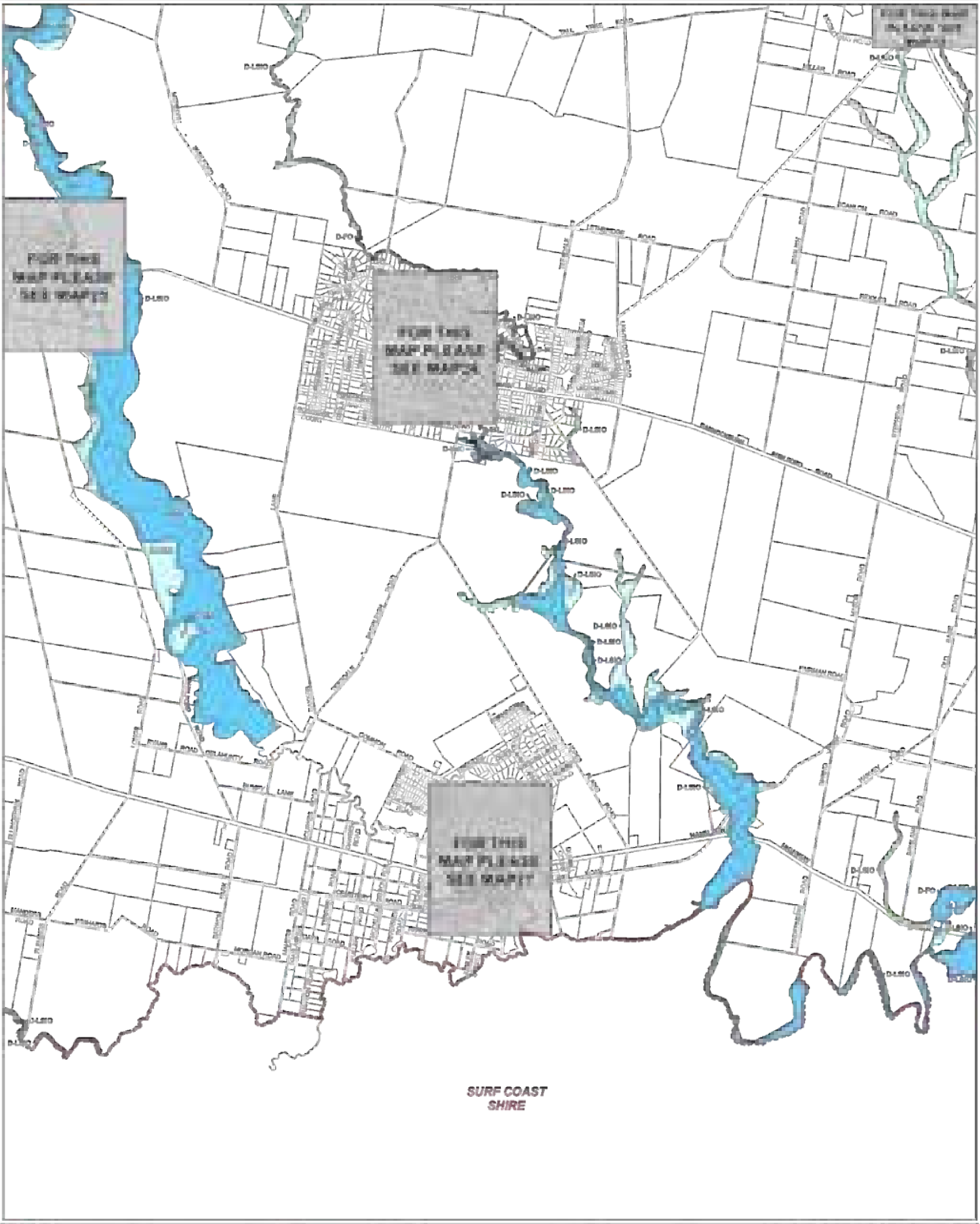
INDEX TO ADJOINING SCHEME MAPS

LAND SUBJECT TO INUNDATION OVERLAY/FLOODWAY OVERLAY **MAP No 24LSIO-FO**

GOLDEN PLAINS PLANNING SCHEME - LOCAL PROVISION

AMENDMENT C104gpla



LEGEND
D-FO - Area to be deleted from a Floodway Overlay
D-LSIO - Area to be deleted from a Land Subject to Inundation Overlay
Municipal Boundary

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INDEX TO ADJOINING SCHEME MAPS

AREA TO BE DELETED FROM A LAND SUBJECT TO INUNDATION OVERLAY/FLOODWAY OVERLAY **MAP No 24LSIO-FO**

GOLDEN PLAINS PLANNING SCHEME - LOCAL PROVISION

AMENDMENT C104gpla

LEGEND

FO2 - Floodway Overlay - Schedule 2

LSIO2 - Land Subject to Inundation Overlay - Schedule 2

Municipal Boundary

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LAND SUBJECT TO INUNDATION OVERLAY/FLOODWAY OVERLAY **MAP No 26LSIO-FO**

GOLDEN PLAINS PLANNING SCHEME - LOCAL PROVISION
AMENDMENT C104gpla

LEGEND

- D-FO - Area to be deleted from a Floodway Overlay
- D-LSIO - Area to be deleted from a Land Subject to Inundation Overlay
- Municipal Boundary

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AREA TO BE DELETED FROM A LAND SUBJECT TO INUNDATION OVERLAY/FLOODWAY OVERLAY **MAP No 26LSIO-FO**