South Gippsland Shire Council

ENGENY
WATER MANAGEMENT

South Gippsland Shire Council

Flood and Drainage Study for Foster and Surrounding Catchments

Final Report

July 2019

V2025_001

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EXECUTIVE SUMMARY

Following recent flooding events at Foster, South Gippsland Shire Council (SGSC) and the West Gippsland CMA (WGCMA) received State funding to undertake a flood and drainage study for Foster including Stockyard Creek and Bennison Creek catchments. The primary objectives of the study are to improve land use planning and emergency response via the development of computer-based flood models and the generation of detailed flood extent, depth, height and velocity information for a range of flood events.

Engeny Water Management (Engeny) has been engaged by South Gippsland Shire Council (SGSC) to undertake the, *flood and drainage study for Foster and the surrounding catchments* (hereafter referred to as, “the Foster flood study”), which includes flood mapping of the Stockyard Creek and Bennison Creek catchments.

Flood modelling for the Stockyard Creek catchment was undertaken for three development scenarios as requested by SGSC. The scenarios modelled are described as follows:

1. 2030 development conditions, where 25 % of greenfield areas have been converted to residential development.

2. 2050 development conditions, where 70 % of greenfield areas have been converted to residential development.

3. 2070 development conditions, where 100 % of greenfield areas have been converted to residential development.

No future development is expected to occur in the Bennison Creek catchment and flood mapping of this catchment was undertaken for existing conditions only in accordance with SGSC’s requirements.

Flood modelling for both the Stockyard Creek and Bennison Creek catchments was undertaken with one and two dimensional (1D/2D) hydraulic models using the industry recognised hydrodynamic modelling software package TUFLOW. The runoff-routing hydrological modelling software program RORB was used to generate inflows to the TUFLOW hydraulic model.

A diverted RORB model of the Foster township (including pipe diversions with estimated capacities) was created to inform the selection of the temporal patterns and critical durations that were used to generate the rainfall excess flows for TUFLOW. Due to the lack of nearby river flow gauging stations with suitable data records, the RORB hydrological models were calibrated to the Regional Flood Frequency Estimator (RFFE) flow estimate for both the Stockyard Creek and Bennison Creek catchments. The methodologies adopted for both the hydrological and hydraulic modelling are considered to be consistent with the recommendations of the Australian Rainfall and Runoff (2016) Guidelines and both the hydrological and hydraulic modelling has been independently

reviewed at separate stages of the project by Department of Environment Land Water and Planning (DELWP) approved reviewers.

Stockyard Creek Flood Modelling Results

The results of the flood modelling found that 62 existing building footprints are impacted by the 10 % AEP 2030 flood event and 121 building footprints by the 1 % AEP 2030 flood event. This is expected to increase for the future development scenario as follows:

- 2050 development scenario: 1 additional building footprint for the 1 % AEP flood event.
- 2070 development scenario: 3 additional building footprints for the 1 % AEP flood event.

Building floor levels are unknown for the study area and were therefore estimated to be equal to the average surface elevation within the building footprint. It is highly recommended that floor level survey be undertaken as this would improve the understanding of flood risk posed to properties in the town. Building footprints were considered impacted if the flood depth was greater than or equal to 100 mm at the building footprint location. This means Properties and roadways are predicted to be impacted by flooding from insufficient stormwater drainage capacity as well as waterway flows exceeding the banks of Stockyard Creek that results in overtopping of key road crossings.

Flooding hotspots for the 5 % AEP storm event and greater in Foster include the following locations: McDonalds Street, Intersection of Main Street and Nelson Street, Between Bruce Court and Landy Road, McMaster Court, Boyd Court, Apex Court, Boundary Road, Intersection of Devlon Road and Nelson Street, Gibbs Street, Bridge Street, Davis Road and the Fish Creek-Foster Road (at multiple road crossings).

The flood modelling results are generally consistent with the communities' understanding of flooding in Foster as follows:

- The service station at the corner of Main Street and Nelson Street was identified as a flooding hotspot that has been inundated many times in recent years and was found to be consistent with the modelling which shows a flow path through this site for the 10 % AEP event.
- Deep flooding of the unit development at 94 Station Road between Boyd Court and Apex Court. This is consistent with the modelling results that predict up to 0.5 m depth of flooding for the 1 % AEP event.
- Flood flows from Stockyard Creek flow up Boundary Road towards Station Street and overtop through properties into Boyd Court.

- Ponding on the Foster Recreational Reserve oval surface possibly due to backwatering through the pipe network from Stockyard Creek which was not consistent with the model results. The sports oval elevation is approximately 1.5 m higher than the peak 1 % AEP water level in Stockyard Creek where the oval pipe system discharges therefore it is considered that the flooding issues raised by the residents could be a product of ineffectively located pit and pipe system and/or system blockage.

Bennison Creek Flood Modelling Results

The results of the flood modelling found that 3 existing building footprints are impacted by the 10 % AEP 2030 flood event and 9 building footprints by the 1 % AEP 2030 flood event.

Flooding hotspots for the 2 % AEP storm event and greater include: Ameys Track on Bennison Creek and east of Bennison Creek, South Gippsland Highway on Bennison Creek, Hobsons Road (at multiple road crossings) Elphicks Road, Jackson Road and the Great Southern Rail Trail.

No information was brought forward by residents with respect to existing flooding conditions in the Bennison Creek catchment at the community consultation sessions.

Bushfire Sensitivity Results

Peak flows at the outlets of both Stockyard Creek and Bennison Creek catchments are estimated to increase by up to 36 % (relative to the base case scenario) for the 1 % AEP event following a high severity bushfire event in the upstream catchment. The increase in flood levels results in 12 additional building footprints being impacted by floodwater and additional overtopping depth (and hazard) to roads. For example, Boundary Road in the Stockyard Creek catchment overtops by 730 mm for the 1 % AEP base case (2030) conditions. Overtopping of this structure is estimated to increase to 900 mm following a high intensity bushfire.

Climate Change Sensitivity Results

The 1 % AEP storm event was modelled to inform the climate change sensitivity for both the Stockyard Creek and Bennison Creek catchments. The RCP8.5 scenario is the ‘business as usual’ climate change scenario wherein minimal curbing of emissions is undertaken. This scenario was adopted per Melbourne Water’s Addendum 2 to the Flood Mapping Project Guidelines and Technical Specifications (November 2016). The estimated percentage increase in rainfall for the year 2100 under this scenario is 19.5 % (relative to existing runoff conditions) as per AR&R DataHub. The increase in flood levels results in 17 additional building footprints being impacted by floodwater and additional overtopping depth (and hazard) to roads. For example, Boundary Road in the Stockyard Creek catchment overtops by 740 mm for full development (2100) conditions. Overtopping of this structure is estimated to increase to 880 mm under 2100 climate change conditions.

Onsite Detention in Foster

An investigation was undertaken into the benefits of retrofitting on-site detention storage systems to residential properties in Foster for the purposes of mitigating increased flooding associated with:

1. future development; and
2. climate change

The 20 % AEP storm event was used as the basis of the analysis and the on-site detention storage system tank volumes and outlet discharge rates were configured in accordance with the requirements of the Infrastructure Design Manual (IDM).

It was found that by applying on-site detention to all existing and proposed residential properties (Scenario 1), flood waters were prevented from reaching unsafe levels for people (flood hazard categories above H2) within properties and roadways for the 20 % AEP storm event. However, the systems do not completely eliminate flooding within roadways for the 20 % AEP storm event. Applying the systems to some existing and proposed properties (Scenario 2, as agreed with SGSC), results in similar flood mitigation outcomes as observed in Scenario 1. The effectiveness of the on-site detention systems varies across the catchment and is impacted by locality and topography. The implementation of on-site detention storages to all existing and proposed properties is not enough to completely offset the rise in flood levels caused by the increase in rainfall intensities predicted to occur under 2100 climate conditions. The implementation of on-site detention systems could reduce the scale of additional mitigation works (such as pit and pipe upgrades) required to fully eliminate flooding within roadways and properties for the 20 % AEP storm event.

Couper Dam Consequence of Failure Assessment

Consequences to both life and property associated with the failure of Couper Dam was undertaken in accordance with Australian National Committee On Large Dams (ANCOLD) guidelines as part of this study. The scenarios modelled included Sunny Day Failure (SDF) and Dam Crest Flood (DCF) failure of the embankment. The investigation involved estimation of population at risk (PAR), potential loss of life (PLL), and severity of damage and loss for the failure of the dam in order to inform a suitable consequence category and fall-back flood capacity for the dam. Upon completion of the investigation, Couper Dam was deemed to be of a Consequence Category of **Significant**. The dam managers should review the outcomes of this assessment and use it as a basis for developing a dam safety management program that is consistent with the recommendations of the ANCOLD Guidelines and other relevant national policies and guidelines on dam management.

Average Annual Damages (AAD) Assessment

An Average Annual Damages (AAD) assessment estimating the average probable tangible flood damages endured every year over a given period for residential, commercial and industrial land use types has been determined for the town of Foster. The AAD estimate for buildings, properties and roadways within the study area is approximately $994,000. However, it is noted that this estimate could be conservative given (refer to Section 6.5.1 for further discussion). The AAD estimate could be refined by utilising localised insurance data from the study area (if available) as well as floor level survey of flood affected buildings will provide for a more accurate damage cost estimate.

Structural Flood Mitigation Options

Engeny has identified flooding hotspots for the 1 % AEP storm event across the study area and has developed 13 concept structural options for mitigating flooding at these locations. The proposed mitigation measures include underground drainage and road crossing upgrades, retarding basins, wetlands, open channels, swales and road surfacing re-grading. A high-level cost estimate for these recommended mitigation works totals approximately $2,397,500 excluding GST ($2018).

Flood Risk Management and Planning Options

Additional non-structural planning and management options are available to reduce the flood risk in the Stockyard Creek and Bennison Creek catchments.

Planning overlays such as a Special Building Overlay (SBO) in flood prone locations in Foster and Land Subject to Inundation (LSIO) overlays on Stockyard and Bennison Creeks would allow SGSC to control future redevelopments and subdivisions and over time will help to improve the level of service experienced by properties by lifting new floor levels above the predicted flood levels.

A flash flood warning service could also be implemented to minimise potential flood hazards to properties, assets and people.

It is recommended that the Victoria State Emergency Services (VicSES) and other emergency authorities such as Country Fire Authority (CFA), Emergency Management Victoria (EMV) and Department of Environment, Land, Water and Planning (DELWP) are informed of this flood study and that SGSC and WGCMA work with these authorities to update the South Gippsland Shire Flood Emergency Plan and other flood emergency planning and procedural documents for Foster and the wider Stockyard and Bennison Creek catchments.

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1. INTRODUCTION

1.1 Study Objectives

Following recent flooding events at Foster, South Gippsland Shire Council (SGSC) and the West Gippsland CMA (WGCMA) received State funding to undertake a flood and drainage study for Foster including Stockyard Creek and Bennison Creek catchments. The primary objectives of the study are to improve land use planning and emergency response via the development of computer-based flood models and the generation of detailed flood extent, depth, height and velocity information for a range of flood events.

1.2 Outcomes

Project outcomes include the following:

- Improved flood awareness for the community of Foster including catchment responsiveness and the expected depth and duration of flooding for major events.
- Improved understanding of flooding in the region, including:
    - SGSC's understanding of flood immunity and flood risk to private properties and Council assets in the study area
    - VicRoads' understanding of the flood immunity of VicRoads roads, including the Fish Creek-Foster Road (C445) at Stockyard Creek and the South Gippsland Highway (A440) at Bennison Creek.
    - WGCMA's understanding of flood patterns and flows in the Stockyard Creek and Bennison Creek catchment.
- Identification of structural and non-structural flood management options to mitigate flooding and inform statutory planning decisions.
- Identification of the consequence of failure of Couper Dam located in the Stockyard Creek catchment which will inform decisions on how to manage the risk associated with this structure.
- Improved understanding of flooding characteristics to inform Flood Emergency planning.

1.3 Scope

The following presents an overview of the scope of work for this project. Detailed scoping of the tasks undertaken for each major component of this project is presented in the body of the report.

- Data collection and analysis

- Community consultation
- Hydrological modelling for the 10 %, 5 %, 2 % 1 %, 0.5 % Annual Exceedance Probability (AEP) and the Probable Maximum Flood (PMF) storm events.
- Hydraulic modelling for the storm events described above.
- Flood risk assessment
- Meetings and stakeholder consultation

Investigations in addition to the original scope of work were also undertaken by Engeny at the request of SGSC, as follows:

- Consequence of failure assessment for Couper Dam located within the Stockyard Creek catchment.
- Investigation into On Site Detention and its potential for resolution of existing flooding problems and offsetting the impact of climate change in Foster.

1.4 Project Stakeholders

The following stakeholders own / manage drainage and waterway assets within the study area:

- Bureau of Meteorology (BoM)
- Department of Land, Water and Planning (DELWP)
- Property owners
- South Gippsland Shire (Council)
- Southern Rural Water
- VicRoads
- Victoria State Emergency Service (VicSES)
- VicTrack
- West Gippsland Catchment Management Authority (WGCMA).

The roles and responsibilities of each of these stakeholders is summarised in the following sub-sections.

1.4.1 Bureau of Meteorology

The Bureau of Meteorology is Australia's national weather, climate and water agency. Its expertise and services assist Australians in dealing with the harsh realities of their natural environment, including drought, floods, fires, storms, tsunami and tropical cyclones. Through regular forecasts, warnings, monitoring and advice spanning the Australian region and Antarctic territory, the Bureau provides one of the most fundamental and widely used services of government.

The Bureau contributes to national social, economic, cultural and environmental goals by providing observational, meteorological, hydrological and oceanographic services and by undertaking research into science and environment related issues in support of its operations and services.

1.4.2 Department of Land, Water and Planning

DELWP brings together Victoria’s planning, local government, environment, energy, suburban development, forests, emergency management, climate change and water functions into a single department to strengthen connections between the environment, community, industry and economy.

DELWP’s key aim is to maintain Victoria’s liveability with a population that is expected to almost double by 2050, while responding to climate change and protecting our natural environment, infrastructure and heritage for future generations.

1.4.3 Property Owners

Under the Water Act 1989 (Section 16), residents and property owners:

- are liable for flow of water from their land
- have a duty of care not to interfere with the flow of water
- must not participate in negligent conduct that will interfere with the flow of water onto any land.

Property owners are required by law to maintain the stormwater pipes, gutters, downpipes, stormwater pits and any other components of their approved stormwater drainage system in good condition and in compliance with any Council requirements. Property owners are also required to accept natural overland flow from adjoining properties or public land and must not divert or redirect the flow from its natural path onto neighbouring properties.

Under the Road Management Act 2004, the responsibility for the maintenance of vehicle and culvert crossings that service private property rests with the owner of the property to which they serve. It is incumbent on the property owner to ensure that water flow through their culvert crossing is not impeded in any way.

A few examples of behaviours that may have a detrimental impact on the performance of the overall drainage system:

- Poor maintenance of private drains may result in premature blockage, reduced pipe capacity and/or prevention of stormwater runoff entering the system. This may result in localised flooding and/or increased overland flows.
- Increasing the proportion of impervious surfaces within a property (such as driveways and paths) will result in increased overland flows onto adjacent properties and / or public roads, as the existing private drain may no longer have adequate capacity.
- When constructing hardstand (hard surfaced) areas e.g. driveways, concrete and paved areas, landscaping and any other impervious surfaces or drains owners must control the stormwater in order to prevent concentrated flows onto the adjacent property.
- The erection of a physical barrier, such as a fence, across an overland flow path may divert stormwater runoff from its flow path and possibly put other properties at risk.
- Easements in private backyards are generally located to minimise impact on surrounding buildings. Sheds, paths, driveway edging and other landscaping are common improvements that are sometimes placed over easements.
- The planting of trees that develop large invasive root systems may lead to burst or blocked pipes.

While each property may only have a minor influence on the performance of the overall drainage network, the cumulative effects of poor maintenance and other activities may become significant.

1.4.4 South Gippsland Shire Council

Councils are not flood management authorities under the Water Act. Councils are local government authorities under the Local Government Act and are Planning Authorities under the Planning and Environment Act. These Acts include roles to provide local drainage services and to provide planning advice.

Councils provide roads and drainage systems to collect and convey stormwater to creeks and rivers; they also maintain the stormwater drains owned by Council on private property. As the drainage authority, SGSC is the responsible authority for managing stormwater drainage assets and any overland flooding resulting from the stormwater drainage network. This includes provision of advice for development in areas at risk of flooding from the stormwater drainage network. Prior to this study, understanding of areas at risk of stormwater flooding were not quantified. The outputs generated from this work, including the attached flood maps, will assist SGSC in their role as drainage authority.

In 2005 the Victorian State Government recognised that the functions of Melbourne based Councils and Melbourne Water in managing drainage and flooding should be reviewed. A study was commissioned by the Victorian Auditor General's Office (VAGO). VAGO recommended that both Melbourne Water and Councils should manage flood risks associated with their systems and that this should be done on a risk-based approach under two headings:

- Structural Measures
- Non-Structural Measures.

Structural Measures include physical works to reduce flooding such as retarding basins, floodways and larger drains. Non-structural measures include flood mapping, planning and building controls, public education and operational tasks.

Flood mapping of SGSC's drainage system and recommendations for areas of improvement, undertaken as part of this study, are both structural and non-structural measures and could lead to introduction of Special Building Overlay (SBO) and Land Subject to Inundation (LSIO) controls that could be used to set conditions on development, including the floor levels of new habitable buildings.

1.4.5 Southern Rural Water

Southern Rural Water are a governing body who work under the *Water Act* 1989 (Vic), with their main purpose to promote the equitable and efficient use of water resources, conserve and manage water resources for the benefit of all Victorians and to increase community involvement to achieve these objectives.

1.4.6 VicRoads

VicRoads is responsible for the overall management (including construction, maintenance, inspection and repair) of a network of freeways and arterial roads (the major connecting roads) throughout Victoria. VicRoads is responsible for the management of major roadways across the Shire including South Gippsland Highway, Fish Creek-Foster Road, Main Street and Foster-Promontory Road. The responsibilities of VicRoads extend to the drainage assets, including cross drainage culverts.

1.4.7 Victoria State Emergency ServiceWest Gippsland Catchment Authority

The WGCMA is the floodplain management authority within SGSC. The CMA is responsible for managing the risk of flooding associated with waterways which includes Stockyard Creek and Bennison Creek (modelled as part of this study).

1.5 Reporting

The following reports were compiled during this study and submitted to SGSC and the stakeholder group for review. The hydrology report and hydraulic report were subject to review by independent reviewers appointed by DELWP.

The following presents a record of the reports submitted for this project:

- Inception report
- Data report
- Hydrology report
    - Independent peer review
- Hydraulic report
    - Independent peer review
- Draft report
    - Presentation of all investigations undertaken for the project.
- Final report

This document has been compiled from the inception, data, hydrology and hydraulic reports that were previously submitted to SGSC and the project stakeholders for review.

2. DATA REVIEW

2.1 Overview

This section presents the data that was utilised to inform the Foster flood study and the investigations that were undertaken by Engeny to confirm that the data was fit for purpose.

2.2 Scope

The scope of the data collection and investigation was as follows:

- Obtain Victorian Coastal LiDAR dataset (Level 3) and interrogate it for suitability as a base DEM for the 1D/2D hydraulic model.
- Obtain GIS and plan data sets of SGSC's drainage system within the study area from SGSC and determine whether the information is sufficient to inform the 1D/2D hydraulic model.
- Obtain waterway crossing details within the study area from VicRoads and determine whether the information is sufficient to inform the 1D/2D hydraulic model.
- Obtain details of waterway crossing structures within the study area on the Great Southern Rail Trail from DELWP and determine whether the information is sufficient to inform the 1D/2D hydraulic model.
- Obtain historical flood photos and other historical information from the WGCMA and SGSC and determine whether this information is sufficient to inform the calibration or validation of the 1D/2D hydraulic model.
- Obtain spillway and bathymetry information for Couper Dam located within the study area that will form the basis of the consequence of failure assessment and determine whether any additional information is required to inform the assessment.
- Based on the findings of the investigations into the above datasets, recommend further investigations that should be undertaken to inform the study.

Table 2.1 presents the primary data sources that were obtained for use on the Foster flood study.

Table 2.1 Data

Data	Source	Use
GIS Council pipe network data (.tab)	SGSC	Used as a basis for the representation of the pipe drainage system in the hydraulic model.

Data	Source	Use
GIS Council pit network data (.tab)	SGSC	Used as a basis for the representation of the pit drainage system in the hydraulic model.
• Drainage system plans for the following locations: ○ Foster streetscape project stage 1A (.dwg) ○ Victory Avenue Foster detail plan (.pdf) ○ Country roads board - 14326 (.pdf)	SGSC	Used to inform the representation of the pipe and pit drainage system in the hydraulic model.
• Waterway structure plans for VicRoads culverts as follows: ○ Bennison Creek culvert at the South Gippsland Highway (.pdf drawing 14,326) ○ Stockyard Creek culvert at the Fish Creek – Foster Road (.pdf drawing 573667) ○ O'Connell Road Aged Care Development (WME110403 series .pdf drawings) ○ Varney Street Residential Development (1157-1(B).pdf and Stage 2 Approved Plans.pdf)	VicRoads	Used to inform the representation of the pipe and pit drainage system in the hydraulic model.
2015 Aerial photography (.ecw)	SGSC	Used to inform the development of the hydraulic and hydrological model including impervious fraction and Manning's roughness selection.
Feature surveys for the following locations: ○ Plan of existing conditions at Victory Avenue Foster - W1191 (.dwg) ○ Plans of existing conditions at O'Connell Road Foster -1600834 Feature.dwg	SGSC	Used to investigate the accuracy of the LiDAR data and to inform changes in land use.
Couper Farm Dam Assessment	SRW	Used to inform the bathymetry of the Couper dam for the purposes of the hydrological modelling and the dam consequence assessment
Planning zones (.tab)	DELWP	Used to inform impervious fraction selection for the hydrological model
Planning overlays (.tab)	DELWP	Used to inform understanding of existing flooding in the catchment.

Data	Source	Use
LiDAR DEM	WGCMA	Used as the basis for the digital elevation model (DEM) used for the hydraulic and hydrologic models.

2.3 Previous Studies

2.3.1 General

The SGSC and WGCMA have advised that no hydrological or hydraulic investigations have previously been undertaken to determine flood extents or flood flows for Stockyard Creek or Bennison Creek. However, the following regional studies are relevant to the study area:

- South Gippsland Shire Flood Emergency Plan version 1.4 (VicSES, South Gippsland Shire Council, 2013).
- Flood Management Plan for South Gippsland Shire Council, Melbourne Water and West Gippsland CMA (Melbourne Water, 2013).
- 2013 Stormwater management strategy for the development at 25 Victory Boulevard, Foster (provided by SGSC).

2.3.2 South Gippsland Shire Flood Emergency Plan (v1.4)

The South Gippsland Shire Flood emergency plan documents the following with respect to the study area:

- Houses backing onto Stockyard Creek are at risk of Riverine Flooding and Flash Flooding.
- In 2012, a dam break in the Stockyard Creek catchment resulted in minor flooding and evacuations in Foster.
- The Bureau of Meteorology does not provide a Flood Warning Service for Foster.
- The Flood Emergency Plan does not document a specific evacuation plan for Foster.

2.3.3 Flood Management Plan for South Gippsland Shire Council

The Flood Management Plan for South Gippsland Shire Council documents the following with respect to the study area:

- Recovery or rectification works have been undertaken by SGSC on Amey’s Track near Maria’s Junk Yard. At this location a major slip occurred damaging the road. Although not documented in the report, this slip may have been due to flooding from Bennison Creek.

- Dam in the catchment upstream of Foster failed in heavy rain.
- Social infrastructure in Foster is under threat from Stockyard Creek flooding and stormwater flooding.

2.4 Victorian Coastal LiDAR data set (Level 3)

2.4.1 Data set information

The Victorian Coastal LiDAR data set (Level 3) was provided for use on this project by the WGCMA. The following summarises the LiDAR data set:

- Victorian Coastal LIDAR Level 3 Classification
- Flown 23 Oct 2008 – 09 Feb 2009 (South Gippsland)
- Vertical accuracy of ±0.10 m
- Horizontal accuracy of ±0.35 m.

2.4.2 Data set application

The LiDAR data set was used on the Foster flood study as follows:

- To inform catchment and flow path definition for the RORB hydrological model
- As the Digital Elevation Model (DEM) for the 1D/2D TUFLOW hydraulic model.

2.4.3 Fit for purpose investigations

The following investigations were undertaken to determine whether the data set was fit for the applications required:

- RORB hydrological model
  - Check spatial coverage to determine whether the data set covers the catchment area.
- 1D/2D TUFLOW hydraulic model
  - Check locations where open water is identified on the aerial photographs (such as dams) in order to determine whether a water surface has been captured by the LiDAR and what implications this may have for the modelling

- Check LiDAR surface levels in Stockyard Creek and Bennison Creek relative to culvert invert information to determine whether the LiDAR is capturing the ground surface or may be subject to interference
- Check LiDAR surface levels at incised and heavily vegetated locations where the LiDAR may be subject to interference
- Check LiDAR surface levels where the aerial image indicates new developments or other land use changes may have occurred since the LiDAR was flown.

The LiDAR Digital Elevation Model (DEM) that will be used for the Stockyard Creek and Bennison Creek TUFLOW models is presented in Figure 2.1 and Figure 2.2 respectively.

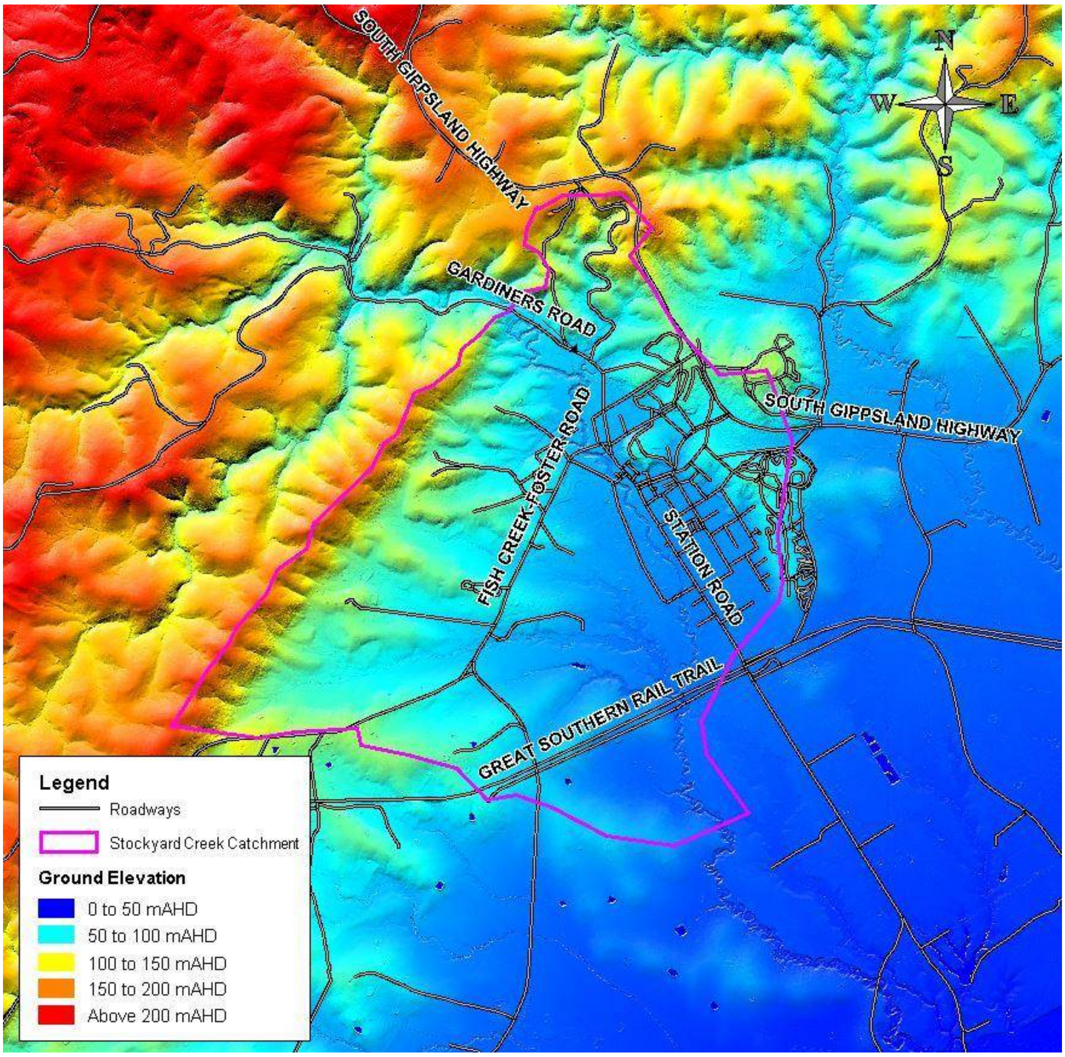

Figure 2.1 **Stockyard Creek catchment LiDAR DEM**

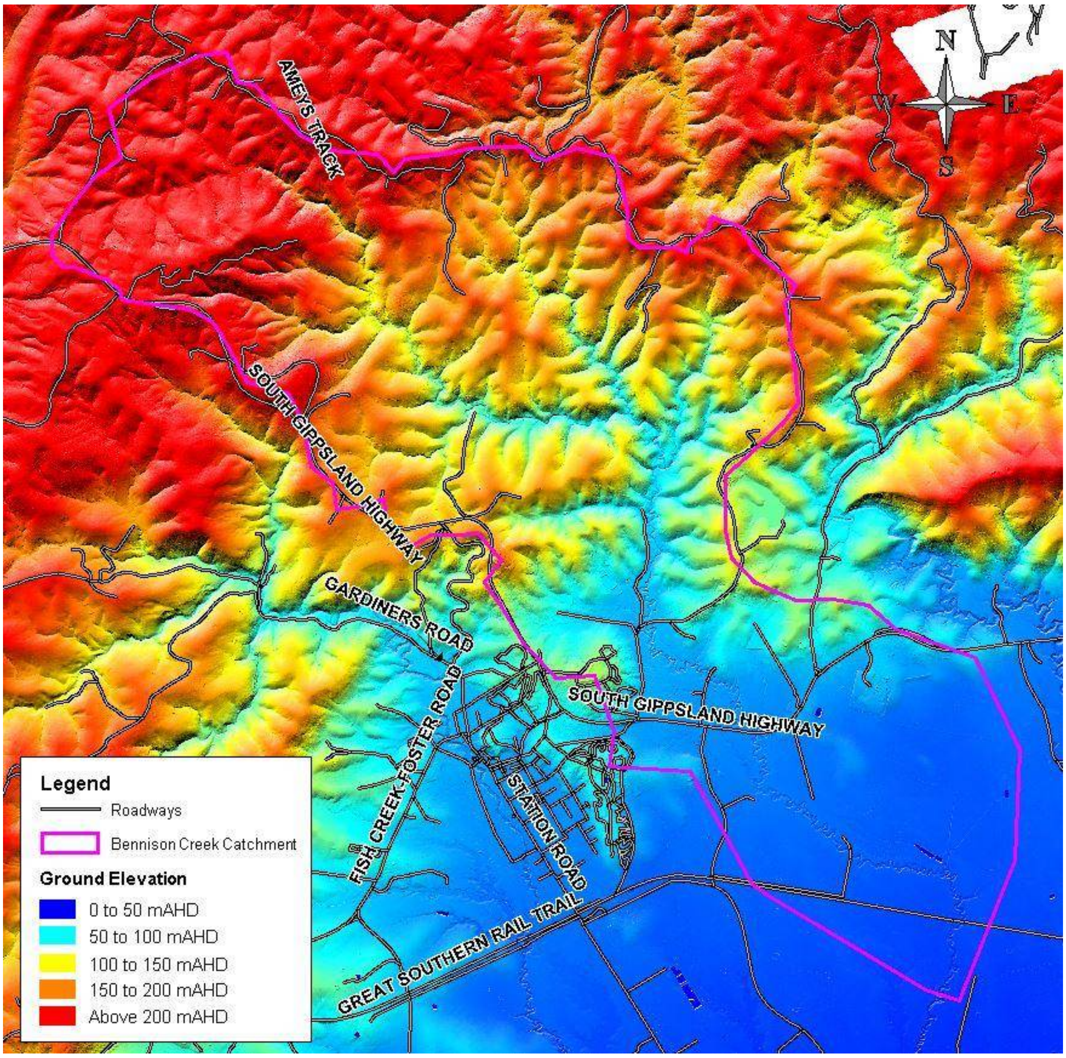

Figure 2.2 **Bennison Creek catchment LiDAR DEM**

Figure 2.3 shows where the available feature survey data was used to verify the accuracy of the LiDAR data. The figure shows that the LiDAR data is generally 150 – 200 mm higher than the survey data. Additional comparisons between the LiDAR data and available design plans for structures on Bennison and Stockyard Creek are presented in Table 2.2. Comparisons with design plans were made where the plans should be consistent with the LIDAR data, such as waterway inverts upstream and downstream of culverts.

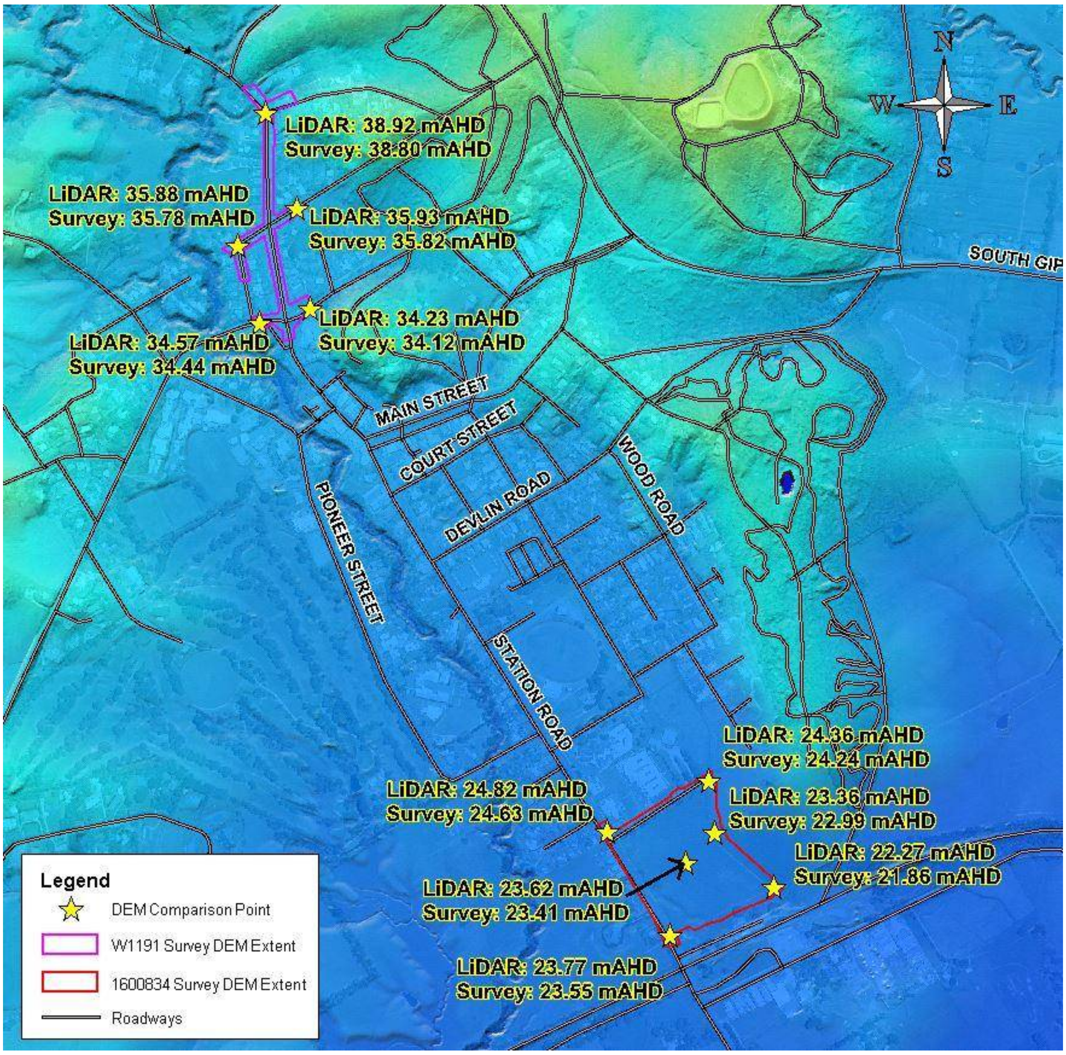

Figure 2.3 **LiDAR ground truthing locations**

Table 2.2 LiDAR data versus design plan comparison

Location	Plans	Waterway invert upstream of the crossing	Road crest elevation	Waterway invert downstream of the crossing
Bennison Creek @ the South Gippsland Highway culverts	VicRoads design plans (Drawing no. 14,326)	Plans: 22.33 m AHD LiDAR: 23.13 m AHD Difference: +0.8 m	Plans: 27.35 m AHD LiDAR: 27.29 m AHD Difference: -0.06 m	Plans: 22.19 m AHD LiDAR: 23.09 m AHD Difference: +0.9 m
Stockyard Creek @ the Boundary Road culverts	SGSC proposed design plans (Drawing no. C09547-06)	Plans: 22.80 m AHD LiDAR: 21.81 m AHD Difference: -0.99 m	-	Plans: 22.60 m AHD LiDAR: 21.69 m AHD Difference: -0.91 m

The results of the LiDAR data investigation are presented in Table 2.3 together with conclusions regarding the use of the LiDAR data for the hydraulic model DEM. The investigation is subject to the inherent assumption that the survey data sources are accurate, which could not be verified.

Table 2.3 LiDAR data set consistency with other sources

Comparison	No. locations	Vertical LiDAR data consistency	Standard Deviation	Hydraulic model DEM use
Ground truthing	11	+0.19 m (LiDAR on average **higher** than survey data)	0.11 m	Adopt LiDAR data as the base data for the DEM. Use engineering feature surveys to represent the hydraulic model DEM where available.
Bennison Creek Design plan comparison	2	+0.85 m (LiDAR on average **higher** than survey data)	0.07	Undertake additional survey within the waterways and around structures to further inform LiDAR data accuracy.
Stockyard Creek Design plan comparison	2	-0.95 m (LiDAR on average **lower** than survey data)	0.06	Undertake additional survey within the waterways and around structures to further inform LiDAR data accuracy.

In addition to the above investigations, surface levels at private dams were determined to be representing the water level in the dams at the time of the LiDAR survey, which were lower than the top of bank. Initial water levels set at dam spillway crest levels will be used in the TUFLOW model to remove the flood mitigation effect that these structures may otherwise have.

2.4.4 Land use changes since 2008 - 2009

SGSC has requested that the following changes, that have occurred since the 2008 - 2009 LiDAR survey or were in construction during the time of this study, should be accounted for as part of the hydrological and hydraulic modelling:

- Victory Avenue streetscape works (Victory Avenue.pdf / 14026 Master – SGQ.dwg)
- Main Street streetscape works (C09386 series .pdf drawings)
- O'Connell Road Aged Care Development (WME110403 series .pdf drawings)
- Varney Street Residential Development (1157-1(B).pdf and Stage 2 Approved Plans.pdf).

2.5 SGSC GIS Drainage System Data

2.5.1 Data set information

GIS data sets of the SGSC drainage network were provided by SGSC for use in the Foster flood study. The data sets contain georeferenced graphical representations of the SGSC pipe, pit and open drain network. Objects within the data sets are attributed with fields such as Invert elevation and Diameter.

2.5.2 Data set application

The GIS data sets represent the base data that will be used to represent the SGSC drainage system within the 1D/2D TUFLOW hydraulic model.

2.5.3 Drainage pipes

The SGSC GIS drainage pipe data contains 459 pipes and 467 pits that are located within the study area. Figure 2.4 presents the SGSC drainage network.

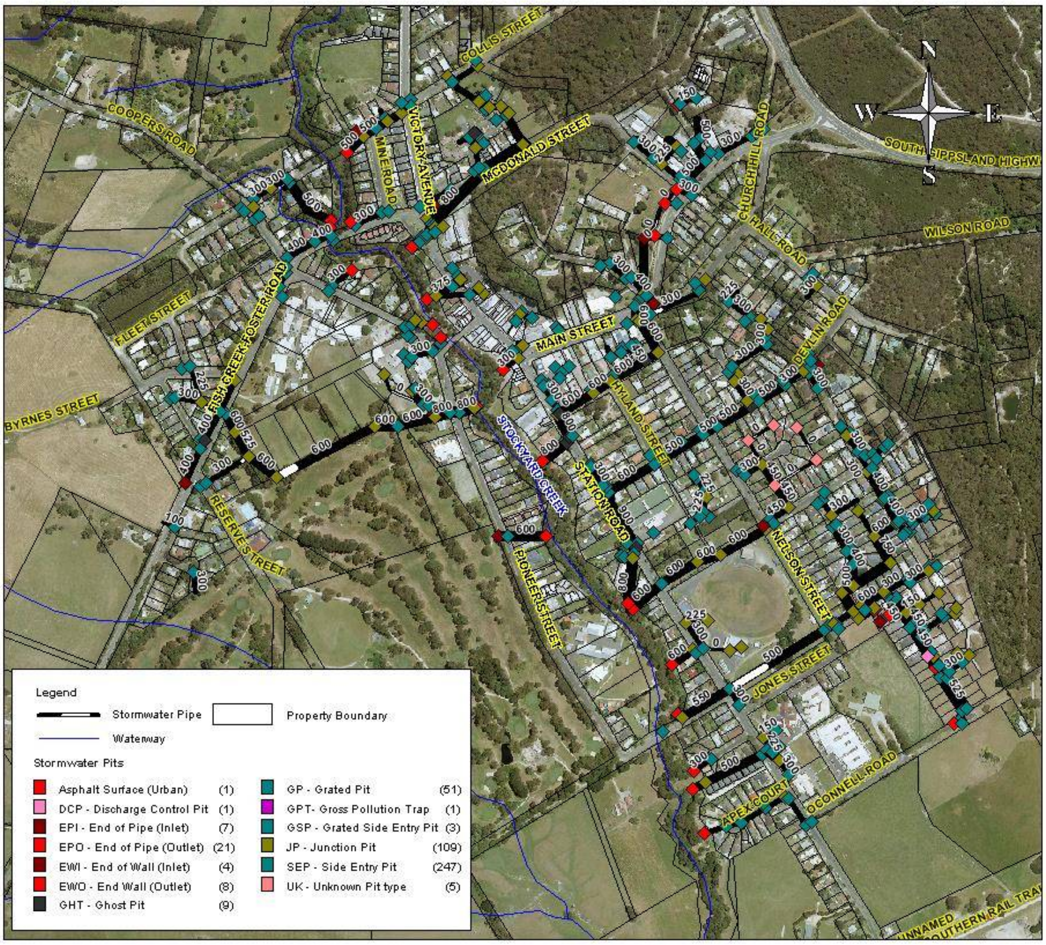

Figure 2.4 **Foster pipe and pit drainage network**

Table 2.4 presents a summary of the SGSC GIS pipe data which shows that the data contains several zero diameter pipes and non-standard diameters. The pipe data was presented to SGSC for advice on the accuracy/validity of the records based on their understanding of how the data was captured. The final column in Table 2.4 presents SGSC's responses to how Engeny should adopt/modify this data for use in the 1D/2D TUFLOW hydraulic model.

Table 2.4 Pipe data

Pipe diameter (mm)	Material	Standard Diameter?	No. pipes	SGSC advised assumption
0	PVC/Concrete (RC)	N	15	Infer where upstream pipe exists.
50	PVC/RC	Y (PVC) / N (RC)	1	Do not model
100	PVC		6	Do not model
150	PVC/RC	Y (PVC) / N (RC)	20	Do not model
200	RC	N	4	Do not model
225	PVC/RC	Y	48	225
250	RC	N	4	225
300	RC	Y	217	300
375	RC	Y	10	375
400	RC	N	23	375
450	RC	Y	20	450
500	RC	N	22	525
525	RC	Y	6	525
550	RC	N	4	525
600	RC	Y	38	600
750	RC	Y	4	750
800	RC	N	13	750
900	RC/Unknown	Y	4	900
TOTAL	**-**	**-**	**459**	**-**

35 of 459 pipes in the GIS layer were attributed with upstream and downstream invert levels. SGSC advised that the invert data was unlikely to be accurate based on the method of capture and that based on their understanding of the pipe drainage system, a 400 mm standard depth of cover should be adopted for all pipes.

Drainage plans for a number of locations were provided (as documented in Table 2.1) and these plans were used to update the SGSC GIS pipe data.

The following procedures were used to ready the GIS pipe data for use in the 1D/2D TUFLOW model:

- Pipe direction:
  - Pipe directions were reversed where the direction was found to be opposite to the direction of flow.
- Snapping pipes together:
  - Some pipes were found to be graphically disconnected
  - Pipes were snapped together where gaps were found between pipes.
- Invert levels:
  - Invert levels were based on the depth of the upstream and downstream pits (as per Stormwater_pits.tab layer provided by SGSC). Where invert levels were not available the following equation was used to set the invert level:
  - Invert Level = Ground level RL – 400 mm (pipe cover) – pipe diameter.

2.5.4 Drainage pits

Table 2.5 presents a summary of the SGSC GIS pit data which shows that the data contains a range of different pit types. The inlet dimension and inlet type that will be adopted for the TUFLOW model and has been agreed with SGSC is also presented in the table.

Table 2.5 Pit data

Type	Abbreviation	Number	Inlet type	Inlet dimensions (mm)
Discharge Control Pit	DCP	1	Grated	1000W x 1000D
End of Pipe (Inlet)	EPI	7	Headwall	As per pipe dimensions
End of Pipe (Outlet)	EPO	21	Headwall	As per pipe dimensions
End Wall (Inlet)	EWI	4	Headwall	As per pipe dimensions
End Wall (Outlet)	EWO	8	Headwall	As per pipe dimensions
Ghost Pit	GHT	9	N/A	No inlet/outlet capacity.
Grated Pit	GP	51	Grated	900W x 600D 70 % of this area assumed available for

Type	Abbreviation	Number	Inlet type	Inlet dimensions (mm)
				inflow (to account for bars)
Gross Pollutant Trap	GPT	1	N/A	No inlet/outlet capacity.
Grated Side Entry Pit	GSP	3	Kerb / Grated	900W x 600D X 115H inlet size to account for SEP and Grated pit opening. 70 % of the grated area assumed available for inflow (to account for bars)
Junction Pit	JO	109	N/A	No inlet/outlet capacity.
Side Entry Pit	SEP	247	Kerb	900W x 115H
Unknown Pit type	UK	5	N/A	No inlet/outlet capacity.
Asphalt Surface (Urban)	-	1	-	N/A
TOTAL		**467**		**-**

2.6 Large Waterway Structures

Large waterway structures on Stockyard and Bennison Creek that will be represented in the TUFLOW hydraulic model are presented in Table 2.6. The data source (or if the data has been provided) that is available to use as a basis for the TUFLOW model representation of each structure is also presented in the table.

Table 2.6 Large waterway structures

Structure	Catchment	Location	Data source
Bridge	Stockyard Creek	Dyrings Road	Site photos (see Appendix A)
Bridge	Stockyard Creek	Great Southern Rail Trail	Site photos (see Appendix B)
Bridge	Stockyard Creek	South Gippsland Railway (abandoned)	Site photos (see Appendix B)
Culvert	Stockyard Creek	Boundary Road	Site photos provided by SGSC (see Appendix A)
Bridge	Stockyard Creek	Pedestrian Bridge adjacent to the Foster Primary	Site photos provided by SGSC (see Appendix A)

Structure	Catchment	Location	Data source
		School	
Bridge	Stockyard Creek	Pedestrian Bridge adjacent to the Scout Hall	Site photos provided by SGSC (see Appendix A)
Culvert	Stockyard Creek	Bridge Street	Site photos provided by SGSC (see Appendix A)
Bridge	Stockyard Creek	Pedestrian Bridge in Pearl Park	Site photos provided by SGSC (see Appendix A)
Culvert	Stockyard Creek	Fish Creek – Foster Rd	Design plans provided by VicRoads
Culvert	Stockyard Creek (tributary)	Gibbs Street	Design plans provided by SGSC
Culvert	Stockyard Creek (tributary)	Gardiners Road 1	Site photos provided by SGSC (see Appendix A)
Culvert	Stockyard Creek	Gardiners Road 2	Site photos provided by SGSC (see Appendix A)
Bridge	Bennison Creek	Great Southern Rail Trail	Design to be assumed as per other rail trail crossings. Span 28 metres as advised by SGSC
Unknown	Bennison Creek	Elphicks Road	Site photos provided by SGSC (see Appendix A)
Culvert	Bennison Creek	South Gippsland Highway	Design plans provided by VicRoads
Unknown	Bennison Creek	Jacksons Road	Site photos provided by SGSC (see Appendix A)
Culvert	Bennison Creek	Ameys Track	Site photos provided by SGSC (see Appendix A)

2.7 VicRoads Waterway Structure Data

2.7.1 Data set information

The following information was provided by VicRoads:

- Design plans for the Bennison Creek Culverts on the South Gippsland Highway

- Design sketches (dimensions but no level information) for the Stockyard Creek culvert on the Fish Creek – Foster Road.

2.7.2 Data set application

The VicRoads plans were used to inform the sizing of structures in the TUFLOW hydraulic model and to check the accuracy of the LiDAR data at Bennison Creek.

2.8 Great Southern Rail Trail data

2.8.1 Data set information

Limited information was available to inform the definition of structures on the Great Southern Rail Trail. The following data was available:

- Figure provided by SGSC indicating that the Great Southern Rail Trail span on Bennison Creek is 28 metres

- Site photographs provided by SGSC of Rail Trail bridges and disused South Gippsland Railway bridges with measurement staff shown in the pictures for scale (refer to **Appendix B**).

2.9 Southern Rural Water Supply Dam data

The bathymetry and spillway data for the large water supply dams that are located on the Fish Creek – Foster Road and O’Grady’s Ridge Road, (known as Couper’s and Eddy’s dams) are required to inform the hydrological modelling and dam break assessment.

Southern Rural Water (SRW) provided the following reports and plans for the Eddy’s and Couper’s dams:

- Inspection of an existing dam at 815 O’Gradys Ridge Road, Foster (Structerre, 2016)

- Couper Farm Dam Assessment (AECOM, 2011).

2.10 Rainfall Gauges

Various rainfall gauges were investigated within Foster and surrounding areas in order to determine their suitability for calibration of the RORB models. Figure 2.5 presents the locations of rainfall gauges in the region. Pluviograph data (rainfall recorded at 6-minute intervals) is required for RORB model calibration. The nearest pluviograph gauge with a period of record covering the key streamflow events is 85227, which is approximately 10 km from the study catchments. The location of this gauge is not ideal for model calibration but is the best available information.

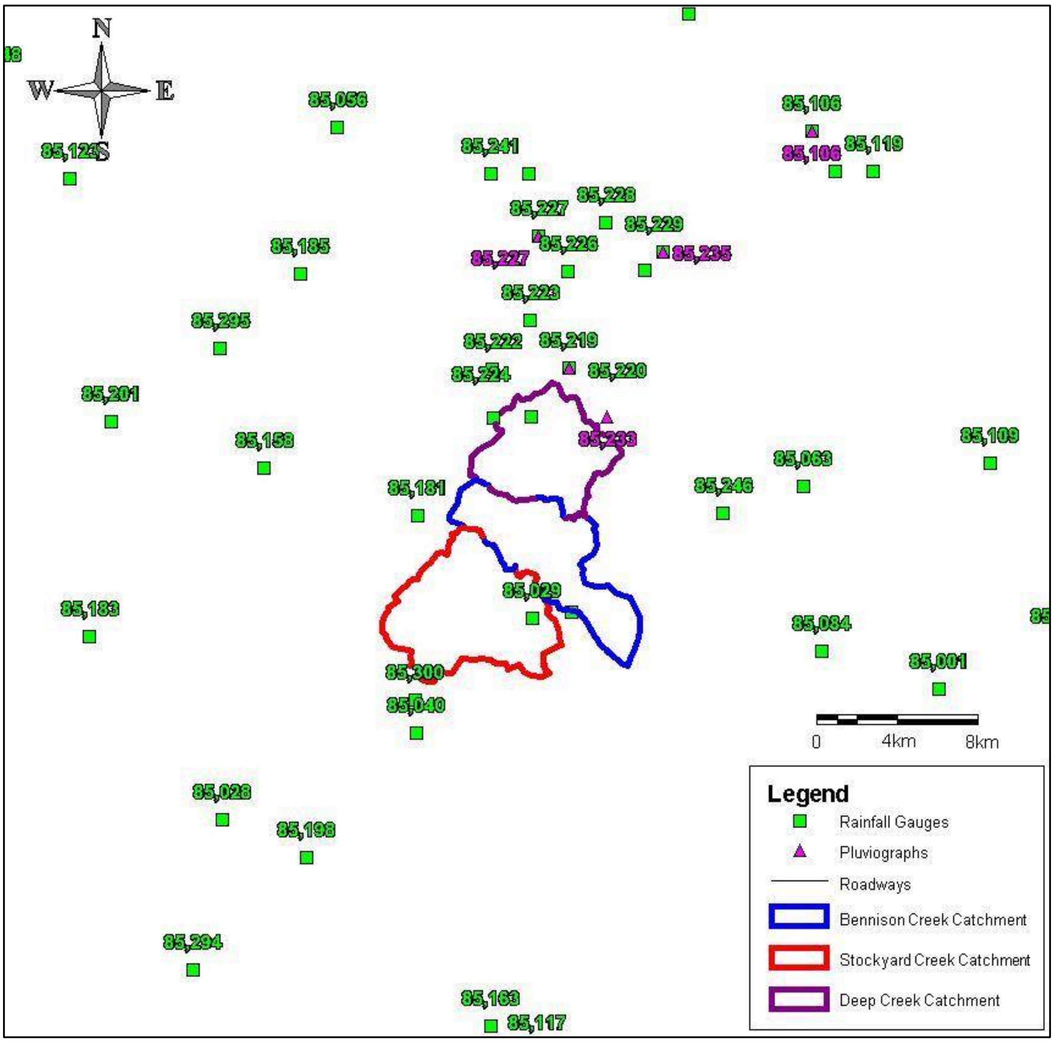

Figure 2.5 **Rainfall gauges and pluviograph locations**

2.11 Streamflow Gauges

The ARR 2016 recommended approach to hydrological modelling is to adopt historical streamflow data for calibration, where this data is available. Ideally, streamflow data from within the study catchment is to be used for calibration. However, where this is not possible, streamflow data from neighbouring catchments can be used, providing the catchment has similar characteristics to the catchment of interest (size, terrain, etc.).

Both the Stockyard Creek catchment and Bennison Creek catchment are ungauged catchments. The only identified stream flow gauge that was considered to be suitably located for calibration was the Deep Creek @ Foster Gauge (227244), which is located in the catchment directly to the north of the Bennison Creek Catchment. The Deep Creek catchment is of similar size to the study catchments and has a period of record from 1993 to present day. Its location in the context of the Stockyard Creek and Bennison Creek catchments is shown in Figure 2.5.

The rating curve for Deep Creek gauge 227244 is shown on Figure 2.6. The rating curve image was downloaded from the Department of Environment, Land, Water & Planning (DELWP) water data website (data.water.vic.gov.au) on 7/26/2017.

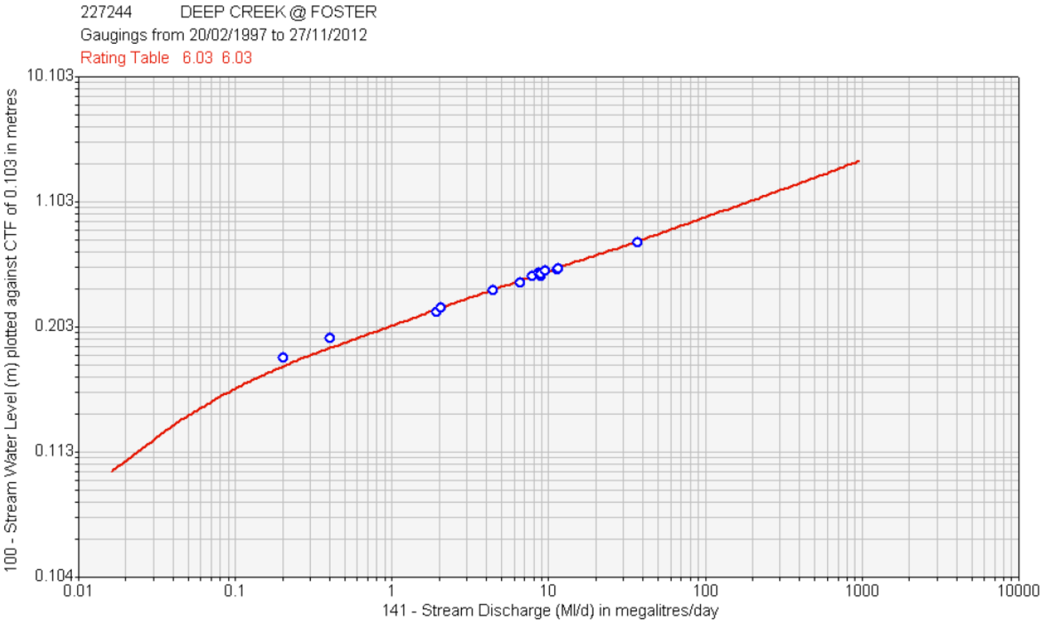

Figure 2.6 **Deep Creek @ Foster gauge rating curve**

Figure 2.7 shows that the largest recorded flow used to create the rating curve was approximately 37 Ml/d or 0.4 m^3/s. The flood frequency curve (FFC) for this gauge is shown in Figure 2.7. The FFC was downloaded from the DELWP water data website on 7/26/2017.

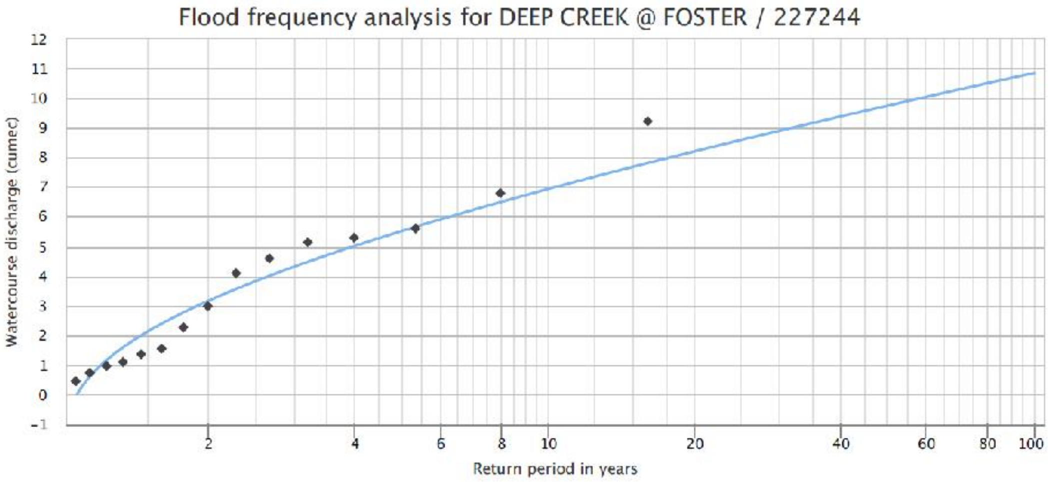

Figure 2.7 **Flood Frequency Curve (FFC) for Deep Creek @ Foster gauge**

Hydrology model calibration is typically undertaken on 2-3 of the largest recorded events. Based on the FFC and a review of the flow data record, these are estimated to be the 1995 storm (9.2 m^3/s), the 1993 storm (6.8 m^3/s) and the 2013 storm (5.6 m^3/s). Considering the FFC, these flows have annual exceedance probabilities (AEP) of approximately 1 in 19, 1 in 13 and 1 in 6 respectively. The 1993 event was unavailable for the purposes of calibration due to a shortfall of pluviograph data at this time.

Consideration was given to the accuracy of the flow record in order to determine whether calibration should be undertaken using the data from the available storm events. Given the rating curve shows that flows in excess of 0.4 m^3/s are estimated based on extrapolation, it was considered that there was a high degree of uncertainty associated with the magnitude of the potential calibration event flows. In addition, the relatively small number and magnitude of flow events (up to the 1 in 19 AEP assuming an accurate flow record) would not have provided a high confidence calibration. For these reasons the Deep Creek @ Foster Gauge was not considered suitable for model calibration and verification.

Furthermore, in using the procedures outlined in Book 5, Section 4.5.2 of AR&R 2016 (Estimating Baseflow in the Absence of Streamflow Data) the baseflow under the peak streamflow was estimated at approximately 2-4 % of the peak surface runoff. Given the uncertainty associated with the RFFE estimates it was decided that including baseflow in the hydrologic modelling would have a negligible impact and it was therefore excluded from the analysis.

3. CATCHMENTS

3.1 Stockyard Creek

The Stockyard Creek catchment is predominantly rural land with large open grass areas and two large dams located in the upper reaches. The town of Foster is located in the eastern part of the catchment and includes commercial, residential and industrial land uses. Hilly terrain with occasionally steep gradients characterise the upper reaches of the catchment, whereas a much gentler and slightly rolling landscape exists closer to the catchment outlet. Ground surface elevations range between approximately 230 mAHD to 13 mAHD. Figure 3.1 represents the stockyard catchment boundary (red polyline) in the context of Foster and the surrounding landscape (represented by the 2015 aerial photograph provided by SGSC).

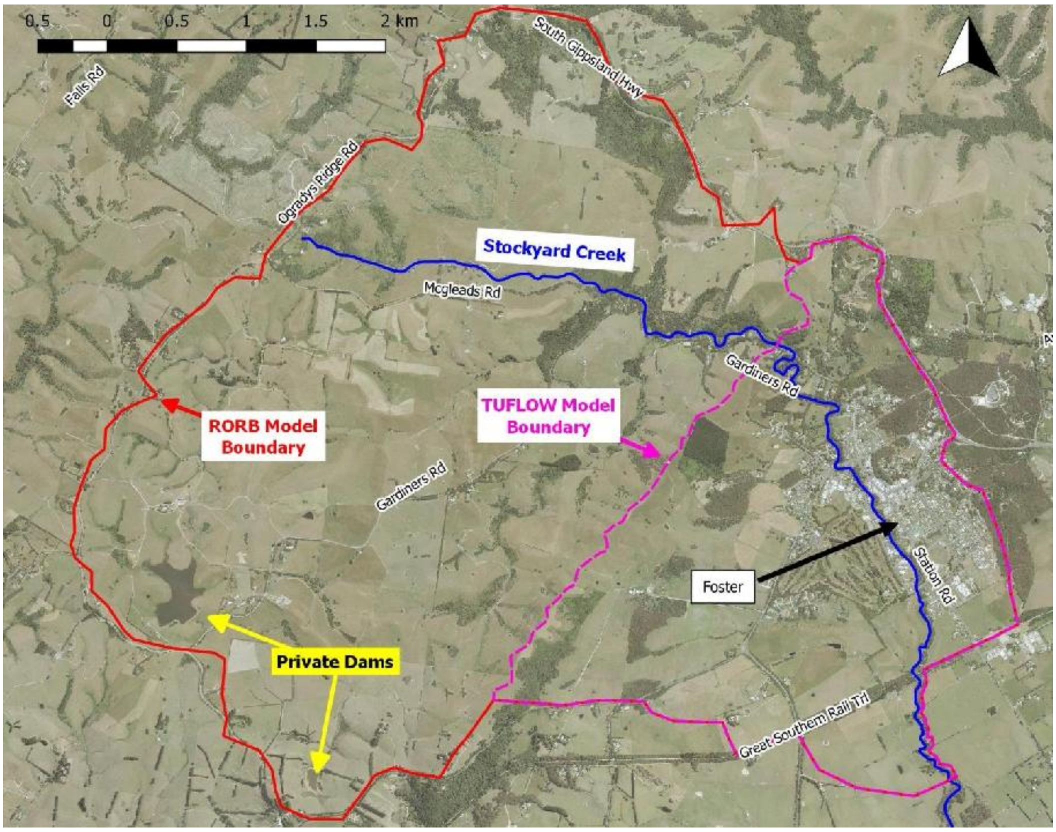

Figure 3.1 Stockyard Creek catchment

The Stockyard Creek catchment covers an area of approximately 24.2 square kilometres. **Appendix C** provides a layout plan of the Stockyard Creek RORB model that was used to estimate waterway inflows to the TUFLOW hydraulic model. **Appendix D** presents a layout plan of the Foster Urban flood model that was used to generate rainfall excess inflows for the TUFLOW model area. Figure 3.2 presents a photo from the South Gippsland Highway showing the upper reaches of the Stockyard Creek catchment.

Figure 3.2 Stockyard Creek catchment from the South Gippsland Highway

3.2 Bennison Creek

The Bennison Creek catchment contains predominantly rural land with areas of open grass. Its terrain is similar to the Stockyard Creek catchment and is hilly in the north with much gentler grades in the south. There are no major water storages within the area. Ground surface elevations range between approximately 290 mAHD to 9 mAHD. Figure 3.3 presents the Bennison Creek catchment boundary (red polyline) and the surrounding landscape (represented by the 2015 aerial photograph).

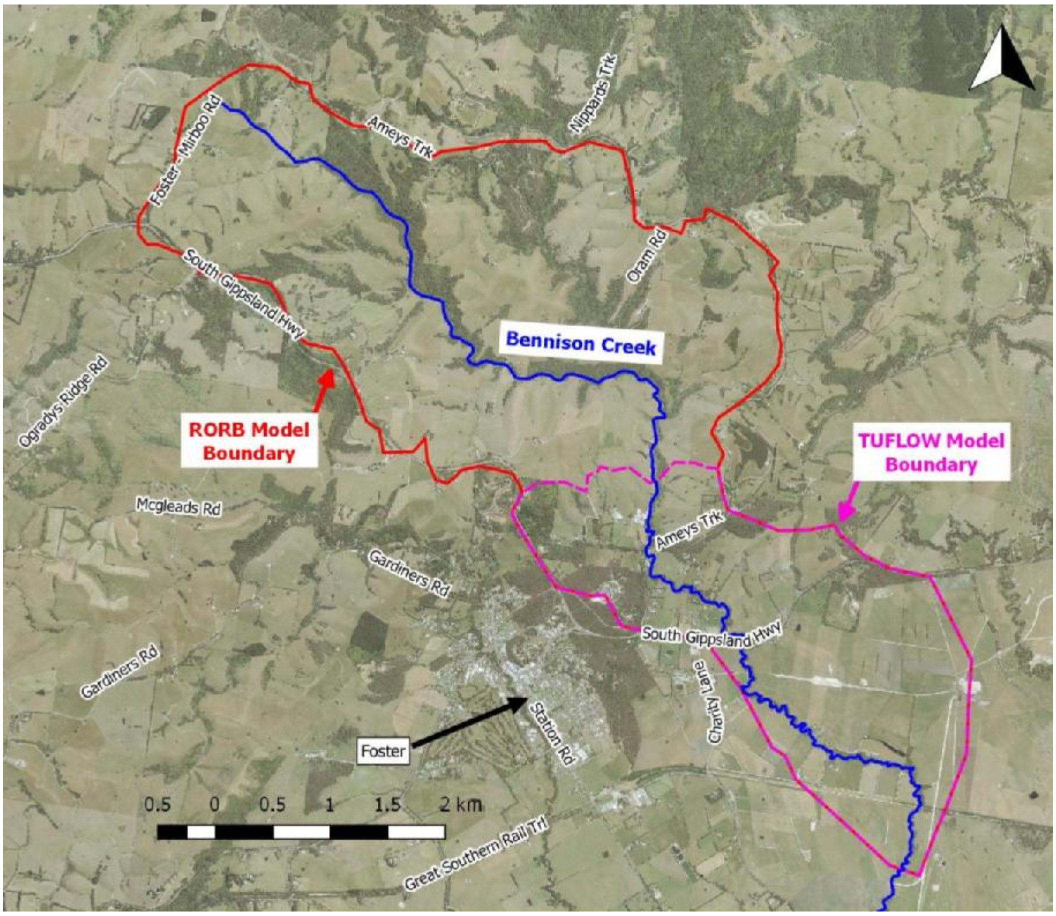

Figure 3.3 **Bennison Creek catchment**

The Bennison Creek catchment area is approximately 18.8 square kilometres. **Appendix E** presents a layout plan of the Bennison Creek RORB model.

4. HYDROLOGY

4.1 Hydrological Investigations

The Stockyard Creek and Bennison Creek catchments include Foster and the surrounding region. Both catchments are similar size and cover a combined area of approximately 43 square kilometres, which includes undulating and predominantly rural land. The town of Foster is located within the Stockyard Creek catchment. The location of both catchments is presented in Figure 4.1.

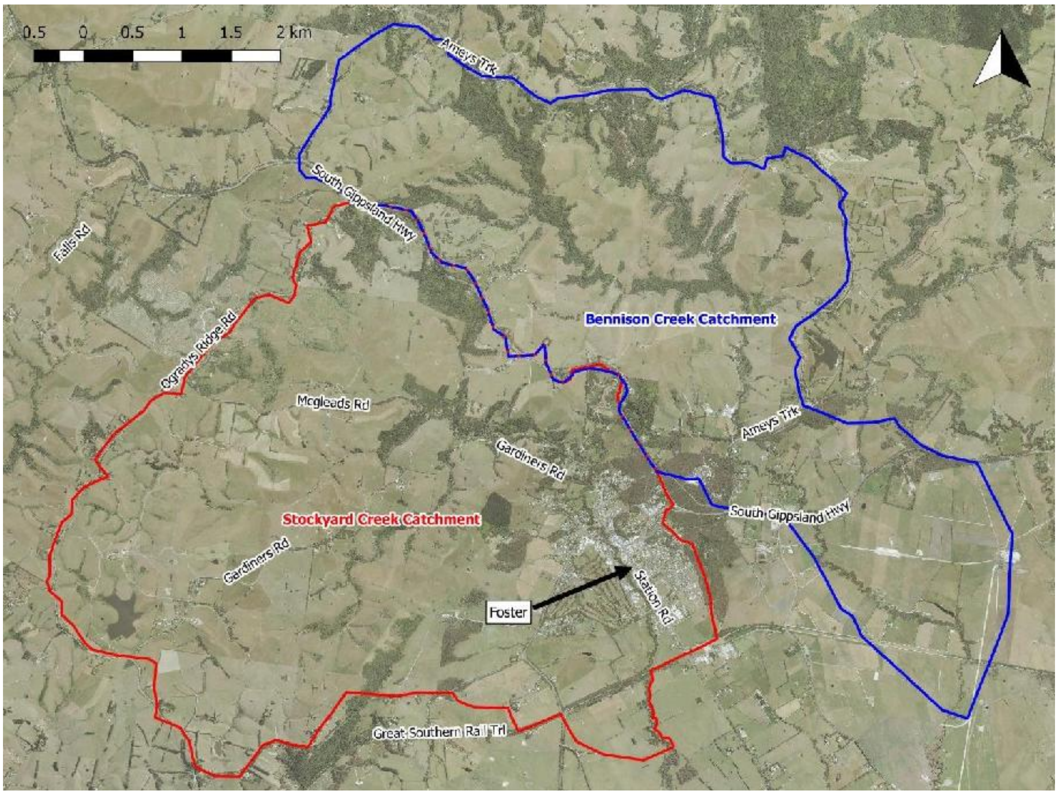

Figure 4.1 Locations of Stockyard Creek and Bennison Creek catchments

This report documents the hydrological investigations and methodology used by Engeny to develop RORB hydrological models for the Stockyard Creek and Bennison Creek catchments within Foster and surrounding areas. The key objective of hydrological modelling was to produce inflow hydrographs for the 1D/2D TUFLOW hydraulic models that will be used to undertake the flood plain investigations.

Engeny believes that the modelling methodology that has been devised is consistent with the recommendations of the Australian Rainfall and Runoff (AR&R) Guidelines (November 2016), and has adopted the revised Intensity-Frequency-Duration (IFD) data, rainfall temporal patterns and model parameters as a basis for the hydrological modelling.

4.2 Scope

The scope for the hydrological investigation was as follows:

- Review of historical hydrological information, including streamflow and rainfall data
- Development of two (2) separate RORB hydrological models for the Stockyard Creek and Bennison Creek catchments respectively
- RORB model calibration (determination of kc parameter) to historical events if sufficient streamflow and rainfall data is available, otherwise kc to be based on regional prediction equations
- RORB model verification to site specific flood frequency analysis (FFA) if sufficient streamflow data is available, or to FFA recommended by the Regional Flood Frequency Estimation Tool (RFFE)
- Extraction of design rainfall depths from the Bureau of Meteorology (BoM) for a range of Average Exceedance Probabilities (AEPs) and storm durations
- Extraction of recommended loss parameters and pre-burst rainfall depths from the ARR data hub
- Undertake design hydrograph estimation using the RORB hydrological models for the 10 %, 5 %, 2 % 1 %, 0.5 % AEP and the Probable Maximum Flood (PMF)
- Investigate the impacts of increased development within the town of Foster for the 1 % AEP storm event.
- Investigate the impacts of climate change following standard methods from Australian Rainfall and Runoff 2016.

4.3 Methodology

RORB models were developed for both the Stockyard Creek and Bennison Creek catchments for the purpose of creating inflow hydrographs for the 1D/2D TUFLOW hydraulic models. A combination of rainfall-excess hydrographs for urban areas and routed hydrographs for waterways was used as inputs for the 1D/2D TUFLOW hydraulic models. RORB modelling was undertaken to create inflow hydrographs for the 0.5 %, 1 %, 2 %, 5 %, and 10 % AEP storm events and Probable Maximum Flood (PMF) event using methodologies recommended by AR&R 2016.

The following summarises the adopted methodology:

- Catchment, subarea, node and reach delineation using the LiDAR DEM. Three diverted RORB models were created to represent:

  - Stockyard Creek waterway flows
  - Bennison Creek waterway flows
  - Foster urban catchment flows.

- RORB models for both the Stockyard Creek and Bennison Creek catchments were developed for subareas upstream and including the hydraulic model extent and used to estimate routed inflows to the upstream boundary of the TUFLOW hydraulic model

- A diverted RORB model was developed to represent the catchment within the TUFLOW model area for the purposes of determining the median temporal patterns and critical durations for areas within the TUFLOW hydraulic model boundary and generating rainfall excess inflows. This model is hereafter referred to as the Foster Urban RORB model.

- The rainfall excess inflow approach was adopted for the Foster TUFLOW hydraulic model for the purposes of investigating flooding within the town. A routed point inflow approach was adopted for the Bennison Creek TUFLOW hydraulic model as it was considered that little additional benefit would be realised for undertaking a rainfall excess modelling approach in this rural catchment.

- Fraction impervious definition in consultation with SGSC and WGCMA – based on a 2030 predicted development scenario in accordance with a framework plan formed and supplied by SGSC

- AR&R 2016 rainfall temporal patterns and depths derived from Bureau of Meteorology (BoM)

- Definition of the model routing parameter k_c using an assortment of recommended rural equations and verification to Rural Flood Frequency Estimator (RFFE) estimates

- Monte Carlo simulations to determine flood quantiles for each modelled duration and event based on the approach described in AR&R 2016 Book IV chapter 3

- Estimation of routed inflow hydrographs for application to the upstream boundary of the 1D/2D TUFLOW models for each catchment and for all required storm events

- Estimation of rainfall excess inflow hydrographs for sub areas located within the TUFLOW model boundary.

4.4 Urban RORB model versus the waterway RORB models

Routed waterway flows for Stockyard Creek and Bennison Creek were used as inflows at the upstream boundary of the respective TUFLOW models. The layout of the RORB models that were created to generate these flows are presented in **Appendix C** and **Appendix E** respectively. A separate RORB model was created to cover the TUFLOW model area (the Foster Urban RORB model) for the purposes of estimating rainfall excess inflows to that model. The layout for this model is presented in **Appendix D**. The separate model was created to allow the definition of significantly smaller subareas that were required to more accurately estimate flows to the urban pipe and pit network.

Whilst rainfall excess flows were used as inflows to the TUFLOW hydraulic model, a diverted RORB model (including pipe diversions with estimated capacities based on the pipe drainage network) was also created to route catchment flows and inform the selection of the temporal patterns and critical durations that will be used to generate the rainfall excess flows for TUFLOW. A number of representative locations were used to inform the selection of temporal patterns and critical durations as it was considered that subareas with similar characteristics (area, shape, land use and drainage) could be assumed to have the same critical duration and temporal pattern. The representative locations where results for critical duration and temporal pattern were investigated are shown in Figure 4.2.

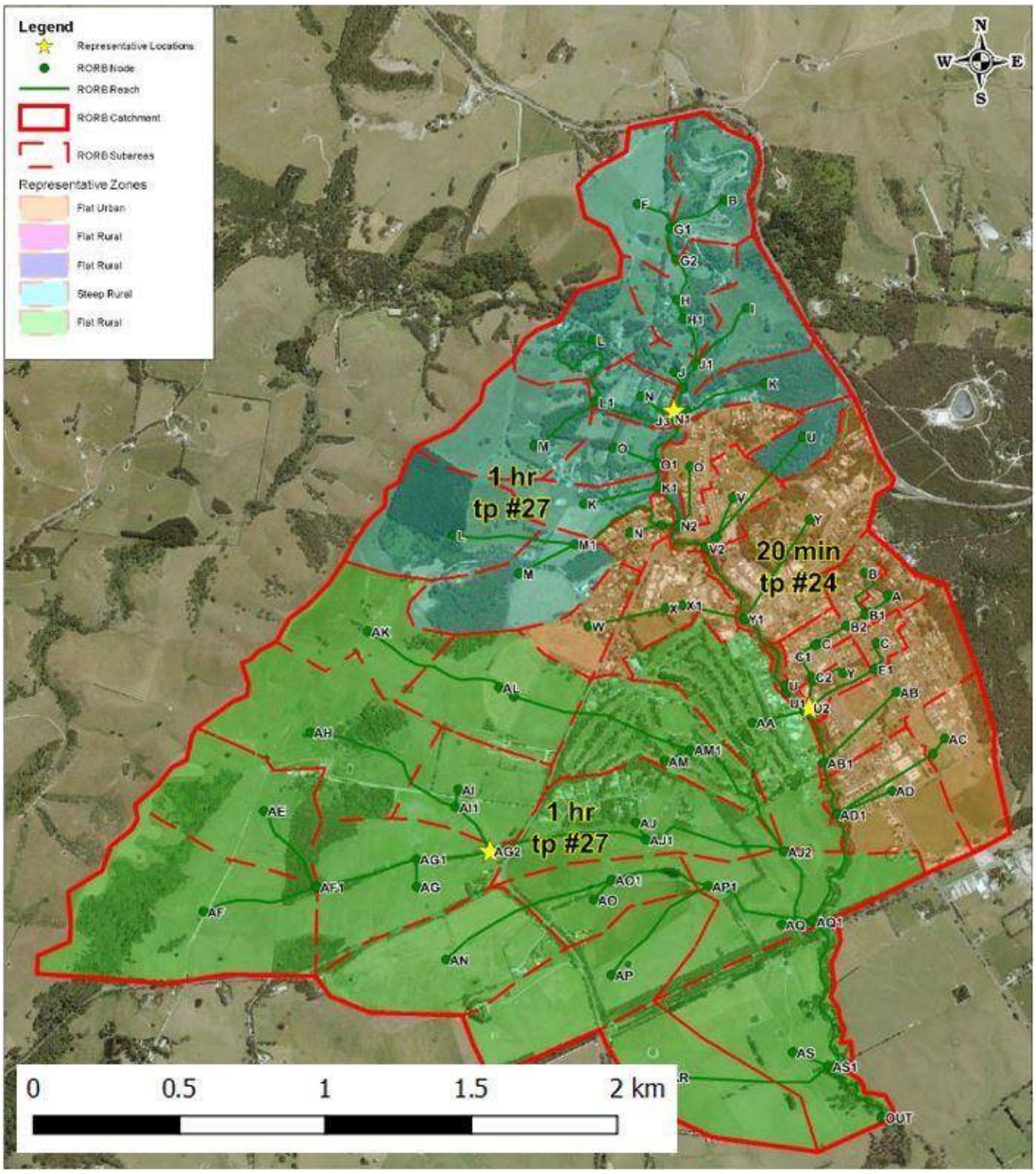

Figure 4.2 Critical duration and temporal patterns urban RORB model

Determining the critical duration and temporal pattern for each return period using RORB was adopted in favour of running the TUFLOW hydraulic model using an ensemble approach for all temporal patterns and durations (and return periods) because of the significant modelling (data and time) burden associated with the latter approach. The limitations with using the RORB approach are primarily associated with the simplistic representation of catchment storage and routing pathways afforded by that model, which theoretically could influence the critical duration and temporal patterns that are returned. Therefore, Engeny has compared the routing times in TUFLOW versus RORB for key flow paths after the initial hydraulic model runs were undertaken in order to determine the adjustments to the RORB reach types and other parameters to more accurately reflect catchment routing. We believe that this approach provides improved confidence regarding the selection of critical durations and temporal patterns.

4.5 Model Definition

4.5.1 Catchment and Sub-Catchment Delineation

Delineation of the Stockyard and Bennison Creek catchment and sub-catchment (sub-area) boundaries was informed by the following information:

- the DEM generated based on the provided Victorian Coastal LiDAR data set (Level 3) and contours generated from the DEM
- land use zones identified in the Victorian Planning Scheme
- property boundaries
- aerial photography (image date 2015)
- SGSC drainage asset locations.

Subareas were developed with consideration given to the predicted 1 % annual exceedance probability (AEP) overland flow paths and the inflow methodology being used for the 1D/2D TUFLOW hydraulic model.

Where appropriate, land use types with different impervious fractions were separated into different sub-catchments in order to reduce the effect of averaging runoff volumes across a sub-catchment.

4.5.2 Fraction Impervious Definition

Fraction imperviousness for both catchments was defined based on a future 2030 development scenario, in accordance with SGSC’s requirements. Victorian planning scheme zones were used in conjunction with recommended fraction impervious (FI) values from Melbourne Water Flood Mapping Guidelines (November 2016) and the available aerial photography (2015) as a basis for assigning preliminary FI values that were then modified in consultation with SGSC and WGCMA to represent a 2030 future development scenario.

Table 4.1 presents the normal range of FI values provided in the Melbourne Water Flood Mapping Guidelines (November 2016) for each land use, as well as the FI value adopted for this study. Where a normal FI value range has not been provided in the Melbourne Water Flood Mapping Guidelines, the Melbourne Water MUSIC Guidelines (2016) normal range was adopted as guidance. These values are presented in *italics* in Table 4.1 where they were available. There are a number of large lots within the catchment which are currently zoned for a higher density of housing than currently exist (based on aerial imagery). To account for the future development that SGSC consider is likely to occur in these catchments to the year 2030, the following methodology has been adopted.

- If the lot was zoned GRZ1 (general residential zoning) and was less than 800 m^2, an FI was assigned based on lot size (higher FI to smaller lots)
- If the lot was zoned GRZ1 (general residential zoning) and was greater than 800 m^2 an FI of 0.6 was assigned, assuming that the lot is likely to be redeveloped into smaller units/duplex/townhouses if the lot did not have an obvious other land use (i.e. school, park, road etc).

Appendix F and **Appendix G** present the impervious fraction and area of each subareas for the Stockyard Creek and Bennison Creek RORB models respectively.

Table 4.1 Fraction impervious values for planning scheme zones

Planning Scheme Zone	Zone Code	Normal Range (MW Guidelines)	Adopted RORB FI Value
Commercial 1 Zone	C1Z	*0.70 – 0.95*	0.9
Farming Zone	FZ	*0.05 – 0.1*	0.1 *(High density)* 0.05 *(Low density)*
General Residential Zone – Schedule 1	GRZ1	*0.80 – 0.95* *(High density)* *0.70 – 0.80* *(Standard density)* *0.50 – 0.80* *(Large residential)*	0.85 *(High density)* 0.75 *(Standard density)* *0.6* *(Large residential)*
Industrial 1 Zone	INIZ	0.70 – 0.95	0.7
Low Density Residential Zone	LDRZ	0.10 – 0.40	0.25
Mixed Use Zone	MUZ	0.50 – 0.80	0.7
Public Conservation and Resource Zone	PCRZ	0.1	0.1
Public Park and Recreation Zone	PPRZ	0.05 – 0.20	0.1
Public Use Zone – Service and Utility	PUZ1	0.05 – 0.10	0.05
Public Use Zone – Education	PUZ2	0.60 – 0.80	0.1 - 0.8

Planning Scheme Zone	Zone Code	Normal Range (MW Guidelines)	Adopted RORB FI Value
Public Use Zone – Health and Community	PUZ3	0.60 – 0.80	0.1 - 0.8
Public Use Zone – Transport	PUZ4	0.60 – 0.90	0.7
Public Use Zone – Cemetery/Crematorium	PUZ5	0.60 – 0.80	0.6
Public Use Zone – Local Government	PUZ6	0.50 – 0.90	0.7
Public Use Zone – Other	PUZ7	0.6	0.6
Road Zone – Category 1	RDZ1	0.60 – 0.90	0.6
Road Zone – Category 2	RDZ2	0.50 – 0.80	0.5
Rural Living Zone	RLZ	*0.1 – 0.2*	0.2
Township Zone	TZ	*0.40 – 0.70*	0.55

4.5.3 Catchment Storages

Two large private dams are located within the Stockyard Creek catchment, adjacent to the Fish Creek – Foster Road and O'Grady's Ridge Road respectively. Both dams are understood to have 150 mm trickle flow pipe outlets that aim to keep the normal water level below the top of bank. This means that in theory both dams could act as detention basins and act to attenuate catchment flows. Despite potentially influencing downstream catchment flows, the decision was made to exclude these dams from the Stockyard Creek RORB model for the following reasons:

- The dams are private and are not dedicated flood mitigation infrastructure that can be relied on for flood mitigation. This means the dams could be removed or reduced in size, which would reduce or eliminate any flood mitigation benefit that they may currently be providing.
- The 150 mm trickle flow pipe outlets may be subject to blockage which may mean dam water levels are full to the top of bank when a storm event occur. This scenario would result in the dams providing little or no attenuation to catchment flows.
- The dams are located very close to the catchment boundary and contain relatively small upstream catchment areas meaning that peak flows reaching the dams are likely to be small and therefore these structures are unlikely to have a significant impact on peak flows in Stockyard Creek at the TUFLOW model boundary.

4.6 RORB Model Parameters

4.6.1 Summary

Table 4.2 provides a summary of the final parameters adopted for the Stockyard Creek RORB model. The following sections provide information on the methodology used to determine each parameter.

Table 4.2 Stockyard Creek RORB model parameter specification

Parameter	Value
k_c	5
m	0.8
Initial Loss (Rural and Urban Pervious Areas)	20 mm
Continuing Loss (Rural and Urban Pervious Areas)	4.5 mm/hr
Initial Loss (Indirectly Connected Areas)	14 mm
Continuing Loss (Indirectly Connected Areas)	2.5 mm/hr
Initial Loss (Effective Impervious Areas)	1.5 mm
Continuing Loss (Effective Impervious Areas)	0 mm/hr

The Foster Urban RORB model is located within the Stockyard Creek catchment and adopted the same model parameters with the exception of the k_c which was 2.14.

Table 4.3 provides a summary of the final parameters utilised to run the Bennison Creek RORB model.

Table 4.3 Bennison Creek RORB model parameter specification

Parameter	Value
k_c	4
m	0.8
Initial Loss	20 mm
Continuing Loss	4.5 mm/hr

4.6.2 Intensity-Frequency-Duration (IFD) Data

AR&R 2016 IFD data for the Stockyard Creek and Bennison Creek catchments was sourced from the Bureau of Meteorology using the online 2016 Rainfall IFD request system. Data was requested for the respective catchment centroids, represented by the coordinates of -38.6473° south and 146.1729° east for Stockyard Creek and -38.6365° south and 146.2054° east for Bennison Creek. **Appendix H** and **Appendix I** present the design rainfall intensities for each duration and AEP for Stockyard Creek and Bennison Creek respectively. The design rainfall intensities for the Stockyard Creek catchment RORB model were also adopted for the Foster Urban RORB model.

As highlighted within AR&R 2016, design rainfall intensities are provided at a point which may not be representative of the areal average rainfall intensity across a catchment. RORB applies Areal Reduction Factors (ARF) which are determined on a per catchment basis via the AR&R DataHub. These values are then applied to the design rainfall intensities as a correction factor.

AR&R 2016 provides procedures for the calculation of ARFs for catchments up to 30,000 km^2 and durations up to and including 7 days. The following methodology, recommended by AR&R 2016 for catchments between 10 and 1000 km^2, was utilised in calculating the ARFs for each standard event and duration.

For each AEP and duration up to and including 12 hours, an ARF was calculated using Equation 4-1.

$$\begin{aligned} ARF = Min\Big[1, 1 - 0.287\left(Area^{0.265} - 0.439\log_{10}(Duration)\right).Duration^{-0.36} \\ + 2.26 \text{ x } 10^{-3} \text{ x } Area^{0.226}.Duration^{0.125}\left(0.3 + \log_{10}(AEP)\right) \\ + 0.0141 \text{ x } Area^{0.213} \text{ x } 10^{\;0.021\frac{(Duration-180)^2}{1440}}\left(0.3 + \log_{10}(AEP)\right)\Big] \end{aligned}$$

Equation 4-1 ARF equation 2.4.1 (AR&R 2016) for durations ≤12 hours

For each AEP and durations greater than or equal to 24 hours, ARFs were computed using Equation 4-2.

$$\begin{aligned} Areal\ reduction\ factor = Min\Big\{1, \Big[1 - a\left(Area^{b} - c\log_{10}Duration\right)Duration^{-d} \\ + eArea^{f}Duration^{g}\left(0.3 + \log_{10}AEP\right) \\ + h10^{iArea\frac{Duration}{1440}}\left(0.3 + \log_{10}AEP\right)\Big]\Big\} \end{aligned}$$

Equation 4-2 ARF equation 2.4.4 (AR&R 2016) for durations between 24 hours and 7 days inclusive

The ARF for the 18-hour duration was calculated based on the ARF derived for the 24 hour and 12-hour durations, according to Equation 4-3.

$$ARF = ARF_{12hour} + (ARF_{24hour} - ARF_{12hour})\frac{(Duration - 720)}{720}$$

Equation 4-3 ARF equation 2.4.2 (AR&R 2016) for durations between 12 hours and 24 hours

4.6.3 Temporal Rainfall Patterns

2016 AR&R temporal patterns, downloaded from the AR&R DataHub, were adopted for all RORB models. AR&R 2016 states that point temporal patterns should be used for catchments less than 75 km^2. The study catchment size for Stockyard Creek is 24.19 km^2 and Bennison Creek is 18.77 km^2 therefore point temporal patterns were adopted.

4.6.4 Spatial Rainfall Patterns

Uniform spatial patterns were adopted for each catchment model.

4.6.5 Initial and Continuing Loss Model

All RORB models adopted an initial loss/continuing loss model approach, in accordance with the recommendations of AR&R 2016.

AR&R 2016 provides a methodology to calculate initial loss and continuing loss values for different land uses. These loss values are calculated based on the concepts of Effective Impervious Area (EIA), Indirectly Connected Areas (ICA) and pervious areas, which are detailed in Chapter 3.4 of Book 5 of AR&R 2016. Table 4.4 summarises the Stockyard Creek model loss values correlating to each of the area types. This approach was not adopted for the Bennison Creek RORB model as it would have a negligible impact on flow estimates compared to the simpler approach of adopting a single set of loss parameters for all surface types, due to all subareas having impervious fractions less than 15 %.

Table 4.4 Stockyard Creek (and Foster Urban) RORB model loss values for impervious and pervious areas

Loss	Effective Impervious Areas (EIA)		Indirectly Connected Areas (ICA)		Pervious Areas	
	AR&R 2016 Guidance	Value Adopted	AR&R 2016 Guidance	Value Adopted	AR&R 2016 Guidance	Value Adopted
Initial Loss	1-2 mm	1.5 mm	60-80 % of pervious area value from AR&R data hub	14 mm (70 % of pervious area value from AR&R data hub)	Derive from AR&R online data hub	20 mm for the coordinates -38.6473, 146.1729
Continuing Loss	0 mm/hr	0 mm/hr	Typical value of 2.5 mm/hr, with a range of 1-3 mm/hr adjusted by engineering judgement	2.5 mm	Derive from AR&R online data hub	4.5 mm for the coordinates -38.6473, 146.1729

Land use within the Stockyard Creek catchment was allocated to four categories:

- rural largely previous areas
- low density residential areas
- medium to high density residential and road areas (grouped together) and
- commercial and industrial areas.

Loss values were calculated for each of these categories to account for the variation in imperviousness within each area. Refer to **Appendix J** for AR&R 2016 data hub outputs.

In accordance with AR&R 2016, the following methodology was utilised to calculate the initial loss and continuing loss values for each category:

1. Determine the total impervious area (TIA). The fraction impervious values for each subarea were utilised as the TIA.
2. Estimate EIA for each subarea based on a ratio of EIA to TIA. AR&R 2016 states that in areas where the TIA is less than 70 % (most residential areas) the EIA is 60 % of the TIA. There is some variation on this between different catchments but it is usually within 10 % of the amount. For areas where the TIA is greater than 80 %, a higher fraction of EIA to TIA can be assumed. This would apply in commercial or industrial

areas, however it does not apply to the Foster and surrounding areas catchment as there are no subareas exceeding 80 % fraction impervious.

3. Estimate indirectly connected area for each subarea. For sub-areas with medium to high levels of development (residential/roads and commercial/industrial categorised sub-areas) areas within each sub-area not considered EIA were deemed indirectly connected areas. Conversely, for low density residential areas, indirectly connected area was calculated as the portion of the subarea classified as TIA, but not EIA. The remainder of these subareas were deemed pervious area.
4. Adopt the rural loss values for urban pervious areas.

4.6.6 Accounting for Rainfall Pre-Burst

The initial losses for rural areas provided on the AR&R data hub are for complete storms (abbreviated as IL_s), however the IFD data provided by the BoM is for rainfall bursts only. To account for this difference, AR&R 2016 recommends reducing the initial loss to represent the burst loss (IL_b), or increasing the burst depth to approximately match the storm depth.

AR&R 2016 states: “The loss values recommended in this chapter (Book 5, Chapter 3 Losses) are intended for application to complete design storms. Therefore, the initial loss is denoted as IL_s to indicate that it is applicable to a complete storm. However, if design bursts, rather than complete storms, are used in design then the burst initial loss needs to be reduced to account for the pre-burst rainfall.”

“If pre-burst rainfalls are included, then the design rainfalls will represent (near) complete design storms and therefore the storm losses can be directly applied without adjustment.”

“However, if design bursts, rather than complete storms, are used in design then the burst initial loss needs to be reduced to account for the pre-burst rainfall.”

“This has implications for all design flood situations, but is particularly important for design situations where the outcome is sensitive to the flood volume, such as the design of retarding basins. The failure to recognise the rainfall prior to design rainfall bursts has the potential to significantly underestimate the design flood.”

AR&R 2016 pre-burst depths are not provided by the data hub for storm durations of less than 60 minutes. However, project 6 of AR&R (*Loss Models for Catchment Simulation – Rural Catchments)* provide a methodology for estimating pre-burst depths for all durations using AR&R equation 4-4 (below).

$$Preburst_{duration} = Preburst_{6h} \times e^{-0.0648(duration-6)}$$

Burst initial losses (IL_b) calculated using Equation 4-4 (IL_s-$IL_{preburst}$=IL_b) for a range of durations were compared to the IL_b calculated using the median pre-burst depth data from the data hub. The predictive equation and the data hub data were consistant for storm durations greater than 6 hours but differed considerably for shorter durations. Figure 4.3 demonstrates the difference between these approaches.

Given the inconsistency between the data hub derived IL_b and equation 4-4 derived IL_b, a number of other peer reviewed papers were investigated to further inform the appropriate the calculation of pre-burst initial loss, and ultimately storm initial loss:

- Rahman, A., Weinmann, P. E., Hoang, T. M. T. and Laurenson, E. M. (2002) Monte Carlo simulation of flood frequency curves from rainfall. Journal of Hydrology 256:196-210
- Hill, P., Mein, R. and Siriwardena, L (1998) How much rainfall becomes runoff? Loss modelling for flood estimation. Industry report 98/5. Cooperative Research Centre for Catchment Hydrology
- Hill, P. I., Maheepala, U. K., Mein, R. G. and Weinmann, P. E. (1996) Empirical analysis of data to derive losses for design flood estimation in south-eastern Australia. Cooperative Research Centre for Catchment Hydrology. Report 96/5

Both Hill *et al.* (1998) and Rahman *et al.* (2002) have developed equations that relate the burst initial loss (IL_b), storm initial loss (IL_s) and duration. These equations are presented below as equations (1) and (2) respectively

$$IL_b = IL_s\left(1 - \frac{1}{1+142\frac{\sqrt{d_b}}{MAR}}\right) \qquad (1)$$

$$IL_b = IL_s(0.5 + 0.25\log_{10}(d_b) \qquad (2)$$

Variable definitions are as follows:

- IL_b is the burst initial loss (mm)
- IL_s is the storm initial loss (mm)
- MAR is the mean annual rainfall (mm). The BOM reports this as 1038 mm for Foster between 1961 and 1990.
- d_b is the burst duration (hours)

The resultant IL_b estimates using the above equations, equation 4-4 and IL_b calculated from the data hub data are compared graphically for the 1 % AEP, assuming an IL_s of 20 mm, on Figure 4.3 (presented on a log scale).

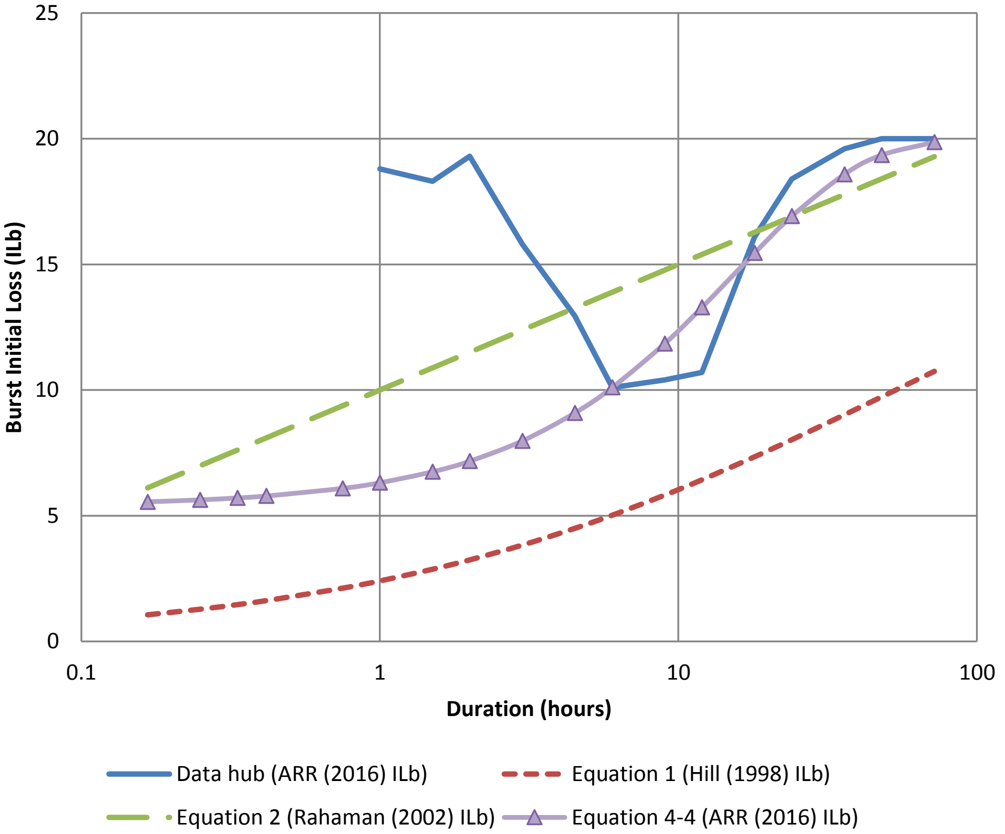

Figure 4.3 **Burst initial loss methodology comparison**

Figure 4.3 highlights the difference between the data hub derived IL_b and the other predictive methods, particularly for storm durations of less than 6 hours. The variance of IL_b with duration has large implications for the determination of the critical duration for peak flooding, particularly in the urban areas. It was decided that the data hub derived estimates for short durations were too inconsistent relative to the predictive estimates to justify adopting that data for short durations (<6 hours). Adopting all of the data hub losses would also have created a problem for what losses to use for events less than 60 minutes in duration. There would either be a big step down in losses between the 60 minute and 45-minute events if the equation 4-4 losses were adopted for durations under 60 minutes or an extrapolation on the data hub burst losses could have been used. The problem with extrapolating the data hub losses is that the burst losses are trending back towards equalling storm losses for durations under 60 minutes. This could have almost completely removed many runoff events for more frequent AEPs in short duration storms where the total rainfall depth may not have exceeded the average initial loss.

IL_b was therefore estimated using equation 4-4 for durations shorter than 6 hours and the data hub data for durations of 6 hours and greater. Critical durations for the waterways and urban areas (Foster) are presented in Section 4.10 and Section 4.11 respectively.

4.7 Model Calibration and Validation

4.7.1 Historical events

The preferred approach for the estimation of RORB model routing parameters and to inform the selection of initial loss values is the calibration of the model to flood data from a gauged catchment. However, given both the Stockyard Creek and Bennison Creek catchments are ungauged and the neighbouring Deep Creek catchment (which is gauged) was considered to be unsuitable for reasons presented in Section 2.11, an alternative methodology was required. In the absence of suitable calibration data, the AR&R 2016 guidelines recommend hydrological models are validated to Regional Flood Frequency Estimation (RFFE) values for the catchment.

4.7.2 Regional Flood Frequency Estimation (RFFE) Model

Flood frequency curves were developed for Stockyard Creek and Bennison Creek using the RFFE method based on the details provided in Table 4.5 and Table 4.6 respectively. Table 4.7 and Table 4.8 present the estimated flood quantiles for a range of annual exceedance probabilities (AEP) for Stockyard and Bennison Creek respectively.

Table 4.5 RFFE input parameters - Stockyard Creek

Detail	Value
Latitude at Outlet (degree)	-38.672
Longitude at Outlet (degree)	146.207
Latitude at Centroid (degree)	-38.6473
Longitude at Centroid (degree)	146.1731
Catchment Area (km2)	24.31

Table 4.6 RFFE input parameters - Bennison Creek

Detail	Value
Latitude at Outlet (degree)	-38.668
Longitude at Outlet (degree)	146.236
Latitude at Centroid (degree)	-38.637
Longitude at Centroid (degree)	146.2054

Table 4.7 **RFFE flow estimates - Stockyard Creek**

AEP (%)	Expected Quantiles (m3/s)	5 % CL (m3/s)	95 % CL (m3/s)
50	12.0	5.77	24.9
20	22.8	11.4	45.6
10	32.2	15.9	65.4
5	42.8	20.7	89.3
2	59.4	27.6	129.0
1	74.0	33.1	166.0

Table 4.8 **RFFE flow estimates - Bennison Creek**

AEP (%)	Expected Quantiles (m3/s)	5 % CL (m3/s)	95 % CL (m3/s)
50	10.1	4.82	20.9
20	19.2	9.57	38.4
10	27.1	13.4	55.2
5	36.1	17.4	75.4
2	50.7	23.2	109
1	62.5	27.9	140.0

4.8 Estimation of RORB Routing Parameter k_c

4.8.1 Stockyard Creek Waterway RORB Model k_c

Calibration of the Stockyard Creek and Bennison Creek RORB models to gauge data was not undertaken due to the lack of suitable data. This is discussed further in Section 2.11. In the absence of suitable calibration data, an assortment of regional equations are available for estimating an appropriate k_c value. Table 4.9 summarises each regional equation investigated, including the resulting k_c and 1 % AEP flows for both the RORB Ensemble and Monte Carlo Simulations.

Table 4.9 Stockyard Creek k_c comparison of median peak 1 % AEP flows at the catchment outlet

Equation	Formula	Kc	Ensemble (m^3/s)	Monte Carlo (m^3/s)
Victoria (MAR>800 mm) – Equation 3.21, ARR (Book V)	$K_c = 2.57 \times A^{0.45}$	10.78	36.59	36
Victoria Data (Pearse et al, 2002)	$K_c = 1.25 \times D_{av}$	8.05	46.52	47
Australia Wide Dyer (1994) data (Pearse et al, 2002)	$K_c = 1.14 \times D_{av}$	7.34	51.15	51
Australia Wide Yu (1989) data (Pearse et al, 2002)	$K_c = 0.96 \times D_{av}$	6.18	61.13	58
Matched to RFFE flow estimates	n/a	5.0	72.51	73

The Victoria (MAR>800 mm) equation, which was developed using data from 18 catchments across Victoria, would typically be considered the most suitable prediction equation for this investigation. This prediction equation estimated a k_c of 10.78, with a standard error of +32 % and -24 %. However, to match the RFFE flow estimate a k_c of 5.0 was required, which lies below the Victoria prediction equation standard error limit k_c of 8.21 (corresponding to -24 %). It should also be noted that a k_c of 5.0 lies below all of the prediction equations investigated.

Given the uncertainty associated with selecting an appropriate routing parameter (k_c), further investigation was conducted by considering the relationship between k_c and the Average Flow Distance (d_{av}). Studies (Pearse et al, 2002; Yu, 1989 and CRCCH) have determined the expected k_c/d_{av} relationship for RORB hydrological models which have been summarised in Table 4.10.

Table 4.10 Summarised k_c/d_{av} relationships for RORB hydrological models

Group	Victorian (Pearse, 2002)	Yu, 1989	CRCCH
Expected	1.25	0.96	1.14
Low (-1 SD in log)	0.75	0.47	0.61
High (+1 SD in log)	2.07	1.94	2.13

A comparison of k_c/d_{av} relationships for all k_c values investigated is presented in Table 4.11.

Table 4.11 Comparison of k_c/d_{av} relationships – Stockyard Creek

Equation	Kc	Dav	Kc/dav
Victoria (MAR>800 mm) – Equation 3.21, ARR (Book V)	10.78	6.45	1.67
Victoria Data (Pearse et al, 2002)	8.05	6.45	1.25
Australia Wide Dyer (1994) data (Pearse et al, 2002)	7.34	6.45	1.14
Australia Wide Yu (1989) data (Pearse et al, 2002)	6.18	6.45	0.96
Matched to RFFE flow estimate	5.0	6.45	0.78

The study by CRCCH suggests that k_c/d_{av} should be approximately 1.14 with upper and lower limits of 2.13 and 0.61 respectively. This is achieved for all of the investigated k_c values, although it is noted that for a k_c of 5, k_c/d_{av} is on the lower end of the three relationships investigated.

The RFFE flood quantiles and AR&R 2016 recommended loss parameters were ultimately adopted as the basis for selecting the k_c value (of 5) as they are representative of the most recent available data. The alternate approach is to adopt the k_c value estimated by the Victoria prediction equation and scale down the AR&R recommended continuing loss to match the RFFE flood quantile. This approach would yield hydrographs with the same peak flow but with delayed timing and larger runoff volumes. If the catchment is sensitive to changes in runoff volume, due to flow constrictions at the downstream extent of the catchment for example, this could have significant impacts on estimated flood extents and depths. Further to this, the capacity of the urban drainage system may be sensitive to the timing of peak flood depths in the receiving waterways.

Stockyard Creek is a steep catchment and is considered likely to be insensitive to changes in runoff volumes. Therefore, it is generally not expected that hydrograph volume plays a significant role in determining peak flood levels within the catchment. In addition, flooding in the urban drainage system at Foster is likely to be governed by shorter duration storms and peak significantly earlier than flows on Stockyard Creek. The methodology used to select the k_c value was discussed and agreed with Council prior to adoption.

4.8.2 Foster Urban RORB Model kc

The Foster Urban RORB model is located within the Stockyard Creek catchment and adopted a k_c value of 2.14, which was calculated using the same k_c/d_{av} ratio as the Stockyard Creek model.

4.8.3 Bennison Creek Waterway RORB Model k_c

Table 4.12 summarises each regional equation investigated, including the resulting k_c and 1 % AEP flows for both the RORB Ensemble and Monte Carlo Simulations.

Table 4.12 Bennison Creek k_c comparison of median peak 1 % AEP flows at the catchment outlet

Equation	Formula	Kc	Ensemble (m^3/s)	Monte Carlo (m^3/s)
Victoria (MAR>800 mm) – Equation 3.21, ARR (Book V)	$K_c = 2.57 \times A^{0.45}$	9.62	33	33
Victoria Data (Pearse et al, 2002)	$K_c = 1.25 \times D_{av}$	9.08	38	35
Australia Wide Dyer (1994) data (Pearse et al, 2002)	$K_c = 1.14 \times D_{av}$	8.28	38	38
Australia Wide Yu (1989) data (Pearse et al, 2002)	$K_c = 0.96 \times D_{av}$	6.97	44	45
Matched to RFFE flow estimate	n/a	4.0	70	72

Applying the same analysis that was undertaken for the Stockyard Creek catchment, matching the RFFE flow estimate required a k_c of 4.0, which also lies below the Victoria Prediction Equation lower standard error limit of 7.3. A comparison of k_c/d_{av} relationships for all k_c values investigated is presented in Table 4.13.

Table 4.13 Comparison of k_c/d_{av} relationships – Bennison Creek

Equation	K_c	D_{av}	K_c/d_{av}
Victoria (MAR>800 mm) – Equation 3.21, ARR (Book V)	9.62	7.24	1.33
Victoria Data (Pearse et al, 2002)	9.08	7.24	1.25
Australia Wide Dyer (1994) data (Pearse et al, 2002)	8.28	7.24	1.14
Australia Wide Yu (1989) data	6.97	7.24	0.96

Equation	K_c	D_{av}	K_c/d_{av}
(Pearse et al, 2002)			
Calibrated to RFFE flow estimates	4.0	7.24	0.55

As per the Stockyard Creek catchment, the RFFE flood quantiles and AR&R 2016 recommended loss parameters were ultimately adopted as the basis for selecting the kc value (of 4).

4.9 Climate Change

The ARR 2016 Data Hub provides interim climate changes factors for calculation of increased rainfall scenarios. For the coordinates -38.65° south and 146.19° east, the Data Hub estimates an increase of 3.21°C in temperature by 2090. This correlates to 16.1 % increase in rainfall by 2090, within the RCP8.5 scenario. These values have been extrapolated to determine the 2100 climate conditions, resulting in a temperature increase of 3.644°C which correlates to an increase in rainfall of 18.3 %. ARR 2016 Chapter 6.3.5 recommends using the following equation to determine the percentage increase in rainfall intensity for the year 2100:

$$p = 100(1.05^{\Delta T} - 1)\ \%$$

Where,

ΔT is the temperature increase to 2100
p is the percentage increase in rainfall intensity

The resultant percentage increase in rainfall for the year 2100 using this method is 19.5 %, ARR 2016 recommends adopting the higher percentage increase out of these two methods and therefore 19.5 % was implemented for the climate change investigation.

The RCP8.5 scenario is the ‘business as usual’ climate change scenario wherein minimal curbing of emissions is undertaken. This scenario was adopted per Melbourne Water’s Addendum 2 to the Flood Mapping Project Guidelines and Technical Specifications (November 2016).

4.10 Waterway Flows

4.10.1 Monte Carlo Approach

The design event approach, in which all parameters other than rainfall are input as fixed values, is the traditional approach to design flood estimation that has been used in Australia for many decades. The design event approach assumes ‘AEP neutrality’, that is, that the resulting flood has the same annual exceedance probability as its causative rainfall. To achieve 'AEP-neutrality' considerable effort is made in selecting the fixed parameters.

Joint probability techniques that attempt to mimic 'mother nature' by considering the variability of modelling inputs can offer improvements to the traditional design event approach. The application of joint probability approaches is incorporated into ARR 2016 and is recommended as more defensible than the design event approach. The RORB user manual (E.M. Laurenson *et. al.,* 2005) provides a good description of the joint probability approach adopted for this investigation. The text below has been extracted from the RORB user manual.

"In the current implementation of RORB, two factors can be treated in a stochastic manner, namely initial loss and the rainfall temporal pattern. While it is possible to consider continuing loss as a variable, its value is dependent on initial loss, and added complexity would be required to deal with this correlation; furthermore, the likelihood distribution of proportional loss has not been studied to date and the required information on its distributional characteristics is not available. However, for most routine flood estimation studies, particularly those focused on estimating peak flows, the stochastic treatment of initial loss and the temporal distribution of rainfalls should be sufficient to capture the influence of variability in the main flood producing factors."

Figure 4.4 shows a schematic illustration of the stochastic and fixed nature of flood producing factors available in RORB (reproduced from the RORB user manual).

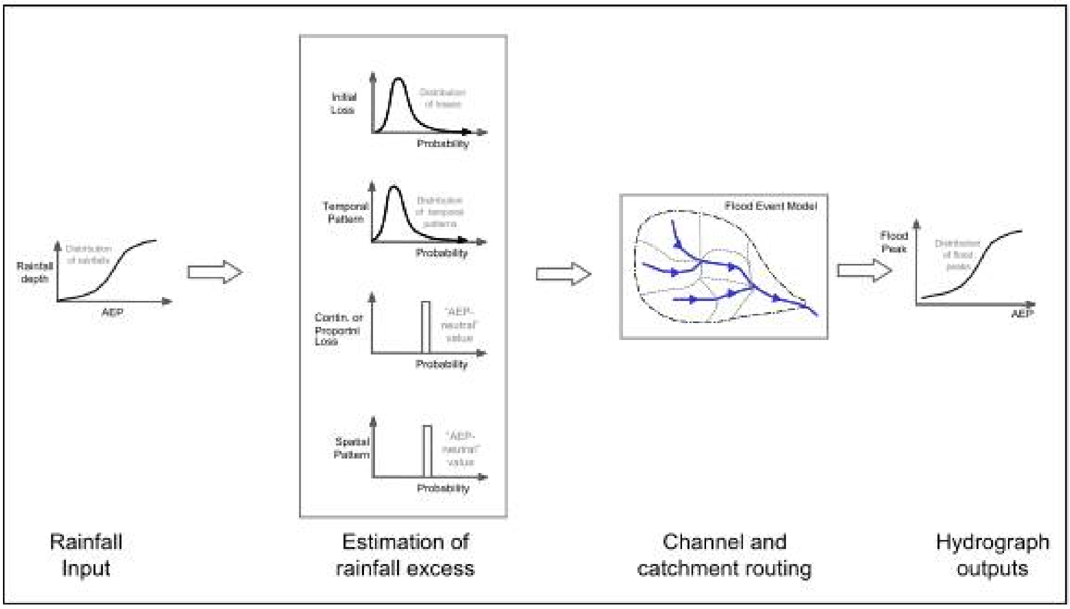

Figure 4.4 Schematic illustration of the stochastic and fixed nature of flood producing factors available in RORB (reproduced from the RORB user manual)

4.10.2 Joint Probability Framework

An overview of the joint probability framework adopted is illustrated in Figure 4.5 (reproduced from the RORB user manual). In essence, the approach involves the undertaking of numerous model simulations where selected model inputs are varied. The inputs are sampled from non-parametric distributions that are either based on readily available design information or the results of recent research.

In developing the joint probability framework, particular attention was given to ensuring that the inputs and the manner in which they are incorporated are consistent with Book 8 of AR&R 2016. The following briefly describes the main elements of the approach.

Selected rainfall depth: Rainfall depths are stochastically sampled from the cumulative distribution of rainfall depths presented in Section 4.6.2. In addition, approximate values of rainfalls more extreme than the Probable Maximum Precipitation (PMP) are derived by simple linear extrapolation in the logarithmic – Normal probability domain. These extrapolation rainfalls represent burst depths down to AEPs approximately one order of magnitude less frequent than that of the PMP.

Selected storm losses: Storm initial losses are stochastically sampled from a non-parametric distribution that was determined from the analysis of a large number of Victorian catchments. There is little information regarding the correlation between initial and continuing loss rates, and since antecedent conditions have most influence on initial loss rates, in this study the continuing loss rates were held constant.

Selected temporal patterns: Temporal patterns are randomly selected from a sample of temporal patterns relevant to the catchment area and duration of the storm.

Other inputs: All other inputs, namely model configuration, continuing loss values, rainfall spatial pattern, and routing parameters, are input as fixed values as applied in the traditional design event approach.

Monte-Carlo simulation: Simulations were undertaken using a stratified sampling approach. The rainfall frequency curve was divided into 50 intervals uniformly spaced over the standardised normal probability domain, and 100 simulations were taken within each division. Thus, a total of 5,000 simulations were undertaken to derive a flood frequency curve for each storm duration modelled.

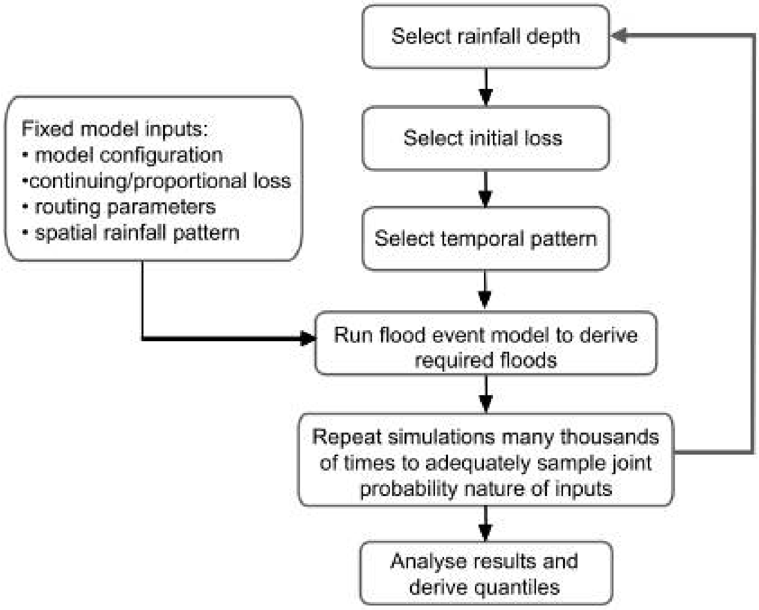

Figure 4.5 **Adopted joint probability approach**

4.10.3 Stockyard Creek Results

Table 4.14 presents the peak flows generated using RORB Monte Carlo simulations for Stockyard Creek at the upstream TUFLOW hydraulic model boundary, which is located on Stockyard Creek approximately 600 metres north west of Law Road.

Table 4.14 **Stockyard Creek upstream TUFLOW model boundary peak flows (m^3/s)**

Duration (hour)	10 % AEP	5 % AEP	2 % AEP	1 % AEP	0.5 % AEP
2	23	35	53	66	80
3	24	35	52	67	80
4.5	22	33	49	63	76
6	23	32	46	59	74

RORB Monte Carlo simulations provide an estimate of peak flood quantiles but do not provide flow hydrographs required for hydraulic modelling. To develop appropriate inflow hydrographs the Monte Carlo results must be interrogated to select a flow value with AEP rainfall closest to the relevant flood AEP, and initial loss and temporal patterns closest to the median values. RORB is then re-run with this parameter set to calculate flow hydrographs. Table 4.15 presents the durations and temporal patterns that correspond to the maximum peak flow for each AEP at the upstream TUFLOW model boundary.

Table 4.15 Stockyard Creek critical durations and temporal patterns at the upstream TUFLOW model boundary

Critical	10 % AEP	5 % AEP	2 % AEP	1 % AEP	0.5 % AEP
Duration (hour)	3	2	2	3	3
Temporal Pattern (#)	15	12	26	25	26

Table 4.16 presents the peak flows generated using RORB Monte Carlo simulations for Stockyard Creek at the RORB model outlet. The RORB model outlet is positioned at the same location as the TUFLOW model downstream boundary, approximately 800 metres south of the Great Southern Rail Trail.

Table 4.16 Stockyard Creek model outlet (downstream TUFLOW model boundary) peak flows (m^3/s)

Duration (hour)	10 % AEP	5 % AEP	2 % AEP	1 % AEP	0.5 % AEP
2	22	33	51	64	79
3	24	35	55	70	87
4.5	25	37	**56**	**73**	**89**
6	**25**	**37**	53	67	83

Table 4.17 presents the durations and temporal patterns that correspond to the maximum peak flow for each AEP at the RORB model outlet (downstream TUFLOW model boundary).

Table 4.17 Stockyard Creek critical durations and temporal patterns at model outlet (downstream TUFLOW model boundary)

Critical	10 % AEP	5 % AEP	2 % AEP	1 % AEP	0.5 % AEP
Duration (hour)	6	6	4.5	4.5	4.5
Temporal Pattern (#)	19	14	30	27	27

The 1 % AEP hydrograph for the 3-hour critical duration on Stockyard Creek at the upstream TUFLOW model boundary and the RORB model outlet is presented in Figure 4.6.

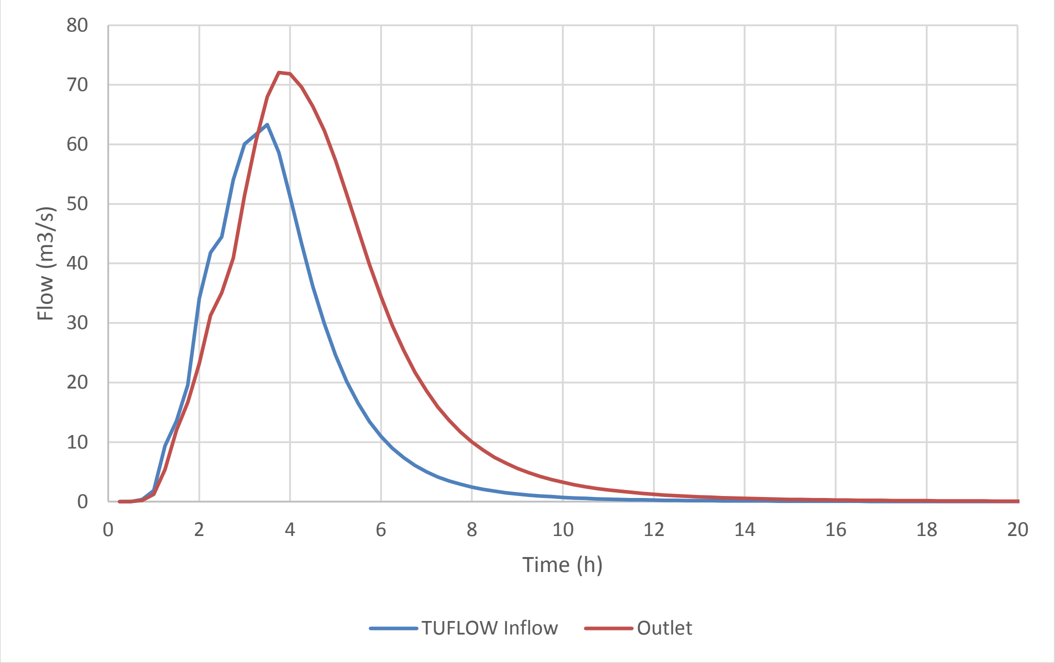

Figure 4.6 Stockyard Creek 1 % AEP critical 3 hr hydrographs (temporal pattern 25)

The critical durations and temporal patterns that have been established to provide the peak flows at the upstream and downstream boundaries of the TUFLOW model using RORB will be modelled with the critical durations and temporal patterns established for the urban areas (refer to Section 4.11) using the TUFLOW model for the purposes of estimating flooding for the Stockyard Creek catchment.

4.10.4 Bennison Creek Results

Table 4.18 presents the peak flows generated using RORB Monte Carlo simulations for Bennison Creek at the upstream TUFLOW hydraulic model boundary, which is located on Bennison Creek approximately 600 metres north of Amey's Track.

Table 4.18 Bennison Creek TUFLOW model boundary peak flows (m^3/s)

Duration (hour)	10 % AEP	5 % AEP	2 % AEP	1 % AEP	0.5 % AEP
1.5	24	35	54	67	81
2	**27**	**39**	**56**	**70**	**84**
3	25	34	51	66	79
4.5	22	33	47	58	71

The critical durations and temporal patterns corresponding to the maximum peak flows at the upstream TUFLOW model boundary are presented in Table 4.19.

Table 4.19 Bennison Creek critical durations and temporal patterns

Critical	10 % AEP	5 % AEP	2 % AEP	1 % AEP	0.5 % AEP
Duration (hour)	2	2	2	2	2
Temporal Pattern (#)	16	14	30	27	28

Table 4.20 presents the peak flows generated using RORB Monte Carlo simulations for Bennison Creek at the RORB model outlet. The RORB model outlet is positioned at the same location as the TUFLOW model downstream boundary, approximately 800 metres south of the Great Southern Rail Trail.

Table 4.20 Bennison Creek model outlet (downstream TUFLOW model boundary) peak flows (m^3/s)

Duration (hour)	10 % AEP	5 % AEP	2 % AEP	1 % AEP	0.5 % AEP
2	25	38	55	70	85
3	**26**	36	**56**	**72**	**88**
4.5	25	**38**	55	69	84
6	25	35	49	66	80

Table 4.21 presents the durations and temporal patterns that correspond to the maximum peak flow for each AEP at the RORB model outlet (downstream TUFLOW model boundary).

Table 4.21 Bennison Creek critical durations and temporal patterns at model outlet (downstream TUFLOW model boundary)

Critical	10 % AEP	5 % AEP	2 % AEP	1 % AEP	0.5 % AEP
Duration (hour)	3	4.5	3	3	3
Temporal Pattern (#)	17	18	25	29	21

The 1 % AEP hydrograph for the 2-hour critical duration on Bennison Creek at the upstream TUFLOW model boundary and the RORB model outlet is presented in Figure 4.7.

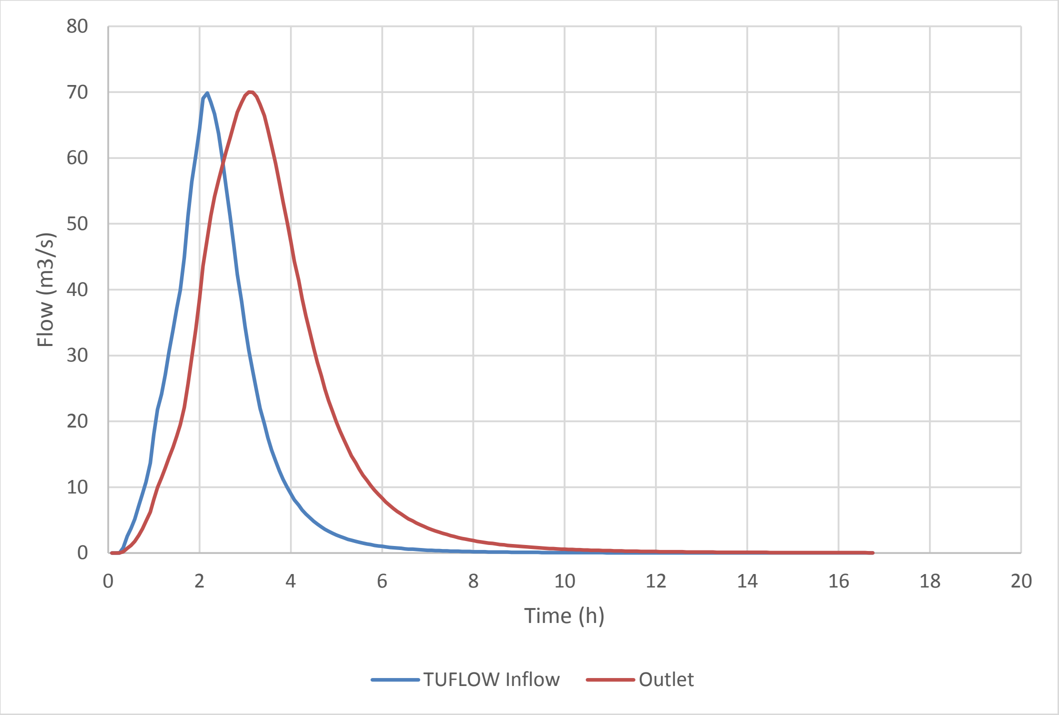

Figure 4.7 **Bennison Creek 1 % AEP critical 2 hr hydrographs (temporal pattern 27)**

The critical durations and temporal patterns that have been established to provide the peak flows at the upstream and downstream boundaries of the TUFLOW model using RORB will be modelled using the TUFLOW model for the purposes of estimating flooding for the Bennison Creek catchment.

4.11 Urban Flows

The Monte Carlo approach was adopted to determine the peak flows at each of the representative locations (refer to Section 4.4 for further discussion and a figure showing these locations). The temporal pattern and critical duration for each representative location within the Foster Urban RORB model boundary for the 1 % AEP is presented in Table 4.22.

Table 4.22 **1 % AEP critical temporal pattern and duration for urban RORB model**

Critical	U2	E3	AG2
Flow (m^3/s)	4	7	14
Duration	20 minute	1 hour	1 hour
Temporal Pattern (#)	24	27	27

The hydrographs from the runs corresponding to the critical durations and temporal patterns presented in Table 4.22 (and for the other return periods) was used as inflows to the TUFLOW hydraulic model. Rainfall excess hydrographs from the Foster Urban RORB model was used as inputs for each of the subareas within the urban RORB model boundary.

4.12 Probable Maximum Flood (PMF)

Procedures for estimating probable maximum precipitation (PMP) rainfall depths have been developed by the BoM for different locations and durations. For durations up to 6 hours and areas up to 1000 km^2 the Generalised Short Duration Method (GSDM) is applicable for all of Australia. The GSDM Calculation Sheet has been provided as **Appendix K** and **Appendix L** for the Stockyard Creek and Bennison Creek catchments respectively.

For this investigation the probable maximum flood (PMF) was assumed to be equivalent to the probable maximum precipitation flood (PMPF).

The PMPF was estimated using Monte Carlo simulation. To undertake Monte Carlo simulation the complete rainfall frequency curve was derived by interpolating between the credible limit of extrapolation for very rare rainfalls (1 in 100 to 1 in 2000 AEP) and the PMP. In accordance with AR&R 2016, very rare rainfalls for durations less than 24 hours were estimated using the growth factors in Jordan et al 2005. For interpolating between the credible limit of extrapolation for very rare rainfalls and the PMP the procedure developed by Siriwardena and Weinmann (1998) was used.

The distribution of burst rainfall depths for short duration events were simulated using the 10 temporal patterns described by Jordan *et al*. (2005). These temporal patterns have been derived from analysis of the temporal patterns of convective thunderstorm events recorded by rainfall stations around Australia.

Non-uniform spatial patterns were adopted based on the GSDM ellipses.

Peak PMPF flow estimates for each RORB model is summarised in Table 4.23.

Table 4.23 Peak PMPF RORB flows (m^3/s)

Duration	Stockyard Creek	Bennison Creek
15 min	245	287
30 min	413	473
1 hour	643	669
2 hour	**791**	**684**
3 hour	731	617
4.5 hour	651	525
6 hour	564	451

4.13 Development Scenario Modelling

SGSC has advised expected levels of increased development for the years 2030, 2050 and 2070. Engeny has utilised SGSC's Framework Plan (see **Appendix M)** to inform the changes in the extent of development, the fraction impervious and manning's roughness across the catchment, which was then input into the hydrological and hydraulic models respectively. In accordance with SGSC requirements it was assumed for the 2030 scenario that 25 % of the Urban, rural living and low-density expansion areas were utilised in the direction of development as indicated by SGSC's Framework Plan. This was considered to be the base case modelling scenario for this flood study. For the 2050 and 2070 development scenarios, 70 % and 100 % of expansion areas were assumed to be consumed respectively.

An investigation into the flooding impacts as a result of these expected developments was conducted for the 1 % AEP storm event only. Refer to **Appendix S** for flood maps.

4.14 Bushfire Investigation

An investigation into the flooding impacts of bushfires was conducted by increasing the impervious fraction of both the Stockyard Creek and Bennison Creek sub-catchments. RORB was utilised to model the 1 % AEP storm event under existing conditions and following a high severity bushfire event.

The impervious fraction for all farming zone (FZ), public conservation and resource zone (PCRZ) and rural activity zone (RAZ) areas within the catchments were increased to 0.9 to represent a high severity burn across the catchment models. The overall impervious fraction was then re-calculated for the sub-catchments and input into the RORB models. The modelling results show noticeable impacts on peak flows throughout the catchments.

Table 4.24 presents a comparison of peak flows for existing and bushfire scenarios for each model.

Table 4.24 Comparison of peak flows

Model	Unburned Catchment Peak Flow		High Intensity Bushfire Peak Flow	
Stockyard Creek	73 m^3/s	6,306 ML/day	99 m^3/s	8,589 ML/day
Bennison Creek	72 m^3/s	6,225 ML/day	96 m^3/s	8,299 ML/day

The RORB flow hydrographs have been input into the TUFLOW hydraulic model to complete the investigation. It was considered whether it was appropriate to alter the manning's roughness values in the TUFLOW model for the bushfire affected catchment however, the values were left unchanged. This was due to the uncertainty of exactly how a bushfire actually affects the surface conditions in terms of roughness and Engeny were unable to locate appropriate literature to inform the decision either way. It was expected that majority of the flooding impacts will come from the additional flows conveyed through Stockyard and Bennison Creek (due to increased FI and not the change in surface roughness).

The flood modelling results show increases in flood depths of up to 590 mm along Stockyard Creek and 390 mm along Bennison Creek for the 1 % AEP storm event. Refer to **Appendix S** for bushfire flood maps.

4.15 Hydrological Conclusions

4.15.1 General

RORB hydrological modelling was undertaken for the Foster and surrounding areas catchment for the purposes of estimating routed hydrographs and rainfall-excess inflows to the TUFLOW hydraulic model. Flows were estimated for the 10 %, 5 %, 2 % 1 %, 0.5 % AEP and PMF storm events. Two separate RORB models were developed in order to estimate routed inflows for the Stockyard Creek and Bennison Creek catchments. A third RORB model was created to estimate rainfall excess inflows for the TUFLOW model covering the Foster area.

The hydrological modelling was undertaken using 2016 AR&R rainfall IFD data, temporal patterns and losses. Monte Carlo simulations were undertaken to determine flood quantiles for each modelled duration to account for aleatory variability, in accordance with the principals of achieving probability neutrality.

4.15.2 Stockyard Creek

The following conclusions were drawn with respect to the Stockyard Creek RORB modelling:

1. The Stockyard Creek RORB model covers an area of approximately 24.2 km^2.

2. The Stockyard Creek catchment is ungauged.

3. No suitable calibration data was found to inform the hydrological model parameters.

4. The initial loss and continuing loss approach recommended by AR&R 2016 was adopted. An initial loss value of 20 mm and a continuing loss value of 4.5 mm were adopted for pervious areas. Loss values for indirectly connected areas and effective impervious areas are reported on in Section 4.6.5.

5. The adopted k_c of 5.0 was evaluated against a number of other recognised k_c methodologies and selected to match the Rural Flood Frequency Estimate (RFFE) flow.

6. The critical duration for the 1 % AEP event at the upstream boundary of the TUFLOW model is 3 hours which corresponds to temporal pattern 25 for 2030 development conditions.

7. The Stockyard Creek peak flow at the upstream TUFLOW model boundary for the 1 % AEP is approximately 67 m^3/s under 2030 development conditions.

8. A summary table of the critical design storm durations and temporal patterns for each AEP that will be modelled using the TUFLOW hydraulic model is presented in Section 4.15.4.

9. There is a 36 % increase in the 1 % AEP storm event peak flow under high severity bushfire conditions at the model outlet for Stockyard Creek.

The following conclusions were drawn with respect to the Foster Urban RORB modelling. The Foster Urban RORB model is located within the Stockyard Creek catchment and covers the area within the TUFLOW hydraulic model for that catchment. It is a diverted model with small subareas that was developed for the primary purpose of determine critical durations, median temporal patterns and ultimately rainfall excess inflows to the TUFLOW hydraulic model.

10. Three (3) locations were selected as having representative upstream catchments for the purposes of selecting critical durations and temporal patterns to run with the TUFLOW hydraulic model. This approach was adopted to avoid running all temporal patterns and durations for each return period using the TUFLOW hydraulic model which would be extremely data and time intensive.

11. The selection of the appropriate temporal pattern and critical duration is subject to an accurate representation of routing within the RORB model. Engeny will therefore undertake a verification of the RORB model routing parameters and reach types by comparing the routing times of the TUFLOW model and RORB model following the initial TUFLOW runs.

4.15.3 Bennison Creek

The following conclusions were drawn with respect to the Bennison Creek RORB modelling. The Bennison Creek RORB model was created to estimate a RORB hydrograph at the upstream catchment and will also be used to provide local inflow hydrographs within the TUFLOW model area:

1. The Bennison Creek RORB model covers an area of approximately 18.8 km^2.
2. The Bennison Creek catchment is ungauged.
3. No suitable calibration data was found to inform the hydrological model parameters.
4. The initial loss and continuing loss approach recommended by AR&R 2016 was adopted. An initial loss value of 20 mm and a continuing loss value of 4.5 mm were adopted for pervious areas.
5. The adopted k_c of 4.0 was evaluated against a number of other recognised k_c methodologies and selected to match the Rural Flood Frequency Estimate (RFFE) flow.
6. The critical duration for the 1 % AEP event is 2 hours which corresponds to temporal pattern 27.
7. The Bennison Creek peak flow at the upstream TUFLOW model boundary for the 1 % AEP is approximately 70 m^3/s.
8. A summary table of the critical design storm durations and temporal patterns for each AEP that will be modelled using the TUFLOW hydraulic model is presented in Section 4.15.4.
9. There is a 33 % increase in the 1 % AEP storm event peak flow under high severity bushfire conditions at the model outlet for Bennison Creek.

4.15.4 Critical design storms for flood modelling

Table 4.25 presents a summary of the critical durations and temporal patterns that were used as a basis for the TUFLOW hydraulic modelling in order to determine flooding in the Stockyard and Bennison Creek catchments.

Table 4.25 Critical durations and temporal patterns

AEP	Stockyard Creek Durations (temporal pattern)	Bennison Creek Durations (temporal pattern)
10 %	4.5 hr (18) and 1.5 hr (13)	2 hr (14) and 3 hr (14)
5 %	4.5 hr (13), 2 hr (17) and 1.5 hr (19)	2 hr (14) and 4.5 hr (18)

AEP	Stockyard Creek Durations (temporal pattern)	Bennison Creek Durations (temporal pattern)
2 %	3 hr (27), 1.5 hr (28) and 2 hr (28)	2 hr (22) and 3 hr (22)
1 %	20 min (23), 1 hr (27) and 3 hr (25)	2 hr (27) and 3 hr (22)
0.5 %	2 hr (28), 1 hr (23) and 20 min (28)	2 hr (21) and 3 hr (28)
PMF	2 hr (GSDM)	2 hr (GSDM)

4.16 Hydrology Peer Review

An independent peer review of the hydrology report was undertaken, which raised 13 queries. Engeny has provided responses to each query and made adjustments to the hydrology section of this report where required. Refer to **Appendix Y** for peer review comments and Engeny's responses.

5. HYDRAULICS

This section documents the methodology and investigations used by Engeny to develop TUFLOW hydraulic models for the Stockyard Creek and Bennison Creek catchments within Foster and surrounding areas. The key objective of hydraulic modelling was to develop accurate, representative flood models to inform flood management and emergency response planning at Foster.

Engeny believes that the modelling methodology that has been devised is consistent with the recommendations of the Australian Rainfall and Runoff (AR&R) Guidelines (November 2016).

5.1 Scope

The scope for the hydraulic investigation was as follows:

- Analysis of existing drainage network
- Construct and validate hydraulic models to accurately replicate flood behaviour
- Sensitivity analysis to investigate the impact of Manning’s roughness
- Sensitivity analysis to investigate the impact of blockages at Boundary Road.
- Preparation of a draft hydraulic report to document methods and results.

5.2 Methodology

Engeny developed a one-dimensional and two-dimensional (1-D/2-D) hydraulic model for the Bennison and Stockyard Creek catchments, in order to estimate flood water levels, extents, flows and other hydraulic variables for a range of scenarios and design events.

Modelling was undertaken using hydrodynamic software package, TUFLOW, using the latest version of the software available at the project start date: TUFLOW.2017-09-AC-w64. The model was run using TUFLOW’s GPU HPC solution scheme to improve model run times. The following steps outline the tasks undertaken to develop a TUFLOW model for the study catchments and to obtain results and outputs which were used for flood mapping:

- Generate DEM
- Compile hydrographs for full range of storm durations for 10 %, 5 %, 2 %, 1 % and 0.5 % AEP for existing conditions using ARR 2016 IFD data (from RORB model)
- Input surface roughness (materials layer)
- Input and verify data for the 1-D network

- Set 1-D and 2-D boundary conditions
- Verify peak flows, critical durations and temporal patterns by comparing RORB model flows to the TUFLOW model at key locations and adjusting the variable depth roughness parameters adopted for the TUFLOW model.
- Undertake a sensitivity analysis to investigate the impact of Manning's roughness along Stockyard Creek and Bennison Creek for the 1 % AEP event.
- Verify model to historical flooding events and local flood knowledge.
- Utilise a 1D HEC-RAS model containing key structures along Stockyard Creek to validate the TUFLOW model representation.
- Run TUFLOW for the full range of storm durations for deliverables comprising:
    - 10 %, 5 %, 2 %, 1 % and 0.5 % AEP events for 2030 development conditions
- Prepare detailed flood extent, depth, height and velocity information for a range of flood events.

5.3 Model Extents

One TUFLOW model was developed for each catchment, using a single shape in the model's 2d_code layer. **Appendix N** provides a layout of the Stockyard Creek hydraulic model and **Appendix O** provides a layout of the Bennison Creek hydraulic model.

5.4 Digital Elevation Model (DEM)

The Victorian Coastal LiDAR data set (Level 3) was provided for use on this project by the WGCMA. The following summarises the LiDAR data set:

- Victorian Coastal LIDAR Level 3 Classification
- Flown 23 Oct 2008 – 09 Feb 2009 (South Gippsland)
- Vertical accuracy of ±0.10 m
- Horizontal accuracy of ±0.35 m
- 1 m LiDAR Digital Elevation Model (DEM).

Refer to Section 2 for additional information relating to the terrain model accuracy and validation.

5.4.1 2-D Grid Size

A three (3) metre grid size has been adopted for the hydraulic model to accurately model surface flows. This cell size is sufficiently small to allow the effects of raised roadside verges and medians to be modelled whilst achieving sensible model simulation times and is consistent with the recommendations from Melbourne Water's Flood Mapping Projects Guidelines and Technical Specifications (November 2016) for urban flood modelling. The Stockyard Creek and Bennison Creek waterways span from 20 metres to 45 metres within the two hydraulic models and are defined by (and carry flow through) at least 5 cells at any given time-step.

5.5 1-D Network Data

5.5.1 SGSC and VicRoads Drainage

The SGSC and VicRoads pipe and pit drainage network was included in the TUFLOW model based on the information provided by SGSC and sourced directly from VicRoads (refer to the Data Report for more details).

Additional queries regarding the SGSC drainage network were submitted to SGSC during the model construction phase which followed the data report. Refer to Section 2 for further information.

5.5.2 Pipes

A Manning's roughness value of 0.013 was adopted for the concrete underground drainage pipes and road culverts. Losses were applied in accordance with the TUFLOW manual as follows:

- Height contraction coefficient = 0 for circular pipes and 0.6 for rectangular pipes
- Width contraction coefficient = 1.0 for circular pipes and 0.9 for rectangular pipes
- Entry loss coefficient = 0.5
- Exit loss coefficient = 1.0

The following procedures were used to ready the GIS pipe data for use in the 1D/2D TUFLOW model:

- Pipe direction:
  - Pipe directions were reversed where the direction was found to be opposite to the direction of flow.
- Snapping pipes together:

    - Some pipes were found to be graphically disconnected
    - Pipes were snapped together where gaps were found between pipes.

- Invert levels:
    - Invert levels were based on the depth of the upstream and downstream pits (as per Stormwater_pits.tab layer provided by SGSC). Where invert levels were not available the following equation was used to set the invert level (as agreed with SGSC):

      Invert Level = Ground level RL – 400 mm (pipe cover) – pipe diameter.

5.5.3 Pits

All pits were:

- modelled on SGSC pipes using GIS data supplied by SGSC
- modelled as side entry, grated side entry or grated pits
- modelled using the “Q” type pits, with a relationship between depth of ponding and inlet capacity calculated using a pit inlet capacity spreadsheet.

Pits were also used to represent back of kerb discharge (discharge to the road as opposed to being directly connected to the underground drainage network) points for properties within the town of Foster. This approach was used to have a more accurate distribution of flow allocation across the model and to prevent nearby drainage pits being allocated more flow (via the 1d_bc layer) than they would otherwise receive in reality.

Refer to Section 2 for further information.

5.5.4 Culverts

Major culverts at road crossings were added to the model using survey data supplied by SGSC. Refer to Data Report for further information.

5.5.5 Pit and Pipe Losses

A manhole layer within TUFLOW can be either automatically or manually created and used to apply the losses to the nodes created in the 1-D network layers in a variety of different ways. Engeny used the automatically generated manhole layer, applying losses using the Engelund method. This method recalculates losses at each time step using the angle of the entry and exit culverts, water levels and flow distributions. The losses calculated by this automatic approach have been checked to ensure that they appear reasonable.

5.6 2-D Network Data

5.6.1 Bridges

Bridges have been modelled in the 2-D domain using a 2-D layered flow constriction layer. The form loss and blockage values due to piers was calculated in accordance with the methodology outlined within *Hydraulics of Bridge Waterways* (Bradley, 1978).

5.6.2 Retarding Basins

There are no formal retarding basins located within either the Stockyard Creek or Bennison Creek catchments, however a number of depressions located upstream of major roads or the railway act as defacto retarding basins and provide varying degrees of attenuation to catchment flows.

5.6.3 Private Dams

There are in excess of 70 farm dams present across both catchments based on inspection of the aerial imagery and DEM. Given the farm dams are not designated flood storage assets and could be removed by the private land owner at any time, the flood retention storage provided by these structures were removed by applying initial water levels respective to each individual site by using “2d_iwl” GIS layers.

5.6.4 Waterways

Both the Stockyard Creek and Bennison Creek waterways have been modelled in the 2D domain using “2d_zsh” GIS layers. As the waterways span from between 20 and 45 metres and a grid size of 3 metres was adopted, this approach is considered to be adequate to accurately determine / model flows within the watercourses.

5.7 Surface Roughness

5.7.1 Adopted Values

Within TUFLOW, a land use (materials) layer is utilised to import surface roughness information into the model. A materials layer for the catchment was constructed by utilising cadastre data in conjunction with planning scheme data and aerial photography. The following Manning’s ‘n’ values have been used based on those considered ‘reasonable’ in the MW technical specifications:

- 0.5 (commercial properties)
- 0.03 (roads/car parks)
- 0.035 (open space with minimal vegetation including open paddocks, tussock grassed areas and swampy areas). A variable manning’s approach was adopted to better

represent the relationship between surface roughness and depth of flow (Barling and Moore, 1994).

  - Manning's roughness value of 0.05 applied for flow depths up to 0.2 m
  - Manning's roughness value of 0.035 applied for flow depths above 0.2 m

- 0.06 (open space with moderate vegetation).
- 0.07 (Stockyard Creek)
- 0.08 (Bennison Creek)

Refer to **Appendix P** for material roughness maps for both Stockyard Creek and Bennison Creek TUFLOW models.

5.7.2 Variable Depth Roughness Sensitivity Analysis

This study utilised the RORB hydrological model to run all standard durations and temporal patterns to select the critical durations and temporal patterns to run through the TUFLOW flood model. This approach considerably reduces the computational and data burden associated with the alternative of running all 10 temporal patterns for each duration, return period and scenario using the TUFLOW hydraulic model. However, in areas where the RORB hydrological model and TUFLOW hydraulic model overlap it relies on consistency between the flow routing between both models.

RORB's routing approach to flow routing utilises a theoretically and empirically justified relationship to simulate reach storage-discharge values as follows:

$S = 3600kQ^m$

Where;

S = reach storage (m^3)

k = Dimensional empirical coefficient dependent on channel roughness, cross-section shape, bed-slope and length

Q = outflow discharge (m^3/s)

m = dimensionless exponent representing catchment characteristics.

There are three different reach types available in RORB to represent flow paths from natural channels to concrete pipes and reaches are represented by an average gradient (where required).

TUFLOW explicitly represents the terrain surface including local changes in roughness due to changes in surface type and variation in catchment storage at a much finer spatial resolution than is achieved in RORB. It is therefore expected that on a small spatial scale there may be significant differences between the flows predicted between RORB and TUFLOW but on larger scales the differences should be less obvious. The RORB model recommends that:

> *at least 5 sub-areas be placed above any hydrograph printout point to allow sufficient smoothing and attenuation of the rainfall excess hyetographs.*

Calibration of TUFLOW model flows was undertaken at a number of key locations in the catchment areas adjacent to Stockyard Creek and modification of the TUFLOW model Manning's roughness (within realistic bounds) was undertaken where required. A variable depth Manning's approach was utilised to more realistically represent the change in hydraulic response with increasing depth. The process involved trialling various roughness and depth values in TUFLOW that were deemed appropriate, in order to achieve similar flow magnitudes at key locations across the catchment. Figure 5.1 below describes how water experiences lower degrees of roughness at larger depths of flow due to reduced resistance from the ground surface and any vegetation that may be present along a flow path.

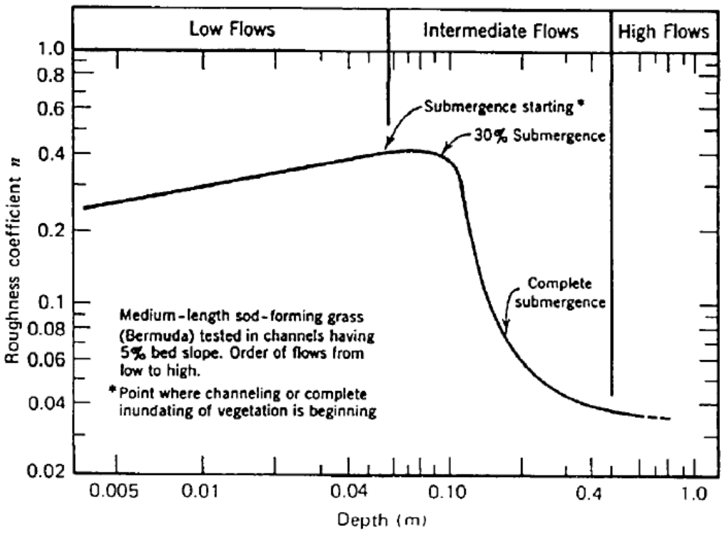

Figure 5.1 **Manning's Roughness coefficient versus depth of flow (Barling and Moore, 1994)**

The final surface roughness and flow depth relationship is described in Section 5.7.1.

5.7.3 Waterway Roughness Sensitivity

An investigation into the flooding impacts of adopting a higher manning's roughness value for both Stockyard Creek and Bennison Creek was conducted. Table 5.1 describes the manning's roughness values used for each waterway for the flood study as well as the values used for the high manning's roughness sensitivity.

Table 5.1 Manning's roughness summary

Waterway	Original Value	High Value
Stockyard Creek	0.07	0.1
Bennison Creek	0.08	0.1

For Stockyard Creek, the modelling results show increases in flood depths in some areas of up to 430 mm for the 1 % AEP storm event.

For Bennison Creek, the modelling results show increases in flood depths in some areas of up to 180 mm and reductions of up to 35 mm for the 1 % AEP storm event. The decreases in flood depths are considered to be a result of changes to the timing in which local peak flows are converging with the waterway peak flows along Bennison Creek. Waterway flows are slightly attenuated with the increase in roughness and therefore the local stormwater runoff can enter the waterway while it has more capacity.

Refer to **Appendix S** and **Appendix T** for flood maps of the high manning's roughness sensitivity.

5.8 Boundary Conditions

5.8.1 1-D Inflow Boundaries

The 1-D boundary condition layer (1d_bc) has been used to read in RORB inflow hydrographs for areas where the dominant drainage mechanism from private lots was considered to be discharge to pipe or kerb outlets. To determine this Engeny utilised Google Street view to map the locations for kerb outlets within Foster and discussed the nature of each drainage system with SGSC prior to determining the inflow boundary condition approach. Apportionment of the RORB subarea was undertaken based on the impervious area where it was necessary to reduce the size of 1d_bc inflow polygons to appropriately distribute inflows.

5.8.2 2-D Source Areas

2-D source areas (2d_sa) were utilised to apply flow to the surface of the TUFLOW model in areas where drainage from private property is generally conveyed overland, rather than in a pipe and pit network. This was typical of farming zones, large parks or low density residential areas. 2d_sa polygons in these areas utilised a rainfall excess approach by using the command “SA ALL” to apply flows to all cells within the digitised polygon. Flow from the source area travels overland until it reaches the 1-D network, or may flow overland to the catchment outlet.

5.8.3 2-D Boundary Conditions

As part of the 1-D network, 2-D SX (source of flow from a 1D model) boundaries were assigned to the pits to allow surcharge of water from the pipe network to the 2-D surface.

2-D HQ (head versus flow) model boundaries have been adopted where overland flow exits the model. This approach was taken to avoid water ponding against the 2-D code boundary.

A combination of 2-D CN and 2-D SX boundaries were utilized on large culverts where appropriate to ensure the capacity of the assets weren't underestimated.

5.9 TUFLOW Parameters

5.9.1 Time Step

Engeny has adopted a 2-D time step of 1 second and a 1-D time step of 0.5 seconds. These time steps were found to provide a good balance between achieving reasonable simulations times and maintaining errors to acceptable limits.

These time steps are consistent with recommendations in Melbourne Water's Flood Mapping Guidelines for a 2-D model grid size of three metres.

5.9.2 Durations Modelled

Engeny conducted hydraulic modelling in TUFLOW for the critical durations determined through RORB hydrological modelling for the 10 %, 5 %, 2 %, 1 % and 0.5 % AEP events**.** A summary of the critical durations for each model is presented in Table 5.2.

Table 5.2 Critical durations summary

Location	AEP	Duration (Temporal Pattern)
Stockyard Creek	10 %	4.5 hr (tp 18) and 1.5 hr (tp 13)
	5 %	12 h (tp 15), 4.5 hr (tp 13), 2 hr (17) and 1.5 hr (tp 19)
	2 %	3 hr (tp 27), 1.5 hr (28) and 2 hr (tp 28)
	1 %	3 hr (tp 25), 1 hr (27) and 20 m (tp 23)
	0.5 %	2 hr (tp 28), 1 hr (23) and 20 m (tp 28)
Bennison Creek	10 %	3 hr (tp 14) and 2 hr (tp 14)
	5 %	2 hr (tp 14) and 4.5 hr (tp 18)

Location	AEP	Duration (Temporal Pattern)
	2 %	2 hr (tp 22) and 3 hr (tp 22)
	1 %	2 hr (tp 27) and 3 hr (tp 22)
	0.5 %	2 hr (tp 21) and 3 hr (tp 28)

5.10 Model Calibration and Validation

5.10.1 Approach

Calibration and validation of the TUFLOW hydraulic model for Stockyard Creek was undertaken as follows:

- Calibration of local flow paths to the RORB hydrological model (as described in Section 5.7.2).
- Validation of TUFLOW flood patterns at Foster to the communities' understanding of flooding based on observations from historical events
- Investigation of the July 2016 rainfall event using the TUFLOW model to determine whether similar flooding patterns were achieved by the model

TUFLOW model parameters from the Stockyard Creek catchment determined through the RORB calibration process were adopted for the Bennison Creek catchment. Engeny was unable to obtain any historical information regarding flooding in the Bennison Creek catchment from the sources contacted, which included VicRoads, SGSC and the Foster community.

5.10.2 Community Consultation Session 1

Community consultation sessions were held at Foster Community Health Centre between on the 4th of July 2017 and the 15th of March 2018. The sessions were advertised in the local paper, *the Mirror*, and invitations to attend mailed to residents on both sides of Stockyard Creek in Foster. Between 20 and 30 people attended each session and some valuable information on existing flood patterns was provided and used to inform this study.

The following summarises the information provided by members of the community at Session 1:

- Boyd Court and the properties on the western side of the Court are prone to flooding from Stockyard Creek and flooding above the floor level of at least one property occurred during the July 2016 rainfall event

- During the July 2016 rainfall event blockage to the Stockyard Creek culverts under Boundary Road was considered by the community to be the main reason contributing to flooding at Boyd Court

- The primary reason for blockage of the culverts was considered by residents to be the excessive vegetation growth within Stockyard Creek

- During the July 2016 rainfall event flood water from Stockyard Creek was observed to overtop Boundary Road and flow in a south easterly direction through the properties on Boundary Road and the West side of Boyd Court before draining back to Stockyard Creek by way of a small culvert located at the western end of Boyd Court.

- Residents also reported having seen flow from Stockyard Creek overtop the Boundary Road culverts and flow overland into Station Street before draining into Boyd Court

- One resident reported that Boundary Road has overtopped five (5) or six (6) times in the last ten (10) years and considered that blockage to the culverts was a major contributor to the overtopping

- Flooding of the Foster Recreation Reserve was also reported as a relatively frequent issue and considered by residents to be a result of insufficient capacity of the drainage system to convey flow from the main oval to Stockyard Creek, particularly when the creek was high

- Other than the locations mentioned above, no other location was considered to be particularly susceptible to flooding within the Foster town boundary

- No information was forthcoming with respect to flooding conditions in the Bennison Creek catchment.

The information gathered at the community session was used to assess the flood modelling results and inform options to mitigate flooding in the study area.

5.10.3 Community Consultation Session 2

Engeny presented the preliminary results of the flood modelling at community session 2 in which areas that were identified by the flood model as prone to flooding were identified and validated against the communities' understanding of flood patterns. The following summarises the outcomes of the community session:

- The flood modelling results were generally consistent with the communities' understanding of flooding in Foster.

- The service station at the corner of Main Street and Nelson Street was identified as a flooding hotspot that has been inundated many times in recent years and was found to be consistent with the modelling which shows a flow path through this site for the 10 % AEP event.

- Deep flooding of the unit development at 94 Station Road between Boyd Court and Apex Court. This is consistent with the modelling results that predict up to 0.5 m depth of flooding for the 1 % AEP event.
- Flood flows from Stockyard Creek flow up Boundary Road towards Station Street and overtop through properties into Boyd Court.
- Ponding on the Foster Recreational Reserve oval surface possibly due to backwatering through the pipe network from Stockyard Creek which was not consistent with the model results.

Following the community session, further investigation was undertaken with respect to the flooding at the sports oval, as follows:

- The sports oval elevation is approximately 1.5 m higher than the peak 1 % AEP water level in Stockyard Creek where the oval pipe system discharges therefore it is considered unlikely that the water levels in the creek are backwatering through the pipe network onto the oval surface.
- It was considered that the flooding issues raised by the residents could be a product of ineffectively located pit and pipe system and/or system blockage. Mitigation options for this site and other locations are discussed in Section 6 of this report.

As a result of the investigation into this area, Engeny modified the inflow arrangement of this location to apply flow as a 2d_SA (ALL) shape to better capture the drainage system characteristics of this area. This approach resulted in the model reporting flood depths of up to 0.3-0.4 m for the 10 % AEP event on the western edge of the oval, which is considered to be more consistent with the flooding reported by the community.

5.10.4 July 2016 Storm Event Model Validation

On the 5th and 6th of July 2016, residents experienced flooding to their properties in the town’s South, between Boundary Road and Apex Court. The flooding occurred at night and some residents in Boyd Court had to be rescued by the SES. The resident of number 2 Boyd Court reported flooding above floor level. Refer to **Appendix Q** for flooding images provided by SGSC of this event (it is understood that these photos were provided by Foster residents). Engeny investigated modelling the July 2016 storm event to validate the results of the hydraulic modelling.

The Bureau of Meteorology archived synoptic charts identified that the weather system responsible for this event was an ‘east coast’ low pressure system that persisted over Victoria between the 5th and 6th of July. Rainfall in Foster was recorded by the daily rainfall gauge located in town as 2 mm for the 5th of July and 81 mm for the 6th of July. Given the critical storm durations for Stockyard Creek are estimated to be between 1.5 and 4.5 hours depending on the event size, historical radar information was investigated further to understand the temporal characteristics of the rainfall event.

The Melbourne and Sale radar locations were found to capture the event however both stations are located some distance from Foster and no reliable conclusions could be drawn regarding the storm burst duration. No nearby pluviograph stations have recorded data for this event. In addition, it was considered that there could be a significant variation in the rainfall depth recorded in Foster and the rainfall depth that fell in the Stockyard Creek catchment.

Considering the site IFD data (presented in the Section 4.6.2) and the rainfall depth recorded in Foster, if 81 mm fell during a 4.5-hour period than the storm event was in excess of 1 % AEP. However, it is also possible that the storm event occurred for a longer duration with a much lower burst depth. For example, if total rainfall 81 mm rainfall depth fell over 24 hours but within that there was an approximately 55 mm burst that occurred over 4.5 hours than the storm would have been closer to a 5 % AEP event.

Given the uncertainty associated with the temporal distribution of rainfall for the July 2016 event was not able to be resolved, Engeny undertook sensitivity analysis to investigate which design events might result in a similar flood pattern to what was experienced by the residents of Boyd Court. Blockage of the Boundary Road culvert (see Figure 5.2 and Figure 5.3 – note this culvert has since been repaired by SGSC), was widely reported by the community to have occurred during this event and is considered by the community to be a major contributing factor to the flooding that resulted in Boyd Court. Evidence of the damage caused by the July 2016 event can be seen in Figure 5.2 and Figure 5.3. As the exact extent of blockage to the Boundary Road culvert could not be determined, Engeny incorporated a 50 % blockage factor to the Boundary Road culvert to the sensitivity model runs undertaken for the July 2016 rainfall event.

Figure 5.2 Upstream face of the Boundary Road culvert (09/04/2017)

Figure 5.3 **Downstream face of the Boundary Road culvert (09/04/2017)**

The following sensitivity simulations were undertaken using design rainfall events and 50 % blockage applied to the Boundary Road culverts:

- 10 % AEP (3hr, 2hr durations)
- 5 % AEP (12 hr, 4.5 hr, 1.5 hr durations)
- 2 % AEP (3 hr, 2hr durations)

The sensitivity modelling found that inundation of number 2 Boyd Court property to depths greater than 100 mm (considered to be sufficient to result in flooding of the property floor) occurred for the 2 % AEP return period (presented in **Appendix S**). The cause of the flooding at this property was found to be flow from Stockyard Creek spilling north along Boundary Road, through the vacant property at 1 Boundary Road and through the rear of 2 Boyd Court. Significant ponding in Boyd Court (up to 0.4 m) was also found to occur and was consistent with the residents' reporting of the event. The major flooding mechanisms identified for the modelled 'simulation' of this event were as follows:

- Overtopping of Stockyard Creek through properties as a result of insufficient culvert capacity and blockage.
- Backflow from Stockyard Creek into Boyd Court via the existing 300 mm diameter drainage pipe results in ponding and prevents stormwater from discharging to the creek.
- Stormwater flooding derived from local flow paths on Nelson Street is a significant contributor to flooding on the south side of Boyd Court and at Apex Court, which was

not reported by residents for the July 2016 event. Possible reasons for this discrepancy include:

- The intensity of rainfall falling in the catchment may have been significantly higher than in Foster, meaning that the flow in Stockyard Creek may have been responding to a significantly higher design event than the local catchment flow. This would lead to a reduced influence of stormwater flooding in the catchment and may not necessarily align with the design storm events modelled as part of this study.
- The residents that did not report flooding were not impacted because their houses are brick and likely to be impervious to stormwater flow if their floor levels are raised sufficiently high above the surrounding terrain.
- The July 2016 event occurred at night, limiting the observations that could be made by the residents.
- Residents impacted by stormwater flooding in Apex Court were not present in either community session to report on flood behaviour for that event (or more generally).

With regards to the final point, it was communicated to Engeny and SGSC by a Boyd Court resident that they knew of flooding that had occurred in the units located between Boyd Court and Apex Court, and that recent flooding of, ‘around half a metre’ in depth at that location had caused flooding to floors. The depth and location of flooding described by the resident is supported by the flood modelling results.

5.10.5 Bridge Street Crossing Model Validation

SGSC attended a site visit with two, ‘long time’ Foster residents and obtained information regarding the highest water levels in Stockyard Creek that they had observed during their residence in Foster at the Bridge Street culvert crossing[1]. The water levels identified by the residents were referenced with respect to a sapling and tree fern and no specific information about the date of the flooding events could be obtained. Water levels for the 10 %, 5 % 2 % and 1 % AEP design events at the downstream face of the Bridge Street culvert are shown with respect to the flood levels reported by the residents on Figure 5.4.

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[1] Note the observed water levels were not from the July 2016 event which occurred at night.

Figure 5.4 Comparison of design flood levels versus observed flood levels

Figure 5.4 shows that the observed flood levels are consistent with predicted inundation for a storm event of between a 5 % and 2 % AEP.

Insufficient data was available to confirm whether an event of this magnitude has been observed by the residents. However, based on a review of the daily rainfall data series between January 1st 1987 and May 31st 2017, there are sixteen (16) rainfall totals that exceed the 57.9 mm rainfall depth referenced by the IFD data for the critical 3 hour duration 2 % AEP event. Whilst it is not possible to draw any strong conclusions from this analysis, it is considered possible that an event(s) of magnitude between 5 % and 2 % AEP event have occurred in living memory and provides some level of confidence that the model is producing results that are generally in line with historical observations.

5.10.6 Key Structures 1D Model Validation

HEC-RAS software was used to validate the TUFLOW model representation of key bridge structures on Stockyard Creek. Structure information provided by SGSC and elevation data from the DEM used in the TUFLOW model was utilised to populate the HEC-RAS model. The structures modelled include:

1. Old Rail Trail Bridge
2. New Rail Trail Bridge and

3. Dyrings Road Bridge

The peak 1 % AEP flow located upstream of the structures was extracted from TUFLOW and used to run a steady flow analysis (using a normal depth downstream boundary) in HEC-RAS. The model extended 100 metres downstream of the bridges to ensure the downstream boundary was not impeding on the flow calculations through the waterway structures.

Figure 5.5, Figure 5.6 and Figure 5.7 present the structure cross sections from the HEC-RAS model.

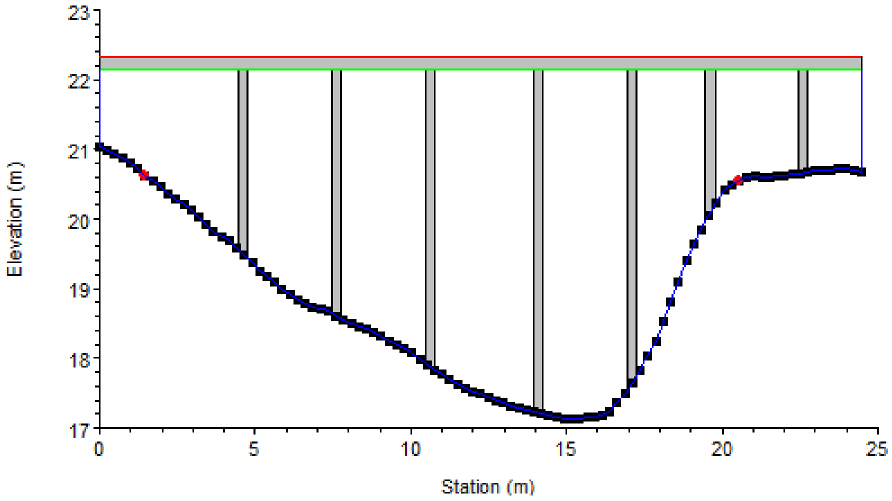


Figure 5.5 **Old Rail Trail Bridge HEC-RAS cross section**

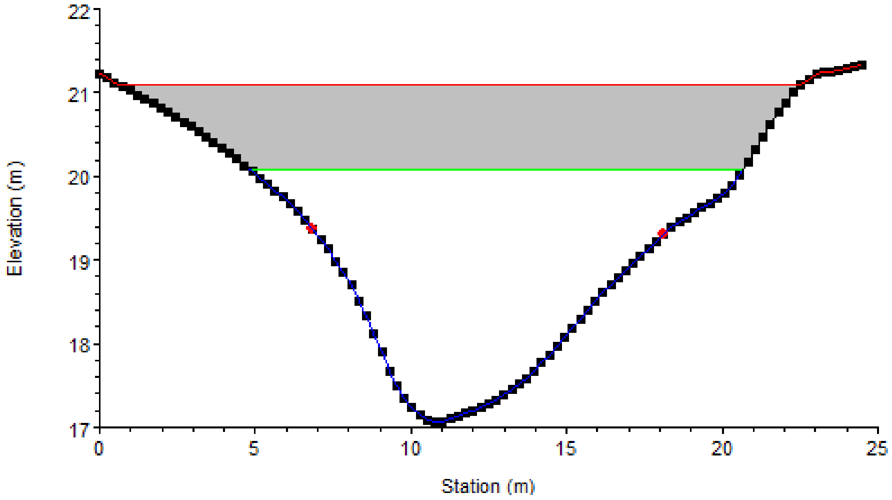


Figure 5.6 **New Rail Trail Bridge HEC-RAS cross section**

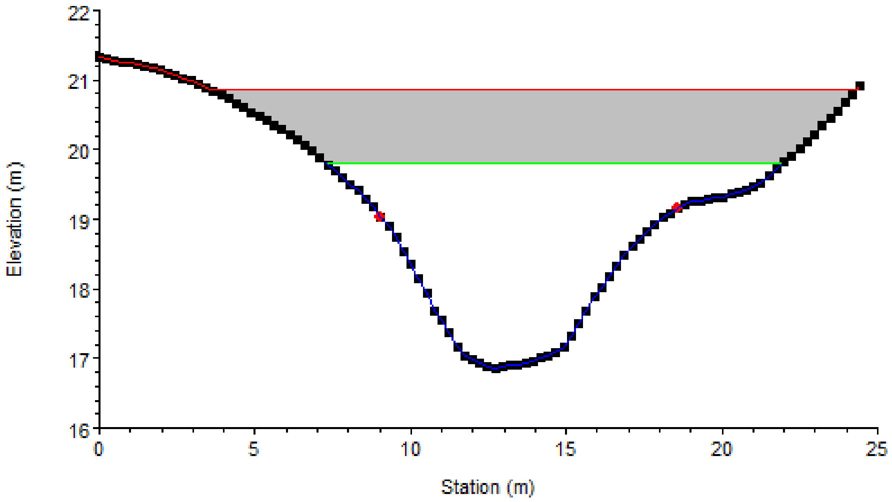


Figure 5.7 **Dyrings Bridge HEC-RAS cross section**

HEC-RAS modelling results closely agreed with the TUFLOW model results. Comparative head losses across all structures were found to be within 100 mm and no changes were made to the TUFLOW model structure representation based on the modelling HEC-RAS validation.

5.11 Quality Assurance

5.11.1 Checking Procedure

As part of Engeny's internal quality assurance procedures for hydraulic modelling, independent internal quality assurance checking has been completed for this study.

Results files such as the 1-D capacity check (ccA), time series (TS) and time series loss (TSL) have been investigated for some of the runs from each event. These files were used to check that pipes are flowing full in the 10 % AEP event and if not flowing full then to confirm that the level of overland flow was minor or there was a legitimate drainage issue resulting in this occurrence. The pipe flow in the 1 % AEP event was also checked to ensure that the network had been modelled correctly and that there were no "brick walls" where pipes had been incorrectly connected to the next pipe downstream. Any unexpectedly large or small flow results have been investigated to understand whether or not they were realistic. Engeny has also undertaken a site inspection within the catchments and we have applied this knowledge of the catchments when determining if flow magnitudes and paths appear reasonable.

The TUFLOW log file provides a summary of key information while the model is running. The GPC solution scheme output provides solver mass balance tracking and other information to inform the users understanding of the stability of the model.

The following model information was reported for the 0.5 % AEP 120-minute duration event which had highest 'instability index':

- Classic 1D Negative Depths: 0
- Classic 2D Negative Depths: 0
- HPC HCN (High Control Number) Repeated Timesteps: Maximum of 68
- HPC NaN (Not a Number) Repeated TimeSteps: 0
- HPSC NaN WARNING 2550: 0

The information above shows that the only simulation stability indicator with a number larger than 0 is for HPC HCN Repeated Timesteps. According to the release notes, *HCN means that one of the three stability criteria was exceeded by more than 20 % forcing a lowering and repeat of the timestep*. Investigation of the model log files revealed that none of the HCN repeated timesteps were consecutive, meaning that the non-conformance was resolved immediately. This combined with the relatively low number of repeats suggests that the models are well constructed and stable.

5.11.2 Warnings and Errors

Table 5.3 Warning Summary

Township	Warning No	Description	No of Warnings	Comment
Stockyard Creek	2124	No 2D connection specified for pit or node	138	Junction pits were not connected to the 2D domain to avoid artificially increasing the pit inlet capacity of the drainage system. Warnings are applicable to junction pit locations.
	1100	Structure X crest/invert (X m) is below bed (Y m) of primary upstream channel Y	26	Warning occurs where invert of a downstream pipe drops below the invert of the upstream pipe through a pit. This is a realistic representation of the drainage system.
	2118	Lowered SX ZC Zpt by X m to 1D node bed level	54	Z-shapes have been utilised at various culvert entries and exits in order to attain a smooth transition from the 1D domain to the 2D domain and vice-versa. Survey information was adopted at most of these locations.

Bennison Creek	2118	Lowered SX ZC Zpt by X m to 1D node bed level	17	Z-shapes have been utilised at various culvert entries and exits in order to attain a smooth transition from the 1D domain to the 2D domain and vice-versa. Survey information was adopted at most of these locations.

5.12 Known Model Issues

The following model issues are known:

1. There are two culverts (road crossings on Bennison Creek at Amey's Track and South Gippsland Highway) within the Bennison Creek model that experience slight unstable flows towards the end of simulations. This was deemed not to be an issue as it is not impacting on the peak flows through the structures or peak water levels in the surrounding terrain.

5.13 Hydraulic Peer Review

An independent peer review of the hydraulic report was undertaken by two (2) experts from DELWP's expert review panel. The hydraulic review raised 30 queries. Engeny has provided responses to each query and made adjustments to the hydraulic section of this report where required. Refer to **Appendix Y** for peer review comments and Engeny's responses.

5.14 Hydraulic Conclusions

TUFLOW hydraulic modelling was undertaken for Foster and surrounding areas for the PMPF, 0.5 %, 1 %, 2 %, 5 % and 10 % AEP storm events. Two separate TUFLOW models were developed, one for the Stockyard Creek catchment and one for the Bennison Creek catchment. The hydraulic modelling was undertaken using AR&R 2016 methodologies. The results presented in this section provide a high-level summary of the results and do not explore the specific locations identified as flood prone (other than has been discussed previously). See Section 6 for potential mitigation measures that could be implemented to reduce flooding.

5.14.1 Stockyard Creek

Table 5.4 presents a summary of maximum flood depths at key locations in the Stockyard Creek catchment. Location IDs correspond to the labelled flooding locations in Figure 5.8. As discussed in Section 5.10.4, Engeny undertook a blockage sensitivity analysis of the Boundary Road culvert that was widely reported by the community to have exacerbated flooding issues reported in Boyd Court during the 2016 storm event. As the exact extent of blockage to the Boundary Road culvert could not be determined, Engeny incorporated a 50 % blockage factor to the Boundary Road culvert for the sensitivity model runs undertaken for the July 2016 rainfall event. The maximum flood depths from this investigation are also presented in Table 5.4 for the 2 % and 10 % AEP storm events. Refer to **Appendix S** for the Stockyard Creek maximum flood depth maps for the 0.5 %, 1 %, 2 %, 5 % and 10 % AEP storm events under 2030 development conditions.

Table 5.4 Stockyard Creek key flooding locations – Maximum flood depths (m)

ID	Location	AEP						
		0.5 %	1 %	2 %	5 %	10 %	2 % (Blockage)	10 % (Blockage)
1	McDonald Street	0.55	0.51	0.50	0.47	0.42	0.50	0.42
2	Intersection of Main Street and Nelson Street	0.48	0.45	0.45	0.43	0.37	0.45	0.37
3	Between Bruce Court and Landy Road	0.34	0.31	0.31	0.30	0.28	0.31	0.28
4	McMaster Court	0.34	0.32	0.32	0.28	0.22	0.32	0.22
5	Boyd Court	0.50	0.45	0.35	0.32	0.26	0.35	0.26
6	Apex Court	1.05	0.89	0.71	0.60	0.34	0.73	0.34
7	Boundary Road on Stockyard Creek	0.74	0.66	0.47	0.13	0.02	0.54	0.23
8	Intersection of Devlon Road and Nelson Street	0.26	0.25	0.25	0.21	0.20	0.25	0.20
9	Coopers Road north of Gibbs Street	0.28	0.22	0.22	0.18	0.10	0.22	0.10
10	Fish Creek-Foster Road on Stockyard Creek	0.37	0.28	0.03	0.00	0.00	0.03	0.00
11	Fish Creek-Foster Road south of Jay Road	0.41	0.37	0.35	0.29	0.17	0.35	0.17
12	Fish Creek-Foster Road south of Allan Court	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Bridge Street on Stockyard Creek	0.33	0.21	0.00	0.00	0.00	0.00	0.00

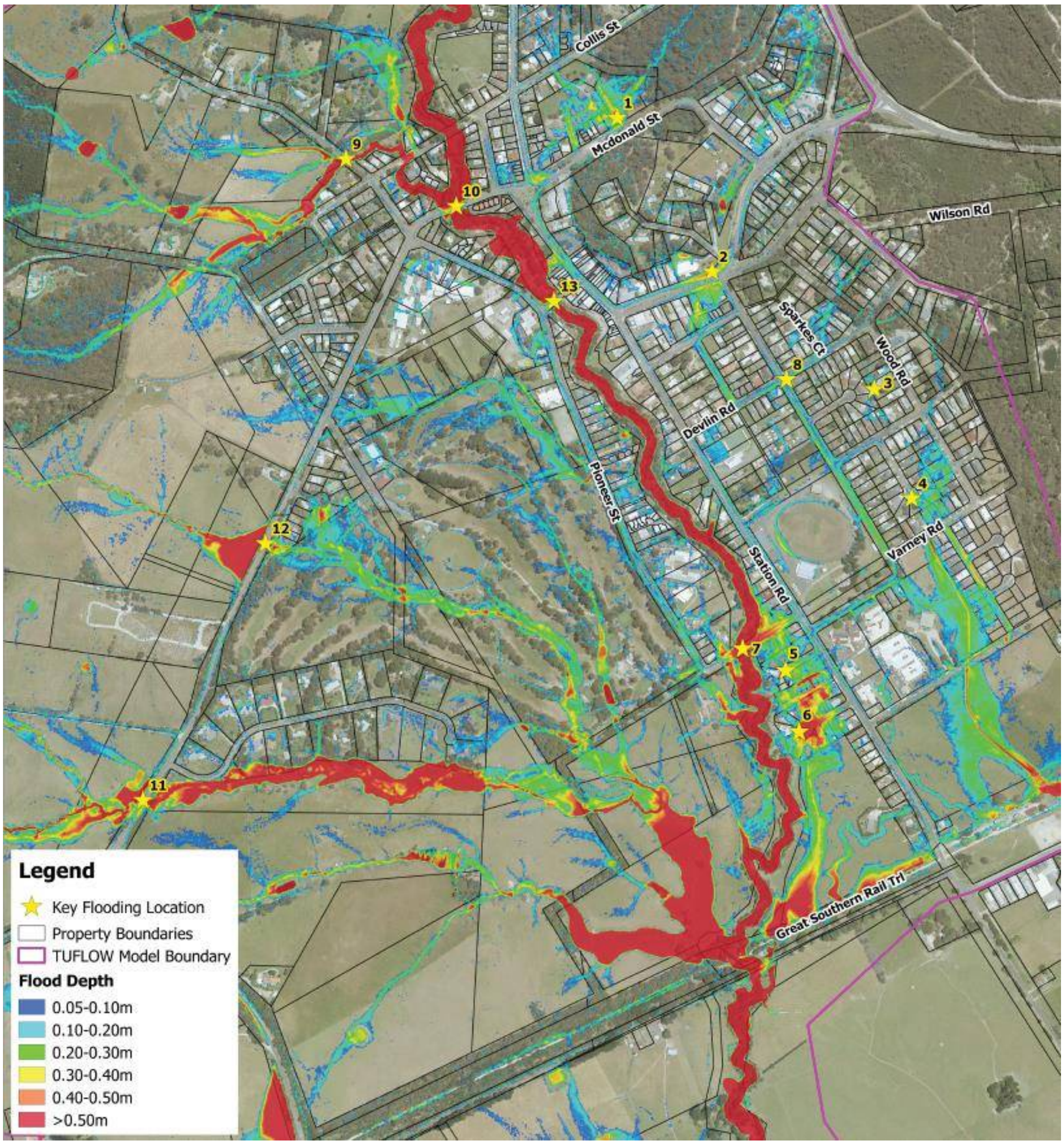


Figure 5.8 **Stockyard Creek key flooding locations**

5.14.2 Bennison Creek

Table 5.5 presents a summary of maximum flood depths at key locations in the Bennison Creek catchment. Location IDs correspond to the labelled flooding locations in Figure 5.8. Refer to **Appendix T** for the Bennison Creek maximum flood depth maps for the 0.5 %, 1 %, 2 %, 5 % and 10 % AEP storm events.

Table 5.5 Bennison Creek key flooding locations – Maximum flood depths (m)

		AEP				
ID	**Location**	**0.5 %**	**1 %**	**2 %**	**5 %**	**10 %**
14	Ameys Track on Bennison Creek	0.32	0.26	0.19	0.01	0.01
15	Ameys Track east of Bennison Creek	0.09	0.05	0.01	0.00	0.00
16	South Gippsland Highway on Bennison Creek	0.14	0.12	0.04	0.00	0.00
17	South Gippsland Highway west of Bennison Creek	0.22	0.12	0.09	0.00	0.00
18	South Gippsland Highway east of Bennison Creek	0.34	0.32	0.26	0.00	0.00

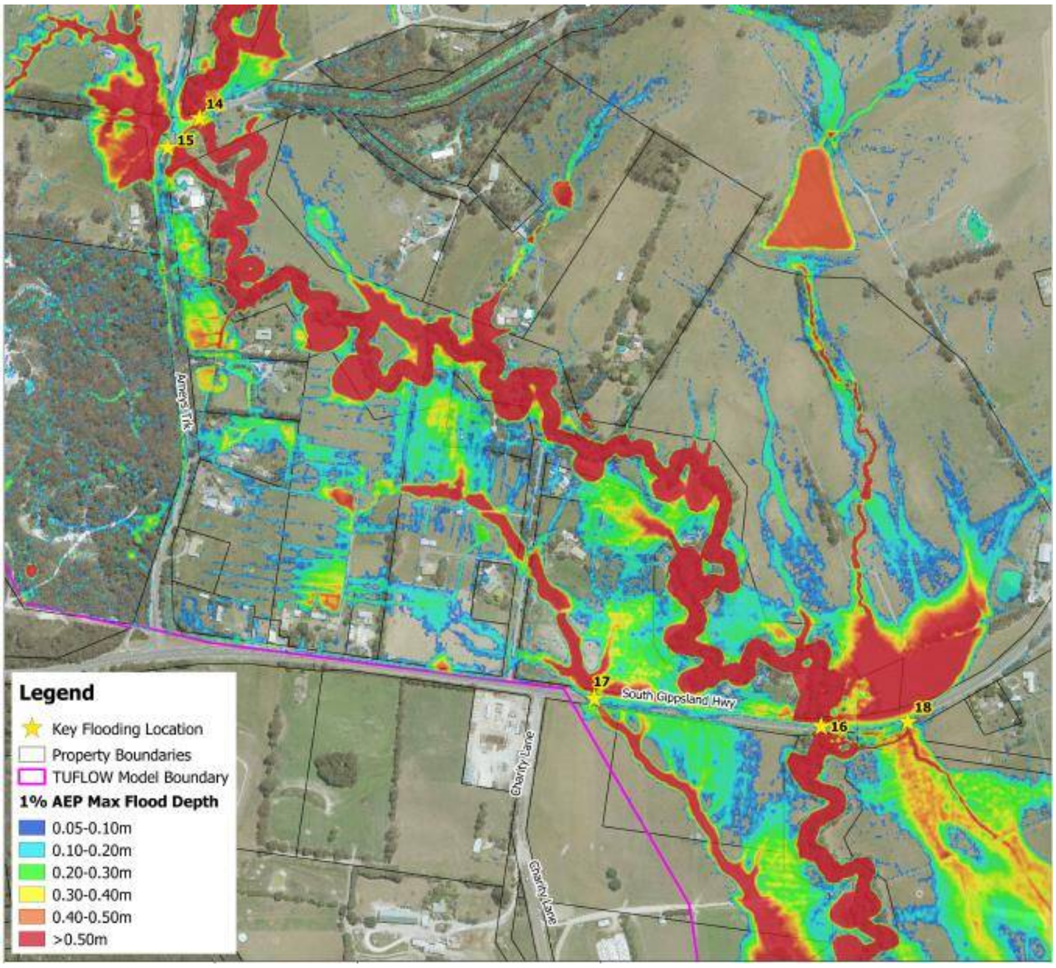


Figure 5.9 Bennison Creek key flooding locations

6. FLOOD RISK

6.1 Objectives

There are various locations where the hydraulic modelling predicts flooding across the town of Foster (refer to Section 5.10). An objective of this study is to determine drainage hotspots, treatment designs and cost estimates for inclusion in the SGSC future capital works program. This section further explores properties and roadways at risk of flooding and the possible drainage improvement and flood mitigation works (and associated estimated costs) that have been investigated to resolve the probable flooding issues identified by the flood modelling.

AR&R 2016 provides newly revised hazard categories which are based on velocity depth product, absolute velocity and absolute depth of flooding. Figure 6.1 shows the new hazard categories which are based around the vulnerability of people and people in vehicles to floodwaters of varying depth and velocities. Roadways that are predicted by the flood modelling to be categorised under the more hazardous categories are highlighted in the following sections for both the Stockyard Creek and Bennison Creek catchments.

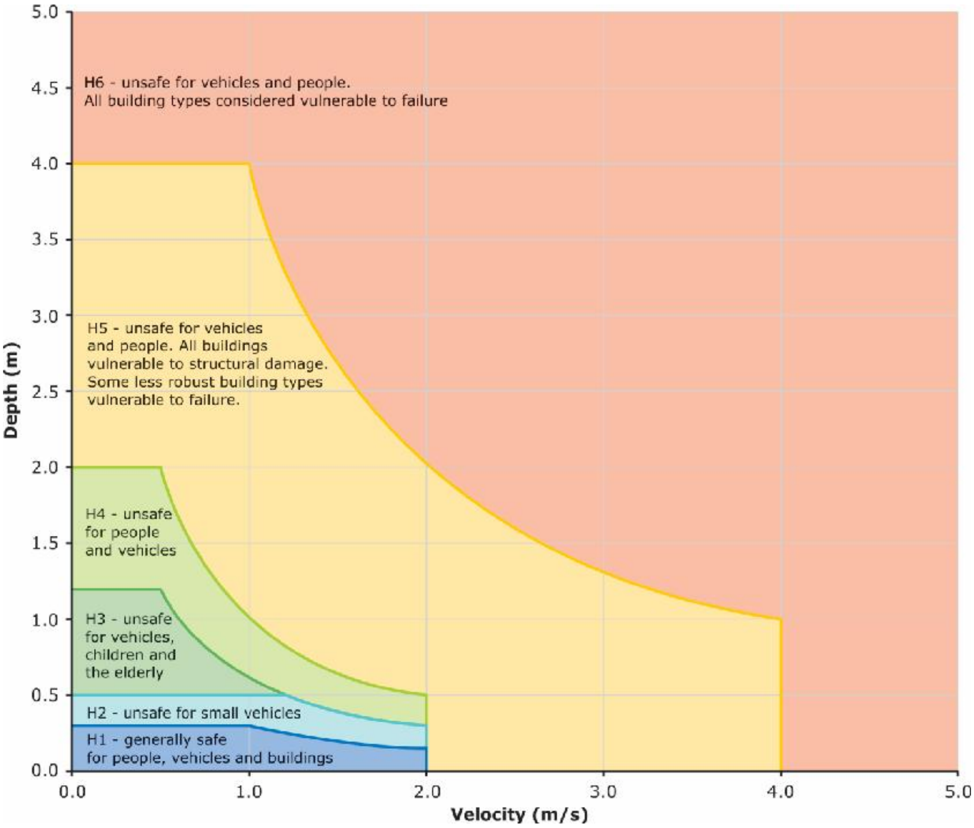


Figure 6.1 AR&R 2016 Flood hazard categories

6.2 Flood Risk by Location

6.2.1 Stockyard Creek Catchment

Flooding to properties

Figure 6.2 presents the modelled drainage level of service for properties and roadways within the Stockyard Creek catchment. Properties have been categorised by the most frequent storm event in which they are predicted to be impacted by flooding (i.e. property is shown in yellow if it is impacted by the 2 % AEP storm event but not impacted by flooding for the 10 % and 5 % AEP storm events). Properties were considered impacted if flood depths were greater than or equal to 100 mm within the property boundary. Table 6.1 presents the number of properties impacted by flooding for the various storm events modelled.

Table 6.1 Properties affected by flood extent – Stockyard Creek

Land Use	AEP event				
	10 %	5 %	2 %	1 %	0.5 %
Residential	299	363	417	435	465
Commercial	11	21	27	30	38
Farming	63	64	64	64	64
Public Space	91	101	105	109	118
TOTAL	464	549	613	638	685

The number of impacted properties steadily increases as the storm rarity rises, with residential, public space and farming land use consuming approximately 67 %, 18 % and 11 % of the flood affected properties for each storm event respectively.

Flooding to buildings

Table 6.2 presents the number of buildings impacted by flooding for various storm events in the Stockyard Creek catchment. The proposed mitigation works discussed in Section 6.6 would be expected to prevent most flooding issues predicted to occur for storms as infrequent as the 1 % AEP storm event if implemented.

Table 6.2 Buildings affected by flood extent – Stockyard Creek

Land Use	AEP event				
	10 %	5 %	2 %	1 %	0.5 %
Residential	50	76	86	104	109
Commercial	7	9	11	11	11
Public Space	5	5	5	6	9
TOTAL	**62**	**90**	**102**	**121**	**129**

Building floor levels are unknown for the study area and were therefore estimated to be equal to the average surface elevation within the building footprint. It is highly recommended that floor level survey be undertaken as this would improve the understanding of flood risk posed to buildings in the town. Building footprints were considered impacted if the flood depth was greater than or equal to 100 mm at the building footprint location. Residential, commercial and public space land uses contribute to approximately 84 %, 10 % and 6 % of the flood affected building footprints for each storm event respectively.

Flooding at roads and egress

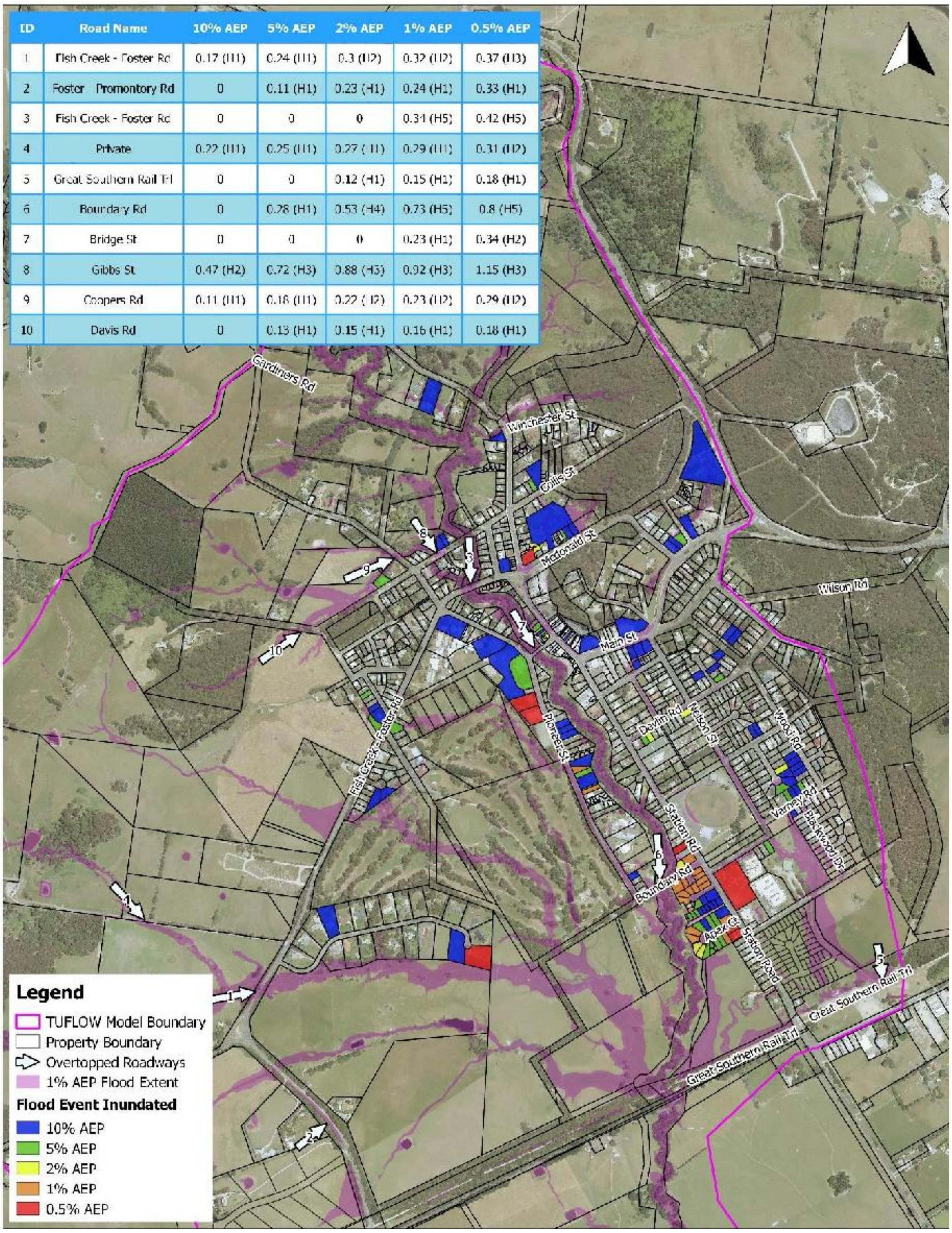
Maximum flood depths (and flood hazard categories) at roads that are overtopped are also presented in Figure 6.2. Road culvert / bridge crossing upgrades are recommended for roadways where:

- The flood hazard is equal to or greater than H3 (hazardous to vehicles and people)
- Frequent overtopping is predicted to occur; and
- Where property egress problems are predicted to arise.

Flows from Stockyard Creek are predicted to overtop at Gibbs Street (in the town's north-west) and is anticipated to land lock up to 7 properties, leaving residents stranded during a 10 % AEP storm event. Overtopping at Coopers Road is also predicted to cause land lock issues for approximately 15 properties for storm events rarer than the 5 % AEP.

Regular overtopping of Fish Creek - Foster Road in the town's west is predicted, with flood depths of up to 370 mm in the 0.5 % AEP storm event which would be expected to prevent access between Foster and other towns to the west. This road as well as Bridge Street are also predicted to overtop due to excessive flows from Stockyard Creek near the town centre for 1 % and 0.5 % AEP storm events, with flood depths reaching up to 420 mm which is hazardous for small vehicles.

More frequent overtopping is expected at Boundary Road, due to insufficient road culvert crossing capacity to convey flows from Stockyard Creek. Flood depths are predicated to reach up to 800 mm in the road, which is hazardous for small vehicles, children and the elderly. The flood modelling suggests that this location is a key flooding hotspot, as excessive flooding to properties and buildings is anticipated. This road crossing should be flagged as a priority location and flood mitigation measures should be implemented whenever first achievable.



ID	Road Name	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP
1	Fish Creek - Foster Rd	0.17 (H1)	0.24 (H1)	0.3 (H2)	0.32 (H2)	0.37 (H3)
2	Foster Promontory Rd	0	0.11 (H1)	0.23 (H1)	0.24 (H1)	0.33 (H1)
3	Fish Creek - Foster Rd	0	0	0	0.34 (H5)	0.42 (H5)
4	Private	0.22 (H1)	0.25 (H1)	0.27 (H1)	0.29 (H1)	0.31 (H2)
5	Great Southern Rail Trl	0	0	0.12 (H1)	0.15 (H1)	0.18 (H1)
6	Boundary Rd	0	0.28 (H1)	0.53 (H4)	0.73 (H5)	0.8 (H5)
7	Bridge St	0	0	0	0.23 (H1)	0.34 (H2)
8	Gibbs St	0.47 (H2)	0.72 (H3)	0.88 (H3)	0.92 (H3)	1.15 (H3)
9	Coopers Rd	0.11 (H1)	0.16 (H1)	0.22 (H2)	0.23 (H2)	0.29 (H2)
10	Davis Rd	0	0.13 (H1)	0.15 (H1)	0.16 (H1)	0.18 (H1)

Figure 6.2 Property and roadway level of service – Stockyard Creek

6.2.2 Bennison Creek Catchment

Flooding to properties

Figure 6.3 presents the modelled drainage level of service for properties and roadways within the Bennison Creek catchment. Properties have been categorised by the most frequent storm event in which they are predicted to be impacted by flooding. Table 6.3 presents the number of properties impacted by flooding for the various storm events modelled.

Table 6.3 Properties affected by flood extent – Bennison Creek

Land Use	AEP event				
	10 %	5 %	2 %	1 %	0.5 %
Residential	0	0	21	21	22
Farming	4	4	54	54	54
Public Space	0	1	10	10	10
TOTAL	4	5	85	85	86

Farming land use contributes to approximately 63 % of the flood affected properties for storm events equal to and rarer than the 2 % AEP.

Flooding to buildings

Table 6.4 presents the number of buildings impacted by flooding for various storm events in the Bennison Creek catchment.

Table 6.4 Buildings affected by flood extent – Bennison Creek

Land Use	AEP event				
	10 %	5 %	2 %	1 %	0.5 %
Residential	0	0	1	2	5
Farming	3	5	6	7	8
TOTAL	3	5	7	9	13

Farming land use contributes to approximately 75 % of the flood affected building footprints for storm events equal to and rarer than the 2 % AEP.

Flooding at roads and egress

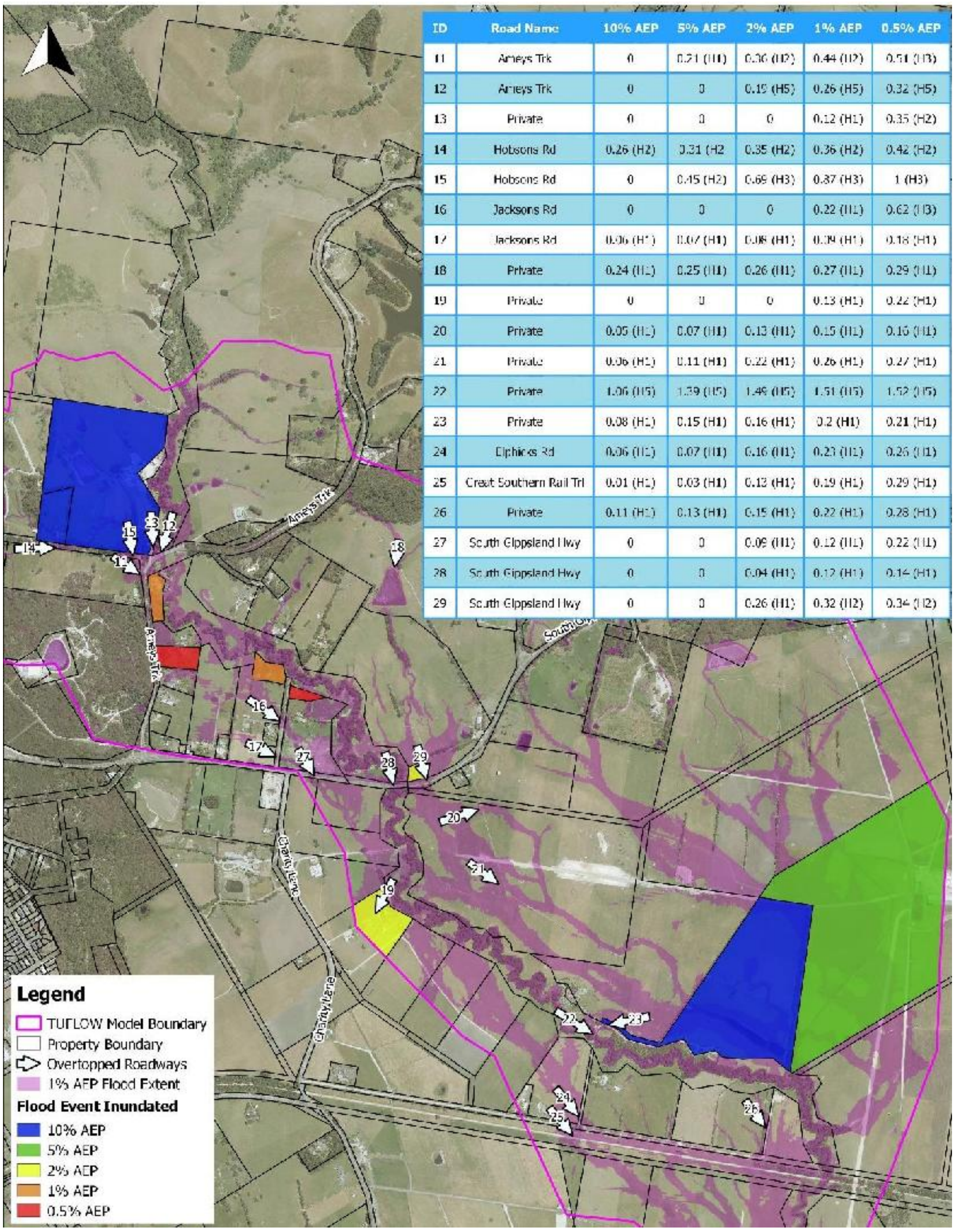
Maximum flood depths (and flood hazard categories) due to road overtopping is presented in Figure 6.3. Road culvert / bridge crossing upgrades are recommended for roadways where:

- The flood hazard is equal to or greater than H3 (hazardous to vehicles and people)
- Frequent overtopping is predicted to occur; and
- Where property egress problems are predicted to arise.

The flood modelling results predict overtopping of Amey's track at two very close locations as a result of excessive flows from Bennison Creek as well as overland flows entering from the local catchment in the north-west. Flood depths are estimated to reach up to 360 mm and 510 mm for the 2 % and 0.5 % AEP storm events respectively which are considered to be hazardous for small vehicles, children and the elderly. Overland flow from the local catchment is also predicted to cause overtopping at Hobsons Road (and where Hobsons Road meets Amey's Track) with depths reaching up to 260 mm and 420 mm for the 10 % and 0.5 % AEP storm events respectively. These depths of flooding in roads would be expected to cause harm to all people and vehicles.

The Great Southern Rail Trail west of Bennison Creek is predicted to overtop for events rarer than the 2 % AEP storm event with flood depths reaching up to 290 mm. As identified previously, this level of flooding is expected to be hazardous for small vehicles.

The modelling results show a number of private (unnamed) roads to be prone to overtopping, with flood depths reaching up to 310 mm in frequent storm events and up to 540 mm for more rare storm events. This is likely to cause egress issues for a number of residents at various locations.



ID	Road Name	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP
11	Ameys Trk	0	0.21 (H1)	0.36 (H2)	0.44 (H2)	0.51 (H3)
12	Ameys Trk	0	0	0.19 (H5)	0.26 (H5)	0.32 (H5)
13	Private	0	0	0	0.12 (H1)	0.35 (H2)
14	Hobsons Rd	0.26 (H2)	0.31 (H2	0.35 (H2)	0.36 (H2)	0.42 (H2)
15	Hobsons Rd	0	0.45 (H2)	0.69 (H3)	0.87 (H3)	1 (H3)
16	Jacksons Rd	0	0	0	0.22 (H1)	0.62 (H3)
17	Jacksons Rd	0.06 (H1)	0.07 (H1)	0.08 (H1)	0.09 (H1)	0.18 (H1)
18	Private	0.24 (H1)	0.25 (H1)	0.26 (H1)	0.27 (H1)	0.29 (H1)
19	Private	0	0	0	0.13 (H1)	0.22 (H1)
20	Private	0.05 (H1)	0.07 (H1)	0.13 (H1)	0.15 (H1)	0.16 (H1)
21	Private	0.06 (H1)	0.11 (H1)	0.22 (H1)	0.26 (H1)	0.27 (H1)
22	Private	1.06 (H5)	1.39 (H5)	1.49 (H5)	1.51 (H5)	1.52 (H5)
23	Private	0.08 (H1)	0.15 (H1)	0.16 (H1)	0.2 (H1)	0.21 (H1)
24	Elphicks Rd	0.06 (H1)	0.07 (H1)	0.16 (H1)	0.23 (H1)	0.26 (H1)
25	Great Southern Rail Trl	0.01 (H1)	0.03 (H1)	0.13 (H1)	0.19 (H1)	0.29 (H1)
26	Private	0.11 (H1)	0.13 (H1)	0.15 (H1)	0.22 (H1)	0.28 (H1)
27	South Gippsland Hwy	0	0	0.09 (H1)	0.12 (H1)	0.22 (H1)
28	South Gippsland Hwy	0	0	0.04 (H1)	0.12 (H1)	0.14 (H1)
29	South Gippsland Hwy	0	0	0.26 (H1)	0.32 (H2)	0.34 (H2)

Figure 6.3 **Property and roadway level of service – Bennison Creek**

6.3 On-site Detention

Refer to **Appendix U** for On-site detention investigation.

6.4 Couper Dam Failure Consequence Assessment

Refer to **Appendix V** for Couper Dam failure consequence assessment.

6.5 Average Annual Damages (AAD) Assessment

6.5.1 Methodology

The AAD assessment estimates the average probable tangible flood damages endured every year over a given period for residential, commercial and industrial land use types. Modelling was undertaken using existing runoff conditions for the 10 %, 5 %, 2 % and 1 % AEP storm events to inform this investigation. The AAD estimate is beneficial for the purposes of quantifying and assessing the economic implications of flood mitigation options (i.e. the cost benefit ratio of mitigation works). Engeny has utilised Melbourne Water's AAD spreadsheet to conduct the assessment for SGSC's existing drainage.

The following outlines key steps and assumptions made when undertaking the AAD assessment:

- Engeny developed a building footprint layer consisting of footprints affected by flooding for the 0.5 % AEP storm event, which was utilised for this investigation to determine the maximum water surface level within each flood affected building footprint for the various flood magnitudes.
- Building footprint representation was produced to coincide with the 2015 aerial photography as provided by SGSC.
- All floor levels were assumed and calculated to be equal to the average surface elevation within each respective building footprint, as determined by the Digital Elevation Model (DEM).
- An up to date property parcel layer generated by the Department of Environment, Land, Water and Planning (DELWP) was utilised for this investigation to determine the total area within each property affected by flood extents of various magnitudes.
- Melbourne Water's AAD spreadsheet contains stage-damage curves that were utilised to inform the cost estimates for this assessment. These stage-damage curves are not intended to represent the full financial impact caused by flood damage. The damage estimation methodology for residential and commercial / industrial properties utilised a combination of the following methods:
  - The Department of Natural Resources & Mines methodology (DNRM, 2002), which is based on the stage-discharge curves developed by ANUFLOOD (Smith & Greenway, 1988). This methodology was adopted for commercial / industrial properties and uses both building size and contents value to inform the costs associated with the stage-damage curve.
  - The Department of Environment and Climate Change Residential Flood Damages Guidelines as documented in the *Floodplain Risk Management Guideline: Residential Flood Damages* (DECCW, 2007). This methodology was used to inform the flood damage costs associated with residential properties.

- It is considered that actual insurance flood damage information would deliver more accurate cost estimates however, this is subject to availability and would need to be investigated for the area.
- The estimated damage costs stated throughout this report are approximations only and were calculated using industry standard methodology.
- Indirect damage costs are assumed to be 30 % of the direct damage costs.
- The AAD assessment does not consider depth or safety in roads.

6.5.2 Flood Damages Types

Actual vs Potential

Various types of flood damage may occur and can be measured in different ways. Figure 6.4 presents a summary of the various categories of flood damages, where each type can be either an ‘actual’ or ‘potential’ damage. Actual damages are a direct result of a flood event whereas, potential damages are the probable damages that could occur from a flood event. Both types of damages can be minimised or in some cases prevented by community awareness and structural or behavioural measures such as flood mitigation works and flood warning procedures.

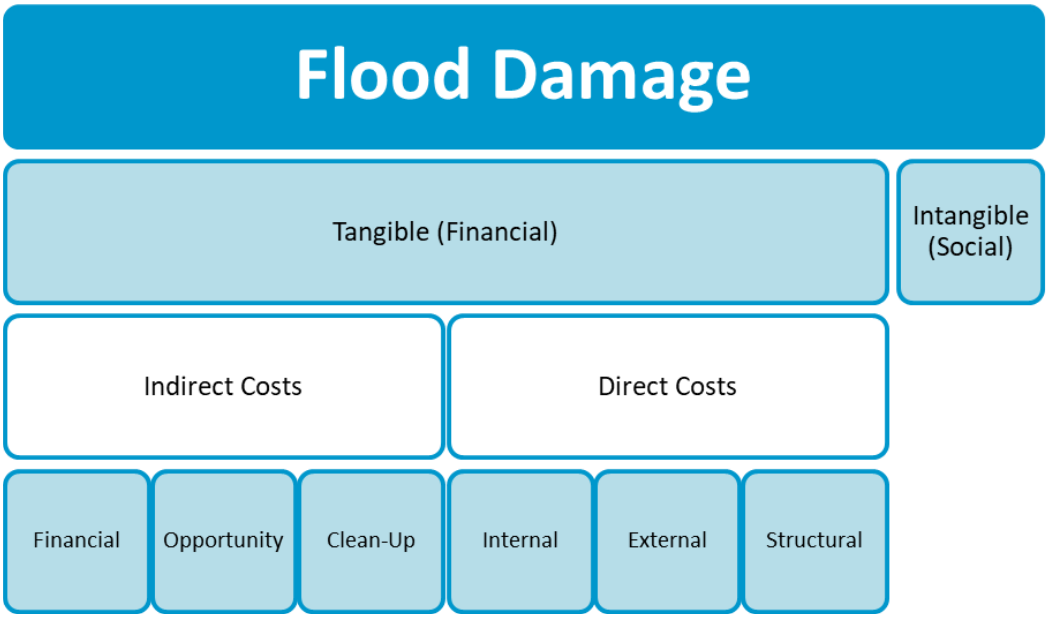


Figure 6.4 **Types of flood damage**

Tangible vs Intangible

Flooding that results in direct damage to a physical building's structure or its contents is considered to be tangible damage and is quantifiable. Intangible damage is when social processes are impacted due to inconvenience, loss of cultural heritage, biodiversity and psychological distress. It is recognised that intangible damages have a level of significance, however their incurred damages can't be quantified in monetary terms.

Direct vs Indirect

As presented in Figure 6.4, tangible damages can be further classified as either direct or indirect flood damages. Direct damages include flood waters contacting a structure or its contents and causing damage due to either high velocities or above floor level flooding. Typical methods for assessing flood damages estimate costs differently for various land use types. This investigation has separated costs between residential and commercial/industrial land uses as well as roadways.

Indirect damages generally include disruptions to community wellbeing, social activities and economic procedures, where costs are incurred to cover inconveniences such as emergency assistance, community support, temporary relocation and transport.

6.5.3 Flood Damages Results

This assessment is primarily focused on tangible costs, while intangible costs have not been addressed. This is due to industry accepted methodologies for potential flood damage assessments.

Table 6.5 describes the number of buildings affected by above floor level flooding. Figure 6.5 and Figure 6.6 summarises the estimated tangible building and property flood damages costs[2] respectively.

Table 6.5 Number of buildings affected by above floor level flooding.

Flood Event	Residential	Commercial / Industrial	Total
10 % AEP	36	10	46
5 % AEP	61	15	66
2 % AEP	74	17	91
1 % AEP	92	18	100

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[2] Cost estimates have been interpolated for the PMF storm event.

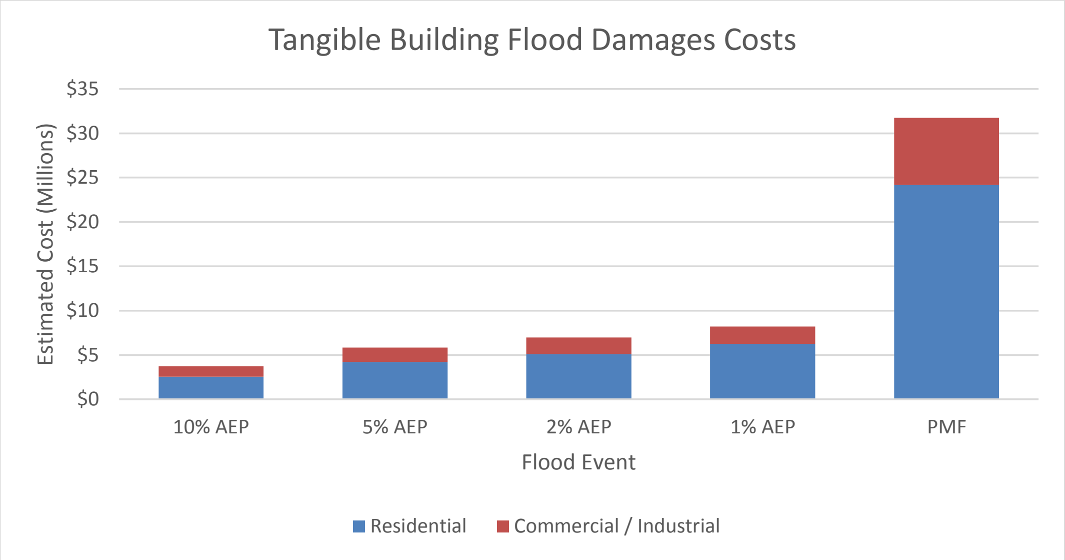

Figure 6.5 Summary of estimated tangible building flood damages costs[2].

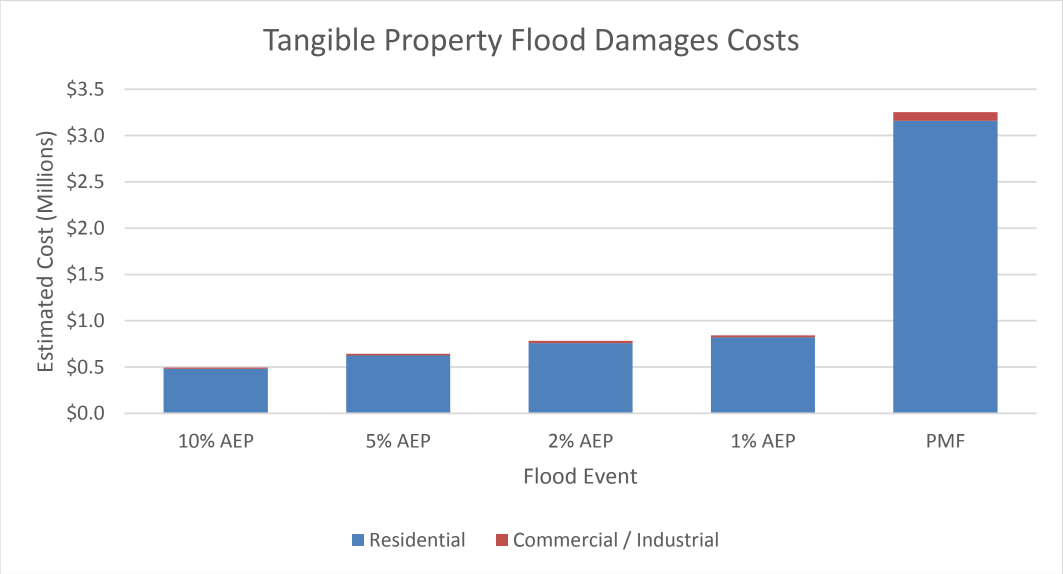

Figure 6.6 Summary of estimated tangible property flood damages costs[2].

Flood damages in roads has been included is this assessment and Table 6.6 summarises the length of road centrelines inundated for the scenarios modelled. Figure 6.7 presents the estimated flood damages costs associated with road inundation[2].

Table 6.6 **Summary of inundated road lengths (km).**

Flood Event	Major Road	Minor Road	Total
10 % AEP	0.09	0.79	0.88
5 % AEP	0.19	1.44	1.63
2 % AEP	0.30	2.26	2.56
1 % AEP	0.37	2.49	2.86

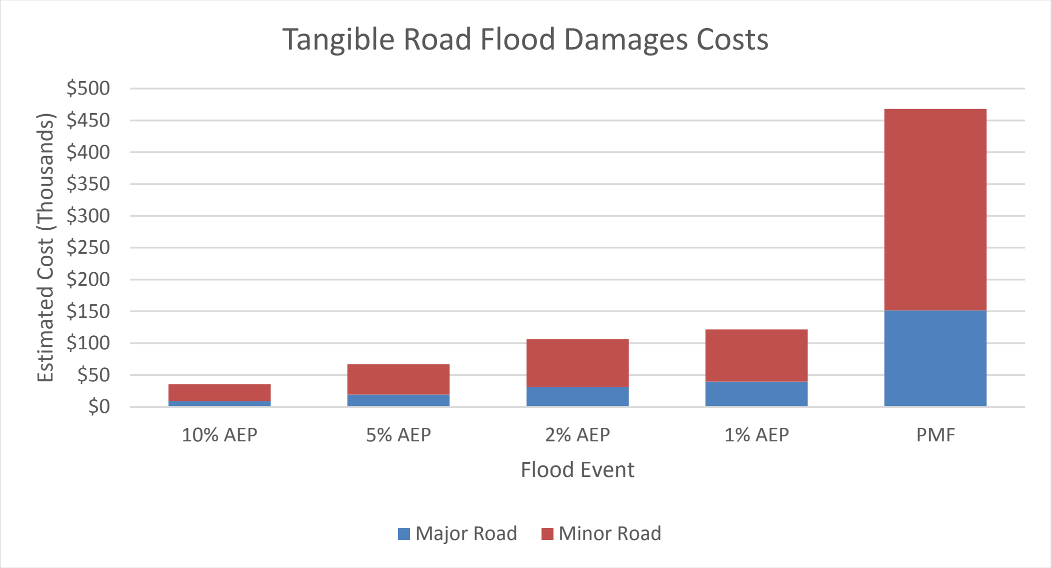

Figure 6.7 **Summary of estimated tangible road flood damages costs[2].**

6.5.4 Average Annual Damages

The damage cost estimates caused by flooding of various magnitudes presented in Section 6.5.3 can be averaged to determine the Average Annual Damage (AAD). Floods of varied sizes result in different amounts of damage and as shown in Figure 6.8, the area under the consequence-probability curve is equal to the total AAD cost estimate. The total AAD estimate inclusive of direct and indirect damage costs is $994,000. Table 6.7 provides a breakdown of AAD direct costs for various types of buildings, properties and roads.

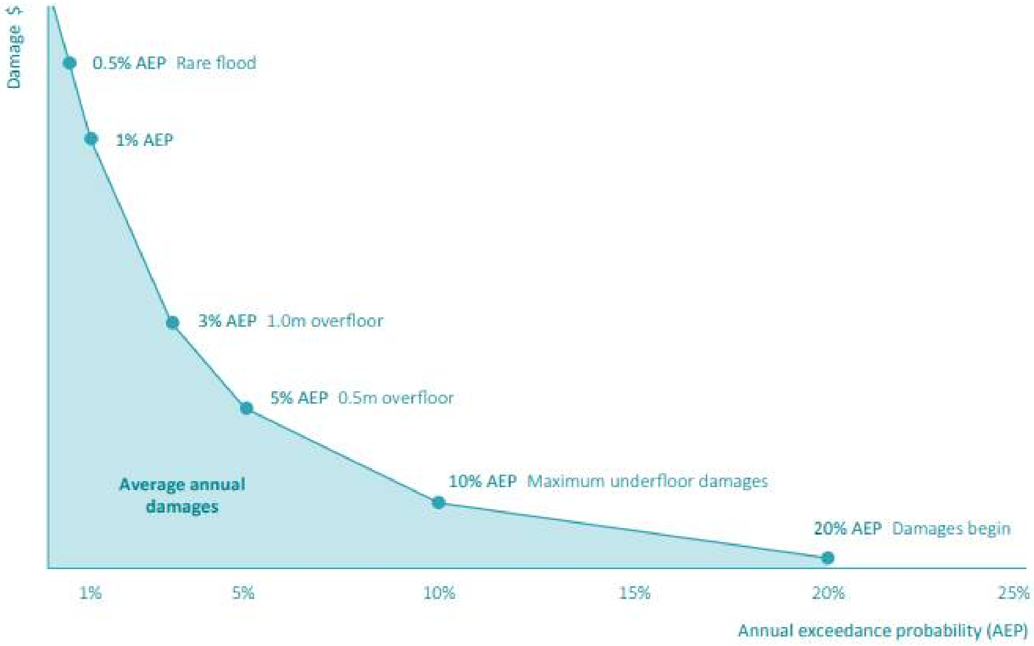

Figure 6.8 Estimated contribution to AAD by floods of varied magnitude.

Table 6.7 Breakdown of estimated AAD direct costs for buildings, properties and roads

Buildings		Properties		Roads	
Res	Com / Ind	Res	Com / Ind	Major	Minor
$498,000	$182,500	$73,500	$2,000	$3,000	$6,000

6.6 Structural Mitigation Measures

6.6.1 Overview

The costed works are predominately pipe upgrades or open channel upgrades due to most of the flooding issues occurring in either existing or proposed developed areas with limited open space. There are areas where retarding basins may be able to be built to help to reduce the size of the pipe upgrades needed downstream. There would also be the option to co-locate WSUD treatment in these retarding basins, such as rain gardens or wetlands. Potential retarding basin locations have been identified but these assets have not been sized or costed. All underground drainage network upgrades have been designed using industry standard pipe on grade calculations and have not been modelled in TUFLOW. It is recommended that if the proposed mitigation works are to be implemented, that further modelling investigations are to be undertaken to refine and inform the detailed design of these structures. Details regarding the recommended mitigation works are presented on the maps in **Appendix W** and the table in **Appendix X.**

6.6.2 Underground Drainage Network Upgrades

Stormwater flooding in Foster occurs in many locations due to a lack of an available overland flow path along roads or through publicly owned reserves. In many cases these are legacy issues from past planning decisions that favoured grid style street alignments with little regard for the natural topography or consideration of areas that would be at risk of flooding. Flood mitigation in these areas can include pipe upgrades to convey major drainage flows (e.g the 1 % AEP event), upstream detention to reduce major drainage flows to the capacity of the existing pipe system and in extreme cases, purchasing properties to provide a major drainage flow path. When implementing underground drainage upgrades, it is important that a whole of catchment approach is considered to ensure that flooding problems are not simply displaced downstream. Key example areas where the recommended structural mitigation measure includes pipe and pit upgrades include McDonald Street, Main Street, Fish Creek-Foster Road, Station Street and Nelson Street. Refer to **Appendix W** for plans of proposed drainage network upgrade works.

6.6.3 Road Crossing Upgrades

There are several roadways within the Stockyard Creek and Bennison Creek catchments identified by the flood modelling results as subject to overtopping by flood water (refer to Section 6.2. for details). Although expensive, an effective way to prevent this from occurring is to remove the existing road culverts and construct a bridge to maximise the cross-sectional flow area at each location. The bridges should be designed to cater for the additional flow that is travelling over the road only. Otherwise, to prevent detrimental flooding impacts downstream of the upgraded structure due to the increase flow capacity at the crossings, it is recommended that SGSC consider also implementing retarding basins / wetlands either immediately upstream or downstream of the crossing to assist in attenuating the increased flows getting through the upgraded structures. This is particularly important for locations upstream of proposed future expansion areas, including the Fish Creek-Foster Road, Foster-Promontory Road, Boundary Road, Coopers Road and Davis Road crossings.

6.6.4 Open Channels / Vegetated Swales

Where space and topographic conditions are suitable, overland flow conveyance solutions generally provide the most cost-effective way to mitigate existing flooding issues. In many urban areas there is not sufficient land available in the required locations to be able to construct swales or open channels, so it is recommended that a proactive approach is adopted for the proposed urban development areas to ensure open spaces are allowed where required to minimise or prevent severe flooding issues in the future. Open channels or swales also provide the great opportunity to vegetate their base surface to make these assets deliver stormwater treatment functionality as well as providing flood mitigation.

6.6.5 Retarding Basins

Large volumes of stormwater can be harvested and detained by constructing open waterbodies or implementing underground storage tanks. Above or below ground storage of stormwater can promote the following benefits:

- Reduce peak flood flows through providing additional flood storage
- Promote groundwater recharge using unlined storages
- Provide the opportunity to co-locate the asset with a rain garden or wetland, depending on the upstream catchment area
- Enable storage of water for reuse on sporting grounds, parklands and assist in industrial processes.

6.6.6 Underground Storages

It may be possible to incorporate water harvesting units (e.g. Atlantis cells) at ‘slow points’ within the road network. Harvested water at each of these units can be used to water landscaped areas adjacent to the low points. Open spaces such as reserves and sporting ovals are ideal locations for underground storages due to ease of implementation/construction, providing there are no significant existing underground service present.

6.6.7 Gross Pollutant Traps

Gross pollutant traps are generally used as a primary treatment of stormwater designed to capture and hold solid waste such as litter and large sediment. Treatment includes physical screening of large non-biodegradable pollutants, fast sedimentation and separation processes. Added benefits of implementing gross pollutant traps are that they exhibit a small footprint and are easily concealed from public view. Gross pollutant traps may assist with flood mitigation by helping to prevent blockage of pipes or culverts and could be considered in areas where this is occurring frequently.

6.6.8 Road Surface Re-grading

An effective flood mitigation measure involves altering the surfaces of roadways to manipulate the existing overland flow paths to direct stormwater towards assets such as drainage pits, swales, wetlands or open waterways. This is to prevent severe flooding/ponding occurring in public spaces, residential/commercial properties or even roadways that may be hazardous to structural assets or pedestrians.

6.7 Non-Structural Mitigation Measures

6.7.1 Planning Controls

From the outputs of the flood modelling undertaken as part of this study it is recommended that SGSC consider the development and implementation of a Special Building Overlay (SBO) for areas directly prone to stormwater flooding and a Land Subject to Inundation Overlay (LSIO) for areas prone to waterway flooding for the study area.

While not reducing the overland flow, the inclusion of planning controls would allow Council to influence building design in areas that are known to be subject to flooding. This can include setting new floor levels above flood levels and limiting the development footprint to allow enough space for overland flow to pass through the site. While this does not resolve issues with existing dwellings, over the long term it is a very effective mitigation measure to reduce future flood risk across the municipality. This planning overlay can also help SGSC to ensure that new developments do not make flooding any worse for existing properties by requiring new developments within the SBO / LSIO to demonstrate that they are not negatively impacting any of their neighbours.

If the proposed mitigation works do proceed the SBO / LSIO could possibly be removed within the affected areas upon completion of the works. Further refinement through detailed design and flood modelling of these works would need to be conducted to verify this.

6.7.2 Flood Warning

South Gippsland has endured a number of significant flood events including in 1934, 1990, 2011 and 2012 (VicSES, 2018). Records show that severe damage to infrastructure and properties as well as loss of life has been incurred from these storm events. The steep ranges in the northern areas and quite flat terrain in the southern areas of the catchment make South Gippsland susceptible to severe flash flooding from short duration, high intensity rainfall. This unfortunately results in a short response time for SGSC and residence to prepare for the worst of a flood event. Therefore, all households and businesses should be equipped with prepared emergency plans and to be aware of their potential flood risk. A Flood Warning Service is an ideal way to give those in a flood prone area the maximum time possible to prepare themselves to prevent severe damage and / or loss.

Currently, the Bureau of Meteorology (BoM) does not provide a Flood Warning Service for any waterways or towns within South Gippsland Shire. The components of a Flood Warning system include monitoring and prediction, interpretation, message construction, communication, protective behaviour and review. In order for a warning system to be effective, each component must be well-developed and implemented. It is highly recommended that SGSC consider getting in contact with BoM to establish a Flood Warning Service, adopting either their Flood Watch or Flash Flood Advisory Resource (FLARE) Flood Warning services (BoM, 2018). These services are free of charge and would involve SGSC being alerted by BoM of when a significant storm event is expected to fall within the Shire, and to allow for all residents in the area to be notified and be instructed to take appropriate action to prevent / minimise damage or even loss of life.

6.7.3 Emergency Planning

SGSC is recommended to use the flood modelling results of this flood study to inform Victoria State Emergency Services (VicSES) and other emergency authorities such as Country Fire Authority (CFA), Emergency Management Victoria (EMV) and Department of Environment, Land, Water and Planning (DELWP) with properties and roadways at risk of flooding. This can allow VicSES to update / development emergency action plans to identify priority locations within the town of Foster specifically that are likely to experience damage due to intense storm events. In 2015, the Victorian Government developed the Fundamentals of Emergency Management document that outlines the emergency management activities undertaken by the authorities mentioned above. Later in 2016, a supplement document - Fundamentals of Extreme Weather and Floods, was created to outline the common emergency procedures that should be undertaken by all emergency response agencies. It is recommended that SGSC become familiar with these emergency procedures to ensure they are sufficiently prepared should an extreme storm event occur.

6.8 Cost Estimates of Recommended Works

Engeny has calculated the costs for the proposed mitigation works. Melbourne Water's costing spreadsheet for Development Services Schemes (drainage schemes) was utilised for this exercise.

All pricings are presented as estimated basic construction costs. The estimates include various adjustment factors for construction through different land uses. The factors used are shown in Table 6.8.

Table 6.8 Cost factors

Condition	Greenfield factor	Additional costs (i.e. traffic management)
Greenfields	1	$0
Developed Private Properties	1.8	$0
Major Council Roads	1.3	$10,430
Minor Council Roads	1.3	$4,560
Pipe Connection to Waterways	1	$11,260
Pipe Jacking	4.7	$0
Railway Line	4.4	$246,140

Condition	Greenfield factor	Additional costs (i.e. traffic management)
Reserve	1.2	$0
VicRoads Roads-Pipe	4.7	$0
VicRoads Roads-Box Culvert	4.7	$52,150

The following aspects of design and construction (and their associated cost rates relative to the total estimated basic cost of works) have been included in the total cost estimates as follows;

- Site establishment, preparation and reinstatement costs (6 %)
- Site environmental and traffic management plans (2.5 %)
- Engineering design fees (15 %)
- Administration fees (9 %)
- Contingencies (30 %).

SGSC should also consider additional costs associated with each of the works including potential service relocating and further detailed design investigations. A detailed breakdown of the estimated costings is presented in **Appendix X.** Table 6.9 presents a summary of the estimated costs for each of the proposed mitigation works.

Table 6.9 Summary of proposed mitigation works costs

ID	Location	Detail of Works	Total Cost
1	McDonald Street	Construct retarding basin to store and attenuate the overland flow path from the north-east, increase pit inlet capacities and add underground drainage	$298,000
2	Gibbs Street at tributary of Stockyard Creek	Construct levee to protect property from waterway flows and remove Gibbs Street culvert to construct a bridge as close to the peak 1 % AEP flood level while allowing appropriate egress to properties nearby	Subject to further investigations[3]
3	Main Street	Intercept overland low in road by increasing pit inlet capacities and adding underground drainage	$40,500

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[3] Estimated bridge and road surface re-grading costs to be confirmed at detailed design stage

ID	Location	Detail of Works	Total Cost
4	On Fish Creek-Foster Road and Power Street	Intercept overland low in road by increasing pit inlet capacities and adding underground drainage	$216,500
5	Church Hill Road down Nelson Street and Court Street to Station Street	Construct a retarding basin to store and attenuate overland low in road, increase pit inlet capacities and add underground drainage	$710,500
6	Sparkes Court and Nelson Street	Increase pit inlet capacities and add underground drainage and increase kerb heights	$115,000
7	McDonald Street at Stockyard Creek	Remove culvert crossing and construct a bridge	Subject to further investigations
8	Wood Road, McMaster Court and Varney Road	Intercept overland low in road by increasing pit inlet capacities and adding underground drainage	$335,000
9	Blackwood Drive	Increase pit inlet capacities and add underground drainage and increase kerb heights	$219,500
10	Pioneer Street	Increase pit inlet capacities and add underground drainage	$36,000
11	Boundary Road, Station Road, Boyd Court and Apex Court	Remove existing Boundary Road pipe culverts and construct box culverts. It is noted that constructing a bridge set at the 1 % AEP flood level will prevent overtopping of the roadway and reduce the blockage risk however, a box culvert is an improvement on the current pipe drainage and is a more cost-effective solution. To improve the blockage resistance of the proposed box culverts, Council should consider constructing debris capturing structures upstream of the roadway (an example is presented in Figure 6.9). Also, increasing pit inlet capacities, adding underground drainage and increasing kerb heights along Boyd Court and Apex Court will allow for more flood storage in the drainage network and roadways and reduce flooding.	$426,500[4]
12	Main Street	Increase pit inlet capacities and re-grade shop rear carpark surface	Subject to further

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[4] Estimate does not include construction costs for Boundary Road crossing of Stockyard Creek

ID	Location	Detail of Works	Total Cost
			investigations[4]
13	Ameys Track at Bennison Creek	Remove culvert crossings and construct bridge set at 1 % AEP flood level to prevent overtopping of roadway	Subject to further investigations[4]

Figure 6.9 **Steel bollards installed at Rosanna Parklands to prevent debris from entering drainage network**

7. CONCLUSIONS

The flood modelling has identified existing overland flow paths within the Stockyard Creek and Bennison Creek model extents and provides detailed information on the risk to public safety during storm events in properties and on roads which may be acting to convey overland flow. The flood modelling results suggest that 65 and 130 building footprints are affected by overland flow paths for the 10 % and 1 % AEP storm events respectively. Key waterway crossings are also predicted to experience overtopping from excessive flows from Stockyard Creek and Bennison Creek, causing hazardous flooding conditions for people and people in small vehicles. 1 additional building footprint is expected to be impacted by flooding for the 2050 development scenario in the 1 % AEP storm event, while an additional 3 buildings are affected under 2070 development conditions relative to base case (2030) conditions.

Peak flows in Stockyard Creek and Bennison Creek were estimated to increase by up to 36 % (relative to the base case scenario) for the 1 % AEP event following a high severity bushfire event in the upstream catchment. The increase in flood levels results in 12 additional building footprints being impacted by floodwater and additional overtopping depth (and hazard) to roads relative to the base case (2030) conditions model results.

The 1 % AEP storm event was modelled to inform the climate change sensitivity for both the Stockyard Creek and Bennison Creek catchments. The estimated percentage increase in rainfall for the year 2100 is 19.5 % (relative to the 2100 full development scenario) as per AR&R 2016 methodologies. The increase in flood levels results in 17 additional building footprints being impacted by floodwater and additional overtopping depth (and hazard) to roads relative to the base case (2030) conditions model results.

A tangible flood damages investigation of the base case (2030) scenario resulted in a total AAD estimate inclusive of direct and indirect damage costs of $994,000. This is considered to be an over-estimate and SGSC should consider undertaking a floor level survey for the flood affected properties to improve the precision of the AAD estimate.

Based on the modelling results, Engeny has developed numerous structural mitigation options for improved stormwater management in order to address the areas impacted by the severe flooding. In total, 13 mitigation projects have been identified / sized at a concept level. The sizing has been based on mitigating flooding associated with the 10 % AEP event, unless hazardous flow paths are impeding through private properties and therefore a 1 % AEP drainage level of service has been designed for. By undertaking these mitigation projects, SGSC would be resolving most of the minor storm flooding issues within the town and will **protect 90 buildings** from above floor level flooding in the 1 % AEP storm event for the base case (2030) conditions.

Concept layouts of the recommended works have been prepared and costed using Melbourne Water’s costing spreadsheet for Development Services Schemes (drainage schemes). The total cost of all proposed works (excluding those costs to be confirmed) is estimated to be in the order of $2,397,500. The proposed mitigation options discussed in this report have been sized at a concept level only. Further design, modelling and investigations are recommended to improve the accuracy of the cost estimates and demonstrate that the proposed works can achieve the desired benefit without creating negative impacts downstream. WSUD design features may be able to be incorporated into some of the mitigation works. Many of the areas that have been identified as having flooding issues are in existing suburbs. In these areas public open space is typically limited, and so underground pipe works can be the only option to reduce flooding. Where overland flow path options are available it would be easier to include some WSUD elements, such as vegetated swales.

A non-structural mitigation measure in the form of a Special Building Overlay (SBO) and Land Subject to Inundation (LSIO) is another mitigation option that SGSC should consider. If implemented, an SBO / LSIO would give council the power to enforce minimum floor levels and design controls on new dwellings built in areas identified of being at risk of flooding. While there are significant costs associated with implementing and enforcing planning scheme controls, they generally provide a much more cost-effective way for a council to reduce the number of dwellings subject to above floor level flooding.

8. RECOMMENDATIONS

Following the completion of this study it is recommended that SGSC consider the following next steps and future projects:

1. Contact VicSES (and other emergency authorities) to inform them of the flood modelling results presented in this report to ensure their emergency action plans and procedures are updated to include key flooding hotspots.
2. Contact BoM to establish a Flood Warning Service to prevent / minimise potential flood hazards to properties, assets and people. Utilising BoM's Flood Watch and FLARE systems to notify and prepare residents in flood prone areas in case flooding should eventuate.
3. Undertake a floor level survey of properties identified as being at risk of inundation to determine whether they are expected to be flooded above floor level, so appropriate mitigation steps can be carried out and to better inform the AAD assessment.
4. Consider undertaking a planning amendment to define Special Building Overlays (SBO) and Land Subject to Inundation (LSIO) in Foster and the Stockyard Creek respectively. This will allow SGSC to control future redevelopments and subdivisions and over time will help to improve the level of service experience by properties by lifting new floor levels above the predicted flood levels.
5. Consider implementing a catchment wide stormwater management strategy to ensure future drainage infrastructure is constructed adequately to prevent / minimise future flooding issues caused by development. It would be beneficial to align this strategy with a Development Control Plan (DCP) to assist in guiding developments that occur within areas susceptible to flooding and overland flows.
6. Utilise the proposed mitigation works to inform future capital works program. Opportunities to create multifunctional assets should be considered as part of the flood mitigation works. For example, WSUD elements could be included as part of some upgrades by utilising vegetated swales or co-locating wetlands or raingardens within retarding basins. Where swales or retarding basins are proposed, these assets could be enhanced as community assets through the integration of WSUD features.
7. Treat the flood model and flood modelling results like an asset. In order to keep the flood model up to date it will need to be revised in the future. Currently, Melbourne Water assumed a 10 year "life" for its flood models and updates them as necessary once they have reached this age. Some Councils in Victoria have also adopted more frequent updates, typically associated with improved pipe/structural asset data information.
8. Consider undertaking flood modelling investigations for other townships to obtain a complete understanding of potential flood risks across the Shire. This will enable SGSC to then produce a comprehensive Emergency Plan for the entire shire and minimise / prevent extreme damage or loss of life from impacting the community.

9. QUALIFICATIONS

a. In preparing this document, including all relevant calculation and modelling, Engeny Water Management (Engeny) has exercised the degree of skill, care and diligence normally exercised by members of the engineering profession and has acted in accordance with accepted practices of engineering principles.

b. Engeny has used reasonable endeavours to inform itself of the parameters and requirements of the project and has taken reasonable steps to ensure that the works and document is as accurate and comprehensive as possible given the information upon which it has been based including information that may have been provided or obtained by any third party or external sources which has not been independently verified.

c. Engeny reserves the right to review and amend any aspect of the works performed including any opinions and recommendations from the works included or referred to in the works if:

    (i) Additional sources of information not presently available (for whatever reason) are provided or become known to Engeny; or

    (ii) Engeny considers it prudent to revise any aspect of the works in light of any information which becomes known to it after the date of submission.

d. Engeny does not give any warranty nor accept any liability in relation to the completeness or accuracy of the works, which may be inherently reliant upon the completeness and accuracy of the input data and the agreed scope of works. All limitations of liability shall apply for the benefit of the employees, agents and representatives of Engeny to the same extent that they apply for the benefit of Engeny.

e. This document is for the use of the party to whom it is addressed and for no other persons. No responsibility is accepted to any third party for the whole or part of the contents of this report.

f. If any claim or demand is made by any person against Engeny on the basis of detriment sustained or alleged to have been sustained as a result of reliance upon the report or information therein, Engeny will rely upon this provision as a defence to any such claim or demand.

g. This report does not provide legal advice.

10. REFERENCES

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