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West Coast Council Stormwater System Management Plan

Flood Study

Prepared for

West Coast Council

Client representative

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Appendix C — Preliminary Cost Estimates

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Executive Summary

Flood Behaviour and Flood Risk

The five urban stormwater catchments in the urban areas of the West Coast Council LGA comprise primarily creeks, streams and rivers. This is generally common across the five study areas assessed. Most flooding issues identified emanate from a defined flow path or creek system affecting private property.

The flood model developed to assess flood behaviour includes topographic detail (ground levels) and a pit and pipe drainage system. Many assumptions were made on pit invert level and pipe sizes. As such, care must be taken when basing decisions on flood model outputs, particularly if they relate to stormwater pit and pipe upgrades.

The Strahan Study area is the only study area with a coastal boundary where sea levels influence flood behaviour in low lying areas. The other four study locations are affected by creek and overland flow flooding.

The key locations identified as flood affected are:

- Downstream areas of Manuka Creek (STR)
- Overland flow paths around Hunter Street, Orr Street and Cutten Street (QUE)
- Behind bridge crossings over the Queen River and Roaring Meg Creek (QUE)
- Properties adjacent to the Zeehan Rivulet (ZEE)
- Properties adjacent to Nike Creek (ZEE)
- Overland flow path between Clemmons and Primrose Street (ROS)

No major flooding issues were identified in the Tullah study area.

Impact of Flooding

In general, flooding is localised and affects isolated properties. it is estimated that 448 properties are impacted by over-floor flooding in the 1% AEP. The economic impact of flooding, as a result of over-floor flooding and garden damage of residential properties, is estimated to be $2.3M (Annual Expected Damage (AED). About 85% of the flood damage in the LGA occurs in Strahan and Queenstown. Table 1 below shows the estimated total damage for events ranging between the 10% AEP to the 1% AEP.

Table 1 Estimated Flood Damage

Design Event	Buildings with Over-floor flooding	Total Damage ($)
1% AEP	448	$18,466,000
5% AEP	298	$10,546,000
10% AEP	228	$7,977,000

Flood Risk Management Options

Structural flood management measures were deemed to be the most appropriate flood risk management approach. This is because the rate of development in the West Coast LGA is low and applying flood related controls on development will be less effective in reducing future flood risk.

Emergency response measures were not considered given the flash flooding nature of most study areas. Hazardous flood water can develop in less 2 hours meaning there is little time to respond.

Structural flood modification measures are aimed at preventing / avoiding or reducing the likelihood of flood risks. These measures reduce the risk through modification of the flood behaviour in the catchment. The options considered in this assessment were confined to overland flow modifications by way of berms, kerb, pit and pipe upgrades and improvements to bridge hydraulics.

The following structural flood management measures are recommended for further analysis and investigation:

Option ID	Option
STR01	Henry Culvert Upgrade
STR02	Gaffney Street West Culvert Upgrade
STR03	Innes Street West Culvert upgrade
STR04	Manuka Creek Flood Protection
STR05	Featherstone Street Culvert Upgrade
STR06	Esplande (Trafford to Vivian) culvert and levees
ROS01	Stormwater Upgrades Between Clemons and Karlson Street
QUE01	Hunter Street Pipe Upgrade
QUE03	Bridge Hydraulic Improvement
ZEE04	Wilson Street Stormwater Main and Geometric Design

All flood management measures assessed for the Strahan study area produced reasonable flood level reductions, although STR04 – Manuka Creek Flood Protection stands out as the option that has the potential for the greatest reduction in flood damage and reducing incidents of property flooding.

Option QUE03 – Bridge Hydraulic Improvements demonstrated a substantial flood level reduction when augmenting an existing bridge to consider flood hydraulics. It is not recommended to only upgrade bridges based on flooding, although when a bridge renewal is planned, it is recommended a hydraulic study be undertaken to confirm the likely benefits or adverse effects a bridge renewal may have.

1. Introduction

1.1 Objectives

West Coast Council is required to prepare a Stormwater System Management Plan (SSMP) for its urban areas to meet the requirements as set out in the *Urban Drainage Act 2013*.

The SSMP will ultimately document the approach to stormwater management within the urban areas of the West Coast Local Government Area (LGA). It will:

- Map locations affected by flooding, including their relative hazard.
- Identification of potential flood management solutions, both structural and non-structural.
- Form the basis to develop and prioritise drainage and flood related capital works.

Five (5) key areas have been identified. These are:

- 1 – Queenstown
- 2 – Strahan
- 3 – Zeehan
- 4 – Rosebery
- 5 – Tullah

This 'Flood Study' is the first step in achieving the above-mentioned objectives. It is the technical flood analysis that identifies where flooding occurs and its severity. The flood risk can be mapped and quantified to provide a basis for a planned and proactive approach to urban stormwater management. It forms the basis for Council to fully develop an SSMP that is integrated into its own system and processes.

The key objectives of this flood study are to:

- Identify the location of overland flow paths and associated impacts within each of the study areas
- Quantify the risk and damage associated with flooding
- Provide recommendations for flood management options, particularly structural measures that can be included in West Coast Council's forward capital program.

Minor drainage issues such as private plumbing and property related drainage issues are not considered to be within the scope for this study. The study focuses on major flooding issues that pose a risk to life or substantial flood damage to critical infrastructure and property.

1.2 Approach

The Flood Study encompasses five distinct communities. These communities are distributed throughout the West Coast LGA. Their relative location is presented in Figure 1.

As the flood behaviour between communities is independent, separate flood models have been developed for each community.

The hydrological methodology uses traditional hydrologic modelling and direct rainfall, depending on the availability of the terrain data.

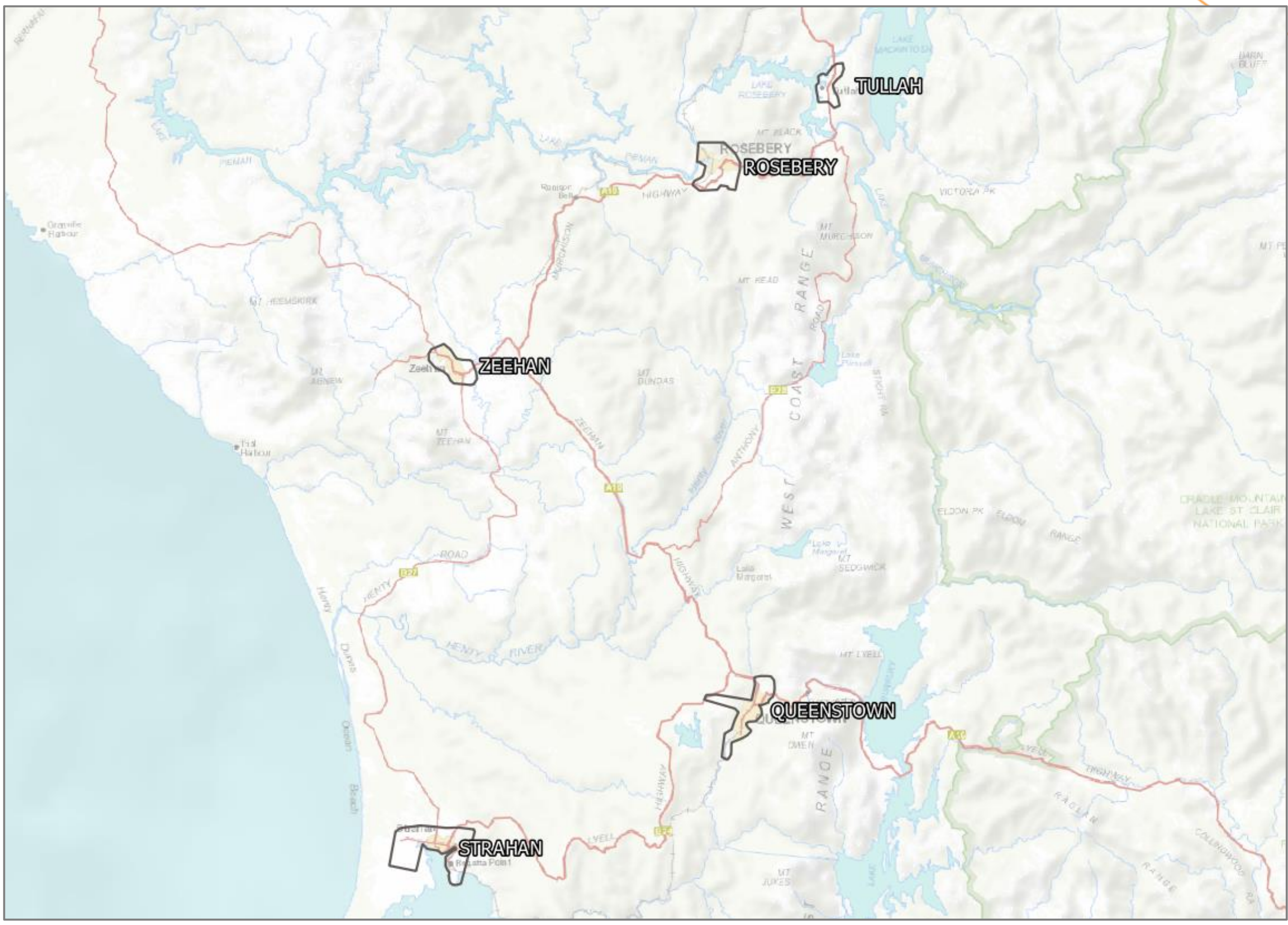

Figure 1: Study Area Locations

1.2.1 Traditional Hydrologic Modelling

A hydrologic model simulates the transformation of rainfall into runoff. Hydrologic models can be simple such as the rational method or more complex such as semi-distributed methods. Hydrologic models are normally developed in software such as XP RAFTS, RORB, WBNM or DRAINS. They all require the definition of several input parameters including but not limited to:

- Catchment Area;
- Catchment Slope;
- Stream Length;
- Rainfall Depth;
- Losses;
- Portion Impervious;
- Time of Concentration;
- Lag Coefficients;
- Storage Coefficients;

Where catchments are well defined, this approach is appropriate as the above parameters can be measured / estimated providing reasonable confidence in the resulting output.

The simulation time of traditional hydrologic models is generally fast which means many simulations can be run in a short period of time. This is advantageous for catchments with a longer time of concentration (e.g. 12 hours)

1.2.2 Rain on Grid

Rain on grid (also known as direct rainfall) applies rainfall directly to the 2D domain. Parameters such as catchment slope and catchment area are not required to be defined by modeller but are rather defined by the definition of a grid cell size and a Digital Elevation Model (DEM), normally derived from LiDAR.

Similar to traditional runoff routing models, runoff from a grid cell depends on the following factors:

- the area of the grid cell;
- the rainfall depth;
- the losses; and
- the storage volume in the cell.

This approach is particularly advantageous in flat areas where catchment boundaries are difficult to define or any areas where cross catchment flow is possible.

The adopted approach was to model the 'study area' with the direct rainfall approach. Any large upstream catchments contributing to the study area were modelled using a semi-distributed hydrologic model.

The study area itself was modelled using the direct rainfall approach. Figure 2 shows an example of the modelling approached adopted for the Queenstown Study Area.

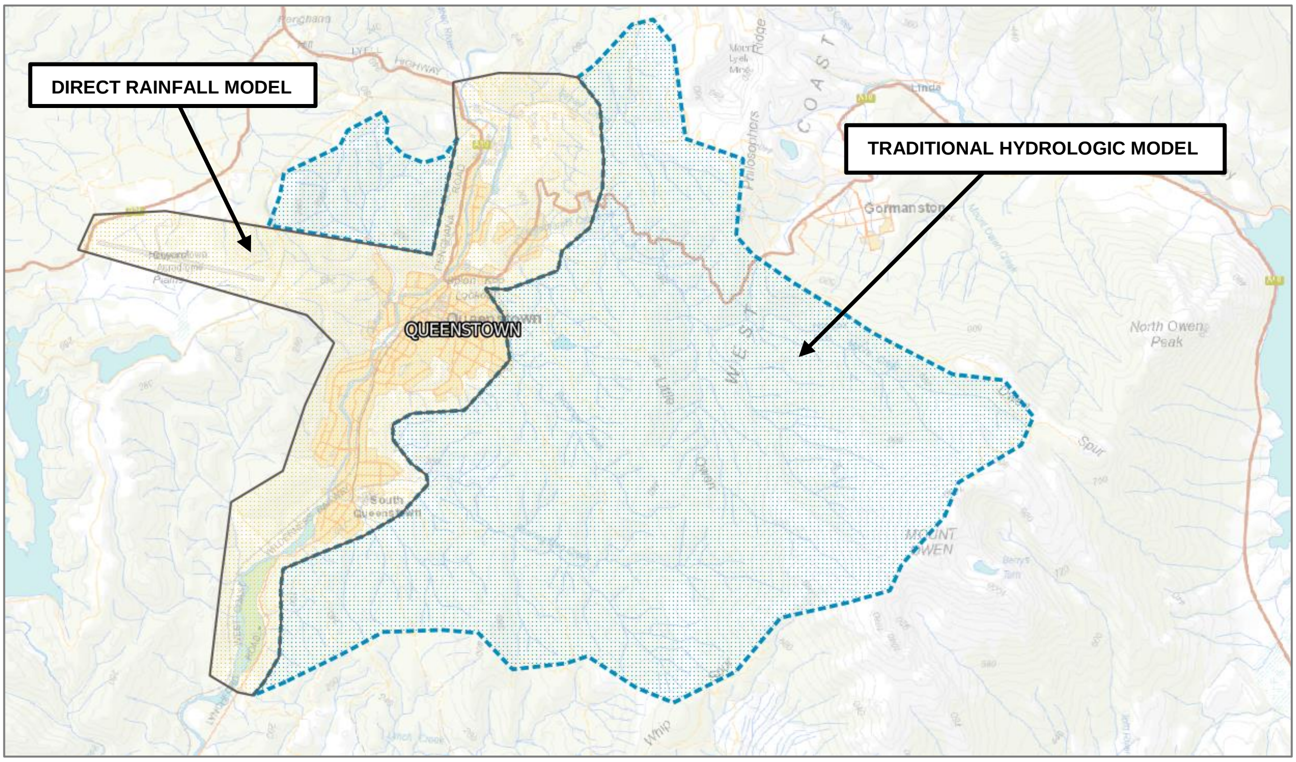

Figure 2: Adopted Modelling Approach

1.2.3 Flood Model Limitations

The flood modelling undertaken for this assessment has been based on various datasets of differing levels of accuracy. Therefore, any decisions based on this report should consider the flood model uncertainty.

2. Data Collection and Review

2.1 Overview

2.2 Previous Assessments

2.2.1 Strahan Flood Mitigation Report (2007)

W.E. Enkelaar Pty Ltd prepared a flood mitigation assessment for Strahan. The assessment was funded under a grant arrangement from the National Disaster Mitigation Program.

The intent of the assessment was to map the 20% AEP (1 in 5 year ARI) and 1% AEP (1 in 100 year ARI) flood events, and to identify possible flood mitigation projects. The following conclusions have been drawn from the report.

- Water levels are recorded by the Hydro Electric Commission (HEC, now known as Hydro Tasmania) in Macquarie Harbour, although no other data within creeks and streams upstream was available at the time.
- The June 2004 storm event is noted as a reference storm for the assessment. Other significant flood events have occurred in 1958 and 1987.
- The assessment presents peak flow rates for various Annual Exceedance Probabilities (AEP) at three locations in the Strahan Area. The methodology to arrive at those flow rates is not provided. The report states it is based on data provided by the HEC.
- The assessment provided several recommendations relating increase the capacity of existing creeks and channel, implementing various observation and monitoring systems and implementing flood related development controls.

2.3 Hydrologic Data

2.3.1 Rain Gauges

Multiple rainfall gauges are present in the West Coast Area. The completeness of rainfall records at each gauge site varies significantly. The rainfall gauge data was used to validate the hydrodynamic flood model against the June 2004 Strahan observed flood extents. Data was obtained from a combination of the Australian Bureau of Meteorology (BOM) and Hydro Tasmania rainfall data.

2.3.2 Stream Flow Gauges

No stream flow gauge data was available for the major watercourses passing through each of the towns. The Australian Rainfall and Runoff Datahub enables a Regional Flood Frequency Estimation to be made for the major streams based on comparison of other stream gauged catchments on the West Coast. The resulting peak flow estimations were used for comparison to the adopted hydrologic model. The RORB program was used for the large catchments with the West Coast Tasmania parameters recommended by ARR19 for ungauged catchments.

2.4 Topographic Information

One-meter gridded lidar was available from Geoscience Australia's elevation data platform 'ELVIS' for much of the Strahan urban area, the entirety of Rosebery. Part way through this study, additional one-meter LiDAR data became available for the remaining study areas. This level of detail is considered appropriate for the purposes on combined 1D-2D hydrodynamic modelling. Outside of the LiDAR surveyed areas, catchments were delineated using the coarse 30m SRTM data available from the Geoscience Australia elevation platform.

2.5 Stormwater Drainage System

GIS information was provided by Council for the underground drainage network, which comprised the locations of pits and pipes and the sizes of some of the pipes. The GIS information did not include most pipe invert levels and pit invert levels, and the data had to be completed with assumed levels. Assumed pipe sizes had to be applied to many pipes.

As much of the modelled stormwater system is based on these assumptions, care must be taken when basing decisions on flood model outputs, particularly if they relate to stormwater pit and pipe upgrades.

2.5.1 Strahan

The pipe and pit layer provided by West Coast Council (WCC) only provided an indictive location of each asset. Less than 10% of the pipes had a specified size and no invert levels were provided. The following additional information was sourced by pitt&sherry:

- Department of State Growth (DSG) bridge drawings (Henty Road and Harvey Street Bridges)
- Harvey Road culverts from pitt&sherry design drawings
- The dimensions of structures of interest, which were estimated from Google street view (2008) and current areal imagery
- The sizes of several culverts from specific requests to WCC, following initial model setup

The following assumptions were made in constructing the hydraulic model:

- Pipe and pit levels were based on surrounding LiDAR elevation
- Pipe sizes in non-critical areas were estimated from catchment characteristics
- Several small culverts were included in the model where it was deemed important to allow movement of water, for example, in low lying areas where dams would be created if an outlet was not provided.

2.5.2 Rosebery

The pipe and pit layer provided by WCC contained most of the pipe network sizes. Pipes of 225mm diameter and smaller were excluded from the model. The following additional information was sourced by pitt&sherry:

- DSG bridge drawings for the Murchison Highway Crossing
- The dimensions of structures of interest, which were estimated from Google street view (2008) and current areal imagery
- The sizes of several structures from specific requests to WCC, following initial model setup

The following assumptions were made in the hydrodynamic model:

- Pipe and pit levels were based on surrounding LiDAR elevation
- Pipe sizes in non-critical areas were estimated from catchment characteristics.

2.5.3 Zeehan

The pipe and pit layer provided by WCC contained good spatial data for pits and pipes, but no pipe size or level information. To provide a reasonable representation of the underground drainage network, WCC inspected and measured the outlets of several major discharges. An assumption has been made on the size of the stormwater networks based on this information. The following additional information was sourced by pitt&sherry:

- DSG bridge drawings for the Little Henty Bridge

- The dimensions of structures of interest, which were estimated from Google street view (2008) and current areal imagery
- The sizes of several structures from specific requests to WCC, following initial model setup

The following assumptions were made in the hydrodynamic model:

- Pipe and pit levels were based on surrounding lidar elevation
- Pipe sizes in non-critical areas were estimated from catchment characteristics.

2.5.4 Queenstown

The pipe and pit layer provided by WCC for Queenstown contained the most detail of all study areas. However, this was still limited in general to pipe size and location. The following additional information was sourced by pitt&sherry:

- The dimensions of structures of interest, which were estimated from Google street view (2008) and current areal imagery
- The sizes of several structures from specific requests to WCC, following initial model setup

The following assumptions were made in the hydrodynamic model:

- Pipe and pit levels were based on surrounding lidar elevation
- Pipe sizes in non-critical areas were estimated from catchment characteristics.

3. Site Inspection

On the 23rd and 24th July 2019, site inspections were undertaken at the five Study areas. The weather was foggy and overcast with rain at times. For the preceding 20 days, daily rainfall totals varied from 5mm to 50mm. The ground was saturated in most areas with most creeks and streams flowing.

Observations relevant to all study areas included the following:

- Most residential properties have floor levels at ground level or up to 150mm above ground level
- Pervious surfaces appeared to be saturated with the groundwater level at ground level.

The following provides a brief description of each study area and any relevant observation or comments that relate to flood modelling.

3.1 Queenstown

Queenstown comprises primarily residential uses. Several distributed streams pass through the town through a combination of open drains and piped infrastructure. The commercial part of the town, located close to the Queen River, has a formal kerb and channel / pit and pipe drainage system. Further away from commercial area, the drainage system becomes less formal with a greater proportion of open drains.

All drains and pipes within the Queenstown study area are directed to the Queen River.

'Half-pipe' open drains are common, which are formed by concrete pipes cut in half as shown in Figure 3. These are common throughout the municipality.

Figure 3: 'half-pipe' open drains – Mellor Street, Queenstown

3.2 Strahan

Strahan is situated on Macquarie Harbour. A large part of the developed area (West Strahan) is situated on low lying, flat land. Drainage is poor because of the low elevation and the lack of positive grade. Tidal variation also affects the ability of the site to drain.

Strahan is primarily a tourist town with seasonal fluctuations in population. Not all persons present at any time will be familiar with flood behaviour in the area.

There are several distinct streams that pass through Strahan to Macquarie Harbour. The lower portions of these streams were tidally influenced. Bridge and culvert structures over these streams were observed to contain little head water and are likely to be prone to debris blockage because of the heavily vegetated areas upstream.

Figure 4: Example Culvert - Hogarth Falls / Esplanade

3.3 Zeehan

Zeehan has several creeks and streams that flow either through or adjacent to the study area. The developed area contains a combination of open drainage and pit and pipe infrastructure.

The most prominent drainage path through the developed area is Nike Creek, which passes through the north-west portion of the settlement, crossing several roads. Immediately downstream of main street, the creek passes under a shed structure.

Nike Creek eventually discharges to the Zeehan Rivulet (also known as Pea-Soup Creek). The rivulet skirts the north-eastern edge of Zeehan, flowing close to property and roads. Figure 5 shows the rivulet and its location next to a building.

The areas comprising residential development were generally flat. Several pipe outfalls to creeks were partially submerged, suggesting poor drainage in low lying areas.

Figure 5: Zeehan Rivulet at Wilson Street

3.4 Rosebery

Rosebery comprises residential use land adjacent to the Rosebery Mine site. The Stitt river flows through the town before meeting the Pieman River directly west of Rosebery. The land is generally steep with all flows from the urban areas discharging to the Stitt River. The bridge over the Stitt River is shown in Figure 6.

Drainage from parts of the Rosebery Mine is directed to a holding basin before being sent to a dam north of the township. This basin and network are not incorporated into the model. Rosebery and Barker Creeks are the two largest tributaries flowing through the town.

Figure 6 Example Bridge - Park Road Bridge (Stitt River)

3.5 Tullah

Tullah is situated on the Murchison Highway and bound by Lake Rosebery to the west. The residential area is a grid system with a kerb and channel and pit and pipe drainage system. The residential area was flat, although there is a considerable elevation difference between the ground level in Tullah and the water surface level in Lake Rosebery, suggesting that a pipe drainage system could be viable.

Further north, directly adjacent to the Murchison Highway, there are several general business developments in an area with considerable topographical relief. A defined stream was observed that collects flow, directing stormwater to Lake Rosebery.

The highway adjacent to the main urban area is relatively flat. During larger rain events, water is expected to pond significantly on the roadside.

Figure 7 Tullah - Looking Towards Lake Rosebery

4. Flood Model

4.1 General

The hydrologic and hydraulic modelling was undertaken in accordance with the guidance and principles of Australian Rainfall and Runoff 2019 (ARR19).

The guidance presented in Australian Rainfall and Runoff 2019 suggests that an ensemble of rainfall temporal patterns be used for design event modelling and the temporal pattern that produces the median flow rate/water level be adopted for further detailed analysis.

This approach recognises the effect the temporal variation of rainfall can have on peak flow rates and flood levels, particularly for longer duration events. This is an important consideration for some of the larger catchments in Strahan, Queenstown and Rosebery.

Spatial variation of rainfall has been incorporated, considering both the geographic variation of the townships and variation within the major catchments themselves. Rainfall can fluctuate considerably with both elevation and proximity to geographic features such as coastal boundaries. Catchments such as the Stitt River at Rosebery vary from approximately 150m AHD at Rosebery to over 1100m AHD at Mount Read. As such, rainfall inputs were varied based upon their location and if there was a substantial change in rainfall intensity.

4.2 Hydrologic Model

Larger upstream catchments entering the study areas were represented by traditional hydrologic models.

Inspection of the subject towns in July 2019 showed a probable baseflow in minor creeks where groundwater exfiltration occurred. It is thought that the exfiltration was due to significant rainfall in the weeks preceding the inspection. These observations helped inform the determination of loss parameters for the hydrologic model.

4.2.1 Major catchments

The hydrologic model adopted for each of the major catchments (Queen River, Manuka River, Little Henty River and Stitt Rivers) was a RORB model. An example of the sub-catchment breakdown for the Manuka River is shown by the blue catchments in Figure 8.

Each of the major catchments is ungauged (this is common for most catchments in Australia), the RORB input parameters were determined from guidance provided by ARR19 in *Section 6.2.1.8*. The recommended values for the West Coast of Tasmania are:

$M = 0.75$

$Kc = 0.86A^{0.57}$

4.2.2 Losses

The initial and continuing soil loss values were adopted from Australian Rainfall and Runoff data-hub values and site observations during inspections. The adopted initial and continuing soil losses were:

Initial Loss = 18mm

Continuing Loss = 0mm

Pre-burst median rainfall depths were applied to the hydrologic model. The pre-burst depths were obtained from the ARR datahub. The pre-burst rainfall depths for sub-hourly events were taken to be the one-hour event pre-burst values.

Temporal rainfall pattern files were obtained from the ARR Datahub, with the Southern Slopes TAS patterns applied to the hydrologic model.

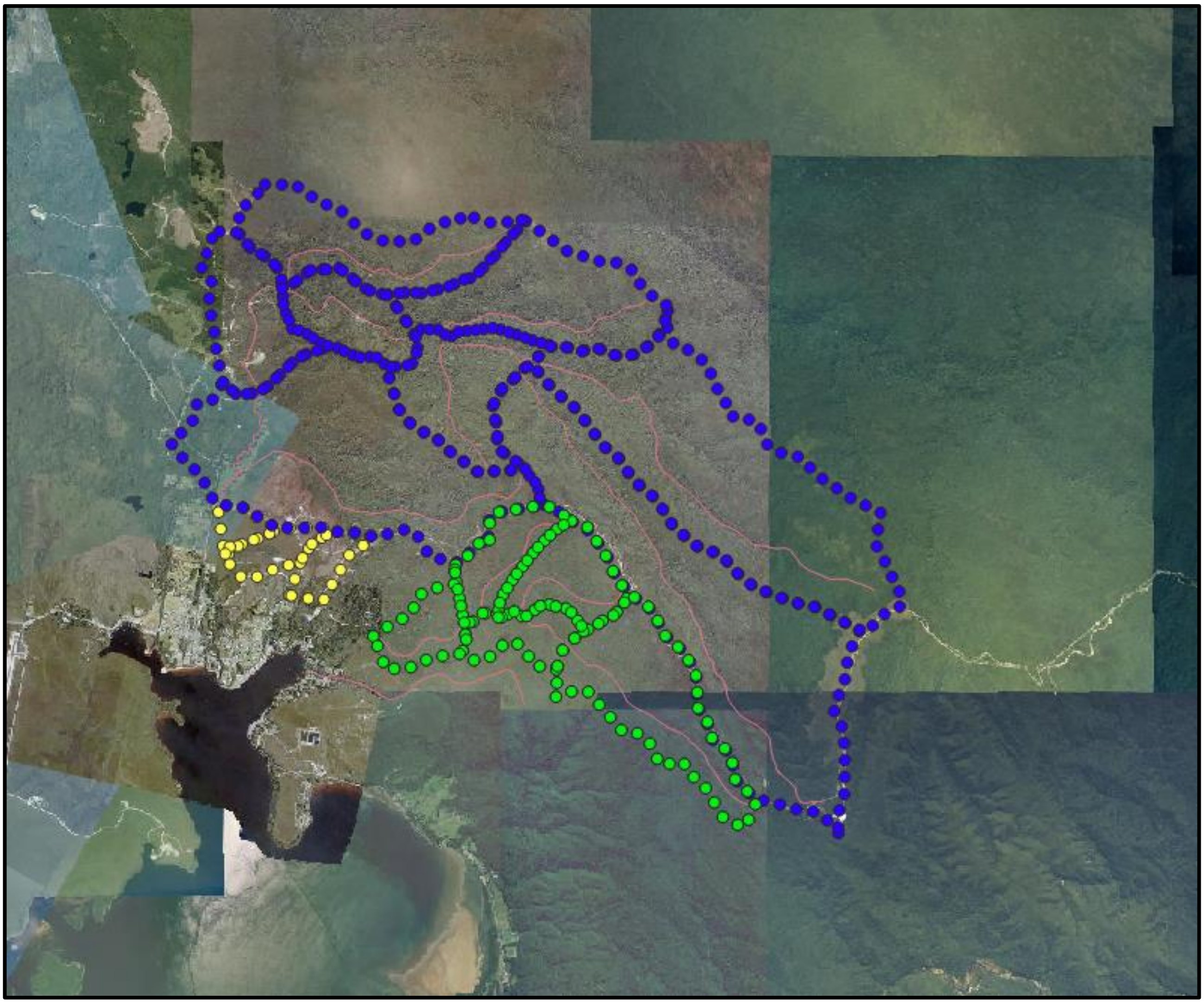

Figure 8: Manuka River (Blue) & Botanical Creek (Green) RORB sub-catchments and example minor catchments (yellow)

4.2.3 Minor catchments

Catchments of less than 1km^2 were represented using a simplistic model with initial loss, continuing loss and time of concentration. These minor catchments were not included in the RORB model, which requires a minimum of five sub-catchments. The following model parameters were adopted for the minor catchment hydrologic models:

- Initial loss = 18mm
- Continuing loss = 0mm
- Time of Concentration Method = Bransby Williams

4.2.4 Direct Rainfall (Rain of Grid)

Direct rainfall was applied only to urban areas within the study area. The rainfall depth was specified in five-minute intervals and included median pre-burst rainfall depths in the preceding hours. Rainfall depth values were obtained from the Bureau of Meteorology Intensity Duration Frequency (IFD) tool. The rainfall depth data is available on a gridded basis with spatial variation of rainfall present across the subject catchments. The adopted rainfall depths for the local townships varied from the larger catchments discharging through the towns.

4.3 Hydraulic Model

A TUFLOW Highly Parallelised Compute (HPC) hydraulic model has been adopted for each of the five study areas. TUFLOW is a capable, benchmarked software commonly used in Australia for flood modelling and is deemed appropriate for the requirements of this study. TUFLOW HPC 2D solver utilises and solves the full two-dimensional Shallow Water Equations. The following provides a description of the key assumptions and decisions relating to the development and use of the TUFLOW hydraulic model.

4.3.1 Flood Model Extent

The flood model extent is the area where flooding is assessed and the extent to which flood model outputs will be produced. Figure 9 provides an example of the Zeehan 2D flood model extents.

The 2D flood model extents were based on:

- The availability of suitable topographic information
- Points of interest within each of the five communities
- The local catchment extents
- Computational limitations (number of cells and run time).

Figure 9 Example 2D Model Extent (Red), Hydrograph and Downstream Boundaries (Green)

4.3.2 2D Computational Grid Size

The 2d model grid size was either 2m x 2m or 2.5m x 2.5m fixed grid cells. These cell sizes were chosen as they provide a reasonable representation of typical hydraulic controls (e.g. roads and large creeks) whilst ensuring the computation time is reasonable and the assumptions of the shallow water equations are not violated.

4.3.3 Manning's 'n' values

Manning's 'n' roughness was specified as a depth varied value with an example provided in Table 2 and illustrated in Figure 10. The roughness values between depth 1 and depth 2 are linearly interpolated. The low Manning's 'n' for buildings at shallow depths represents the rapid runoff from roofs. The high values at shallower depths represents the significant obstruction to flood flows.

Table 2: Depth varied Manning's 'n' roughness values

Surface	**Manning's 'n' Roughness**
Roads	0.015
Buildings	0.03 (< 100mm), 0.5 (>500mm)
Grass Paddocks	0.15 (<100mm), 0.05 (>300mm Depth)
Medium Vegetation	0.2 (<100mm), 0.07 (>400mm Depth)
Heavy Vegetation	0.2 (<100mm), 0.1 (>600mm Depth)
Natural Channel	0.15(<100mm), 0.035 (>300mm Depth)

Figure 10: Example Materials File Layer (Roughness Layer) (Blue Pavement, Brown Buildings, Pink Medium Vegetation, Green Creek Default (Other) Light Vegetation.)

4.3.4 Buildings

Buildings have been modelled as a roughness layer rather than an elevation adjustment or removal of cells from the model. The reasoning for this is twofold:

- Rainfall falling on buildings will contribute to runoff
- Buildings will provide flood storage when flood waters deepen.

The building layer is also used to determine flood related damage cost.

4.3.5 Culverts

Many culverts are present within the study areas. Pipe inverts were estimated from the surrounding terrain where detailed invert data was unavailable.

Modification to the terrain at the inlet and outlet has been undertaken to ensure that an unrealistic inlet constriction does not occur. Loss coefficients from pipe inlets and outlets were set to 0.5 and 1.0 respectively.

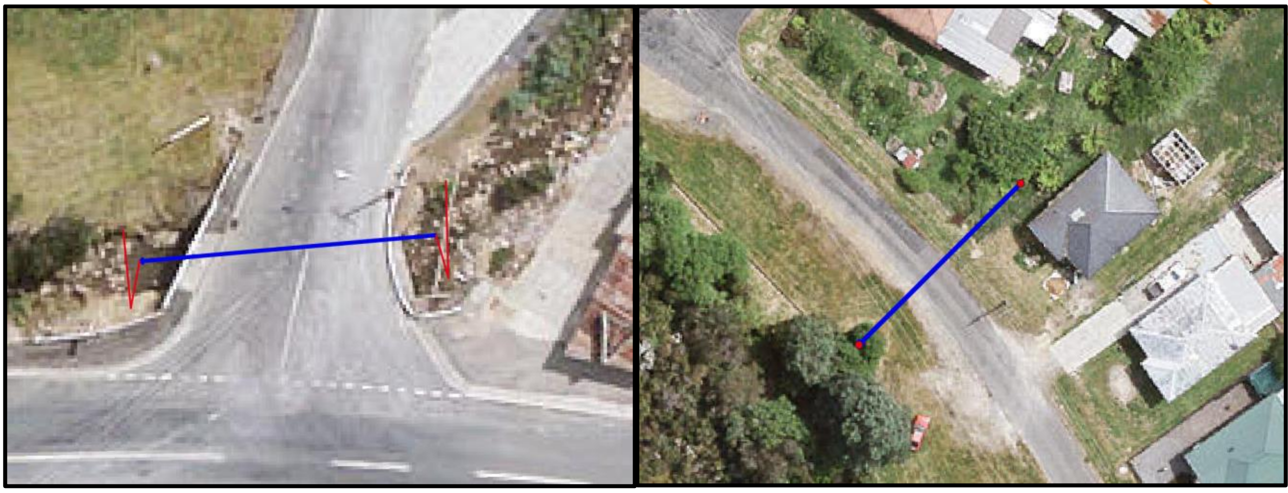

Figure 11: Example of TUFLOW 2d_nwk (pipe) connection to 2d cells SX-CN (left) and SX (right)

4.3.6 Pits & Manholes

The values for form losses for pit inlets and junction pits were based on guidance provided in *ARR19 Book 9 Chapter 5.5.3*. Side entry pits and gully pits were nominated as pits with manually defined inlet capture curves. Pit inlet capture curves were defined as follows:

- Side entry pits were generally assumed to have a 1.2m lintel with depth-discharge relationships estimated from ARR Book 9 Chapter 5.5.2.
- Grated pit inlet depth-discharge relationships were estimated from the inlet capacity procedures recommended in ARR Book 9 Chapter 5.5.2.

Figure 12: Example of pit and pipe network (pipes blue, pits/manholes green) Beech Drive, Rosebery

4.3.7 Bridges

Bridges were defined in the model as layered flow constriction polygon layers as illustrated in Figure 13. This approach is intended to represent losses associated with bridge contractions and obstructions that are at a scale finer than the grid. The method specifies three layered flow constrictions:

- Constriction below the bridge soffit (e.g. piers and abutments)
- Constriction through the bridge superstructure (beams and deck)
- Constriction through the bridge guard rails

Form loss coefficients were estimated using *Austroads Part 8 - Hydraulic Design of Waterway Structures.*

The layered flow constriction polygon method allows for skewed and cambered bridge decks to be sufficiently modelled on a rectilinear grid.

Figure 13: Example of TUFLOW layered flow constriction Bridge Representation at Park Road, Rosebery

4.3.8 Creek Channels and Terrain Adjustments

Major creeks and channels are not always clearly represented with LiDAR data sets due to the limitations of the survey technology. The accuracy of LiDAR is reduced in the dense vegetation that grows around creeks, and the LiDAR does not penetrate below water surfaces. This is problematic when using LiDAR data to model creeks and channels.

Adjustments were made to the LiDAR data to ensure the channels were adequately represented. TUFLOW has a tool that allows creek inverts to be smoothed. The illustration in Figure 14 shows the following:

- The purple region has cut the channel below Henty Street Bridge to a defined elevation
- The long green lines have a specified width to represent Manuka Creek and the red points define the elevation of the creek bed. The final cell elevation between the points along the line is interpolated linearly.
- The short green line represents the minor levee on the east of Henty road, this line has a single elevation assigned.

Other terrain adjustments were made to adequately represent hydraulic controls, including critical road formations, artificial levees and bunds.

Figure 14: Example: of TUFLOW terrain adjustments (region (purple), line (green) with point elevations (red)) Henty Road, Strahan

4.3.9 Boundary Conditions

Figure 15 provides an example of the boundary conditions used in the TUFLOW models. The following boundary conditions were used in the models:

- QT boundary conditions where a hydrograph of flow (Q) vs time (T) is specified. This is generally drawn as a line perpendicular to the flow direction. QT boundaries are defined from the RORB hydrologic modelling
- HT boundary conditions where a head (H) vs time (T) is specified. The tidal boundary water level was set at a constant level for the Strahan model runs
- 2d_rf Rainfall layer where rainfall is applied directly to the 2d computational area for the direct rainfall condition. The rainfall depth was specified in 5-minute intervals.

Single rainfall patterns were selected, based on the median temporal pattern, or an appropriate temporal pattern close to the median, resulting from the hydrological model inputs. This was applied as direct rainfall and the corresponding hydrographs were applied at inflow boundaries.

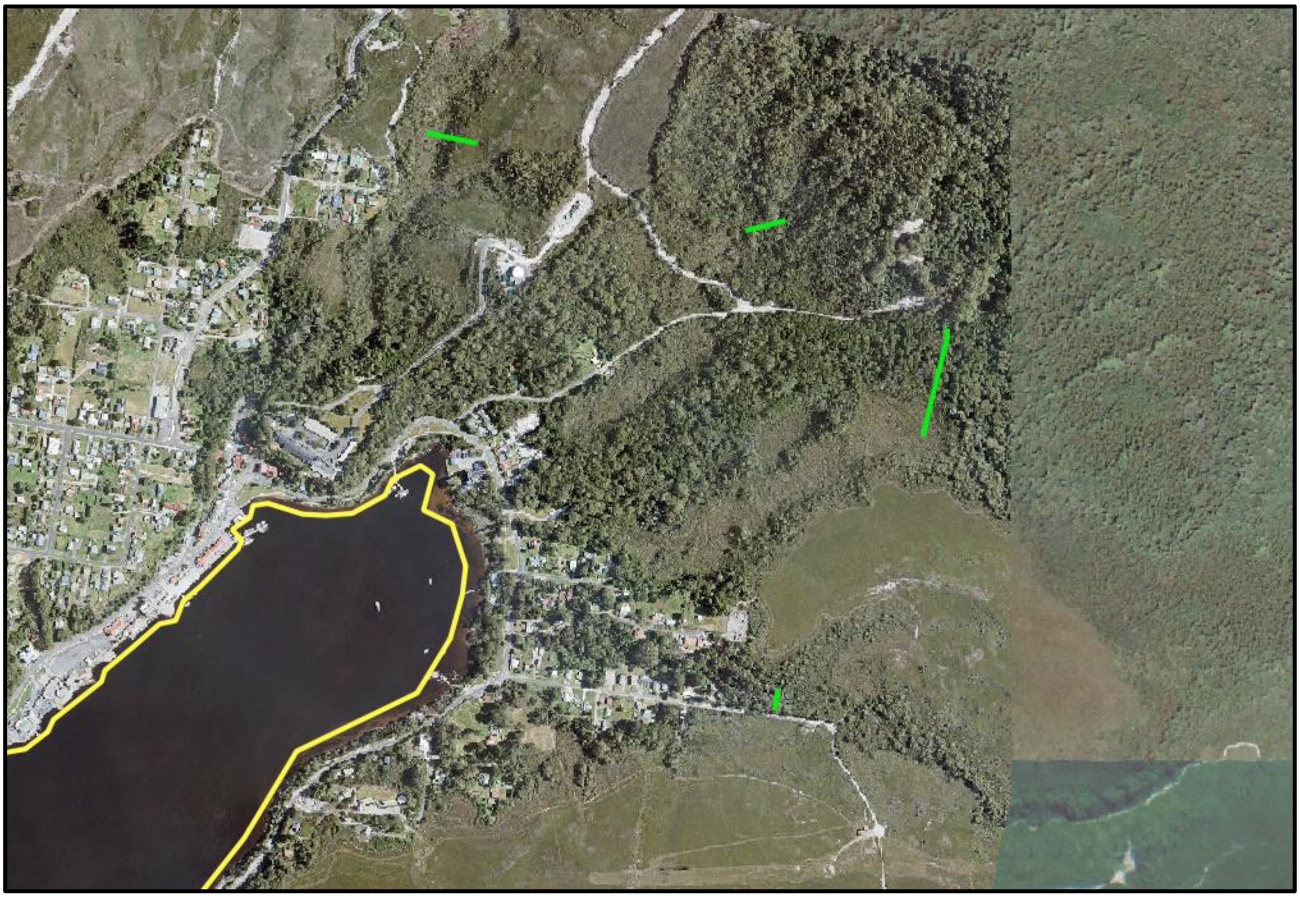

Figure 15: Example of TUFLOW boundary conditions (QT Hydrographs green, HT Tidal Boundary yellow) Main Wharf, Strahan

4.4 Model Parameter Sensitivity

4.4.1 Soil Loss Model Parameters

Soil loss models inherently contain significant uncertainty when considering natural catchments. Models with high initial soil loss will not generate runoff until a large depth of rain has fallen. Models with high continuing soil losses will not generate runoff when the rate of rainfall does not exceed the rate of loss, as is the case with longer storms.

The West Coast of Tasmania experiences high rainfall and soils are frequently saturated. During the Site Inspection, all 5 towns exhibited groundwater exfiltration with water seeping out of the ground in many places. Where soils are already saturated peak discharge outflows do not vary greatly with changes to the soil loss parameters.

4.4.2 RORB Hydrologic Routing Parameters

As it was not possible to calibrate the RORB model to recorded gauges, the values for its routing parameters, for Kc and m, are those recommended in ARR19, which are based on historical analysis of West Coast catchments. It should be noted that:

- The Manuka River has a relatively normal catchment shape with no apparent significant man-made storage,
- The Stitt River also has a relatively normal catchment shape and contains no obvious significant man-made storages,

- The West Queen River contains two significant man-made storages which are assumed to be full for all assessments, the above-crest storage capacity of these reservoirs was not included in the assessment. The East Queen River appears less impacted by unnatural storages, and
- The Little Henty River catchment above Zeehan contains a large storage area in Parting Creek Lake and many natural catchment wetland flood storages. Flood attenuation in the man-made storages has not been included in the assessment.

4.4.3 Blockage of Structures

Blockage of hydraulic structures is an important consideration in the design of bridges and critical culverts. Australian Standard 5100 Bridge design and ARR19 chapter on Blockage of Culverts and Small Bridges recommend design processes. The impacts of blockage vary considerably, depending on location. At Henty Road Bridge at Strahan, a full blockage of the opening could divert a significant amount of flood water away from the natural channel.

Small culverts are prone to blockage in large storm events because of the mobilisation and transport of debris that would not be moved in lesser storm events. For the purposes of this assessment, it has been assumed that culverts are 25% blocked for all storm events.

The blockage of bridges has been assessed on a case by case basis, considering the width of the opening and the presence of piers. Guard rails and parapet fences were assumed to be 100% blocked.

4.4.4 Roughness Parameters

The roughness of the surface is a variable feature of the natural environment. The roughness parameter, Manning's n, will vary according to the nature and density of vegetation, which varies according to season. It will also vary with the morphology of natural channels, which will change in response to flood events. These natural variations are problematic in validating historic flood events, because the model might not be accurately represent the real roughness conditions at the time of the historic floods.

5. Flood Model Validation

5.1 Overview

Flood models are a tool that aim to provide an estimate of flood behaviour. They include many input parameters that are sometimes difficult to estimate over the catchment scale. For example, an assumption is required on whether or not a culvert will block or how wet the ground is before a rainfall event occurs. The values adopted for these parameters has the potential to greatly impact the estimated flood behaviour.

Ideally, flood models should be calibrated. This means simulating a known rainfall event and cross-checking simulated results against measured flood levels (i.e. a water level gauge). The flood model parameters can be modified iteratively within reasonable bounds to produce modelled flood heights that match the recorded flood event.

A review of available data suggests a water level gauge is not available in any of the study areas. Therefore, a full calibration of the flood model is not possible.

However, several pieces of anecdotal information (in the form of photos, complaints and reports) have been provided which provide an indication of likely flood levels.

Furthermore, development within most study areas is generally small, and hence most anecdotal and historical reports will still be valid today.

5.2 June 2004 Storm Event in Strahan

Several pieces of information were provided relating to a flood event in Strahan in June 2004. A summary of the data made available is provided below.

- Series of daily rainfall from the region (measured from 9AM to 9AM the following day), sourced from the BoM.
- Community survey information, provided by WCC
- Information of flooding at Harvey Street bridge at the WCC depot
- A recorded water level at the Corner of Jack and Gaffney street
- Observations of Manuka creek bursting its banks.

From this information the following assessment was undertaken to validate the 2D flood model:

- Rainfall contour maps for 24 and 48 hours were produced to show the distribution of rainfall from 9am-9am data in the surrounding region
- Pluviograph data at the nearest site was applied to the Strahan catchments with an adjustment factor to represent the spatial variation
- The corresponding flood hydrograph was then routed through the 2d model and the water levels compared to those observed in 2004

Results of this assessment showed the modelled flood levels were similar to the historical observations. STR11 in Appendix A presents reported flood locations overlayed on the modelled flood extent for the June 2004 event. Table 3 summarises the comparison between reported and calculated flood depths:

Table 3: Flood model validation - Strahan

Location	Reported flood depth (mm)	Simulated Flood Depth (m)
Harvey Street Depot	400mm inside building	500-600mm to natural surface outside building
Meredith Street	Flood water from Harvey Street flows towards Meredith	The flood model predicts flooding both north and south of Harvey Street on Meredith Street. Flood depth ~400mm north and south of Harvey Street
Corner Gaffney and Jack	Flood water lapped at floor boards	~300mm
Pontifex Street	Flooding reported	~400mm
Andrew Street	Flooding at rear of properties	Creek floods rear of properties. Peak depth ~400mm
Innes Street West	Flooded road	Between 250mm to 400mm within sag in the road
Harry Street	Flooding in private property	Flooding and ponding recorded on several properties on Harry Street.

The comparison at the Harvey Street Depot between the reported flood depth inside the building and calculated flood depth outside the building suggests that the model is producing a credible representation of the 2004 flood event.

The 2004 event occurred before upgrades to the Harvey Street Bridge, but the hydraulic model is based upon the upgraded bridge. The model therefore might not accurately yield 2004 flood levels at the bridge.

Several data sets recorded flooding with no level or depth information. These locations have been plotted on the maps in Appendix A, which show that flooding locations align with those presented in the validation flood event.

6. Design Event Modelling

For each of the study areas, the following design events have been assessed.

- 10% AEP
- 5% AEP
- 1% AEP

In addition to the base design flood events, the following climate change scenarios are also assessed.

- 5% AEP plus 30% increase in rainfall intensity
- 1% AEP plus 30% increase in rainfall intensity

For the Strahan study area only, an additional climate change scenario is assessed that considers the both a 30% increase in rainfall intensity and a 0.9m increase in sea level.

The assessment has been undertaken in accordance with Australian Rainfall and Runoff 2019. Therefore, the design event modelled corresponds to the temporal pattern that produces the median flow rate at the most critical location in each of the study areas assessed.

6.1 Existing Flood Behaviour

6.1.1 Strahan

Design event modelling within the Strahan study area shows several distinct flow paths discharging to Strahan Harbour. The major flow path is the Manuka River. The river grade flattens as it approaches the bay. Drainage in the downstream, low lying areas of Manuka Creek are affected by the tidal boundary. Substantial flooding is observed directly upstream of Harvey Street. For the 1% AEP flood event, the peak flood depth on the road is approximately 0.5m.

The critical duration for the Manuka River, and thus much of the Strahan study area, is 6 hours.

Complete flood maps presented in Appendix B show flood behaviour within the Strahan study area.

Manuka Creek breaks its banks in several locations. In particular:

- Manuka Creek breaks its southern bank downstream of Henty Road, A flow path directs flood water in a southerly direction toward the Henry Road / Andrew Street intersection.
- Manuka Creek also breaks its eastern banks north of the sports oval directing flood water in an easterly direction towards Henry Road / Andrew Street intersection, as shown in Figure 16.
- At the outlet of Manuka Creek, flood level is impacted by both restricting in the flood and the tidal boundary. Much of flood affected area in close proximity to the Harvey Street Bridge is low lying (below 2m AHD) as shown in Figure 17.
- The second largest catchment discharging at Strahan is Botanical Creek. Flood water is conveyed under the road via two large box culverts before discharging into the harbour. As illustrated in Figure 18, floodwater overtops the road where Botanical Creek discharges to Macquarie Harbour. Flooding also affects properties on Hospital Creek. The Botanical Creek outfall is heavily influenced by the tide level and the existing road level.
- A watercourse immediately north of the main wharf discharges flood water into a stormwater pipe prior to crossing carparks and roads. In the 1% AEP event, floodwater will move overland once the pipe becomes blocked or has its capacity exceeded as shown in Figure 19.

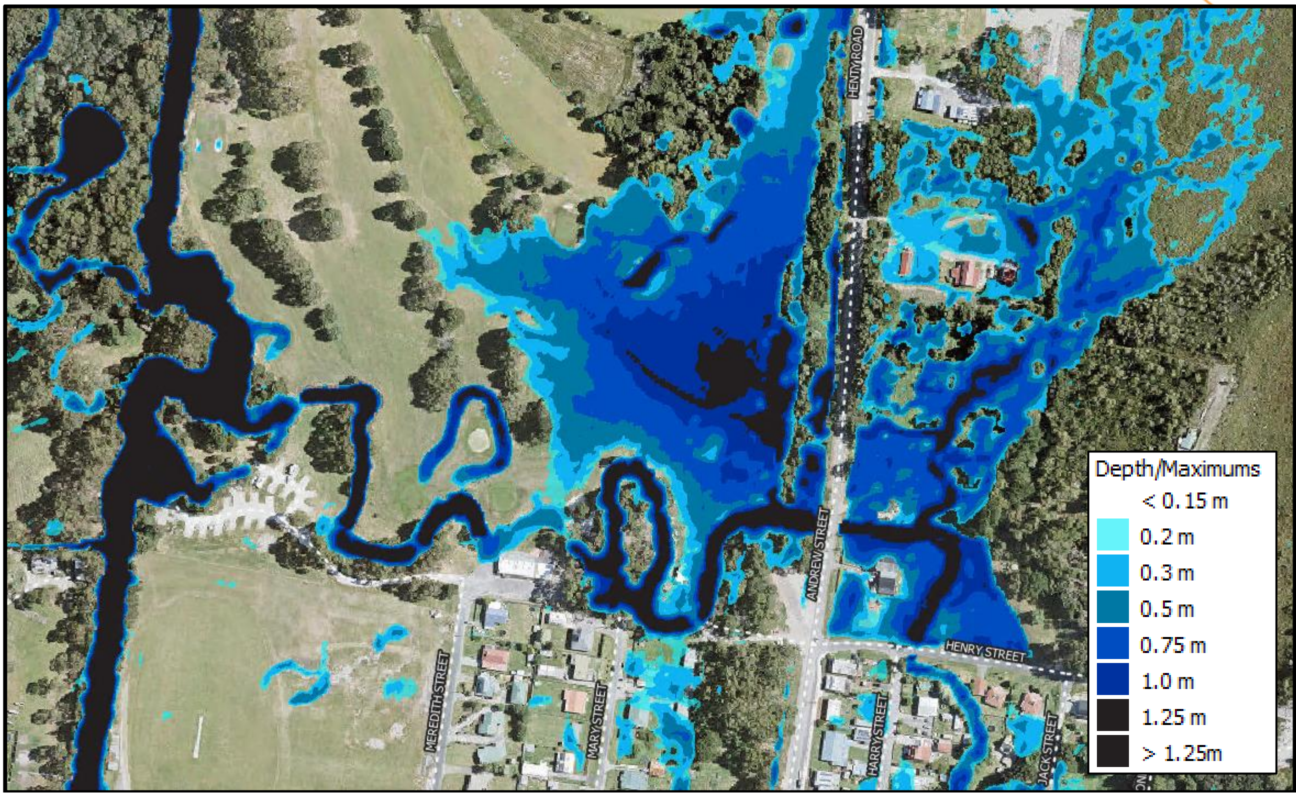

Figure 16: 1% AEP Peak Flood Depth – Manuka Creek Break Out Impacts – Andrew Street / Henty Road

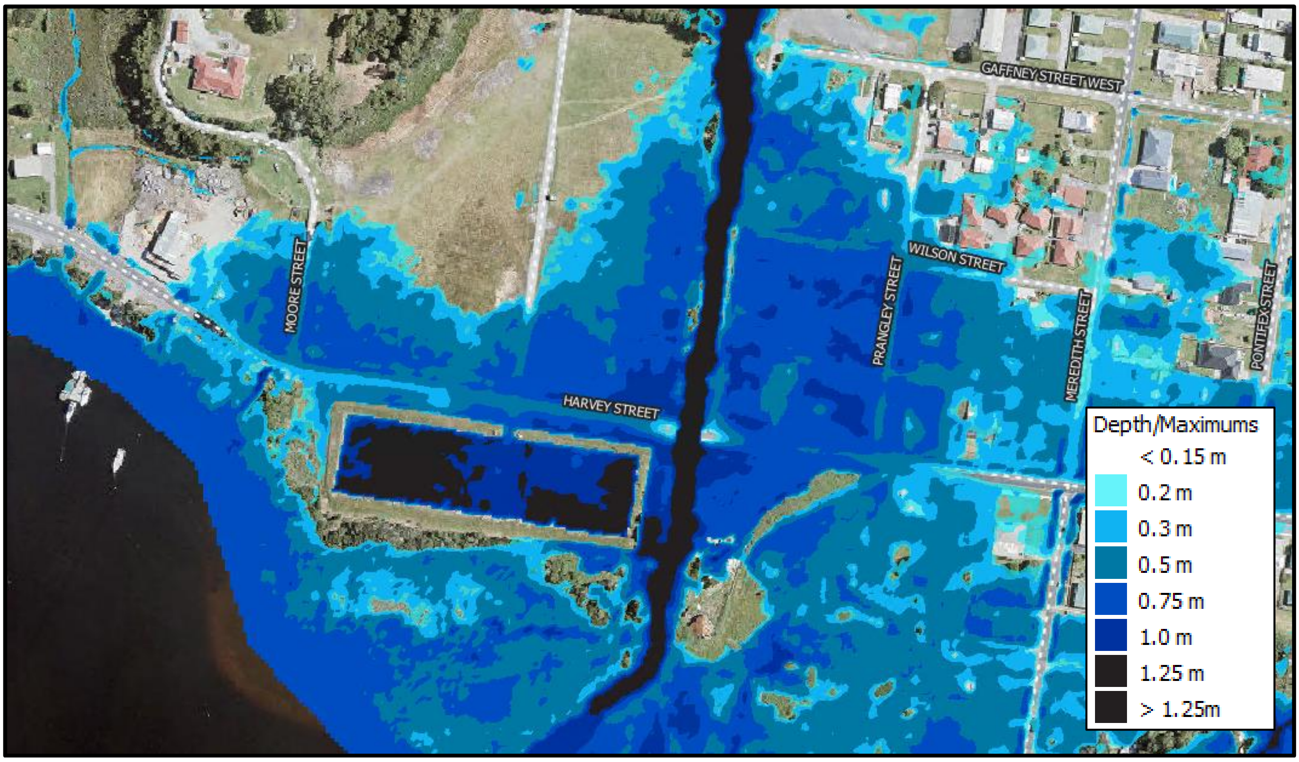

Figure 17: 1% AEP Peak Flood Depth – Manuka Creek Outlet – Harvey Street

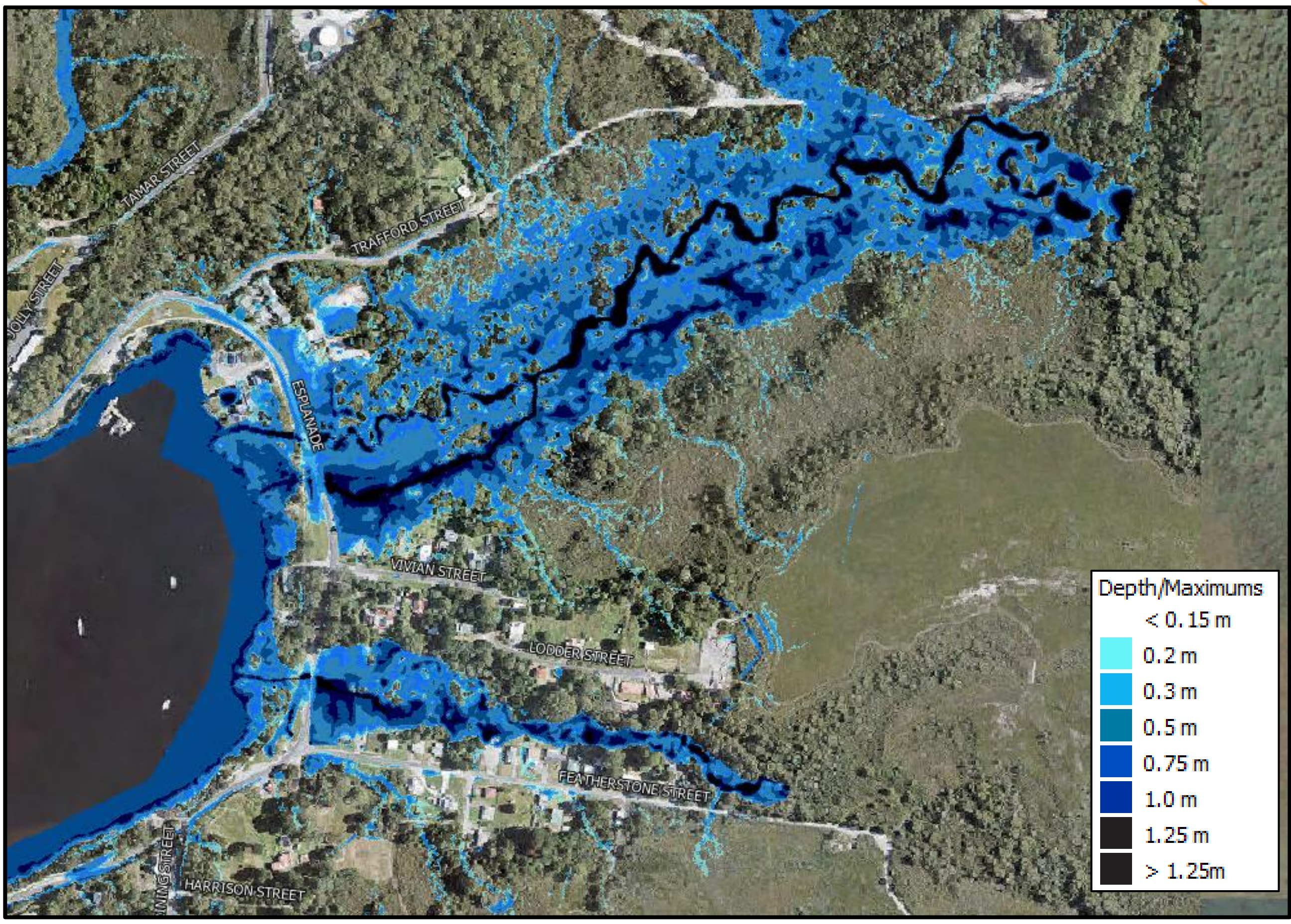

Figure 18: 1% AEP Peak Flood Depth Botanical and Hospital Creeks

Figure 19: 1% AEP Flooding Through to Strahan Wharf

6.1.2 Rosebery

The Stitt River is the dominant watercourse through the Rosebery township, generally contained in a relatively deep local gorge. The major breakout from the river is adjacent to the Rosebery sportsground, which floods adjacent parking areas, as shown in Figure 20. The Park Street Bridge is overtopped by at least 200mm and the footbridge near the sportsground is overtopped by at least 700mm.

Several overland flow paths can been be observed in the eastern urban area of Rosebery (Figure 21). Pipe networks generally have little capacity. Flow emanates from the hills above the urban area, creating overland flow through properties. Property damage is likely in the 1% AEP event.

Figure 22 shows 1% AEP flooding in the west Rosebery urban area, which comprises a combination of ponded water trapped in sags and overland flow.

The model does not incorporate the drainage system in the mine. The exclusion of the mine drainage system is expected to yield conservatively high estimates of flows approaching the urban area. This is because the mine drainage system would need to meet environmental conditions such as the limitation of runoff flows approaching nearby urban areas.

Ponding is present at several locations. Local ponding may be alleviated by small pipes that are not included in the model.

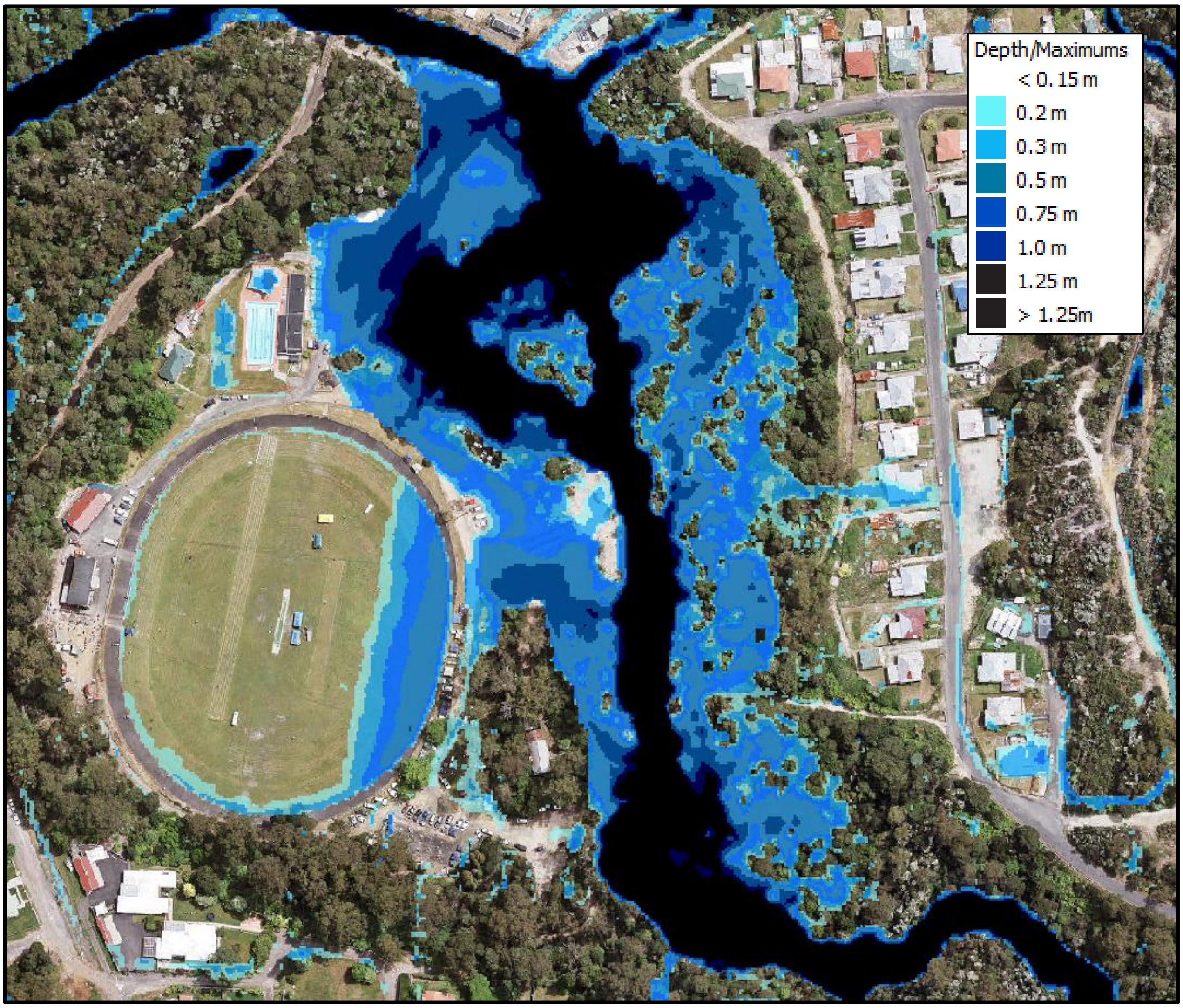

Figure 20: 1% AEP Flood Depths – Adjacent to Rosebery Sportsground

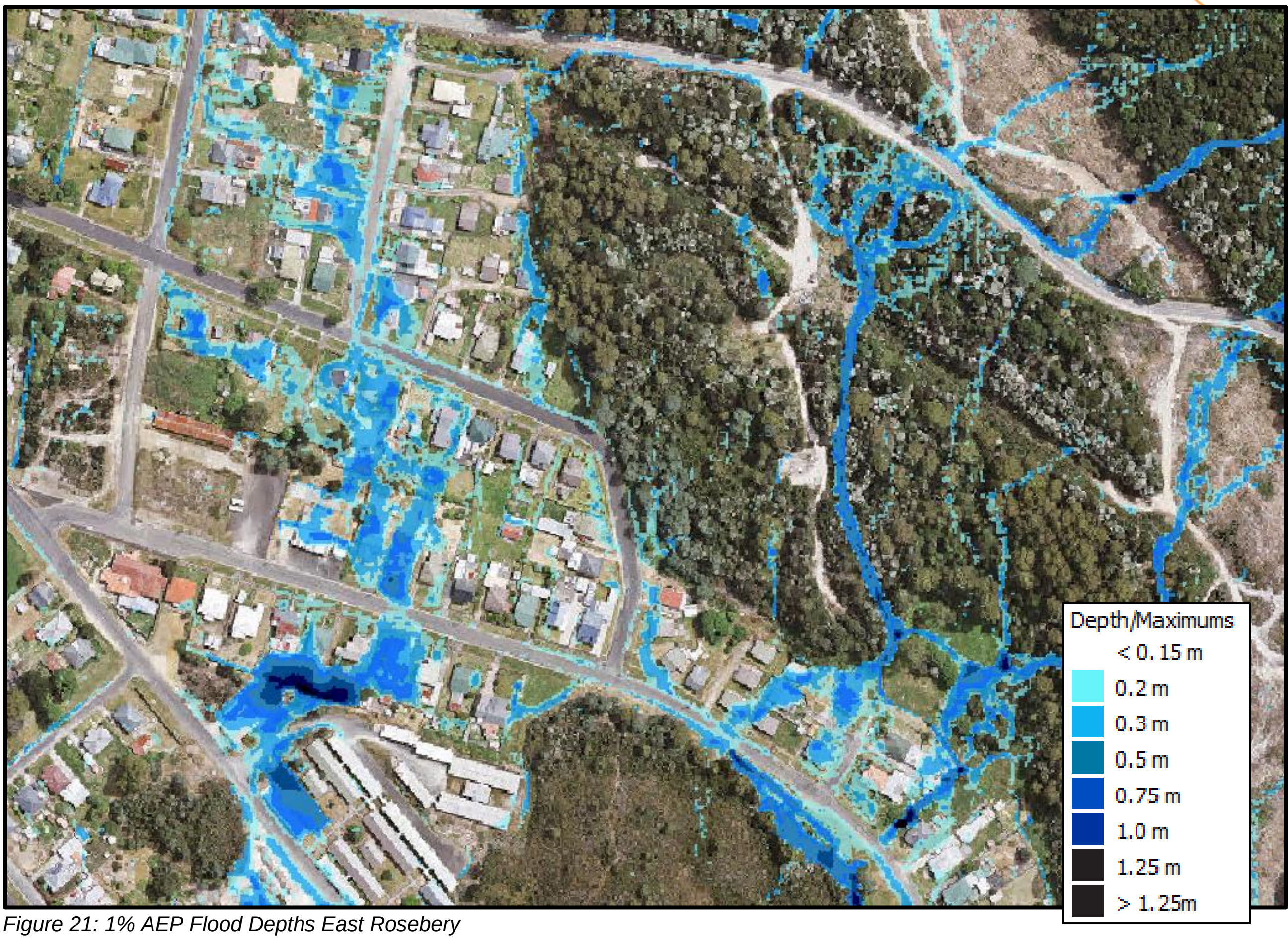

Figure 21: 1% AEP Flood Depths East Rosebery

Figure 22: 1% Flood Depths West Rosebery

6.1.3 Queenstown

The Queen river is one of the dominant features of Queenstown with the river flowing through the heart of the town and separating the urban areas. Several tributaries join the river as the river moves downstream to the south

Queen River Flooding

Modelling of the 1% AEP flood event indicated that a significant amount of flooding will be present along parts of the Queen River. At the site inspection, its was observed that many dwellings are barely elevated above the banks of the river and the river was flowing more than half full despite only light rain falling in the preceding hours. Bridges provide a significant constriction to flow when the superstructure becomes submerged causing a large increase in flood levels upstream.

The first large breakout from the main channel is in the vicinity of the Wilson Street road bridge, as shown in Figure 23.When the water reaches the soffit of the bridge, the inlet becomes submerged, causing a large increase in flood levels upstream . Several properties are flooding between the Wilson Street road bridge and Glover Creek.

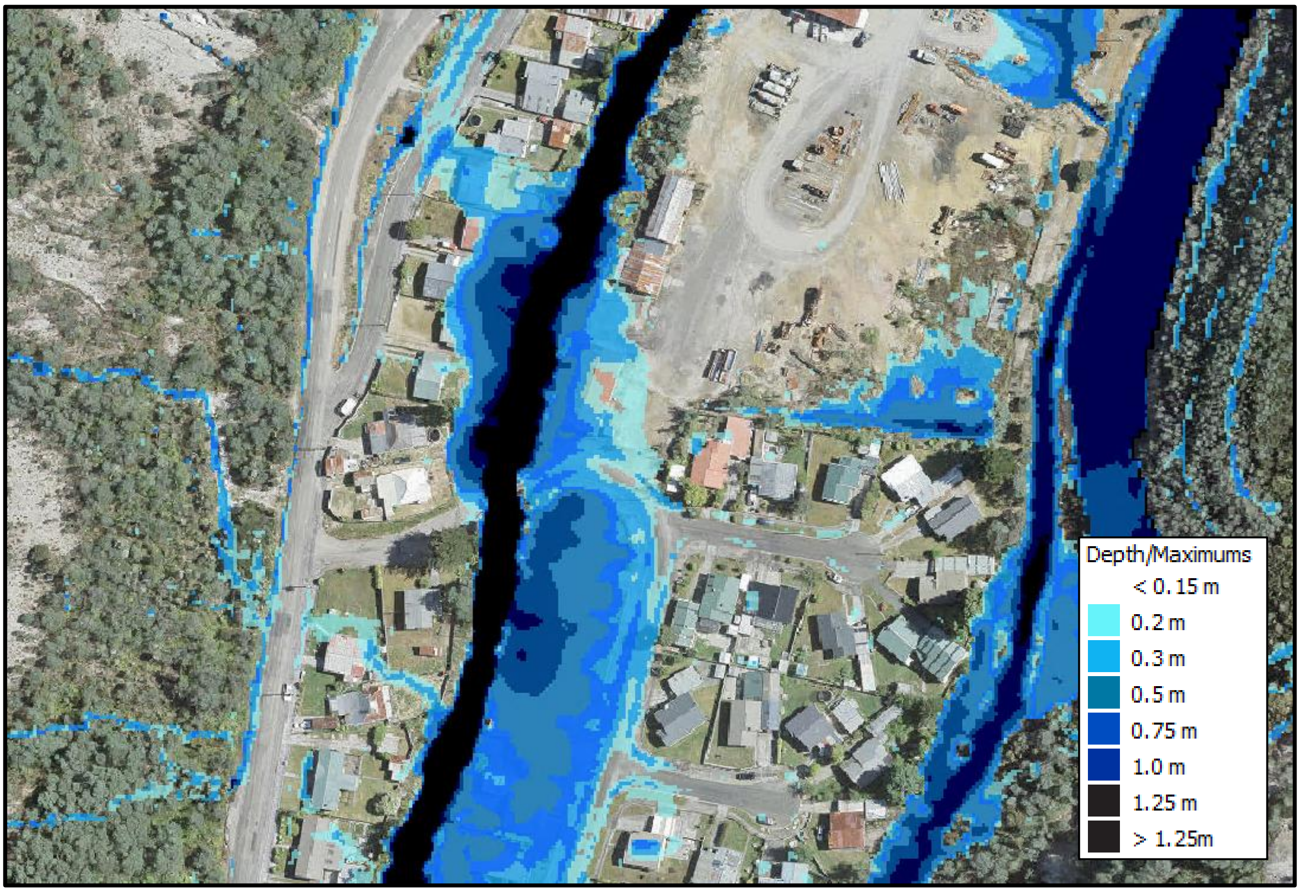

Figure 23: 1% AEP Flood Depths – Around Wilson Street Road Bridge

Confluence of Queen River and Roaring Meg Creek

Flooding occurs at the confluence of the Queen River and Roaring Meg Creek, as shown in Figure 24, Which arises from a combination of Queen River overbank flow and overflow across Conlan Street when the capacity of the twin 3.45mx2m box culvert is exceeded.

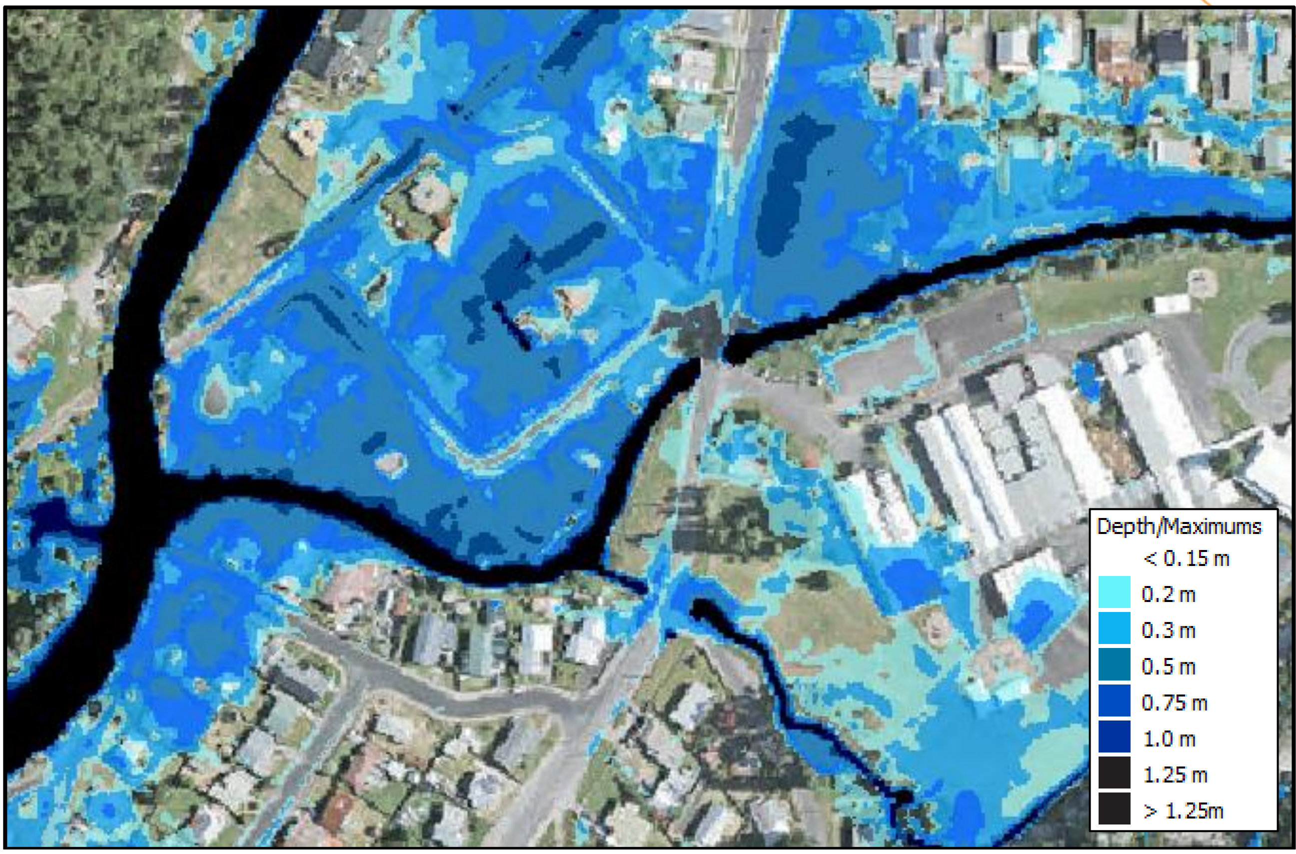

Figure 24: 1% AEP Flood Depths – Confluence of Queen River and Roaring Meg Creek

Queenstown Town Centre

There are two primary flow paths in the town centre:

- Reservoir Creek, which flows to the inlet to a 1200mm pipe at the junction of Hunter and Bowes Street this pipe, which joins an arch pipe at approximately Driffield Street. The pipe capacity is exceeded in the 1% AEP event with significant overland flow moving down Hunter Street and spilling towards Orr Street
- An unnamed watercourse, which flows to the corner of Colville and Dixon Streets before being conveyed in a 600mm pipe down Williams avenue and connecting to larger pipes on Cutten Street. Overland flow occurs when the 600mm pipe capacity is exceeded. This flow moves down Williams Avenue before zig-zagging through the centre of the town.

A significant amount of ponding occurs around Orr street and between McNamara and Bowes Streets. It is slowly relieved by the road drainage network. Overland flow moving through the town centre tends to find its way to Orr street.

Figure 25: 1% AEP Flood Depths Through Queenstown Town Centre

6.1.4 Zeehan

The most prominent flow path through Zeehan is the Zeehan Rivulet (Pea Soup Creek) which generally skirts the edge of the town. The Little Henty River flows to the east of the township, which influences flood levels in the smaller tributaries, such as Zeehan Rivulet and the sewerage treatment ponds. Several other smaller rivulets and creeks flow through the town.

Nike Creek crosses Main Street adjacent to Dodds Street as shown in Figure 26. At this location significant overland flow is anticipated to back up behind and cross over Main Street in the 1% AEP flood event. The existing bridge inlet appears to be constricted by sedimentation and vegetation growth and is likely to have less capacity than some of the structures immediately downstream. A shed has been constructed over the creek at 128-130 Main Street which may also impact flood conveyance capacity.

Wislon Street is overtopped in the 1% AEP flood event as shown in Figure 27. Once the road overtops, water is trapped in the sags to the south of the road and is drained only when the pit and pipe system is free to discharge. The bridge just downstream provides a constriction to the flow and the road is seen to overtop Robinson Street before returning to the Zeehan Rivulet downstream of the bridge. Flooding of low-lying ground adjacent to the Zeehan Rivulet is prominent along much of the town edge.

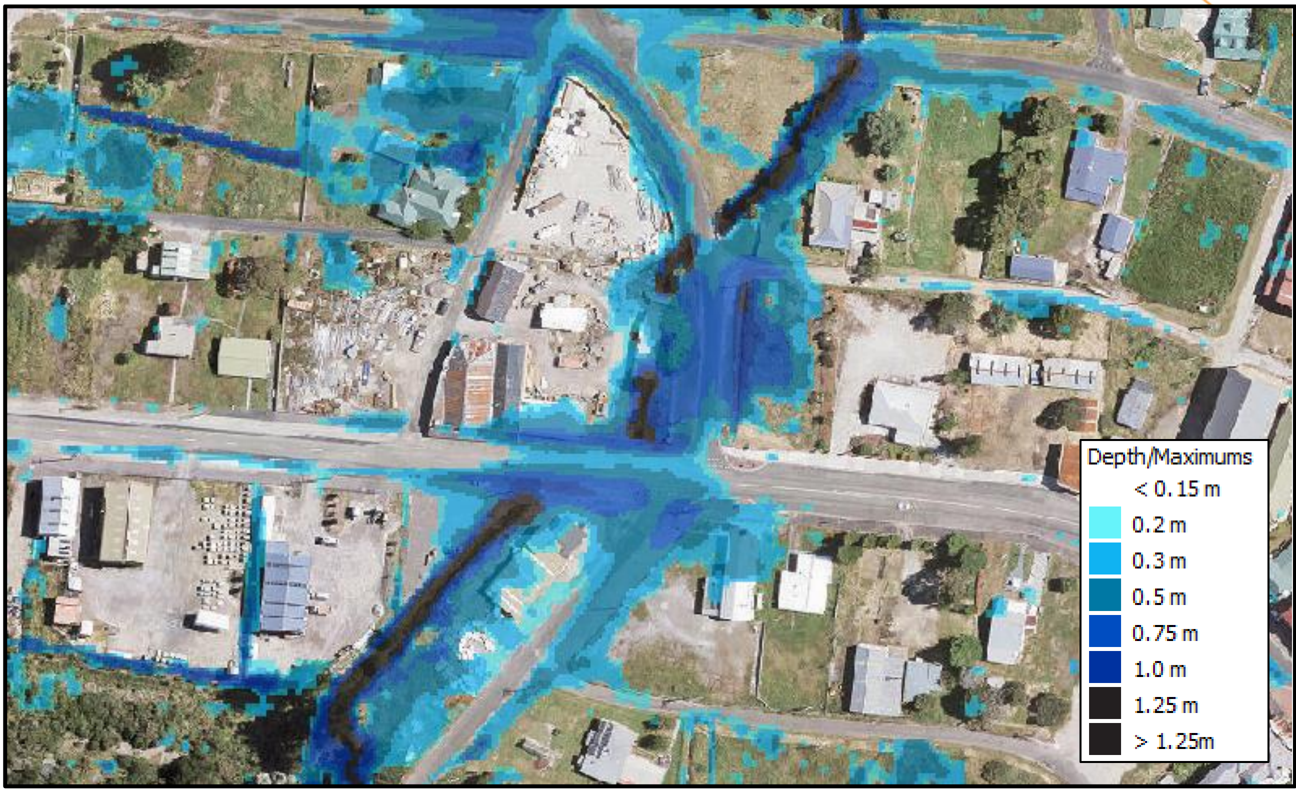

Figure 26: 1% AEP Flooding Across Main Street from Nike Creek

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Figure 27: 1% AEP Flooding Zeehan Rivulet Adjacent to Wilson Street

6.1.5 Tullah

Tullah has no significant watercourses flowing though or near to the township. The largest catchment in the vicinity is the Central Creek catchment, which discharges via a box culvert under the Murchison Highway immediately south of the main residential area. Stormwater flowing towards the main residential area is intercepted by the highway drains and an open drain to the east. This water flows north under Farrell Street before discharging to the lake. In general, localised stormwater drainage issues are more likely to present a problem than major creek flooding. Potential locations for watercourse flood damage include the Farrell Heritage Park and 25 to 33 Peters Street, as shown in Figure 28.

Figure 28: 1% AEP Flooding Tullah

6.2 Climate Change

The following climate change scenarios have been modelled:

- Queenstown, Zeehan, Rosebery, Tullah 1% AEP + 30% increase in rainfall intensity
- Strahan - 1% AEP + 30% increase in rainfall intensity + 0.9m sea level rise

When planning for flood mitigation works, it is recommended that these scenarios be considered to ensure any proposed works will suitable over their intended life.

The following provides a summary of the climate change impacts in the West Coast Council municipality.

Strahan

- For the increase in rainfall intensity only, the flood extent in the upper reaches pf the Strahan study area is relatively similar. The greatest impact is around the Pontifex / Mary Street area where the flood extent and depth increased to about 300mm for the 1% AEP event
- The increased sea level effects the low-lying areas of Strahan. For the 1% AEP, the flood extent expands, affecting more properties around Beach Street. Flood depths are increased to the south of Harvey Street, but change little to the north. Many locations with the Hazard Classification of H2 are increased to H3 following the rise in sea-levels.

Queenstown

- Climate change impacts within the Queenstown study area are generally consistent throughout. Major creek and rivers, such as the Queen River and Conglomerate Creek, experience increased flood depths and flood extents with more private property being affected by flood water. Bridges are likely to be overtopped more frequently. For example, the Kings Street crossing at the Queen River would see an increase in flood depth of about 200mm following the increased rainfall intensity.

- Under a climate change scenario, areas with Hazard Classifications of H5 are mostly adjacent to creeks and overland flow paths, namely:
    - Hunter Street;
    - Orr Street;
    - William Street; and
    - Driffield Street.

Rosebery

- Rosebery sees a minor increase in flood impact as a result of the increase in rainfall intensity due to climate change. The greatest impact is on the Clemons Street flow path. The flood extent does not expand, although flood depths increase, so that those properties that are already affected by flood water would experience a greater depth of flooding.
- Properties in Chester Avenue, which are currently unaffected by 1%AEP flooding, will experience flooding under a climate change scenario.
- Flood hazard classifcations remain relatively consistent throughout the study area. Climate change does not cause significant changes to the hazard classifications.

Tullah

- The increased rainfall intensity yields no obvious impacts, compared to current conditions.

Zeehan

- Flood extents for creeks increase under a climate change scenario. The main impacts arise from the Zeehan Rivulet and Nike Creek.
- Overbank flooding from the Zeehan Rivulet directs more flow towards Shield Street, increasing the impacts of flooding on the adjoining cul-de-sacs
- Flood depth at the Zeehan Sewage Treatment Plant increases, with both lagoons affected under a climate change scenario
- Flood hazard remains relatively consistent with little change arising from the climate change scenario.

6.3 Flood Hazard

Flood hazard mapping has been prepared for each study area for a range of design flood events in accordance with Australian Rainfall and Runoff 2019.

The combined flood hazard categorisations presented in Figure 6.7.9 (ARR, 2019[1]) are reproduced below in Figure 29.

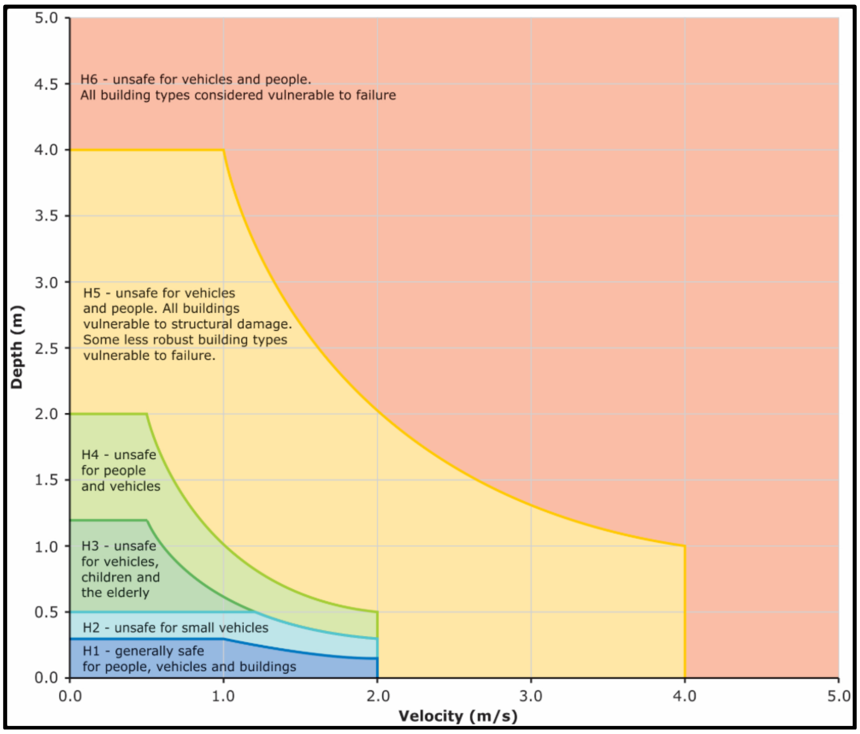

Figure 29: Combined Hazard Curves

The following identifies locations within with areas assessed that have a flood hazard rating of H4 or higher for the 10% AEP event. These locations should be considered for flood safety intervention. This does not necessarily mean structural flood modification measures are required, but other measure such as education, signage and fencing could be considered.

Most hazardous flooding incidents occur in Queenstown. Many distributed narrow streams contribute flood water to the town, allowing for depth and velocity to increase and develop hazardous flooding. No high flood hazard incidents were identified in Tullah for the 10% AEP event.

[1] Australian Rainfall and Runoff 2019, Book 6: Flood Hydraulics, Ch 7: Safety Design Criteria

Table 4: Flood Hazard Summary – 10% AEP event.

Study Area	Location	Hazard Rating	Description
QUE	Queen River	H6	Flows in the Queen River mostly contained within the banks. This is a primary water course so most people would be aware of flooding in the river.
	Glover Creek	H6	Hazardous flooding over private access road.
	Conglomerate Creek	H6	Flows within the creek. Batchelor Street crossing could be subject to hazardous flooding
	Hunter Street	H5	Hunter Street is located on a watercourse. Hazardous flooding occurs from Bowes Street to Stitch Street
	Williams Avenue	H5	Hazardous flooding develops along Williams Avenue.
	Roaring Meg Creek	H5	Crossings at Roaring Meg Creek at Hall Street and Conlan Street
ROS	Hospital Road / Agnes Street intersection	H5	Hazardous flooding upstream and downstream of Hospital Road Crossing
	Primrose Road Crossing and access to Rosebery Mine	H5/H6	Hazardous flooding upstream of the access
	Rosebery Recreation Ground Accesses and Carpark	H4-H6	Flooding from the Stitt River causes hazardous flooding in areas close to the recreation ground (particularly car parks)
ZEE	Main Street to Adams Street	H5	Nike Creek crosses several roads and travels through vacant land. Presents a hazardous flood condition.
	Upstream Hurst Street	H5	Flood water in Silver lead Creek presents a hazardous flood condition.
	Wilson Street	H4	Flood water spills from the Zeehan Rivulet and affects several properties.
STR	Harvey Street (Council Depot)	H3/H4	Flooding from Manuka Creek. Hazard category of H6 for much of the Manuka Creek in bank area, although well contained until Gaffney Street West. Peak Hazard of H3 for most affected areas, isolated H4 category close to Council Depot.
	Manuka Creek / Henty Road crossing	H5/H6	Potential for bridge overtopping

7. Economic Impact of Flooding

7.1 Building Floor Levels

No building floor level information was available for this study; therefor floors were assumed to be 150mm above the natural ground level shown in the LiDAR data.

7.2 Property Damage Analysis

The property damage assessment is based upon the methodology and guidelines provided by the NSW Office of Environment and Heritage[2]. The method has been simplified to be commensurate with the accuracy of flood model results.

7.2.1 Residential Damage Curves

Residential damage curves have been drawn from AAD (Annual Average Damage) damage calculation worksheet provided by the NSW Office for Environment and Heritage.

The following assumptions have been made in determining a suitable flood damage curve.

- A single residential damage curve is applied to all structures within the study areas. The curve is based upon a single storey house
- A regional cost variation factor for Queenstown is applied. This is 1.25 drawn from Rawlinson's
- The source flood damage calculation is based on Average Weekly Earnings (AWE) from 2001. The full time total earning AWE for Tasmania in 2001 (Full time, total earnings) is $781.50. For 2019, the AWE is $1,517.10. Therefore, a factor of 1.94 is applied to the base estimate to adjust costs from 2001 to 2019.
- As the flood behaviour is generally short, flash flooding, the average time of inundation is assumed to be 0.5 hours.
- An average house size of 240m^2 is assumed.
- The average value of contents contained in each house is assumed to be $60,000
- The typical table bench height is assumed to be 0.9m
- In the event of substantial damage where a person or family is no longer able to reside in the primary residence, it is assumed they will not be able to return for 3 weeks and the cost of temporary relocation is $220 per week
- All buildings are assumed to be residential.
- All buildings are assumed to be 150mm above natural surface level (LiDAR)

The adopted damage curve is presented below in Figure 30.

[2] *Residential flood damage guideline:* https://www.environment.nsw.gov.au/topics/water/floodplains/floodplain-guidelines

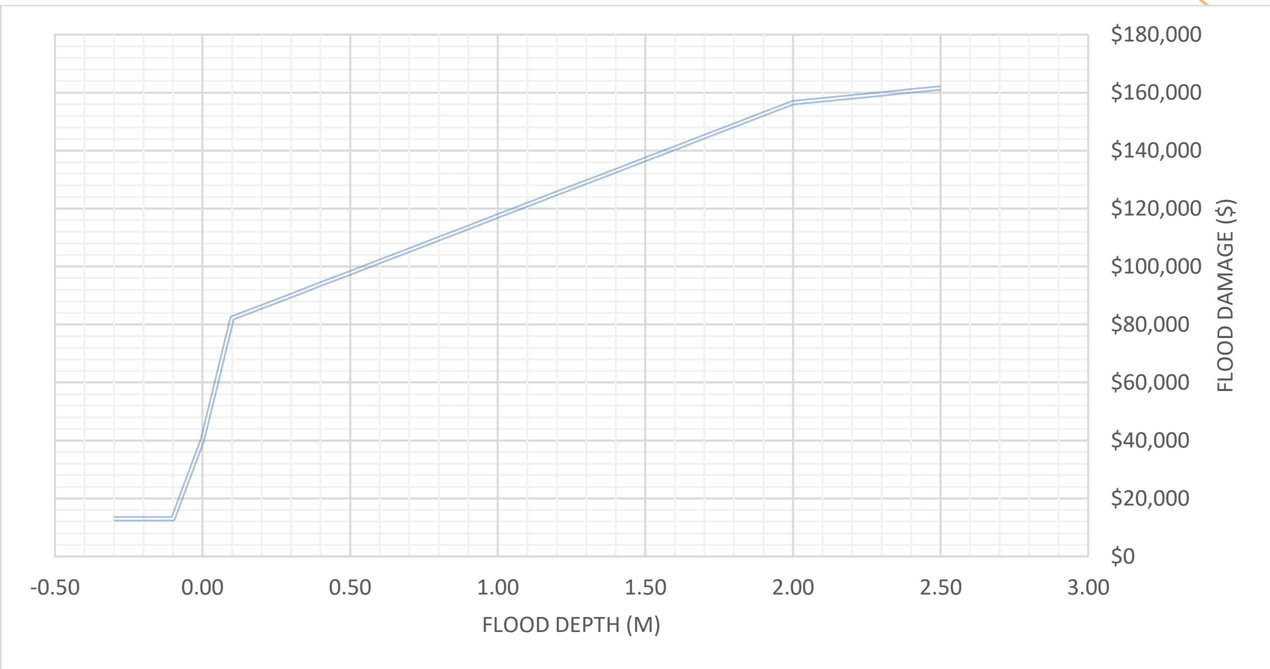

Figure 30: Residential Flood Damage Curve

7.2.2 Expected Annual Damage

Flood damage assessments generally consider a range of storm probabilities to build an estimate of the expected annual damage (EAD). The EAD is calculated by summing total damage caused by a single design storm event (i.e. the 1% AEP), then multiplying the total damage by the event probability (i.e. 0.01 for the 1% AEP event).

For this assessment, the 1% AEP, 5% AEP and 10% AEP storm events were considered. Normally, a flood damage assessment would consider a broader range for event probabilities to develop a complete AED estimate that is inclusive of frequent and rare storm events. Figure 31 shows an example of how the AED can be determined.

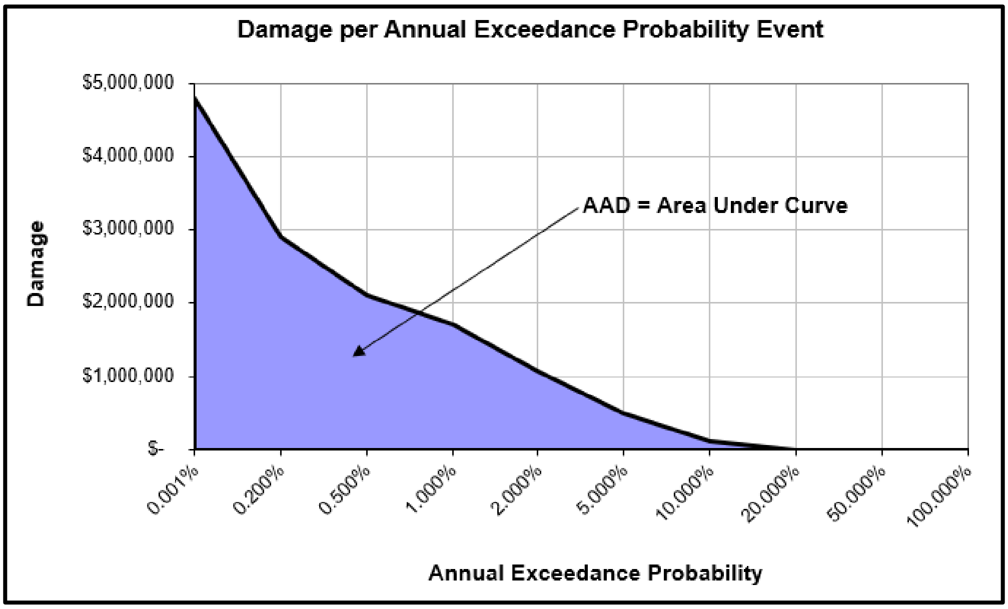

Figure 31: Example AAD/AED calculation (Residential Flood Damages – Floodplain Risk Management Guideline - https://www.environment.nsw.gov.au/topics/water/floodplains/floodplain-guidelines

It is assumed the limiting storm event for damage is the 1% AEP event. A proportional assumption is applied for damage for more frequent storm events (20% AEP and 50% AEP). These assumed damages for smaller events are italicised in Table 5 to Table 9, which present the flood damage results for urban areas in the WCC LGA.

Table 5: Zeehan Flood Damage Results

AEP	Probability	Total Damage	Change in Damage	Contribution to AAD
1%	0.01	$519,868.85		$13,256.94
5%	0.05	$142,978.00	72%	$5,849.10
10%	0.1	$90,986.00	36%	$7,549.30
20%	0.2	*$60,000.00**	33%	$13,500.00
50%	0.5	*$30,000.00**	50%	
			AED	**$40,150.00**

Table 6: Queenstown Flood Damage Results

AEP	Probability	Total Damage	Change in Damage	Contribution to AAD
1%	0.01	$9,505,547.47		$271,833.91
5%	0.05	$4,086,148.03	57%	$164,997.98
10%	0.1	$2,513,771.36	38%	$165,688.57
20%	0.2	*$800,000.00**	68%	$150,000.00
50%	0.5	*$200,000.00**	75%	
			AED	**$752,500.00**

Table 7: Rosebury Flood Damage Results

AEP	Probability	Total Damage	Change in Damage	Contribution to AAD
1%	0.01	$1,585,776.07		$55,741.50
5%	0.05	$1,201,298.76	24%	$52,151.00
10%	0.1	$884,741.43	26%	$64,237.07
20%	0.2	*$400,000.00**	55%	$75,000.00
50%	0.5	*$100,000.00**	75%	
			AED	**$247,100.00**

Table 8: Strahan Flood Damage Results

AEP	Probability	Total Damage	Change in Damage	Contribution to AAD
1%	0.01	$6,632,927.49		$232,611.01
5%	0.05	$4,997,623.04	25%	$234,164.99
10%	0.1	$4,368,976.37	13%	$318,448.82
20%	0.2	*$2,000,000.00**	54%	$412,500.00
50%	0.5	*$750,000.00**	62%	
			AED	**$1,200,000.00**

Table 9: Tullah Flood Damage Results

AEP	Probability	Total Damage	Change in Damage	Contribution to AAD
1%	0.01	$222,103.68		$6,804.47
5%	0.05	$118,119.68	47%	$5,905.98
10%	0.1	$118,119.68	0%	$10,905.98
20%	0.2	*$100,000.00**	15%	$22,500.00
50%	0.5	*$50,000.00**	50%	
			AED	**$46,100.00**

Figure 32 presents the flood damage results graphically. The area under the graph represents the AED. Figure 32 demonstrates that both Queenstown and Strahan make up the majority of flood damage within the LGA, suggesting flood management options in these locations will provide the most favourable return on investment.

Strahan has a greater portion of damage for frequent events than Queenstown. In Queenstown the flood damage rapidly increases as the severity of the flood increases.

Interestingly, for Tullah, the flood damage does not increase from the 10% AEP event to the 5% AEP event. This is because several properties are affected by shallow flooding. The depth increase attributed to the 5% AEP event does not increase the depth enough for the flood damage cost to increase.

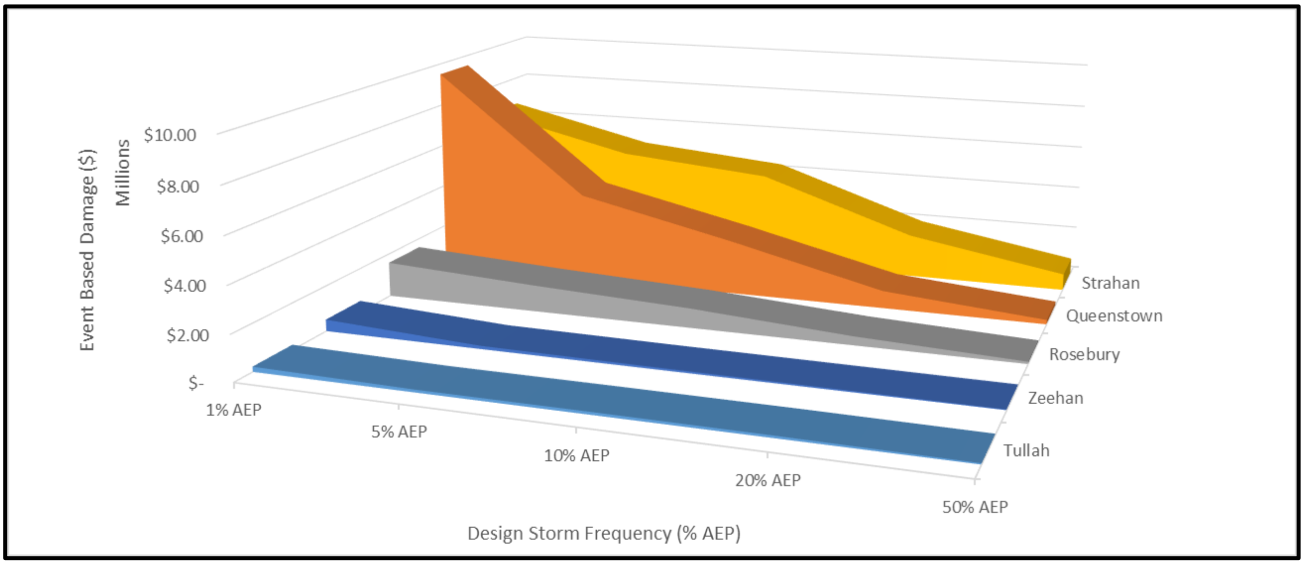

Figure 32: Flood Damage Results

The total AED for urban areas in the West Coast Council LGA is estimated to be 2.3M. Table 10 presents the number of properties that experience over floor flooding[3] and the total event based damage per modelled event.

Table 10: Event based flood damage

AEP	No. properties Overfloor flooding	Total Damage ($)
1% AEP	448	$18,466,000
5% AEP	298	$10,546,000
10% AEP	228	$7,977,000

[3] *Based upon the assumption that floor levels are 150mm above natural ground level. No floor level survey is available for this study.*

8. Flood Risk Management Options

8.1 Managing Flood Risk

Flood Risk can be categorised as existing, future or residual risk:

- Existing Flood Risk – existing buildings and developments on flood prone land. Such buildings and developments are exposed to a current risk of flooding by virtue of their presence and location on the flood prone land;
- Future Flood Risk – buildings and developments that may be built on flood prone land. Such buildings and developments would be exposed to a flood risk when they are built; or
- Residual Flood Risk – buildings and development that would be at risk if a flood were to exceed management measures already in place. Unless a floodplain management measure is designed to withstand the PMF, it may be exceeded by a sufficiently large event at some time in the future.

Generic categories of options to managing risk are outlined in Table 11

Table 11: Flood Risk Management Options

Alternative	**Examples**
Preventing / Avoiding risk	Appropriate development within the flood extent, setting suitable planning levels
Reducing likelihood of risk	Structural measures to reduce flooding risk such as drainage augmentation, levees, and detention
Reducing consequences of risk	Development controls to ensure structures are built to withstand flooding
Transferring risk	Via insurance – may be applicable in some areas depending on insurer
Financing risk	Natural disaster funding
Accepting risk	Accepting the risk of flooding as a consequence of having the structure where it is

For the West Coast Council LGA, reducing the likelihood of risk will be preferred approach to flood plain management. The rate of development within the LGA is generally low, and as such development related controls are unlikely to have an impact on the management of flood risk.

This study focusses on structural flood modification measures that reduce the likelihood of flooding.

8.2 Base Case

In order to assess various mitigation options, it is necessary to define a base case. The base case provides a reference against which the effectiveness of various options can be assessed. The base case is the model of current or existing conditions at each of the five study areas.

8.3 Flood Modification Measures

8.3.1 Preliminary Options Identification

Option ID	Option	Details	Expected Benefit	Constraints
STR01	Henry Culvert Upgrade	The existing culvert is a single 750mm pipe. Flood modelling for the 1% AEP events shows the culvert restricting flood conveyance and causing flood water to back up.	• An upgraded culvert could lower the flood level upstream,	• Will increase the flow rate downstream. Will need to consider the capacity of the downstream network. Unlikely to be implemented without also implementing STR02.
STR02	Gaffney Street West Culvert Upgrade	An existing DN1200 culvert conveys approx. 2m^3/s in the 1% AEP. A short distance downstream, 3 x 2.1m x 3.1m box culverts, plus a single 900 pipe exist on the same flow path. The Gaffney Street West culvert should be a similar size to this.	• An upgraded culvert could lower the flood level upstream • This would enable STR01 to be implemented	• Not likely to provide substantial benefit without first implementing STR01
STR03	Innes Street West Culvert upgrade	Flood modelling results show area north of Innes Street West to be affected by flood water. Innes Street West appears to be acting as dam, with the existing DN1350 culvert unable to pass the required flow rate.	• An upgraded culvert upgrade will reduce the flood level upstream. This will increase the capacity of the adjacent piped stormwater network by lowering the tailwater level (hence increasing the hydraulic grade line slope)	• Consideration to be given to downstream flow path, ensure flood level increase is not substantial.
STR04	Manuka Creek Flood Protection	The raised embankment around timber storage causes a blockage within the floodplain. It is recommended to remove part of the embankment to provide more flood conveyance for Manuka Creek. This option would have several components, including: • Installation of a levee from Gaffney Street West to Harvey Street on the Eastern side on Manuka Creek. This would preferentially direct water to the western side of Manuka Creek. • Property access level directly north of timber storage to be raised so that overflow from Manuka Creek does not spread further west. • Remove eastern half of wood pile embankment. This would allow flow to be directed back toward Manuka Creek and the creek outlet.	• Reduce the flood level on several properties east of Manuka Creek • Have greater confidence on flood behaviour.	• Flood level would be increased on vacant land to the west of Manuka Creek. This may restrict the development potential of the land. • Flood level across Harvey Street may be increased. Frequency of flooding of road may increase.

Option ID	Option	Details	Expected Benefit	Constraints
		• Ensure ground levels west of the bridge are lower than levels east of the bridge.		
STR05	Featherstone Street Culvert Upgrade	An existing 2.1m by 1.2m Box Culvert drains a flow path immediately north of Featherstone Street (Hospital Creek). For the 1% AEP flood event, peak flood depths of up to 1.0m form with at least 5 properties affected by some degree of flooding. The proposed option would be to increase the capacity of the culvert by adding additional cells	• Reduction in flood level for at least 5 properties, and hence reduction in damage	• Works within a coastal area • May not have enough space to expand culvert size in public land. (although noted if culvert and channel works are required on private property, it will be to the benefit of affected parties)
STR06	Esplande (Trafford to Vivian) culvert and levees	Botanical Creek flow through Peoples Park before flow is directed towards the esplanade. For the 1% AEP, flow is restricted and cause flooding upstream of the Esplanade. Approximately 5 properties are affected by flood water, north of Botanical Creek. A low flood levee or bund could be installed south of the southernmost property. The purpose of the levee or bund would be to direct flood water towards Risby Cove.	• Reduction in flood level for at least 5 properties, and hence reduction in damage	• Flood levees can affect local drainage and flow paths. Careful consideration should be made to how plumbing and drainage of subject properties is affected and appropriately managed.
ROS01	Stormwater Upgrades Between Clemons and Karlson Street	Several Overland Flow paths move between Clemons Street and Karlson Street. Generally, the existing pipe network sizes indicated are very deficient. Some larger mains (525mm) existing down a Karlson street but the size of the upstream pipes is likely to limit the ability of this pipe to flow full. Upgrading multiple sections of the stormwater network and road would help minimise flood potential through private property.	• Reduction in flooding for 20+ properties including damage reductions.	• Large general area to consider, doing isolated works may not provide benefit.
ROS02	Beech Drive and Banksia Place Stormwater Drains	Properties that back onto the mine show flood water ponding. As the mine site piped system is not included in the model the flooding may not be as bad as presented. If the issues are present, then upgrading pit/pipe and open drains to protect property would be beneficial.	• Reduce flooding on 10 properties and associated damages.	• Working on private property, uncertainty about mine drainage.
ROS03	Dalmeny Street Stormwater Upgrades	Flooding is present in the vicinity of 31-37 Dalmeny Street. Several steep watercourses converge at the rear of these properties and spill through at various locations. Ensuring upstream catch drains and overland flow paths are large enough to convey water past properties will help prevent damage. Upgrade the road culvert outside 35 Dalmey Street.	• Reduce flood potential for approximately 5 properties and associated damage costs.	• Open drain/creek upgrade size may be limited by existing easement.
QUE01	Hunter Street Pipe Upgrade	Reservoir Creek flows along an open channel until the corner of Hunter and Bowes Streets. A 1.2m pipe culvert then receives the water and approximately 3m^3/s flows through the pipe while another	• Reduction in volume of flooding and damage to properties including	• Increasing the size of the pipe may be limited by proximity of other services and infrastructure. The existing pipe also

Option ID	Option	Details	Expected Benefit	Constraints
		approximately another 7m^3/s will flood the streets in 1% AEP event. Upgrading this pipe would reduce volume of flood water entering the town centre.	businesses on Hunter, Orr and Sticht Streets in particular.	transitions to an old arch drainage line which my need to be replaced or duplicated to increase capacity.
QUE02	Cutten Street and Little Orr Street Pipe Upgrades	Insufficient pipe data was available to accurately model the pipe network, however when the existing pipe capacity is exceeded an overland flow path occurs where water likely flows down Williams Avenue and then across to, and along Orr street. Upgrading and/or optimising the existing pipe system may provide some relief but given the lack of capacity in other pipes an upgrade may be more sensible. An overland flow path develops form Colville Street. Stormwater is directed to an inlet with an immediate pipe size of DN600. The inlet capacity is exceeded in the 1% AEP event, directing water overland toward the rear of properties in Dixon Street and ultimately to Cutten Street buildings become inundated. The existing network is at capacity for the 10% AEP event. This option could include a substantial pipe and pit upgrade from Colville Street to the Esplanade.	• Reduction in volume of flooding and damage to properties including businesses on, Cutten, Little Orr, Bowes, Orr and Sticht Streets.	• Service clashes may limit the potential size of pipe upgrades. An old arch pipe exists down Little Orr Street which may be an issue.
QUE03	Bridge Flooding impacts	Several bridges crossings over the Queen River and Roaring Meg Creek are subject to the potential for overtopping. Once the bridge becomes submerged, the upstream water levels increases, potentially impacting properties. If bridges are up for renewal the flood conditions should be considered to reduce upstream water level impacts through suitable design for overtopping. It may not be feasible to raise bridge deck levels to cater for all storms. One affected bridge is the Wilson Street Bridge crossing the Queen River.	• Reduction in flood level for properties upstream of bridges. • Improve hydraulic condition around bridge.	• Recommended when bridges are due for renewal.
ZEE01	Main Road Bridge Mitigation/Upgrade Nike Creek	Where Nike Creek crosses Main Road the existing bridge inlet appears to be constricted by sedimentation and vegetation growth. As a starting point, the inlet and part of the opening could be cleared to increase the system capacity. This would require stabilising the banks for at least a few metres upstream. Upgrading the bridge would be beneficial but may be limited by the downstream shed and next downstream bridge capacity.	• Reduction in floodwater behind Main Road. Reduce overtopping potential of road.	• The bridge is the responsibility Department of State Growth. Upgrade benefits may be negated by the constrictions on the creek imposed by the shed and bridge downstream

Option ID	Option	Details	Expected Benefit	Constraints
ZEE02	Wilson Street Stormwater Main and Geometric Design	A small watercourse is intercepted by a pipe at Bayley Street where water is directed across to and down Wilson Street. When the pipe capacity is exceeded, or blockage occurs overland flow moves through properties and is trapped at several sags. A stormwater main upgrade and/or optimisation combined with appropriate earthworks such as kerb and channel and driveway crossovers may help move overland flow down roads and not through property. Note the flood model does not include accurate pipe information.	• Reduce overland flow volumes through at least 10 private properties. Improve development potential on property in flow paths. Reduce flood damage costs.	• Potentially a considerable amount of works. Main road is Department of State Growth road also.
ZEE03	Stormwater Upgrades between Gellibrand Street and Westwood Street	A watercourse flows to the rear of 35-35A Counsel Street where a pipe then takes flow through the property and along Counsel and Westwood Streets before going across Main street and across property to Gellibrand Street. The pipe continues down streets to Zeehan Rivulet. Overland flooding of property is likely in major storms between Council and Gellibrand Streets. The main could be upgraded and extra pits included. A surcharge could be provided at Gellibrand Street if the main was not upgraded further downstream.	• Reduce overland flooding potential over 7-8 properties, and hence reduce flood damage costs. Increase recapture potential.	• Stormwater mains are located in private property. This could worsen downstream flooding.
ZEE04	Wilson Street Adjacent to Zeehan Rivulet	Wilson Street adjacent to the Zeehan Rivulet is low lying with a trapped sag behind the road. In a large flood, water will spill from the rivulet and across the road flooding property. Raising the road or adding a levee or bund on the northern side could help mitigate flooding to some extent but given the trapped sag any local water may become trapped behind the road and not escape until floodwater recedes.	• Reduce flood level and damage for 3-4 properties.	• Adding a levee or bund may worsen the local flooding as the trapped water is limited

8.3.2 Preliminary Options Assessment

The following provides a summary of the options assessment modelling undertaken. It presents a possible flood mitigation measure for each of the flood issues. It is recognised that there may be several approaches to managing flooding issues. The following assessment provides a recommendation of a suitable flood mitigation option, although several approaches may be available to manage any one flooding issue.

Therefore, the following should be interpreted as the likely benefits produced from implementing a management measure. Further analysis may be required for complex flooding issue to determine the most cost effective and efficient flood management measures.

Furthermore, parts of the underground drainage system did not contain survey information, meaning invert levels have been assumed in several instances. Where flood management measures are recommended in these locations, it is recommended that an updated assessment be undertaken prior to an option be implemented.

STR01 Henry Street Culvert Upgrade

Options assessment modelling was undertaken for the Henry Street culvert for both the 1% and 5% AEP flood event. The culvert was nominally modelled as a 3x1200mm pipe culvert to match the culvert immediately upstream under Andrew Street. The results showed:

- Flood levels are reduced by up to 150mm and 300mm locally behind the culvert in the 5% and 1% AEP events respectively and water levels are reduced for up to 400m upstream.
- More flood water is now directed to the main channel which reduces the overtopping of Henry Street and subsequently reduces flooding on at least 6 properties between Harry and Andrew Streets, it also reduces flood depths on properties on Mary Street as upstream water levels are also reduced.
- The flow rate contributing the Henry Street culvert increases rapidly when the Manuka Creek break its banks and directs flow towards the culvert.
- For the flood event modelled, the downstream water levels behind Innes Street West have increased by approximately 150mm and 100mm in the 5% and 1% events respectively due to the release of the flood storage.

As the existing culvert is deficient for the local catchment (excluding Manuka River overflows), it is recommended that this culvert is upgraded. However, the size of the designed culvert should be nominated based on whether other flood mitigation measures are undertaken. An upgrade should consider:

- Whether other flood mitigation options are to be undertaken (such as closing the Andrew Street culvert and diverting flood water back to Manuka Creek), this will dictate the size of the culvert,
- An upgrade should consider the sensitivity of overbank flood flows from Manuka Creek. The overbank flow arrives at the triple 1200mm pipe culvert under Andrew street and this effectively controls the peak flow arriving at the Henry Street culvert (larger flows will spill away from Andrew Street and down Mary Street),
- The hydraulic head difference either side of the culvert is low and must be carefully considered when sizing the culvert,
- The potential negative impacts on downstream properties, this may necessitate upgrading the Gaffney Street West and Innes Street culverts to prevent worsening impacts downstream.

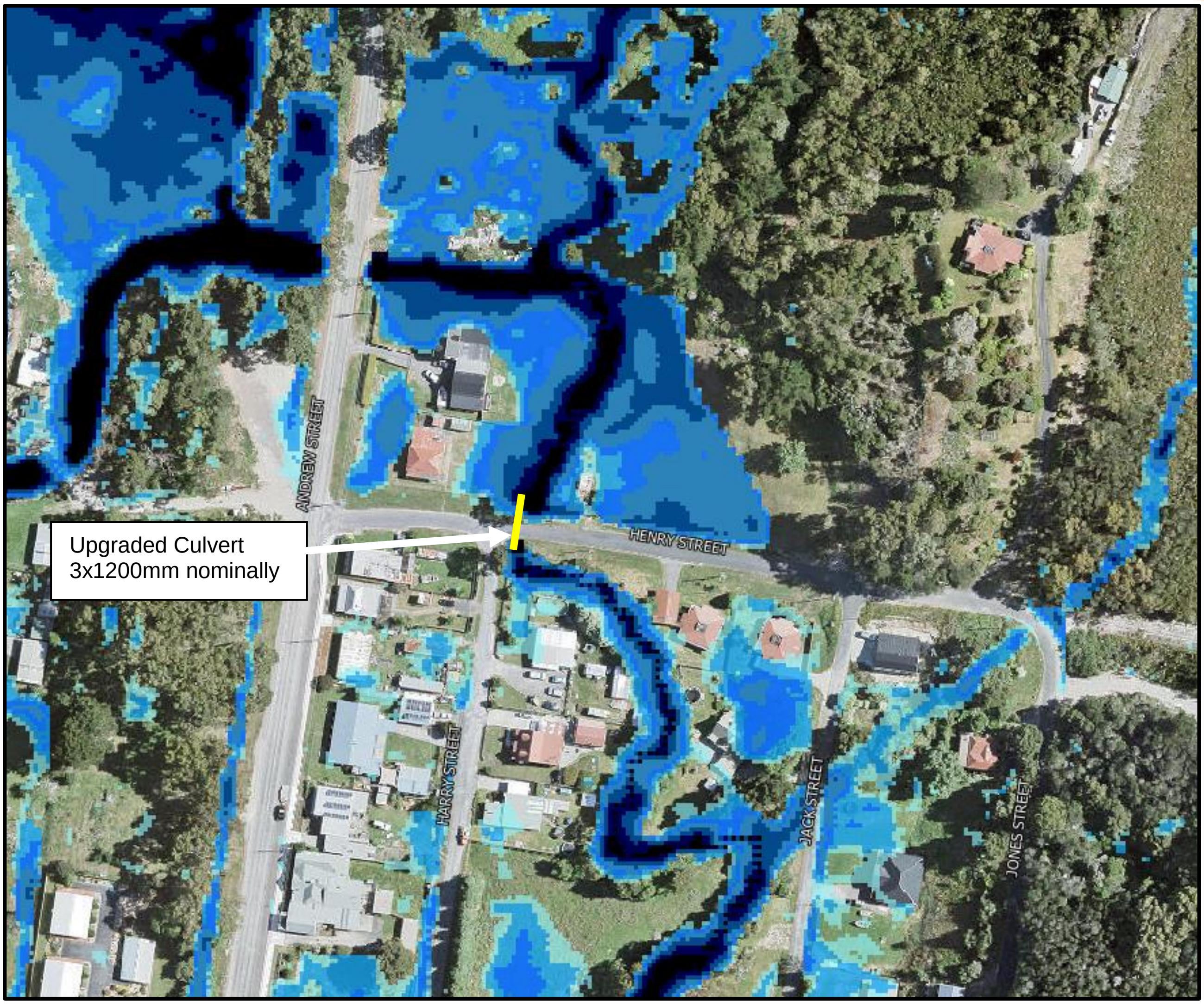

Figure 33: STR01 Henry Street Culvert Upgrade

STR02 Gaffney Street West Culvert Upgrade

The options assessment modelling undertaken for Gaffney Street West included a 3x1200mm culvert as per STR01. Results showed the following:

- A reduction in flood level behind the culvert in the main channel in the order of 200mm and 350mm for the 5% and 1% AEP events respectively. However, the low point in the street is west of the culvert, at this location the flood depth decreased marginally. This is likely due to water spilling over Henry Street and not flowing back to the main channel but rather following an adjacent path.
- Although marginal flood level reductions are observed on properties near Gaffney Street West (adjacent to Andrew Street) a more significant benefit is possible if both Henry Street and Gaffney Street West culverts were upgraded.
- Flood levels behind the Innes Street West culvert increased marginally in the order of 50mm in the 1% AEP event and no difference was observed in the 5% AEP event.

If this culvert is to be upgraded, then Henry Street culvert (STR01) should similarly be upgraded. An upgrade should consider:

- All considerations as per STR01, plus,
- Benefits of upgrading this culvert will be much more effective if the Henry Street culvert is upgraded also.

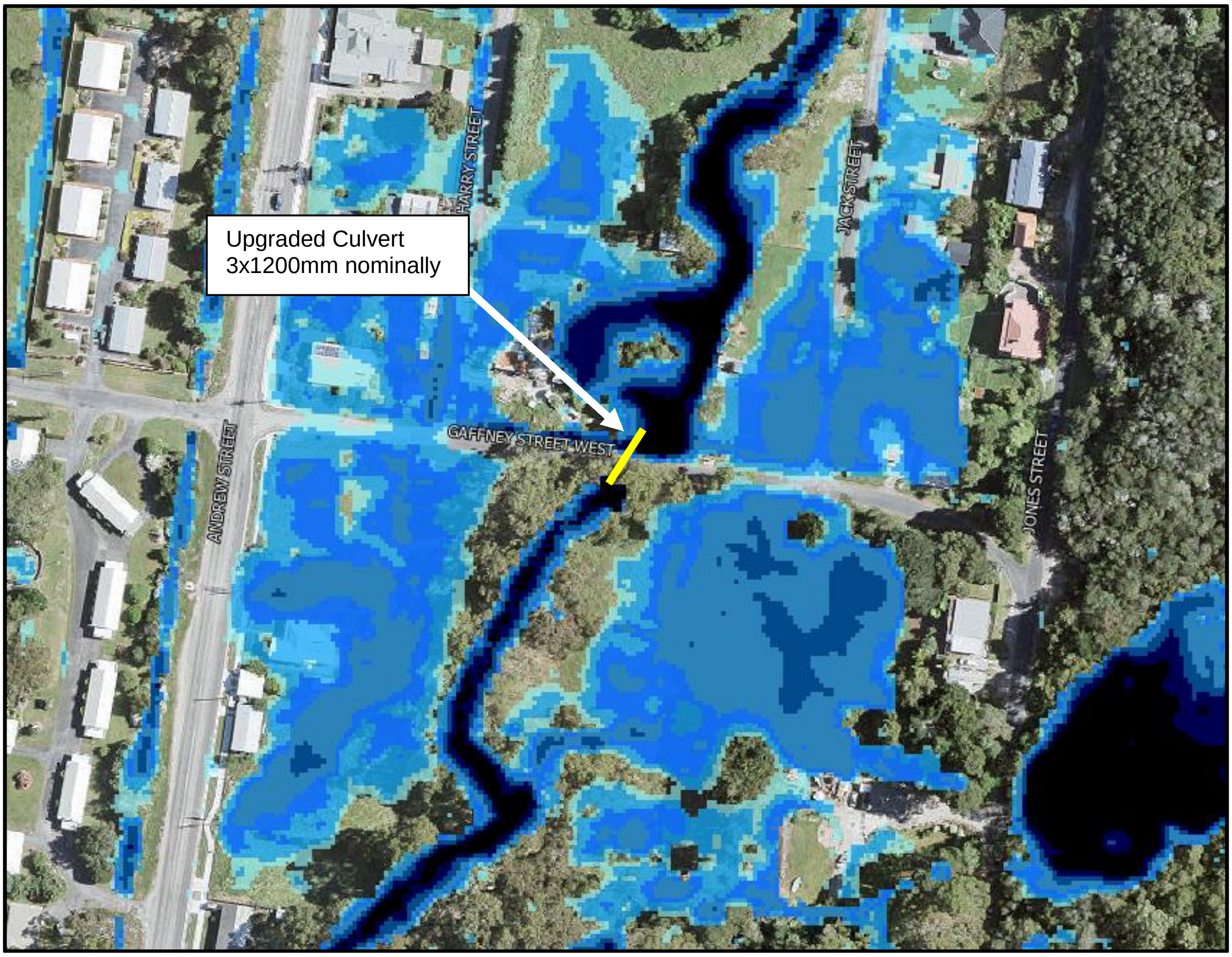

Figure 34: STR02 Gaffney Street West Culvert Upgrade

STR03 Innes Street Culvert Upgrade

The options assessment modelling undertaken for the Innes Street West culvert included a twin 2.44x1.2m box culvert. Results demonstrated the following:

- Upgrading the culvert at this location provided very little reduction in water level behind the culvert <100mm in both the 1% and 5% AEP events,
- The culvert capacity is constrained by the downstream tailwater levels, these levels are dictated by the creek capacity and the recently constructed footbridge at Beach Street,
- A more detailed assessment of the creek and footbridge may demonstrate a higher capacity along the creek, and as such, a culvert upgrade may provide a more substantial benefit.

Upgrading this culvert would only be recommended if:

- Further information was gathered regarding the creek downstream including the pedestrian bridge demonstrating that the culvert tailwater is lower than modelled (bearing in mind the high-level nature of the SSMP),
- STR01 and/or STR02 were implemented and it was necessary to upgrade this culvert to ensure non-worsening impacts on properties.

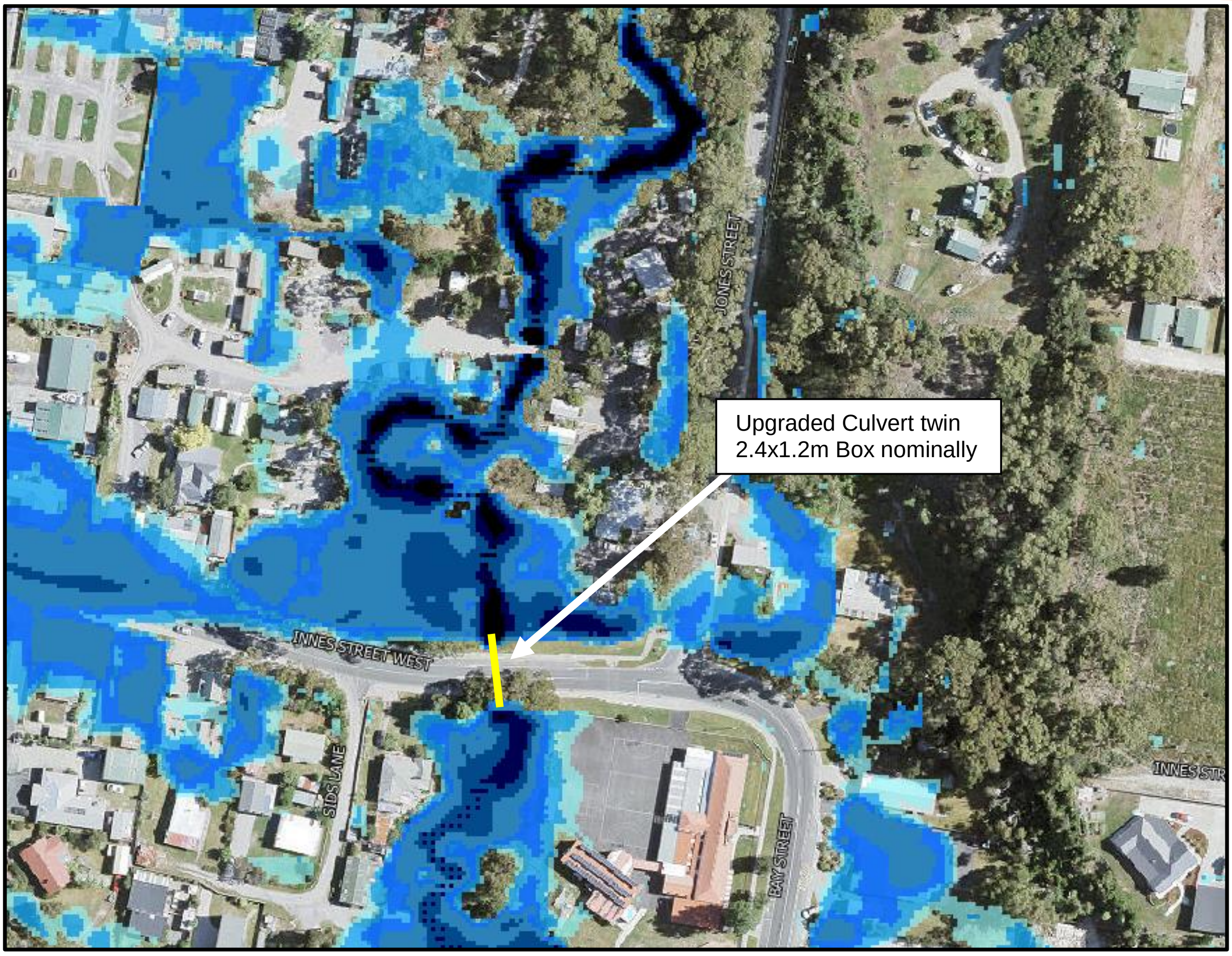

Figure 35: STR03 Innes Street West Culvert Upgrade

STR04 Manuka Creek Flood Levee / Bund Removal

This option included providing a small levee along the eastern side of the Manuka river from Harvey Street Bridge up to the Strahan Golf course, removing half of the bund protecting the wood storage area and raising the property access on the property east of the bunded area. The intent of this is to direct flood water to spill to the western side of the river and then across Harvey Street west of the Harvey Street Bridge. Results of this option assessment showed the following:

- A reduction in the number properties flooded and depth of flooding near the river between Gaffney Street West and Harvey Street,
- Backwater impacts still caused flooding in the areas noted above as the water level downstream of Harvey Street was still high enough to flow back north across Harvey Street at a low point just east of the bridge. It may be possible however, to lower the land past Harvey Street where the bunded area is and thus lower the water level by provided increased flood conveyance area.

It is recommended that structural flood mitigation options along the Manuka River floodplain be further pursued. There are several components to this option that should be investigated in detail to ensure the best approach is adopted. If implemented correctly, there is an opportunity to protect a significant proportion of West Strahan. The following actions/considerations are recommended:

- Explore in detail the STR04 mitigation option including investigating:
    - Eastern bank levee from Harvey to golf course,
    - Investigate cutting any protruding parts of the top of the western bank to enable preferential flooding to the western side of the river.

    - Removing all or part of the existing woodpile bund and lowering the landform in the vicinity to reduce water levels downstream of Harvey Street bridge,
    - Raising of the eastern approach of Harvey Street to prevent backwater flooding and or lowering of the western approach to lower upstream water levels (unlikely to be preferred as it is a DSG road),
- At the Henty Road Bridge crossing there is apparently a small levee that prevents water spilling along the eastern side of Henty Road. It is recommended that this is checked and formalised to direct floodwater across the road should the bridge be overtopped.
- Redirect floodplain flows from Andrew Street/Henty Road back across to the main Manuka River channel. The means to achieve this would be to provide a combination of bund/levee and channel earthworks. It would require:
    - A nominated earthwork height across the golf course sufficient to convey 1% AEP (or greater if preferred) flood water back to the main river channel,
    - The bund/levee would have to extend far enough up Andrew Street/Henty Road to ensure that that road acts a levee also and is not overtopped,
    - Providing small culverts to drain local flows (non-flood flows),
    - Redirecting this flood water would have the added benefit of reducing flows to the culverts in STR01, STR02 and STR03, this may negate need for culvert upgrades although STR01 culvert is recommended to be upgraded regardless.
    - There is significant uncertainty about the volume of floodwater that spills from Manuka River, this option could provide a large amount of redundant capacity where culvert upgrades would not.
- Drainage of any area confined by new levees or earthworks, it may be necessary to provide new drainage for the area near any levee such as the properties enclosed by, Harvey Street, Gaffney Street West and Meredith Streets.
- Backwater flows must be carefully considered, particularly through pipes when flood waters are high
- Although many properties may benefit from flood mitigation, it needs to be ensured that other properties are not negatively impacted by mitigation works.

The outcome of this option may impact the economic benefit of other options in the West Strahan area (namely culvert upgrades), it is recommended that this option be perused first.

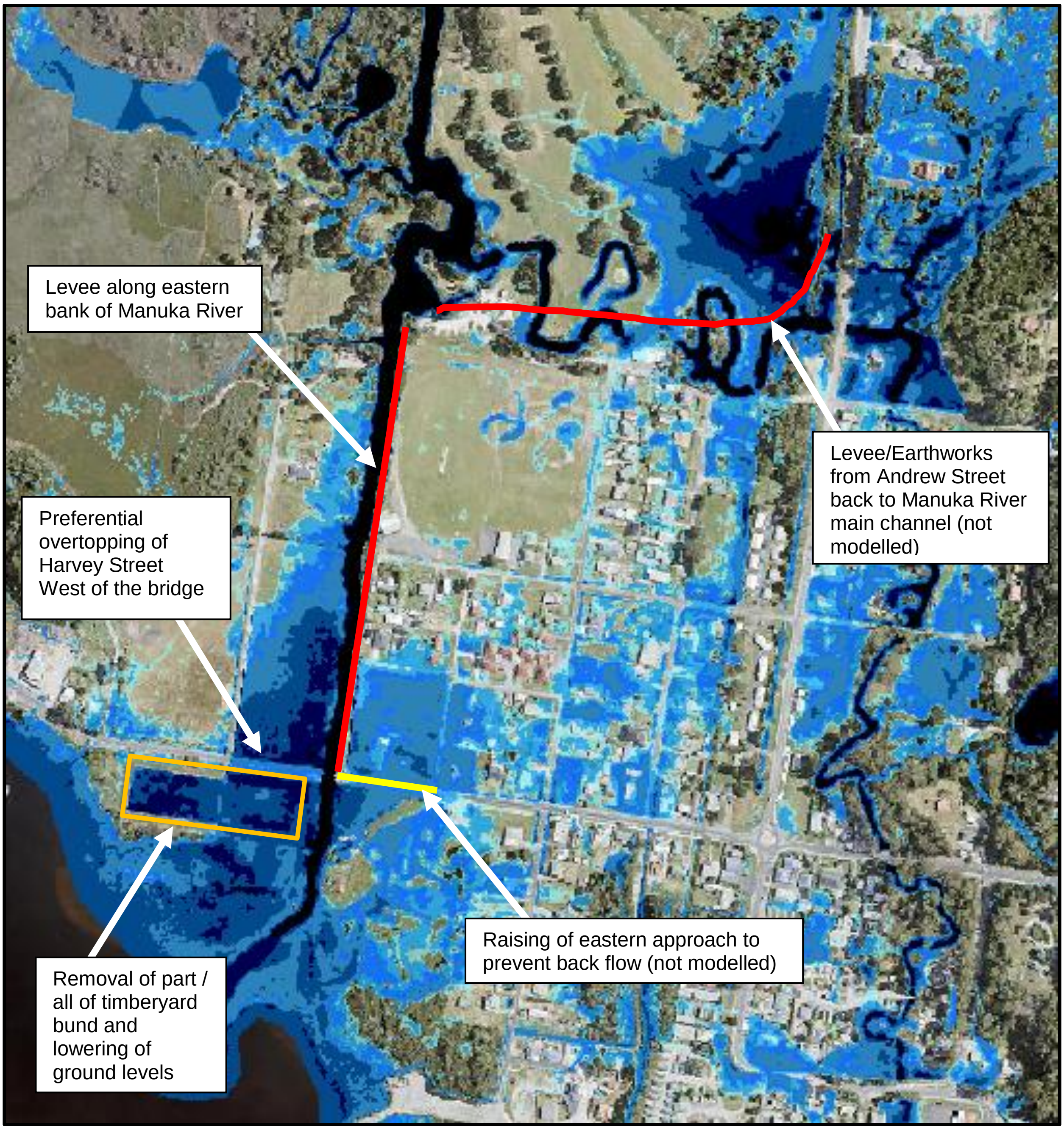

Figure 36: Structural Flood Mitigation Options Manuka River

STR05 Featherstone Creek Culvert Upgrade

Options assessment modelling for this culvert upgrade included widening the creek downstream to provide a larger conveyance area and lower the downstream tailwater. The level of the Esplanade is such that if the road is overtopped the backwater impacts flood multiple properties. There is also a pedestrian bridge immediately downstream of the road culvert which will impact water levels. Based on the results:

- A reduction in flood levels immediately upstream of the culvert was shown for both the 5% AEP and 1% AEP events (400mm and 200mm respectively), however these results should be treated with caution as the "existing case' model may underrepresent the capacity of the downstream channel and footbridge.

If this mitigation option is undertaken, the following should be carefully considered:

- A detailed investigation should clearly determine the geometry of both the downstream foot bridge and channel. It may have been underestimated in the existing case modelling,
- Significant widening of the channel both between the culvert and footbridge and past the footbridge could provide significant benefit without touching either structure,
- Consolidating the two structures into a single structure to reduce the headloss associated with the expansion and contraction between the crossings,

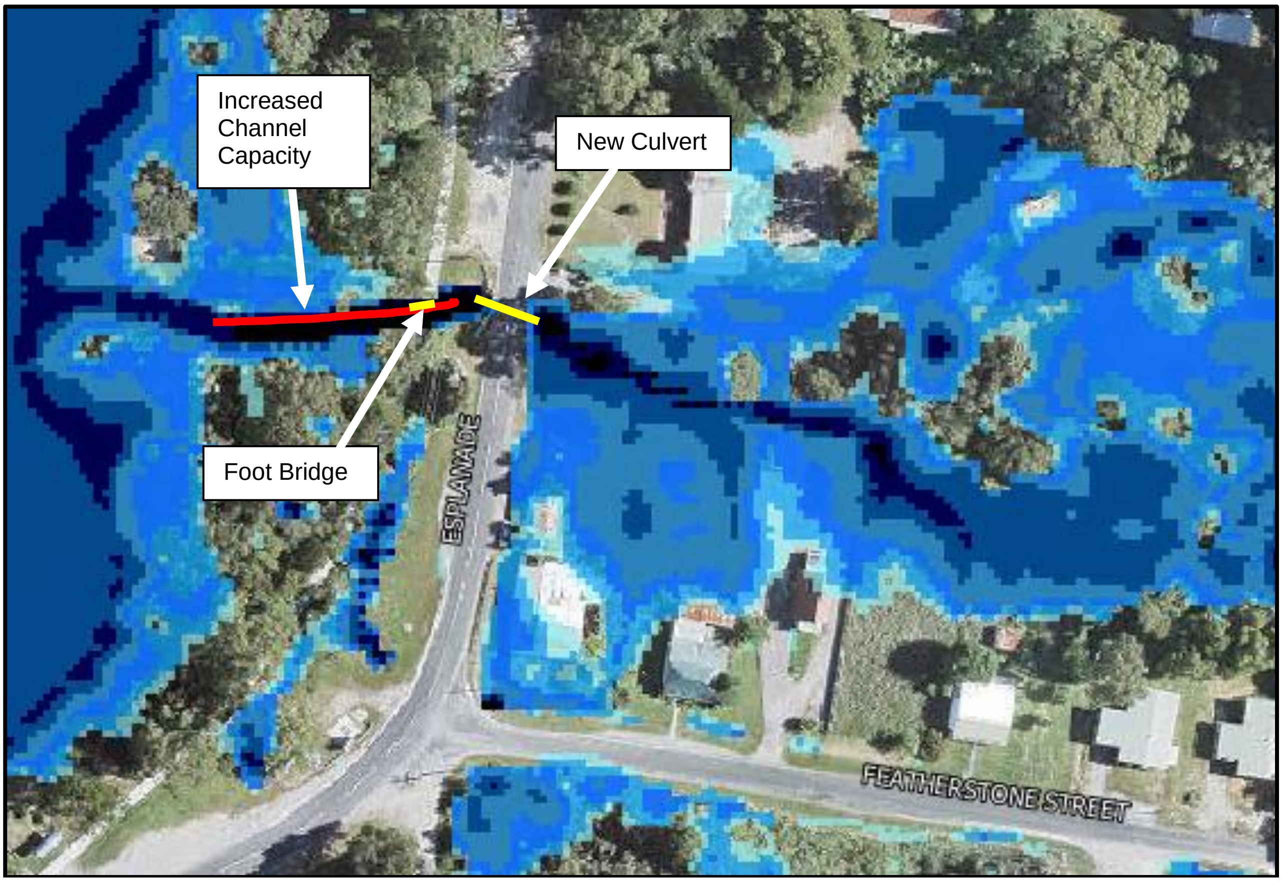

Figure 37: STR05 Upgraded Culvert and Channel Widening

STR06 Botanical Creek Levee and Culvert

Options assessment modelling for this arrangement included placing a raised levee / bund, cutting a drain at the bottom and providing a new culvert 750mm nominally under Esplanade Road (Figure 38). Results indicate the following:

- There is a noticeable decrease in flood level of 300-400mm for both the 1% and 5% AEP events,
- Five low lying properties on the northern side of the creek have reduced flood impacts
- Decreasing flood levels further would be difficult to achieve because of the downstream tailwater.

If this option is pursued, the following actions are recommended:

- Local discharge from behind any bund/levee that is directed overland will become trapped, potentially causing localised ponding. A suitable drainage system should be implemented to manage local runoff must not discharge through the bund as back flooding will occur.
- The culvert under the road should be as low as practical and must consider the high tailwater condition downstream when sizing the culvert.
- A drain is necessary on the property side of the bund to direct local drainage to the new road culvert.
- A similar arrangement on the southern side could provide flood protection for 2 properties.

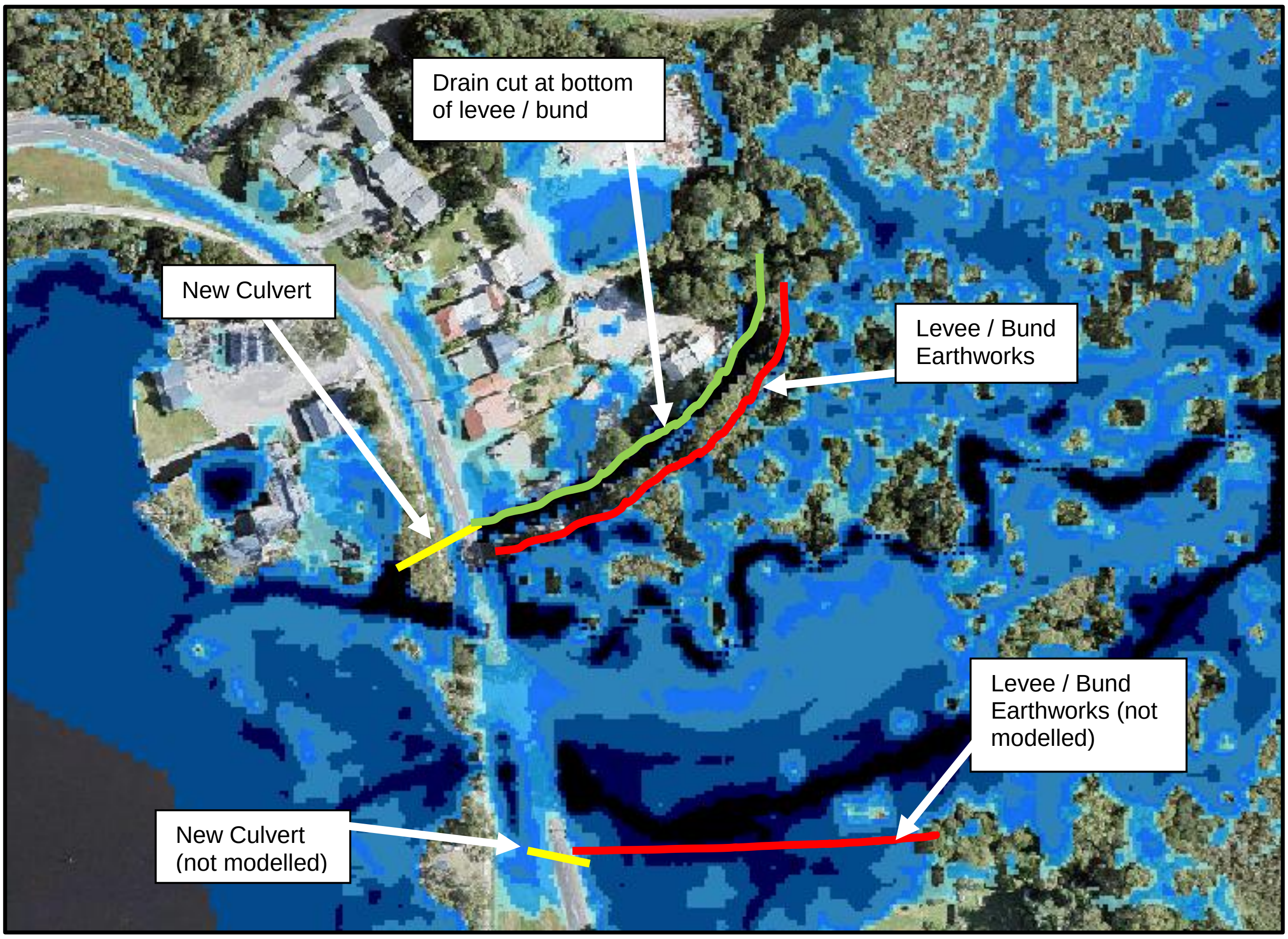

Figure 38: STR06 Flood Levee / Bund and Culvert

ZEE04 Wilson Street Levee and Pipes

Options assessment modelling for this arrangement included providing a levee along the edge of Wilson Street and a nominal 750mm new pipe arrangement discharging downstream of the Robinson Street bridge (Figure 39). The pipe upgrade is required to managed local stormwater that would have previously drainage overland to the creek. This is now blocked by the proposed flood levee. Results from this option showed:

- It is feasible to provide a levee and new pipe as flood protection with reduction in flood levels seen on the southern side of Wilson Street,
- The required size of the new pipe would to divert water is relatively large and given the length required is potentially expensive for the benefit it would provide.

This option is likely cost prohibitive. If it were to be undertaken the following would have to be considered:

- If this option is implemented without consideration of local hydraulic behaviour, there is the potential that the flooding issue may worse after implementing the option.
- The Robinson Street bridge and creek capacity may have been underestimated in this assessment, a more detailed survey may show greater capacity and reduced flood levels in this area of interest.
- The low point sag on the southern side of the creek is only marginally above the main creek level, meaning directing a pipe system to the creek is difficult.
- Any pipe from the southern side of the levee will backflow when the main creek level is high, thus the option assessment included a new pipe discharging downstream of Robinson Street bridge, the required pipe size would likely be 900mm plus diameter to provide a reasonable benefit.
- The existing incoming pipe networks could be retained / realigned up to the point where backwater flooding would become a problem, this may necessitate new plumbing connections for the low-lying areas.
- The volume of overland flow coming from the local catchment (not Zeehan Rivulet) is such that it will significantly flood the space behind the levee. Raising the levee has potential to make this worse if not considered.
- The above discussion and modelling is for one option to manage flooding in this location. Other solutions may be available and could be investigated further. These may be:
    - Review the upstream catchment and determine if parts can be directed elsewhere, reducing the extent of piped drainage required.
    - Fill in the low points behind the levee although this may affect existing properties

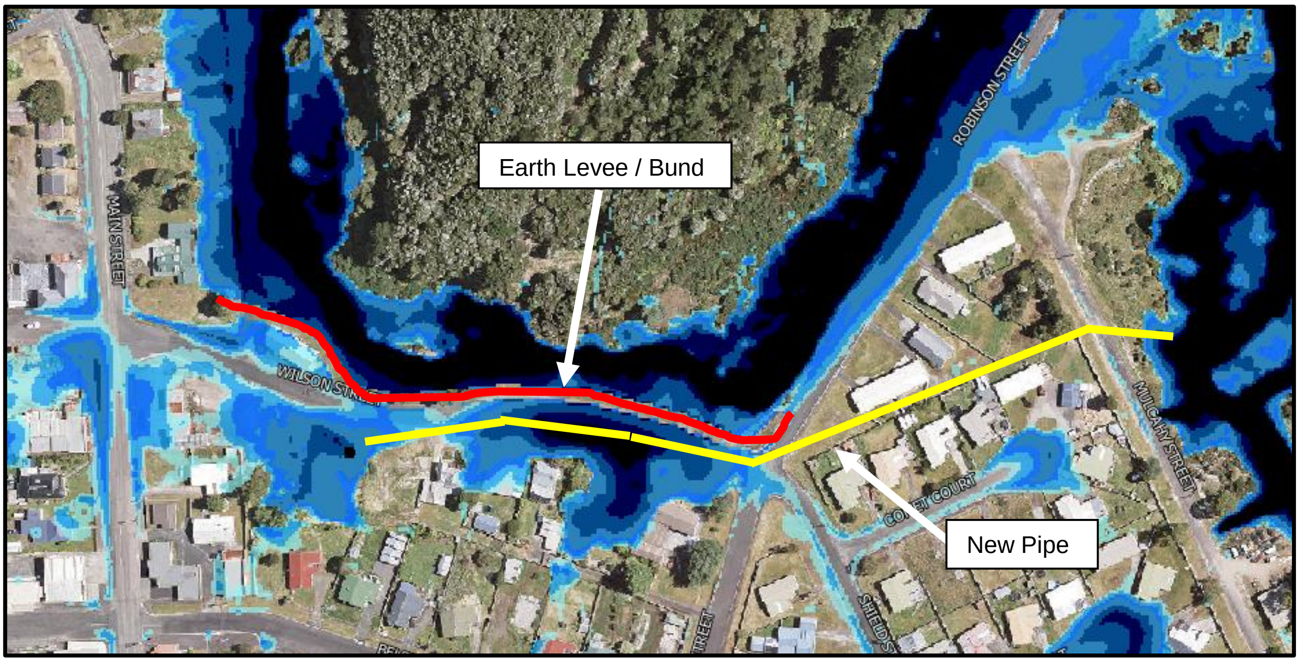

Figure 39: ZEE04 Flood Levee and Pipes

QUE01 Hunter Street Pipe Upgrade

Options assessment modelling was undertaken for an upgraded stormwater main down Hunter Street, the pipe was modelled as a 1500mm pipe culvert aimed at conveying the 5% AEP flood flow (Figure 40). Results showed the following:

- An approximately 1500mm circular pipe is sufficient to convey the 5% AEP event from the creek above,
- 1% AEP reductions in flooding down Hunter Street and spill to adjacent streets,
- A pipe suitable to convey the 1% AEP flow is estimated to be in the order of a twin DN1350 pipe or a single DN2100 pipe depending on the depth of the pipe,

This option should be considered as it could provide a significant reduction in flood risk. The following should be considered for a stormwater main upgrade:

- Underground drainage systems are usually designed for the 5% AEP (typical urban roads) although it is recommended that a larger storm such as the 1% AEP be considered as there is minimal area available for an overland flow path that can convey flow safely. Any overflow will likely be trapped by sags, potentially flooding property and businesses.
- The inlet hydraulic structure (Hunter/Bowes Street) is critical to ensure flows are captured and directed to the pipe, a debris assessment is recommended to understand blockage potential, a debris guard (upstream of the culvert and not over the inlet) may be suitable but may reduce the inlet capacity. *Australian Rainfall and Runoff 2019, Book 6, Chapter 6: Blockage of Hydraulic Structures* provides guidance on how to quantify blockage and possible treatment measures.
- The tailwater levels in the Queen River must be considered, as the same critical storm for the local catchment will also elevate flood levels in the Queen River significantly. Elevated levels in the Queen river will reduce the capacity of the piped system.
- If the stormwater main is upgraded then it presents an opportunity to connect new stormwater lines from Orr Street back to the new Hunter Street main, the purpose of these mains would be to convey excess floodwater away from the low points on Orr Street where flooding has occurred previously, if feasible it would likely require:
  - A series of extra-large stormwater inlet pits.
  - New mains back to the Hunter street main these would likely be much larger than nominal 300mm pipe.
  - Consideration of surcharge potential.
- Flow recapture (flow that bypasses the culvert inlet) infrastructure such as extra-large pits along Hunter Street would provide additional redundancy if the primary inlet was to block.
- Associated road design should consider the overland flow paths when overflow occurs, an appropriate geometric design (profile changes, kerbs etc) may help direct overflow to preferential paths such as down Hunter Street and not to Orr Street.
- Overland or surcharge flows will be trapped at several locations including behind Driffield Street and in the Rail Reserve. This should be considered in a stormwater main upgrade with infrastructure such as large gully pits considered to redirect flow to the pipe.
- Any new alignment or new connections should consider possible surcharge locations, surcharging at some pits may be undesirable and create new flooding problems.

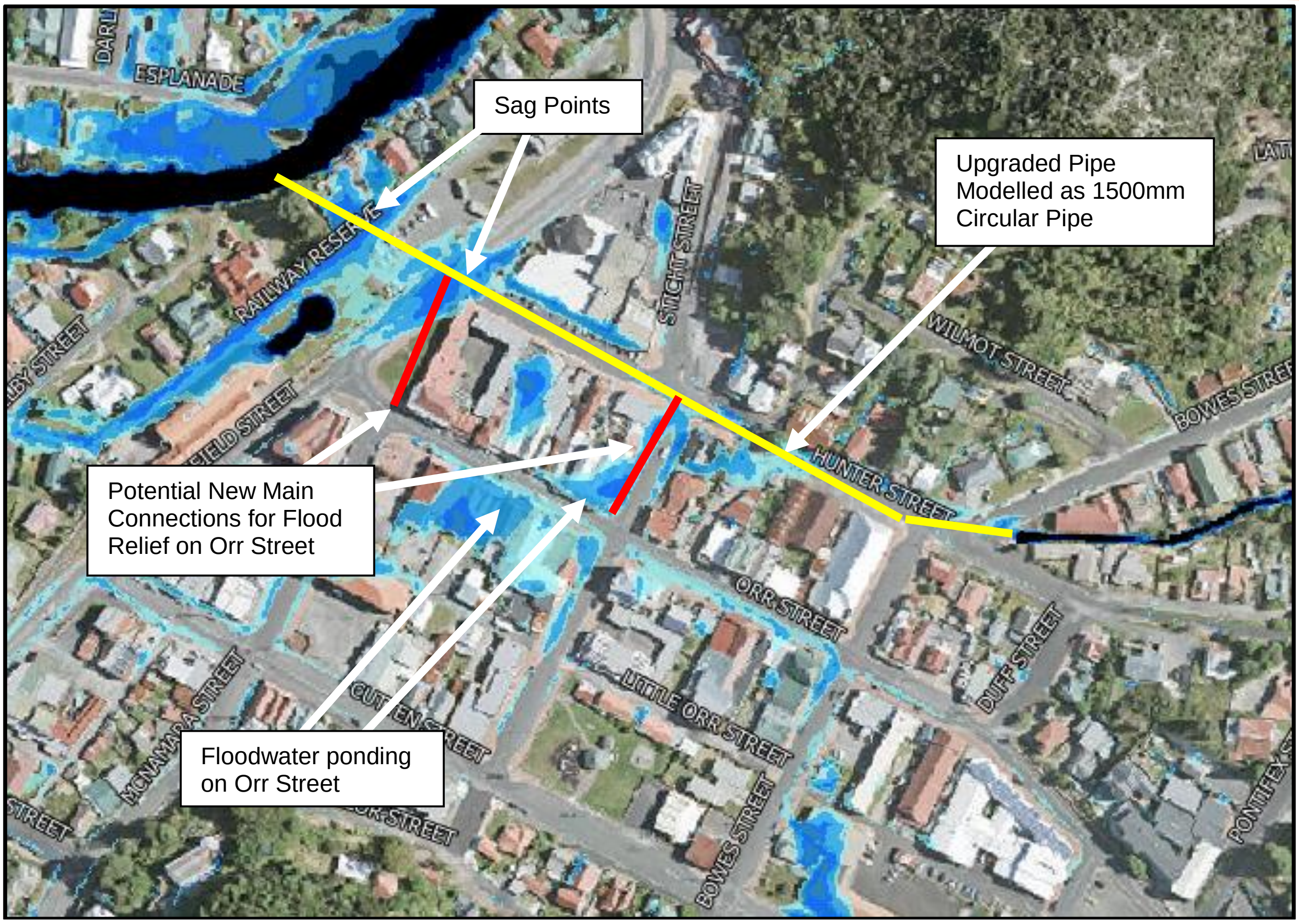

Figure 40: QUE01 Hunter Street Pipe Upgrade

QUE03 Wilsdon Street Bridge Upgrade Example Case

Options assessment modelling for the Wilsdon Street bridge was undertaken to demonstrate the opportunity and importance of hydraulic considerations for bridge renewals. The option assessed raising the bridge soffit to 148m AHD (from 147 m AHD) and the approaches to suit. The waterway way was widened around the bridge and the central pier was removed. Results showed the following:

- Significant reduction in flood levels immediately behind the bridge of approximately 700mm for both the 5% AEP and 1% AEP events.

Given the significant flood impacts of many of the Queen River bridges it is essential that all proposed bridges and bridge renewals require a hydraulic and flood assessment that considers the following:

- Improving flood conditions near flood impacted properties with appropriate designs.
- Ensuring there are not adverse effects to property from new or renewed bridges.
- Newly proposed bridges and culverts should consider the hydraulic implications of new crossings, low immunity pedestrian crossings for example have potential, if flood hydraulics are not considered, to significantly increase flood levels due to the constrictions of the superstructure and the guard rails in particular.
- Hydraulic capacity of existing bridges can be improved by stream widening but must incorporate bank stabilisation.
- All hydraulic aspects of the Australian Standards AS5100 - Bridge Design Set including but not limited to:
    - Scour potential and design velocities / shear stress for structural design (0.05% AEP (1 in 2000-year ARI event).
    - Debris potential and subsequent hydraulic loading.
    - Scour protection (1% AEP or nominated serviceability level).
    - Potential flood impacts of bridge.

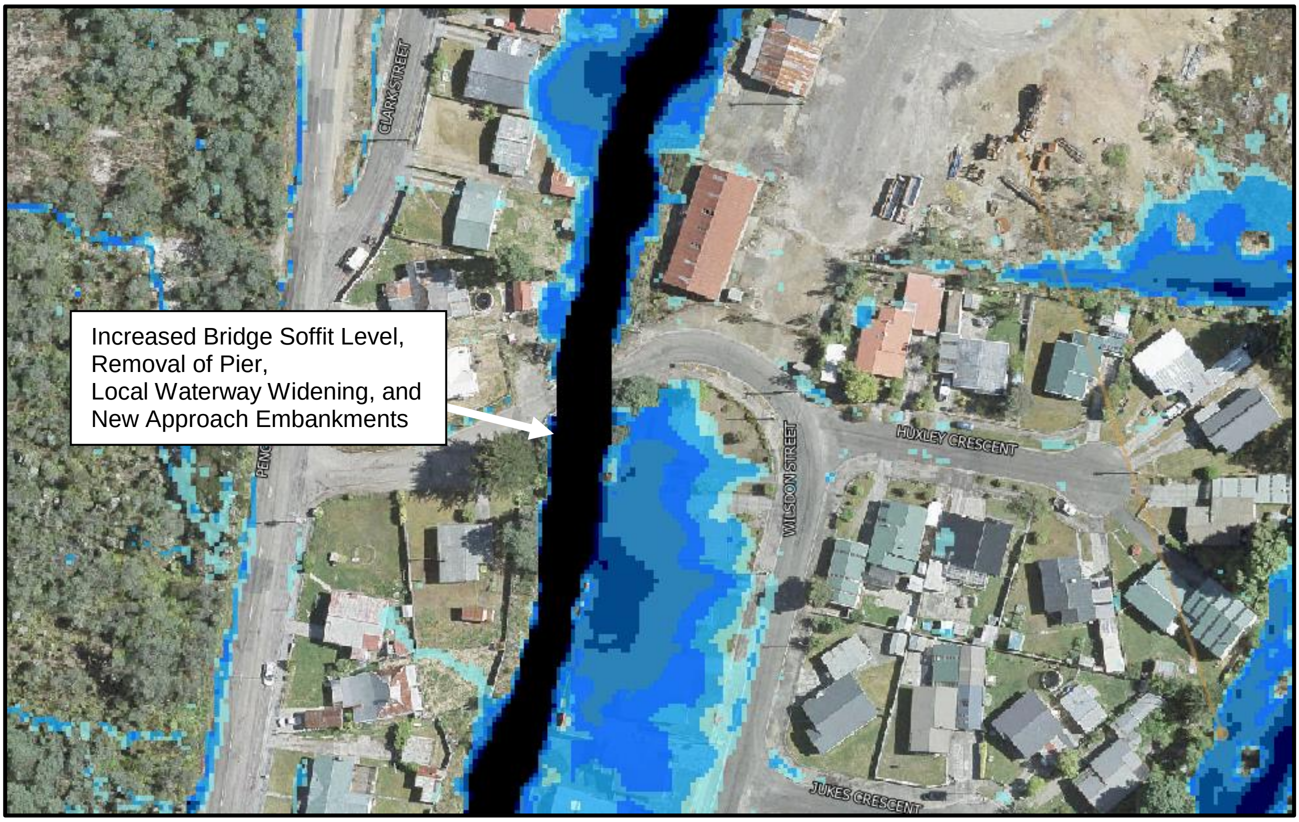

Figure 41: QUE03 Hydraulic Improvement Wilsdon Street Bridge Upgrade (Example Case)

ROS01 Pipe Network Upgrades Karlson to Clemons Street Area

Options assessment modelling was undertaken for a stormwater main upgrade from Read Street to the bottom of Karlson Street. The intent of this option is to capture two concentrated flow paths above Read Street and direct to a single pipe (nominally modelled as 750mm pipe to capture 5% AEP flows). Results indicate the following:

- For the 5% AEP event most of the overland flow is captured above Read Street in the pipes and approximately $1m^3/s$ is conveyed in the 750mm pipe.
- Ponding is still present in between Daumeny and Karlson Streets but an appropriate detailed design could mitigate most of this.

If any pipe upgrades are to be made in this area the following needs to be considered:

- Culvert / pipe inlet structures should be strategically located and shaped to allow maximum capture.
- The stormwater mains should preferably follow the general overland flow path to provide opportunities to recapture flows, this will also allow for small connections to a new main.
- Although not modelled, if a large stormwater main upgrade is undertaken then the following should accompany:
    - Strategically located stormwater capture pits
    - Road geometry improvements such as formalised kerb and driveway crossovers to direct overland flow along roads
- This is a single example of an upgraded main, there are many other possible arrangements to convey flood water and reduce flood risk. Factor such as constructability and maintenance should be considered when adopting a preferred alignment.
- Roadways can be used as flood conveyance in preference to the flooding of private property. Locations such as down Clemons Street provide opportunity to formalise and upgrade kerb and driveway crossovers to direct flow down the road. However, re-capturing flow from a roadway is more difficult that from a culvert for example.

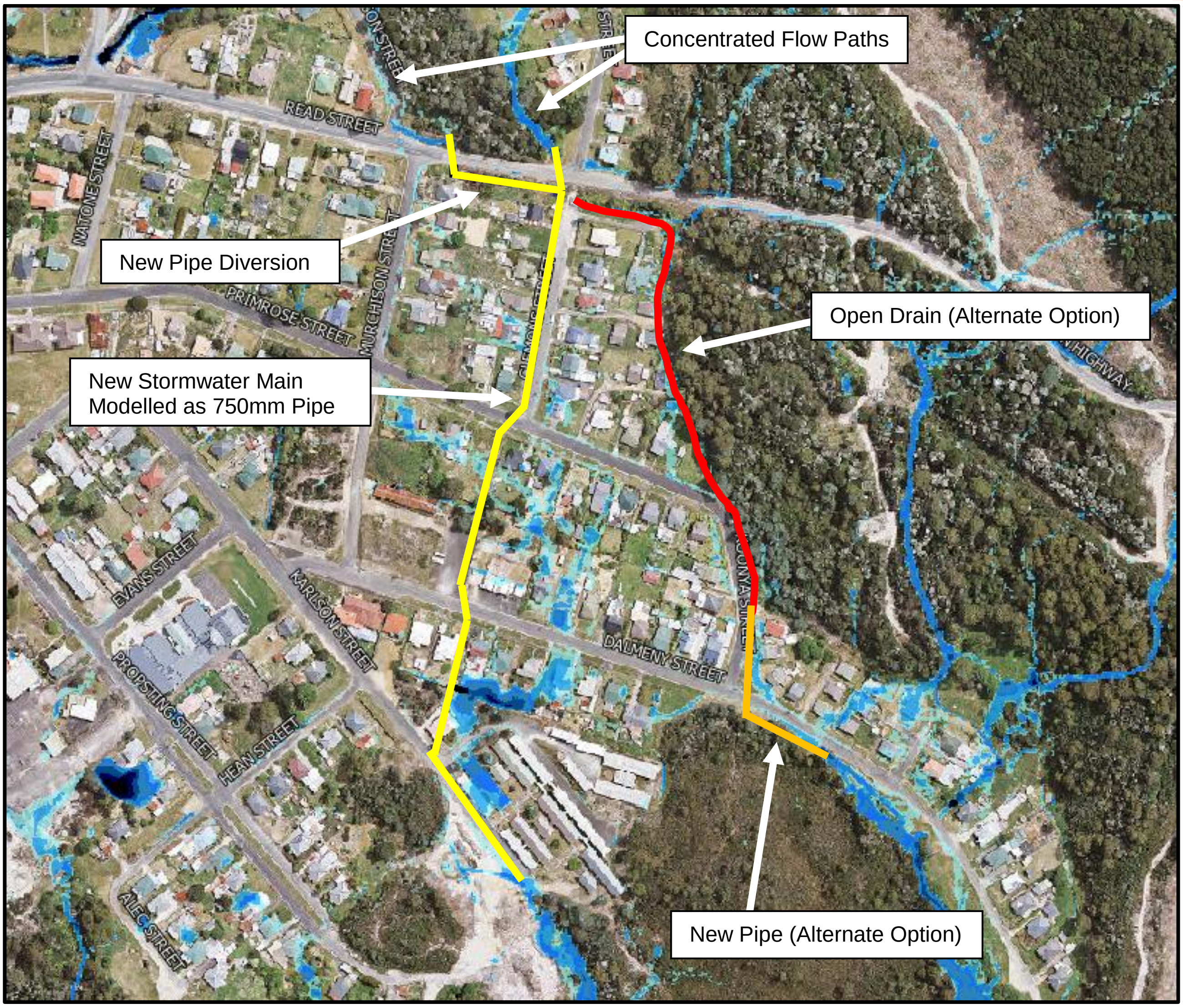

Figure 42: ROS01 Potential Pipe Upgrade Option

8.3.3 Preliminary Cost Estimate

For the flood management options assessed, a preliminary cost estimate has been prepared. These cost estimates are broad and represent an order of magnitude cost. Further design and investigation is required to confirm the true cost of these options. A summary of the cost estimate is provided below in Table 12.

Table 12: Preliminary Cost Estimate

Option ID	Option	Cost Estimate
STR01	Henry Culvert Upgrade	$240,000
STR02	Gaffney Street West Culvert Upgrade	$290,000
STR03	Innes Street West Culvert upgrade	$400,000
STR04*	Manuka Creek Flood Protection	$460,000
STR05	Featherstone Street Culvert Upgrade	$350,000
STR06	Esplande (Trafford to Vivian) culvert and levees	$320,000
ROS01	Stormwater Upgrades Between Clemons and Karlson Street	$800,000
QUE01	Hunter Street Pipe Upgrade	$1,400,000
ZEE04	Wilson Street Adjacent to Zeehan Rivulet	$980,000

**cost estimate is based on a bund being include across the golf course. Flood modelling was based on flood levee adjacent to Manuka Creek only.*

9. Summary

This report documents a flood study for urban areas within the West Coast Council LGA. It documents the technical analysis undertaken and forms the basis for the West Coast Council Stormwater System Management Plan (SSMP).

The intent of the study was to:

- Identify flood behaviour, especially overland flow paths
- Inform flood risk
- Quantification and estimation of the economic cost of flooding.
- Identify flood management measures suitable consideration in a forward capital works program.

The study has identified that flood damage and risk to life is primarily contained to the Queenstown (risk to life) and Strahan (flood damage). The reaming areas (Zeehan, Tullah and Rosebery) were found to have less severe flooding issues. It is recommended that the flooding issues be prioritised in the Queenstown and Strahan areas.

For the West Coast Council LGA, structural flood management measures were deemed to be the most appropriate flood risk management approach. The rate of development in the municipality is generally low meaning flood related development controls will have a lesser impact on reducing future flood risk.

Emergency response measures were not considered because the nature of most flooding in the study areas is short term or flash flooding. Hazardous flooding can develop in less 2 hours, it is unlikely that authorities and communities will be able to respond to flood events quickly enough.

Flood modification measures are options aimed at preventing, avoiding or reducing the likelihood of flood risks. These measures reduce the risk through modification of the flood behaviour in the catchment. Options considered were confined to overland flow modifications by way berms and kerb, pit and pipe upgrades and bridge hydraulic improvements.

Of the flood management options assessed, STR04 – Manuka Creek Flood Levee, and QUE03 – Bridge Hydraulic improvements stand out as the most effective stormwater management options.

Flood Model Validation

Appendix A

Design Event Flood Maps

Appendix B

Preliminary Cost Estimates

Appendix C

STR01 Henry Street Culvert Upgrade

DESCRIPTION	QUANTITY	UNIT	RATE $	AMOUNT $
PART 1 - PROJECT SPECIFIC ITEMS				
PART 1 - PROJECT SPECIFIC ITEMS CARRIED TO SUMMARY			**TOTAL $**	**0**
PART 2 - EARTHWORKS				
Excavation & Embankment				
Clearing and grubbing	150	m²	$25.00	3,750
Excavation in all materials	175	m³	$65.00	11,375
PART 2 - EARTHWORKS CARRIED TO SUMMARY			**TOTAL $**	**15,125**
PART 3 - DRAINAGE				
Culverts & Endwalls				
Removal of pipe > 600mm dia				
Under existing pavement (existing road culvert)	14.00	m	$180.00	2,520
Remove endwalls > 600mm dia	2	No.	$200.00	400
Headwall slab				
In-Situ concrete base slab with SL81 top and bottom. Include cutoff.	4	No.	$3,500.00	14,000
Surface Drainage				
Excavation of open channels (outlets / inlets)	82	m³	$40.00	3,280
Rock lining of open channels	125	m²	$40.00	5,000
PART 3 - DRAINAGE CARRIED TO SUMMARY			**TOTAL $**	**25,200**
PART 4 - PAVEMENT				
Construction				
Supply, spread and compact sub-base 2 material				
150 mm depth	55	m²	$35.00	1,925
Supply, spread and compact base material Class 3				
250 mm depth	55	m²	$30.00	1,650
Supply, spread and compact unsealed road and unsealed shoulder wearing surface				
Shoulder	55	m²	$10.00	550
Maintenance				
Saw Cutting of existing surface/pavement	14	m	$15.00	210
PART 4 - PAVEMENT CARRIED TO SUMMARY			**TOTAL $**	**4,335**

<u>PART 5 - BITUMINOUS SURFACING</u>				
New pavements				
Two Coat Sprayed Seal	55	m²	16.00	880
PART 5 - BITUMINOUS SURFACING				
CARRIED TO SUMMARY			**TOTAL $**	**880**
<u>PART 6 - TRAFFIC FACILITIES</u>				
Supply and installation of W-Beam Safety Barrier	100	m	120.00	12,000
Terminal	4	no.	4,700.00	18,800
PART 6 - TRAFFIC FACILITIES				
CARRIED TO SUMMARY			**TOTAL $**	**30,800**
<u>PART 8 - MISCELLANEOUS</u>				
Traffic Management	1	Item	$5,000.00	5,000
PART 8 - MISCELLANEOUS				
CARRIED TO SUMMARY			**TOTAL $**	**5,000**
<u>PART 9 - PRECAST UNITS</u>				
<u>EXCAVATION</u>				
Excavation	60	m3	$45.00	2,700
Supply, place and compact special fill	30	m3	$100.00	3,000
Extra over Item 9.03 for supply and placing 100 mm dia. Subsoil drain pipe with filter and aggregate surround	75	m	$60.00	4,500
<u>MANUFACTURE AND SUPPLY</u>				
<u>Supply of precast units</u>				
Supply of concrete base slabs (per 2.44m)	6	No.	$3,250.00	19,500
Construction of blinding concrete	50	m2	$70.00	3,500
Supply 3 cell, 1200 dia pipe culvert (per 1.22m)	12	No.	$2,500.00	30,000
Supply culvert headwalls	4	No.	$800.00	3,200
Delivery of Pre-cast units	1	No.	$15,000.00	15,000
<u>HANDLE AND PLACE</u>				
<u>Handle and place precast crown units on prepared base</u>				
Units greater than 3 m wide	12	No.	$1,000.00	12,000
<u>Handle and place precast slabs on prepared mortar bed slabs</u>				
Slabs greater than 3 m wide	6	No.	$1,000.00	6,000
<u>Handle and place precast wingwall units on prepared mortar bed units</u>				
Units greater than 2.4 m high	4	No.	$500.00	2,000
PART 9 - PRECAST UNITS				
CARRIED TO SUMMARY			**TOTAL $**	**101,400**

CULVERT UPGRADE

SUMMARY

	AMOUNT $
PART 1 - PROJECT SPECIFIC ITEMS	$0
PART 2 - EARTHWORKS	$15,125
PART 3 - DRAINAGE	$25,200
PART 4 - PAVEMENT	$4,335
PART 5 - BITUMINOUS SURFACING	$880
PART 6 - TRAFFIC FACILITIES	$30,800
PART 8 - MISCELLANEOUS	$5,000
PART 9 - PRECAST UNITS	$101,400

CULVERT UPGRADE	**SCHEDULE TOTAL**	**$182,740**
	PROJECT CONTINGENCY	**30%**
	OVERALL TOTAL	**$237,562.00**

ASSUMPTIONS

3x1200 pipe culvert

length = 13.8 m

area = 55 m2 (contingency)

STR02 Gaffney Street West Culvert Upgrade

DESCRIPTION	QUANTITY	UNIT	RATE $	AMOUNT $
PART 1 - PROJECT SPECIFIC ITEMS				
PART 1 - PROJECT SPECIFIC ITEMS CARRIED TO SUMMARY			**TOTAL $**	**0**
PART 2 - EARTHWORKS				
Excavation & Embankment				
Clearing and grubbing	200	m^2	$25.00	5,000
Excavation in all materials	225	m^3	$65.00	14,625
PART 2 - EARTHWORKS CARRIED TO SUMMARY			**TOTAL $**	**19,625**
PART 3 - DRAINAGE				
Culverts & Endwalls				
Removal of pipe > 600mm dia				
Under existing pavement (existing road culvert)	20.00	m	$180.00	3,600
Remove endwalls > 600mm dia	2	No.	$200.00	400
Headwall slab				
In-Situ concrete base slab with SL81 top and bottom. Include cutoff.	4	No.	$3,500.00	14,000
Surface Drainage				
Excavation of open channels (outlets / inlets)	82	m^3	$40.00	3,280
Rock lining of open channels	125	m^2	$40.00	5,000
PART 3 - DRAINAGE CARRIED TO SUMMARY			**TOTAL $**	**26,280**
PART 4 - PAVEMENT				
Construction				
Supply, spread and compact sub-base 2 material				
150 mm depth	75	m^2	$35.00	2,625
Supply, spread and compact base material Class 3				
250 mm depth	75	m^2	$30.00	2,250
Supply, spread and compact unsealed road and unsealed shoulder wearing surface				
Shoulder	75	m^2	$10.00	750
Maintenance				
Saw Cutting of existing surface/pavement	20	m	$15.00	300
PART 4 - PAVEMENT CARRIED TO SUMMARY			**TOTAL $**	**5,925**

<u>PART 5 - BITUMINOUS SURFACING</u>				
New pavements				
Two Coat Sprayed Seal	75	m²	16.00	1,200
PART 5 - BITUMINOUS SURFACING				
CARRIED TO SUMMARY			**TOTAL $**	**1,200**
<u>PART 6 - TRAFFIC FACILITIES</u>				
Supply and installation of W-Beam Safety Barrier	100	m	120.00	12,000
Terminal	4	no.	4,700.00	18,800
PART 6 - TRAFFIC FACILITIES				
CARRIED TO SUMMARY			**TOTAL $**	**30,800**
<u>PART 8 - MISCELLANEOUS</u>				
Traffic Management	1	Item	$5,000.00	5,000
PART 8 - MISCELLANEOUS				
CARRIED TO SUMMARY			**TOTAL $**	**5,000**
<u>PART 9 - PRECAST UNITS</u>				
<u>EXCAVATION</u>				
Excavation	60	m3	$45.00	2,700
Supply, place and compact special fill	30	m3	$100.00	3,000
Extra over Item 9.03 for supply and placing 100 mm dia. Subsoil drain pipe with filter and aggregate surround	75	m	$60.00	4,500
<u>MANUFACTURE AND SUPPLY</u>				
<u>Supply of precast units</u>				
Supply of concrete base slabs (per 2.44m)	9	No.	$3,250.00	29,250
Construction of blinding concrete	50	m2	$70.00	3,500
Supply 3 cell, 1200 dia pipe culvert (per 1.22m)	17	No.	$2,500.00	42,500
Supply culvert headwalls	4	No.	$800.00	3,200
Delivery of Pre-cast units	1	No.	$15,000.00	15,000
<u>HANDLE AND PLACE</u>				
<u>Handle and place precast crown units on prepared base</u>				
Units greater than 3 m wide	17	No.	$1,000.00	17,000
<u>Handle and place precast slabs on prepared mortar bed slabs</u>				
Slabs greater than 3 m wide	9	No.	$1,000.00	9,000
<u>Handle and place precast wingwall units on prepared mortar bed units</u>				
Units greater than 2.4 m high	4	No.	$500.00	2,000
PART 9 - PRECAST UNITS				
CARRIED TO SUMMARY			**TOTAL $**	**131,650**

CULVERT UPGRADE

SUMMARY

	AMOUNT $
PART 1 - PROJECT SPECIFIC ITEMS	$0
PART 2 - EARTHWORKS	$19,625
PART 3 - DRAINAGE	$26,280
PART 4 - PAVEMENT	$5,925
PART 5 - BITUMINOUS SURFACING	$1,200
PART 6 - TRAFFIC FACILITIES	$30,800
PART 8 - MISCELLANEOUS	$5,000
PART 9 - PRECAST UNITS	$131,650

CULVERT UPGRADE	**SCHEDULE TOTAL**	**$220,480**
	PROJECT CONTINGENCY	**30%**
	OVERALL TOTAL	**$286,624.00**

ASSUMPTIONS

3x1200 pipe culvert

length = 19.8 m

area = 75 m2 (contingency)

STR03 Innes Street Culvert Upgrade

DESCRIPTION	QUANTITY	UNIT	RATE	AMOUNT
DESCRIPTION	QUANTITY	UNIT	RATE $	AMOUNT $
PART 1 - PROJECT SPECIFIC ITEMS				
PART 1 - PROJECT SPECIFIC ITEMS CARRIED TO SUMMARY			**TOTAL $**	**0**
PART 2 - EARTHWORKS				
Excavation & Embankment				
Clearing and grubbing	325	m²	$25.00	8,125
Excavation in all materials	350	m³	$65.00	22,750
PART 2 - EARTHWORKS CARRIED TO SUMMARY			**TOTAL $**	**30,875**
PART 3 - DRAINAGE				
Culverts & Endwalls				
Removal of pipe > 600mm dia				
Under existing pavement (existing road culvert)	25.00	m	$180.00	4,500
Remove endwalls > 600mm dia	2	No.	$200.00	400
Headwall slab				
In-Situ concrete base slab with SL81 top and bottom. Include cutoff.	4	No.	$3,500.00	14,000
Surface Drainage				
Excavation of open channels (outlets / inlets)	82	m³	$40.00	3,280
Rock lining of open channels	125	m²	$40.00	5,000
PART 3 - DRAINAGE CARRIED TO SUMMARY			**TOTAL $**	**27,180**
PART 4 - PAVEMENT				
Construction				
Supply, spread and compact sub-base 2 material				
150 mm depth	120	m²	$35.00	4,200
Supply, spread and compact base material Class 3				
250 mm depth	120	m²	$30.00	3,600
Supply, spread and compact unsealed road and unsealed shoulder wearing surface				
Shoulder	120	m²	$10.00	1,200
Maintenance				
Saw Cutting of existing surface/pavement	25	m	$15.00	375
PART 4 - PAVEMENT				

<u>PART 5 - BITUMINOUS SURFACING</u>				
New pavements				
Two Coat Sprayed Seal	120	m²	16.00	1,920
PART 5 - BITUMINOUS SURFACING				
CARRIED TO SUMMARY			**TOTAL $**	**1,920**
<u>PART 6 - TRAFFIC FACILITIES</u>				
Supply and installation of W-Beam Safety Barrier	100	m	120.00	12,000
Terminal	4	no.	4,700.00	18,800
PART 6 - TRAFFIC FACILITIES				
CARRIED TO SUMMARY			**TOTAL $**	**30,800**
<u>PART 8 - MISCELLANEOUS</u>				
Traffic Management	1	Item	$5,000.00	5,000
PART 8 - MISCELLANEOUS				
CARRIED TO SUMMARY			**TOTAL $**	**5,000**
<u>PART 9 - PRECAST UNITS</u>				
<u>EXCAVATION</u>				
Excavation	60	m3	$45.00	2,700
Supply, place and compact special fill	30	m3	$100.00	3,000
Extra over Item 9.03 for supply and placing 100 mm dia. Subsoil drain pipe with filter and aggregate surround	75	m	$60.00	4,500
<u>MANUFACTURE AND SUPPLY</u>				
<u>Supply of precast units</u>				
Supply of concrete base slabs (per 2.44m)	10	No.	$5,500.00	55,000
Construction of blinding concrete	50	m2	$70.00	3,500
Supply twin 2.44 x 1.2m box culvert (per 1.22m)	20	No.	$4,000.00	80,000
Supply culvert headwalls	4	No.	$800.00	3,200
Delivery of Pre-cast units	1	No.	$15,000.00	15,000
<u>HANDLE AND PLACE</u>				
<u>Handle and place precast crown units on prepared base</u>				
Units greater than 3 m wide	20	No.	$1,000.00	20,000
<u>Handle and place precast slabs on prepared mortar bed slabs</u>				
Slabs greater than 3 m wide	10	No.	$1,000.00	10,000
<u>Handle and place precast wingwall units on prepared mortar bed units</u>				
Units greater than 2.4 m high	4	No.	$500.00	2,000
PART 9 - PRECAST UNITS				
CARRIED TO SUMMARY			**TOTAL $**	**198,900**

CULVERT UPGRADE

SUMMARY

	AMOUNT $
PART 1 - PROJECT SPECIFIC ITEMS	$0
PART 2 - EARTHWORKS	$30,875
PART 3 - DRAINAGE	$27,180
PART 4 - PAVEMENT	$9,375
PART 5 - BITUMINOUS SURFACING	$1,920
PART 6 - TRAFFIC FACILITIES	$30,800
PART 8 - MISCELLANEOUS	$5,000
PART 9 - PRECAST UNITS	$198,900

CULVERT UPGRADE	**SCHEDULE TOTAL**	**$304,050**
	PROJECT CONTINGENCY	**30%**
	OVERALL TOTAL	**$395,265.00**

ASSUMPTIONS

twin 2.44x1.2m box culvert

length = 24.4 m

area = 120 m2 (contingency)

STR04 Manuka Creek Flood Levee / Bund Removal

DESCRIPTION	QUANTITY	UNIT	RATE $	AMOUNT $
PART 1 - PROJECT SPECIFIC ITEMS				
Provision for difficulty (Manuka River levee)				8,500
PART 1 - PROJECT SPECIFIC ITEMS				
CARRIED TO SUMMARY			**TOTAL $**	**8,500**
PART 2 - EARTHWORKS				
Excavation & Embankment				
Existing timberyard bund				
Clearing and grubbing	1500	m²	$20.00	30,000
Excavate half of timberyard bund	1430	m³	$15.00	21,450
Lowering ground levels in vicinity (500mm)	1000	m³	$10.00	10,000
Topsoil reinstatement	2430	m²	$7.00	17,010
New flood levees				
Clearing and grubbing	2500	m²	$20.00	50,000
Excavate topsoil	420	m³	$6.00	2,520
Foundation improvement (compaction & trim)	2500	m²	$4.00	10,000
Clay Core	2100	m³	$50.00	105,000
Embankment placement (fill)	700	m³	$100.00	70,000
Topsoil reinstatement	2800	m²	$7.00	19,600
PART 2 - EARTHWORKS				
CARRIED TO SUMMARY			**TOTAL $**	**335,580**
PART 8 - MISCELLANEOUS				
Traffic Management	1	Item	$5,000.00	5,000
PART 8 - MISCELLANEOUS				
CARRIED TO SUMMARY			**TOTAL $**	**5,000**

FLOOD LEVEE / BUND REMOVAL

SUMMARY

	AMOUNT $
PART 1 - PROJECT SPECIFIC ITEMS	$8,500

PART 2 - EARTHWORKS	$335,580
PART 8 - MISCELLANEOUS	$5,000

CULVERT UPGRADE	**SCHEDULE TOTAL**	**$349,080**
	PROJECT CONTINGENCY	**30%**
	OVERALL TOTAL	**$453,804.00**

ASSUMPTIONS

excludes raising of eastern access road
678m long embankment levee (1.5m wide)
450m long top levee (4m wide)
existing timberyard bund 1m high and 10m wide
assume clay core 3/4 of levee volume
both levees assume 1m high

STR05 Featherstone Creek Culvert Upgrade

DESCRIPTION	QUANTITY	UNIT	RATE $	AMOUNT $
PART 1 - PROJECT SPECIFIC ITEMS				
Provision for difficulty (removal of existing box culvert)				2,500
PART 1 - PROJECT SPECIFIC ITEMS CARRIED TO SUMMARY			**TOTAL $**	**2,500**
PART 2 - EARTHWORKS				
Excavation & Embankment				
Clearing and grubbing	550	m^2	$22.00	12,100
Excavation in all materials	600	m^3	$62.00	37,200
Channel widening				
Widening of downstream channel (cut)	200	m^3	$65.00	13,000
Foundation improvement (compaction & trim)	200	m^2	$6.00	1,200
Reinstatement	200	m^2	$9.00	1,800
PART 2 - EARTHWORKS CARRIED TO SUMMARY			**TOTAL $**	**65,300**
PART 3 - DRAINAGE				
Culverts & Endwalls				
Removal of box > 600mm dia				
Under existing pavement (existing road culvert)	13.00	m	$200.00	2,600
Remove endwalls > 600mm dia	2	No.	$200.00	400
Headwall slab				
In-Situ concrete base slab with SL81 top and bottom. Include cutoff.	4	No.	$3,500.00	14,000
Surface Drainage				
Excavation of open channels (outlets / inlets)	82	m^3	$40.00	3,280
Rock lining of open channels	125	m^2	$40.00	5,000
PART 3 - DRAINAGE CARRIED TO SUMMARY			**TOTAL $**	**25,280**
PART 4 - PAVEMENT				
Construction				
Supply, spread and compact sub-base 2 material				
150 mm depth	55	m^2	$35.00	1,925
Supply, spread and compact base material Class 3				
250 mm depth	55	m^2	$30.00	1,650

Supply, spread and compact unsealed road and unsealed shoulder wearing surface				
Shoulder	55	m²	$10.00	550
New footbridge	20	m²	$800.00	16,000
Maintenance				
Saw Cutting of existing surface/pavement	13	m	$15.00	195
PART 4 - PAVEMENT				
CARRIED TO SUMMARY			**TOTAL $**	**20,320**
PART 5 - BITUMINOUS SURFACING				
New pavements				
Two Coat Sprayed Seal	55	m²	16.00	880
PART 5 - BITUMINOUS SURFACING				
CARRIED TO SUMMARY			**TOTAL $**	**880**
PART 6 - TRAFFIC FACILITIES				
Supply and installation of W-Beam Safety Barrier	100	m	120.00	12,000
Terminal	4	no.	4,700.00	18,800
PART 6 - TRAFFIC FACILITIES				
CARRIED TO SUMMARY			**TOTAL $**	**30,800**
PART 8 - MISCELLANEOUS				
Traffic Management	1	Item	$5,000.00	5,000
PART 8 - MISCELLANEOUS				
CARRIED TO SUMMARY			**TOTAL $**	**5,000**
PART 9 - PRECAST UNITS				
EXCAVATION				
Excavation	60	m3	$45.00	2,700
Supply, place and compact special fill	30	m3	$100.00	3,000
Extra over Item 9.03 for supply and placing 100 mm dia. Subsoil drain pipe with filter and aggregate surround	75	m	$60.00	4,500
MANUFACTURE AND SUPPLY				
Supply of precast units				
Supply of concrete base slabs (per 2.44m)	6	No.	$5,250.00	31,500
Construction of blinding concrete	50	m2	$70.00	3,500
Supply twin 2.1 x 1.2m box culvert (per 1.22m)	11	No.	$3,750.00	41,250
Supply culvert headwalls	4	No.	$800.00	3,200
Delivery of Pre-cast units	1	No.	$15,000.00	15,000
HANDLE AND PLACE				
Handle and place precast crown units on prepared base				
Units greater than 3 m wide	11	No.	$1,000.00	11,000

Handle and place precast slabs on prepared mortar bed slabs				
Slabs greater than 3 m wide	6	No.	$1,000.00	6,000
Handle and place precast wingwall units on prepared mortar bed units				
Units greater than 2.4 m high	2	No.	$500.00	1,000

PART 9 - PRECAST UNITS
CARRIED TO SUMMARY **TOTAL $** **122,650**

CULVERT UPGRADE & CHANNEL WIDENING

SUMMARY

	AMOUNT $
PART 1 - PROJECT SPECIFIC ITEMS	$2,500
PART 2 - EARTHWORKS	$65,300
PART 3 - DRAINAGE	$25,280
PART 4 - PAVEMENT	$20,320
PART 5 - BITUMINOUS SURFACING	$880
PART 6 - TRAFFIC FACILITIES	$30,800
PART 8 - MISCELLANEOUS	$5,000
PART 9 - PRECAST UNITS	$122,650

CULVERT UPGRADE	**SCHEDULE TOTAL**	**$272,730**
	PROJECT CONTINGENCY	**30%**
	OVERALL TOTAL	**$354,549.00**

ASSUMPTIONS

existing 2.1 x 1.2m culvert
channel widening extent (assume 1m widening each side)
footbridge alterations (have just costed price for a new one)
new culvert dual cell, 2.1 x 1.2m culvert

STR06 Botanical Creek Levee and Culvert

DESCRIPTION	QUANTITY	UNIT	RATE $	AMOUNT $
PART 1 - PROJECT SPECIFIC ITEMS				
PART 1 - PROJECT SPECIFIC ITEMS				
CARRIED TO SUMMARY			**TOTAL $**	**0**
PART 2 - EARTHWORKS				
Excavation & Embankment				
Culvert				
Clearing and grubbing	500	m^2	$22.00	11,000
Excavation in all materials	550	m^3	$62.00	34,100
Levee				
Clearing and grubbing	600	m^2	$20.00	12,000
Excavate topsoil	65	m^3	$8.00	520
Foundation improvement (compaction & trim)	420	m^2	$6.00	2,520
Clay Core	315	m^3	$50.00	15,750
Embankment placement (fill)	105	m^3	$100.00	10,500
Topsoil reinstatement	420	m^2	$8.00	3,360
PART 2 - EARTHWORKS				
CARRIED TO SUMMARY			**TOTAL $**	**89,750**
PART 3 - DRAINAGE				
Culverts & Endwalls				
Removal of pipe ≤ 600mm dia				
Under existing pavement (existing road culvert)	30.00	m	$150.00	4,500
Remove endwalls ≤ 600mm dia	2	No.	$100.00	200
Headwall slab				
In-Situ concrete base slab with SL81 top and bottom. Include cutoff.	2	No.	$3,500.00	7,000
Surface Drainage				
Excavation of open channels (outlets / inlets) including drain cut at levee bottom	200	m^3	$40.00	8,000
Rock lining of open channels	125	m^2	$40.00	5,000
Reinstatement of drain cut grass	500	m^2	$9.00	4,500
PART 3 - DRAINAGE				
CARRIED TO SUMMARY			**TOTAL $**	**29,200**
PART 4 - PAVEMENT				
Construction				
Supply, spread and compact sub-base 2 material				

150 mm depth	30	m²	$35.00	1,050
Supply, spread and compact base material Class 3				
250 mm depth	30	m²	$30.00	900
Supply, spread and compact unsealed road and unsealed shoulder wearing surface				
Shoulder	30	m²	$10.00	300
Maintenance				
Saw Cutting of existing surface/pavement	30	m	$15.00	450
PART 4 - PAVEMENT CARRIED TO SUMMARY			**TOTAL $**	**2,700**
PART 5 - BITUMINOUS SURFACING				
New pavements				
Two Coat Sprayed Seal	30	m²	16.00	480
PART 5 - BITUMINOUS SURFACING CARRIED TO SUMMARY			**TOTAL $**	**480**
PART 6 - TRAFFIC FACILITIES				
Supply and installation of W-Beam Safety Barrier	100	m	120.00	12,000
Terminal	4	no.	4,700.00	18,800
PART 6 - TRAFFIC FACILITIES CARRIED TO SUMMARY			**TOTAL $**	**30,800**
PART 8 - MISCELLANEOUS				
Traffic Management	1	Item	$5,000.00	5,000
PART 8 - MISCELLANEOUS CARRIED TO SUMMARY			**TOTAL $**	**5,000**
PART 9 - PRECAST UNITS				
EXCAVATION				
Excavation	60	m3	$45.00	2,700
Supply, place and compact special fill	30	m3	$100.00	3,000
Extra over Item 9.03 for supply and placing 100 mm dia. Subsoil drain pipe with filter and aggregate surround	75	m	$60.00	4,500
MANUFACTURE AND SUPPLY				
Supply of precast units				
Supply of concrete base slabs (per 2.44m)	13	No.	$3,250.00	42,250
Construction of blinding concrete	50	m2	$70.00	3,500
Supply 750dia pipe culvert (per 1.22m)	25	No.	$2,500.00	62,500
Supply culvert headwalls	2	No.	$800.00	1,600
Delivery of Pre-cast units	1	No.	$15,000.00	15,000
HANDLE AND PLACE				

Handle and place precast crown units on prepared base				
Units greater than 3 m wide	25	No.	$1,000.00	25,000
Handle and place precast slabs on prepared mortar bed slabs				
Slabs greater than 3 m wide	13	No.	$1,000.00	13,000
Handle and place precast wingwall units on prepared mortar bed units				
Units greater than 2.4 m high	4	No.	$500.00	2,000

PART 9 - PRECAST UNITS
CARRIED TO SUMMARY **TOTAL $ 175,050**

LEVEE, CULVERT UPGRADE & DRAIN CUT

SUMMARY

	AMOUNT $
PART 1 - PROJECT SPECIFIC ITEMS	$0
PART 2 - EARTHWORKS	$0
PART 3 - DRAINAGE	$29,200
PART 4 - PAVEMENT	$2,700
PART 5 - BITUMINOUS SURFACING	$480
PART 6 - TRAFFIC FACILITIES	$30,800
PART 8 - MISCELLANEOUS	$5,000
PART 9 - PRECAST UNITS	$175,050

CULVERT UPGRADE	**SCHEDULE TOTAL**	**$243,230**
	PROJECT CONTINGENCY	**30%**
	OVERALL TOTAL	**$316,199.00**

ASSUMPTIONS

existing < 600 dia culvert
new levee (assume 1m high)
cutting an open drain at bottom (assume 400mm deep and 0.75m total width)
new 750mm culvert
140m x 3m levee area
costing includes one culvert and levee combo only (x2 for both)

ZEE04 Wilson Street Levee and Pipes

DESCRIPTION	QUANTITY	UNIT	RATE $	AMOUNT $
PART 1 - PROJECT SPECIFIC ITEMS				
Protection and/or relocation of existing services	3	no.	$2,000.00	6,000
Mobilisation and Site Facilities	1	item	$20,000.00	20,000
PART 1 - PROJECT SPECIFIC ITEMS CARRIED TO SUMMARY			**TOTAL $**	**26,000**
PART 2 - EARTHWORKS				
Excavation & Embankment				
Levee				
Clearing and grubbing	1000	m²	$20.00	20,000
Excavate topsoil	150	m³	$8.00	1,200
Foundation improvement (compaction & trim)	1000	m²	$5.00	5,000
Clay Core	750	m³	$50.00	37,500
Embankment placement (fill)	250	m³	$100.00	25,000
Topsoil reinstatement	1000	m²	$9.00	9,000
PART 2 - EARTHWORKS CARRIED TO SUMMARY			**TOTAL $**	**97,700**
PART 3 - DRAINAGE				
Removal of pipes ≤ 600mm dia				
Along existing roadside	172.00	m	$150.00	25,800
Stormwater Pipes inc. excavation, placement and backfill				
750mm Dia Pipe Class 4	350.00	m	$750.00	262,500
Manholes & Pits				
DN1500 Manhole	5	no.	$8,000.00	40,000
New Side Entry Pits	4	no.	$8,000.00	32,000
High Capacity Inlet Pits	5	no.	$8,000.00	40,000
Headwalls				
Headwalls to suit DN750	1	no.	$8,000.00	8,000
PART 3 - DRAINAGE CARRIED TO SUMMARY			**TOTAL $**	**408,300**
PART 4 - PAVEMENT				
Construction				
Supply, spread and compact sub-base material class 3				
150 mm depth	60	m³	$150.00	9,000
Supply, spread and compact base material Class 2				
150 mm depth	60	m³	$150.00	9,000

PART 4 - PAVEMENT				
CARRIED TO SUMMARY			**TOTAL $**	**18,000**
PART 5 - BITUMINOUS SURFACING				
New pavements				
AC10 40mm Thick Asphalt	400	m²	$40.00	16,000
PART 5 - BITUMINOUS SURFACING				
CARRIED TO SUMMARY			**TOTAL $**	**16,000**
PART 8 - MISCELLANEOUS				
Renew Pavement Markings	40	m	$20.00	800
Renew Driveways	3	no.	$6,000.00	18,000
Traffic Management	1	Item	$25,000.00	25,000
PART 8 - MISCELLANEOUS				
CARRIED TO SUMMARY			**TOTAL $**	**43,800**

LEVEE, CULVERT UPGRADE & DRAIN CUT

SUMMARY

	AMOUNT $
PART 1 - PROJECT SPECIFIC ITEMS	$26,000
PART 2 - EARTHWORKS	$97,700
PART 3 - DRAINAGE	$408,300
PART 4 - PAVEMENT	$18,000
PART 5 - BITUMINOUS SURFACING	$16,000
PART 8 - MISCELLANEOUS	$43,800

CULVERT UPGRADE	**SCHEDULE TOTAL**	**$609,800**
	PROJECT CONTINGENCY	**30%**
	OVERALL TOTAL	**$792,740.00**

ASSUMPTIONS

levee/bund length = 262m

350m of new 750mm pipe

width assume = 4m

height assume = 1m

QUE01 Hunter Street Pipe Upgrade

DESCRIPTION	QUANTITY	UNIT	RATE $	AMOUNT $
PART 1 - PROJECT SPECIFIC ITEMS				
Protection and/or relocation of existing services	5	no.	$2,000.00	10,000
Mobilisation and Site Facilities	1	item	$30,000.00	30,000
PART 1 - PROJECT SPECIFIC ITEMS				
CARRIED TO SUMMARY			**TOTAL $**	**40,000**
PART 3 - DRAINAGE				
Removal of pipes > 600mm dia				
Along existing roadside	370.00	m	$180.00	66,600
Remove endwalls > 600mm dia	2	no.	$200.00	400
Stormwater Pipes inc. excavation, placement and backfill				
1500mm Dia Pipe Class 4	370.00	m	$2,000.00	740,000
Manholes & Pits				
Manholes ≥ DN1500	5	no.	$8,000.00	40,000
New Side Entry Pits	4	no.	$8,000.00	32,000
Headwalls				
Headwalls to suit DN1500	2	no.	$12,000.00	24,000
PART 3 - DRAINAGE				
CARRIED TO SUMMARY			**TOTAL $**	**903,000**
PART 4 - PAVEMENT				
Construction				
Supply, spread and compact sub-base material class 3				
150 mm depth	60	m^3	$150.00	9,000
Supply, spread and compact base material Class 2				
150 mm depth	60	m^3	$150.00	9,000
PART 4 - PAVEMENT				
CARRIED TO SUMMARY			**TOTAL $**	**18,000**
PART 5 - BITUMINOUS SURFACING				
New pavements				
AC10 40mm Thick Asphalt	400	m^2	$40.00	16,000
New footpath	230	m	$44.00	10,120
PART 5 - BITUMINOUS SURFACING				
CARRIED TO SUMMARY			**TOTAL $**	**26,120**
PART 8 - MISCELLANEOUS				
Renew Pavement Markings	45	m	$20.00	900
Renew Driveways	1	no.	$6,000.00	6,000

Traffic Management	1	Item	$50,000.00	50,000

PART 8 - MISCELLANEOUS
CARRIED TO SUMMARY **TOTAL $** **56,900**

LEVEE, CULVERT UPGRADE & DRAIN CUT

SUMMARY

	AMOUNT $
PART 1 - PROJECT SPECIFIC ITEMS	$40,000
PART 3 - DRAINAGE	$903,000
PART 4 - PAVEMENT	$18,000
PART 5 - BITUMINOUS SURFACING	$26,120
PART 8 - MISCELLANEOUS	$56,900

CULVERT UPGRADE	**SCHEDULE TOTAL**	**$1,044,020**
	PROJECT CONTINGENCY	**30%**
	OVERALL TOTAL	**$1,357,226.00**

ASSUMPTIONS

upgraded SW main from 1200dia to 1500mm dia

doesn't include connectors from Orr Street

ROS01 Pipe Network Upgrades Karlson to Clemons Street Area

DESCRIPTION	QUANTITY	UNIT	RATE	AMOUNT
DESCRIPTION	QUANTITY	UNIT	RATE $	AMOUNT $
PART 1 - PROJECT SPECIFIC ITEMS				
Protection and/or relocation of existing services	5	no.	$2,000.00	10,000
Mobilisation and Site Facilities	1	item	$30,000.00	30,000
PART 1 - PROJECT SPECIFIC ITEMS				
CARRIED TO SUMMARY			**TOTAL $**	**40,000**
PART 3 - DRAINAGE				
Removal of pipes ≤ 600mm dia				
Along existing roadside and under existing pavement	340.00	m	$150.00	51,000
Remove endwalls ≤ 600mm dia	1	no.	$100.00	100
Stormwater Pipes inc. excavation, placement and backfill				
525mm Dia Pipe Class 4	80.00	m	$525.00	42,000
600mm Dia Pipe Class 4	20.00	m	$600.00	12,000
750mm Dia Pipe Class 4	480.00	m	$750.00	360,000
Manholes & Pits				
Manholes ≥ DN1500	3	no.	$8,000.00	24,000
New Side Entry Pits	6	no.	$8,000.00	48,000
Headwalls				
Headwalls to suit DN525	1	no.	$5,000.00	5,000
Headwalls to suit DN750	3	no.	$8,000.00	24,000
PART 3 - DRAINAGE				
CARRIED TO SUMMARY			**TOTAL $**	**566,100**
PART 4 - PAVEMENT				
Construction				
Supply, spread and compact sub-base material class 3				
150 mm depth	60	m³	$150.00	9,000
Supply, spread and compact base material Class 2				
150 mm depth	60	m³	$150.00	9,000
PART 4 - PAVEMENT				
CARRIED TO SUMMARY			**TOTAL $**	**18,000**
PART 5 - BITUMINOUS SURFACING				
New pavements				
AC10 40mm Thick Asphalt	400	m²	$40.00	16,000
New footpath	150	m	$44.00	6,600

CARRIED TO SUMMARY			**TOTAL $**	**22,600**
PART 8 - MISCELLANEOUS				
Renew Pavement Markings	10	m	$20.00	200
Renew Driveways	10	no.	$6,000.00	60,000
Traffic Management	1	Item	$50,000.00	50,000
PART 8 - MISCELLANEOUS **CARRIED TO SUMMARY**			**TOTAL $**	**110,200**

LEVEE, CULVERT UPGRADE & DRAIN CUT

SUMMARY

	AMOUNT $
PART 1 - PROJECT SPECIFIC ITEMS	$40,000
PART 3 - DRAINAGE	$566,100
PART 4 - PAVEMENT	$18,000
PART 5 - BITUMINOUS SURFACING	$22,600
PART 8 - MISCELLANEOUS	$110,200

CULVERT UPGRADE	**SCHEDULE TOTAL**	**$756,900**
	PROJECT CONTINGENCY	**30%**
	OVERALL TOTAL	**$983,970.00**

ASSUMPTIONS

upgrade existing and install new 750mm dia

doesn't include costings for Alternate Option pitt&sherry

West Coast Council SSMP

Flood Study

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