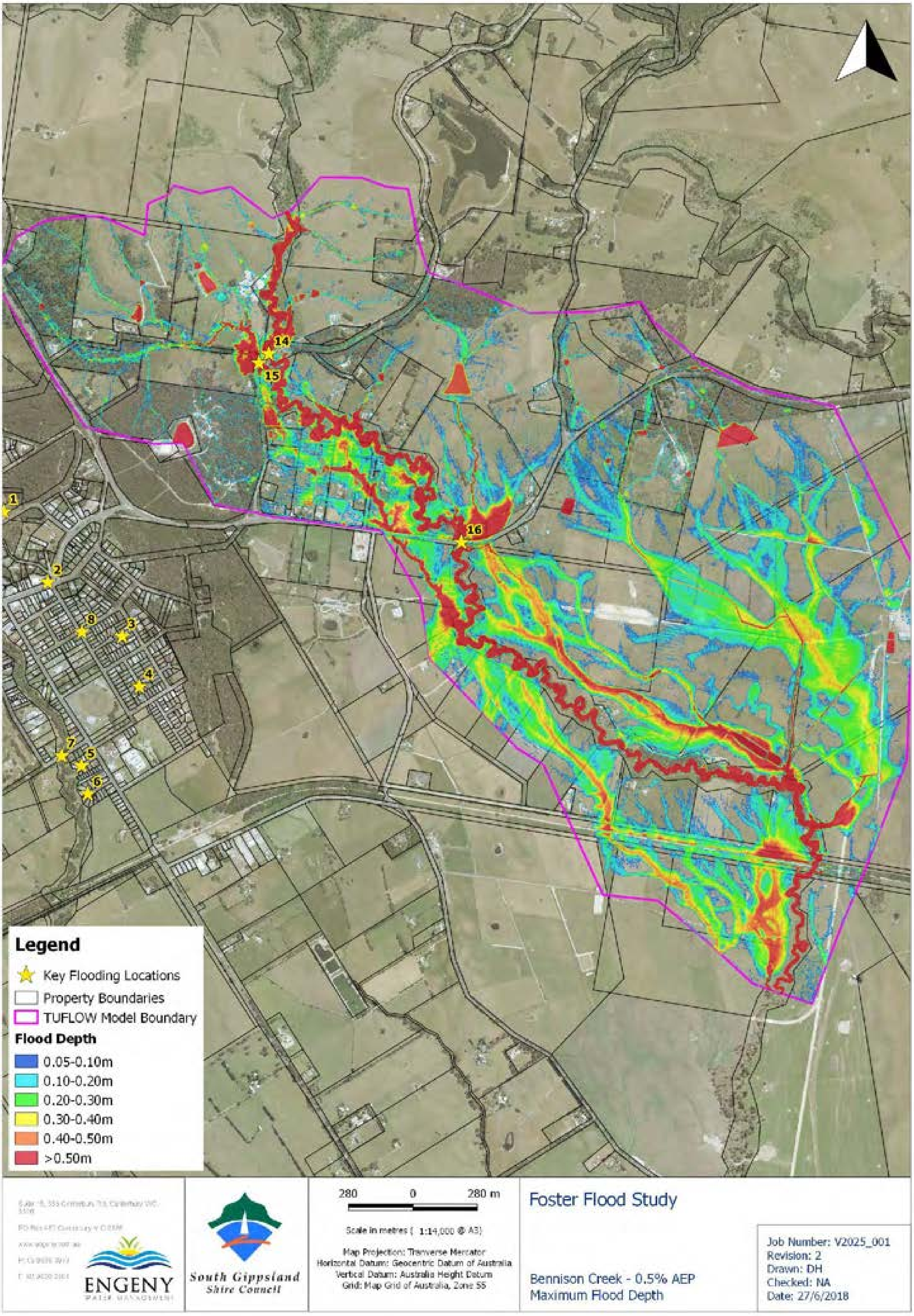
APPENDIX T

Bennison Creek Maximum Flood Depth Maps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Legend
Key Flooding Locations
Property Boundaries
TUFLOW Model Boundary
Flood Depth
0.05-0.10m
0.10-0.20m
0.20-0.30m
0.30-0.40m
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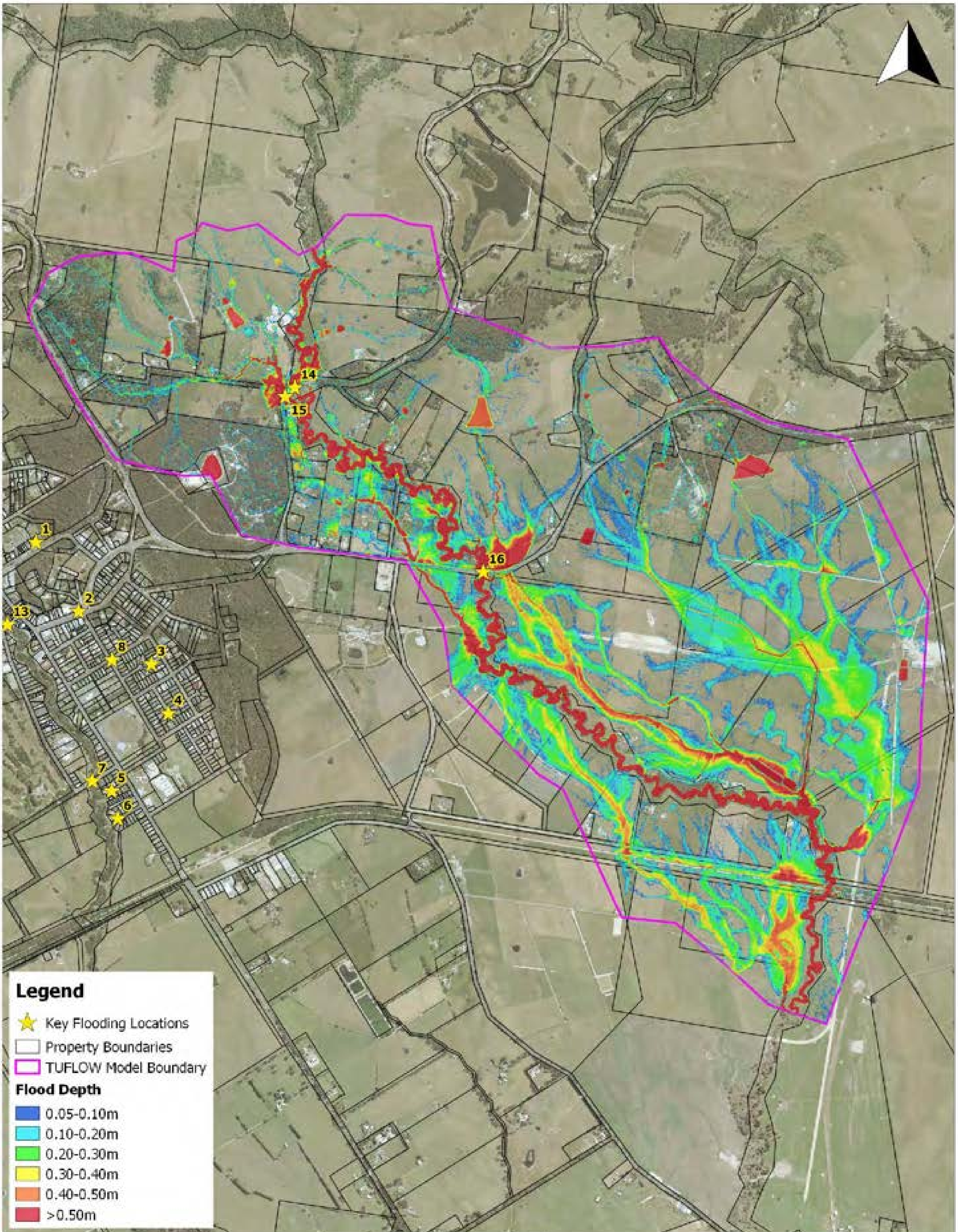
>0.50m
ENGENY
WATER MANAGEMENT
South Gippsland
Shire Council
280 0 280 m
Scale in metres (1:14,000 @ A3)
Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55
Foster Flood Study
Bennison Creek - 0.5% AEP
Maximum Flood Depth
Job Number: V2025_001
Revision: 2
Drawn: DH
Checked: NA
Date: 27/6/2018



ENGENY WATER MANAGEMENT

South Gippsland Shire Council

300 0 300 m

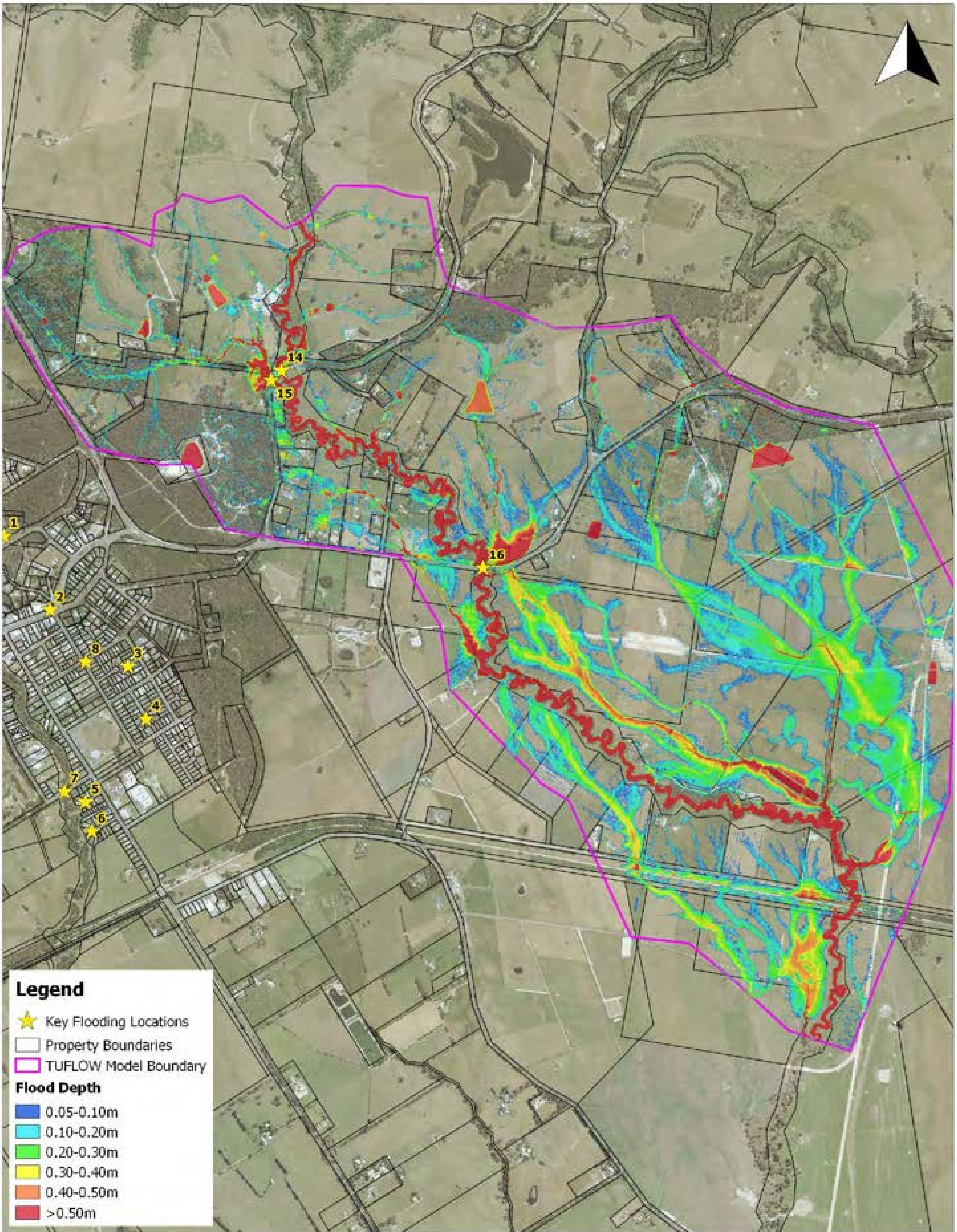
Scale in metres (1:15,000 @ A3)

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Foster Flood Study

Bennison Creek - 1% AEP Maximum Flood Depth

Job Number: V2025_001
Revision: 2
Drawn: DH
Checked: NA
Date: 27/6/2018



ENGENY WATER MANAGEMENT

South Gippsland Shire Council

280 0 280 m

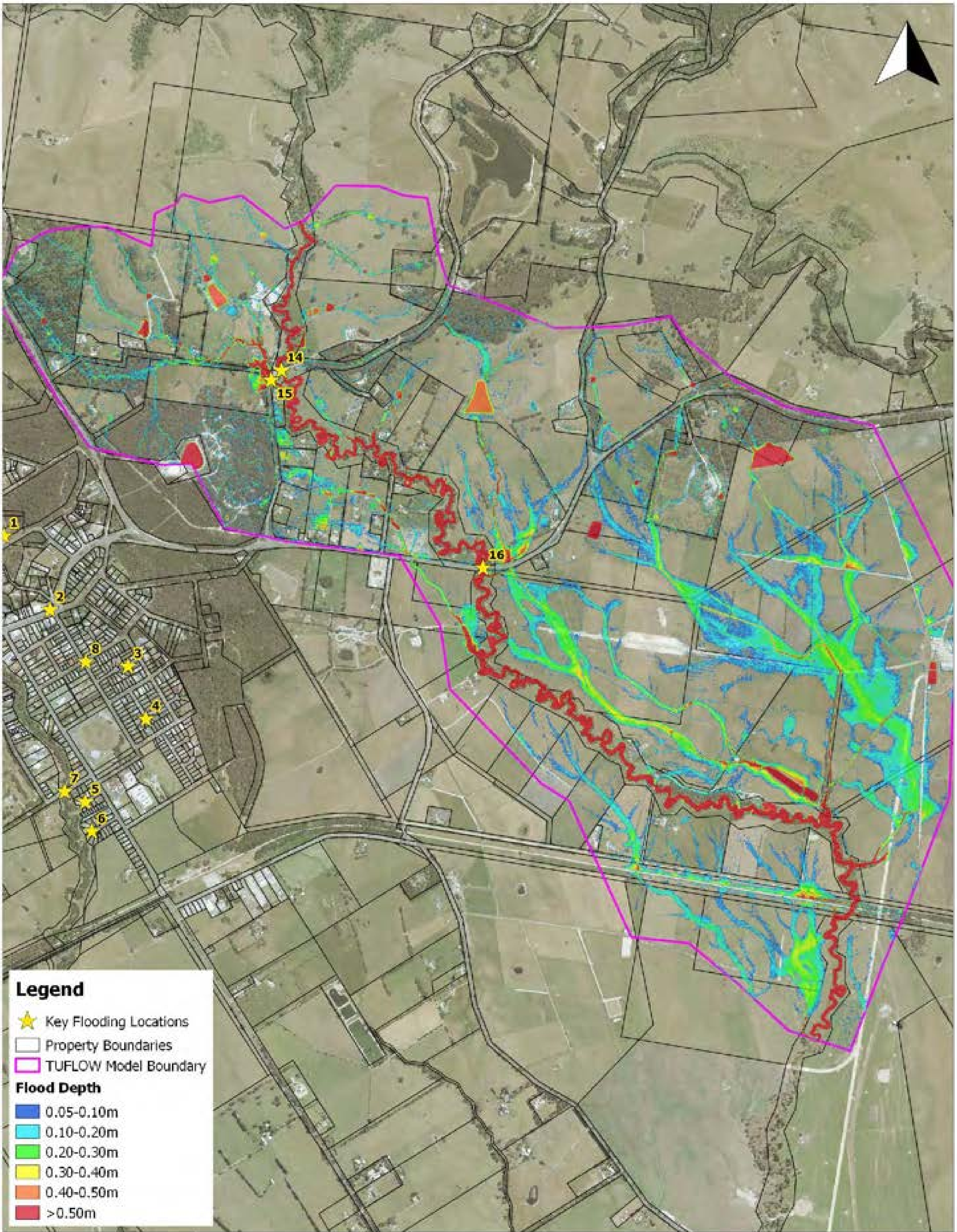
Scale in metres (1:14,000 @ A3)

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Foster Flood Study

Bennison Creek - 2% AEP Maximum Flood Depth

Job Number: V2025_001
Revision: 2
Drawn: DH
Checked: NA
Date: 27/6/2018



ENGENY WATER MANAGEMENT

South Gippsland Shire Council

280 0 280 m

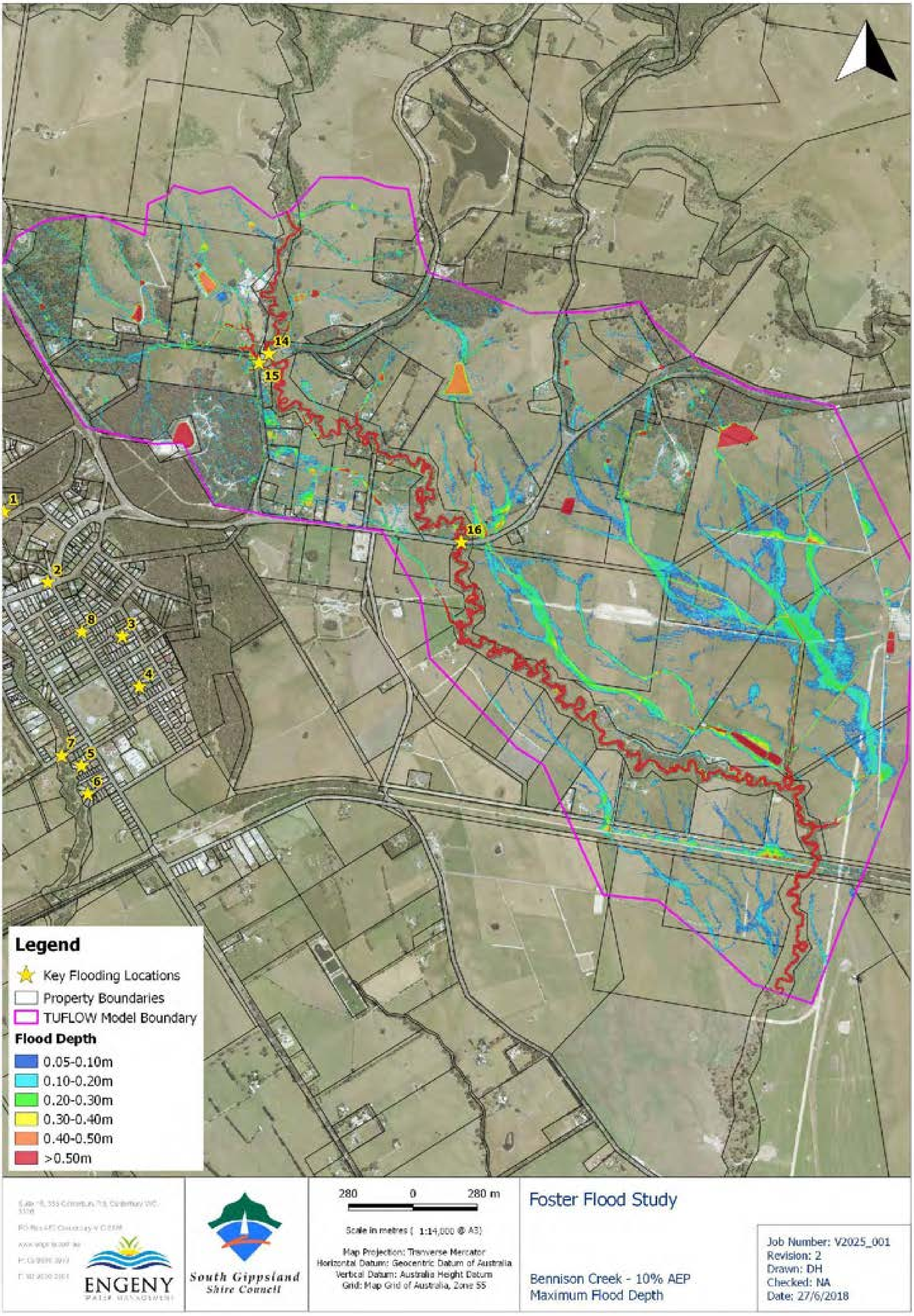
Scale in metres (1:14,000 @ A3)

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Foster Flood Study

Bennison Creek - 5% AEP Maximum Flood Depth

Job Number: V2025_001
Revision: 2
Drawn: DH
Checked: NA
Date: 27/6/2018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ENGENY
South Gippsland Shire Council
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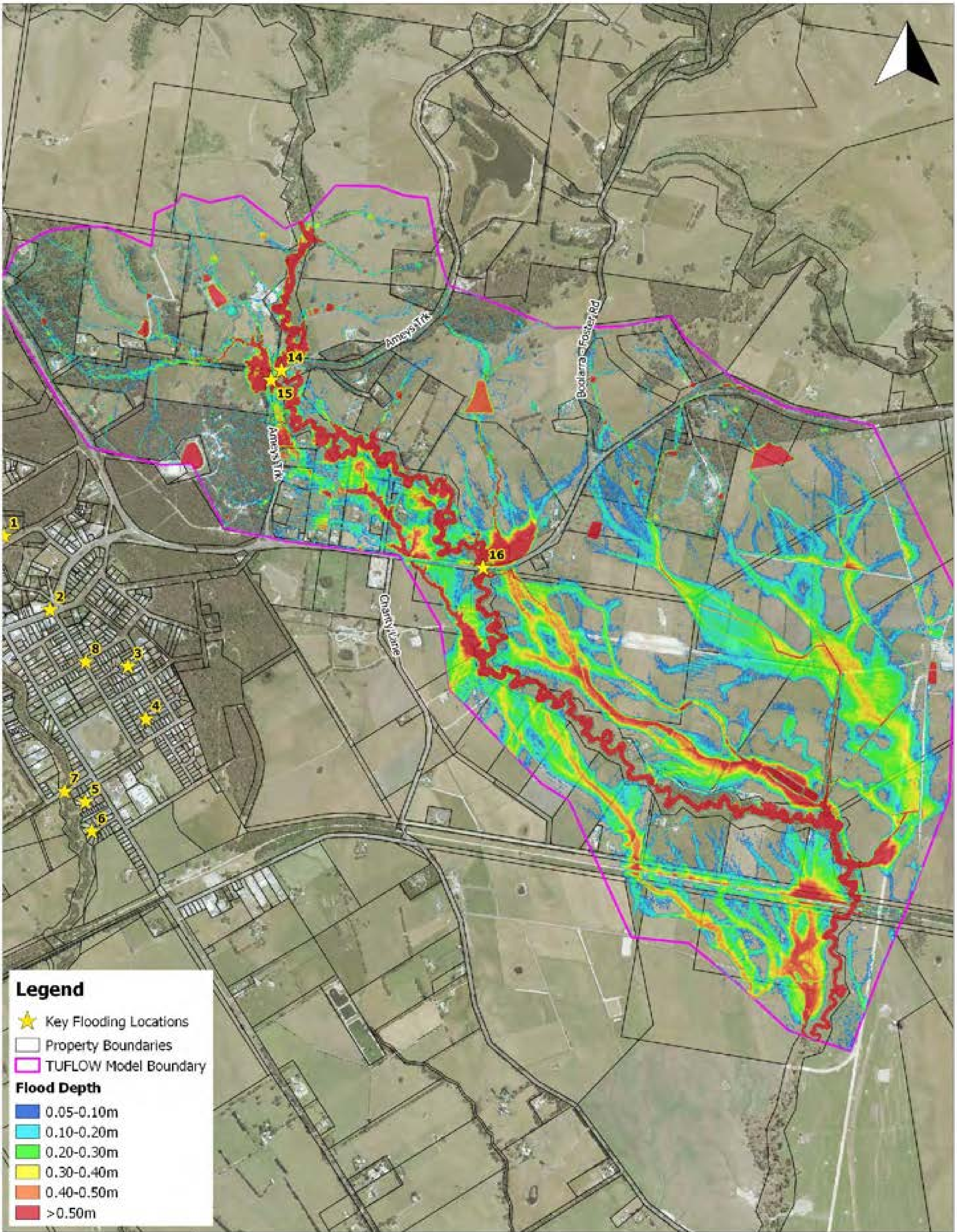
Scale in metres (1:14,000 @ A3)
Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55
Foster Flood Study
Bennison Creek - 10% AEP
Maximum Flood Depth
Job Number: V2025_001
Revision: 2
Drawn: DH
Checked: NA
Date: 27/6/2018



ENGENY WATER MANAGEMENT

South Gippsland Shire Council

280 0 280 m

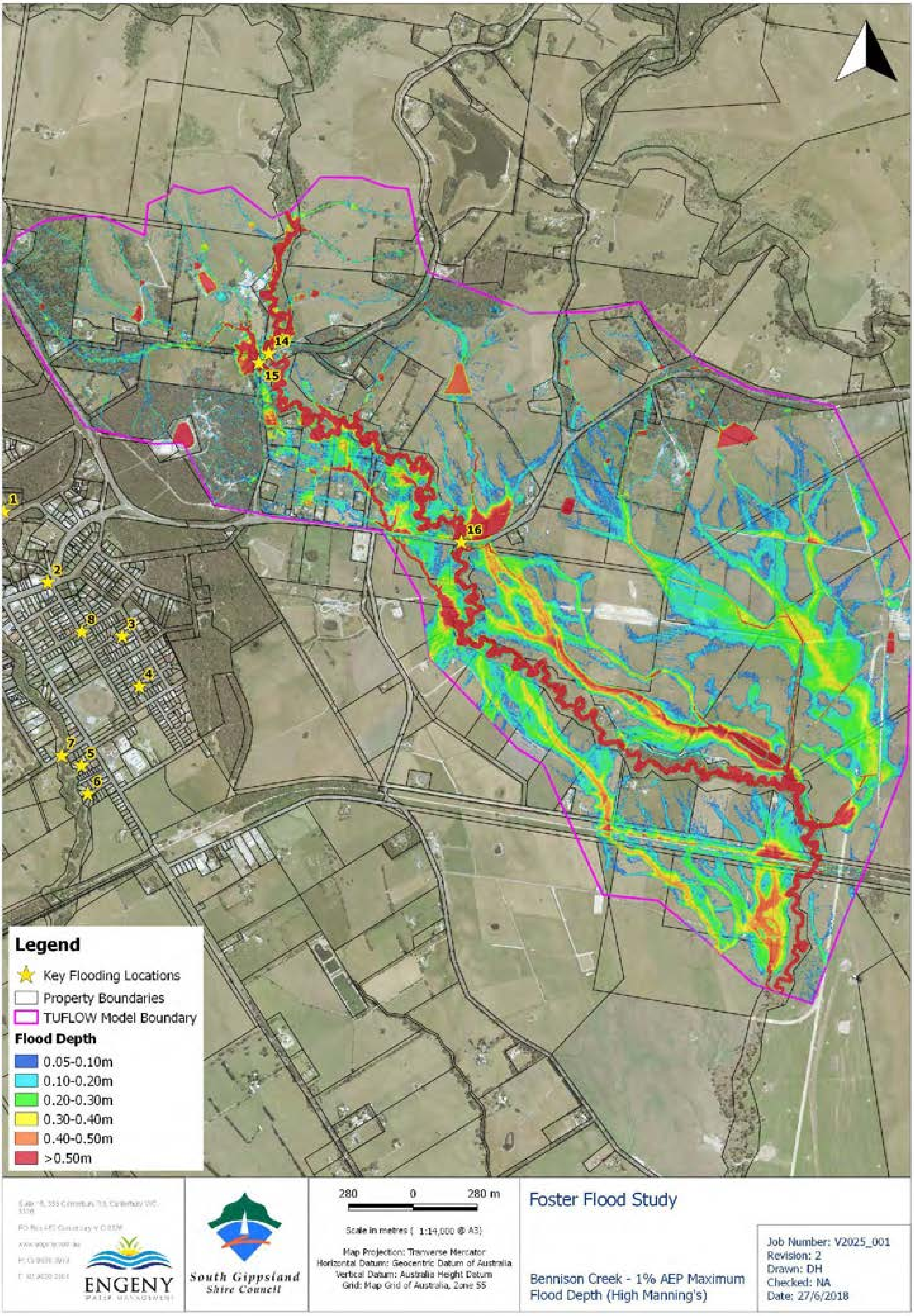
Scale in metres (1:14,000 @ A3)

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Foster Flood Study

Bennison Creek - 1% AEP Maximum Flood Depth (2030 Bushfire Scenario)

Job Number: V2025_001
Revision: 3
Drawn: DH
Checked: NA
Date: 25/7/2018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Legend
Key Flooding Locations
Property Boundaries
TUFLOW Model Boundary
Flood Depth
0.05-0.10m
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0.40-0.50m
>0.50m
ENGENY WATER MANAGEMENT
South Gippsland Shire Council
280 0 280 m
Scale in metres (1:14,000 @ A3)
Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55
Foster Flood Study
Bennison Creek - 1% AEP Maximum Flood Depth (High Manning's)
Job Number: V2025_001
Revision: 2
Drawn: DH
Checked: NA
Date: 27/6/2018

APPENDIX U

On-Site Detention Investigation

South Gippsland Shire Council

ENGENY WATER MANAGEMENT

South Gippsland Shire Council

Flood and Drainage Study for Foster and Surrounding Catchments

On-Site Detention Investigation




October 2018

V2025_001

www.engeny.com.au

P: 03 9888 6978 | F: 03 9830 2601

T5, Lvl 34, 360 Elizabeth St Melbourne VIC 3000 | PO Box 12192, A'Beckett St VIC 8006

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JOB NO. AND PROJECT NAME: V2025_001 Foster Flood and Drainage Study					
DOC PATH FILE: V:\Projects\V2025 South Gippsland Shire Council\V2025_001 Foster Flood and Drainage Study\07 Deliv\Docs\Report\On-Site Detention Report\V2025_001 Foster Flood and Drainage Study - On-Site Detention Investigation_Rev0.docx					
REV	DESCRIPTION	AUTHOR	REVIEWER	APPROVED BY	DATE
Rev 0	Client Issue	Daniel Hatzihristodoulou	Paul Clemson	Nick Andrewes	23/10/2018
Signatures					

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1. INTRODUCTION

Engeny has undertaken an analysis of the potential flood reduction benefits provided by on-site detention storage tank systems in Foster. The analysis was undertaken as part of the Flood and Drainage Study for Foster and Surrounding Catchments (2018).

2. ON-SITE DETENTION

2.1 Overview

The flood mitigation benefits provided by on-site detention across the town of Foster have been investigated and described, along with all modelling assumptions and methodology in this report.

Three on-site detention scenarios have been investigated, which are:

- **Scenario 1:** On-site detention applied to all existing/proposed residential properties (under 2070 full development scenario with existing climate conditions) within the town of Foster.
- **Scenario 2:** On-site detention only applied to some existing/proposed residential properties (under 2070 full development scenario with existing climate conditions) as defined by Council.
- **Scenario 3:** On-site detention applied to all existing/proposed residential properties (under 2070 full development scenario with 2100 climate conditions) within the town of Foster.

Refer to Figure 2.1 for a layout plan depicting areas providing on-site detention in Scenario 2 (shaded blue) and additional areas within on-site tanks included in Scenarios 1 and 3 (shaded red).

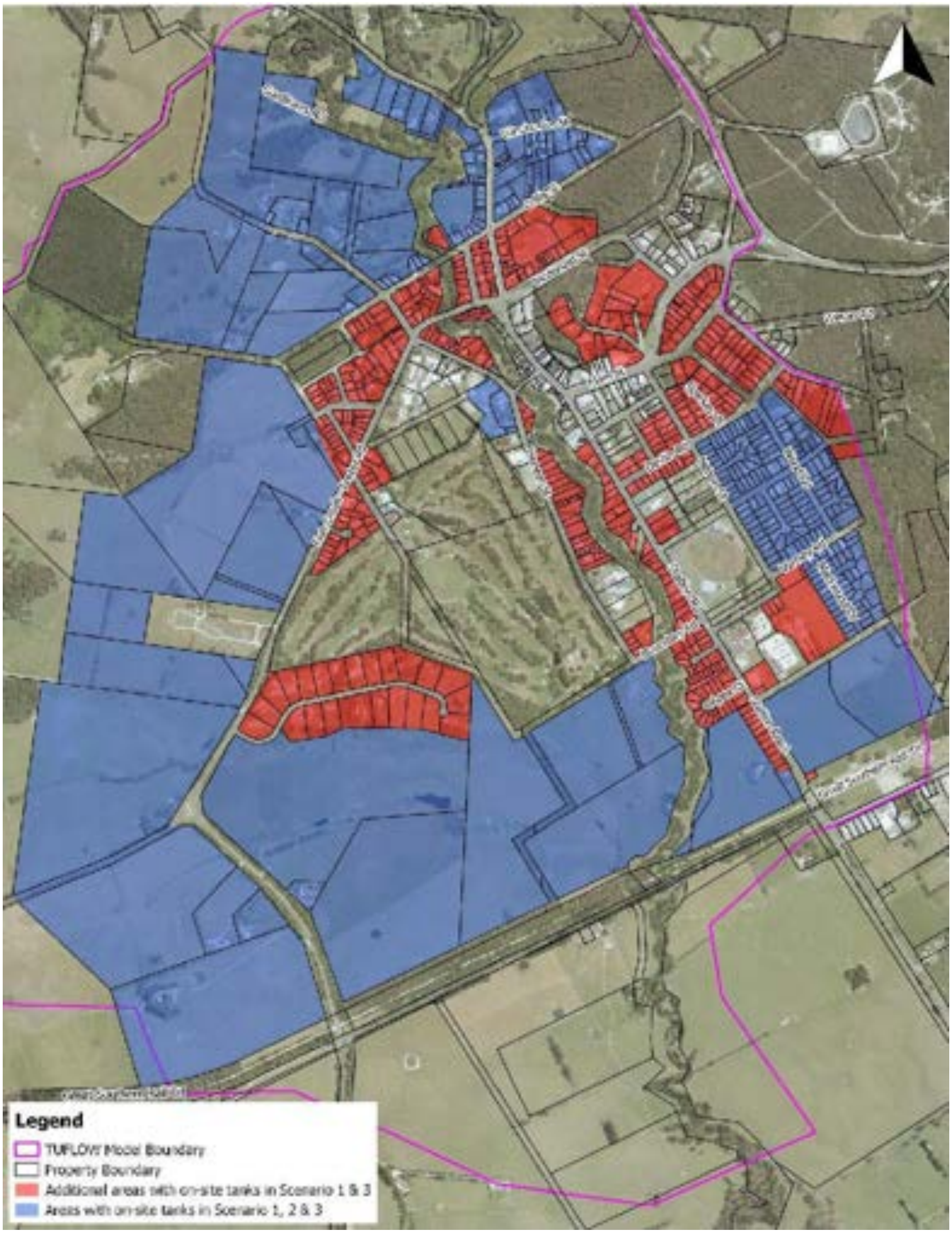

Figure 2.1 On-site detention layout plan

The temporal pattern of a rainfall event can impact the performance of on-site detention tanks as runoff into the tanks is not at a steady continuous rate. For this investigation, the critical storm duration and temporal pattern identified in the urbanised areas was utilised to analyse the feasibility and performance of this distributed storages system.

2.2 Modelling Assumptions

The following assumptions have been made for this investigation:

- Rainwater is captured from residential buildings only and detained on site and is released to the local underground drainage network at a controlled discharge rate (refer to Section 2.3 for further details).
- 100% of a residential building's roof area is connected directly to the storage tank, with the remaining property parcel area connecting to the underground stormwater system (thus bypassing the storage tank).
- The roof area connected to the storage tank is 100% impervious and does not contain any landscaped areas (i.e. green roofs).
- Fraction imperviousness of moderate to high density residential zoned lots is assumed to be 60% for all existing and proposed residential lots across the town.
- Fraction imperviousness of low density residential and rural living zoned lots is assumed to be 20% for all existing and proposed low residential lots across the town.
- For this investigation, the storage tanks are designed (and have been modelled) as detention storages only and do not harvest any stormwater for re-use purposes. The tanks could be designed to retain some rainwater in order to provide a potable water alternative.
- A climate change scenario has been modelled for the on-site detention investigation. As per ARR 2016 recommendations, rainfall intensities have been increased by 19.5% (refer to hydrology section of Foster Flood and Drainage Study [2018] report for further details).

2.3 Hydrology Model Setup

The methodology for modelling the distributed storages is consistent with the approach adopted by Engeny in a previous distributed storages analysis for Melbourne Water, with the storage tanks reflected in the hydrology (RORB) models. The hydrology models are used to convert rainfall events to runoff hydrographs, which are then applied to the hydraulic model. The intended impact of modelling the storages in the hydrology model is a reduction in the peak flow of the runoff hydrographs. Engeny believes that this is the best approach to model distributed storages and is most representative of what actually occurs.

The key steps and assumptions to adjust the existing RORB model to represent the distributed storages are as follows:

- For each subarea containing existing/proposed residential lots within the town of Foster, the average building footprint size within the subarea was estimated based on measuring a sample of existing building footprint sizes using 2015 aerial photography. The total roof area that will drain to the storage tanks within each subarea was then estimated by multiplying the average roof size by the number of existing and future residential lots within the subarea.

- For each subarea, a sample investigation was conducted to determine the average parcel size based on the "parcel_view" GIS layer provided by DELWP. This information was used to estimate the number of properties assumed to infill the new development areas for the 2070 full development scenario, as presented in the Foster Framework Plan.

- The subareas have been split into two new subareas reflecting the component of the subarea that will drain to storage tanks (roof areas within developed/developable parcel areas) and the remainder of the subarea. The combination of the split subareas still provides the same total impervious and pervious areas as the baseline model (which excludes on-site detention).

- A new storage has been added downstream of the roof subarea draining to storage tanks. A one metre long natural reach (short length to make impact of the new reach on routing of flow in the model negligible) has been included to connect the subarea to the storage. Storages in the RORB model were developed based on the following process:

  - The storage volume was initially based on 12 litres of tank storage per square metre of total roof area in the subarea, based on on-site detention sizing guidelines in the Infrastructure Design Manual (IDM). However, initial iterations of the RORB modelling indicated that the storages did not have enough storage capacity to contain the 20% AEP event without overflowing. The tank volumes were increased, with the optimum tank volume to roof area relationship determined to be 13 litres of tank storage per square metre of connected roof area.
  - Under 2100 climate change runoff conditions, the tank capacities have been increased further to account for the increased rainfall intensities. The RORB modelling determined a volume to area relationship of 17 litres of tank storage per square metre of roof area under 2100 climate change conditions.
  - The tanks include a low flow outlet with a capacity of 37 litres per second per hectare of roof area connected to the tank. This low flow discharge rate is in-line with on-site detention sizing guidelines in the IDM. The inclusion of a low flow outlet prevents the storage volume from being exceeded early in the storm event so that it still has capacity to control flows at the peak of the storm.
  - Each tank has been modelled with a wide overflow weir at the top of the storage volume so that the tank is unable to store flow in excess of the storage volume.
  - The investigation was undertaken for the 20% AEP 90-minute duration temporal pattern 7 storm event, which is the critical storm for residential areas under 2070 full development scenario existing runoff conditions. It should be noted that there can be impacts on the performance of the storage systems under different temporal patterns. This approach is consistent with the likely design of on-site detention systems to control peak flows in minor storm events for the catchment.

  - The tanks have been assumed to be empty at the start of the storm.

- The downstream end of the storage was then connected back into the model at the same location as the corresponding subarea reflecting the portion of the subarea not draining to the storage.

Based on the adopted tank sizing approach for existing climate conditions, an average sized dwelling with a roof area of 220 m^2 would have a storage tank with a volume of 2,860 litres and a low flow outlet with a capacity of 0.82 litres per second.

Table 2.1 provides a summary of the total number of existing and estimated proposed buildings where on-site detention has been investigated and the overall storage volume achieved for all scenarios.

Table 2.1 Number of buildings with storages and total storage volume for all scenarios modelled

Detail	Scenario 1	Scenario 2	Scenario 3
Number of residential buildings with on-site detention	1,816	1,347	1,816
Total storage volume	6.3 ML	4.9 ML	8.2 ML

Figure 2.2 provides an example of the setup of the hydrology model to include the distributed storages.

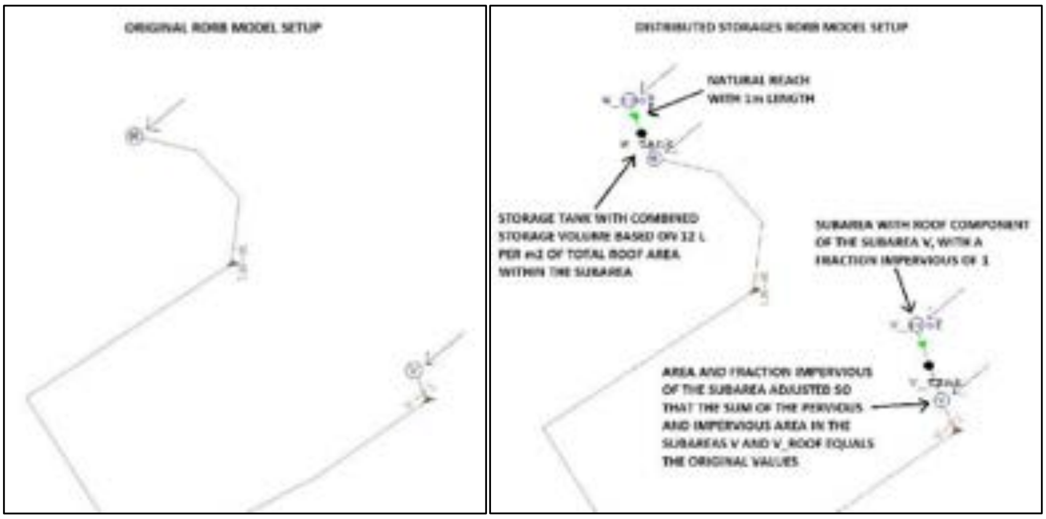

Figure 2.2 Changes to the RORB model to reflect distributed storages

Figure 2.3 presents an example of the impact distributed storages have on the RORB subarea hydrographs. The figure compares the RORB subarea hydrographs for existing conditions and a combined hydrograph of the outlet of the tank and remainder of subarea.

The tank inlet and outlet hydrographs are also depicted to demonstrate the proportion of total flow that is controlled by the tank storage.

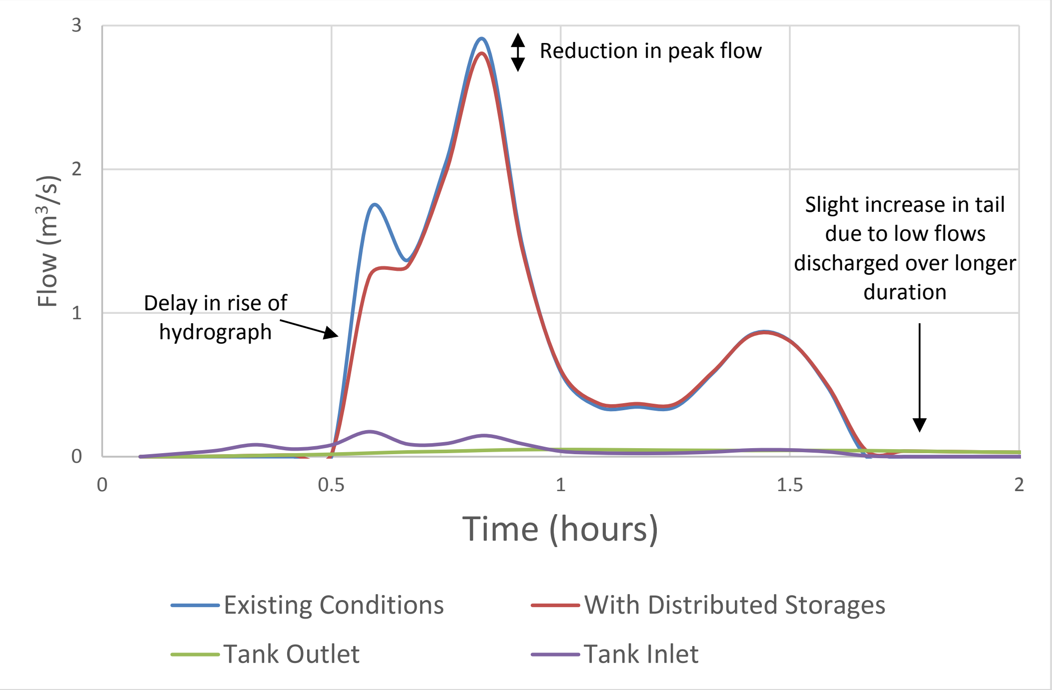

Figure 2.3 Impact of distributed storages on RORB hydrographs

2.4 Results and Analysis

The on-site detention investigation has been undertaken the 20% AEP storm event under both existing climate and 2100 climate conditions. This event has been modelled in accordance with the IDM and as South Gippsland Shire Council are seeking to achieve a 20% AEP level of service provided by the distributed storage system.

For each climate scenario, the critical duration and temporal pattern storm for the 20% AEP event (under existing drainage conditions) has been modelled to quantify the flood mitigation benefits provided by the distributed storages.

The following flood maps are provided in this report's appendices to demonstrate the impact of the distributed storages:

- **Appendix A:**
  - Existing climate conditions baseline (existing drainage) flood depth map
  - Existing climate conditions with distributed storages (Scenario 1) flood depth map
  - Existing climate conditions with distributed storages (Scenario 2) flood depth map

- **Appendix B:**
  - Existing climate conditions Scenario 1 flood afflux map
  - Existing climate conditions Scenario 2 flood afflux map
- **Appendix C:**
  - 2100 climate conditions baseline (existing drainage) flood depth map
  - 2100 climate conditions with distributed storages (Scenario 3) flood depth map
- **Appendix D:**
  - 2100 climate conditions Scenario 3 flood afflux map

Table 2.2 provides a summary of the modelled performance of the distributed storages for the modelled scenarios. The baseline results presented in Table 2.2 reflect the results based on the 2070 full development scenario without the distributed storages.

Table 2.2 Predicted performance of storage options on flooding within the town of Foster for the 20% AEP storm event

Scenario	Flood Extent Area (ha)			Area Where Peak Flood Depths > 0.35 m (ha)			Area Where Peak Flood Depths > 0.75 m (ha)		
	Baseline	With Storages	Change	Baseline	With Storages	Change	Baseline	With Storages	Change
Scenario 1	30.3	28.0	-7.6%	7.8	7.2	-7.7%	3.1	2.8	-9.7%
Scenario 2	30.3	28.4	-6.3%	7.8	7.3	-6.4%	3.1	2.9	-6.5%
Scenario 3	44.5	42.0	-5.6%	13.1	12.6	-3.8%	5.0	4.8	-4.0%

The results in Table 2.2 show that the distributed storages provide some flood mitigation benefits for all scenarios modelled. The results show that Scenario 1 provides slightly better reduction in total flood extent area. However, the predicted reduction in areas impacted by flood depths greater than 0.35 metres is similar for Scenario 1 and 2 as surface water reaching this depth is primarily contained in Stockyard Creek and its tributaries or open channels and the additional on-site storages in Scenario 1 have little impact in these areas.

Scenario 1 includes implementing on-site detention storages to all existing and proposed residential properties, while Scenario 2 only utilises on-site detention storages for a number of selected residential areas (as identified by SGSC). The flood modelling results indicate that the additional storages in Scenario 1 offer only a minor improvement in flood reduction compared to Scenario 2. The additional distributed storages modelled in Scenario 1 are within properties primarily located near the existing underground drainage system, where very minor flooding is predicted for the 20% AEP event under baseline conditions. This indicates that the current drainage network is generally performing adequately, with flooding mostly limited to be within roads. Therefore, by implementing additional storages in these areas there is only a minor incremental reduction to the flood extent area.

2.4.1 Flooding of Buildings

Building floor levels are unknown for the study area and were therefore estimated to be equal to the average surface elevation within the building footprint. It is recommended that floor level survey is undertaken to improve the understanding of flood risk posed to buildings in the town. Buildings were considered impacted by flooding if flood depths were greater than or equal to 100 mm at the building footprint location and the water level exceeded the estimated building floor level. Table 2.3 provides a summary of the number of buildings predicted to be impacted by flooding for the scenarios modelled.

Table 2.3 Buildings impacted by above floor level flooding

Existing Climate Baseline	Scenario 1	Scenario 2	2100 Climate Baseline	Scenario 3
5	5	5	10	9

For all modelled scenarios, the depths of overland flow paths through residential properties are only reduced by up to 20 mm throughout the town. While this is a visible reduction, it is only enough to protect one of the existing buildings from above floor level flooding under 2100 climate conditions (scenario 3). The five buildings impacted by above floor level flooding under existing climate baseline conditions are not protected by the storage tanks as:

- In two instances, the buildings are not located in areas where on-site detention is being implemented and
- In three instances, the existing drainage network is performing inadequately and the on-site detention systems are not enough to subsidise the insufficient drainage system.

2.4.2 Flooding in Roadways

There are several roadways predicted to be subject to hazardous flooding for the 20% AEP storm event for both existing climate and 2100 climate conditions. Table 2.4 provides a summary of the key flood depths and reductions within roadways for all scenarios modelled:

Table 2.4 Reduction in flood depths in roadways for the 20% AEP storm event.

Location	Baseline flood depth *(Existing Climate)*	Scenario 1 reduction in flood depth	Scenario 2 reduction in flood depth	Baseline flood depth *(2100 Climate)*	Scenario 3 reduction in flood depth
Main Street (at Station Road)	110 mm	-	-	110 mm	-
Boyd Court (at court bowl)	250 mm	50 mm	30 mm	280 mm	40 mm
Apex Court (at court bowl)	330 mm	90 mm	-	350 mm	85 mm
Blackwood Drive (at O'Connell Road)	400 mm	115 mm	50 mm	410 mm	40 mm
Nelson Street (North of Landy Road)	180 mm	160 mm	10 mm	200 mm	60 mm
McDonald Street (at Main Street)	190 mm	70 mm	40 mm	200 mm	60 mm
Between McMaster Court & Varney Road	65 mm	25 mm	15 mm	80 mm	30 mm
Foster-Fish Creek Road (at Nelson Street)	260 mm	60 mm	-	320 mm	10 mm

With the implementation of on-site detention systems there are considerable reductions to flood depths in roadways predicted although, flood hazards are not completely removed for the 20% AEP storm event. There is a more noticeable reduction in flooding within roads compared to flooding within properties. This is due to a smaller volume of surface water being present in properties for baseline conditions that limits the effectiveness of the storages in these areas.

The modelling suggests that the flood mitigation benefits provided by the on-site detention systems do not out way the additional flooding impacts due to increased rainfall intensities expected under 2100 climate conditions.

3. CONCLUSIONS

An investigation into the implementation of on-site detention storage to assist in mitigating predicted flooding issues associated with increases in development and climate change has been conducted for the town of Foster. Three scenarios have been modelled as part of this investigation, which are:

- **Scenario 1:** On-site detention applied to all existing/proposed residential properties (under 2070 full development scenario with existing climate conditions) within the town of Foster.
- **Scenario 2:** On-site detention only applied to some existing/proposed residential properties (under 2070 full development scenario with existing climate conditions) as defined by Council.
- **Scenario 3:** On-site detention applied to all existing/proposed residential properties (under 2070 full development scenario with 2100 climate change conditions) within the town of Foster.

The following conclusions were drawn based on the TUFLOW flood modelling undertaken for scenario 1:

1. The tanks provide some reduction to the flood extent and prevent flood waters from ponding to hazardous levels (greater than 350 mm as per Melbourne Water's Guidelines for Development in Flood-prone Areas) within properties and roadways.
2. Flooding to buildings is not eliminated for the 20% AEP storm event. This is due to:
   a. Buildings being in areas where on-site detention systems are not being implemented and
   b. That the existing drainage network is performing inadequately in some locations and the on-site detention systems are not enough to subsidise the insufficient drainage system.
3. Additional mitigation measures are required to meet a 20% AEP drainage level of service.

The following conclusions were drawn based on the TUFLOW flood modelling undertaken for scenario 2:

4. By implementing on-site detention systems to all residential properties in Scenario 1, there are only minor additional flood reduction benefits compared to Scenario 2. The additional distributed storages modelled in Scenario 1 are within properties primarily located near the existing underground drainage system, where very minor flooding is predicted for the 20% AEP event under baseline conditions.

The following conclusions were drawn based on the TUFLOW flood modelling undertaken for scenario 3:

5. The implementation of on-site detention systems is not enough on its own to offset the increase in rainfall intensities predicted to occur under 2100 climate conditions.

6. Additional measures are required to eliminate flooding to buildings for the 20% AEP storm event under 2100 climate conditions.

The following general conclusions were drawn:

7. The implementation of on-site detention systems could reduce the scale of additional works (such as pit and pipe upgrades) required to eliminate flooding in the 20% AEP storm event. It is likely to eliminate the need to implement large end-of-line structures (such as retarding basins) that can be challenging and costly to construct in dense areas. Engeny's Foster Flood and Drainage Study (2018) report presents mitigation measures that can be implemented to effectively manage flooding across the town.

8. The flood mitigation effectiveness of on-site detention systems can vary from catchment to catchment due to reasons including topography, land surface types and geographical locations. Therefore, the effectiveness of the on-site detention systems to achieve flood mitigation outcomes may vary for other towns across South Gippsland Shire.

4. RECOMMENDATIONS

The following recommendations are made based on the outcomes of the TUFLOW flood modelling undertaken for this study:

1. SGSC consider undertaking specific on-site detention flood modelling investigations for other towns to determine their expected effectiveness in these areas.
2. If SGSC choose to adopt on-site detention systems for flood mitigation or offsetting the need for drainage system upgrades, then Engeny recommends that SGSC develop an On-Site Detention Management Guide to:
    a. Define Council's approach to tracking all on-site detention assets.
    b. Assign responsibility for maintenance of the asset (either to Council or the landowner).
    c. Outline design considerations and requirements of on-site detention systems, which may be specific to different catchments or township areas.
    d. Educate the community about the benefits of on-site detention systems.

5. QUALIFICATIONS

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

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

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g. This report does not provide legal advice.

6. REFERENCES

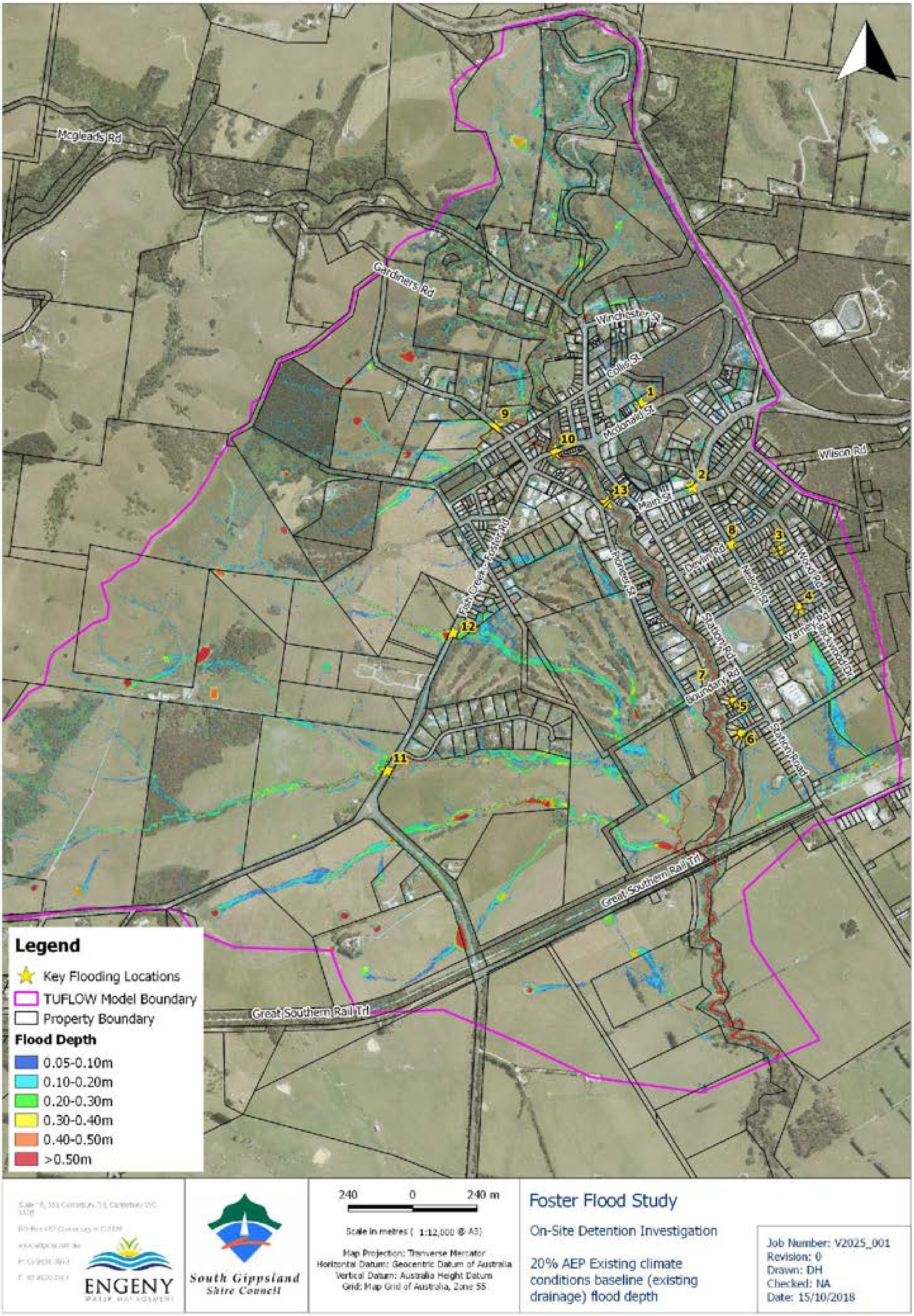
Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors) Australian Rainfall and Runoff: A Guide to Flood Estimation, © Commonwealth of Australia (Geoscience Australia), 2016.

Local Government Infrastructure Design Association, September 2017, Infrastructure Design Manual Version 5.10.

Melbourne Water, 2006, Guidelines for Development in Flood-prone Areas Version 1.0.

APPENDIX A

20% AEP Flood Depth Maps (Existing Climate Conditions)


Mcgleads Rd
Gardiners Rd
Winchester St
Collis St
McDonald St
Wilson Rd
Main St
Devlin Rd
Nelson St
Pioneer St
Fish Creek - Foster Rd
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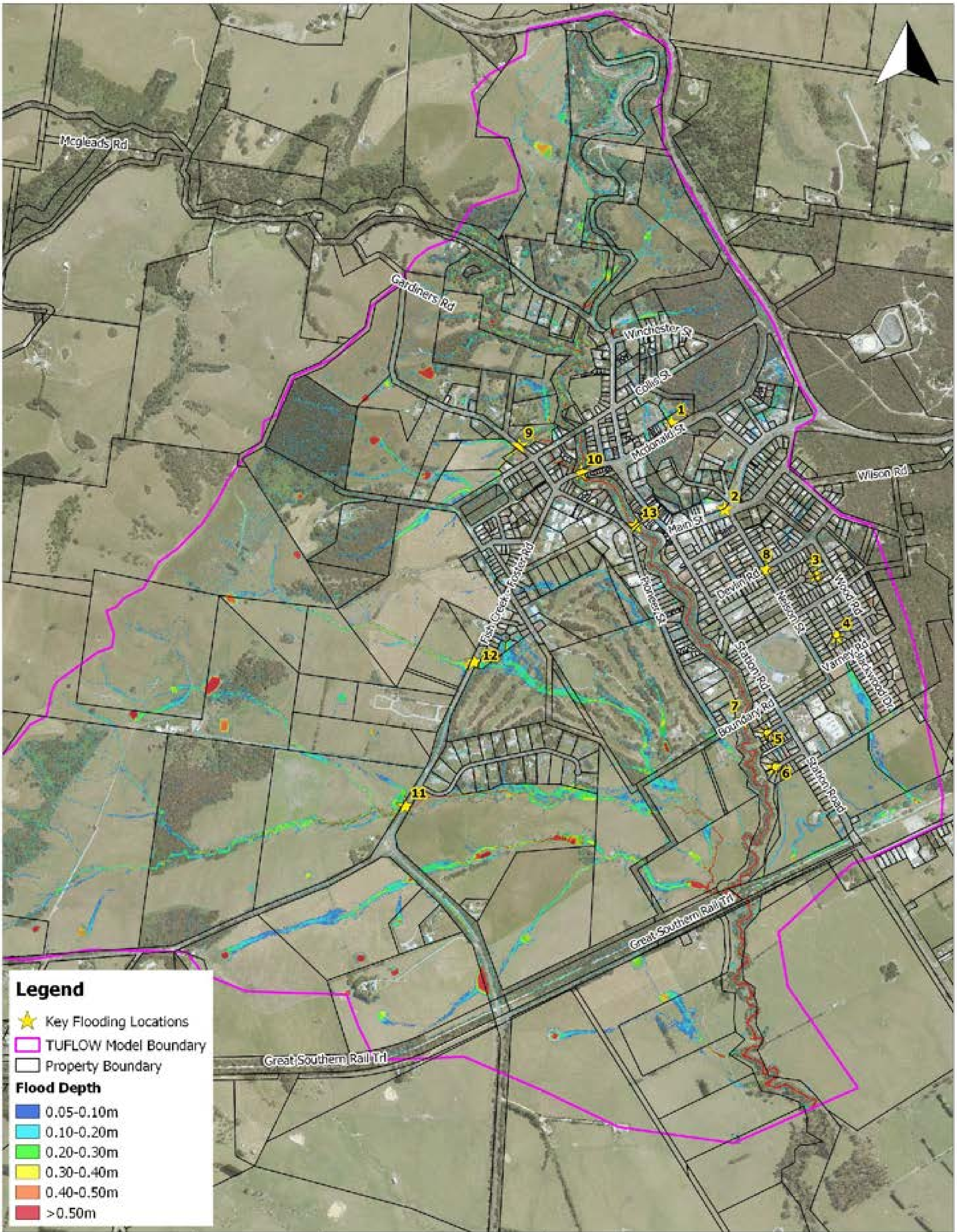
0.10-0.20m
0.20-0.30m
0.30-0.40m
0.40-0.50m
>0.50m
ENGENY
South Gippsland Shire Council
240 0 240 m
Scale in metres (1:12,000 @ A3)
Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55
Foster Flood Study
On-Site Detention Investigation
20% AEP Existing climate conditions baseline (existing drainage) flood depth
Job Number: V2025_001
Revision: 0
Drawn: DH
Checked: NA
Date: 15/10/2018



ENGENY WATER MANAGEMENT

South Gippsland Shire Council

240 0 240 m

Scale in metres (1:12,000 @ A3)

Map Projection: Tranverse Mercator
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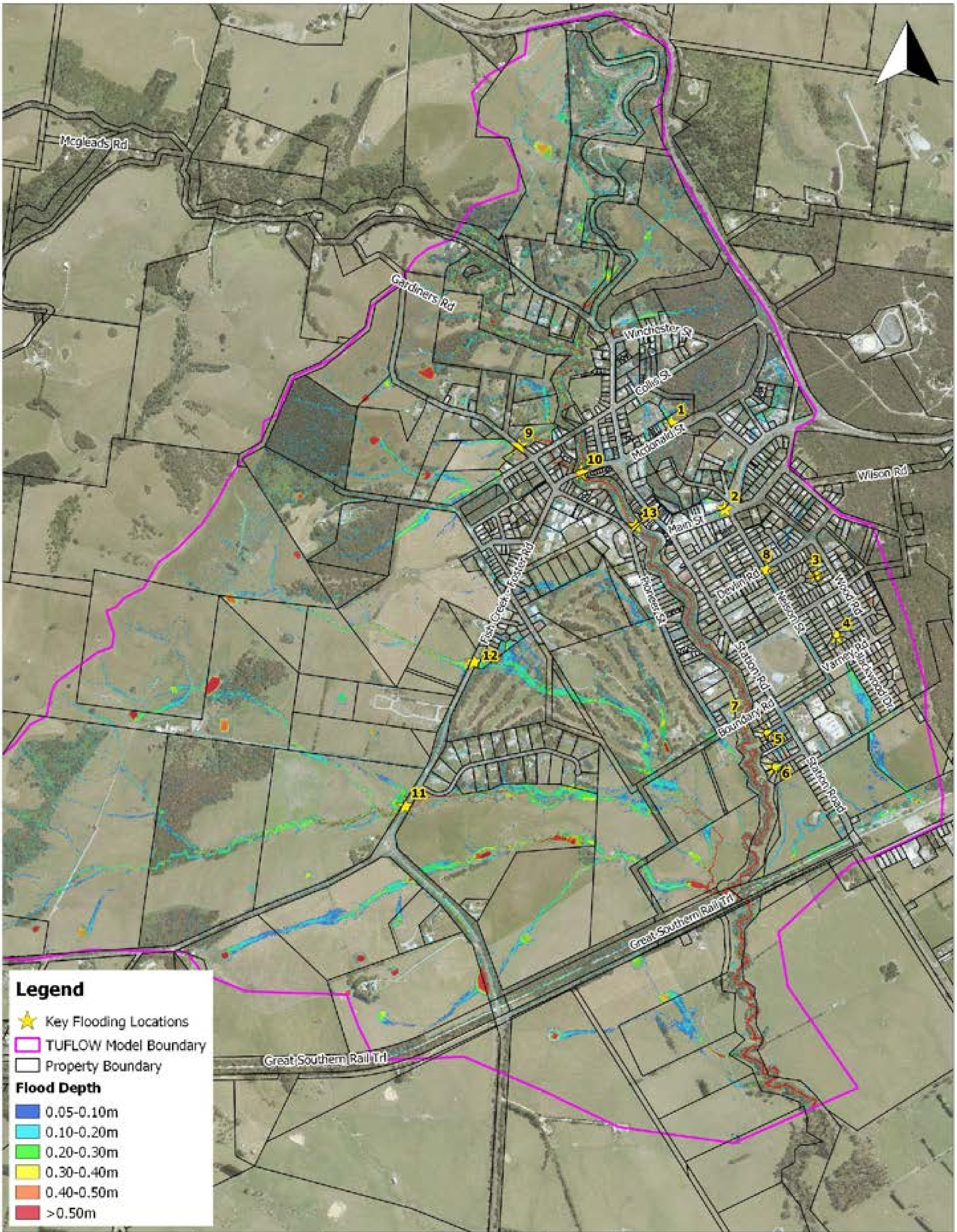
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Foster Flood Study

On-Site Detention Investigation

20% AEP Existing climate conditions with distributed storages (Scenario 1) flood depth

Job Number: V2025_001
Revision: 0
Drawn: DH
Checked: NA
Date: 15/10/2018



ENGENY WATER MANAGEMENT

South Gippsland Shire Council

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Scale in metres (1:12,000 @ A3)

Map Projection: Tranverse Mercator
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Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Foster Flood Study

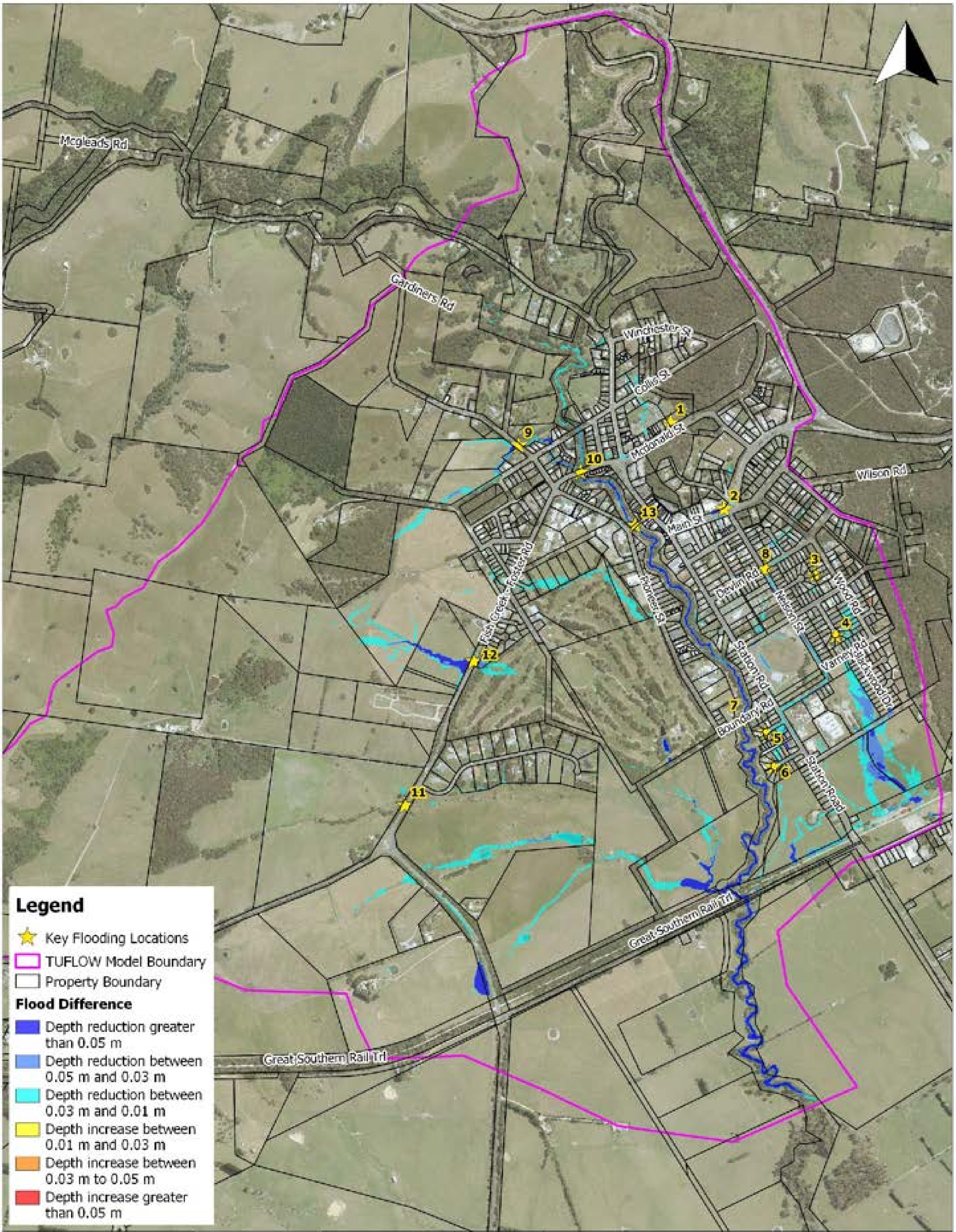
On-Site Detention Investigation

20% AEP Existing climate conditions with distributed storages (Scenario 2) flood depth

Job Number: V2025_001
Revision: 0
Drawn: DH
Checked: NA
Date: 15/10/2018

APPENDIX B

20% AEP Flood Afflux Maps (Existing Climate Conditions)



ENGENY WATER MANAGEMENT

South Gippsland Shire Council

240 0 240 m

Scale in metres (1:12,000 @ A3)

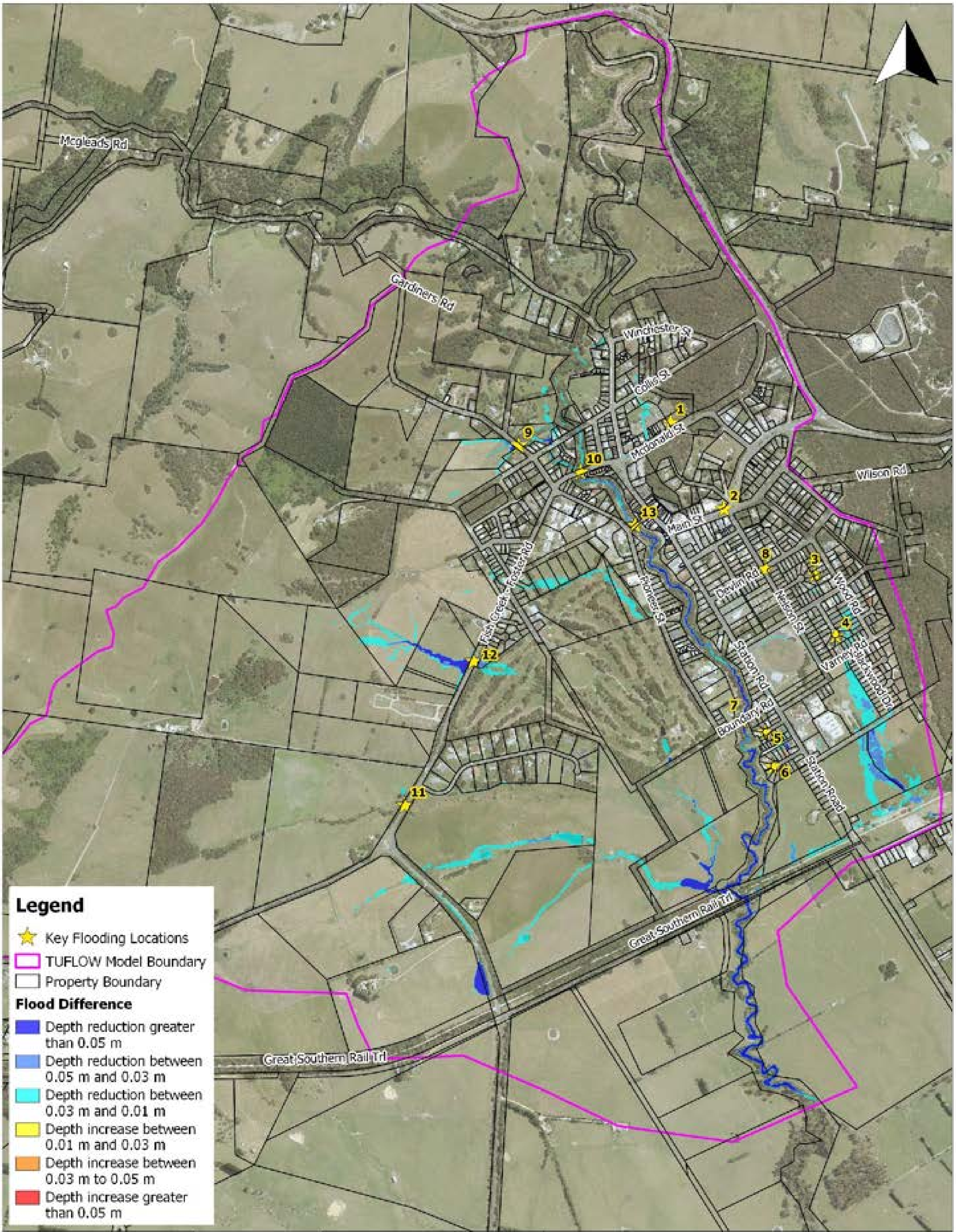
Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Foster Flood Study

On-Site Detention Investigation

20% AEP Existing climate conditions Scenario 1 flood afflux

Job Number: V2025_001
Revision: 0
Drawn: DH
Checked: NA
Date: 15/10/2018



ENGENY

South Gippsland Shire Council

240 0 240 m

Scale in metres (1:12,000 @ A3)

Map Projection: Transverse Mercator
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Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Foster Flood Study

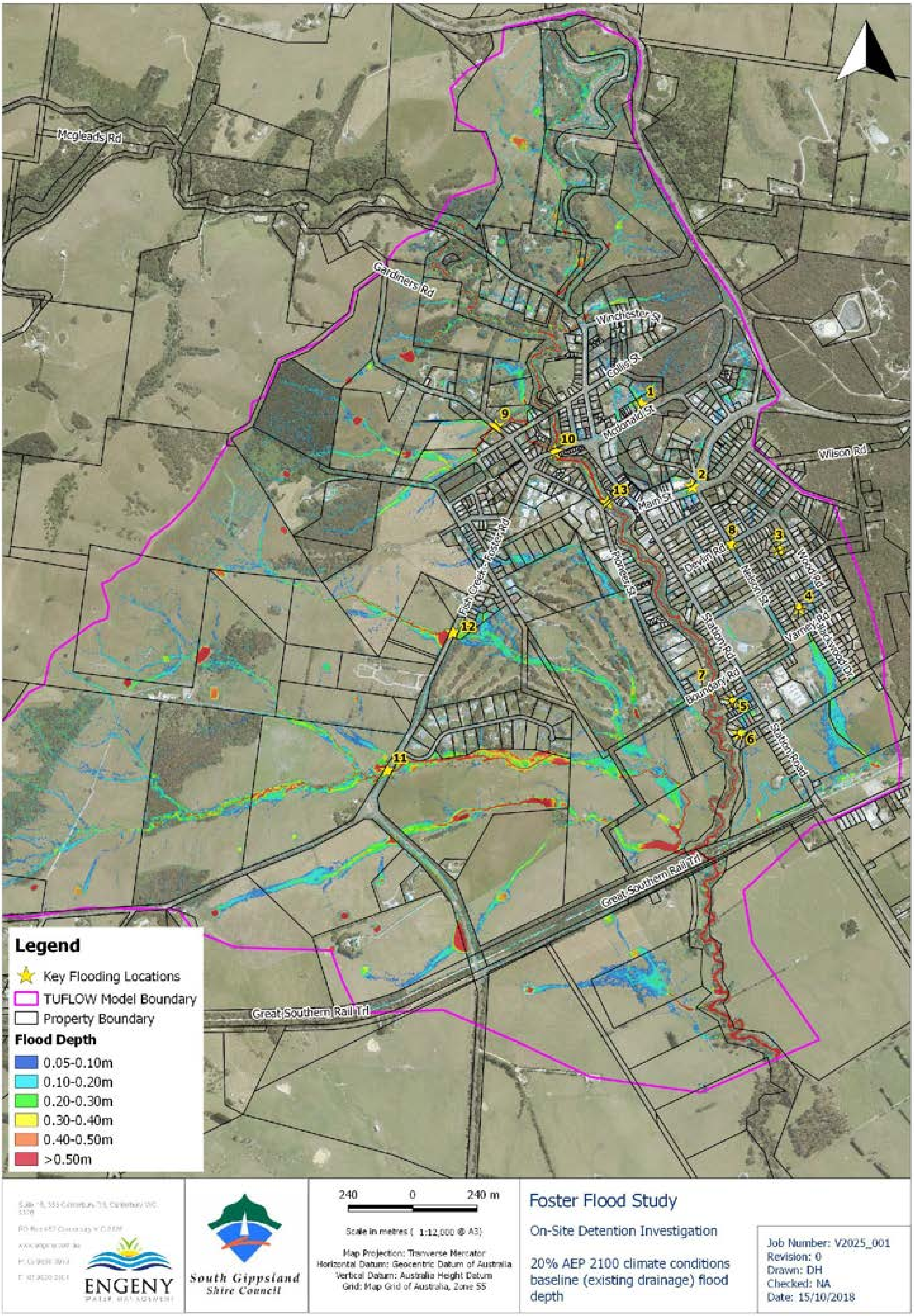
On-Site Detention Investigation

20% AEP Existing climate conditions Scenario 2 flood afflux

Job Number: V2025_001
Revision: 0
Drawn: DH
Checked: NA
Date: 15/10/2018

APPENDIX C

20% AEP Flood Depth Maps (2100 Climate Change Conditions)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Gardiners Rd
Winchester St
Collie St
Mcdonald St
Wilson Rd
Main St
Devlin Rd
Nelson St
Ward Rd
Varney Rd
Station Rd
Boundary Rd
Station Road
Pioneer St
Fish Creek - Foster Rd
Great Southern Rail Trl
1
2
3
4
5
6
7
8
9
10
11
12
13
Legend
Key Flooding Locations
TUFLOW Model Boundary
Property Boundary
Flood Depth
0.05-0.10m
0.10-0.20m
0.20-0.30m
0.30-0.40m
0.40-0.50m
>0.50m
ENGENY
South Gippsland Shire Council
240 0 240 m
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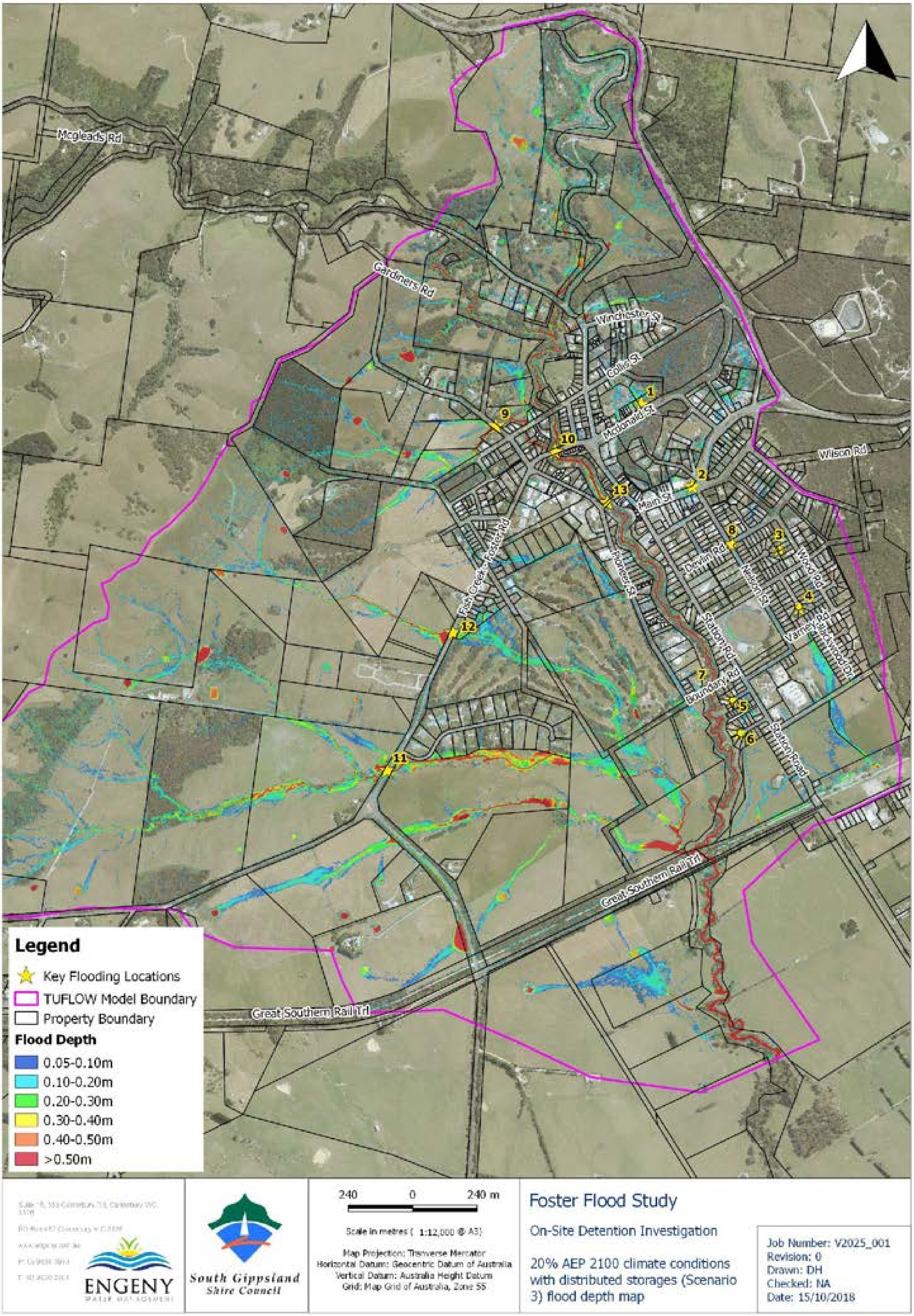
Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55
Foster Flood Study
On-Site Detention Investigation
20% AEP 2100 climate conditions baseline (existing drainage) flood depth
Job Number: V2025_001
Revision: 0
Drawn: DH
Checked: NA
Date: 15/10/2018



ENGENY WATER MANAGEMENT

South Gippsland Shire Council

Foster Flood Study

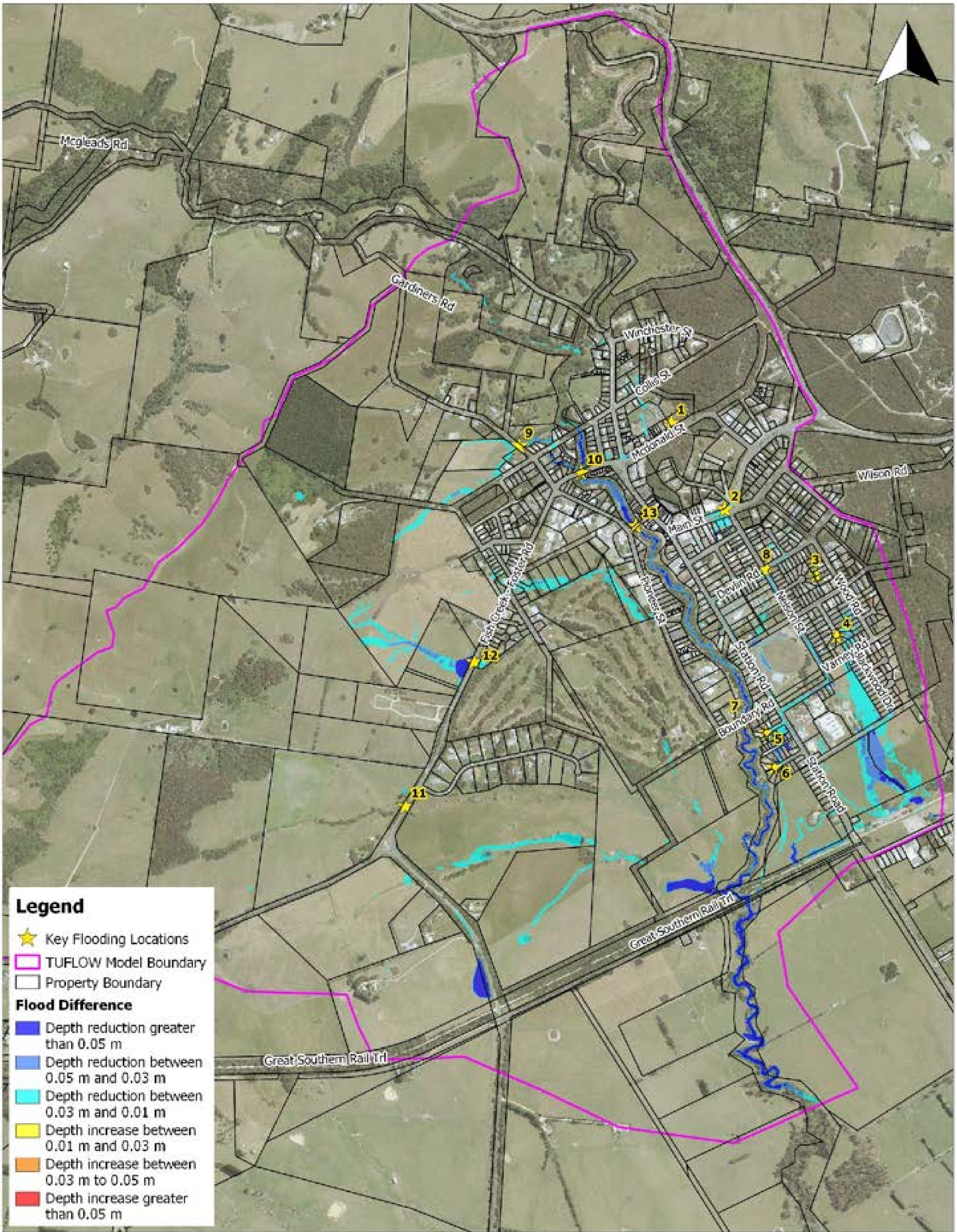
On-Site Detention Investigation

20% AEP 2100 climate conditions with distributed storages (Scenario 3) flood depth map

Job Number: V2025_001
Revision: 0
Drawn: DH
Checked: NA
Date: 15/10/2018

APPENDIX D

20% AEP Flood Afflux Maps (2100 Climate Change Conditions)



ENGENY WATER MANAGEMENT

South Gippsland Shire Council

240 0 240 m

Scale in metres (1:12,000 @ A3)

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Foster Flood Study

On-Site Detention Investigation

20% AEP 2100 climate conditions
Scenario 3 flood afflux

Job Number: V2025_001
Revision: 0
Drawn: DH
Checked: NA
Date: 15/10/2018

APPENDIX V

Couper Dam Failure Consequence Assessment

South Gippsland Shire Council

Flood and Drainage Study for Foster and Surrounding Catchments

Couper Dam Failure Consequence Assessment




March 2019

V2025_001

www.engeny.com.au
P: 03 9888 6978 | F: 03 9830 2601
T5, Lvl 34, 360 Elizabeth St Melbourne VIC 3000 | PO Box 12192, A'Beckett St VIC 8006

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JOB NO. AND PROJECT NAME V2025_001 Foster Flood and Drainage Study

DOC PATH FILE: \\EGIMELAPP02\Melbourne_management$\Projects\V2025 South Gippsland Shire Council\V2025_001 Foster Flood and Drainage Study\07 Deliv\Docs\Report\Consequence Assessment Report\V2025_001-REP-002-1-Couper Consequence Assessment.docx

REV	DESCRIPTION	AUTHOR	REVIEWER	APPROVED BY	DATE
Rev 1	Client Issue	Daniel Hatzihristodoulou	Sean Cowan	Nick Andrewes	19 October 2018
Rev 1	Client Issue	Daniel Hatzihristodoulou	Nick Andrewes	Nick Andrewes	6 March 2019
Signatures					

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1. SCOPE

The consequences to both life and property associated with a failure of Couper Dam, located upstream of Foster, has been assessed as part of this study.

Two (2) scenarios were modelled for the dam, namely:

- Sunny Day Failure (SDF) of the embankment with the dam at full supply level at the time of failure
- Dam Crest Flood (DCF) failure of the embankment. For this scenario the DCF with and without embankment failure were modelled.

The following briefly describes the key steps of the modelling:

- Confirmation of the dam storage and discharge characteristics
- Estimation of the inflow and outflow hydrographs to the dam and determining the AEP of the DCF
- Estimation of coincident flooding for the DCF scenario
- Identification of the dam breach mechanisms and estimation of breach outflows
- Hydraulic modelling and mapping of dam failure inundation downstream of Couper Dam
- Estimation of population at risk (PAR), potential loss of life (PLL), and severity of damage and loss for the failure of the dam
- Determining a suitable consequence category and fall-back flood capacity for the dam.

1.1 Description of Dam

Couper Dam is a privately owned and operated embankment, located on a tributary of Stockyard Creek approximately 5 km upstream of the township of Foster. The dam was originally constructed in 1980 under approval of the Royal Water Commission. The embankment is approximately 120 metres long and 14 metres tall and provides a total storage capacity of 332 ML.

The key characteristics of the dam are summarised in Table 1.1.

Table 1.1 Key Characteristics of Couper Dam

Parameter	Value
Storage Volume at Full Supply Level (FSL)	332 ML
Storage Volume at Embankment Crest Level	435 ML
Embankment Crest Elevation	182.5 m AHD
Embankment Height (from downstream toe)	14 metres
Embankment Length	120 metres
Embankment Crest Width	5 metres
Embankment Batter Slopes	1V:2.8H
Catchment Area	0.97 km2
Outlet Arrangement	Outlet pipe through base of embankment and 4 metre wide (at base) unlined earthen spillway located on right abutment at 181.5 m AHD

2. METHODOLOGY

RORB was adopted as the runoff routing model for generation of flow and simulation of the dam storage. A stand-alone RORB model was developed for Couper Dam as its upstream catchment was not sufficiently delineated in the Stockyard Creek RORB model. This model was used to determine the AEP of the DCF and for estimation of the DCF inflow and outflow hydrographs. The DCF is defined as the flood event which, when routed through the reservoir, results in a still water level in the reservoir, excluding wave effects, which for an embankment dam equates to the lowest point of the embankment crest (ANCOLD, 2000). For Couper Dam the DCF level was taken to be 182.5 m AHD.

The hydrologic modelling approach was based on joint probability techniques using the RORB Monte Carlo simulator as described in the Foster Flood and Drainage Study Report (2018).

The Stockyard Creek waterways RORB model was also utilised to apply rainfall excess and routed hydrographs to the TUFLOW hydraulic model for modelling coincident flooding.

2.1 Design Rainfall Estimation

Complete rainfall frequency curves for the dam catchment were derived by estimating burst depths for the full range of AEPs in accordance with the recommendations contained in ARR 2016.

The hydrological modelling indicated that the critical storm duration for the dam is less than 12 hours, which is expected given the small catchment size. Whilst long duration PMP rainfall depths were derived in order to interpolate intermediate durations (>6 hours and <24 hours), all other inputs to the hydrology model were derived for short durations only (12 hours and less).

Table 2.1 provides a summary of the various procedures used to estimate burst depths for the full range of AEPs and durations. Further explanation on these procedures is presented in the Foster Flood and Drainage Study Report (2019).

Table 2.1 Procedures for estimating burst depths

	Sub-daily rainfall (less than 24 hour)	Long duration rainfall (24 hour or greater)
Rare Rainfalls (1 in 50 to 1 in 100 AEP)	BoM 2016 Rainfall IFD request system	
Very Rare Rainfalls (1 in 100 to 1 in 2000 AEP)	Growth Curve Factors	BoM 2016 Rainfall IFD request system
Extreme Rainfalls (1 in 2000 AEP to PMP)	Interpolation between the credible limit of extrapolation for Very Rare rainfalls and the PMP	
PMP	GSDM	GSAM

Figure 2.1 presents the areal rainfall frequency curves developed for the assessment.

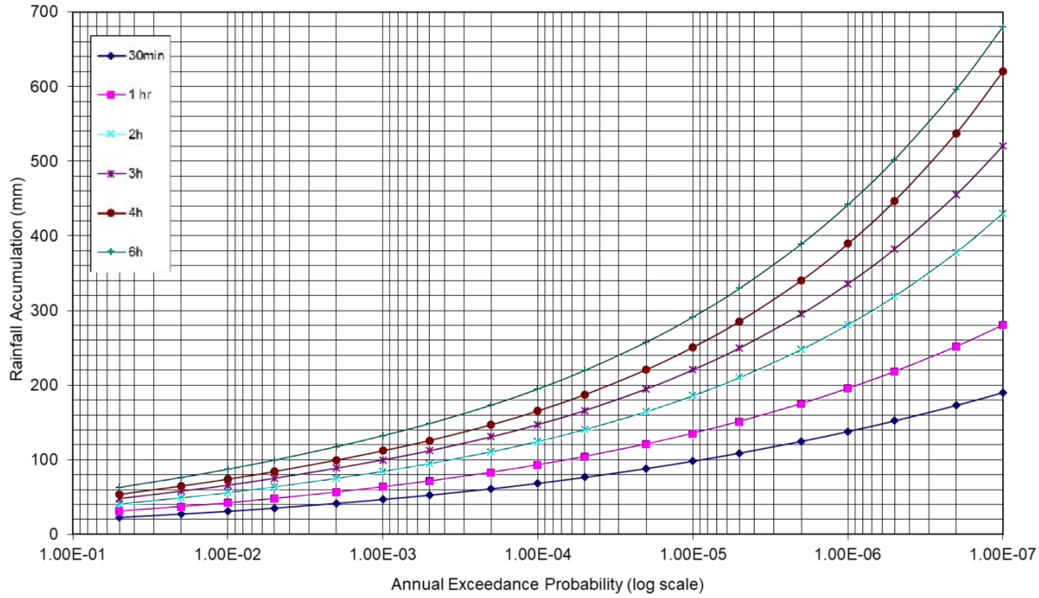

Figure 2.1 Areal rainfall frequency curves

The temporal distribution of burst rainfall and pre-burst rainfall depths were based on the analysis undertaken by Jordan et al. (2005). Due to the small size of the Couper Dam catchment uniform spatial patterns were adopted.

2.2 Couper Dam RORB Modelling

2.2.1 Adopted Parameters

As Couper Dam is in the Stockyard Creek Catchment, k_c for the Couper Dam RORB model was adjusted so that the k_c/d_{av} ratio was equivalent to the Stockyard Creek model. The initial and continuing loss values were extracted from the ARR DataHub and are consistent with those used for the Stockyard Creek modelling. A summary of the RORB model parameters adopted is presented in Table 2.2.

Table 2.2 Couper Dam RORB model parameters

Parameter	Value Adopted
k_c	0.55
m	0.8
Initial Loss	21 mm
Continuing Loss	4.5 mm

2.2.2 Model Validation

The RORB model was validated by comparing to flood quantiles produced by the RFFE method using the parameters presented in Table 2.3.

Table 2.3 RFFE input parameters – Couper Dam

Detail	Value
Latitude at Outlet (degree)	-38.66
Longitude at Outlet (degree)	146.144
Latitude at Centroid (degree)	-38.655
Longitude at Centroid (degree)	146.141
Catchment Area (km2)	0.97

Figure 2.2 presents the results of the RORB model validation. Adopting the RORB model parameters presented in Table 2.2, a good match was achieved with the RFFE estimates.

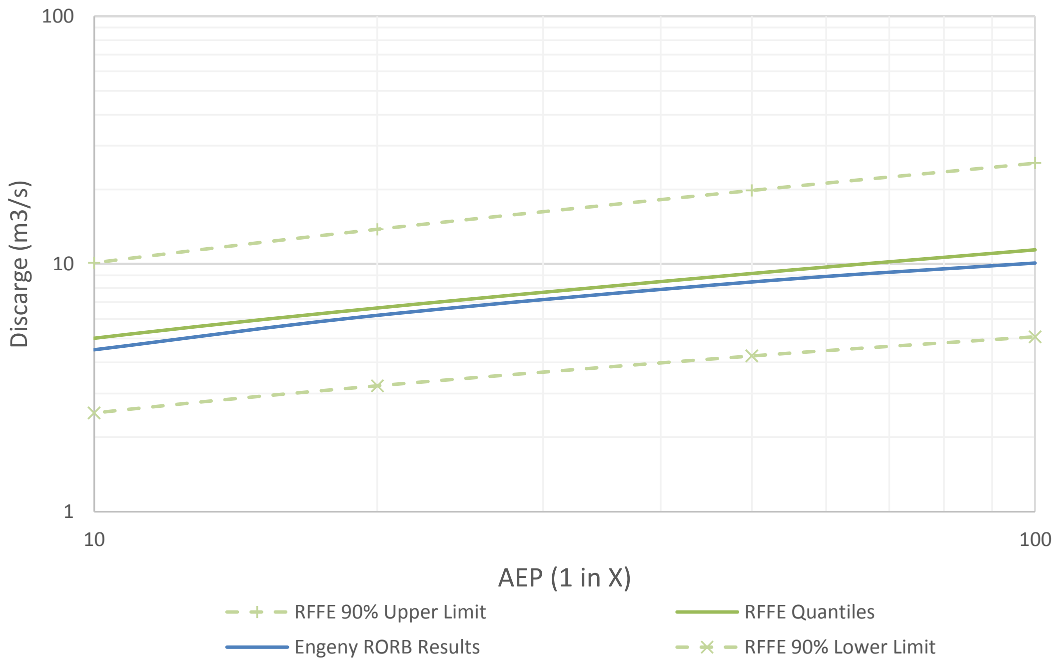

Figure 2.2 **Validation of RORB model to RFFE**

2.2.3 Dam Storage Volume

Below FSL the storage volume of the dam was based on historical information provided by Council and above FSL the LiDAR digital elevation model (DEM) was used. The adopted elevation-storage relationship for Couper Dam is presented in Figure 2.3.

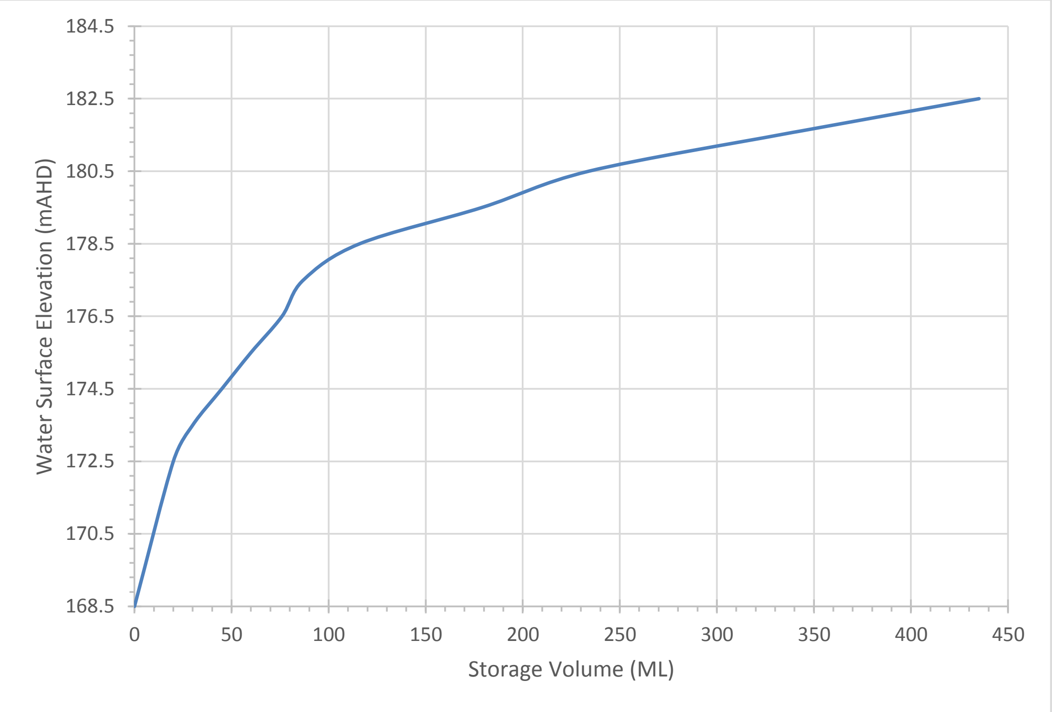

Figure 2.3 **Adopted stage-storage relationship for Couper Dam**

2.2.4 Dam Discharge

Couper Dam has an outlet pipe through the base of the embankment and an unlined earthen spillway located on the right abutment. Flow over the spillway was estimated using the broad crested weir equation assuming a base width of 4 metres and discharge coefficient of 1.7. Flow through the outlet pipe was not considered.

2.2.5 Results

Based on the results of the RORB modelling the AEP of the DCF is approximately 1 in 27,131. Table 2.4 and Figure 2.4 show the peak outflow and water level frequency curve for the dam.

Table 2.4 **Design flood modelling results**

AEP (1 in X)	Peak Outflow (m^3/s)	Peak Water Level (m AHD)	Critical Storm Duration (hrs)
100	1.28	181.77	6
200	1.67	181.84	6
500	2.29	181.97	6

AEP (1 in X)	Peak Outflow (m^3/s)	Peak Water Level (m AHD)	Critical Storm Duration (hrs)
1000	2.82	182.05	6
2000	3.46	182.12	6
5000	4.44	182.12	6
10000	5.32	182.23	6
20000	6.33	182.45	6
50000	7.85	182.60	4

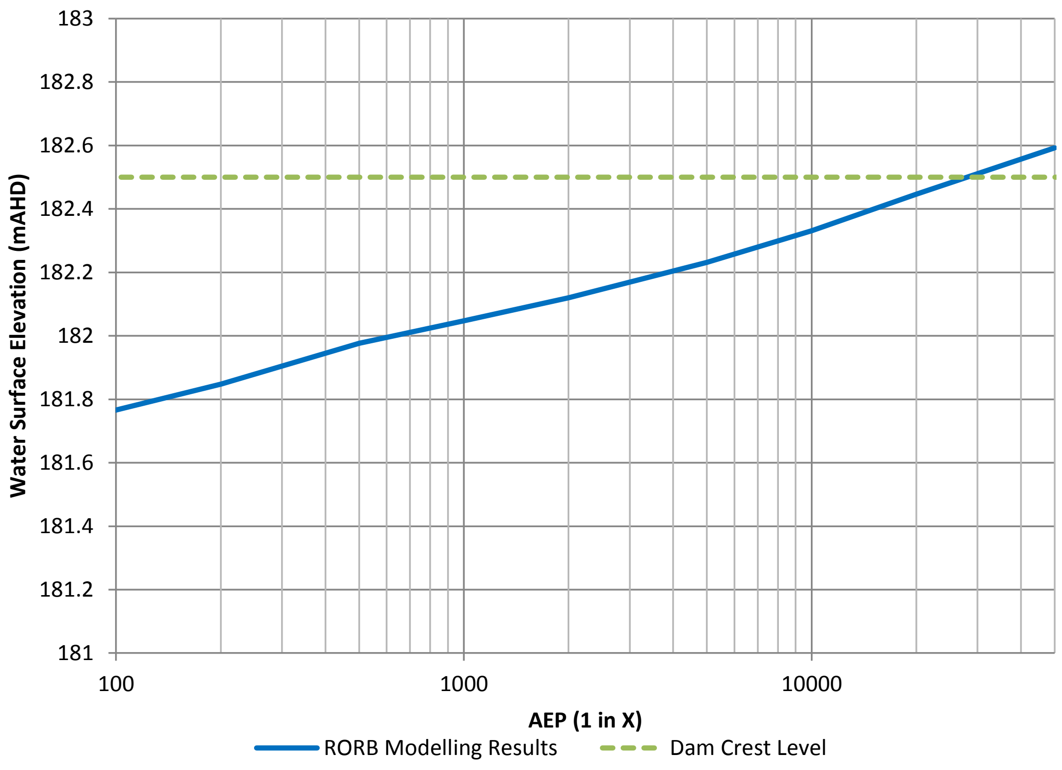

Figure 2.4 Design flood modelling results (100 % blockage of low level outlet)

2.2.6 Selection of RORB Hydrographs for hydraulic modelling

A key input into the hydraulic modelling of the DCF scenario is the outflow hydrograph for the dam. Following the traditional design event procedure, a single outflow hydrograph is generated in RORB for each duration and AEP storm event modelled. The critical duration hydrograph that results in the dam water level reaching the dam embankment crest level (DCF) is selected for hydraulic modelling of embankment failure.

Selection of a suitable hydrograph using a Monte Carlo RORB model is more difficult because the approach generates many thousands of hydrographs for each duration and rainfall AEP, each with different temporal patterns and losses. To select a single hydrograph for hydraulic modelling, the hydrograph was selected from the model run with rainfall AEP closest to the DCF, and losses and temporal patterns closest to the median values. The key input parameters of the model run selected for input onto the DCF hydraulic model is summarised in Table 2.5.

Table 2.5 DCF hydrology input parameters

Parameter	Value
Critical Duration	4 hour
Rainfall AEP	1 in 27,131
Rainfall Depth	209.3 mm
Initial Loss	21 mm
Continuing Loss	4.5 mm
Temporal Pattern	GSDM PMP (BOM, 2003)

2.3 Dam Breach Estimation

2.3.1 Dam Break Parameters

For the SDF and DCF failure scenarios, the following key breach formation parameters were estimated:

- Width of breach base
- Time for breach development
- Breach side slopes
- Height of breach.

The selection of these breach parameters has a significant influence on the estimated peak outflow from the breach and hence the downstream inundation extent. There are several methods for estimating these parameters, all of which have considerable uncertainty associated with them. ANCOLD guidelines are not prescriptive regarding parameter selection.

For this investigation, breach parameters were estimated using several empirical equations that are based on documented historical dam failures. Many of the empirical equations are based on historical failures of large water supply dams which are not representative of smaller dams with low embankment heights and storage volumes. The empirical equations should therefore be used with caution when applied to failure of small dams.

The estimation of breach parameters using the empirical equations is based on a number of key embankment characteristics that are summarised in Table 2.6.

Table 2.6 Key embankment characteristics

Parameter	Value
Breach base elevation (m AHD)	170.0
Embankment crest level / DCF breach top elevation (m AHD)	182.5
FSL / SDF breach top elevation (m AHD)	181.5
Embankment height (m)	12.5
Embankment batter slopes	1H:2.8V
Crest width (m)	4.0
Pool volume at embankment crest (ML)	435
Pool volume at FSL (ML)	332

The breach parameters estimated using the selected empirical equations and those adopted for this investigation are presented in Table 2.7 and Table 2.8.

Table 2.7 Estimated and adopted breach parameters for SDF

Empirical Approach	Time for Breach Development (hr)	Average Breach Width (m)	Breach Side Slopes (H:V)
McDonald and Langridge Monopolis (1984)	0.34	8	0.5
Von Thun and Gillette (1990)	0.51	39	0.5
Froelich (1995)	0.21	17	0.9
Froelich (2008)	0.23	17	0.7
Adopted	**0.3**	**17**	**1**

Table 2.8 Estimated and adopted breach parameters for DCF Failure

Empirical Approach	Time for Breach Development (hr)	Average Breach Width (m)	Breach Side Slopes (H:V)
McDonald and Langridge Monopolis (1984)	0.38	9	0.5
Von Thun and Gillette (1990)	0.53	41	0.5
Froelich (1995)	0.23	27	1.4
Froelich (2008)	0.26	25	1
Adopted	**0.3**	**27**	**1**

From documented historical events the range of breach formation time is generally between 0.1 hour and 4 hours and the range of average breach widths between 0.5 to 5 times the dam height. When compared to these rules of thumb the adopted breach parameters are considered reasonable.

2.3.2 Dam Breach Hydrograph

Dam breach hydrographs for the SDF and DCF scenarios were estimated using HEC-HMS. HEC-HMS is a Hydrologic Modelling System developed by the U.S. Army Corps of Engineers Hydrologic Engineering Centre. To establish the breach hydrograph, the critical duration hydrograph from RORB was input into HEC-HMS along with the estimated dam breach parameters presented in Table 2.7.

For validating the HEC-HMS estimated peak failure flow the Froehlich (1995) empirical approach is one of the better available methods for direct prediction of peak breach discharge (USBR, 1998). For the DCF failure scenario, the HEC-HMS estimated peak failure flow of 796 m^3/s is consistent with the Froehlich (1995) empirical estimate of 737 m^3/s. For the SDF scenario, the HEC-HMS estimate of 796 m^3/s is larger than the Froehlich (1995) estimate of 621 m^3/s. However, given the large degree of uncertainty associated with the empirical estimates, it is considered reasonable to adopt the more conservative HEC-HMS estimate. A sensitivity analysis could be undertaken on the adopted breach outflow but given the low PLL estimated (refer Section 3) with the more conservative outflow, the additional modelling effort is unwarranted.

2.4 Hydraulic Modelling

2.4.1 TUFLOW Model Configuration

The TUFLOW hydraulic model developed for this flood study was utilised and extended to include the additional catchment directly to the north to include Couper dam.

2.4.2 Coincident Flooding

Downstream of the embankment there are catchment inflows that, depending upon timing, may influence the incremental consequences of failure. These coincident flows were determined using the Stockyard Creek Waterways RORB model. The corresponding rainfall depths and temporal patterns adopted in the Couper Dam RORB model for the DCF event were used for the Stockyard Creek Waterways RORB model. These depths were spatially reduced using the GSDM ellipses as recommended in the AR&R 2016 guidelines.

3. CONSEQUENCE ASSESSMENT

Determination of the consequence category of the embankment was undertaken in accordance with the ANCOLD Guidelines on the Consequence Categories for Dams (2012). The consequence category is based on the Population at Risk (PAR), Potential Loss of Life (PLL) and the Severity of Damage and Loss arising from downstream inundation caused by a dam break.

Consequences are based on the incremental impacts of a dam failure, which is estimated as the difference between the dam crest flood with and without breach of the embankment.

3.1 Population at Risk (PAR)

The ANCOLD Guidelines defines the Population at Risk (PAR) as all people who would be directly exposed to flood waters assuming they took no action to evacuate.

Estimating the PAR involves determining the following:

- Number and type of properties directly impacted by the flood inundation extent
- Occupancy rates for impacted properties
- Exposure factors for impacted properties (how frequently is the property occupied).

To estimate the PAR, the following key assumptions were adopted:

- The adopted occupancy rate for residential properties was 2.0, which was taken from the Australian Bureau of Statistics (ABS, 2016) for the suburb of Foster.
- For residential properties an exposure factor of 0.5 was adopted for the day (8am to 6pm) and 1 for the night (6pm to 8am)
- Road users were not included in the PAR given those on suburban roads at the time of dam failure are likely to have been counted in estimates of residential PAR, working PAR, or itinerant PAR at businesses and other public properties (e.g. schools).

The estimated PAR for each scenario assessed is presented in Table 3.1.

Table 3.1 Estimated PAR downstream of Couper Dam

Scenario	Day	Night	Day / Night
SDF	192	184	187
DCF - Failure	320	424	381
DCF - No Failure	318	420	378
DCF - Incremental	2	4	3

3.2 Potential Loss of Life (PLL)

The Potential Loss of Life (PLL) is estimated by applying a fatality rate to the estimated PAR downstream of the embankment. There are several methods available for estimating PLL which are based on data from historical dam failures. These methods assign a fatality rate to each PAR which is based on warning time and flood severity. For this assessment, PLL was estimated using the model developed by Graham (1999) in accordance with ANCOLD (2012).

Empirical approaches for estimating PLL from dam failures are not applicable to the estimation of loss of life in non-dam failure flood scenarios. Non-failure PLL was estimated using a fatality rate of 0.0002, which is recommended by Hill et al. (2007) for low severity flooding (DV less than 4.6 m^2/s).

Further to the discussion above, on reviewing the results it was noted that whilst the inundation extent was extensive, a large portion of properties experienced shallow and slow moving (very low DV) flow for all scenarios assessed. Australian Rainfall and Runoff released a draft publication on “Appropriate Safety Criteria for People” in 2010. This document indicates that a DV of between 0 to 0.4 m^2/s is a low flow hazard for children. To account for this, a lower fatality rate of 0.0001 was adopted for properties with a DV less than 0.4 m^2/s (for both failure and no failure scenarios).

The estimated PLL for each modelled scenario is presented in Table 3.2.

Table 3.2 Estimated PLL downstream of Couper Dam

Scenario	Day	Night	Day / Night
SDF	0.02	0.02	0.02
DCF - Failure	0.64	0.22	0.39
DCF - No Failure	0.04	0.04	0.04
DCF - Incremental	0.60	0.18	0.35

3.3 Severity of Damage and Loss

The severity of damage and loss is determined by evaluating the impact of a dam failure with respect to:

- Total infrastructure costs
- Impact on dam owner's business
- Health and social impacts
- Environmental impacts.

The impact on dam owner's business, health, social, and environmental aspects were assessed using ratings contained in the ANCOLD (2012) Guidelines on the Consequence Categories of Dams.

Total infrastructure costs are summarised in Table 3.3 and were determined using the cost method outlined in the Foster Flood and Drainage Study Report (2018).

Table 3.3 Total infrastructure costs

Damages types	SDF	DCF fail	DCF no fail	DCF Incremental
Direct damages to residential buildings	$4,994,500	$16,159,000	$13,883,500	$2,275,500
Direct damages to commercial / industrial buildings	$1,975,500	$6,910,500	$6,395,500	$515,000
Direct damages to residential properties	$2,000	$856,000	$194,500	$661,500
Direct damages to commercial / industrial properties	$1,500	$83,500	$22,000	$61,500
Direct damages to regional infrastructure (roads)	$145,500	$369,500	$344,000	$25,500
Indirect damages (30 % of direct damages)	$2,135,500	$7,313,500	$6,252,000	$1,061,500
Cost to repair dam	$5,000,000	$5,000,000	-	$5,000,000
Total estimated damages	$14,255,000	$36,692,000	$27,091,500	$9,600,500

A severity of damage and loss of Medium is recommended for the SDF and DCF failure scenarios. Assessment of severity of damage and loss is presented in **Appendix A**.

3.4 Consequence Category

The Consequence Category is based on the severity of damage and loss in conjunction with the incremental risk to human life expressed as either the Population at Risk (PAR) or Potential Loss of Life (PLL). Consequence Categories based on both PAR and PLL are reproduced from ANCOLD (2012) in Table 3.4 and Table 3.5 respectively.

Table 3.4 Consequence Category based on PAR (from Table 3 in ANCOLD 2012)

Population at Risk	Severity of Damage and Loss			
	Minor	**Medium**	**Major**	**Catastrophic**
<1	Very Low	Low	Significant	High C
≥ 1 to <10	Significant (Note 2)	Significant (Note 2)	High C	High B
≥ 10 to <100	High C	High C	High B	High A
≥ 100 to <1000	(Note 1)	High B	High A	Extreme
≥ 1000	(Note 1)	(Note 1)	Extreme	Extreme

Note 1 With a PAR in excess of 100, it is unlikely damage will be minor. Similarly, with a PAR in excess of 1,000 it is unlikely damage will be classified as medium.

Note 2 Change to 'High C' where there is the potential of one or more lives being lost.

Table 3.5 Consequence Category based on PLL (from Table 4 in ANCOLD 2012)

Incremental Potential Loss of Life (PLL)	Severity of Damage and Loss			
	Minor	**Medium**	**Major**	**Catastrophic**
<0.1	Very Low	Low	Significant	High C
≥ 0.1 to <1	Significant	Significant	High C	High B
≥ 1 to <5	(Note 1)	High C	High B	High A
≥ 5 to <50	(Note 1)	High A	High A	Extreme
≥ 50	(Note 1)	(Note 1)	Extreme	Extreme

Note 1 With an incremental PLL equal to or greater than one (1), it is unlikely damage will be minor. Similarly, with an incremental PLL in excess of 50 it is unlikely damage will be classified as medium.

The recommended consequence category for the embankment based on both PLL and PAR are presented in Table 3.6.

Table 3.6 Recommended consequence category

Approach	PAR / PLL	Severity of Damage and Loss	Consequence Category
SDF			
PAR	≥ 100 to <1000	Medium	High B
PLL	<0.1	Medium	Low
DCF			
PAR	≥ 1 to <10	Medium	Significant
PLL	≥ 0.1 to <1	Medium	Significant

Although the PLL estimates represent a more comprehensive approach to consequence assessment, the ANCOLD Guidelines indicate that the PAR and PLL approaches should not result in widely different consequence categories. The large PAR estimated for the SDF scenario consists mostly of properties experiencing shallow and slow moving (very low DV) flow. Whilst these flow characteristics are captured in the PLL estimates, the PAR includes all properties inundated by dam failure regardless of the severity of flooding. If properties subject to a DV < 0.4 m^2/s are removed from the SDF PAR, the PAR is reduced to 0. For this reason, it is recommended that Couper Dam is assigned a Consequence Category of **Significant**.

3.5 Fall-back Flood Capacity

The ANCOLD Acceptable Flood Capacity Guidelines (ANCOLD, 2000) provide “Fall-back” flood capacities (spillway capacity) based on the flood failure consequence category of a dam. The guidelines state that the selection of the flood AEP is to be taken within the continuum, with the flood capacity selected from the conservative end of the range, relative to the order of consequences, particularly the assessment of potential fatalities.

Table 3.7 presents the required spillway capacities for each Consequence Category (formerly known as Incremental Flood Hazard Category (IFHC)).

Table 3.7 Fall-back Flood Capacity (ANCOLD 2000)

IFCH	Flood AEP
Extreme	Probable Maximum Flood (PMF)
High A	Probable Maximum Precipitation Design Flood
High B	$10^{-5} – 10^{-6}$
High C	$10^{-4} – 10^{-5}$
Significant	$10^{-3} – 10^{-4}$
Very Low/ Low	$10^{-2} – 10^{-3}$

Based on a consequence category of Significant and PLL of 0.35 the recommended fall-back flood capacity for the dam is the 0.02 % (1 in 5,000) AEP event. Based on the estimated probability of the DCF of approximately 1 in 27,131 AEP, the existing spillway is adequately sized (based on the ANCOLD Acceptable Flood Capacity Guidelines).

4. RECOMMENDATIONS

The “Significant”, consequence category that has been found by this study provides an indication of the level of dam safety practice that should be applied to managing the Couper dam. The dam managers should review the outcomes of this assessment and use it as a basis for developing a dam safety management program that is consistent with the recommendations of the ANCOLD Guidelines and other relevant national policies and guidelines on dam management.

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5. QUALIFICATIONS

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

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

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

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

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

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

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

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

g. This report does not provide legal advice.

6. REFERENCES

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APPENDIX A

Severity of Damage & Loss

Wet Day Flood with Failure

	Type	Explanatory Notes	Estimate	Category
1. Total Infrastructure Costs				
	Residential	Total number of houses affected, some destroyed and some damaged.	$31,692,000	
	Commercial	Including business and agriculture, e.g. retail, manufacturing, resources, agriculture. These services should be assessed in terms of average annual wage.		
	Infrastructure	Such as roads, railways, power, communications, gas, water supply, sewerage, irrigation, drainage, schools, hospitals, community facilities and public buildings. May be expressed in terms of annual cash flow or turnover.		
	Dam repair and replacement cost	Repairs to the embankment or wall and appurtenant works which will return the dam to its previous level of service.	$2,000,000	
		Total (including indirect damages)	$33,692,000	2
		Assessment:		**Medium**
2. Impact on dam Owner's Business				
	Importance to the business	Loss of storage is likely to affect the service provided to some degree. It may be appropriate, on one hand, to increase the severity level because of the importance of the reservoir. On the other hand, a less vital water resource may lead to a reduction in the severity of the cost of replacement or repair.	Restrictions needed during dry periods	Minor
	Effect on services provided by the owner	Water supply, power or recreational facility is no longer available or disrupted to a proportion of the community supplied by the agency.	Minor difficulties in replacing services	Minor
	Effect on continuing credibility	Standing or reputation of the organisation in the community	Some reaction but short lived	Minor
	Community reaction and political implications	There may be community objection to replacement of the dam. Also, the relationship between the dam owner and local, state and federal legislature.	Some reaction but short lived	Minor
	Impact on financial viability	Economic and legal liability; ability to meet the costs of repairs and damage; and ability to meet claims from	Able to absorb in one financial year	Minor

	Type	Explanatory Notes	Estimate	Category
		others.		
	Value of water in the storage	Loss of income from loss of the stored water.	Can be absorbed in one financial year	Minor
		Assessment:		**Minor**
3. Health and Social Impacts				
	Public Health	Human health could be affected by: * Contamination of drinking water * Failure of lack of water supplies, sewage treatment works, power Contamination of services such as food, health, recreation areas and facilities caused by the uncontrolled release of sewage, industrial or toxic waste as a result of a dam break	100 to 1,000 people affected	Medium
	Loss of Services to the community	Loss of gas/power/communications and transport. Distribution of medical supplies, food, especially perishable food item	<100 people affected for one month	Minor
	Cost of emergency management	Police, Emergency Services and volunteers will incur a cost both direct and indirect	<1,000 person days	Minor
	Dislocation of people	People whose homes are destroyed or damaged will need to be housed or billeted for various times.	100 to 1,000 person months	Medium
	Dislocation of businesses	Business will be prevented from trading in the short term and may be affected in the long term.	<20 business months	Minor
	Employment affected	Loss of employment.	<100 jobs lost	Minor
	Loss of heritage	Historic sites, both pre and post European settlement.	Local facility	Minor
	Loss of recreational facility	Many communities rely, to various degrees, on bodies of water for boating, fishing and other recreational aspects, including visual relief. Other recreational facilities may be located downstream of the reservoir, eg golf course, sports grounds.	Local facility	Minor
		Assessment:		**Medium**

	Type	Explanatory Notes	Estimate	Category
4. Environmental Impacts				
	Area of impact	Land damaged by dam failure exclusive of land prone to natural flooding. For tailings dams, the damage will relate to the toxicity of the material in relation to both area of impact and the depth of penetration of the toxic materials	<1km2	Minor
	Duration of impact	Habitats may take a long time to recover. (e.g. Substantial erosion, deposition of flood borne materials). The duration of the impact will also relate to the toxicity of discharged material (e.g. saline, tailings, sewerage, cold water, deoxygenated water)	< 1year	Minor
	Stock and Fauna	Stock and fauna may ingest contaminated water/fodder. Stock may need to be removed from the area or destroyed. Contaminants may cause damage in relation to reproduction cycle.	Discharge from dam break would not contaminate water supplies used by stock and fauna	Minor
	Ecosystems	Includes organisms and non-living components which interact to form a stable system. Consideration should be given to their environment, habitat, breeding grounds and food chain.	Discharge from dam break is not expected to impact on ecosystems. Remediation possible.	Minor
	Rare and Endangered Species	Information can be gained from state and federal agencies in relation to areas known to contain rare and endangered flora and fauna.	Species exist but minimal damage expected. Recovery within one year	Minor
Assessment:				**Minor**
OVERALL ASSESSMENT				**Medium**

Wet Day Flood without Failure

Type		Explanatory Notes	Estimate	Category
1. Total Infrastructure Costs				
	Residential	Total number of houses affected, some destroyed and some damaged.	$27,091,500	
	Commercial	Including business and agriculture, e.g. retail, manufacturing, resources, agriculture. These services should be assessed in terms of average annual wage.		
	Infrastructure	Such as roads, railways, power, communications, gas, water supply, sewerage, irrigation, drainage, schools, hospitals, community facilities and public buildings. May be expressed in terms of annual cash flow or turnover.		
	Dam repair and replacement cost	Repairs to the embankment or wall and appurtenant works which will return the dam to its previous level of service.	$2,000,000	
		Total (including indirect damages)	$29,091,500	2
Assessment:				**Medium**
2. Impact on dam Owner's Business				
	Importance to the business	Loss of storage is likely to affect the service provided to some degree. It may be appropriate, on one hand, to increase the severity level because of the importance of the reservoir. On the other hand, a less vital water resource may lead to a reduction in the severity of the cost of replacement or repair.	Restrictions needed during dry periods	Minor
	Effect on services provided by the owner	Water supply, power or recreational facility is no longer available or disrupted to a proportion of the community supplied by the agency.	Minor difficulties in replacing services	Minor
	Effect on continuing credibility	Standing or reputation of the organisation in the community	Some reaction but short lived	Minor
	Community reaction and political implications	There may be community objection to replacement of the dam. Also, the relationship between the dam owner and local, state and federal legislature.	Some reaction but short lived	Minor
	Impact on financial viability	Economic and legal liability; ability to meet the costs of repairs and damage; and ability to meet claims from	Able to absorb in one financial year	Minor

	Type	Explanatory Notes	Estimate	Category
		others.		
	Value of water in the storage	Loss of income from loss of the stored water.	Can be absorbed in one financial year	Minor
		Assessment:		**Minor**
3. Health and Social Impacts				
	Public Health	Human health could be affected by: * Contamination of drinking water * Failure of lack of water supplies, sewage treatment works, power Contamination of services such as food, health, recreation areas and facilities caused by the uncontrolled release of sewage, industrial or toxic waste as a result of a dam break	100 to 1,000 people affected	Medium
	Loss of Services to the community	Loss of gas/power/communications and transport. Distribution of medical supplies, food, especially perishable food item	<100 people affected for one month	Minor
	Cost of emergency management	Police, Emergency Services and volunteers will incur a cost both direct and indirect	<1,000 person days	Minor
	Dislocation of people	People whose homes are destroyed or damaged will need to be housed or billeted for various times.	100 to 1,000 person months	Medium
	Dislocation of businesses	Business will be prevented from trading in the short term and may be affected in the long term.	<20 business months	Minor
	Employment affected	Loss of employment.	<100 jobs lost	Minor
	Loss of heritage	Historic sites, both pre and post European settlement.	Local facility	Minor
	Loss of recreational facility	Many communities rely, to various degrees, on bodies of water for boating, fishing and other recreational aspects, including visual relief. Other recreational facilities may be located downstream of the reservoir, eg golf course, sports grounds.	Local facility	Minor
		Assessment:		**Medium**

Type	Explanatory Notes	Estimate	Category
4. Environmental Impacts			
Area of impact	Land damaged by dam failure exclusive of land prone to natural flooding. For tailings dams, the damage will relate to the toxicity of the material in relation to both area of impact and the depth of penetration of the toxic materials	<1km2	Minor
Duration of impact	Habitats may take a long time to recover. (e.g. Substantial erosion, deposition of flood borne materials). The duration of the impact will also relate to the toxicity of discharged material (e.g. saline, tailings, sewerage, cold water, deoxygenated water)	< 1year	Minor
Stock and Fauna	Stock and fauna may ingest contaminated water/fodder. Stock may need to be removed from the area or destroyed. Contaminants may cause damage in relation to reproduction cycle.	Discharge from dam break would not contaminate water supplies used by stock and fauna	Minor
Ecosystems	Includes organisms and non-living components which interact to form a stable system. Consideration should be given to their environment, habitat, breeding grounds and food chain.	Discharge from dam break is not expected to impact on ecosystems. Remediation possible.	Minor
Rare and Endangered Species	Information can be gained from state and federal agencies in relation to areas known to contain rare and endangered flora and fauna.	Species exist but minimal damage expected. Recovery within one year	Minor
Assessment:			**Minor**
OVERALL ASSESSMENT			**Medium**

Sunny Day Flood with Failure

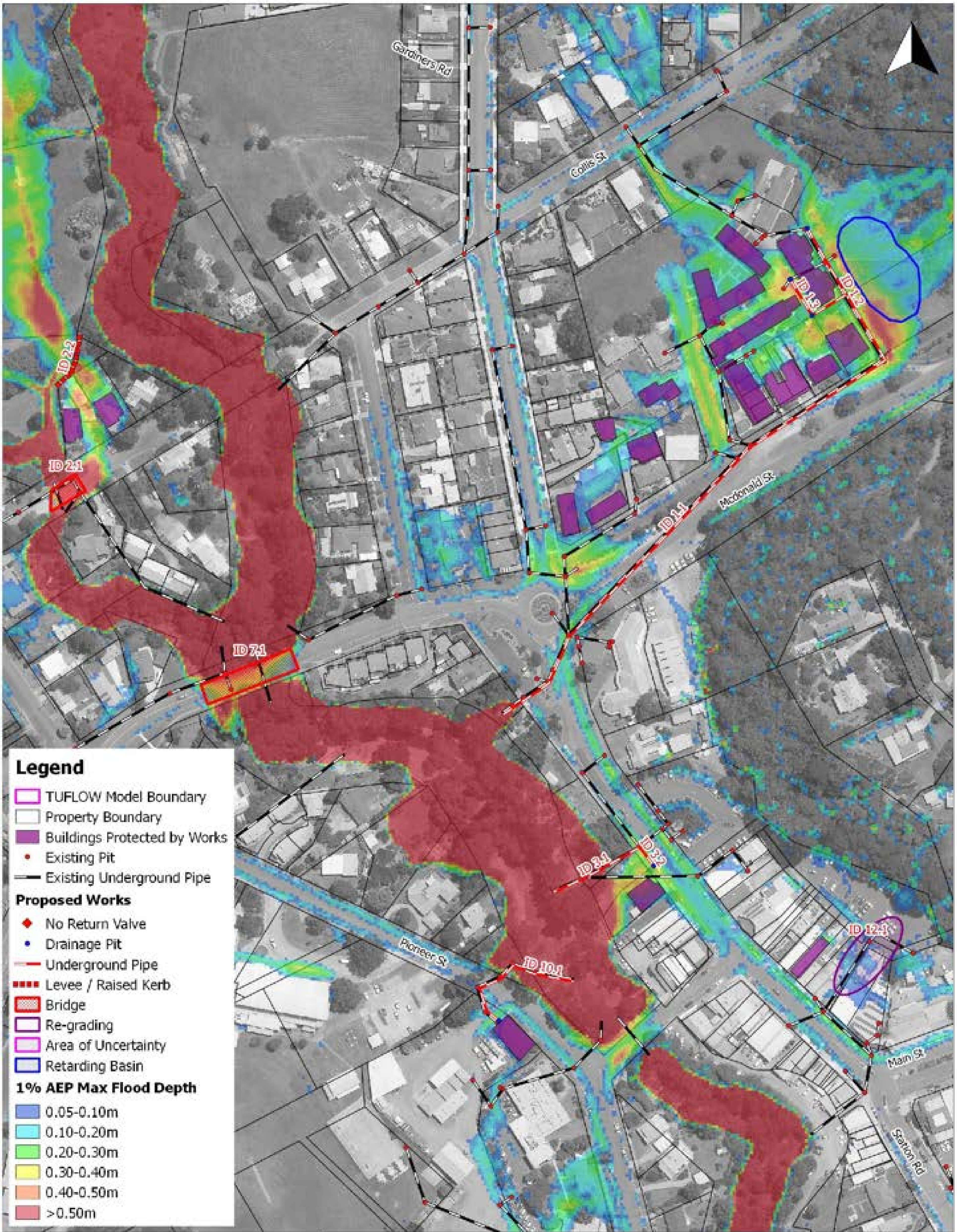
Type		Explanatory Notes	Estimate	Category
1. Total Infrastructure Costs				
	Residential	Total number of houses affected, some destroyed and some damaged.	$9,255,000	
	Commercial	Including business and agriculture, e.g. retail, manufacturing, resources, agriculture. These services should be assessed in terms of average annual wage.		
	Infrastructure	Such as roads, railways, power, communications, gas, water supply, sewerage, irrigation, drainage, schools, hospitals, community facilities and public buildings. May be expressed in terms of annual cash flow or turnover.		
	Dam repair and replacement cost	Repairs to the embankment or wall and appurtenant works which will return the dam to its previous level of service.	$2,000,000	
		Total (including indirect damages)	$11,255,000	2
		Assessment:		**Medium**
2. Impact on dam Owner's Business				
	Importance to the business	Loss of storage is likely to affect the service provided to some degree. It may be appropriate, on one hand, to increase the severity level because of the importance of the reservoir. On the other hand, a less vital water resource may lead to a reduction in the severity of the cost of replacement or repair.	Restrictions needed during dry periods	Minor
	Effect on services provided by the owner	Water supply, power or recreational facility is no longer available or disrupted to a proportion of the community supplied by the agency.	Minor difficulties in replacing services	Minor
	Effect on continuing credibility	Standing or reputation of the organisation in the community	Some reaction but short lived	Minor
	Community reaction and political implications	There may be community objection to replacement of the dam. Also, the relationship between the dam owner and local, state and federal legislature.	Some reaction but short lived	Minor
	Impact on financial viability	Economic and legal liability; ability to meet the costs of repairs and damage; and ability to meet claims from	Able to absorb in one financial year	Minor

	Type	Explanatory Notes	Estimate	Category
		others.		
	Value of water in the storage	Loss of income from loss of the stored water.	Can be absorbed in one financial year	Minor
		Assessment:		**Minor**
3. Health and Social Impacts				
	Public Health	Human health could be affected by: * Contamination of drinking water * Failure of lack of water supplies, sewage treatment works, power Contamination of services such as food, health, recreation areas and facilities caused by the uncontrolled release of sewage, industrial or toxic waste as a result of a dam break	100 to 1,000 people affected	Medium
	Loss of Services to the community	Loss of gas/power/communications and transport. Distribution of medical supplies, food, especially perishable food item	<100 people affected for one month	Minor
	Cost of emergency management	Police, Emergency Services and volunteers will incur a cost both direct and indirect	<1,000 person days	Minor
	Dislocation of people	People whose homes are destroyed or damaged will need to be housed or billeted for various times.	100 to 1,000 person months	Medium
	Dislocation of businesses	Business will be prevented from trading in the short term and may be affected in the long term.	<20 business months	Minor
	Employment affected	Loss of employment.	<100 jobs lost	Minor
	Loss of heritage	Historic sites, both pre and post European settlement.	Local facility	Minor
	Loss of recreational facility	Many communities rely, to various degrees, on bodies of water for boating, fishing and other recreational aspects, including visual relief. Other recreational facilities may be located downstream of the reservoir, eg golf course, sports grounds.	Local facility	Minor
		Assessment:		**Medium**

	Type	Explanatory Notes	Estimate	Category
4. Environmental Impacts				
	Area of impact	Land damaged by dam failure exclusive of land prone to natural flooding. For tailings dams, the damage will relate to the toxicity of the material in relation to both area of impact and the depth of penetration of the toxic materials	<1km2	Minor
	Duration of impact	Habitats may take a long time to recover. (e.g. Substantial erosion, deposition of flood borne materials). The duration of the impact will also relate to the toxicity of discharged material (e.g. saline, tailings, sewerage, cold water, deoxygenated water)	< 1year	Minor
	Stock and Fauna	Stock and fauna may ingest contaminated water/fodder. Stock may need to be removed from the area or destroyed. Contaminants may cause damage in relation to reproduction cycle.	Discharge from dam break would not contaminate water supplies used by stock and fauna	Minor
	Ecosystems	Includes organisms and non-living components which interact to form a stable system. Consideration should be given to their environment, habitat, breeding grounds and food chain.	Discharge from dam break is not expected to impact on ecosystems. Remediation possible.	Minor
	Rare and Endangered Species	Information can be gained from state and federal agencies in relation to areas known to contain rare and endangered flora and fauna.	Species exist but minimal damage expected. Recovery within one year	Minor
Assessment:				**Minor**
OVERALL ASSESSMENT				**Medium**

APPENDIX W

Mitigation Works Maps



ENGENY WATER MANAGEMENT

South Gippsland Shire Council

35 0 35 m

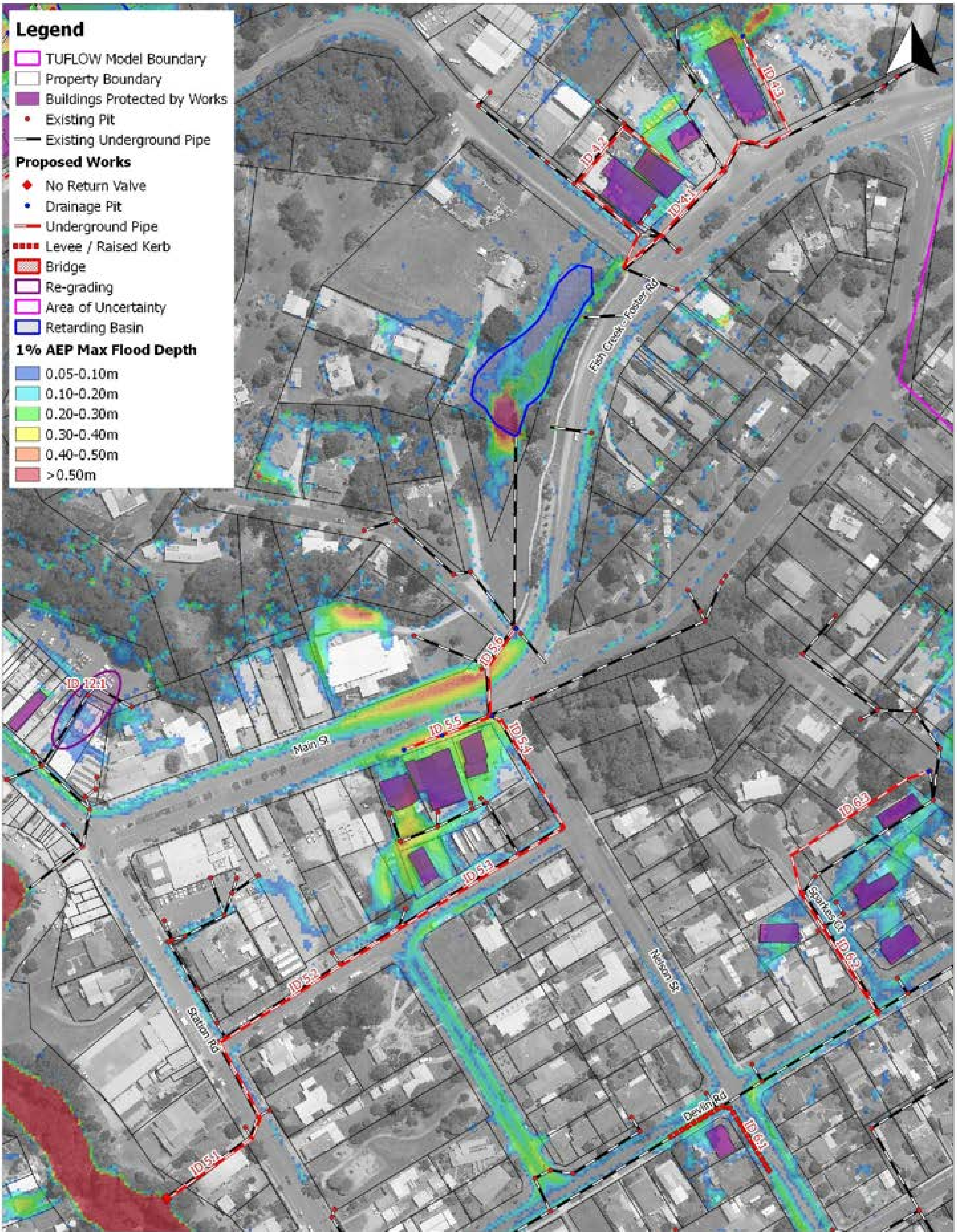
Scale in metres (1:1,750 @ A3)

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Foster Flood Study

Proposed Mitigation Works (1 of 5)

Job Number: V2025_001
Revision: 0
Drawn: DH
Checked: NA
Date: 15/8/2018



ENGENY WATER MANAGEMENT

South Gippsland Shire Council

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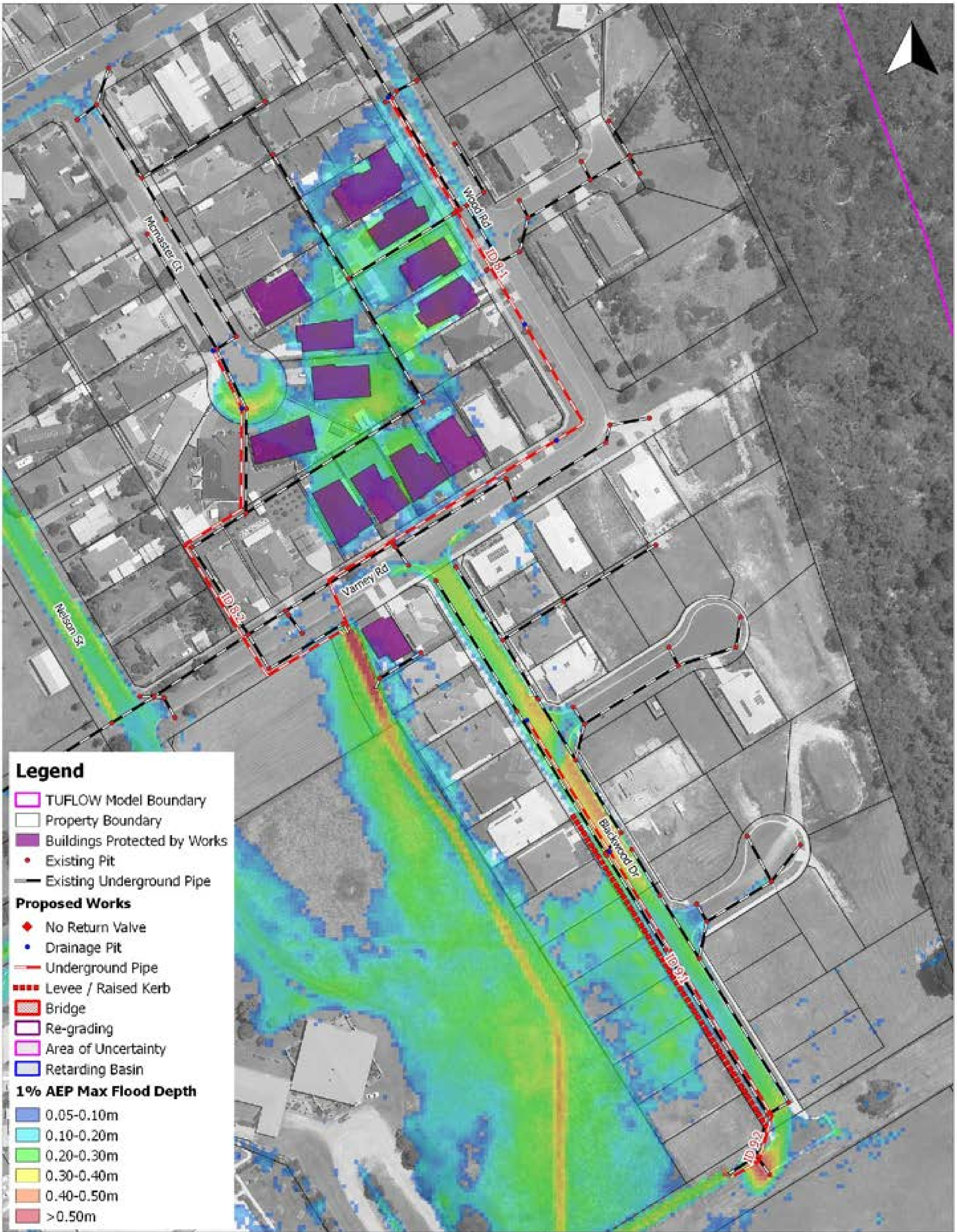
Scale in metres (1:1,750 @ A3)

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Foster Flood Study

Proposed Mitigation Works (2 of 5)

Job Number: V2025_001
Revision: 0
Drawn: DH
Checked: NA
Date: 15/8/2018



ENGENY WATER MANAGEMENT

South Gippsland Shire Council

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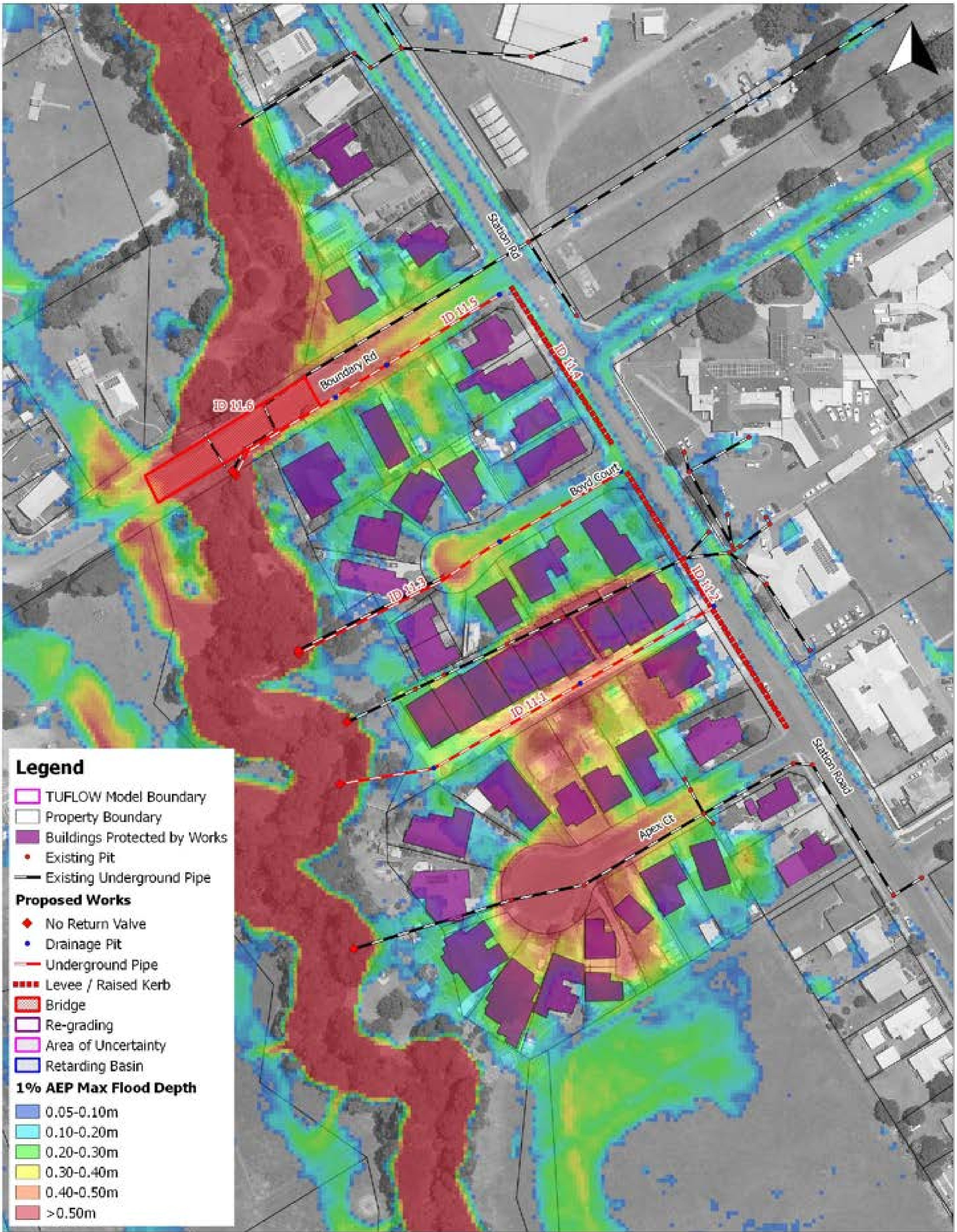
Scale in metres (1:1,250 @ A3)

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Foster Flood Study

Proposed Mitigation Works (3 of 5)

Job Number: V2025_001
Revision: 0
Drawn: DH
Checked: NA
Date: 15/8/2018



ENGENY WATER MANAGEMENT

South Gippsland Shire Council

25 0 25 m

Scale in metres (1:1,250 @ A3)

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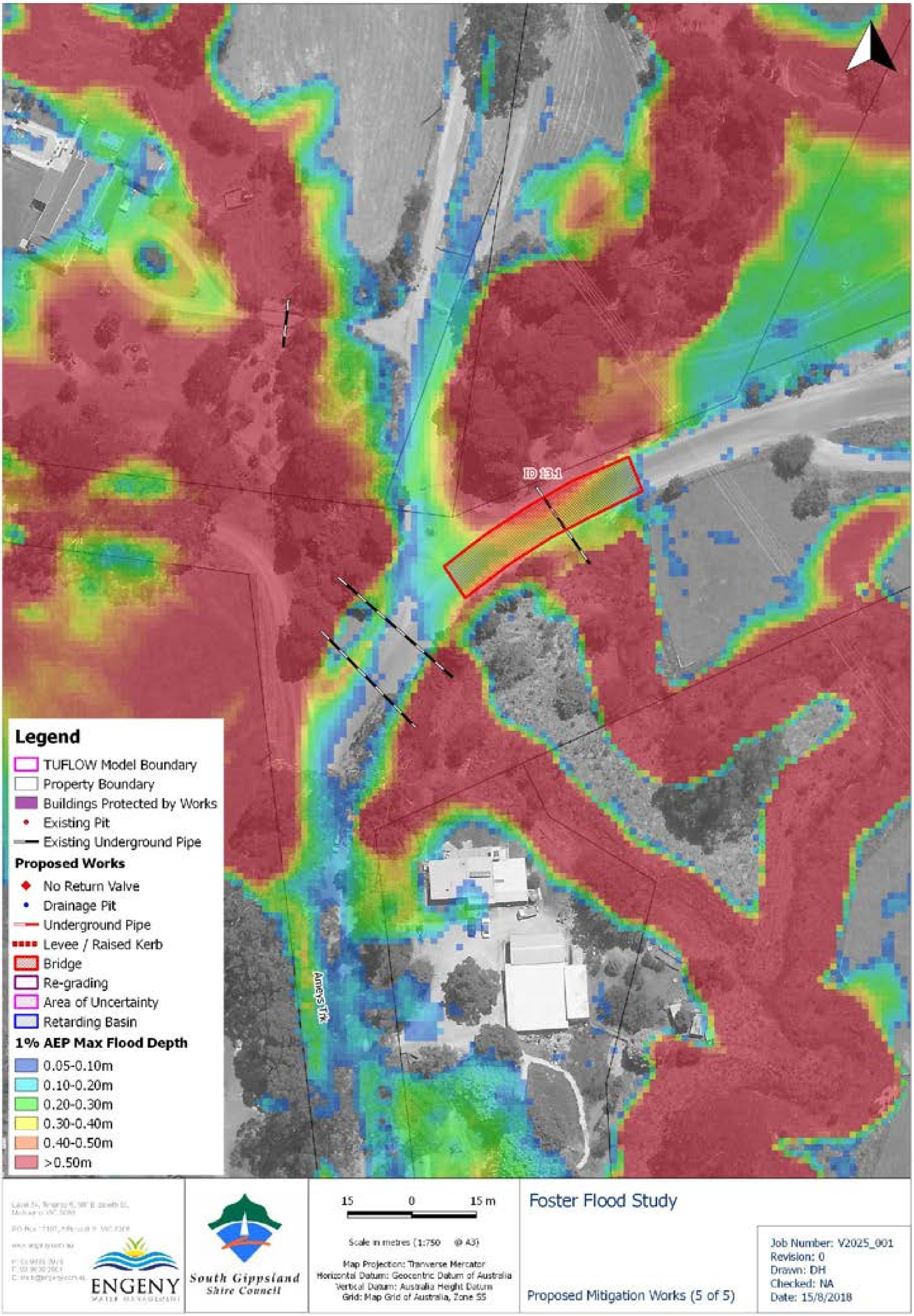
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Foster Flood Study

Proposed Mitigation Works (4 of 5)

Job Number: V2025_001
Revision: 0
Drawn: DH
Checked: NA
Date: 15/8/2018


ID 13.1
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Legend
TUFLOW Model Boundary
Property Boundary
Buildings Protected by Works
Existing Pit
Existing Underground Pipe
Proposed Works
No Return Valve
Drainage Pit
Underground Pipe
Levee / Raised Kerb
Bridge
Re-grading
Area of Uncertainty
Retarding Basin
1% AEP Max Flood Depth
0.05-0.10m
0.10-0.20m
0.20-0.30m
0.30-0.40m
0.40-0.50m
>0.50m
ENGENY
South Gippsland Shire Council
15 0 15 m
Scale in metres (1:750 @ A3)
Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55
Foster Flood Study
Proposed Mitigation Works (5 of 5)
Job Number: V2025_001
Revision: 0
Drawn: DH
Checked: NA
Date: 15/8/2018

APPENDIX X

Mitigation Works Detailed Table

ID	Location	Description	Design Flow (m³/s)	Pipe/Kerb/Channel Length (m)	Number of Pipes	Pipe Diameter (mm)	Condition	Estimated Cost
1.1	McDonald Street	Increase pit inlet capacity and add underground drainage	0.36	274	1	525	Minor Council Road	$192,000
1.2	North of McDonald Street	Increase pit inlet capacity and add underground drainage	0.23	80	1	525	Developed Private Property	$74,500
1.3	North of McDonald Street	Increase pit inlet capacity and add underground drainage	0.12	43	1	375	Developed Private Property	$25,500
2.1	Gibbs Street	Construct a bridge	8.5	-	-	-	Council Minor Road	Subject to further investigations
2.2	North of Gibbs Street	Construct a levee	-	28	-	-	Reserve	$57,500
3.1	Main Street	Increase pit inlet capacity and add underground drainage	0.17	50	1	300	Major Council Road	$15,500
3.2	Main Street to Stockyard Creek	Increase pit inlet capacity and add underground drainage	0.17	12	1	450	Reserve	$23,500

ID	Location	Description	Design Flow (m^3/s)	Pipe/Kerb/Channel Length (m)	Number of Pipes	Pipe Diameter (mm)	Condition	Estimated Cost
4.1	Fish Creek-Foster Road	Increase pit inlet capacity and add underground drainage	0.41	118	1	450	Minor Council Road	$72,500
4.2	Power Street	Increase pit inlet capacity and add underground drainage	0.2	34	1	375	Developed Private Property	$80,000
4.3	North side of Fish Creek-Foster Road	Increase pit inlet capacity and add underground drainage	0.41	55	1	600	Developed Private Property	$62,000
5.1	Station Road to Stockyard Creek	Increase pit inlet capacity and add underground drainage	0.94	54	1	675	Developed Private Property	$72,000
5.2	Station Street	Increase pit inlet capacity and add underground drainage	0.94	166	1	825	Minor Council Road	$238,500
5.3	Court Street	Increase pit inlet capacity and add underground drainage	0.94	133	1	825	Minor Council Road	$193,000
5.4	Nelson Street	Increase pit inlet capacity	0.94	38	1	825	Minor Council Road	$61,000

ID	Location	Description	Design Flow (m^3/s)	Pipe/Kerb/Channel Length (m)	Number of Pipes	Pipe Diameter (mm)	Condition	Estimated Cost
		and add underground drainage						
5.5	Church Hill Road	Increase pit inlet capacity and add underground drainage	0.57	49	1	750	Major Council Road	$73,000
5.6	Church Hill Road	Increase pit inlet capacity and add underground drainage	0.94	50	1	675	Major Council Road	$65,000
6.1	Nelson Street	Increase kerb height	-	40	-		Minor Council Road	$3,500
6.2	Sparkes Court	Increase pit inlet capacity and add underground drainage	0.3	95	1	450	Minor Council Road	$59,500
6.3	Between Wood Court and Sparkes Court	Increase pit inlet capacity and add underground drainage	0.3	84	1	375	Minor Council Road	$50,000
7.1	McDonald Street at Stockyard Creek	Remove culvert crossing and construct a bridge	-	-	-	-	Major Council Road	Subject to further investigations
8.1	Wood Road and	Increase pit inlet capacity	0.28	272	1	525	Minor Council Road	$190,500

ID	Location	Description	Design Flow (m^3/s)	Pipe/Kerb/Channel Length (m)	Number of Pipes	Pipe Diameter (mm)	Condition	Estimated Cost
	Varney Road	and add underground drainage						
8.2	McMaster Court and Varney Road	Increase pit inlet capacity and add underground drainage	0.17	177	1	450	Developed Private Property	$134,500
9.1	Blackwood Drive	Increase kerb height	-	136	-	-	Council Minor Road	$11,500
9.2	Blackwood Drive	Increase pit inlet capacity and add underground drainage	0.57	203	1	675	Council Minor Road	$204,000
10.1	Pioneer Street	Increase pit inlet capacity and add underground drainage	-	75	1	300	Minor Council Road	$34,000
11.1	Between Boyd Court and Apex Court	Increase pit inlet capacity and add underground drainage	0.26	155	1	525	Minor Council Road	$112,000
11.2	Station Street	Increase kerb height	-	111	-	-	Minor Council Road	$9,500
11.3	Boyd Court	Increase pit inlet capacity and add underground	0.54	137	1	675	Minor Council Road	$140,500

ID	Location	Description	Design Flow (m^3/s)	Pipe/Kerb/Channel Length (m)	Number of Pipes	Pipe Diameter (mm)	Condition	Estimated Cost
		drainage						
11.4	Station Road	Increase kerb height	-	68	-	-	Minor Council Road	$6,000
11.5	Boundary Road	Increase pit inlet capacity and add underground drainage	1.31	120	1	750	Minor Council Road	$142,500
11.6	Boundary Road	Remove culvert crossings and construct bridge	59.1	-	-	-	Minor Council Road	Subject to further investigations
12.1	Main Street	Re-grade road surface and increase pit inlet capacity	-	-	-	-	Developed Private Property	Subject to further investigations
13.1	Ameys track at Bennison Creek	Remove culvert crossings and construct bridge	-	-	-	-	Major Council Road	Subject to further investigations

APPENDIX Y

Peer Review Comments and Engeny's Responses

Foster Flood and Drainage Study

Hydraulics report V2025_001

Collated comments

The following table contains collated comments in response to the following report:

- Engeny (2018) Flood and Drainage Study of Foster and Surrounding Catchments – Hydraulics Report. Engeny for South Gippsland Shire Council.

Guide to colour coding:

For resolution before the report will be approved. These are 'red light' issues. The project should not continue until these issues are resolved to the satisfaction of the CMA. Areas of concern that have serious implications for the quality or accuracy of project outputs will be listed here.	(red)
For review and resolution for the final project report. These are 'amber light' issues that need to be addressed before the final project report is prepared, however work on subsequent stages of the project can continue in the meantime. Areas of the report that need further detail or explanation will be listed here.	(amber)
Comments, feedback and advice. These are 'green light' comments including feedback that does not need to be actioned for this project. The consultant and CMA may find these comments useful when considering future work.	(green)

Feedback	Flag	DELWP comments / Suggested response	Action/comments from consultant
Review 1			
Assessment of response by Engeny to review comments on the first version of the hydrology report			
The collated comments on the hydrology report, and Engeny's responses, are published as Appendix A in the hydraulics report (Engeny, 2018). I have assessed Engeny's responses and annotated the Appendix (attached to this memo). Most of the responses are appropriate. The following list highlights some key remaining issues.			
Climate change The reviewers noted that climate change had not been addressed. Engeny has still not attended to climate change in the revised hydrology report, or the hydraulics report, but do state that it will be addressed in a risk mitigation report. This remains to be delivered.			Engeny has completed its Climate Change investigation and has discussed the outcomes and provided outputs as necessary.
Land use change and bush fires Similar to the issue of climate change, land use change for 2050 and 2100 scenarios is to be addressed in the risk mitigation report. Bushfires will also be addressed in the risk mitigation report.			Engeny has completed modelling the various development scenarios and has discussed the outcomes and provided outputs as necessary.
Flood warning Flood warning is required as a deliverable in the brief but has not been addressed in the revised hydrology report or the hydraulics report.			Engeny has discussed flood warning procedures in the final report.
Fraction impervious A reviewer questioned the use of non-zero fraction impervious values for rural areas. Engeny requested further information from the reviewer but this request was never passed on. Subsequently Engeny, in consultation South Gippsland Shire Council, decided not to address this issue. Given other uncertainties in modelling, this is not likely to greatly affect results for large floods. The argument for using zero values of fraction impervious in rural areas, is made in Section 3.3 of Ladson (2016).			
Pre-burst rainfall values for short duration storms Pre-burst rainfall is required to estimate initial losses for hydrologic modelling. Pre-burst values for durations of 60 min and longer are available from the ARR data hub (data.arr-software.org) but there is currently no information for shorter durations. This is an issue for the whole industry, not just for Engeny. Engeny sought information from the reviewer about the best way to estimate short-duration pre-burst rainfalls - but this request was not passed on. There is little evidence to support the values adopted by Engeny but their approach is reasonable given: (1) there is no standard approach to determine these values, (2) Engeny considered a range of different methods, (3) Engeny's approach is conservative, and 4) they have agreement from the Council.			
Generating hydrographs in RORB for input at the hydraulic model boundary A reviewer questioned the generation of hydrographs for input to the hydraulic model. In particular, whether a RORB model calibrated to the catchment outlet was appropriate for generating hydrographs at upstream inflow points. Engeny argue that catchment characteristics at the outlet and the inflow points are similar and state they discussed this issue with the Council and received support for their approach. These checks should be noted in the report.			Engeny to expand on their discussions with Council in the hydrological and hydraulic reports.
Minor issues Several minor issues where noted during the review. Engeny state that they will update the report in accordance with the reviewers' comments. However, most of these issues have not been addressed.			Engeny has undertaken a thorough review and updated the hydrological section of the final report in accordance with reviewers' comments.
Specific comments on the hydrology report			
The revised and original hydrology reports were compared. There are few changes, with the most substantial being the removal of estimates for the 20% AEP flood, which was not required by the project brief but which was included in the original report. There are several places in the hydrology report where follow up investigations were proposed as part of hydraulic modelling. Now that the hydraulics report is available, it is possible to assess if this work has been undertaken. Issues and quoted sections from the revised hydrology report are noted below.			
Stockyard Creek sensitivity analysis (Page 32, Section 4.6.1) "…it is proposed that a sensitivity analysis is undertaken using the hydraulic model to determine the impact			Engeny has discussed this with Council. It was considered that the validation of the modelling results to known flood levels was sufficient to warrant not

Feedback	Flag	DELWP comments / Suggested response	Action/comments from consultant
of flooding associated with hydrographs derived from the Victoria Prediction Equation kc (10.78) and scaled down AR&R losses to confirm this assessment."			undertaking this sensitivity investigation.
Selection of kc value for urban RORB modelling (Page 32 and 33, Section 4.6.2) "The Foster Urban RORB model is located within the Stockyard Creek catchment and adopted a kc value of 2.14, which was calculated using the same kc/dav ratio as the Stockyard Creek model. This value may be adjusted subject to the findings of the comparison between TUFLOW modelled flows and the RORB model flows that will be undertaken following the setup of the TUFLOW hydraulic model."			An investigation was undertaken to compare flows between RORB and TUFLOW at key locations within the Foster Urban model. Rather than adjusting the kc value, Engeny conducted a variable manning's sensitivity (based on industry supported values) that satisfied the selection of kc.
Selection of kc value for Bennison Creek (Page 34, Section 4.6.3) "The kc value may be revisited following the initial hydraulic investigation."			See above.
Checking of RORB routing (Page 42, Section 5.2) "…the RORB model routing may be subject to revision following a check of the routing performance against the intial (sic) TUFLOW hydraulic model. This may ultimately lead to adjustement (sic) of the critical durations and temporal patterns reported in Table 5.9 if required."			An investigation was undertaken and there was a prominent flow path in the urban area of the TUFLOW model that wasn't accounted for in the RORB model. Therefore, the RORB model was updated with a diversion to replicate this routing characteristic.
None of these issues are explicitly addressed in the hydraulics report. It would be appropriate for Engeny to investigate and report on these issues.			Engeny has updated the hydraulics section of the final report to include commentary on the above investigations if deemed appropriate.
Review 2			
Whether an industry standard hydraulic model was used to generate inundation extents.			
The modelling software used in this study was TUFLOW, which is used throughout the world for projects of this type. This software combines 2D and 1D approaches, with 2D used for modelling of broader flood plain areas and 1D to model areas where more detail is required such as key waterway cross-sections and structures). This is consistent with current best-practice. The version of TUFLOW used for this work is the 2017-09-AC-w64, which was the latest available at the commencement of this study. The model was run using TUFLOW's GPU HPC solution scheme, which reduces run times by 10 to 100 times. One later version has been released since then (2018-03-AA) and while the TUFLOW Release Notes state that TUFLOW Classic results should be unchanged from 2017-09-AC, and HPC results should be unchanged or have very slight changes, they also state (in red) that all users of the 2017-09 release are strongly recommended to upgrade to the 2018-03 release. Normally a change in the TUFLOW model version during a study does not require changing to the new version and in fact it is often better not to change it because results are usually very similar and minor differences in the code of later versions can occasionally result in slightly different results that could re-introduce stability issues that have previously been fixed. These tiny differences in water levels are inconsequential for flood mapping studies like this. Given that the advice to upgrade to 2018-03 was in red it was confirmed with BMT WBM, who develop and market TUFLOW, that it is not necessary to use the latest TUFLOW version for this study. BMT WBM advised that "it is common for studies that have entered "production" mode (i.e. design flood simulations) to lock into a version of TUFLOW." "If the simulations are to be re-run or reworked at a future date, this would be a good time to transition to the latest version."		No response required. These comments are for noting only. Please provide response in section labelled "Questions for Engeny"	
If a 1-D hydraulic model was used, whether this was appropriate.			
TUFLOW is a 1D/2D model and is appropriate for a study such as this. HEC-RAS was used to validate TUFLOW's modelling of key bridges. HEC-RAS is appropriate for this purpose, however please see the section on "*Key 1D structures model validation*" and **Question 19** below.			
Digital Elevation Model (DEM)			
The Victorian Coastal LiDAR data set (Level 3), which was flown between October 2008 and February 2009, was used as the basis for the DEM in this study. The LiDAR had a stated vertical accuracy of +/- 0.10m and horizontal accuracy of +/- 0.35m, which are standard accuracies. From ENGENY's Data Review, some effort was put into improving this dataset by; • checking open water locations such as farm dams and eventually deciding to model these as full at the commencement of the events so as not to over-estimate the available storage – this is the normal			

Feedback	Flag	DELWP comments / Suggested response	Action/comments from consultant
way of modelling these dams, • checking LiDAR levels in Stockyard Creek and Bennison Creek relative to culvert invert information, • checking heavily vegetated areas where the LiDAR may not have picked up the ground levels, • comparing LiDAR to design plans for structures on Bennison and Stockyard Creeks, • considering land use changes (as advised by SGSC) that have occurred since the LiDAR was flown The above work led to recommendations in ENGENY's Data Review to: • Adopt the LiDAR data for the TUFLOW hydraulic model DEM but use feature surveys to improve the DEM representation where they are available and deemed to be of suitable accuracy (based on the location and number of elevation points collected) • Consider undertaking additional survey to improve the accuracy of the waterway representation. This could be undertaken with engineering feature survey of the key structures on Stockyard Creek and Bennison Creek where structure data is not available and to further inform the accuracy of the LiDAR data • Apply initial water levels corresponding to the spillway crest levels of private dams located within the TUFLOW model area. Additional survey was undertaken that provided cross-section information along Stockyard creek, including details of bridges along the section of the creek through Foster. Suitable rigour has been applied to the preparation of the DEM.			
Reasonableness of model parameters used to generate hydraulic model outputs.			
Manning's n (roughness) values ENGENY derived roughness values from Planning Scheme data and aerial photography, and compared the values to those in Melbourne Water's Tech Specs. The report would be improved by the inclusion of Figures showing the roughness values adopted throughout the models. If the scale makes it impossible to see the roughnesses then sample areas should be shown. A close-up of the roughnesses adopted for the town of Foster should also be provided. Please see **Question 1** for DELWP/ENGENY. A variable roughness has been used for areas of "open space with minimal vegetation including open paddocks, tussock grassed areas and swampy areas" to "better represent the relationship between surface roughness and depth of flow". The report should include a comment on why this approach was applied to the open space described above but not to "open space with moderate vegetation". Please see **Question 2** below. It would provide more information if the "areas where the RORB hydrological model and TUFLOW model overlap" (ENGENY's Section 2.5.2) were shown in a figure. Also, more detail needs to be provided on why "on a small spatial scale there may be significant differences between the flows predicted between RORB and TUFLOW but on larger scales the differences should be less obvious" (ENGENY's page 12). Please see **Questions 3 and 4** below.			
Cell / grid size and mesh development The Foster Flood and Drainage study used a 3m grid size. This is consistent with advice in Melbourne Water's Tech Specs November 2016, however whether this is sufficient to represent Stockyard Creek and Bennison Creek adequately has not been demonstrated. Please see **Question 5** below.			
Time step Section 3.4 of the TUFLOW manual and section K5 of Melbourne Water's Tech Specs state that as a general rule the 2D time step (in seconds) should be 1/2 to 1/5 of the cell size i.e. 0.6 to 1.5 seconds in this case where the cell size is 3m. The 1D time step should generally be a minimum of 1/10 and 1/5 of the 2D time step. For this study a 2D time-step of 1 second and a 1D time step of 0.5 seconds have been adopted. While the 2D value is slightly low, it is consistent with the type of value used in many flood studies and the 1D value is within the normal range.			
Durations modelled			

Feedback	Flag	DELWP comments / Suggested response	Action/comments from consultant
The durations modelled for the various AEP events are listed in ENGENY's Table 2.1 (~~reproduced in Table 1~~). These were selected based on the critical durations from the RORB results. This report assumes that these durations have been selected in accordance with the methods in ARR 2016.			
<u>Representation of 1D Hydraulic Structures</u> *Pipes and pits* SGSC and VicRoads pipes and pits have been included in the 1D component of the models. The Manning's roughness adopted for the pipes is appropriate and the height contraction coefficient, width contraction coefficient, entry and exit loss coefficients are in accordance with the TUFLOW manual. The Engelund method has been adopted for losses at manholes, which is consistent with normal practice. Some work was put into ensuring that all pipes were connected and were correctly drawn in the GIS from upstream to downstream. Many invert levels were available from the GIS data and where they were not the invert level was estimated to be Invert level = ground level – 400mm (cover) – pipe diameter This was agreed with SGSC so presumably is fairly representative of site conditions. From the Data Report, a significant amount of effort has gone into including the pits in the TUFLOW models. They have been modelled as one of three types, which is a good amount of detail. ENGENY's report states that "pits were also used to represent back of kerb discharge points for properties within the town of Foster." It's not clear to me what this means. There is a reference that more information is available in the Data Report but it couldn't be located. Please see **Question 6** below.			
Bridges ENGENY used HEC-RAS to validate TUFLOW's modelling of the peak 1% AEP flow at • the Old Rail Trail bridge • the New Rail Trail bridge • Dryings Road bridge The results showed that the comparative head loss across the structures was within 100 mm for all bridges, which is a good result. However, please see Section 4.2.5.5 and **Question 19** below.			
<u>Representation of 2D Hydraulic Structures</u> Major culverts and bridges have been modelled where information was available, although they are not shown on the Hydraulic Model Layouts shown in ENGENY's Appendix B (Stockyard Creek) or Appendix C (Bennison Creek). Please see **Question 7** below. Private dams have been assumed to be full at the commencement of events so that storage that may not exist in reality is not over-estimated. This is the usual practice.			
<u>Boundary Conditions</u> *1D Inflow Boundaries* Where the dominant drainage mechanism was considered to be from pipes, RORB hydrographs have been applied to pits in the models, apportioned where necessary based on impervious areas. ENGENY discussed the nature of each drainage system with SGSC to assist in developing an appropriate approach. These are shown clearly on the TUFLOW model layout for Stockyard Creek (ENGENY's Appendix B) but there are none on the layout for Bennison Creek despite them being listed in the Legend. It is possible that there were none of these sources for Bennison Creek, but this needs to be clarified. Please see **Question 8** below.			
2D Inflows Inflows have also been introduced to the models using TUFLOW's "2d_sa" (2D Source Area) polygons. These would normally be shown on the model layouts (ENGENY's Appendix B and Appendix C) but they haven't been shown. Please see **Question 9** below.			
Outflow Boundaries			

Feedback	Flag	DELWP comments / Suggested response	Action/comments from consultant
Head versus flow relationships have been provided at all locations where flows exit the models. These can be seen on the TUFLOW model layout for Bennison Creek but as the model layout for Stockyard Creek focusses on the town of Foster the outflow boundaries can't be seen on that layout. A separate Figure should be provided for the entire Stockyard Creek catchment. Please see **Question 10** below.			
Whether the assumptions around waterway blockage at culverts and bridges were reasonable. At a community information session it was widely reported by residents that blockage of the Boundary Road culvert occurred during the 2016 event, and that they strongly believe this blockage contributed to the flooding in Boyd Court. The extent of blockage is unknown. For the modelling, ENGENY adopted a 50% blockage factor and ran 2 or 3 storm durations for the 10%, 5% and 2% AEP events. Appendix E of ENGENY's report provides a flood extent for a 2% AEP event, with blockage at Boundary Road. Table 3.4 of ENGENY's Data Report mentions that for some of the pits it has been assumed that only 70% of the inlet area is available for inflows due to the presence of bars. These are all reasonable assumptions.			
Whether the uncertainty in model output has been adequately considered Section 1.4 of ENGENY's report states that part of the scope was to undertake sensitivity analysis of the impact on flood levels of Manning's roughness values and blockages at Boundary Road. Roughnesses were varied somewhat during the calibration process, but an actual sensitivity analysis hasn't been presented. Please see **Question 11** below. As mentioned in Section 4.2.4.8 of this report, blockage at Boundary Road was investigated by adopted a 50% blockage factor and running 2 or 3 storm durations for the 10%, 5% and 2% AEP events. Appendix E of ENGENY's report provides a flood extent for a 2% AEP event, with blockage at Boundary Road.			
Calibration of the hydraulic model			
General comments Little information on actual rainfall events was available to assist with the calibration of the hydraulic model. Some severe flooding resulted from an event in July 2016, which was bad enough that "some residents in Boyd Court had to be rescued by the SES." Some 81 mm of rainfall occurred, however the period of time over which it fell is unknown, meaning that the Annual Exceedance Probability (size) of the event is also unknown, though it was probably "larger" rather than "smaller". Some photographs of the 2016 event are provided in ENGENY's Appendix D, but they all seem to have been taken well after the peak of the event and it doesn't look as if the photos would have been useful to assist with calibration. No Victorian Flood Database flood shapes are available for these catchments to compare the model results to.			
Model calibration With no actual rainfall and flood levels to use, the calibration of this model relies largely on community feedback regarding their recollections of past flooding locations and depths. In this case this seems to be the best available information. Two community consultation meetings were held, which generated the following useful information: • the flood modelling results are generally consistent with the community's understanding of flooding in Foster, • deep flooding occurred at 94 Station Road during one event, and the model predicts 0.5 m of flooding in that area for the 1% AEP event, • ponding reported by residents to have occurred on the Foster Recreational Reserve oval surface was not initially shown in the model however following adjustments of the inflow arrangements to better capture the drainage system in this area, the model now reports 0.4 m of flooding for the 10% AEP event. Additionally, the following information was obtained, but requires further comment from ENGENY: • the service station at the corner of Main Street and Nelson Street was identified as having been flooded many times in recent years, and while the model shows a flow path through this site for the			

Feedback	Flag	DELWP comments / Suggested response	Action/comments from consultant
10% AEP event, it could be expected that a flow path through here would exist for more frequent events. Please see **Question 12** below. • flood flows from Stockyard Creek flow up Boundary Road towards Station Street and overtop through properties into Boyd Court. There is no comment on how the model matches this. Please see **Question 13** below. No flooding information at all was available from VicRoads, SGSC, the VFD or the Foster community for the Bennison Creek catchment and ENGENY state (Section 2.8.1) that the "TUFLOW model parameters from the Stockyard Creek catchment … were adopted for the Bennison Creek catchment." It is not clear which parameters this refers to. Please see **Question 14** below. ENGENY's Section 2.8.1 mentions the 2016 storm validation in the second dot point and the community feedback sessions in the third dot point, but Section 2.8.2 describes the community feedback session and Section 2.8.3 describes the 2016 storm validation. The second and third dot points in Section 2.8.1 should be swapped over. Please see **Question 15** below. It would be worth including the year in ENGENY's Section 2.8.2, first paragraph. Please see **Question 16** below.			
July 2016 model validation Two or three durations of the 10%, 5% and 2% AEP design events were run through the TUFLOW model to investigate "which design events might result in a similar flood pattern to what was experienced by the residents of Boyd Court" during this event. As the community were strongly of the opinion that the Boundary Road culverts were blocked to some extent during the event, ENGENY assumed a 50% blockage of those culverts for these model runs. For these model runs the 2% AEP event resulted in depths of approximately 100 mm on 2 Boyd Court (considered by ENGENY to be deep enough to be above-floor, so the dwelling is presumably at ground level), and depths up to 0.4 m of ponding in the court, both of which are consistent with the residents' reports. The model also shows flooding on the south side of Boyd Court and at Apex Court, which was not reported by residents following this event. Some possible reasons for this discrepancy are provided. The first point needs clarification but the other three are reasonable. Please see **Question 17** below. Importantly, one resident reported to ENGENY and SGSC that he knew of flooding of "around half a metre" in depth between Boyd and Apex Courts. The depth and location of flooding described by the resident agree with the flood modelling results.			
Bridge Street crossing model validation Information was provided by two "long-term" Foster residents regarding the highest water levels in Stockyard Creek at the Bridge Street culvert crossing. Their observed levels did not include the 2016 event, which occurred at night. The residents' information was referenced to a sapling and tree fern on the bank so could be considered reasonably accurate. ENGENY compared the levels provided by the residents to the 1%, 2%, 5% and 10% AEP levels from the model and it can be seen from ENGENY's Figure 2.4 (~~reproduced below~~) that the residents' levels lie between the 2% and 5% AEP events. ENGENY reviewed daily rainfall data series to January 1st 1987 and there are 64 rainfall totals that exceed the 57.9 mm rainfall depth required for a 2% AEP event of 3 hour duration. ENGENY's conclusion that "it is considered possible that an event(s) of magnitude between 5% and 2% AEP have occurred in living memory and provides some level of confidence that the model is producing results that are generally in line with historical observations" is reasonable. Information is not provided on when the period of record was from, or why it only went to 1987. Please see **Question 18** below.			
Key 1D structures model validation HEC-RAS was used to validate TUFLOW's modelling of the;			

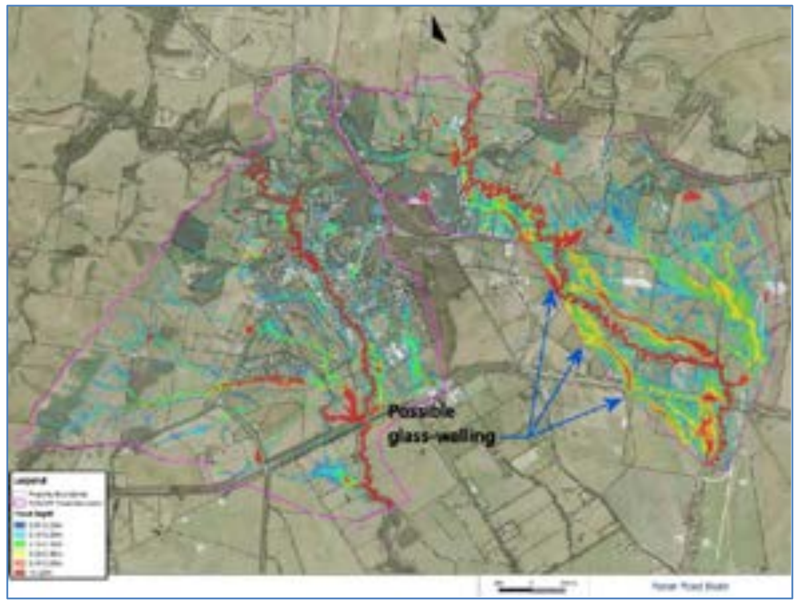
Feedback	Flag	DELWP comments / Suggested response	Action/comments from consultant
• Old Rail Trail bridge, • New Rail Trail bridge, • Dyrings Road bridge. These models used structure information provided by SGSC and elevation data from the TUFLOW DEM. The difference in the head losses across each of the structures was less than 100 mm, which is good agreement. However, it is important to know what distances were covered by these models and how the tailwaters were selected as these factors could influence the results. Please see **Question 19** below.			
Model log file			
TUFLOW log files, which are written for each TUFLOW run, contain useful information that can be used to help determine "model health" (including identifying data input problems and model stability). The results provided in ENGENY's Section 2.9.2 are good, especially considering these are the results for the run that had the highest instability index.			
Warnings and errors			
ENGENY's Table 2.2 lists the Warnings generated by the TUFLOW runs. These are typical messages and in this case aren't cause for concern.			
Known model issues (as reported by ENGENY)			
Two culverts within the Bennison Creek model have some instability near the end of the model runs. This does not affect the peak flows and will be fixed for the submission of the draft deliverables and so is not an issue at this stage.			
The clarity and completeness of the description of the hydraulic analysis.			
Addition of more road names, including Boundary Road where the blockage was modelled, would make it easier to reconcile comments in the report with locations on the flood extents. Please see **Question 20** below. The labelled flood locations in ENGENY's Figure 3.1 should be repeated on all of the other Stockyard Creek flood extent figures in Appendix F as well. Please see **Question 21** below. The paragraph in ENGENY's Section 3.3 has been copied from the Stockyard Creek section (3.2) and is incorrect. Please see **Question 22** below. The labelled flood locations in ENGENY's Figure 3.2 should be repeated on all of the other Bennison Creek flood extent figures in Appendix G as well. Please see **Question 23** below. It is noted that some of the flood levels presented in ENGENY's Table 3.1 are higher for more frequent events than they are for less frequent events (see Table 2). The differences are mostly small, and there can be explanations for this, but a comment should be included in the report about it. Please see **Question 24** below.			

Feedback	Flag	DELWP comments / Suggested response	Action/comments from consultant

ID	Location	AEP 0.5%	1%	2%	5%	10%	2% (Blockage)	10% (Blockage)
1	McDonald Street	0.49	0.48	0.50	0.47	0.42	0.50	0.42
2	Intersection of Main Street and Nelson Street	0.45	0.44	0.45	0.43	0.37	0.45	0.37
3	Between Bruce Court and Landy Road	0.29	0.31	0.31	0.30	0.28	0.31	0.28
4	McMaster Court	0.34	0.32	0.32	0.28	0.22	0.32	0.22
5	Boyd Court	0.50	0.45	0.35	0.32	0.26	0.35	0.26
6	Apex Court	1.05	0.89	0.71	0.60	0.34	0.71	0.34
7	Boundary Road on Stockyard Creek	0.74	0.66	0.47	0.13	0.02	0.54	0.23
8	Intersection of Devlon Road and Nelson Street	0.25	0.24	0.25	0.21	0.20	0.25	0.20
9	Coopers Road north of Gibbs Street	0.24	0.20	0.22	0.18	0.10	0.22	0.10
10	Fish Creek-Foster Road on Stockyard Creek	0.37	0.28	0.03	0.00	0.00	0.03	0.00
11	Fish Creek-Foster Road south of Jay Road	0.40	0.32	0.35	0.29	0.17	0.35	0.17
12	Fish Creek-Foster Road south of Allan Court	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Bridge Street on Stockyard Creek	0.33	0.21	0.00	0.00	0.00	0.00	0.00

Table 2 - locations where flood levels rise for more frequent events (ENGENY's Table 3.1)

Feedback	Flag	DELWP comments / Suggested response	Action/comments from consultant
Whether the hydrologic analysis adequately informs the hydraulic modelling.			
The approach used to include the hydrology in the model is appropriate for the purposes of the study. The types of inflows used are consistent with those normally applied. This report assumes that the hydrology has been undertaken in a manner that is suitable for the TUFLOW models that were developed.			
Consistency with Australian Rainfall and Runoff and/or recent literature / Hydraulic analysis consistency with or leading of current industry practice			
Given that no actual event rainfall and flood level information exists for these catchments, the approach used was to try to match the hydraulic model's results to information provided by the community. In this case this appears to be the best information available, and therefore a reasonable approach. Australian Rainfall and Runoff (ARR), which is the major guide to flood estimation used throughout Australia to carry out work like this, underwent a major update in 2016. Most of the changes to ARR involve the hydrology (rainfall and runoff), where an additional 30 years of rainfall data is now available, and new methods of estimating peak flows are being introduced. Developments in hydraulic modelling have been taking place within the industry over the years as computer power has increased and flood modelling software has been able to include additional detail, enabling new approaches to be trialled and adopted. ARR 2016 documents much of the advancement that has occurred over the past 20 to 30 years in hydraulic modelling, and hasn't generally needed to provide guidance that is different to industry practice.			
Possible glass walling			
Glass walling is the term given to the situation where the model extent is not large enough in a particular			

Feedback	Flag	DELWP comments / Suggested response	Action/comments from consultant
area, with the result that flows that would normally continue to flow overland across/through those areas are unable to do so because they reach the artificial edge of the model. The flow that is unable to escape from the model can result in unrealistically high flood levels in those areas. There are some areas along the Bennison Creek model that may be exhibiting this effect (see Figure 3). This seems to be occurring for the 0.5%, 1% and 2% AEP events. Please see **Question 25** below.  **Figure 3 - locations of possible glass-walling**			
Climate Change modelling			
One of the aims of the study was to examine the impact of projected sea level rise in Corner Inlet from climate change and a major storm event. In Section 1.5 of their report ENGENY state that climate change modelling is mentioned in the Risk mitigation report. There is no mention of it elsewhere in the hydraulic report. Please see **Question 26** below.			
Methodology			
The extent to which the methodology meets the objectives and scope of the project brief, in light of the project budget. Additional information has been requested on a number of aspects, but the overall approach followed is consistent with achieving the aims of the study.			
Conclusion and Recommendations			
The overall approach taken by ENGENY to develop the hydraulic model is reasonable for a situation where no rainfall data and flood levels are available. A number of questions have been raised for ENGENY (please see Section 6), and assuming satisfactory responses are provided to these queries it would be recommended that the model be accepted for the remainder of the study.			
Questions for Engeny			
Question Number 1, Page 11, Section 2.5, Paragraph N/A *Roughness* The report would be improved by inclusion of figures showing plan views of the roughness values throughout			Engeny has provided roughness plans in the final report.

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the catchments. If the scale would make these unreadable then typical examples should be provided. Roughnesses through the town of Foster should be shown on another figure.			
Question Number 2, Page 11, Section 2.5.1, Paragraph Dot points *Variable roughness* A comment should be included in the report explaining why a variable roughness was used for "open space with minimal vegetation" but not for "open space with moderate vegetation".			The reason for adopting variable roughness for the "open spaces with minimal vegetation" only was due to industry recognised literature that describes how shallow sheet flow navigates through grass vegetation specifically. Therefore, this approach was not considered appropriate for other vegetation / surface types.
Question Number 3, Page 11, Section 2.5.2, Paragraph 1 *RORB / TUFLOW overlap* A figure should be provided showing where these models overlap, therefore showing the boundary of these two modelling approaches.			There is a figure in the Hydrological report on page 13 that shows the extent of each model.
Question Number 4, Page 12, Section 2.5.2, Paragraph Third-last *Small vs larger scale results* Can further explanation please be provided on why "on a small spatial scale there may be significant differences between the flows predicted between RORB and TUFLOW but on larger scales the differences should be less obvious"?			As presented in the sentence directly before the one mentioned here, "TUFLOW explicitly represents the terrain surface including local changes in roughness due to changes in surface type and variation in catchment storage at a much finer spatial resolution than is achieved in RORB".
Question Number 5, Page 8, Section 2.3.1, Paragraph N/A *Cell size* There is no mention of the watercourses being modelled in 1D, so information on how appropriate the cell size is for representing the watercourses needs to be provided. How many cells generally define the waterways? [Potentially could require changes to the model before continuing, but could be OK.]			The watercourses span from 20m up to 45m from bank to bank along Stockyard Creek and Bennisons Creek, so Engeny deems the 3m grid size to be adequate to accurately determine flows within the watercourses. The report has been updated to include this discussion.
Question Number 6, Page 10, Section 2.4.3, Paragraph First on page *Clarification - back of kerb discharge points* Can further information please be provided on the statement that "pits were also used to represent back of kerb discharge points for properties within the town of Foster"? What is the methodology that this is referring to?			Pits were added to the hydraulic model at locations where properties discharge out to the road as opposed to being directly connected to the underground drainage network. This approach was adopted to facilitate a more accurate flow distribution was achieved and to prevent the likelihood of nearby drainage pits being allocated more flows (via 1d_bc layer) than they would otherwise be receiving in reality.
Question Number 7, Appendices B and C *Bridges* Locations of bridges included in the models should be shown on these layouts.			TUFLOW model layout figures have been amended.
Question Number 8, Appendix C *2D_bc points* Presumably there were no 2D_bc points in the Bennison Creek model. If there were, they need to be shown, if not the Legend should be updated to avoid confusion. This comment may apply to other items in the legend as well, and possibly to Appendix B.			There are 2d_bc points within the Bennison Creek model, as shown in Appendix O.
Question Number 9, Appendices B and C *2d_sa polygons* These polygons should be shown on the model layouts.			Engeny has added the 2d_sa polygons to the layout plan.
Question Number 10, Appendix B *2d_bc lines* Appendix B is good in that it shows details of the model in Foster. Another plan should be provided showing the entire Stockyard Creek model extent, including the 2d_bc line locations.			There are 2d_bc points within the model layout plans, as shown in Appendix N and O.
Question Number 11, Page 6, Section 1.4, Paragraph Third dot point *Sensitivity analysis* Part of the scope was to do a sensitivity analysis to investigate the impact of roughness values. The roughness was varied somewhat as part of the calibration process, but an actual sensitivity analysis has not been provided. Can this be included? [Roughness sensitivity analysis was part of the scope.]			A high manning's roughness sensitivity along the waterways has been modelled and has been added to the final report.
Question Number 12, Page 16, Section 2.8.2, Paragraph Second dot point			The model may show flooding at this location for more frequent events than the

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Service station hot spot The community identified the service station to be a flooding hot spot, having been flooded many times in recent years. The model shows a flow path through the site for the 10% AEP event. It sounds like a flow path should appear here for more frequent events than the 10% EP event. Does the model need to be altered to reflect this?			10% AEP storm event, however Engeny haven't been engaged to run these smaller events. Based on the 10% AEP results we expect that flooding will occur for smaller events.
Question Number 13, Page 16, Section 2.8.2, Paragraph Fourth dot point *Do modelled flood flows match actual?* There is a statement that "flood flows from Stockyard Creek flow up Boundary Road towards Station Street and overtop through properties into Boyd Court", but nothing saying whether this agrees with what really happens.			This flow path has been identified with Council and the community. The section discussing community consultation explains that this is consistent with community experiences.
Question Number 14, Page 15, Section 2.8.1, Paragraph Last *Bennison Creek TUFLOW parameters* Which TUFLOW parameters were adopted for the Bennison Creek TUFLOW model?			Refer to section 5.9 for TUFLOW parameters adopted.
Question Number 15, Page 15, Section 2.8.1, Paragraph Dot points *Dot points* Section 2.8.1 mentions the 2016 storm validation in the second dot point and the community feedback sessions in the third dot point, but Section 2.8.2 describes the community feedback session and Section 2.8.3 describes the 2016 storm validation. The second and third dot points in Section 2.8.1 should be swapped over.			
Question Number 16, Page 16, Section 2.8.2, Paragraph 1 *Year of storm* The year should be added to "the 15th of March".			
Question Number 17, Page 19, Section 2.8.3, Paragraph Fourth-last dot point *Further explanation required* It's not clear why "a reduced influence of stormwater flooding in the catchment" would result in significant flooding from local flow paths on Nelson Street and to flooding on the south side of Boyd Court and at Apex Court. Can this be re-written perhaps, or more information provided?			The statement has been reworded to improve clarity. Engeny are identifying the possibility that due affects such as spatial variation within a catchment, the July 2016 storm event may have had less intense rainfall across the town of Foster and more intense rainfall in the catchment upstream of the town that would result in more significant flooding from Stockyard Creek as opposed to local stormwater sources. This potential scenario may not align with the critical storm durations and temporal patterns that have been run through the hydraulic model.
Question Number 18, Page 20, Section 2.8.4, Paragraph Last *Period of record* When did the period of record commence, and why were values only up to January 1 1987 used?			The time period between January 1st 1987 and May 31st 2017 was selected as this 30 year period was considered to capture the historical flood level observations by the community.
Question Number 19, Page 22, Section 2.8.5, Paragraph N/A *HEC-RAS models* How far downstream of the bridges did the HEC-RAS models extend, and what method was adopted to estimate the tailwater levels? Plan views of these models should be included in the report.			The HEC-RAS model extended 100m downstream of the bridges. A steady-flow analysis was undertaken using a normal depth downstream boundary.
Question Number 20, All Stockyard Creek plans including model layout in Appendix B and flood extents in Appendix F *Road names* Inclusion of more road names, including Boundary Road (where the blockage was modelled) would make it easier to reconcile comments in the report with locations on the plans.			Engeny has added more road labels.
Question Number 21, All Stockyard Creek plans in Appendix F *Labelled locations* The labelled flood locations in Figure 3.1 should be repeated on all of the other Stockyard Creek flood extent plans as well.			Engeny has added the key locations to the flood maps
Question Number 22, Page 28, Section 3.3, Paragraph 1 *Copy and paste* This paragraph has been copied from Section 3.2 and is incorrect.			Engeny has amended this.
Question Number 23, All Bennison Creek plans in Appendix G			Engeny has added the key locations to the flood maps

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Labelled locations The labelled flood locations in Figure 3.2 should be repeated on all of the other Bennison Creek flood extent plans as well.			
<u>Question Number 24, Page 26, Section 3.2, Paragraph Table 3.1</u> *Relative flood levels* Some of the flood levels in Table 3.1 are higher for more frequent events than they are for less frequent events. For example, the 0.5% AEP level between Bruce Court and Landy Road (0.29m) is lower than that of the 10% AEP event (0.28m). This can be a peculiarity of modelling, but a statement needs to be made about how/why it has occurred in this study.			Engeny to further investigate the flood levels at these locations.

ID	Location	AEP						
		0.5%	1%	2%	5%	10%	2% (Blockage)	10% (Blockage)
1	McDonald Street	0.70	0.66	0.50	0.57	0.42	0.50	0.57
2	Intersection of Main Street and Nelson Street	0.45	0.44	0.45	0.41	0.37	0.45	0.37
3	Between Bruce Court and Landy Road	0.29	0.31	0.31	0.30	0.28	0.38	0.28
4	McMaster Court	0.54	0.37	0.32	0.26	0.22	0.32	0.19
5	Boyd Court	0.50	0.45	0.35	0.32	0.25	0.35	0.26
6	Apex Court	1.05	0.89	0.71	0.60	0.34	0.71	0.34
7	Boundary Road on Stockyard Creek	0.74	0.66	0.47	0.13	0.02	0.54	0.23
8	Intersection of Devlin Road and Nelson Street	0.75	0.74	0.75	0.71	0.70	0.75	0.70
9	Couper's Road north of Gibbs Street	0.24	0.20	0.22	0.18	0.10	0.22	0.10
10	Fish Creek-Foster Road on Stockyard Creek	0.57	0.26	0.03	0.00	0.00	0.01	0.00
11	Fish Creek Foster Road south of [illegible] Road	0.40	0.32	0.30	0.25	0.17	0.30	0.17
12	Fish Creek-Foster Road south of Allan Court	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Bridge Street on Stockyard Creek	0.22	0.21	0.00	0.00	0.00	0.00	0.00

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<u>Question Number 25, Bennison Creek model</u> *Possible glass-walling* Flow seems to be occurring along the south-western boundary of this model. Does the model need to be extended in these areas or have outflow boundaries incorporated? If not, a comment on what looks like glass-walling should be included in the report.			Engeny has extended the model boundary

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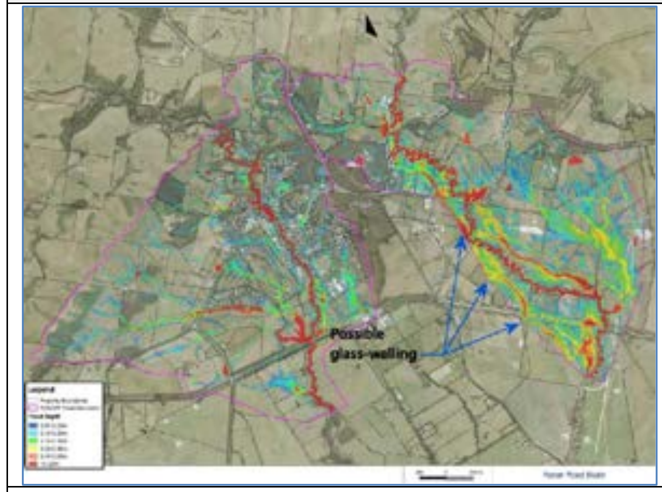 			
Question Number 26, N/A *Climate change* One of the aims of the study was to examine the impact of projected sea level rise in Corner Inlet from climate change and a major storm event, however there is no information on this in the report. Was this supposed to be modelled at this stage and reported on in this report? Climate change modelling and a major storm event was part of the scope.			Engeny has undertaken Climate Change investigations and included commentary and flood plans in the final report.
Minor issues (hydrology report)			
Most of the issues identified in the previous review of the hydrology report remain. These, and others are noted below.			
• Please include a printout of the any information from the ARR Data Hub as an appendix to the report. This is a recommendation of ARR2016. • Throughout. Please provide scales for figures that are presented as maps e.g. Figure 1.1, Figure 3.1, Figure 3.3, Figure 4.1. Some maps indicate orientation e.g. the compass points in Figure 4.1, while other maps do not, e.g. Figure 3.1. (I agree that indication of orientation is not required on maps where north is up the page). • Page numbering. The standard is that page numbering starts at 1 following roman numerals for table of contents etc. • Page 6. "The primary objectives of the study is [are]…". • Page 8. Spelling error, "exceedance" rather than "exceedence". • Page 9. Spelling error, "gauge" rather than "guage". • Page 10, final paragraph. The stream gauge, Deep Creek at Foster, is listed as number 85227. The gauge number is 227244. • Page 10. Should "suitabily" by "suitably"? • Page 11, first sentence. Replace "It's" with "Its". • Page 11, Figure 2.3. The text above the figure states the flood frequency curve has been downloaded from "the DELWP water data website". Was this actually taken from water data on-line (http://www.bom.gov.au/waterdata/) ? • Page 14, paragraph under heading 3.2. Replace "It's" with "Its". Remove stray spaces before full stop. • Page 16, first sentence. Please provide a definition of "diverted". Please briefly describe how a "diverted" RORB model differs from a normal RORB model. I realise this is a common term for Melbourne Water flood modelling projects but it is not generally used for rural modelling. • Page 16, first paragraph. Replace "in flow" with "inflow".			Engeny has updated the hydrology section of the final report as per reviewer's comments. - Page 11: The flood frequency curve was downloaded from the referenced DELWP website "data.water.vic.gov.au". - Page 36: This discussion refers to the estimation of losses compared to historical data and is not prescriptive about the application of the losses which is dependent on the modelling approach (burst verses storm).

Feedback	Flag	DELWP comments / Suggested response	Action/comments from consultant
• Page 16. Should "refered" be "referred"? • Page 17. Spelling errors: "qauntiles", "repectively", "crticial", "crtitical". • Page 23, second paragraph below heading 4.4.2. Remove "as" in: "determined on [a] as per catchment basis…". • Page 28. Repeated word "storm storm". • Page 29. Check "alternaive". • Page 32. Spelling: "qauntiles", "recieving". • Page 34. Spelling error; check the spelling of "initial" in the final sentence and "qauntiles". • Page 36. There is discussion of stochastic sampling of storm losses. Should this refer to burst losses rather storm losses? • Page 42. Spelling error; check the spelling of "initial" not "intial". • Page 42. Spelling error; check the spelling of "adjustement". • Page 44. Check spelling of "qauntiles" and "Frequencey" • Page 45. Check spelling of "intial", "Frequencey".			
Minor issues (hydraulics report)			
• Page 6. Should "PMPF" be "PMF"? • Page 15 elsewhere. Should "communities'" actually be "community's"? • Page 23. Should "non" be "none"?			Engeny has updated the hydraulic section of the final report as per reviewer's comments.
• Page 4, 1.2.1 "in flow" should be inflow • Page 4, 1.2.1 says the hydrographs WILL BE USED … They have already been used • Page 5, First sentence: … rather THAN the critical … • Page 6, Should PMPF be PMP? • Page 8, Section 2.2 Model Extents would be better called something like Model Schematics to separate the meaning from the modelled flood extents. • Page 11, Is "+n" a typo in "0.06 (open space with moderate vegetation+n)? If not it needs to be explained. • Various, Engelhund should be Engelund • Page 13, 2.6.2 final sentence "travel" should be "travels" • Page 14, Last sentence - should "each township" be "each Creek"? • Page 15, Reference to Section 2.5.1 should be to Section 2.5.2 • Page 16, communities' should be community's unless there was more than 1 community commenting on the results • Page 16, 4th dot point, court should be Court • Page 16, Last dot point first sentence • Page 17, Second paragraph last sentence • Page 17, Fourth paragraph, first sentence			Engeny has updated the hydraulic section of the final report as per reviewer's comments.
References			
• DELWP (not dated) Foster flood and drainage study: hydrology report – collated comments. There is also an updated version of the collated comments, with responses by Engeny in Appendix A of the Engeny hydraulics report. • Engeny (2017a) Flood and drainage study of Foster and the surrounding catchments: data review report (Rev 0, 13 July 2017) V2025_001 • Engeny (2017b) Flood and drainage study of Foster and the surrounding catchments: hydrology report (Rev 0, 6 September 2017) V2025_001 • Engeny (2017c) Flood and drainage study of Foster and the surrounding catchments: hydrology report (Rev 1, 25 November 2017) V2025_001 • Engeny (2018) Flood and drainage study of Foster and the surrounding catchments: hydraulics report			

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(Rev 0, 10 April 2018) V2025_001 • Ladson, A. R. (2016). The state of hydrologic practice in Victoria, Australia. 37th Hydrology and Water Resources Symposium. Queenstown, New Zealand, Engineers Australia: 260-267. • South Gippsland Shire Council (not dated) Tender documents for the provision of services for the Foster Flood and Drainage Study – Section E, Service Specification			