Moorabool Shire Council

Bungaree Flood Study

Report




May 2018

V2027_001

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1. INTRODUCTION

Moorabool Shire Council has engaged Engeny Water Management (Engeny) to undertake flood mapping of the Bungaree Township located 14 kilometres east of Ballarat. The modelling has focused on producing a 1 % Annual Exceedance Probability (AEP) flood extent for the study area of 4.4 km^2 displayed in Figure 1.1. The flood extent has accounted for flooding from both the local catchments within the study area and also the inflows from the external catchments to the north of the Western Highway. The overall catchment area including these external rural catchments is approximately 22 km^2.

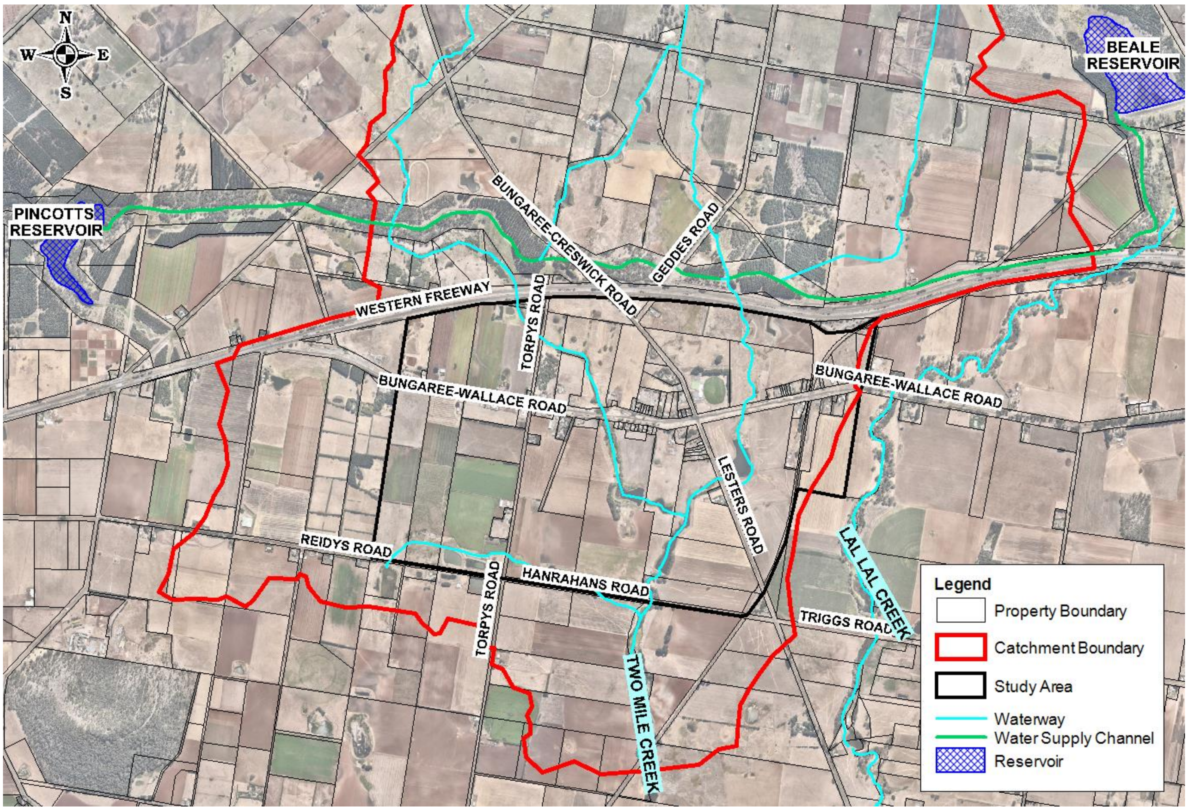

Figure 1.1 Bungaree Study Area Key Features

1.1 Objective

Engeny understands that the key objective of this study is to identify areas subject to inundation by the resultant flood extent. This will be an important input to aid Council with the proposed development of a structure plan. The plan will allow for residential and commercial growth within Bungaree while ensuring adequate flood protection for new developments.

1.2 Scope

The following key tasks were undertaken as part of this scope of works:

- Develop a Hydrological RORB model in accordance with the new Australian Rainfall and Runoff 2016 (ARR2016) standards.
- Develop a Hydraulic TUFLOW model for the study area including inflows from upstream tributaries.
- Produce a 1 % AEP flood extent polygon with respective flood depth layout plans.
- Produce a plan identifying key overland flow paths as a result of runoff generated from both the local catchment and the larger external catchment.
- Summarise the assumptions and modelling methodology within a concise report providing technical details and specific parameters utilised within the appendices.

1.3 Study Area Description

Two key tributaries of the Two-Mile Creek flow through Bungaree before combining into one, south of the study area. The valleys containing the waterways are well defined and there are clear ridges between the two branches of the tributaries.

The study area is bounded by the Western Freeway to the north, Hanrahans Road to the South and the railway line to the east. The land within the study area is predominately zoned farm land (Plan Zone FZ) and the inner township area located at the Bungaree-Wallace and Bungaree-Creswick Road intersection consists of slightly higher density rural living in addition to a few commercial areas zoned town zone (Plan Zone TZ).

The Beale Reservoir and Pincotts Reservoir are located north of the Bungaree study area. A water supply channel (as shown in Figure 2.4 below) conveys water between these assets and runs west-east north of the Western Freeway. Numerous minor farm dams and storages also exist within the study area however these are largely located along the main tributaries.

2. COLLATION AND REVIEW OF INFORMATION

2.1 Summary of data

Table 2-1 provides a summary of the data Engeny has used for this study in addition to the purpose and source. The subsequent sections include further detail where relevant.

Table 2-1 Summary of data

Data	Description	Purpose	Source
LiDAR	Corangamite_2008mar18_dem5m_v50cm Ballarat_2011oct05_dem2m_v15cm Bungaree_2011oct19_dem2m_v15cm	Used to define catchment and sub-catchment boundaries for the hydrologic RORB model. Utilised as the 2D terrain surface input to the TUFLOW model to represent surface flow paths.	Council
Drainage	GIS table/ information of pipe diameters within study area Onsite measurements, observations and photographs of culvert crossings. As constructed/ design drawing plans of drainage infrastructure along VicRoads owned Roads.	Culvert crossings were included in the TUFLOW model to accurately represent the hydraulic constriction to overland flow paths.	Council Engeny VicRoads
Australian Rainfall and Runoff 2016 (ARR2016) Data	Data contains information of temporal patterns and storm losses. 2016 Rainfall data for 1% AEP storm event and all standard durations.	Used as an input parameters for the hydrological RORB model.	ARR2016 Data Hub and Bureau of Meteorology (BOM)
Catchment Plan Zones	GIS table covering the catchment area	Used to inform the preliminary fraction impervious values for the hydrological model and manning's roughness values for the hydraulic model	DELWP
Aerial Photograph	Photograph dated 24/01/2018	Used to ensure adopted fraction impervious and manning's roughness values are appropriate to current land uses.	Nearmaps

2.2 LiDAR Data

Engeny was provided with the following LiDAR data sets;

- Corangamite_2008mar18 (with cell size of 5 m and vertical accuracy ± 50 cm)
- Bungaree_2011oct19 (with cell size of 2 m and vertical accuracy ± 15 cm)
- Ballarat_2011oct05 (with cell size of 2 m and vertical accuracy ± 15 cm)

When combined these data sets covered the entire Bungaree catchment area. Following the review of this combined Digital Elevation Model (DEM) a minor elevation difference was noted along the merged seams. This was as a result of the different DEM cell sizes and vertical accuracies however as there was no significant impact to the modelling results no adjustments to the provided data were made. Where available the higher accuracy LiDAR data sets (Ballarat and Bunagree) were used over the Corangamite data set which has lower accuracy.

The developed DEM was used to define catchment and sub-catchment boundaries for the hydrologic RORB model. This data was also utilised as the 2D terrain surface input to the TUFLOW model in order to represent the surface flow paths. Figure 2.1 displays the DEM where the catchment boundary has been outlined in red.

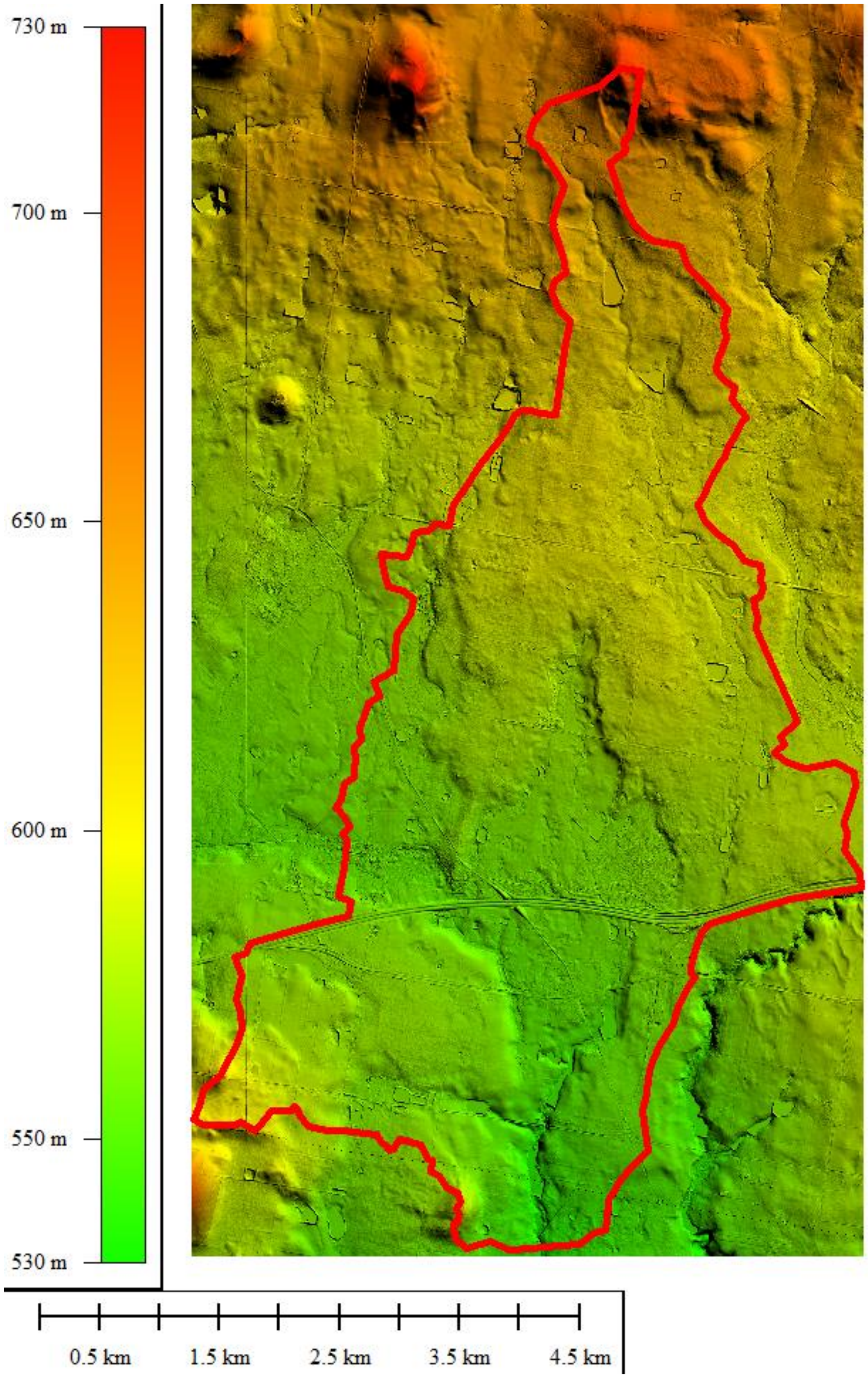

Figure 2.1 Bungaree Catchment DEM

2.3 Council and VicRoads Drainage Data

Geographic Information System (GIS) tables of Council's drainage assets were provided for the study area. The majority of these drains were 375 mm in diameter or smaller resulting in minimal conveyance capacity for storm events greater than the 20% AEP. As the 1 % AEP storm event was the focus of this study, these minor pipes were not included within the modelling undertaken.

All major culvert crossings along VicRoads and Council owned roads were included in the TUFLOW model as they represented important hydraulic constrictions to overland flow paths. Engeny requested information on the diameters and culvert configurations of key major crossings. The data was sourced from:

- Council which included information from internal data records as well as onsite measurements / observations.
- VicRoads which included as constructed/ design drawing plans and photographs / observations taken onsite.
- Engeny site visits which included measurements and photos of safely accessible culverts.

During the data collection phase, emphasis was taken to ensure data gaps for the major culvert crossings along the Western Freeway were resolved. The accuracy of representing the correct culvert diameters in these locations was considered particularly important, as they control the inflows into the study area which would ultimately influence the flood modelling results.

Table 2-2 provides a summary of the culvert crossings included within the TUFLOW model. Utilising the referenced IDs, the locations of these are displayed within Figure 2.2.

Table 2-2 Existing culvert structures

Location ID	Culvert Configuration
1	No.4 x 1200 mm
2	375 mm
3	750 mm
4	No. 6 x 1200 mm x 600 mm
5	No. 5 x 1200 mm x 600 mm
6	375 mm
7	375 mm

8	1000 mm x 2400 mm
9	No. 3 x 900 mm
10	No. 2 x 1800 mm
11	No. 2 x 2400 mm x 600 mm
12	375 mm
13	450 mm
14	Bridge

Figure 2.2 Location of existing culvert structures

2.4 Australian Rainfall and Runoff Data

Engeny has used methodology consistent with Australian Rainfall and Runoff 2016 to undertake this study. Engeny sourced catchment specific temporal patterns and storm losses from the ARR2016 Data Hub. The relevant rainfall Intensity-Frequency-Duration (IFD) data for the 1 % AEP storm event was obtained from the BOM. **Appendix A** provides this rainfall data which was used for the hydrological modelling undertaken. Discussion on the use of this data is provided in Section 3 of this report.

2.5 Site Visit

Engeny undertook a site visit during the early stages of the project to gain a better understanding of the general catchment characteristics. The following key features were observed onsite:

- Culvert crossings along local council roads which were easily accessible.
- Water supply channel connecting flows from the Beale Reservoir and Pincotts Reservoir.
- Catchments land use and topography

The following provides some photographs taken onsite.

Figure 2.3 Culvert crossing on Bungaree-Wallace Rd for western tributary

Figure 2.4 Water Supply Channel connecting the Beale Reservoir and Pincotts Reservoir

Figure 2.5 Bungaree-Wallace Road looking South West towards railway line

Figure 2.6 Box culvert crossing on Bungaree-Wallace Road for eastern tributary

Figure 2.7 High point along Bungaree-Wallace Rd at the eastern edge of the study area catchment

3. HYDROLOGIC MODELLING

The methodology adopted for this study is in accordance with the latest Australian Rainfall and Runoff (ARR2016) guidelines and is summarised in the following sections of the report. RORB, an industry standard software package was utilised for the hydrologic modelling. Details on the parameters utilised in the RORB modelling have been included in **Appendix C**.

3.1 Purpose

The hydrological RORB model was developed to determine the amount of runoff generated from both within the study area and that generated from upstream external sub-catchments. The following provides a summary of the main outputs from this modelling which were utilised to develop the subsequent TUFLOW hydraulic model:

- Runoff hydrographs (also referred to as Rainfall excess hydrographs) (Time vs. Flow relationships) for each sub-catchment within the study area and those immediately surrounding this area.
- Routed inflow hydrographs (Time vs. Flow relationships) located north of the Western Freeway predominantly upstream of the major culvert crossings.

3.2 Methodology

The following provides a brief overview of the different components involved within the hydrological modelling:

- RORB model definition: including GIS digitisation of Bungaree sub-catchments, reaches, nodes and overall catchment boundary ensuring appropriate attributes are associated particularly areas and fraction impervious values.
- RORB model run: including the relevant rainfall and runoff data inputs and parameters.
- Comparison of resultant flow to Regional Flood Frequency Estimation (RFFE) flow.

3.3 RORB model definition

The RORB model layout plan is presented within **Appendix B**. The development of the model consisted of digitising the following key components in GIS utilising the MapInfo plugin MiRORB:

- Sub-catchment which each contained attributes on the area and impervious fraction. Delineation of these boundaries was based on the contours generated from the LiDAR data provided. The sub-catchment’s fraction impervious value was obtained from an area weighted average value. A description on this methodology and the values adopted are presented within **Appendix C.**

- Sub-catchment Nodes identifying the centroid of each sub-catchment.
- Junction Nodes utilised at the downstream end of each sub-catchment or to represent the junction of 2 flow paths.
- Reaches utilised to route the runoff generated from each of the sub-catchments. 'Natural' reach types were used for all reaches.

It is important to note that although a water supply channel exists north of the study area which could potentially intercept overland flow in some locations it has not been included in the modelling. It was excluded as it is not designed as a flood mitigation channel and there is no certainty of the capacity it could provide in a flood event or if it will be maintained as an open channel in the long term. As a result, the digitised sub-catchments have all been directed through the study area towards the one outlet at Two Mile Creek.

3.4 RORB Model Design Run

The RORB model runs utilised a number of direct inputs as presented in **Appendix A** sourced from the ARR2016 Data Hub and the BOM. These were available in data formats which could be read into RORB directly where in general minor modifications were required.

An important input to the RORB model is the routing parameter, Kc. This parameter aims to represent the catchment's characteristics specifically representing the flow paths and their ability to detain/store water prior to reaching the outlet. As an example, a lower Kc value results in higher flows due to the well-defined incised flow paths it aims to represent where as in contrast a catchment with wide and relatively flat flow paths would adopt a higher Kc value resulting in smaller more detained flows at the outlet.

Numerous Kc values derived from industry standard regional equations were analysed for the Bungaree Catchment. The adopted Kc value was obtained utilising the Pearse et al. 2002 regional equation resulting in a value of 6.58. This equation was considered the most appropriate for the Bungaree catchment and resulted in a peak flow of 36.6 m^3/s.

A summary of the final parameters adopted for the developed Bungaree Catchment RORB model is provided below in Table 3-1. Further details on the parameters utilised has been provided within **Appendix C.**

Table 3-1 Summary of Bungaree Catchment RORB model parameters

Parameter	Value
Initial Loss	4.4 mm
Continuing Loss	25 mm
m	0.8
K_c	6.58

3.5 RFFE Comparison

Table 3-2 provides a summary of the key outputs from the RFFE online tool. As shown, although there is a difference between the RFFE flood quantile and the developed RORB model's result of 36.6 m³/s, the developed RORB model still produces a value which is well within the confidence limit ranges. Therefore the adopted Kc value was considered appropriate.

Table 3-2 1% AEP RFFE online tool outputs

	Value
Flood Quantile	19.4 m³/s
Lower Confidence Limit (5%)	6.01 m³/s
Upper Confidence Limit (95%)	63.0 m³/s

4. HYDRAULIC MODELLING

4.1 Purpose

The hydraulic modelling aims to;

- Utilise the inflows and rainfall excess hydrographs produced from the hydrological modelling undertaken.
- Produce flood extents for all standard durations and temporal patterns for the 1 % AEP storm event.
- Process all gridded results to produce the maximum of the median for the 1 % AEP storm event.

4.2 Methodology

TUFLOW software was used for the hydraulic modelling. The following provides a summary of the tasks undertaken to develop the TUFLOW model and to obtain results and outputs for the Bungaree catchment:

- Generate DEM from provided LiDAR data sets.
- Compile hydrographs for full range of storm durations for the 1 % AEP storm event and 10 temporal patterns for each duration. The durations modelled have included the 10 min, 15 min, 30 min, 60 min,120 min,180 min, 360 min, 540 min, 720 min.
- Input surface roughness (materials layer)
- Input and verify data for the 1-D network including the major culvert crossings along VicRoads and Council owned roads.
- Set 1-D and 2-D boundary conditions for model's external inflow and outflow locations in addition to the boundary conditions representing culvert end walls.
- Compile gridded outputs and interpret/ validate results.
- Produce the maximum of the median flood depths and prepare flood maps from this modelled result.
- Develop layout plans which identify key overland flow paths within the study area.

4.3 TUFLOW Inputs and Parameters

A layout plan of the hydraulic model extent and the general input layers has been included in **Appendix G.**

Details on the specific parameters and inputs utilised has been included in **Appendix E** where the following points provide a summary:

- Grid Size - 4 metres
- DEM- compiled utilising the provided LiDAR data
- 2D and 1D time step – 1 second (in line with Melbourne Water recommended value of ¼ to ½ of the model's grid size)
- Upstream Inflow Boundary Conditions – Flow versus Time relationships for routed inflows from the main flow paths applied upstream of the study area.
- Study area sub-catchment Inflow Boundary Condition – Flow versus Time relationships for rainfall excess hydrographs applied over each sub-catchment
- Downstream boundary condition- Head versus Flow relationship based on automatically generated TUFLOW generated relationship with terrain slope required as an input.

4.4 Model Validation

Engeny has validated the model by checking that flows, water depths and velocities produced by the TUFLOW model are reasonable. Any unusual results were investigated to understand whether they were as a result of associated model instabilities.

The 1 % AEP flood depth layout plan has been included as **Appendix F**. These contours have been filtered to display depths greater than 50 mm only.

4.5 Key Flood Prone Areas

Utilising the flood mapping results produced, a number of key areas subject to inundation were identified. The following provides a summary of these locations;

- Key overland flow paths along the main tributaries and other minor watercourses (identified within the DELWP GIS watercourses layer).
- Numerous low lying areas within the Bungaree township area.
- Low lying area north of the Bungaree-Wallace Rd within the study area's western catchment.

- Significant flood depths within a low lying area along the western boundary of the study area.

- Localised low lying areas throughout the study catchment.

Appendix G provides layout plans of these key areas subject to inundation in the 1 % AEP storm event. These are the areas in which Council should focus on controlling future development. Depending on the depth of flooding and the velocity of flow, development may be permissible but it should be subject to conditions that ensure that dwellings are not subject to flooding and that people are not placed at risk from flood waters.

5. CONCLUSIONS AND RECOMMENDATIONS

From the flood modelling undertaken, Engeny provides the following summary of outcomes;

- Major overland flow paths though the study area coincide with the existing watercourses, the two tributaries of Two Mile Creek.
- There is significant flooding shown in some areas due to the presence of existing dams. If these dams are removed as part of the development of this area then the flood extents through this area may change.
- Minor overland flow paths are present to the east of the railway line and through Bungaree's township area.
- Numerous localised low lying trapped low points exist within the study area. Some of these areas pond to significant depths (greater than 500 mm) within the township and the western catchment.
- Development of this area will significantly increase the fraction imperviousness of the land and will increase runoff volumes.

Considering the findings of this study, Engeny recommends;

- Appropriate waterway setbacks are included in any development plan which would prevent development in areas subject to flooding in a 1 % AEP adjacent to waterways. The final discretion for waterway setbacks resets with the Corangamite catchment Management Authority, who should be consulted on this matter.
- Finished floor levels of future developments are set at least 600 mm above the water surface elevations along the main tributaries.
- The numerous trapped low points which are shown as flooding should not be developed unless the topography is regarded so that they are free draining. This could be achieved through filling these areas or boxing out roads so that they drain towards the waterways. Relying on underground drains alone in these areas would present a significant risk of flooding in the future should a storm occur which exceeds the underground drainage capacity of the system. This should be set as a condition of developing these areas of land.
- Upgrades will be required to the existing drainage infrastructure within the town zone as it is currently sized to provide a level of service suitable in a small urban town with low levels of development and would be undersized if development densities are increased.
- Any future development within this area should adopt the drainage requirements outlined in the Infrastructure Design Manual (IDM) in addition to what is listed above.

- Mitigation measures should be included in any development plan to protect the waterways from an increase in peak flow discharges from the developed areas. While outside the scope of this report, frequent flows and stormwater quality should also be addressed prior to discharge into the waterways.

6. 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.

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7. GLOSSARY

AEP – Annual Exceedance Probability. The probability that a given rainfall total accumulated over a given duration or peak flow rate at a point in a catchment will be exceeded in any one year

AHD – Australian Height Datum. The datum that sets mean sea level as zero elevation. Mean sea level was determined from observations recorded by 30 tide gauges around the coast of the Australian continent for the period 1966–1968

ARI – Annual Recurrence Interval. The average or expected value of the periods between exceedances of a given rainfall total accumulated over a given duration, or of a peak flow rate at a point in a catchment. It is implicit in this definition that the periods between exceedances are generally random

ARR – Australian Rainfall and Run-off

BOM – Bureau of Meteorology

DELWP – Department of Environment, Land, Water and Planning

DEM – Digital Elevation Model

FI – Fraction Impervious

GIS – Geographical Information System

IFD – Intensity Frequency Duration

LiDAR Data- Light Detection And Ranging Data. A remote sensing method which uses light in the form of a pulsed light to measure ranges to the Earth and generate topographic data.

RFFE – Regional Flood Frequency Estimation. An industry standard online tool developed by Engineers Australia and Western Sydney University and used to provide a range of peak flows for different AEP with associated confidence limit.

RORB – Run-Off Routing Burroughs. An industry standard package used in hydrologic modelling (the “Burroughs” refers to the fact that the original software package was developed and maintained on a Burroughs B6700 computer)

TUFLOW – Two-dimension Unsteady FLOW. The name of an industry standard flood modelling package

APPENDIX A

Hydrological Model Rainfall and Runoff Inputs

Intensity-Frequency-Duration (IFD) Data

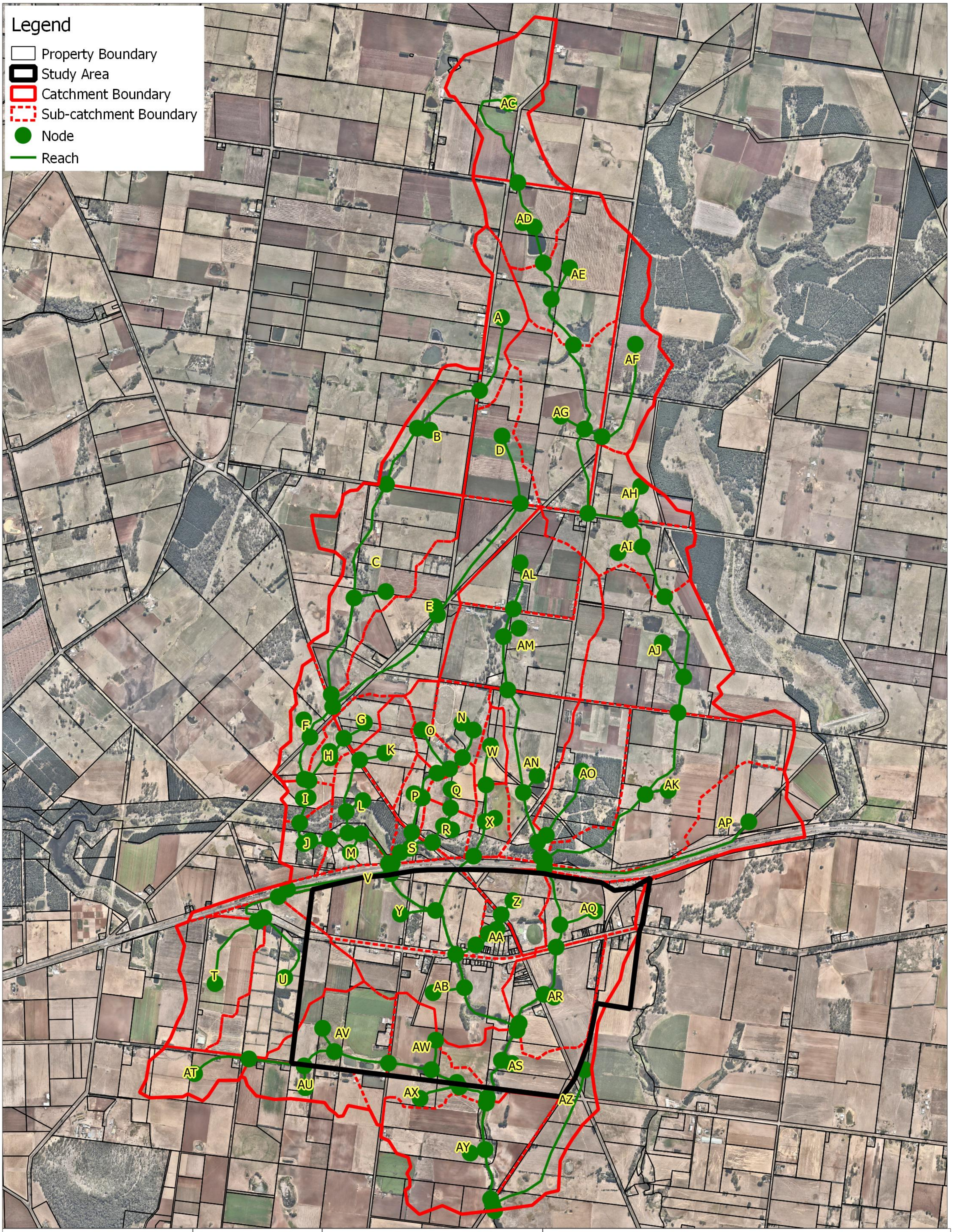
ARR 2016 IFD data for the Bungaree catchment was sourced from the Bureau of Meteorology (BOM) using the online 2016 Rainfall IFD request system. Data was requested for the coordinates of -37.53°south and 143.99°east (the centroid of the catchment) and yielded the design rainfall intensities listed in Appendix Table A. 1 for each duration of the 1% AEP storm event modelled in RORB.

Appendix Table A. 1 2016 IFD design rainfall intensities

Duration	1 % AEP (mm)
10 min	26.3
15 min	32.2
30 min	41.7
1 hour	49.8
2 hour	57.8
3 hour	63.5
4.5 hour	70.7
6 hour	77
9 hour	88
12 hour	97.7
10 min	26.3

APPENDIX B

RORB Model Layout Plan



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MOORABOOL SHIRE COUNCIL

600 0 600 m

1:35,000

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 54

Bungaree Flood Study

RORB Layout Plan

Job Number: V2027_001
Revision: 0
Drawn: MM
Checked: GO
Date: 3/5/2018

APPENDIX C

Hydrological Calculations and RORB Model Parameters

C1 ARR2016 METHODOLOGY DISCUSSION

A key difference between this ARR2016 methodology and the previously recognised industry standard (ARR1987) is that it aims to reduce aleatory uncertainty. This type of uncertainty is associated with naturally occurring processes (like how rain falls from the sky). The new methodology utilises a range of temporal patterns as inputs instead of just the one pattern in order to produce a range of results all of which are correct under certain circumstances. The answer that appears most often or is closest to the middle of the range of answers is then the selected result and is generally defined by the maximum of the medians.

C2 RORB MODEL SUB CATCHMENT PARAMETERS

C2.1 Fraction Impervious

Each sub-catchment within the RORB model was assigned an area weighted average fraction impervious value. These were based on individual fraction impervious values assigned to parcel areas of different land uses. Appendix Table C. 1 summarises the fraction impervious values applied to the corresponding land uses.

Appendix Table C. 1 Adopted fraction impervious values for various land uses

Land Use	Fraction Impervious Value
Farm Land / Open Space	0.05
Rural Living Areas	Varies from 0.15 – 0.65 (depending on Aerial photography)
Major and Minor Roads	0.3

As discussed previously a majority of the Bungaree catchment farm land resulted in area weighted average fraction impervious values of less than 15%.

C3 RORB ARR2016 DATA HUB INPUTS

C3.1 IFD Data

The IFD Data presented within Appendix A was sourced from the BOM. As highlighted within AR&R 2016, design rainfall intensities are provided at a point which may not be representative of the areal average rainfall intensity across a catchment. RORB applies Areal Reduction Factors (ARF) to the design rainfalls as a correction factor.

C3.2 Temporal Rainfall Patterns

The temporal patterns utilised as an input to the RORB model were sourced from the ARR 2016 DataHub. The 2016 guidelines state that point temporal patterns should be used for catchment areas less than 75 km^2. As the Bungaree catchment area is 22 km^2, adoption of the point temporal patterns is appropriate. 10 temporal patterns were obtained for each duration.

C3.3 Spatial Rainfall Patterns

Uniform spatial patterns were adopted.

C3.4 Initial and Continuing Loss Model

As the Bungaree catchment predominately has impervious fraction values of less than 15%, a single set of loss parameters was adopted representing a rural loss model approach. These rural loss values were consistent with the data obtained from the ARR2016 Data Hub and were as follows;

- Initial Loss = 25 mm
- Continuing Loss = 4.4 mm

C3.5 Rainfall Pre-burst Duration Factors

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

To account for this, IL_s was reduced to an initial loss relevant to the burst (IL_b) using Equation 4-4 from AR&R 2016 (IL_s-$IL_{preburst}$=IL_b) using the median pre-burst depth data from the data hub for storm durations greater than 6 hours. IL_b was estimated using the equation shown below for durations shorter than 6 hours.

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

C4 RORB MODEL VALIDATION

Appendix Table C. 2 presents the various Kc values analysed for the Bungaree Catchment. These values were derived from the industry standard regional equations displayed. They were used to analyse the resulting range of flows (maximum of the median) obtained at the catchment outlet. A Kc value of 6.58 was adopted as the Pearse et al. 2002 regional equation was considered the most appropriate for Bungaree's specific catchment characteristics.

Appendix Table C. 2 Various Kc Routing Parameter Values

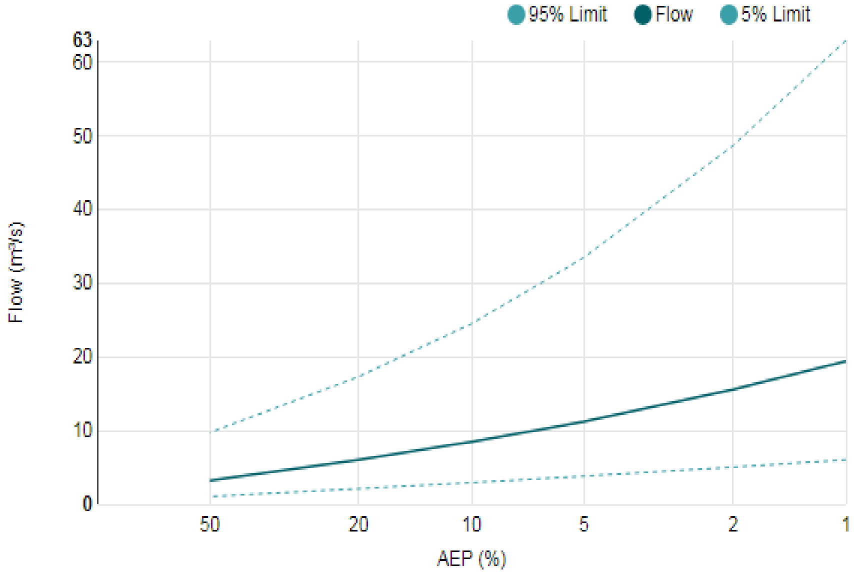
No.	Regional Equation	Source	Bungaree Catchment Kc	Maximum of Median Flow at Catchment Outlet (m^3/s)
1	$Kc = 0.49 \times A^{0.65}$ (Areas with rainfall < 800 mm per year)	Australian Rainfall and Runoff	3.84	63.0
2	$Kc = 2.57 \times A^{0.45}$ (Areas with rainfall > 800 mm per year)	Australian Rainfall and Runoff	10.69	24.2
3	$Kc = 2.2 \times A^{0.5}$	RORB V6 User Manual	10.73	24.1
4	$Kc = 1.25 \times d_{av}$	RORB V6 User Manual (Pearse et al. 2002)	6.58	36.6
5	$Kc = 1.19 \times A^{0.56}$ (Yarra and Maribyrnong areas)	Melbourne Water	7.02	34.8
6	$Kc = 1.53 \times A^{0.55}$ (South East ("DVA") area	Melbourne Water	8.74	29.2

C5 RFFE FLOWS

The RFFE online estimation tool has been utilised to validate the flow obtained from the developed RORB model with a kc value of 6.58. The tool used the following details as an input:

- Catchment Area = 23.77 km2
- Catchment Centroid Co-ordinates = -37.534° south and 143.992° east
- Catchment Outlet Co-ordinates = -37.578° south and 143.995° east

Appendix Figure C. 1 provides the RFFE online output report indicating that the 1% AEP flow equals 19.4 m^3/s. Although this value is lower than the value obtained from the developed RORB model of 36.6 m^3/s, the associated lower and upper confidence limit range of 6.01 m^3/s to 63.0 m^3/s indicates the adopted Kc value still lies well within the confidence limits.



AEP (%)	Discharge (m^3/s)	Lower Confidence Limit (5%) (m^3/s)	Upper Confidence Limit (95%) (m^3/s)
50	3.20	1.05	9.72
20	6.02	2.09	17.3
10	8.45	2.92	24.5
5	11.2	3.80	33.5
2	15.6	5.03	48.7
1	19.4	6.01	63.0

Statistics

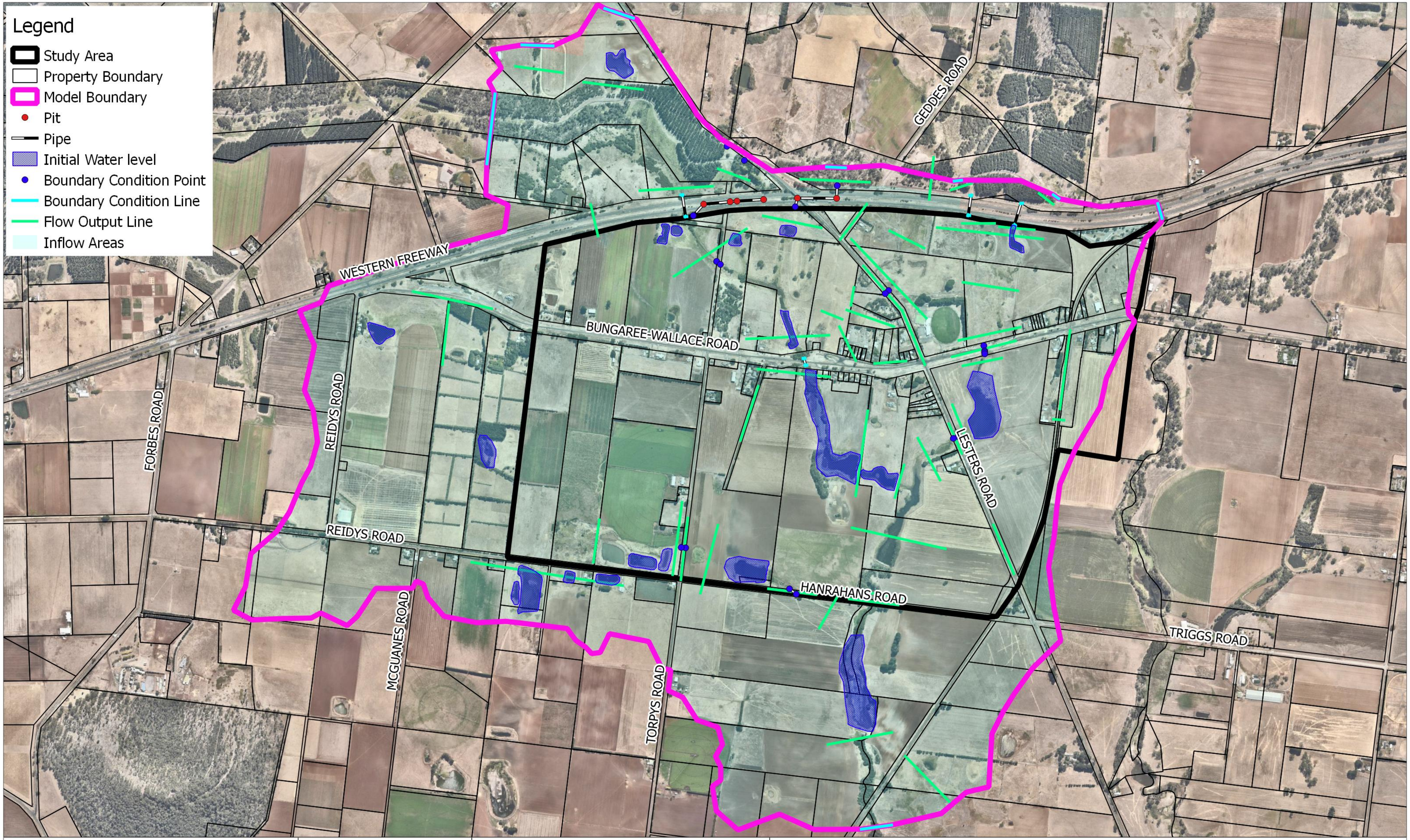
Variable	Value	Standard Dev
Mean	1.234	0.653
Standard Dev	0.729	0.232
Skew	0.138	0.030

Correlation		
1.000		
-0.330	1.000	
0.170	-0.280	1.000

Appendix Figure C. 1 RFFE online tool report

APPENDIX D

Tuflow Model Layout Plan



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ENGENY WATER MANAGEMENT

MOORABOOL SHIRE COUNCIL

390 0 390 m

1:20,000

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 54

Bungaree Flood Study

TUFLOW Model
Layout Plan

Job Number: V2027_001
Revision: 0
Drawn: MM
Checked: GO
Date: 3/5/2018

APPENDIX E

Tuflow Model Inputs and Parameters

E1. TUFLOW MODEL INPUTS

E1.1 Digital Terrain Model

Engeny obtained LiDAR (Light Detection And Ranging) data sets covering the study area. LiDAR is an optical remote sensing technology that measures properties of scattered light to find range and other information of a distant target. The resulting data set consists of a regularly spaced grid of ground levels over the covered area.

Engeny triangulated the LiDAR data sets to produce a Digital Terrain Model (DTM) for carrying out hydraulic modelling in TUFLOW. The purpose of the DTM is to enable allocation of spot levels to points within the 2-D grid layer which is utilised by TUFLOW. Figure 2.1 shown above displays the DEM for the Bungaree Catchment where the study area portion was utilised as the terrain surface within the hydraulic model.

E1.2 Grid Size

Engeny adopted a grid size of four metres for the Bungaree TUFLOW model. This grid size allows for appropriate definition of the catchment terrain and reasonable simulation times to run the model. A grid size of four metres is consistent with recommendations in Melbourne Water's Flood Mapping Guidelines for mapping in rural catchments.

E1.3 1-D Network Data

Engeny has modelled all key culvert assets within the Bungaree study area. These were located along VicRoads and Council owned roads. Cross drainage assets along the Western Freeway were of particular interest and details of these pipes and pits were obtained from as constructed drawings supplied by VicRoads where available. For instances where drawings were not available, onsite observations and measurements were undertaken. Invert levels were based on the produced DEM and ensuring the pipe's end walls were positioned within the low lying areas.

E1.4 Open Channels or waterways

The Bungaree study area includes a number of open channels/ waterways. The representation of these was found to be reasonable with the developed DEM and no significant modifications were made to the terrain levels along these flow paths.

However as several culverts have been included in the model along these flow paths minor modifications to lower elevations at the upstream and downstream end wall locations were made as LiDAR data can fail to pick up the invert due to heavy vegetation or ponded water.

E1.5 Surface Roughness

Within TUFLOW a land use (materials) layer was utilised to assign surface roughness information into the model. A surface roughness value has been assigned to each property polygon based on land use and aerial photography. This roughness defines the resistance to flow as it flows overland across a property or road. In some instances, Engeny added additional shapes or split property polygons (such as parks with buildings and open space or farm land with rural living) in order to accurately model surface roughness.

Appendix Table E. 1 provides the Manning's 'n' roughness values applied to the Bungaree model. The roughness values are based on Melbourne Water Guidelines and Technical Specifications, November 2012.

Appendix Table E. 1 TUFLOW surface roughness values

Land use	Manning's n roughness
Low density residential	0.20
Open space with low vegetation density	0.035
Open space with moderate vegetation density	0.06
Open space with high vegetation density	0.09
Car parks and roads	0.03
Open water with reedy vegetation submerged	0.025
Waterway with moderate vegetation	0.06

E2. TUFLOW MODEL BOUNDARY CONDITIONS

E2.1 2-D Boundary Conditions

The TUFLOW model includes a series of 2-D boundary conditions to control points where flow enters or leaves the 1-D pipe network. SX lines are drawn at locations where flow interacts between the 1-D network and the 2-D floodplain, with CN lines drawn to connect the SX lines to the 1-D network.

As part of the 1-D network, 2-D SX boundaries have been assigned to each pit included along the Western Freeway to allow discharge of water from the pipe network to the 2-D surface and also allow runoff to enter the 1-D network if the pipe capacity allows it.

HQ (head versus flow) lines were drawn at the catchment boundaries to allow overland flow to leave the model at the catchment outlets. The relationship is based on the downstream terrain slope as an input. These were positioned in the following locations:

- Downstream of the study area where Two Mile Creek discharges south.
- North of the Western Freeway where due to the terrain, minor outflows could occur within the water supply channel.

E2.1.1 2-D Source Areas

As many of the sub-catchments used to define the hydrological model do not have any or have very few inlet pits 2-D source areas were used to apply flow to the hydraulic model.

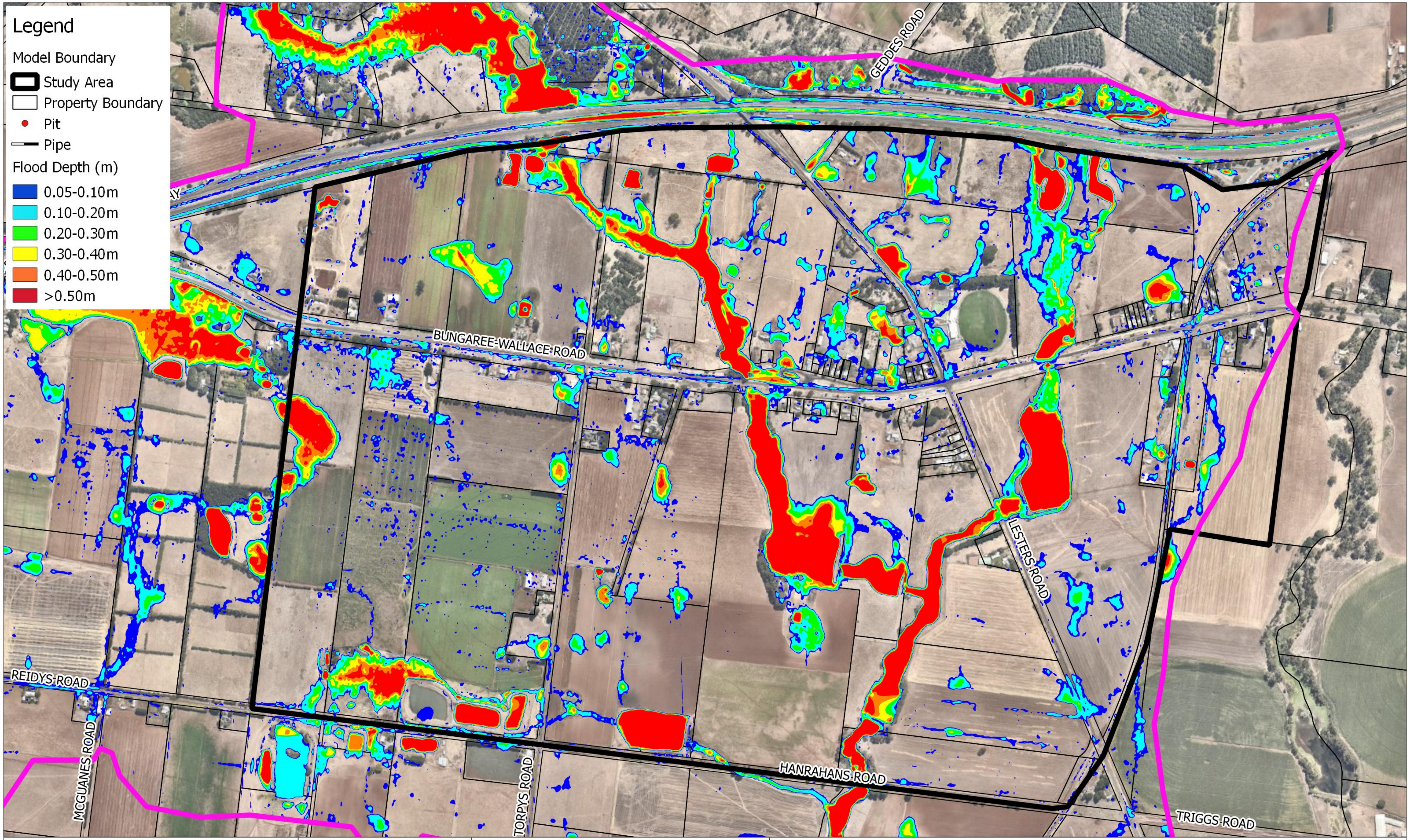
A 2-D source area is a polygon matching the hydrological RORB sub-catchment where an inflow is applied evenly to each cell within the 2-D domain. Flow from the source area travels overland until it reaches the 1-D network, or may flow overland to the catchment outlet.

E2.1.2 Initial Water Levels

Polygons were digitised and assigned an initial water level for all significant dams along the major tributaries within the model. This was also done for other farm dams that displayed significant storage capacity. As LiDAR generally defines the water level in the dam at the time of the LiDAR capture, the initial water level shapes have been used to fill the dams to just below the spilling point so that the dams do not provide flood storage in the modelled storm events. This is a conservative approach.

APPENDIX F

1 % AEP Flood Depth Layout Plan



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200 0 200 m

1:12,000

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 54

Bungaree Flood Study

1% AEP Existing Conditions Flood Depth
Layout Plan

Job Number: V2027_001
Revision: 0
Drawn: MM
Checked: GO
Date: 3/5/2018

APPENDIX G

Key Flooding Areas Layout Plan

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Bungaree Flood Study

Key Flooding Areas
Layout Plan

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