Colac Otway Shire

Birregurra Flood & Drainage Strategy

Detailed Report – Exhibition Version

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The Colac Otway Shire and Engeny Water Management proudly acknowledges the Gulidjan and Gadubanud peoples of the Eastern Maar Nation as the traditional custodians of the Colac Otway Region.

We pay our respects to their Ancestors and Elders, past, present and emerging. We recognise and respect their unique cultural heritage, beliefs and relationship to their traditional lands, which continue to be important to them today and into the future.

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ABBREVIATIONS AND TERMS

The following abbreviations and terms are used and referenced in the Strategy.

Abbreviation / Term	Explanation
Annual Exceedance Probability (AEP)	Refers to the probability or risk of a rainfall event of a given magnitude (intensity and duration) occurring or being exceeded in any given year. A 90 % AEP event has a high probability of occurring or being exceeded; it would occur quite often and would be a relatively minor rainfall event. A 1 % AEP event has a low probability of occurrence or being exceeded; but is likely to cause extensive damage. A 1 % AEP event has the same probability as a 1 in 100-year ARI.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level. Introduced in 1971 to eventually supersede all earlier datums.
Average Recurrence Interval (ARI)	Refers to the average time interval between a given flood magnitude occurring or being exceeded. For instance, a 100-year ARI flood is expected to be exceeded on average once every 100 years. The AEP is the ARI expressed as a percentage.
Best Practice Environmental Management Guidelines (BPEMG)	Guidelines developed by the Victorian Stormwater Committee and published by the CSIRO in 1999. Guidelines include the required stormwater pollutant removal load and flow attenuation targets.
Birregurra Flood and Drainage Strategy (BFDS)	Detailed within the separate full technical detailed document and summarised within this document.
Development Contribution Plan (DCP)	A DCP is a levy for developments that are proposing to increase the number of dwellings on a site. The contributions collected are used to fund infrastructure required for development and can include shared drainage infrastructure.
Freeboard	A factor of safety above design flood levels typically used in relation to the setting of floor levels or crest heights of flood levees. It is usually expressed as a height above the level of the design flood event.
Hydraulics	The term given to the study of water flow in a river, channel or pipe, in particular, the evaluation of flow parameters such as depth and velocity.
Flooding 'Hot Spot'	An area which has a history of repeat flooding highlighted through flood modelling, anecdotal information and / or customer complaints.
Hydrograph	A graph that shows how the discharge changes with time at any particular location.
Hydrology	The term given to the study of the rainfall and runoff process as it relates to the derivation of hydrographs.
Intensity Frequency Duration (IFD)	Statistical analysis of rainfall, describing the rainfall intensity (mm/hr), frequency (probability measured by the AEP), duration (hrs). This analysis is used to generate design rainfall estimates.
Light Detection and Ranging (LiDAR)	Airborne surveying technology that provides a regularly spaced grid (one metre horizontal interval in this case) of ground levels. The data allows for the representation of elevations along waterways and other key topographical features across the study area.
Representative Concentration Pathway (RCP)	Greenhouse gas concentration trajectories adopted by the Intergovernmental Panel on Climate Change. These projections consist of four different climate futures relative to temperature and sea level rises possible depending on the volume of greenhouse gases emitted in the years to come.
RORB	Hydrological modelling software used in this study to calculate the runoff generated for rainfall events.
TUFLOW	Hydraulic modelling software used in this study to simulate the flow of flood water through the study area. The model uses numerical equations to describe the water movement.

EXECUTIVE SUMMARY

The Birregurra Flood and Drainage Strategy has involved a series of investigations including:

1. Data collation and review.
2. Hydrologic and hydraulic modelling.
3. Flood damages assessment.
4. Structural mitigation works assessment.
5. Stormwater quality assets assessment.
6. Development of planning overlays and schedules.
7. Flood intelligence, warning and planning assessment.
8. Development of Flood Spatial Data Specifications (SDS) outputs.

These have been undertaken to gain a better understanding of the flood behaviour affecting the Birregurra township and the associated structural and non-structural mitigation measures which could be implemented to reduce impacts on existing developments and future proposed developments. The study was delivered by Engeny Water Management in collaboration with planning specialists, Rod Bright & Associates and floodplain risk management specialists, HARC. The project was commissioned by Colac Otway Shire in partnership with the Project Steering Committee (PSC) which consisted of the Corangamite Catchment Management Authority (CCMA), Victorian State Emergency Service (VICSES), Department of Environment, Land, Water and Planning (DELWP), Eastern Maar Aboriginal Corporation and residents of the Birregurra township / community representatives. This report provides the details of each of the investigations undertaken noting that the updated Municipal Flood Emergency Plan (MFEP) has been delivered as a separate document.

Birregurra has a known history of flooding predominantly associated with the flows from Atkin Creek and an Unnamed Tributary which enter the township at Warncoort-Birregurra Road and Ennis Street respectively and discharge into the Barwon River. During the data collation and review phase several flood photos and anecdotal recounts were made available. Additional community knowledge was also sought throughout the project through a formal engagement session at the commencement of the project and direct one-on-one communications with residents and community representatives outside of the formal engagement session. Based on the data available, the September 2016 flood event was considered the only event where sufficient information was available to enable a comprehensive hydrologic analysis and the calibration of modelled flood levels to surveyed flood marks. The magnitude of this event was estimated to relate to a storm event in the range of 10 % to 20 % Annual Exceedance Probability (AEP).

In addition to adopting an approach consistent with the latest Australian Rainfall and Runoff guidelines (ARR2019), the ability of the developed September 2016 calibration model to produce flood levels which replicate 8 of the 9 captured surveyed flood marks provides confidence in the accuracy of the flood mapping outputs. This model was also used to simulate the full suite of AEP design events (39.25 %, 20 %, 10 %, 5 %, 2 %, 1 % AEP and Probable Maximum Flood (PMF)).

Flood mapping outputs for the 20 % to 1 % AEP storm event were utilised to estimate the Average Annual Damage (AAD) for existing conditions. This assessment considered the properties and dwellings which intersect the produced flooding overlays based on the 1 % AEP flood mapping results. Table 1 provides a summary of the number of properties affected and dwellings affected by above floor level flooding in addition to the associated total flood damages. Based on these results, the flood related damages in Birregurra can be considered high.

Table 1: Summary of Flood Damages

AEP	Number of Dwellings	Number of Properties	Total Damages (S)
20 %	5	14	$1,316,613
10 %	7	27	$2,543,329

AEP	Number of Dwellings	Number of Properties	Total Damages (S)
5 %	9	34	$3,662,597
2 %	23	44	$5,664,210
1 %	26	47	$6,576,244
		AAD	**$746,741 / year**

To reduce both flood risk and flood damages, structural and non-structural mitigation works were investigated. Structural mitigation works typically consist of engineered solutions which are constructed to improve the conveyance of overland flows or provide flood storage (e.g. pipe upgrades / diversions, new retarding basin, etc.). Non-structural mitigation works relate to planning overlays and controls as well as flood emergency management plans.

Following discussions with Council and the wider PSC, five (5) structural mitigation works were assessed within the hydraulic TUFLOW model for the 20 % to 1 % AEP storm events. Where relevant, the flood mitigation benefits were assessed with the calculation of the AADs and the resultant reduction in damages when compared to existing conditions. Other factors such as the capital costs were also estimated in addition to considerations of the social impacts / benefits, environmental impacts / benefits and construction / feasibility risks. The five (5) mitigation works assessed included:

1. Atkin Creek waterway widening downstream of Roadknight Street.
2. Drainage upgrades along Sladen Street.
3. Unnamed Tributary retarding basin upstream of Ennis Street.
4. Hopkins Street Pipe Diversion.
5. Drainage upgrades between Prime and Sladen Street.

The high-level multi-criteria assessment highlighted the significant benefits in widening Atkin Creek downstream and the Hopkins Street Pipe Diversion. However, further investigations which considers areas of cultural and heritage significance and outcomes of a flora and fauna impact assessment would be required to gain a better understanding of the feasibility of the works.

Non-structural mitigation measures in the form of planning overlays and controls formed a key study deliverable. The 1 % AEP flood depth, water surface elevation, velocity and hazard outputs were used to develop the proposed planning overlays which consisted of a Special Building Overlay (SBO), Land Subject to Inundation Overlay (LSIO) and a Floodway Overlay (FO). Using the latest technical guidelines and best available data, these overlays have highlighted that the existing overlays and flood planning controls in the Colac Otway planning Scheme for Birregurra do not sufficiently identify flood prone land. As such the updated overlays are intended to replace the existing overlays within the township. Updates to the existing planning schemes and controls were also prepared and a draft has been provided for Council's review and implementation. Planning controls are one of the most cost-effective non-structural mitigation means of reducing the community's flood risk by:

- Encouraging people to, where possible, avoid development on flood-prone land.
- Minimising the potential impacts on existing flood-prone developments by raising floor levels of proposed habitable buildings and ensuring the development does not increase the risk of flooding on other properties.

Improved emergency flood warning management also provides a non-structural means for reducing the flood risk to the Birregurra community. A flood warning or alerting system does not currently exist for Birregurra. Essential building blocks (elements) of a Total Flood Warning System (TFWS) have, however, been delivered as part of this study via a series of flood modelling outputs. This has included the delivery of flood inundation mapping, an updated Municipal Flood Emergency Plan (MFEP), an indicative flood guidance tool and other outputs also suitable for inclusion in a local flood guide such a property inundation tables and associated flood intelligence information.

The existing effective flood warning time has been estimated to be around 3 to 5 hours for Atkin Creek and the Unnamed Tributary under severe flood conditions. With the use of the developed indicative flood guidance tool and flood intelligence and mapping outputs, delivered with this study, it is estimated that this effective flood warning time could be extended by at least 3 hours. It is likely that even with this effective warning time, the emergency services driven flood response actions within Birregurra in the lead up to flooding would be limited. Local residents however, armed with the indicative flood tool and with access to rain data from the gauge at Ricketts Marsh and an overall improved awareness of the flood risk offer substantial opportunity for improved preparedness. A feasibility assessment was undertaken into how this effective flood warning time could be further extended through improved alerting and warning systems. The identified options range from no / low cost options such as making better use of existing rainfall monitoring resources through enabling near real-time public access to rain data at Ricketts Marsh gauge to options which would require a greater level of investment. These more costly options would involve improved rain and / or river monitoring and automated messaging immediately upstream of the Birregurra township for Atkin Creek and the Unnamed Tributary.

In addition to the management of flood risks within Birregurra, consideration of the opportunities available to manage stormwater quality were also assessed. This was particularly relevant given the township's expected future growth informed by the Birregurra Structure Plan and the additional pollutant loads generated through increased impervious areas from new developments. Current policy requires new developments to achieve the Best Practice Environmental Management Guidelines (BPEMG) pollutant removal targets. A range of Water Sensitive Urban Design (WSUD) options were thus investigated and sized in order to achieve these BPEMG targets for the predicted increase in impervious area. These included a centralised wetland option and a street-scale bioretention assets option in addition to reporting on the additional benefits rainwater tanks can provide on a lot basis.

Following the completion of these investigations, the following recommendations are provided:

1. Colac Otway Shire Council:
    a) Seek internal endorsement of the flood study and undertake public exhibition to ensure the Birregurra community has the opportunity to comment and provide feedback.
    b) Update the planning scheme to incorporate the findings of this study.
    c) Consider the outcomes of the high level multicriteria assessment and findings of additional investigations and consider options which may progress to further feasibility assessments, subject to funding requirements.
    d) Commission cultural heritage, flora and fauna, and geotechnical investigations to help inform the location of any flood mitigation assets.
    e) Reference the provided flood modelling outputs, in particular the flood level information, to provide advice on recommended minimum floor levels for new developments for which Council is the responsible authority.
    f) Review the Municipal Flood Emergency Plan with input from VICSES and adopt revised document.
2. Corangamite CMA:
    a) Seek internal endorsement of the flood study and use mapping outputs to manage floodplain risk and inform development advice to ensure risks are minimised.
    b) Reference the provided flood modelling outputs, in particular the flood level information, to provide advice on recommended minimum floor levels for new developments for which CCMA is the responsible authority.
    c) Add the produced Flood Spatial Data Specification (SDS) outputs and other relevant mapping outputs to FloodZoom.
3. Victorian State Emergency Services:
    a) Continue to engage with the community to increase their awareness of flood related risks.
    b) Review and discuss the updated MFEP.

1 INTRODUCTION

1.1 OVERVIEW

Engeny Water Management (Engeny) in collaboration with specialists in planning schemes and emergency flood warning plans have developed the Birregurra Flood and Drainage Strategy. The study was commissioned by Colac Otway Shire (Council) in partnership with the Project Steering Committee (PSC) which consists of the following stakeholders:

- Corangamite Catchment Management Authority (CCMA);
- Victorian State Emergency Service (VICSES);
- Department of Environment, Land, Water and Planning (DELWP);
- Eastern Maar Aboriginal Corporation; and
- Residents of the Birregurra township.

Several investigations and tasks were undertaken to develop the Birregurra Flood and Drainage Strategy including:

1. Data collation and review.
2. Hydrologic and hydraulic modelling.
3. Peer Review of hydrologic and hydraulic modelling.
4. Flood damages assessment.
5. Structural mitigation works assessment.
6. Stormwater quality assets assessment.
7. Development of planning overlays and schedules.
8. Flood intelligence, warning and planning assessment.
9. Development of Flood Spatial Data Specifications (SDS) outputs.

This report provides all the details from each of these project phases and a summarised version of this document will be prepared for public exhibition.

1.2 CATCHMENT DESCRIPTION

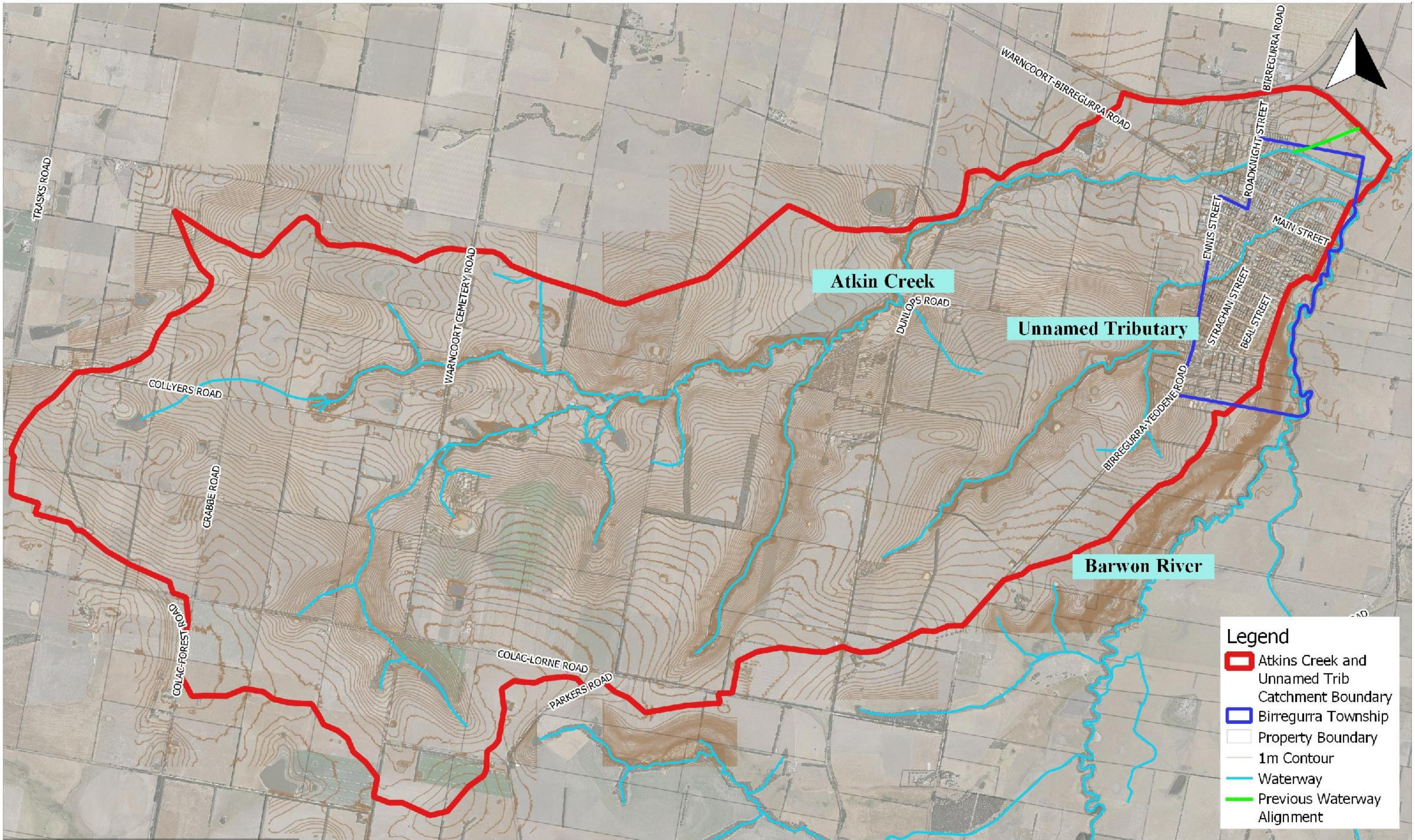
The township of Birregurra is located approximately 130 kilometres south-west of Melbourne. Atkin Creek and an Unnamed Tributary of the Barwon River flow through the town. The Unnamed Tributary is referred by some locals as Kettles Creek however is referred to herein as Unnamed Tributary. These waterways have a contributing catchment area of approximately 23 km² and 5.5 km² respectively prior to discharging into the Barwon River which forms the town's eastern boundary.

The catchment generally consists of well-defined flow paths and ridges rising from a level of approximately 198 m AHD at the top of the Atkin Creek catchment to 106 m Australian Height Datum (AHD) at the confluence to the Barwon River over a distance of 10.5 kilometres.

Birregurra has experienced growth and infill development in recent times with a high number of properties reported to be flood affected from the local waterways flowing through the town. During the September 2016 storm event, properties within the new developments along Scouller Street and Anderson Street were affected by significant flooding in addition to other established residential areas within the township.

The limited capacity provided by Atkin Creek downstream of Anderson Street contributes to flooding impacts in the new development areas along Scouller Street. This section of the creek (running along the southern side of Scouller Street) represents the diversion channel constructed several years ago. It is understood that under natural catchment conditions, Atkin Creek originally continued in a north easterly direction towards the Barwon River. However, with new developments and the establishment of the now abandoned regional rail link embankment, the creek was channelised towards the east along the southern side of Scouller Street, towards the Barwon River.

Figure 1.1 provides an overview of the Birregurra township including the upstream Atkin Creek and Unnamed Tributary catchment areas.



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ENGENY WATER MANAGEMENT

Colac Otway SHIRE

600 0 600 m

Scale in metres (1:5000 @ A3)

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

Birregurra Flood Study

Figure 1.1
Birregurra Township Catchment Overview

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 14/1/2021

1.3 OBJECTIVES

The following provides a list of the project objectives:

1. To improve the understanding of flooding within Birregurra for a range of flood events (minor and major).
2. To assist with the protection of property and life.
3. Inform Planning Scheme Amendments which enable the update of existing flood overlays.
4. To improve decision making about development proposals in flood prone areas.
5. Inform development advice to ensure new developments consider and do not worsen existing flooding behaviours and risks.
6. Inform Council's future growth strategy such as the Birregurra Structure Plan to understand which areas are appropriate for growth.
7. Identify structural mitigation measures[1] which could be implemented to reduce existing flood risks.
8. Understand Water Sensitive Urban Design (WSUD) measures which could be implemented to ensure future development meets stormwater quality requirements for new development areas.
9. Update Council's Flood Emergency Plan and develop flood intelligence outputs to inform emergency response planning.

Whilst the Strategy has a focus on flood management related objectives, it is important to note the importance of waterways in relation to broader ecological, cultural, and aesthetic values. Waterways serve wider ecological functions as habitat and places of biodiversity including for the growling grass frog (*Litoria raniformis*) listed as vulnerable by the *Environment Protection and Biodiversity Conservation Act 1999*. There are areas of cultural sensitivity and significance for Aboriginal people, in addition to places of aesthetic and recreational value. It is important that these values continue to be upheld and enhanced whilst balancing the flood mitigation objectives and outcomes of this strategy.

1.4 STAKEHOLDERS

The following stakeholders own / manage drainage and waterway assets within Birregurra:

1. Colac Otway Shire Council (Council).
2. Corangamite Catchment Management Authority (CCMA).
3. VicRoads.
4. VicTrack.
5. Eastern Maar Aboriginal Corporation (EMAC).
6. Department of Environment, Land, Water and Planning (DELWP).
7. Victorian State Emergency Service (VicSES).

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

1.4.1 Colac Otway Shire Council

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

Councils provide roads and drainage systems to collect and convey stormwater to creeks and rivers; they also maintain the stormwater mains owned by Council on private property. Across Birregurra, Council is the drainage authority and the responsible authority for managing stormwater drainage assets and any overland flooding resulting from the stormwater drainage network. This includes provision of advice for development in areas at risk of flooding from the stormwater drainage network. Prior to the development of this strategy knowledge of areas at risk of stormwater flooding were not well understood or documented and the

[1] Structural mitigation measures refer to engineered works which are constructed to reduce flooding impacts this could include the upgrade of existing drainage assets, new diversion pipes, formalised above or underground flood storage areas or levee works.

outputs generated from the development of this strategy, including the attached flood maps, will assist Council in their drainage authority role particularly in areas assigned with a Special Building Overlay (SBO).

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

- Structural Measures.
- Non-Structural Measures.

Whilst acknowledging the recommendation refers to Melbourne based Councils and Melbourne Water, it was considered a useful approach to managing flood risks and has been adopted for this strategy.

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

Flood mapping of Council's drainage system, undertaken as part of the development of this strategy, is a non-structural measure which has been used to inform the introduction of Special Building Overlay (SBO) controls that will be used to set conditions on development, including the floor levels of habitable buildings.

1.4.2 Corangamite Catchment Management Authority

In Victoria the floodplain management authorities are the various Catchment Management Authorities. In Birregurra the Corangamite Catchment Management Authority (CCMA) is the floodplain management authority as defined in the Water Act.

Under Part 10 of the Water Act 1989, CMAs are designated with responsibility for a waterway management district and have the lead role in developing and delivering regional programs for waterway management. The Water Act outlines their functions and powers in relation to waterway management, floodplain management and regional drainage. Within Birregurra and surrounds key functions of the CCMA include:

- Declaration of flood levels and flood fringe areas to find out how far floodwaters are likely to extend and how high they are likely to rise.
- Declaration of building lines.
- Controlling developments that have occurred or that may be proposed for land adjoining waterways.
- Taking any action necessary to minimise flooding and flood damage.
- Provision of advice about flooding and controls on development to local councils, the Secretary for Planning and Environment, and the community.

In its statutory role the CCMA co-ordinates the process for permitting works on designated waterways and designated land within the Corangamite region. This applies to Atkin Creek, the Unnamed Tributary (referred to by some locals as Kettles Creek) and Barwon River. The CCMA are a recommending referral authority in the planning system (under Section 55 of the Planning and Environment Act 1989), providing advice and recommendations to Council for proposed developments within the floodplain.

1.4.3 Regional Roads Victoria

VicRoads is responsible for the overall management (including construction, maintenance, inspection and repair) of a network of freeways and arterial roads (the major connecting roads) throughout Victoria. VicRoads is responsible for the management of the following roads within Birregurra and surrounds (note these road names are as defined by VicRoads and may be referred to differently by the Birregurra community):

- Birregurra Road.
- Warncoort-Birregurra Road.
- Birregurra-Forrest Road.

The responsibilities of VicRoads within Birregurra and surrounds extends to the drainage assets, including culverts and bridges, which have been constructed as part of roads managed by VicRoads.

1.4.4 VicTrack

VicTrack is responsible for Victoria's transport land, assets, and infrastructure. This includes the drainage infrastructure that cross railways and the associated maintenance. Within the Birregurra township there are no VicTrack owned assets except for the drainage identified crossing the now abandoned rail embankment north of Scouller Street.

1.4.5 Property Owners

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

- Are liable for the unreasonable flow of water from their land onto any other land if that water causes injury, damage or economic loss.
- Have a duty of care not to interfere with the flow of water.
- Must not participate in negligent conduct that will interfere with the flow of water onto any land.

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

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

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

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

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

1.4.6 VICSES

The Victoria State Emergency Services is a volunteer-based organization which provides emergency assistance to minimize the impact of emergencies and strengthen the community's capacity to:

- Plan / mitigate by assisting Council in the development of emergency management plans and increasing individual capacity and capability by providing communities with information and undertaking community education and engagement work.
- Respond by providing continuous protection of life, property and the environment.
- Recover by undertaking assessments, restoration, clearing and rehabilitation of public buildings and assets where VICSES is the manager of that building or asset in addition to also supporting and providing assistance and advice to individuals, families and communities affected by floods or other natural disasters.

In the context of this flood and drainage strategy, VICSES has provided feedback on the emergency flood warning assessment undertaken and the separate Municipal Flood Emergency Plan (MFEP) document. VICSES will utilize the study's outputs to distribute and engage with the Birregurra community to improve their capacity to plan and respond to future flood events.

1.4.7 Eastern Maar Aboriginal Corporation (EMAC)

The EMAC is an organization which represents the Eastern Maar People of South West Victoria. As traditional owners of the region, the group manages the native title rights and interests of Birregurra and as such were consulted during the development of the strategy. Alongside this engagement, the study also highlights the need to undertake investigations to understand the cultural heritage values which exist in specific locations through further archaeological and anthropological investigations.

1.4.8 DELWP

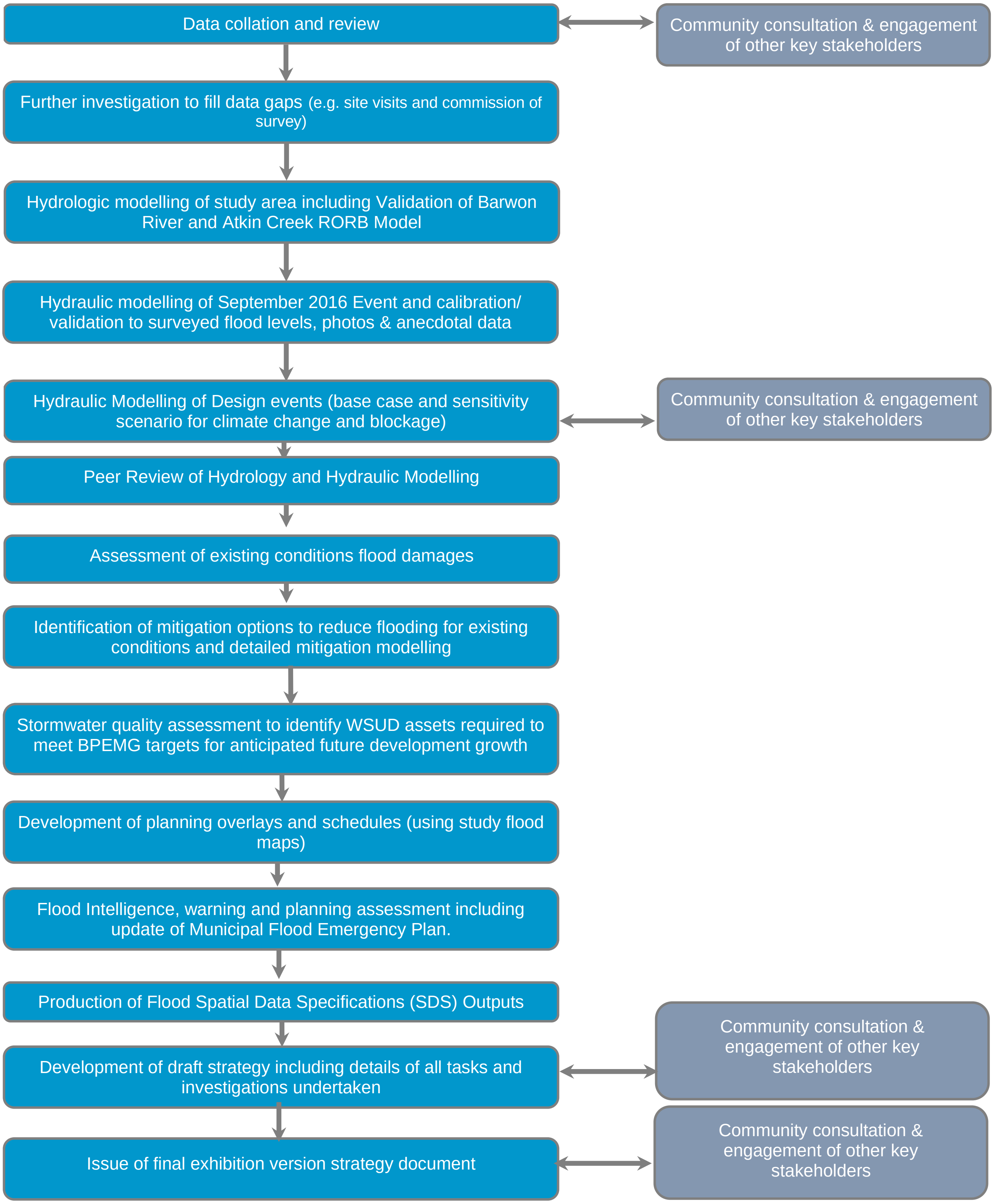
DELWP is a state government department that encompasses several agencies and brings together Victoria's climate change, energy, environment, water, forest, planning and emergency management functions. The department aims to care for and protect the environment whilst maximising the connections between the community, industry, and economy.

In line with DELWP's role to protect natural environments, the water associated with the Barwon River floodplain / crown land is managed by DELWP. Proposed works within this area would require DELWP's approval.

1.5 STUDY METHODOLOGY

Figure 1.2 illustrates the key steps undertaken to achieve the objectives of this study.

Figure 1.2: Study Methodology Flow Chart



2 DATA COLLATION AND REVIEW

2.1 DATA SUMMARY

A series of data sets were collated and reviewed to inform the Birregurra township Flood and Drainage Strategy. This information was sourced from the following agencies and individuals:

- Colac Otway Shire Council.
- Corangamite Catchment Management Authority (CCMA).
- Department of Environment, Land, Water and Planning (DELWP).
- Bureau of Meteorology (BoM).
- Birregurra Historical Society.
- South West Survey Group (SWSG).
- Residents of the Birregurra township.

The data consisted of GIS layers and reports in addition to other technical data such as rainfall data, streamflow recordings, historical flood photos, etc. The following sections provide further details.

2.2 DRAINAGE

Council provided Engeny with GIS layers of drainage pipes and pits within the township. This data contained pipe diameter attributes which were used as an input to the hydraulic model. A thorough review of this data identified gaps where missing assets were identified on site and verified with development plans where available. In critical locations where development plans were not available and a site inspection was not possible, surveyors were engaged to verify the pipe diameters and drainage connectivity.

Key hydraulic structures such as culvert crossings and bridge structures along Atkin Creek and the Unnamed Tributary as well as evident private driveway crossings were also measured on site where access was possible. On site measurements included obtaining the following details:

- Culvert widths and heights.
- Bridge deck thickness and approximate height of flow area beneath deck.
- Railing heights and an indication of opening flow area.
- Number of bridge piers or culverts.

Where measurements on site could not be undertaken, private property access was arranged by Council and surveyors were engaged to obtain details on the existing inlet / outlet structures in addition to the associated pipe diameter. The surveyor details were also verified with data measured during the site visits.

2.3 AERIAL PHOTOGRAPHY

Aerial photography of the study area captured on the 28th of January 2019 was supplied by Council. This photography was compared to the latest www.nearmap.com aerial photography which resembled the same level of development across the study area. The date of the latest aerial photography on Nearmap is unknown, whilst it is listed as being captured on the 1st of January 2005 it is clearly more recent as recent developments north of Scouller Street are displayed. Although, based on discussions with Council and observations made on site, these aerials have not captured the most recent lots which have since been subdivided and developed north of Scouller Street.

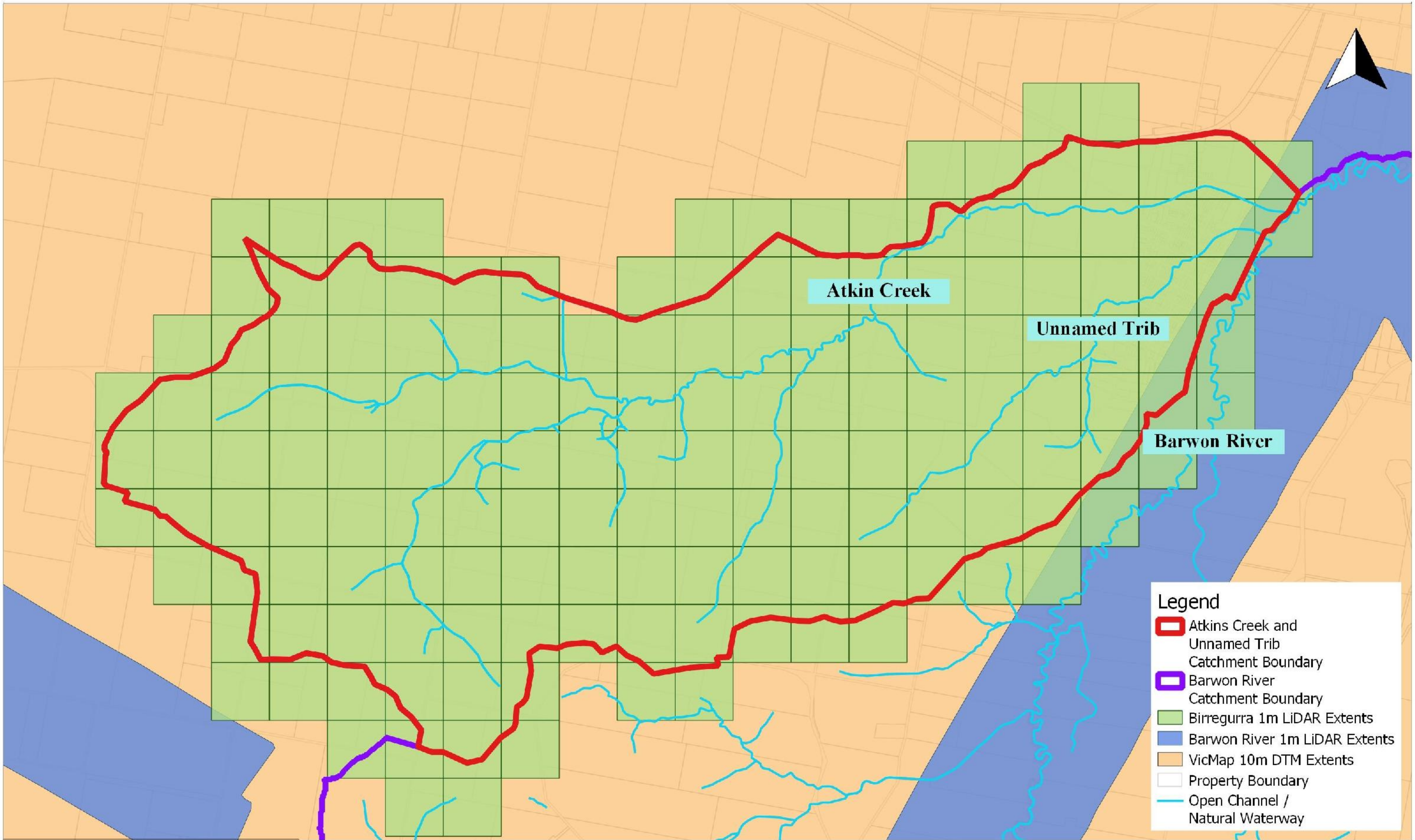
2.4 TOPOGRAPHY

2.4.1 Summary

A series of data sets were collated and reviewed to define the topography of the study area and contributing catchments. Table 2.1 provides a summary of these data sets including details on the resolution, accuracy and source. Figure 2.1 depicts the extent of the topographical data sets utilised in this study.

Table 2.1: Summary of Topography Data Sets

Data Set	Resolution	Quoted Accuracy	Source	Purpose
Birregurra LiDAR data (11th September 2019)	1 metre	Vertical 0.1 m Horizontal 0.3 m	Council	Utilised to define hydrological sub-catchment delineation for Atkin Creek and Unnamed Tributary hydrology model. Utilised to represent the 2D domain in hydraulic flood model.
Barwon River LiDAR data (Corangamite 15th May 2010)	1 metre	Vertical 0.2 m Horizontal 0.3 m	DELWP	Utilised to fill gaps and define Barwon River flood plain terrain in hydraulic flood model.
VicMap 2008 DTM	10 metre	Vertical 5.0 m Horizontal 12.5 m	DELWP	Utilised to define hydrological sub-catchment delineation of wider Barwon River hydrology model.
Survey Data	Cross sections at the upstream and downstream end of key culvert structures and at approx. 100 m intervals along Atkin Creek downstream of Anderson Street.	-	South West Survey Group	Used to better define ground elevations at critical locations along Atkin Creek and at culvert crossing structures.
Permanent Survey Marks	-	Vertical typically < 40 mm Horizontal typically < 30 mm	DELWP (Survey Marks Enquiry Service online portal)	Used to verify accuracy of Birregurra LiDAR data to known survey marks.



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Birregurra Flood Study

Figure 2.1

Extent of Topography Data Sets

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 14/1/2021

2.4.2 Birregurra township LiDAR

Council provided LiDAR (Light Detection and Ranging) data tiles covering the Birregurra township and the upstream catchment areas of Atkin Creek and the Unnamed Tributary. This data was captured on the 11th September 2019 and is an airborne surveying technology that provides a regularly spaced grid (one metre horizontal interval in this case) of ground levels. This data was used to produce a Digital Terrain Model (DTM), which allows for the waterways and other key topographical features across the study area to be defined in a flood model.

The LiDAR data was commissioned specifically for this study where the output data report shows that after processing and comparison to field survey, the following level of accuracy was achieved:

- Vertical accuracy +/- 100 mm.
- Horizontal accuracy less than 300 mm.

2.4.3 Barwon River LiDAR

As part of DELWP's data sharing agreement, LiDAR data captured as part of the 2009-10 Victorian State Wide Rivers LIDAR Project for the Corangamite CMA was utilised to define the topography along the Barwon River floodplain. This data was captured on the 15th May 2010 with a grid resolution of one metre and the following levels of accuracy:

- Vertical accuracy +/- 200 mm.
- Horizontal accuracy less than 300 mm.

2.4.4 VicMap DTM

The VicMap database includes a state-wide DTM generated utilising contours at 10 metre intervals. Due to the extent of the DTM and the various input resolutions, accuracies and ages used to generate the grid the following level of accuracy applies:

- Vertical accuracy +/- 200 mm.
- Horizontal accuracy less than 300 mm.

This data was utilised to delineate the wider Barwon River catchment and associated sub-catchments (or subareas) as inputs to the hydrology model.

2.4.5 Feature and Level Survey Data

South West Survey Group (SWSG) were engaged to provide drainage data in addition to ground elevation data at key culvert structures and along Atkin Creek downstream of Anderson Street. Typical cross-sections of the creek at intervals of 100 metres were requested along Atkin Creek in addition to cross-sections at the upstream and downstream end of key drainage structures.

This data was requested due to the uncertainties identified with the LiDAR data and its ability to capture waterway invert levels without interpolation issues[2] particularly within highly vegetated areas.

2.4.6 Permanent Survey Marks

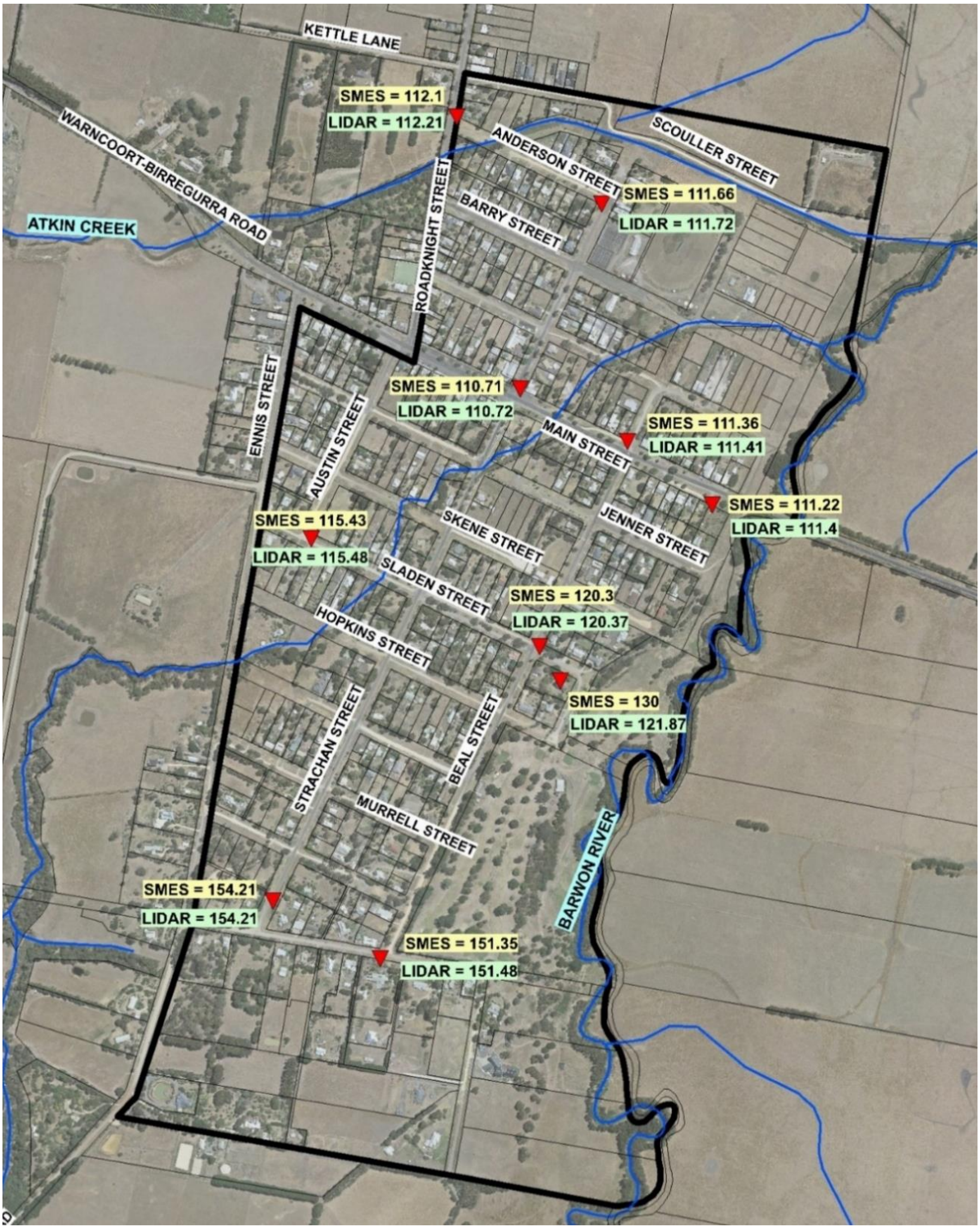
The Survey Marks Enquiry Service (SMES) online portal was accessed to extract the existing permanent survey marks across the Birregurra study area. These elevations were utilised to verify the accuracy of the Birregurra LiDAR data adopted for the overall hydraulic TUFLOW model.

Figure 2.2 displays the comparison of elevations indicating that in general the difference is within 100 mm at key locations. It was however noted that the survey mark near the intersection of Sladen Street and Beal Street differs by approximately 8 metres. This is because the marker is located on the top of the church spire and would be filtered out of the LiDAR data set.

[2] Linear Interpolation is used to fill gaps in irregularly space LiDAR elevation data sets. This can cause a loss of information and introduce possible errors in producing the Digital Elevation Model (DEM) especially in areas with various ground cover types because vegetation may limit ground elevation detection.

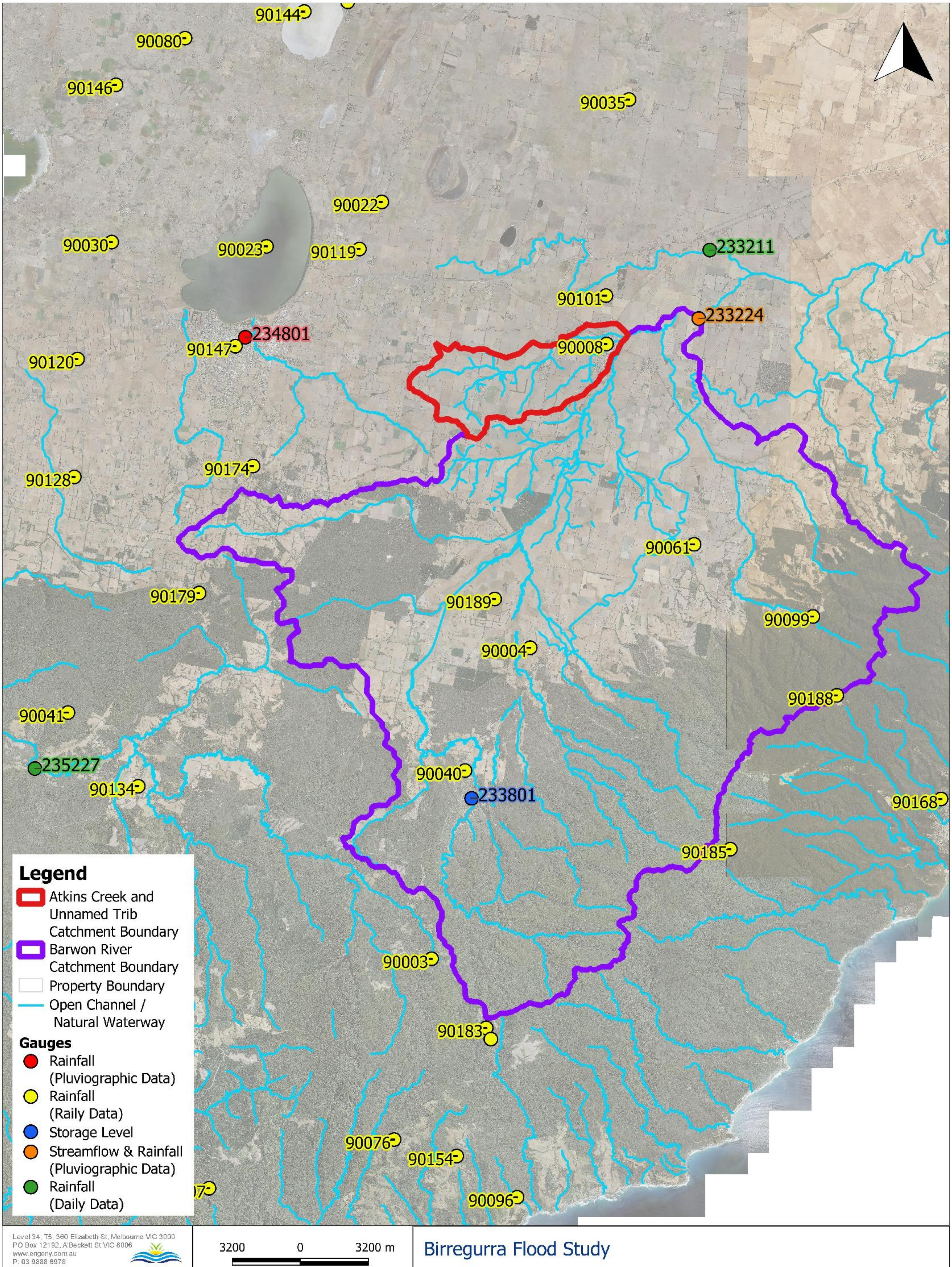
Overall, the findings indicate the LiDAR data forming the basis behind the flood modelling is accurate and can be compared to other survey marks such as the flood levels provided by the CCMA.

Figure 2.2: LiDAR Verification to Known Survey Marks



2.5 GAUGES

A series of rainfall and stream flow gauge data sets were identified within and surrounding the Birregurra study area. The locations of these stations are displayed within Figure 2.3 and are described in the following sections. This data was sourced from both the Bureau of Meteorology and DELWP's rivers and streams online portal.



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Scale in metres (1:15800@ A3)

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

Birregurra Flood Study

Figure 2.3
Location of Rainfall and Streamflow Gauges

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 23/11/2020

2.5.1 Rainfall Data

Both daily and where available pluviographic rainfall data sets were reviewed as part of the hydrological modelling undertaken and discussed in Section 3. Table 2.2 provides a summary of the rainfall stations where pluviographic data was extracted and analysed.

Daily rainfall averages were also assessed for the remaining stations displayed in Figure 2.3 to understand the spatial variability across the study area and surrounding catchments for historic storm events. The comparison of total daily rainfall depths at the Birregurra (Post Office) station (90008) to the Barwon River at Ricketts Marsh station confirmed that the pluviographic data was of poor quality for the September 2016 event as noted below.

Table 2.2: Rainfall Data

Gauge Location	Station Number	Start Date	End Date
Lake Colac @ Colac	234801	23/01/2016	22/04/2020
Barwon River @ Ricketts Marsh	233224	21/05/1993	22/04/2020 Poor Quality Data for September 2016 event

2.5.2 Streamflow Data

Table 2.3 provides a summary of the streamflow gauge data collated and assessed as part of the hydrological calibration component. It is important to note that the local Atkin Creek and Unnamed Tributary catchments are ungauged.

Table 2.3: Streamflow Data

Gauge Location	Station Number	Catchment Area (km2)	Start Date	End Date
Birregurra Creek @ Ricketts Marsh	233211	87	07/05/1953	13/11/2013
Barwon River @ Ricketts Marsh	233224	593	27/07/1971	22/04/2020
Gellibrand River @ Bunkers Hill	235227	311	20/03/1970	20/02/2018

2.5.3 Reservoir Data

Given the West Barwon Reservoir is located within the Barwon River catchment upstream of the gauge at Ricketts Marsh, storage level data was obtained from DELWP's online portal.

Table 2.4: Reservoir Data

Gauge Location	Station Number	Start Date	End Date
West Barwon Reservoir	233244	28/05/2002	Ongoing

2.5.4 Birregurra Structure Plan

The Birregurra Structure Plan (2013) displayed in Figure 2.4 forms the framework for future growth within the township. Following a review of the structure plan report, the following references to flooding were identified:

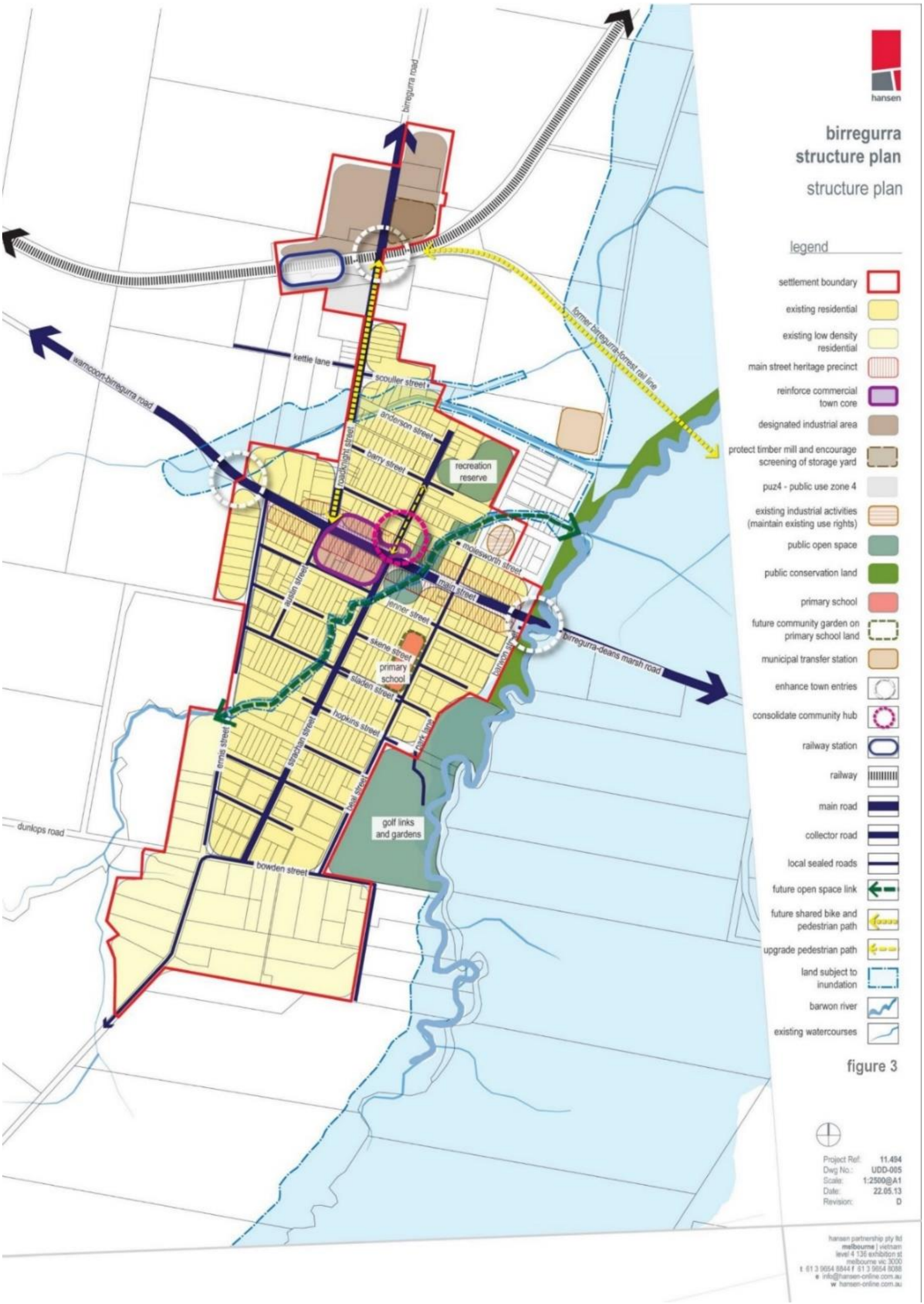
- The northern half of the town is relatively flat and has several areas of poorly drained land that is prone to flooding.
- Given the constraints posed by the Barwon River and its floodplains to the east of town, and topography / escarpment to the south, options for future urban expansion are limited to the north and west.

- Direct future growth of the township away from designated floodplains [3].
- If or when a need is identified for urban expansion, the following principles should be applied in identifying and assessing potential areas of future rezoning.
- The land is not constrained by slope or flooding / drainage issues.

As these flooding considerations are informed by existing flood overlays (discussed within Section 2.5.5), it is anticipated that the findings from this study will inform future updates to the current structure plan.

[3] "Designated floodplains" wording has been referenced directly from the Birregurra Structure Plan. "Designated" here does not take on the same meaning as in the Water Act

Figure 2.4: Birregurra Structure Plan / Framework Plan



2.5.5 Existing Flood Overlays

Land Subject to Inundation Overlays (LSIO) currently cover the Atkin Creek and Unnamed Tributary waterways traversing the township in addition to the Barwon River floodplain as depicted in Figure 2.5 below. These are included within Council's Planning Scheme, however particularly after recent flood events the LSIO extents have been shown to not adequately represent existing flooding conditions. This is because these LSIO extents represented the best available knowledge of the time based on the available data inputs and different overall modelling practices and technologies which are now considered outdated.

Figure 2.5: Existing Flood Overlays

2.6 SITE VISIT

Engeny conducted a site visit of the study area on the 26th February 2020 with members of the Project Steering Committee (PSC). The site visit focused on key areas of the catchment in order to:

- Gain an understanding of site conditions including flow paths and low-lying areas.
- Verify the existence of drainage assets.
- Obtain measurements of drainage culvert and bridge structures.
- Understand the general feasibility and key constraints which could influence the selection of structural mitigation works.

Appendix A includes photos taken during the site visits.

2.7 HISTORIC INFORMATION

A series of historic flood information data was collated during the progression of the study from various sources. This data typically consisted of flooding photos and videos, anecdotal recounts and surveyed flood marks provided by Council, stakeholder agencies and the local Birregurra community.

Daily and hourly rainfall data sets sourced from the Bureau of Meteorology and DELWP's online portal were also referenced to understand the related storm event magnitudes. The following sections provide a summary of the data collated and reviewed. This phase formed a critical component in the September 2016 event calibration and verification of flood modelling outputs discussed within Section 3.

2.7.1 Flood History

Based on the anecdotal descriptions and flood photos / videos collated from stakeholder agencies and community members noteworthy floods that have impacted the township include:

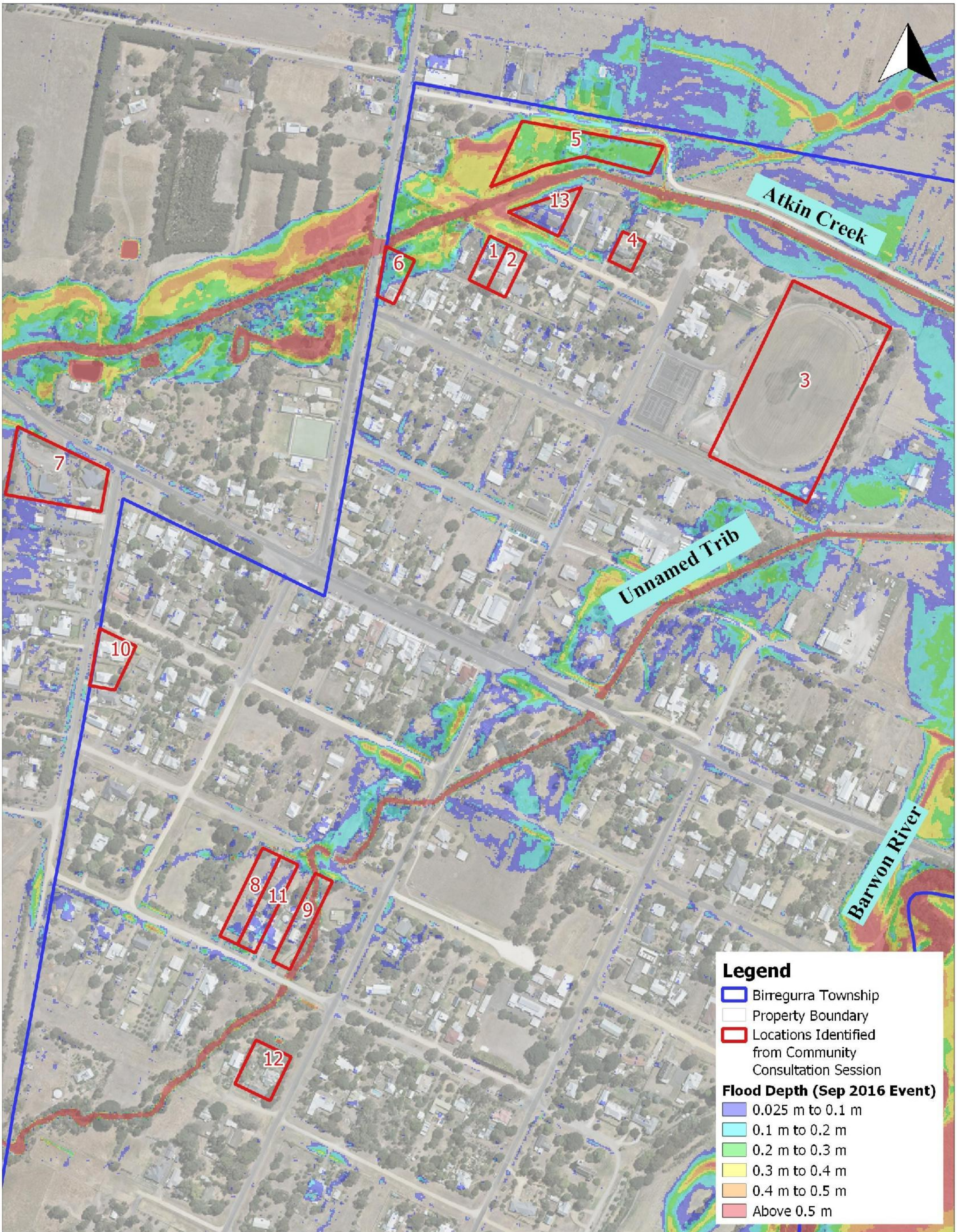
- November 1995.
- September 2016.
- September 2017.

It is important to note that due to the lack of data detailed calibration and verification of flood modelling results was only possible for the September 2016 event.

2.7.2 Community Engagement

To gain a better understanding of the flooding behaviour within Birregurra, several community engagement sessions were held at different stages of the study.

Appendix B provides a summary of the information captured from residents during consultation session held on December 7th and 8th 2019 led by Council and the CCMA. This data was referenced during the calibration and verification of flood modelling results discussed in Section 4.4. The corresponding address / location of each resident comment has been referenced within Figure 2.6 with the underlying September 2016 event modelling results for comparison purposes.



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70 0 70 m

Scale in metres (1:3500 @ A3)

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

Birregurra Flood Study

Figure 2.6

Locations Identified from Community Consultation Session

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 14/1/2021

2.7.3 Surveyed September 2016 Flood Marks

Surveyed flood marks from the September 2016 event were captured along the Atkin Creek and Unnamed Tributary flow paths and provided by the CCMA. Figure 2.7 displays the location of these across the township and Table 2.5 references the location's description and the surveyed level.

These flood levels were critical during the calibration and verification of the September 2016 modelled results. A comparison of the modelled versus surveyed flood levels is provided in Section 4.4.

Table 2.5: Surveyed Flood Marks for September 2016 Event

Location	Description	Flood Level m AHD
1	Warncoort-Birregurra Rd (Fence line)	113.44
2	Roadknight Street	111.61
3	Scouller St (Side of Shed)	Unable to access property
4	Scouller St (Sewer pit)	110.49
5	Anderson St (Fence post)	111.3
6	Main Street (US left bank bride abutment)	109.89
7	Skene St (Top of crossing)	112.4
8	Skene St (Base of letter box)	112.63
9	Bridge abutment (DS Right bank)	114.3

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100 0 100 m

Scale in metres (1:5000 @ A3)

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

Birregurra Flood Study

Figure 2.7
Location of Surveyed Flood Marks

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 14/1/2021

3 HYDROLOGICAL MODELLING

3.1 PURPOSE

The purpose of the hydrologic modelling was to generate runoff hydrographs[4] for input to the hydraulic model. This included the generation of:

- Rainfall excess hydrographs for the sub-catchments covering the local Birregurra township.
- Routed hydrographs to represent the inflows from Atkin Creek, the Unnamed Tributary and Barwon River.

Table 3.1 provides a summary of the model scenarios.

Table 3.1: Hydrological Modelled Scenarios

Storm Event	Existing Conditions	Climate Change Conditions
39.35 % AEP or 2-year ARI [5]	x	
18.13 (20) % AEP or 5-year ARI	x	
10 % AEP or 10-year ARI	x	x
5 % AEP or 20-year ARI	x	
2 % AEP or 50-year ARI	x	
1 % AEP or 100-year ARI	x	x
0.5 % AEP or 200-year ARI	x	
0.2 % AEP or 500-year ARI	x	
Probable Maximum Flood (PMF)	x	
September 2016 validation event	x	

3.2 METHODOLOGY

RORB was utilised as the rainfall runoff software where numerous inputs were generated in accordance with the Australian Rainfall and Runoff Guidelines (ARR 2019). A combination of both the Monte Carlo and ensemble simulation approach was adopted to the hydrologic modelling undertaken. The following provides the basis for adopting each of the simulation approaches:

- **Monte Carlo Approach** was adopted to define the design flows along the Atkin Creek, Unnamed Tributary and Barwon River watercourses. These flows correspond to longer critical durations with larger contributing catchments. The approach was adopted to more accurately account for the catchment's inherent variability and probabilistic nature of key variables such as initial loss, rainfall depths and temporal patterns.
- **Ensemble Approach** was adopted to define the design flows for the local Birregurra township catchments. These flows correspond to shorter critical durations associated with smaller contributing catchments. The approach was adopted to

[4] A runoff hydrograph is a graph that shows how the discharge changes with time at any particularly location.
[5] Annual Exceedance Probability (AEP) or Average Recurrence Interval (ARI)

consider the variability from different temporal patterns and the more accurate application of losses for the different surface types within the township.

Two (2) hydrological RORB models were developed to represent the combined Atkin Creek and Unnamed Tributary catchments in one RORB model and the larger Barwon River catchment in the other.

The Atkin Creek and Unnamed Tributary are ungauged catchments and as such the calibration of the Barwon River RORB model to the gauge was used to define the input parameters for the Atkin Creek and Unnamed Tributary RORB model.

The following provides a summary of the hydrologic methodology adopted:

1. Undertake a Flood Frequency Analysis (FFA) for the Barwon River at Ricketts Marsh Gauge.
2. Develop the Barwon River RORB model to the gauging station at Ricketts Marsh.
3. Calibrate the design Barwon River RORB model to the Flood Frequency Analysis (FFA) using the Monte Carlo simulation approach.
4. Verify the Design Barwon River RORB model flows and parameters to literature findings and the Rural Flood Frequency Estimate (RFFE).
5. Generate a series of design hydrographs for the various AEP storm events and scenarios (base and climate change conditions) for input to the hydraulic TUFLOW model.
6. Develop the Atkin Creek and Unnamed Tributary RORB model to the Barwon River confluence.
7. Utilise the k_c / distance average (d_{av}) ratio to determine the k_c value for the Atkin Creek and Unnamed Tributary RORB model and adopt the defined FFA design calibration loss parameters.
8. Simulate the local township catchment design flows using the ensemble approach for durations between the 10 minute to 2 hour storm durations (where relevant) accounting for the indirectly and directly connected impervious proportions as recommended within the ARR 2019 guidelines.
9. Simulate the routed waterway inflows (Atkin Creek, Unnamed Tributary and Barwon River) using the Monte Carlo approach for the given critical durations.
10. Collate the relevant ensemble rainfall excess hydrographs and routed inflows for the 10 minute to 2 hour storm durations (where relevant) in addition to the Monte Carlo rainfall excess hydrographs and routed inflows for the given Atkin Creek and Unnamed Tributary critical durations for input to the hydraulic TUFLOW model discussed in Section 4.
11. Utilise the design Barwon River RORB model to simulate the September 2016 storm event and calibrate to the gauged hydrograph by varying the input loss parameters. Utilise these parameters to generate the relevant Barwon River inflow hydrograph for application to the hydraulic September 2016 TUFLOW model scenario discussed in Section 4.4.
12. Utilise the design Atkin Creek and Unnamed Tributary RORB model to simulate the September 2016 event in order to generate the rainfall excess and routed inflow hydrographs for application to the hydraulic TUFLOW model. Iterative hydrologic and hydraulic modelling was undertaken varying the loss parameters and hydraulic model parameters to calibrate the modelled flood levels to the surveyed flood levels discussed in Section 4.4.

The following sub-sections provide details on the various inputs, assumptions and calibration / verification processes undertaken.

3.3 FFA FOR BARWON RIVER AT RICKETTS MARSH GAUGE

A Flood Frequency Analysis (FFA) was undertaken using FLIKE. The available recorded streamflow data between 1971 to 2020 was used for the Barwon River at Ricketts Marsh gauge (Station 233224). This 50-year data set was analysed to determine the maximum recorded flow for each year. The censoring of data was considered, however due to the relatively limited data set of 50 years, was not adopted as it would require the exclusion of several records resulting in significantly wider confidence limit ranges.

The Log Pearson III distribution output is displayed in Figure 3.1 and Table 3.2. This distribution was preferred in contrast to the Generalised Extreme Value distribution (GEV) as the upper and lower confidence limits were within a closer range to the mean values. These outputs formed the basis of the Barwon River calibration discussed within Section 3.4.8.

The analysis also confirms that the following three storm events, considered notable within the Birregurra township based on anecdotal information, contributed to the given annual peak flow recorded at the Ricketts Marsh gauge:

- November 1995 – recorded 446.6 m^3/s with estimated magnitude of 1 in 30.75 years.
- September 2016 – recorded 99.5 m^3/s with estimated magnitude of 1 in 3.62 years.
- September 2017 – recorded 34.5 m^3/s with estimated magnitude of 1 in 1.56 years.

Figure 3.1: Barwon River at Ricketts Marsh FFA Graph Output

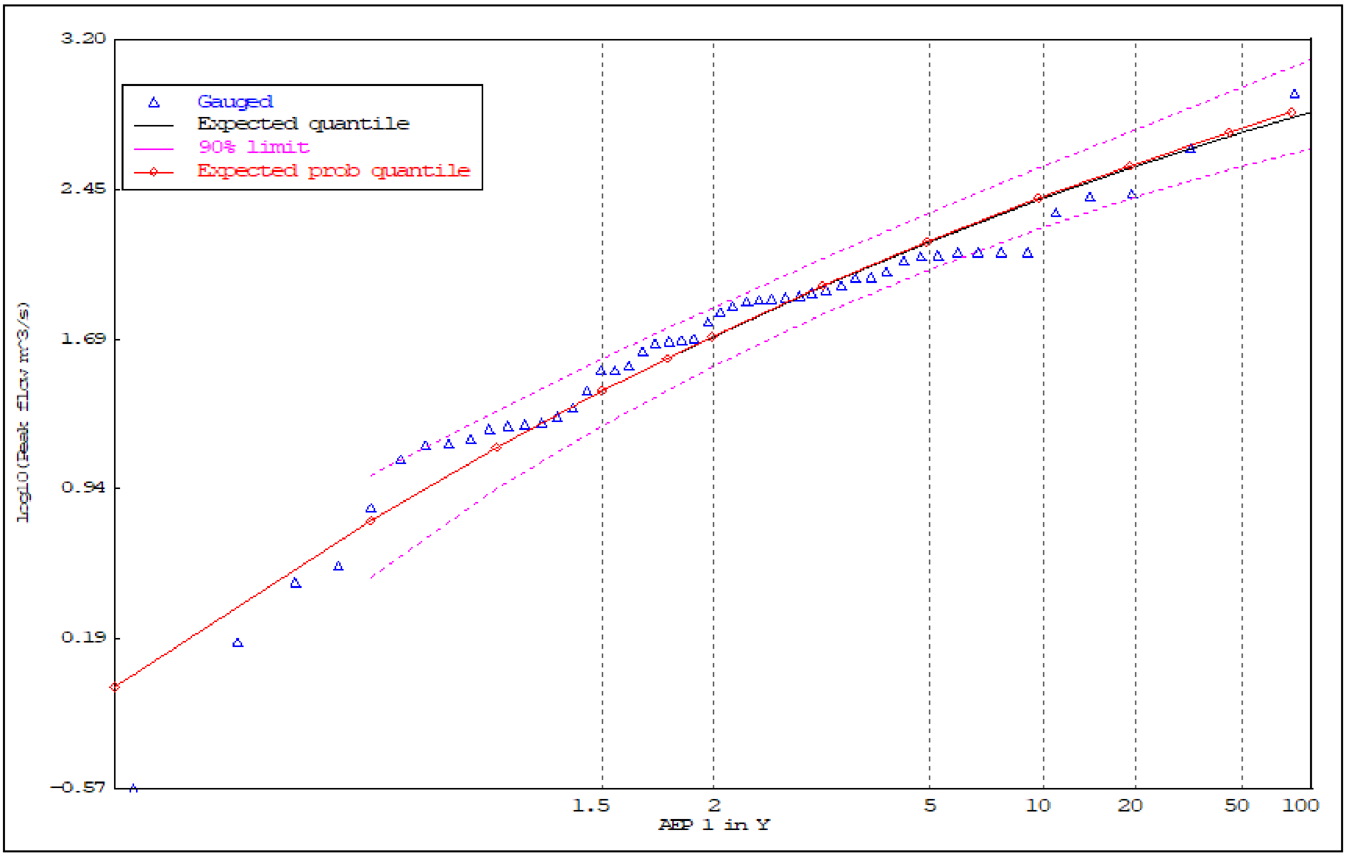


Table 3.2: Barwon River at Ricketts Marsh FFA Table Output

AEP (%)	Expected Quantiles (m³/s)	5 % Confidence Limit (m³/s)	95 % Confidence Limit (m³/s)
50	50.9	36.0	71.5
20	151.7	110.7	214.2
10	250.1	180.5	363.8
5	364.7	257.9	560.3
2	537.8	366.4	911.3
1	682.4	449.9	1251.6
0.5	836.7	533.2	1699.3
0.2	1053.0	636.8	2393.7

3.4 BARWON RIVER MODEL DEVELOPMENT

3.4.1 Catchment Boundary

The Barwon River catchment boundary was defined utilising the VicMap 2008 DTM and the corresponding 10 metre contours. Figure 3.2 provides the overall catchment boundary of approximately 572 km² and structure of the RORB model including the location of the Barwon River at Ricketts Marsh gauging station (Station ID 233224) at the annotated Node ID of 'Y4'.

3.4.2 Sub-catchment Boundaries

A watershed analysis was run for the Barwon River catchment based on the VicMap DTM from which sub-catchment boundaries were generated. These were reviewed and modified where possible to ensure sub-catchments were generally consistent in size and land use.

3.4.3 Fraction Impervious

A weighted fraction impervious value was calculated for each sub-catchment based on typical values assigned to each land use type. Table 3.3 provides a summary of the typical values adopted. Fraction impervious is a vital component of the hydrological model as it is a key parameter in the process of converting rainfall into runoff. The values adopted were within the industry standard ranges where the resultant weighted values were cross-checked against the aerial photography.

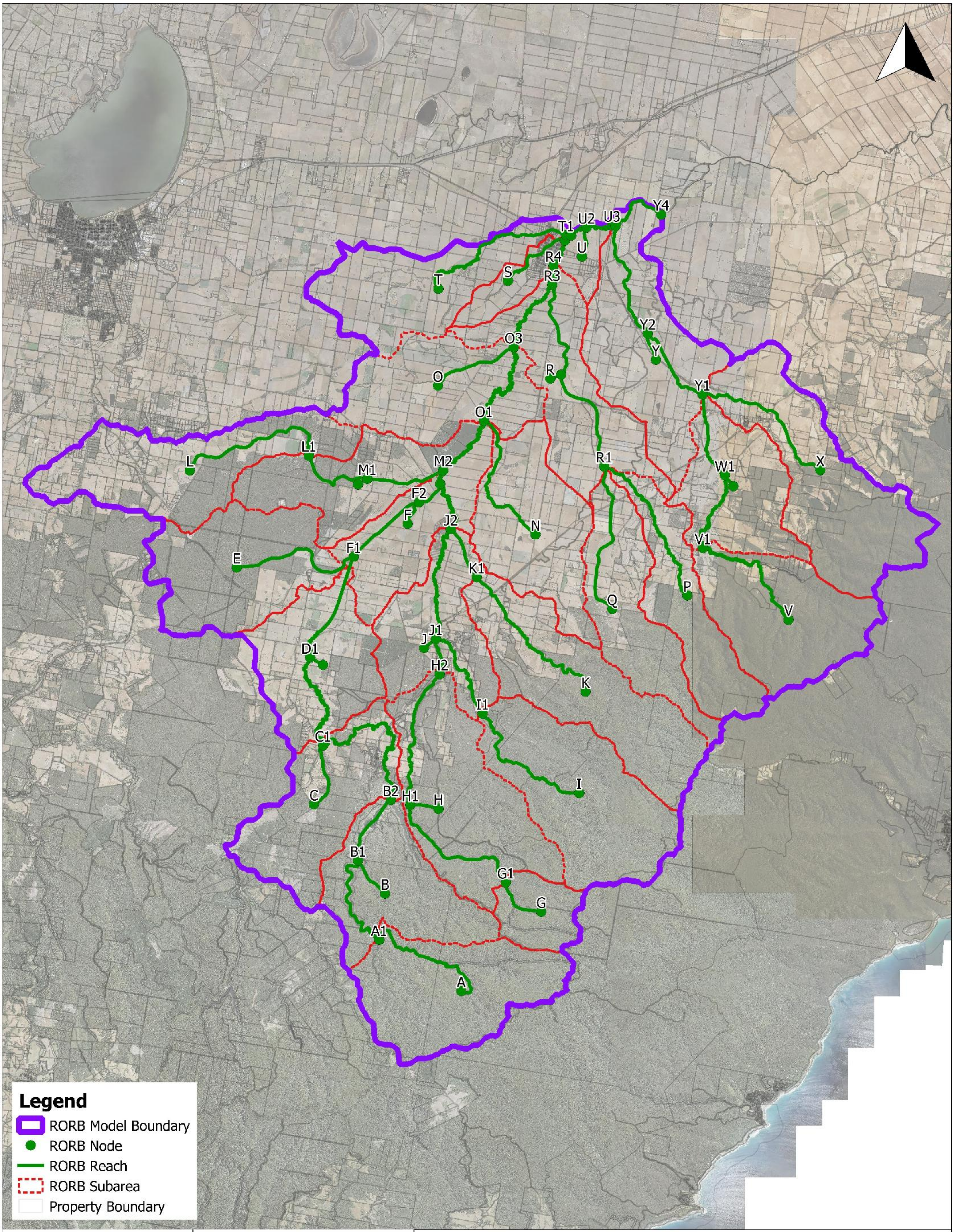
Table 3.3: Typical Fraction Impervious Values for Land Uses

Land-use Type	Fraction Impervious
General Residential / township / Low Density Residential Zone	20 - 75 % (informed by lot sizes and aerial photography)
Farming Zone	0 - 5 %
Commercial / Industrial Zone	80 - 90 %
Public Park and Recreation Zone	10 %
Local roads & car parks	40 - 60 %

3.4.4 Other Modelling Input Considerations

Appendix C provides details of other modelling considerations which informed the inputs during the development of the Barwon River RORB model including:

- Intensity-Frequency-Duration (IFD) Data adopted for base conditions, climate change and PMF scenarios.
- Application of spatial rainfall patterns.
- Application of pre-burst rainfall depths.
- Temporal patterns adopted.
- Areal Reduction Factors (ARFs) calculations and resultant factors.



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Colac Otway SHIRE

2600 0 2600 m

Scale in metres (1:130000@ A3)

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

Birregurra Flood Study

Figure 3.2
Barwon River RORB Hydrologic Model Layout

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 24/7/2020

3.4.5 West Barwon Reservoir

The West Barwon Reservoir is located within the Barwon River catchment upstream of the gauging station at Ricketts Marsh. The reservoir is located at the junction of the West Barwon River and Munday Creek and has a catchment area of approximately 51 km^2. It serves as a source of drinking water for the greater Geelong region and has a total capacity of approximately 21,500 ML (when full) with a release capacity of up to 300 ML/day (3,500 L/s) via the outlet tower and valve house (*Barwon Water, West Barwon Reservoir Factsheet, 2020)*. These controlled outflows are directed into the West Barwon River where some flows are diverted into the Wurdee Boluc inlet channel and ultimately directed towards the Wurdee Boluc Reservoir for storage prior to treatment at the Wurdee Boluc Water Treatment Plant. In addition to these controlled water supply outflows, a minimum of 4ML/day (45 L/s) is released to meet environmental flow requirements.

During rare flood events when the water level within the reservoir exceeds 192.8 m AHD, the reservoir spills via a large concrete weir into the downstream West Barwon River. (*Barwon Water, West Barwon Reservoir Factsheet, 2020).*

During the development of the RORB model, considerations were made to represent the reservoir as a storage within the RORB model. The following information was collated and reviewed to inform the approach and whether inclusion of the storage provided by the reservoir was required:

- Contributing catchment area into West Barwon Reservoir = 51km^2 (consists of less than 10 % of the catchment area which reaches the gauge at Ricketts Marsh).
- The controlled outflows from the reservoir are minor and focused on water supply or environmental flow requirements with diversion channels in place that are not considered flood conveyance assets.
- The available peak storage levels recorded within West Barwon Reservoir did not correlate to peak flows recorded at the downstream Ricketts Marsh gauging station. Table 3.4 summarises the peak flows recorded at the Ricketts Marsh gauge and the corresponding peak water level recorded at the reservoir. The data has been sorted from highest recorded flow to lowest highlighting no correlation to the recorded storage levels nor engagement of the large concrete weir spillway.

Table 3.4: Analysis of West Barwon Reservoir Storage Levels

Date	Peak Flow recorded at Barwon River @ Ricketts Marsh Gauge (m^3/s)	Peak Water level recorded at West Barwon Reservoir (m AHD)
4/11/2007	136.0	185.73
5/06/2012	134.7	191.057
14/09/2016	99.5	188.632
12/08/2010	81.6	184.492
22/07/2011	72.2	190.337
15/08/2004	67.1	190.316
25/08/2003	50.3	184.773
4/02/2005	49.2	188.124
16/09/2017	34.5	188.175
28/08/2010	27.1	188.621
18/07/2006	18.5	181.277
30/08/2009	18.0	182.519
24/07/2016	17.7	183.881
30/06/2002	14.5	192.711

Date	Peak Flow recorded at Barwon River @ Ricketts Marsh Gauge (m^3/s)	Peak Water level recorded at West Barwon Reservoir (m AHD)
15/08/2010	12.4	185.331
8/11/2007	7.1	186.576
12/02/2012	3.0	185.239
19/05/2013	0.3	189.816

Based on the above findings it was concluded that the reservoir did not significantly contribute to the flows recorded at the gauging station and as such was not included within the developed Barwon River RORB model.

3.4.6 Initial and Continuing Loss Model

The RORB model utilises an initial loss (IL) /continuing loss (CL) model approach, in accordance with the recommendations of ARR 2019. Losses in RORB were assigned based on three surface types:

- **Effective Impervious Area (EIA)** – comprising areas which are effectively impervious and are connected to the drainage system.
- **Indirectly Connected Area (ICA)** – comprising impervious areas which are not directed to the drainage system (e.g. a paved patio or footpath) and pervious areas that interact with impervious areas which are not directly connected (e.g. nature strips and garden areas).
- **Rural Area** – comprising pervious areas which do not interact with impervious areas (e.g. parklands and bushlands)'.

Table 3.5 presents the approach adopted for the EIA / ICA / Rural proportioning of subareas within the catchment based on different land use types and Total Impervious Area (TIA) percentages. These TIA values were obtained from the weighted FI for each subarea calculated and discussed in Section 3.4.3.

Table 3.5: Subarea Land Use Proportioning in Barwon River RORB Model

Land Use Type	Total Impervious Area (TIA)	EIA proportion	ICA proportion	Rural proportion
Rural / Pervious Urban	0-15 %	Not utilised as rural subareas are assumed to have no direct connections to drainage	Total impervious area	Total pervious area (area – impervious area)
Low Density Residential	15 – 30 %	60 % of total impervious area (ARR 2016, Book 5. Ch. 3 - Section 3.4.2.2.2 quotes 50-70 %)	40 % of total impervious area	Total pervious area (area – impervious area)

Based on the proportion summary provided above and the Barwon River catchment characteristics, the majority of the subareas were assigned a rural land use with the exception of the two subareas covering the Birregurra township which were assigned a land use of low density residential.

3.4.7 Run Parameters

The Barwon River RORB model including the associated inputs described above were utilised to simulate the design flows for a series of storm events. As previously noted, the model was run using the Monte Carlo approach. The parameters summarised below were used as the starting point prior to the calibration and adoption of final loss values, discussed within Section 3.4.8:

- m = 0.8.
- k_c = 39.7 (derived utilising the Pearse et al. (2002) equation).
- Loss values were initially informed by rural losses extracted from the ARR Data Hub and the relevant recommendations provided within ARR 2019 guidelines. Table 3.17 displays the values adopted for each surface type prior to the loss changes undertaken as part of the design calibration discussed in Section 3.4.8.

Table 3.6: Initial ARR Datahub Barwon River Loss Values

Surface Type	Initial Loss	Continuing Loss
Rural	23 mm (sourced from ARR Data Hub)	3.4 mm/hr (sourced from ARR Data Hub)
EIA	1 mm (ARR 2019 recommendation)	0 mm/hr (ARR 2019 recommendation)
ICA	16.1 mm (70 % of Rural IL – ARR 2019 recommendation)	2.38 mm/hr (ARR 2019 recommends a CL of 2.5 mm/h for South-East Australia, typically ranging between 1-3 mm/h. 70 % of Rural CL was adopted)

3.4.8 Design Calibration to FFA

Several simulation iterations varying the initial loss, continuing loss and k_c values listed above were undertaken to match the modelled peak flows to those presented within the FFA curve for each AEP event.

The Monte Carlo approach was adopted for the calibration of the Barwon River RORB model flows at Ricketts Marsh to the FFA Curve in order to account for the catchment's inherent variability with regards to losses, rainfall depths and temporal patterns.

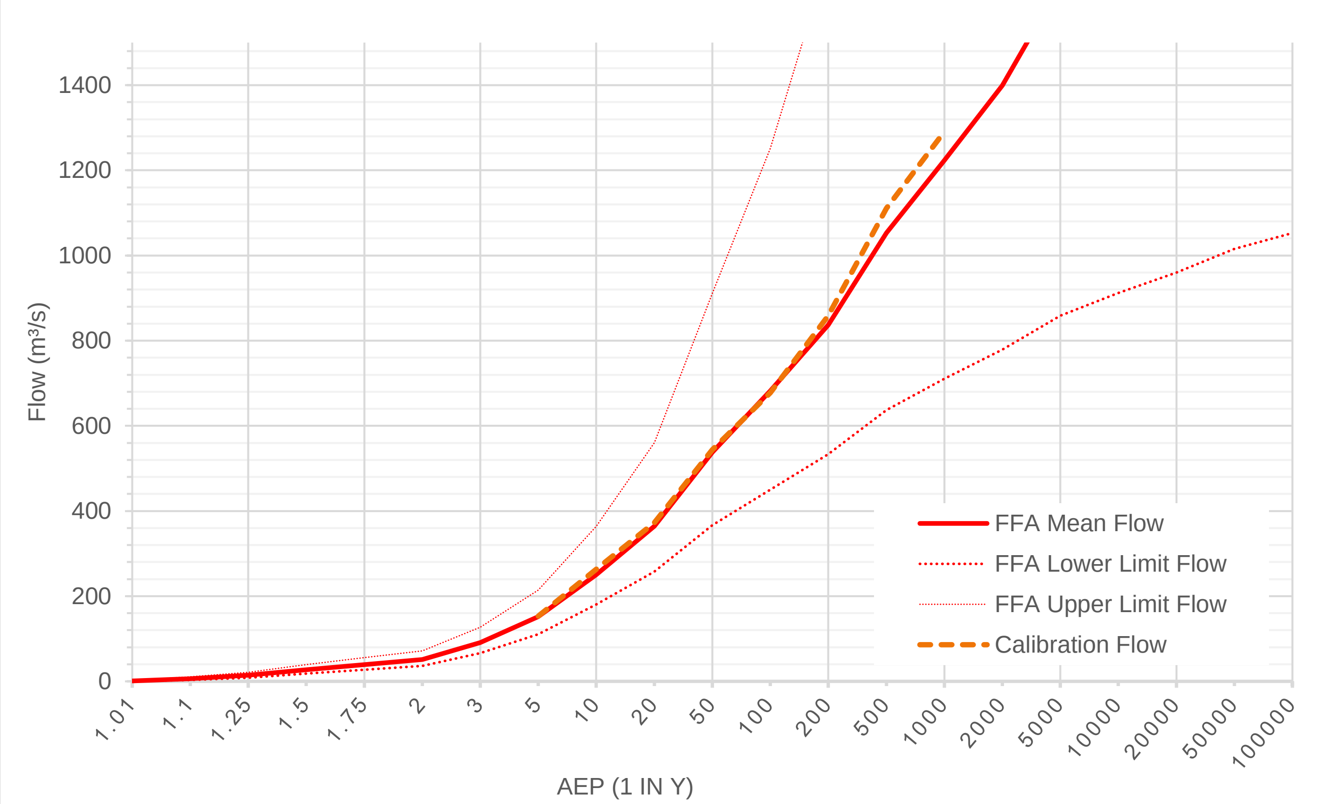
Table 3.7 provides a summary of the final design calibration parameters utilised to calibrate the Barwon River RORB model to the FFA output. The losses presented were utilised as the mean inputs to the Monte Carlo simulation.

Figure 3.3 displays a comparison between the FFA curves and the resultant design peak flows highlighting the similarities between flows.

Table 3.7: Barwon River Design FFA Calibration Parameters

Parameter	Value
Rural Initial Loss	14.95 mm
Rural Continuing Loss	2.21 mm/hr
ICA Initial Loss	10.47 mm (70 % of Rural IL – ARR 2019 recommendation)
ICA Continuing Loss	1.55 mm/hr (70 % of Rural CL was adopted)
EIA Initial Loss	1 mm (ARR 2019 recommendation)
EIA Continuing Loss	0 mm/hr (ARR 2019 recommendation)
k_c	35
m	0.8

Figure 3.3: Comparison of Barwon River Design Flows to FFA Curve



3.4.9 Validation of Design Parameters

Following the selection of calibration parameters for the Barwon River RORB model, a comparison to industry standard equations, study findings and Regional Flood Frequency Outputs was undertaken. The following subsections provide further details.

Regional k_c Equations

The adopted k_c value of 35 was compared to other values which could be derived utilising a series of regional equations. Table 3.8 provides a summary of this comparison and highlights the adopted k_c value lies within acceptable ranges providing confidence that the parameter is adequate.

Table 3.8: Barwon River RORB Model kc Comparison to Regional Equation Values

Source	Formula	kc value
RORB Default (Eqn. 2.5 RORB Manual	$k_c = 2.2 \times A^{0.5}$	52.6
Victoria (Mean Annual Rainfall<800 mm) – Equation 3.21 from AR&R Book V	$k_c = 0.49 \times A^{0.65}$	30.4
Victoria (Mean Annual Rainfall>800 mm) – Equation 3.21 from AR&R Book V	$k_c = 2.57 \times A^{0.45}$	44.8
Victoria Data (Pearse et al, 2002)	$k_c = 1.25 \times d_{av}$	39.7
Australia Wide Dyer (1994) data (Pearse et al, 2002)	$k_c = 1.14 \times d_{av}$	36.2
Australia Wide Yu (1989) data (Pearse et al, 2002)	$k_c = 0.96 \times d_{av}$	30.5
Adopted kc Value		35

Previous Studies of k_c / d_{av} Relationship

Analysis of the relationship between k_c and the average flow distance (d_{av}) was also undertaken to further validate the adopted k_c value. The calculated Barwon River k_c / d_{av} ratio of 1.1 was compared to previous studies (Pearse et al, 2002; Yu, 1989 and CRCCH) which have determined the expected, low and high confidence limits k_c / d_{av} relationships for RORB hydrological models.

Table 3.9 provides a summary of these previous study values which highlight the calculated k_c / d_{av} ratio for the Barwon River RORB model is within the expected ranges.

Table 3.9: Summary of k_c / d_{av} Relationships from Previous Studies

Confidence Limits	Victorian (Pearse, 2002)	Yu, 1989	CRCCH
Expected	1.25	0.96	1.14
Low	0.75	0.47	0.61
High	2.07	1.94	2.13

Regional Flood Frequency Estimation (RFFE)

Flood frequency curves were generated using the RFFE method available online. The catchment's area, centroid and model outlet coordinates were used as inputs. This analysis was undertaken to validate the peak flows produced with the adopted input parameters. Table 3.10 presents the resultant flood quantiles for a range of AEP events.

Table 3.10: RFFE Flow Estimates for Barwon River at Ricketts Marsh Gauge

AEP (%)	Expected Quantiles (m^3/s)	5 % Confidence Limit (m^3/s)	95 % Confidence Limit (m^3/s)
50	144	54.3	380
20	270	108	680
10	378	149	969
5	503	193	1330
2	695	252	1920
1	865	301	2500

By undertaking this analysis, the online RFFE portal also highlighted the correlation between the catchment's area, intensity, shape and recorded flows to a neighbouring catchment recorded by the Gellibrand River at Bunkers Hill Gauge (Station - 235227). This catchment has an area of 311 km^2 with Table 3.11 presenting the associated flood frequency curves.

Table 3.11: RFFE Flow Estimates for Gellibrand River at Bunkers Hill Gauge

AEP (%)	Expected Quantiles (m^3/s)	5 % Confidence Limit (m^3/s)	95 % Confidence Limit (m^3/s)
50	51	41	64
20	101	78	133
10	147	109	212
5	202	143	325

AEP (%)	Expected Quantiles (m^3/s)	5 % Confidence Limit (m^3/s)	95 % Confidence Limit (m^3/s)
2	294	189	557
1	380	224	817

Utilising a simplified factoring approach based on the Barwon River catchment area (572 km^2) and the neighbouring Gellibrand River catchment area (311 km^2), factored flows were obtained for each AEP event as shown within Table 3.12 below. As displayed, the marginal differences between these flows provide additional certainty that the adopted parameters produce peak flows within acceptable ranges even when compared to neighbouring catchments with similar characteristics.

Table 3.12: Calibrated Barwon River Flows Comparison to RFFE Estimates

AEP (%)	Calibrated Barwon River Flows (m^3/s)	Barwon River @ Ricketts Marsh FFA Expected Quantile (m^3/s)	Barwon River RFFE flows (m^3/s)	Factored Neighboring Catchment RFFE flows (m^3/s)
20	153	151.7	270	186
10	263	250.1	378	270
5	373	364.7	503	372
2	544	537.8	695	541
1	677	682.4	865	700

3.4.10 September 2016 Event Calibration

Calibration of the RORB model was undertaken for the September 2016 event using the data available. The Barwon River catchment did not have a pluviographic station that contained data suitable for the exact representation of the September 2016 event. A rainfall station at the Barwon River at Ricketts Marsh gauge station (233224) was identified however following a review was considered erroneous when compared to the daily rainfall totals and was not utilised.

As such some assumptions were made in relation to the storm's spatial distribution and temporal pattern. The following provides details on these assumptions and the associated basis:

- 'The Weather Chaser' website was accessed to gain an understanding of the storm's duration, spatial variation and intensity across the Barwon River catchment. The website provides radar images where Figure 3.4 displays a still image taken during the September 2016 event. The image confirms the relatively uniform distribution and intensity of rainfall across the study catchment. Based on this, it was considered appropriate to assume a uniform rainfall depth for each modelled subarea. This was further justified by the review of available daily rainfall totals recorded at gauges within the Barwon River catchment.

Table 3.13 provides the available recorded depths for the gauges within the catchment sourced from the BoM.

Figure 3.4: 'The Weather Chaser' website Radar Images

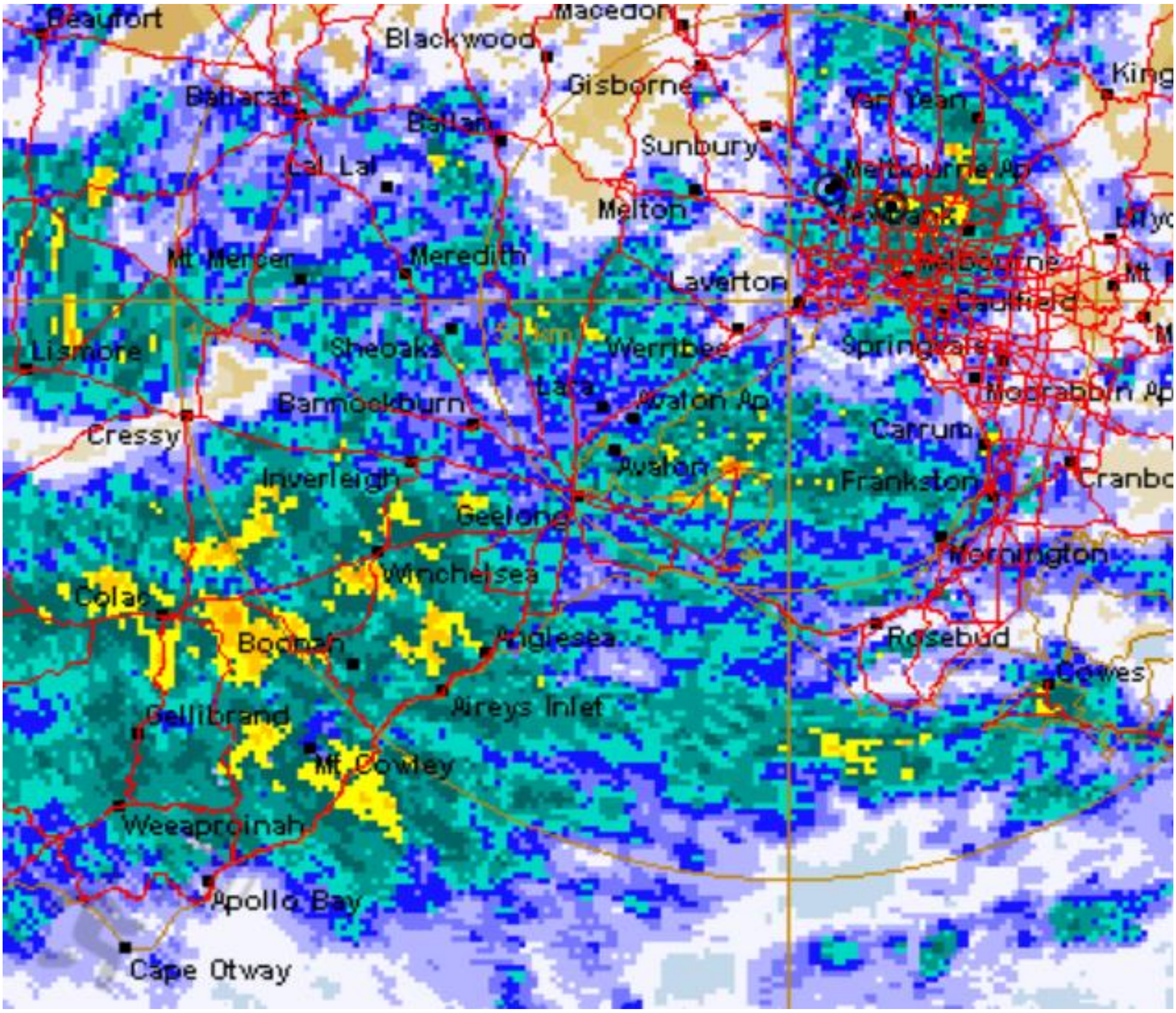
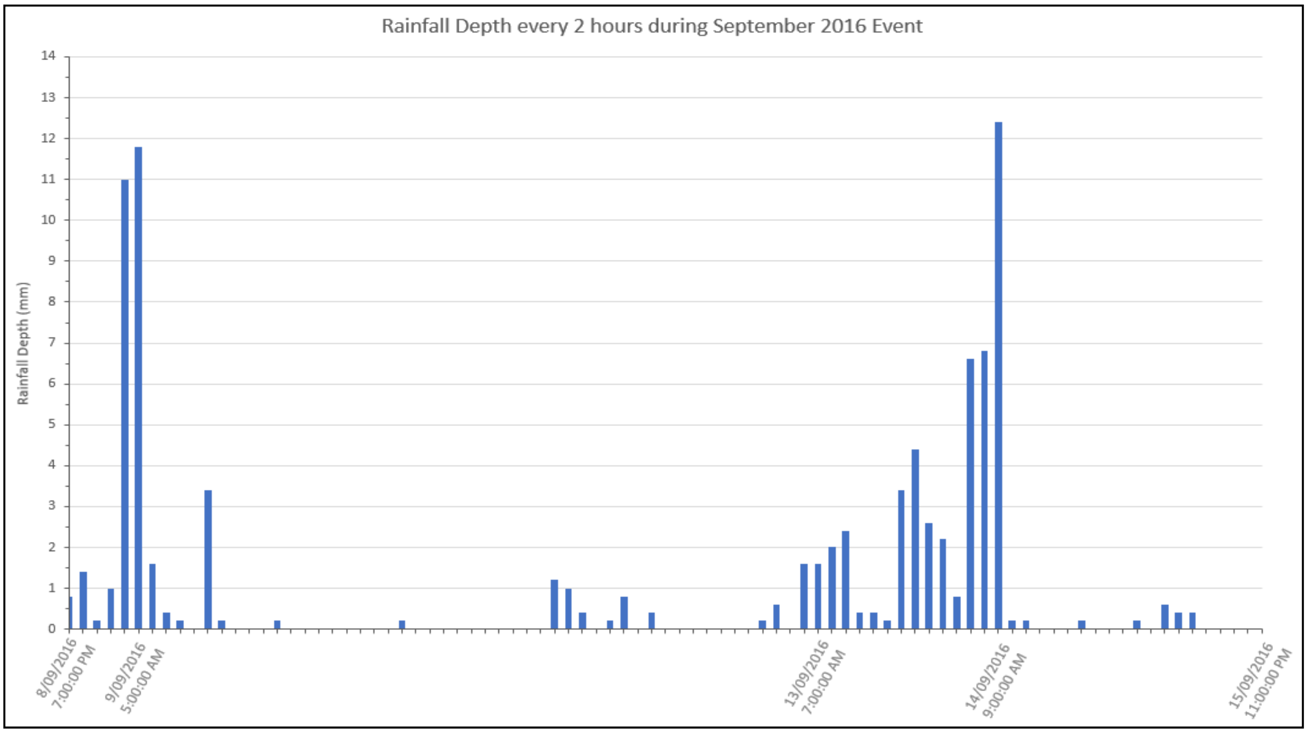


Table 3.13: September 2016 Event Daily Rainfall Depths within Barwon River Catchment

Rainfall Station Gauge Name	Rainfall Station Gauge ID	Recorded Rainfall Depth on 14th September 2016
Birregurra (Post Office)	90008	43 mm
Pennyroyal Creek	90061	31.4 mm
Barwon Downs (Gerangamete)	90189	42.2 mm
Forrest State Forest	90040	37.2 mm
Benwerrin	90188	53.4 mm
Lorne (Mount Cowley)	90185	65.4 mm
West Barwon River @ West Barwon Dam	233801	41.2 mm
Lake Colac	234801	47.8 mm

- Due to the observed relative uniform rainfall which fell across the catchment and wider area including the Colac township, the rainfall data recorded at the Lake Colac station in Colac station (234801) was utilised. A total rainfall depth of 47.8 mm which fell between the 13th September to the 14th September 2016 was applied to the catchment. The Lake Colac pluviographic data was considered suitable as it more closely related to the total daily rainfall depth recorded within the township at the Birregurra Post Office Station (90008) of 43 mm. This contrasts to the pluviographic data at the Barwon River at Ricketts Marsh station which recorded a total rainfall depth of 170 mm which was considered erroneous and not utilised.
- The temporal pattern of the September 2016 event was defined by the rainfall data extracted from the Lake Colac station in Colac (234801). Figure 3.6 displays the rainfall distribution from the 8th of September to the 15th September 2016 noting that the September 2016 calibration event focused on the temporal pattern between the 13th September to the 15th September 2016.

Figure 3.5: September 2016 Event Rainfall Distribution



Following the application of these assumptions into the RORB model, the parameters presented within Table 3.14 were determined. These parameters achieve the required calibration between the modelled and gauged peak September 2016 flow. As shown the initial loss was not modified from the FFA calibration value as an analysis of the September 2016 temporal pattern indicated it did not have a bearing on the peak flow due to the pattern's rear loaded distribution. In contrast the lowering of the continuing loss had a greater influence.

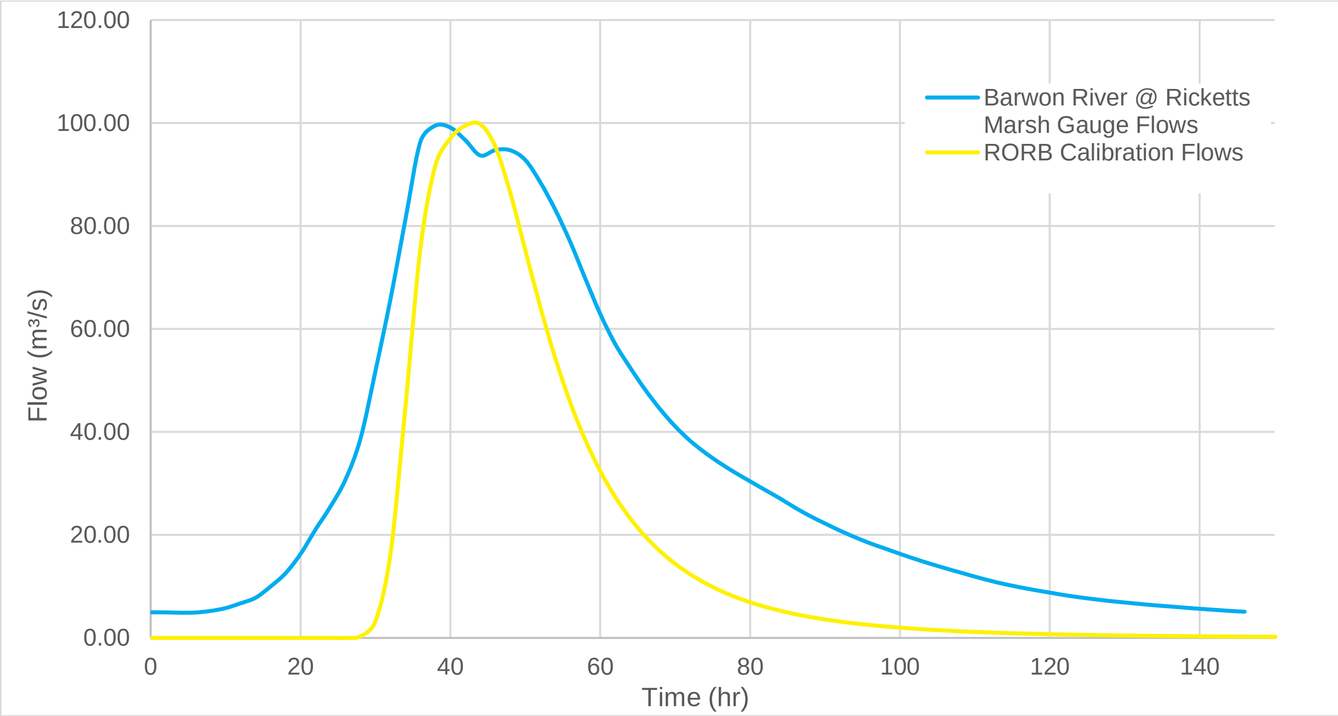
Table 3.14: September 2016 Barwon River Calibration Parameters

Parameter	Value
Rural Initial Loss	14.95 mm
Rural Continuing Loss	1.76 mm/hr
ICA Initial Loss	10.47 mm (70 % of Rural IL – ARR 2019 recommendation)
ICA Continuing Loss	1.23 mm/hr (70 % of Rural CL was adopted)
EIA Initial Loss	1 mm (ARR 2019 recommendation)

Parameter	Value
EIA Continuing Loss	0 mm/hr (ARR 2019 recommendation)
k_c	35
m	0.8

Figure 3.6 displays the comparison between the modelled and gauged September 2016 hydrograph. As shown, the parameters adopted have resulted in a match of peak flows and peak durations however differences between the hydrograph volume were noted.

Figure 3.6: Comparison of September 2016 Recorded and Modelled Hydrograph



As the Barwon River is not a focus of this study, this difference was considered acceptable particularly when taking into account the following factors:

- Baseflow – as prescribed within ARR 2019, baseflow was not extracted from the recorded gauge hydrograph as its contribution was estimated to be less than 5 %. However, this flow would still contribute to the additional volume recorded at the gauge and reduce the difference of volumes between the rising and falling limbs of the gauged September 2016 hydrograph.
- Limited rainfall data – although efforts have been made to utilise appropriate rainfall inputs with the information available, pluviographic data was not available for the September 2016 event within the Atkin Creek and Unnamed Tributary catchments nor was there pluviographic data within the Barwon River catchment that could be reliably used for this study (pluviographic data at the Ricketts Marsh gauge was noted as erroneous and could not be utilised for the September 2016 Event). Rainfall data from the 8th of September was also extracted from the Lake Colac Station and represented as an extended storm within the RORB model, however similar hydrograph volume differences were also noted.
- Spatial variation – for the September 2016 event spatial variation was not accounted for in the Barwon River RORB model. The fact that the Barwon River RORB model produced a set of loss parameters which resulted in a good match to the majority of survey marks across the Birregurra township meant that flooding within the township was not sensitive to spatial variation within the Barwon River catchment. This is logical considering the large difference in catchment sizes and resultant times of concentration.

- Limited data for other rainfall events (e.g. survey marks) within the study catchment results in challenges with the calibration / verification of model parameters.
- The loss parameters adopted for the Barwon River September 2016 calibration event do not inform the design loss parameters which will be used to define the flood overlays for the Birregurra township. The FFA Calibration parameters have been used to define the Atkin Creek and Unnamed Tributary design flood event modelling.
- The k_c parameter adopted for the Barwon River has been validated against regional equations and studies with the resultant flows validated against the neighbouring Gellibrand River at Bunkers Hill catchment RFFE analysis. These comparisons have indicated that it is appropriate for adoption and can be used to derive the k_c values for the Atkin Creek and Unnamed Tributary catchments.
- Comparisons of the modelled flood levels to surveyed marks for the September 2016 event within the township confirms the parameter's suitability with flood levels at 8 out of the 9 survey marks within an acceptable range for event calibration. This is described further in Section 4.2.2 along with a comparison of photos and anecdotal evidence providing further confidence that the hydraulic modelling results for the September 2016 event are a good match to those reported by residents across the township.
- Coincidence of flows (refer to Section 4.3.7) – if the peak flow for the Barwon River at Birregurra from the critical 24 hour duration event (considered to be the township's highest tailwater boundary condition) was to coincide with the peak flow from the waterways within the township for their critical duration (12 hours), the difference in flood levels would be less than 30 mm when compared to a scenario whereby the 12 hour rainfall event fell consistently across the Barwon River, Atkin Creek and Unnamed Tributary catchments. The modelling undertaken also indicates this flood depth difference is limited to the downstream end of the township. This confirms that even though the difference in hydrograph volumes is significant (4000 ML) the resultant influence on flood levels and tailwater levels for the Birregurra township was considered minor.

3.5 ATKIN CREEK AND UNNAMED TRIBUTARY MODEL DEVELOPMENT

3.5.1 Catchment Boundary

The boundary of the Atkin Creek and Unnamed Tributary catchments was defined utilising Council provided LiDAR data and the corresponding 1 metre contours. Figure 3.7 displays the overall catchment area of approximately 30 km² and structure of the RORB model.

3.5.2 Sub-catchment Boundaries

A watershed analysis was run for the Atkin Creek and Unnamed Tributary catchment based on the Council provided LiDAR data from which sub-catchment boundaries were generated. These were further reviewed within the township in particular to ensure sub-catchments considered the key overland flow paths in addition to Council's drainage system and likely legal points of discharge. The sub-catchments were also modified to ensure consistency in areas and land use.

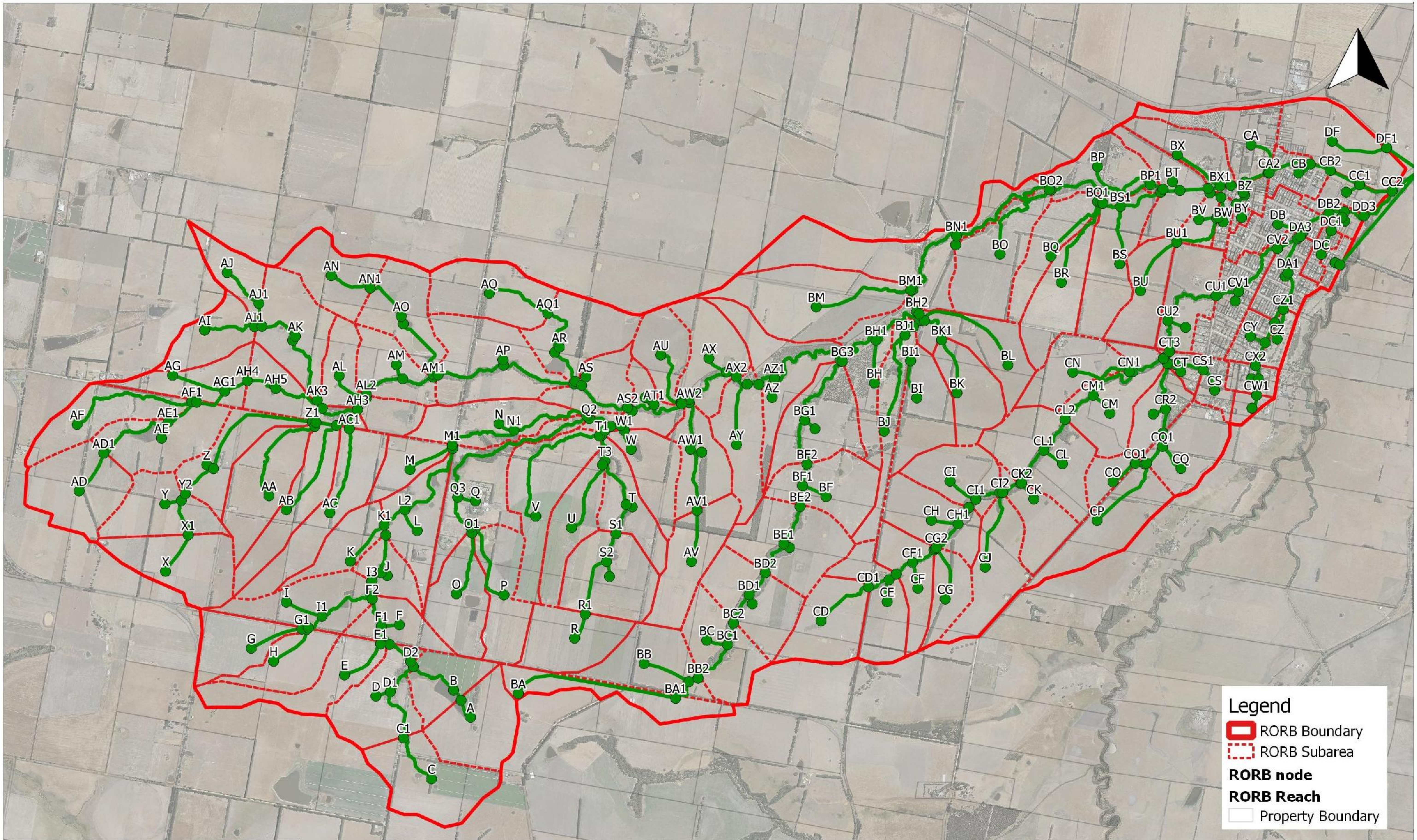
3.5.3 Fraction Impervious

A weighted fraction impervious value was calculated for each sub-catchment based on typical values assigned to each land use type. Table 3.3 presented above includes the typical fraction impervious values which were adopted for the key land uses. These values adopted were within the industry standard ranges where the resultant weighted values were cross-checked against aerial photography.

3.5.4 Other Modelling Input Considerations

Appendix D provides details of other modelling considerations which informed the inputs during the development of the Atkin Creek and Unnamed Tributary RORB model including:

- Intensity-Frequency-Duration (IFD) Data adopted for base conditions, climate change and PMF scenarios.
- Application of spatial rainfall patterns.
- Application of initial loss duration factors to account for pre-burst rainfall depths.
- Temporal patterns adopted.
- Areal Reduction Factors (ARFs) calculations and resultant factors.



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600 0 600 m

Scale in metres (1:5000 @ A3)

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

Birregurra Flood Study

Figure 3.7

Atkin Creek and Unnamed Trib Hydrologic Model Layout

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 14/1/2021

3.5.5 Initial and Continuing Loss Model

The Atkin Creek and Unnamed Tributary RORB model utilised the same initial loss (IL) /continuing loss (CL) model approach discussed in Section 3.4.6 with the proportioning of the three surface types; EIA, ICA and Rural areas.

Table 3.15 presents the approach adopted for the subareas within the Atkin Creek and Unnamed Tributary RORB model based on the different land use types and Total Impervious Area (TIA) percentages. These TIA values were obtained from the weighted FI for each subarea calculated and discussed in Section 3.5.3.

Table 3.15: Subarea Land Use Proportioning for Atkin Creek and Unnamed Tributary RORB Model

Land Use Type	Total Impervious Area (TIA)	EIA proportion	ICA proportion	Rural proportion
Rural / Pervious Urban	0-15 %	Not utilized as rural subareas are assumed to have no direct connections to drainage	Total impervious area	Total pervious area (area – impervious area)
Low Density Residential	15 – 30 %	60 % of total impervious area (ARR 2016, Book 5. Ch. 3 - Section 3.4.2.2.2 quotes 50-70 %)	40 % of total impervious area	Total pervious area (area – impervious area)
General Residential / township	40- 75 %	60 % of total impervious area (ARR 2016, Book 5. Ch. 3 - Section 3.4.2.2.2 quotes 50-70 %)	Remaining area (40 % of total impervious area and total pervious area)	Not utilized as residential subareas are assumed to either have direct or indirect connections to drainage.

Based on the proportion summary provided above and the Atkin Creek and Unnamed Tributary catchment characteristics, the majority of the subareas were assigned a land use of either rural or low density residential. Subareas located within the Birregurra township which contained drainage or well-defined roadside swales were categorised as a General Residential / township land use to account for the greater portion of directly connected impervious areas.

The resultant directly and indirectly connected impervious areas were applied to each subarea within the RORB interface. In order to more accurately account for the application of losses for each surface type within the township, the RORB model was split to represent the EIA, ICA and Rural components separately. This approach was adopted for the ensemble runs only as it was focused on more accurately representing the flooding within the township area. RORB was utilised to generate the separate EIA, ICA, and Rural rainfall excess hydrographs for input to the ensemble simulations. As the Monte-Carlo simulations focused on more accurately representing the flooding associated to the waterways, a single set of rainfall excess hydrographs were generated. The averaging of losses across the township was acknowledged for the Monte-Carlo simulations. However, as the ensemble simulations were focused on representing flooding outside of the waterways, it was considered acceptable.

3.5.6 Design Run Parameters

The parameters summarised below were utilised for the design runs:

- m = 0.8.
- k_c values were derived from the Barwon River RORB model, using the k_c/ d_{av} ratio), and are shown in Table 3.16 below. As displayed, different k_c values were adopted to account for the different characteristics of the catchments reflected by the distance average parameter.

Table 3.16: Atkin Creek and Unnamed Tributary RORB Model k_c Values

Catchment	Distance Average (d_{av})	Adopted k_c
Atkin Creek	8.93 km	9.85
Unnamed Tributary	3.65 km	4.02

- Loss values informed by the Barwon River RORB model calibration to the FFA curve and recommendations within ARR 2019 guidelines. Table 3.17 displays the values adopted for each surface type.

Table 3.17: Atkin Creek and Unnamed Tributary Design RORB Model Loss Values

Surface Type	Initial Loss	Continuing Loss
Rural	14.95 mm (from Barwon River RORB model FFA calibration)	2.21 mm/hr (from Barwon River RORB model FFA calibration)
EIA	1 mm (ARR 2019 recommendation)	0 mm/hr (ARR 2019 recommendation)
ICA	10.47 mm (70 % of Rural IL – ARR 2019 recommendation)	1.55 mm/hr (ARR 2019 recommends a CL of 2.5 mm/h for South-East Australia, typically ranging between 1-3 mm/h. 70 % of Rural CL was adopted)

3.5.7 Validation of Design Parameters

Regional k_c Equations

The adopted k_c values for the Atkin Creek and Unnamed Tributary catchment was compared to other values which could be derived utilising a series of regional equations.

Table 3.18 provides a summary of this comparison and highlights the adopted k_c values generally lie within acceptable ranges except for the Victorian mean annual rainfall less than 800 mm equation. This overall similarity provides confidence that the parameters adopted are appropriate.

Table 3.18: Atkin Creek and Unnamed Tributary RORB Model k_c Comparison to Regional Equation Values

Source	Formula	Atkin Creek k_c value	Unnamed Tributary k_c value
RORB Default (Eqn. 2.5 RORB Manual	$k_c = 2.2 \times A^{0.5}$	10.5	5.1
Victoria (Mean Annual Rainfall < 800 mm) – Equation 3.21 from AR&R Book V	$k_c = 0.49 \times A^{0.65}$	3.7	1.5
Victoria (Mean Annual Rainfall > 800 mm) – Equation 3.21 from AR&R Book V	$k_c = 2.57 \times A^{0.45}$	10.5	5.5
Victoria Data (Pearse et al, 2002)	$k_c = 1.25 \times dav$	11.2	4.6
Australia Wide Dyer (1994) data (Pearse et al, 2002)	$k_c = 1.14 \times dav$	10.2	4.2
Australia Wide Yu (1989) data (Pearse et al, 2002)	$k_c = 0.96 \times dav$	8.6	3.5
Adopted k_c Value		9.85	4.02

Regional Flood Frequency Estimation (RFFE)

Flood frequency curves were generated using the RFFE method available online to validate the Atkin Creek and Unnamed Tributary inflows estimated within the township mid-way along the watercourses at location CA2 and CV2. The Atkin Creek and Unnamed Tributary catchment area, centroid and model outlet coordinates were used as inputs. Table 3.19 and Table 3.20 provides a comparison of the resultant RFFE flood quantiles and modelled design flows for the range of AEP events.

As shown, the Atkin Creek design flows are within a marginal range to the expected RFFE Quantiles. In contrast however, the RFFE outputs obtained for the Unnamed Tributary resulted in flood quantiles which were consistently lower than the modelled design flows. This is likely to be as a result of the catchment's characteristics based on the area, centroid coordinates and model outlet coordinates which as highlighted by the RFFE online interface 'has an unusual shape' noting that the 'results have lower accuracy and may not be directly applicable in practice'.

Table 3.19: RFFE Comparison to Design Flow Estimates for Atkin Creek within township

AEP (%)	Expected Quantiles (m^3/s)	5 % Confidence Limit (m^3/s)	95 % Confidence Limit (m^3/s)	Design RORB flow (m^3/s)
50	6.3	2.3	17.0	-
20	11.8	4.6	30.5	10.8
10	16.5	6.4	43.2	15.3
5	21.9	8.3	59.0	19.3
2	30.4	10.9	85.1	28.6
1	37.8	13.1	110.0	36.4

Table 3.20: RFFE Comparison to Design Flow Estimates for Unnamed Tributary within township

AEP (%)	Expected Quantiles (m^3/s)	5 % Confidence Limit (m^3/s)	95 % Confidence Limit (m^3/s)	Design RORB flow (m^3/s)
50	1.5	0.5	4.1	-
20	2.8	1.1	7.3	6.9
10	3.9	1.5	10.3	9.6
5	5.2	2.0	14.1	13.1
2	7.2	2.6	20.3	18.1
1	9.0	3.1	26.2	22.2

Based on the nearby gauged catchments utilised to inform the RFFE outputs, the catchment draining to the Atkin Creek West Branch at Wyelangta gauge (235205) was identified as having comparable catchment characteristics including a similar catchment area of 3 km^2 and rainfall intensities. Table 3.21 provides this neighbouring catchment's RFFE output in addition to a factored expected quantile informed by the slightly greater area of the Unnamed Tributary catchment. A comparison of these flows to the design RORB flows provides confidence that the design parameters adopted are appropriate.

Table 3.21: Nearby Catchment's RFFE Comparison to Design Flow Estimates for Unnamed Tributary

AEP (%)	Expected Quantiles (m^3/s)	5 % Confidence Limit (m^3/s)	95 % Confidence Limit (m^3/s)	Factored Expected Quantiles (m^3/s)	Design RORB flow (m^3/s)
50.0	1.8	1.5	2.1	2.7	-
20.0	3.3	2.6	4.4	5.1	6.9

AEP (%)	Expected Quantiles (m^3/s)	5 % Confidence Limit (m^3/s)	95 % Confidence Limit (m^3/s)	Factored Expected Quantiles (m^3/s)	Design RORB flow (m^3/s)
10.0	4.9	3.5	7.6	7.6	9.6
5.0	7.2	4.7	12.7	11.1	13.1
2.0	11.6	6.7	24.6	17.8	18.1
1.0	16.4	8.6	40.8	25.2	22.2

3.5.8 September 2016 Event Validation

A uniform rainfall depth of 47.8 mm in addition to the corresponding temporal pattern as described in Section 3.4.10 was applied to the Atkin Creek and Unnamed Tributary RORB model. The routed local watercourse inflows and rainfall excess hydrographs representing the September 2016 event were generated as outputs.

These outputs were applied to the hydraulic TUFLOW model described in Section 4.4 where iterative modifications to the losses were undertaken to calibrate the modelled flood levels to the surveyed flood levels.

Similar to the September 2016 event calibration undertaken for the Barwon River catchment, due to the storm's rear loaded rainfall distribution, the initial loss did not have a significant impact on the generated peak flows. As such the continuing loss was the only adjusted parameter. Table 3.17 summarises the loss values applied to represent the Atkin Creek and Unnamed Tributary September 2016 event RORB model.

As presented, the rural continuing loss value was reduced to 0.25 mm/hr which could be considered low particularly when compared to the rural continuing loss adopted for the Barwon River calibration of 1.76 mm /hr. However, this was considered appropriate given:

- The difference in antecedent catchment conditions particularly between the larger Barwon River catchment and the local Atkin Creek & Unnamed Tributary catchments.
- The continuing loss value of 0.25 mm/hr results in a close match between the modelled and surveyed flood levels discussed in Section 4.4.
- The continuing loss value of 0.25 mm/hr are within the ranges utilised for previous flood studies including the neighbouring Deans Creek and Barongarook Creek calibration events.

Table 3.22: Atkin Creek and Unnamed Tributary September 2016 Event RORB Model Loss Values

Surface Type	Initial Loss	Continuing Loss
Rural	14.95 mm (from Barwon River RORB model FFA calibration)	0.25 mm/hr (from Barwon River RORB model FFA calibration)
EIA	1 mm (ARR 2019 recommendation)	0 mm/hr (ARR 2019 recommendation)
ICA	10.47 mm (70 % of Rural IL – ARR 2019 recommendation)	0.18 mm/hr (ARR 2019 recommends a CL of 2.5 mm/h for South-East Australia, typically ranging between 1-3 mm/h. 70 % of Rural CL was adopted)

3.6 SUMMARY OF RORB DESIGN FLOWS

Table 3.23 provides a summary of the design flows generated from the RORB model and the associated critical duration. These formed the inflows applied to the hydraulic TUFLOW model. The Barwon River flow at Node Location 'R4' was applied directly as the inflow hydrograph to the TUFLOW model. The separate upstream hydrographs used to produce the combined flows presented at location CA2 and CV2 were extracted and applied to the hydraulic TUFLOW model.

Table 3.23: Atkin Creek and Unnamed Tributary Design RORB Flows

AEP (%)	Atkin Creek flow at CA2		Unnamed Tributary flow at CV2		Barwon River flow at R4	
	Flow (m^3/s)	Critical Duration	Flow (m^3/s)	Critical Duration	Flow (m^3/s)	Critical Duration
39.35	5.9	12hr	3.9	6hr	76.0	12hr
20	10.8	12hr	6.9	3hr	145.6	12hr
10	15.3	12hr	9.6	3hr	256.9	12hr
5	19.3	12hr	13.1	2hr	373.9	24hr
2	28.6	12hr	18.1	2hr	512.3	12hr
1	36.4	12hr	22.2	2hr	602.1	24hr

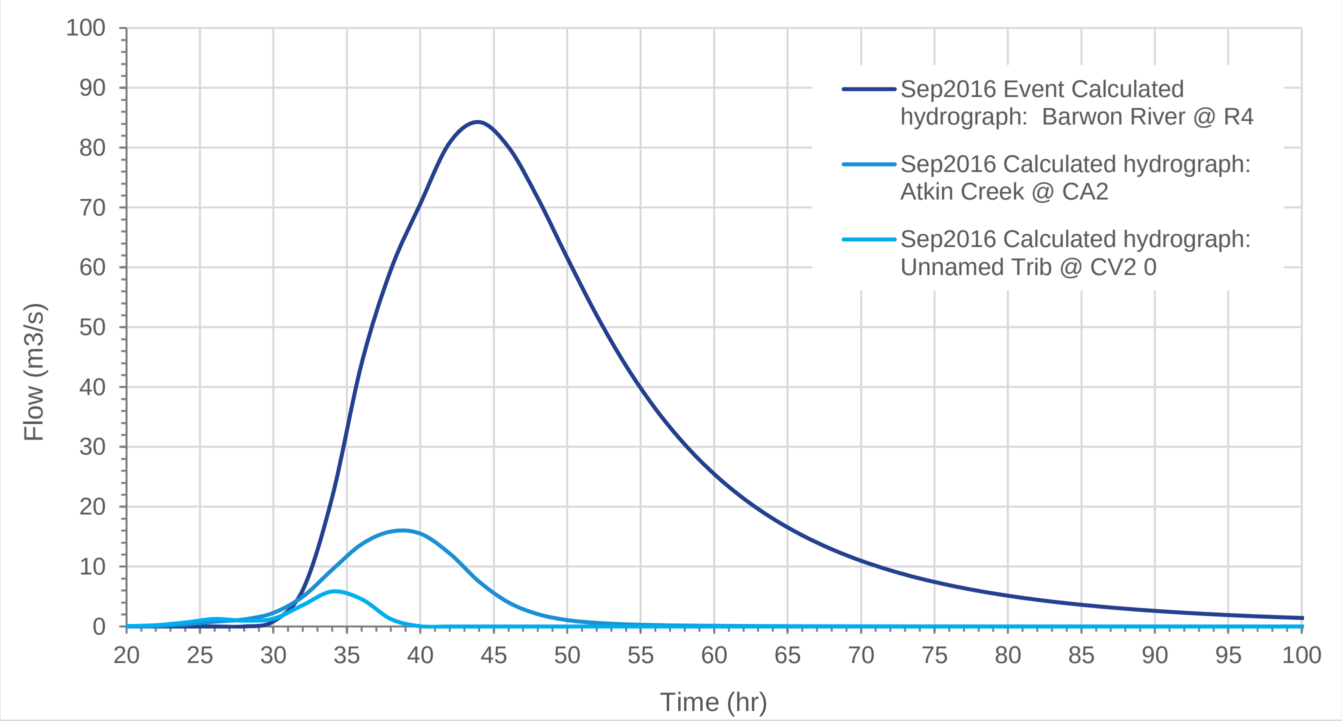
3.7 SUMMARY OF RORB SEPTEMBER 2016 EVENT FLOWS

Table 3.24 provides a summary of the September 2016 calibration flows generated from the RORB model and utilised to form the inflows applied to the hydraulic TUFLOW model. Figure 3.8 displays the corresponding hydrographs and highlights the differences in each catchment's response to generate the peak flow. When the Atkin Creek flows and the Unnamed Tributary flows are compared to the previous outlined design flows, the September 2016 event which affected the Birregurra township is estimated to be between a 10 % AEP event and a 20 % AEP event.

Table 3.24: Atkin Creek and Unnamed Tributary September 2016 Event RORB Flows

Event	Atkin Creek flow at CA2	Unnamed Tributary flow at CV2	Barwon River flow at R4
September 2016	15.9 m^3/s	5.9 m^3/s	84.3 m3/s

Figure 3.8: Comparison of September 2016 Event Hydrographs



4 HYDRAULIC MODELLING

4.1 OVERVIEW

Combined one-dimensional (1D) and two-dimensional (2D) dynamic hydraulic modelling of the study area was undertaken using TUFLOW version 2020-01-AA-iDP-w64 to estimate flood water levels, extents, flows and other hydraulic variables for a range of scenarios and design events. The model has been run using the TUFLOW HPC (Heavily Parallelised Compute) scheme. Although HPC does not typically require the use of double precision, in this instance due to the terrain elevations being above 100 m AHD, it was required to ensure sufficient decimal places were available for the correct computation of flows and velocities within the 1D domain. A sensitivity run utilising the single precision solver highlighted issues with the 1D mass error particularly during the model's start-up phase which confirmed the requirement to use the alternative double precision server for all flood modelling simulations.

A single hydraulic model was constructed using a 3-metre cell size to represent urban areas and the associated Council drainage networks. Urban areas include and are limited to the Birregurra township as defined by Council's brief.

4.2 METHODOLOGY

The following steps outline the tasks undertaken to develop the TUFLOW model for the study area and to obtain the flood mapping outputs:

- Generate Digital Elevation Model (DEM).
- Create inflow boundary conditions in order to reference the relevant inflow hydrographs generated in RORB including both rainfall excess hydrographs and routed inflow hydrographs.
- Input surface roughness (materials layer) based on given parcel's existing land use defined by the obtained aerial photographs and standard industry values.
- Input and verify data for the 1-D network (pits and pipes).
- Improve the representation of waterways / open channels / drains where required (utilising z-shapes and the obtained survey data).
- Set 1-D and 2-D boundary conditions to pipes / pits and overland flows where required.
- Undertake a blockage assessment as detailed within the ARR 2019 guidelines to assess the potential for blockage and the associated flood impact.
- Run the TUFLOW model for the September 2016 flood event where the generated inflow hydrographs are applied and undertake iterative modelling to calibrate / validate the modelled flood levels to the surveyed flood marks with modifications to hydrology loss values (influencing the magnitude of waterway inflows), roughness values along Atkin Creek and the Unnamed Tributary and the refinement of waterway invert levels using the commissioned survey data.
- Run the TUFLOW model for the 0.2 %, 0.5 %, 1 %, 2 %, 5 %, 10 %, 20 %, 39.35 % AEP design events including both the Monte Carlo inflows and the ensemble inflows. This included:
  - Monte Carlo simulations representing the critical durations for the waterway inflows
  - Ensemble simulations representing flooding within the local township for the 10 minute to 2 hour storm durations
- Run the TUFLOW model for the PMF scenario.
- Run the TUFLOW model for the 1 % and 10 % AEP Climate Change Conditions.
- Prepare relevant outputs including flood depth, extents, velocities layout plans in addition to GIS deliverables compliant with the Flood Spatial Data Specifications requirements.

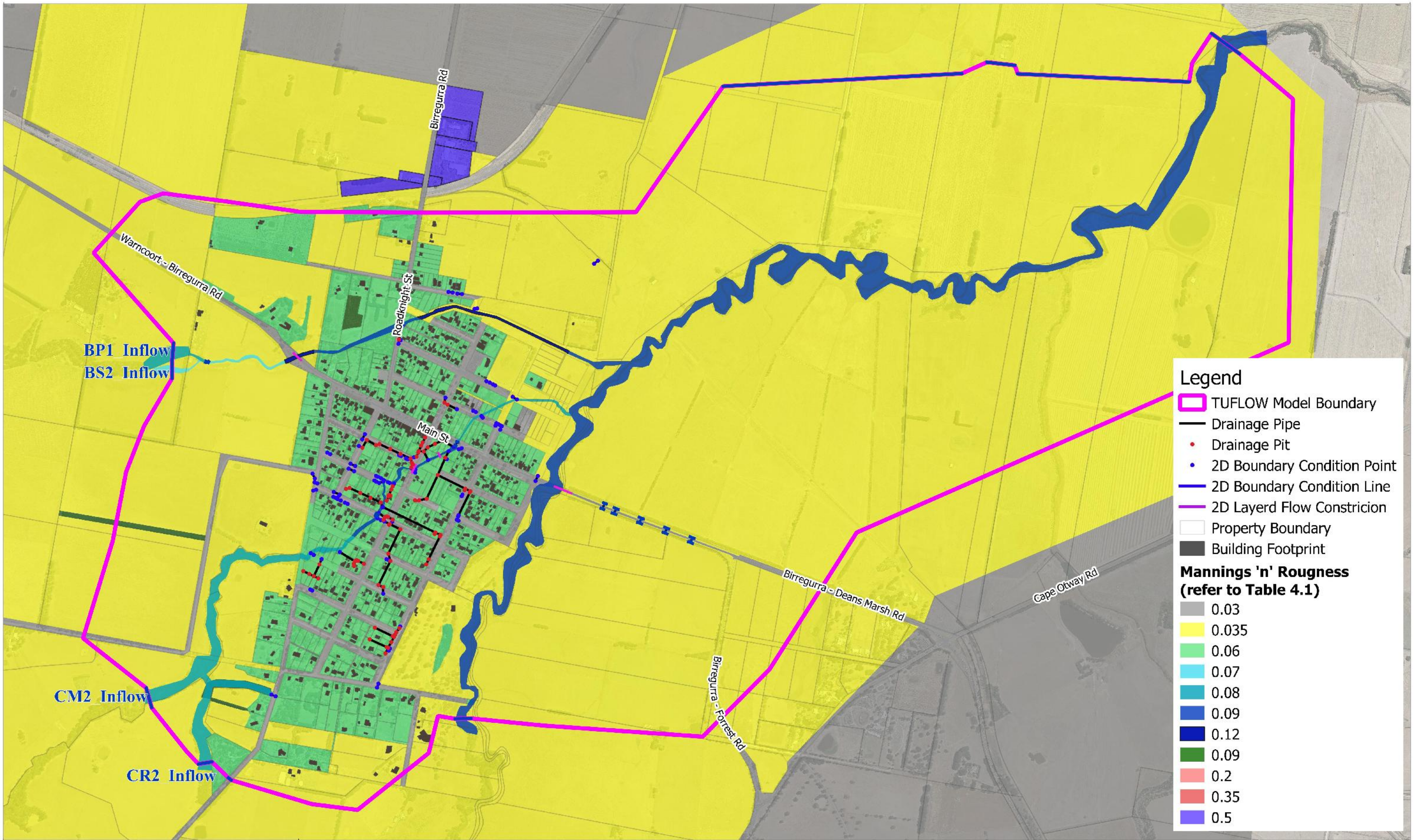
4.3 MODEL DEVELOPMENT

4.3.1 Model Extent

The extent of the hydraulic model is based on enabling the key topographical features of the study area (such as waterways and open drains) to be modelled focussing on the Birregurra Town. It was not necessary to model the entire hydrologic catchment. Use of inflow boundaries from the RORB models developed for the Barwon River and Atkin Creek and Unnamed Tributary catchments discussed in Section 3 assisted to limit the required extent of the TUFLOW model.

The extent of the TUFLOW hydraulic model is sufficient to ensure that runoff through Birregurra township and surrounds is accurately modelled, as well as being able to identify key flooding hotspots.

Figure 4.1 shows the extent of the hydraulic model and depicts some of the key inputs to the model which are described further in the following sections of this report.



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WATER MANAGEMENT

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Scale in metres (1:5000 @ A3)

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

Birregurra Flood Study

Figure 4.1
Birregurra TUFLOW Model Layout

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 23/11/2020

4.3.2 Topography

A model resolution (grid size) of three metres has been used, resulting in the definition of elevation every 1.5 horizontal metres in the model. This grid size is in accordance with recommendations in industry guidelines and allows for key catchment features such as waterways, open channels, and roads to be defined in the model.

The hydraulic model uses a combination of LiDAR and Digital Terrain Model data as detailed within Section 2.4 to assign elevations throughout the flood model. Where appropriate, survey data was used to address uncertainties in the Atkin Creek and Unnamed Tributary LiDAR data. Z-shapes were used to represent waterway / open channel sections and to improve the overall representation of the Atkin Creek and Unnamed Tributary waterways. Atkin Creek downstream of Anderson Street was represented with a DEM that was created from the cross-sections surveyed at 100 metre intervals. Due to the width of the channel in this area, a Sub-grid Sampling (SGS) approach was also adopted within the TUFLOW model to allow for a finer resolution of the DEM at a grid size of 1 metre rather than 3 metres.

4.3.3 Drainage Assets

All assets identified in Council's Geographic Information System (GIS) database have been included in the model and considerable effort has gone into the capture of additional drainage assets missing from the GIS database so that they can be included in the model.

Particular emphasis was placed on accurately modelling the drainage assets that convey significant overland flow paths under roads, driveways and into waterways and open channels. A large number of those assets were inspected and measured during the site visit conducted by Engeny and/ or by the engaged surveyors.

The hydraulic model requires invert levels at upstream and downstream ends of all pipes and culverts. This information is not available for most pipes within Council's GIS database. Invert levels were estimated by adopting the following formula:

- Invert level = Ground level RL – 600 mm (pipe cover) – pipe diameter.

The estimated invert levels were then checked to ensure that they were connected appropriately with the inverts of upstream and downstream pipes and adjusted where necessary to produce a downward grade.

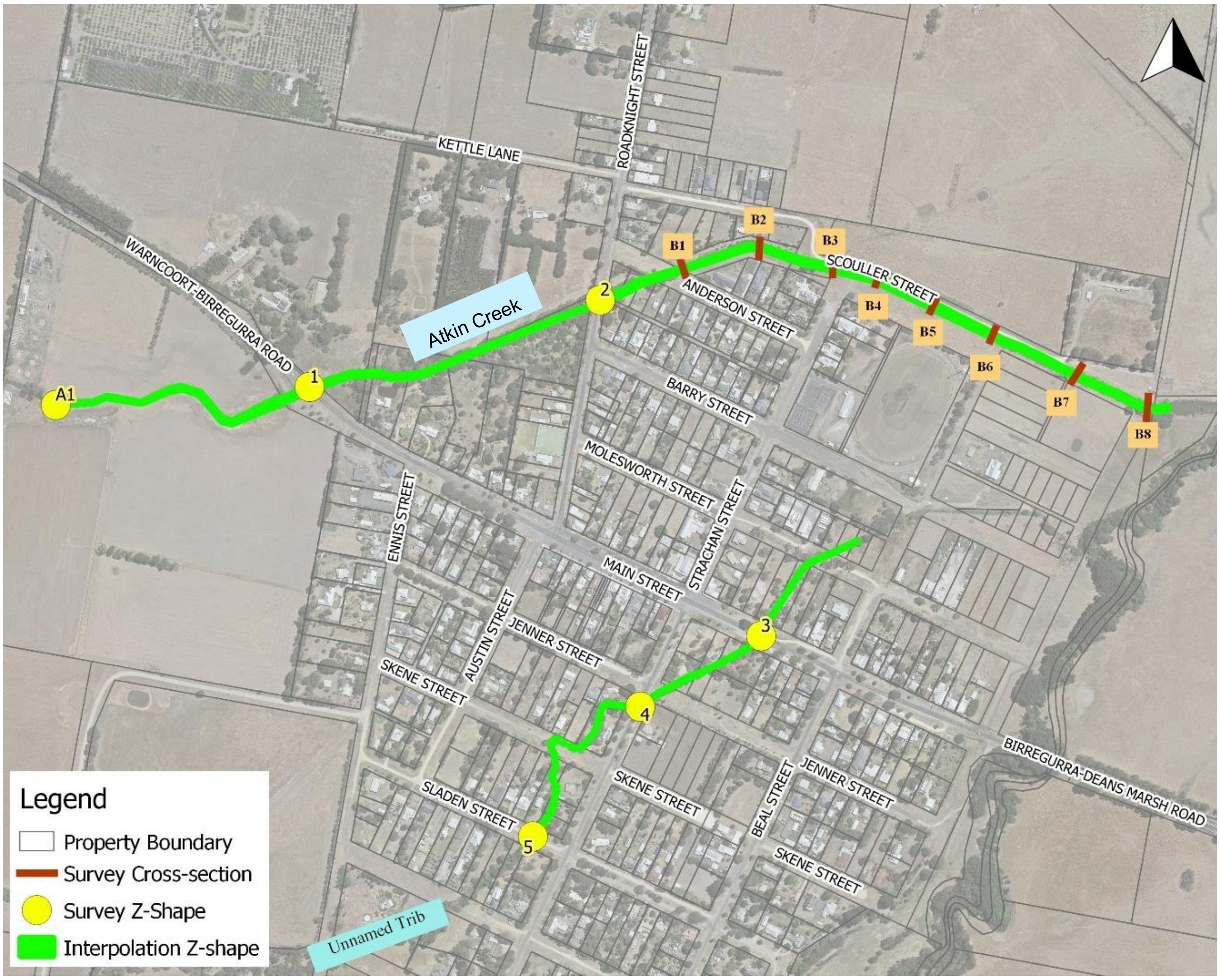
4.3.4 Waterways and Open Drains

The study area includes three main waterways: Atkin Creek; Unnamed Tributary and Barwon River that run through / or adjacent to the Birregurra township. The available terrain data consisting of both LiDAR and survey data provides a satisfactory definition of these watercourses and open drains and as such it's representation within the 2-D domain was deemed acceptable. Culverts and bridge structures have been included in the model, with the culverts modelled as pipes in the 1-D domain and bridges modelled as layered flow constrictions in the 2-D domain.

Survey data (as discussed in Section 2.4) was captured to address uncertainties in the Atkin Creek and Unnamed Tributary LiDAR data. This data was supplied in the form of cross sections representing waterway invert levels and bridge / overpass structures. Particular emphasis was put on accurately representing cross-sections at the key drainage structures along Atkin Creek and Unnamed Tributary. Z-shapes were used in TUFLOW to represent channel invert levels as shown in the survey plans and to address inaccuracies with the LiDAR data at drainage structure surface levels and densely vegetated areas where appropriate. Figure 4.2 displays the location of the model's terrain modifications including:

- The yellow highlighted areas which were informed by the survey obtained at the upstream and downstream end of key drainage structures along the waterways.
- The green highlighted areas which consisted of a series of interpolation z-shapes from the known surveyed locations ensuring the waterway's slope (defined by the LiDAR data) was maintained.

Figure 4.2: Location of Model's Terrain Modifications Informed by Survey Cross-Sections



As shown in Figure 4.2 above, additional cross-sectional survey data captured along Atkin Creek downstream of Anderson Street was also provided (orange lines). Engeny utilised this data to generate a DEM in 12d which was integrated into the hydraulic model to further improve the model accuracy and representation of the Atkin Creek waterway upstream of its confluence with the Barwon River.

Figure 4.3, Figure 4.4, Figure 4.5, Figure 4.6 and Figure 4.7 presents a series of cross-sections comparing the surveyed data and the LiDAR data along Atkin Creek downstream of Anderson Street in addition to other locations upstream and downstream of key drainage structures. These highlight the improved representation of the waterway's invert level when compared to the LiDAR data elevations which were typically higher due to overgrown vegetation and / or ponded water.

Figure 4.3: Comparison of Survey Cross-Sections to LiDAR data for Atkin Creek at Location B2 Atkin

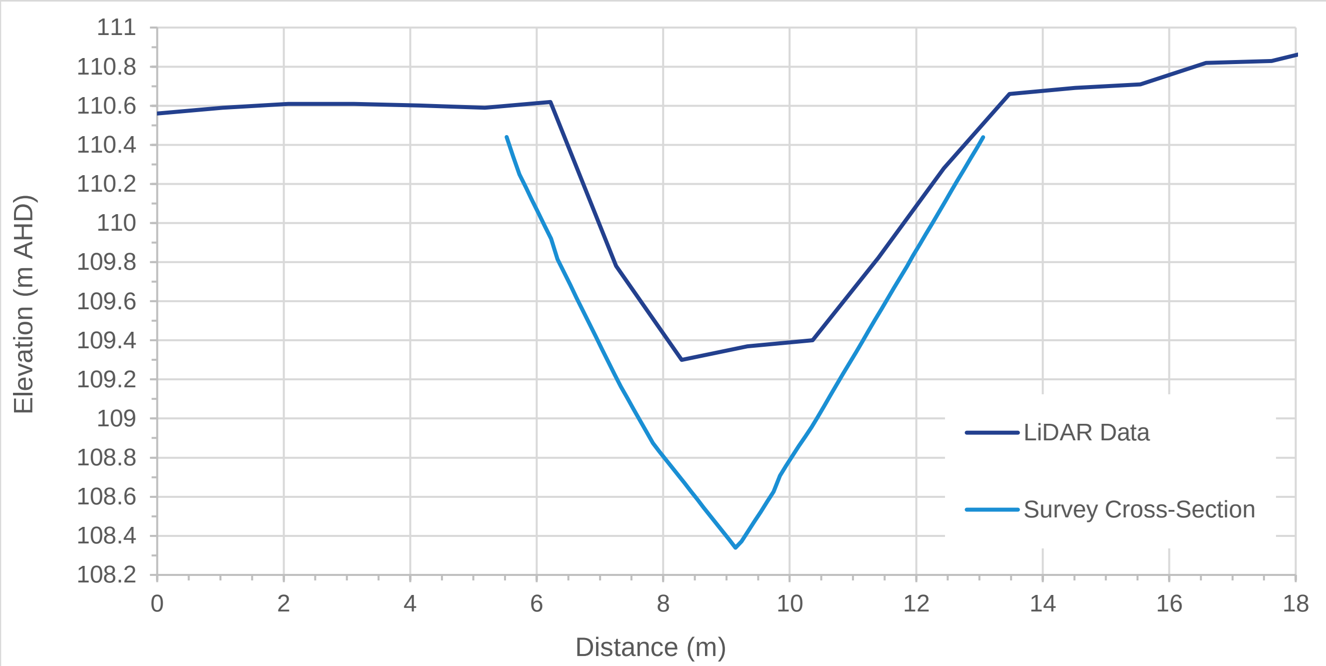


Figure 4.4: Comparison of Survey Cross-Sections to LiDAR data for Atkin Creek at Location B5

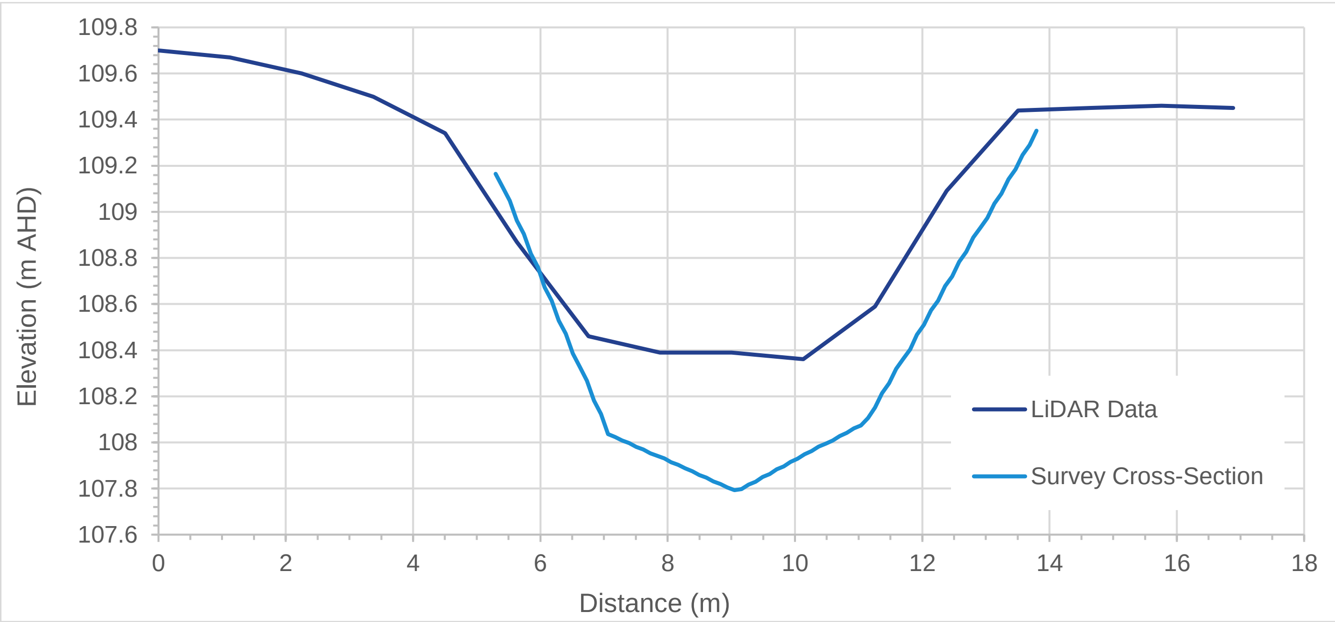


Figure 4.5: Comparison of Survey Cross-Sections to LiDAR data for Atkin Creek at Location 1

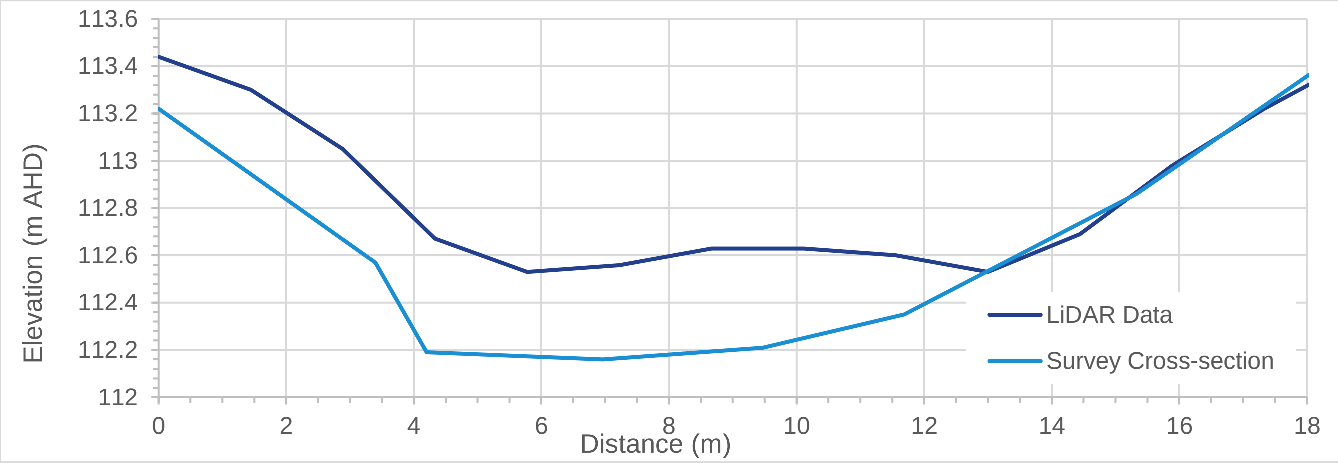


Figure 4.6: Comparison of Survey Cross-Sections to LiDAR data for Atkin Creek at Location 2

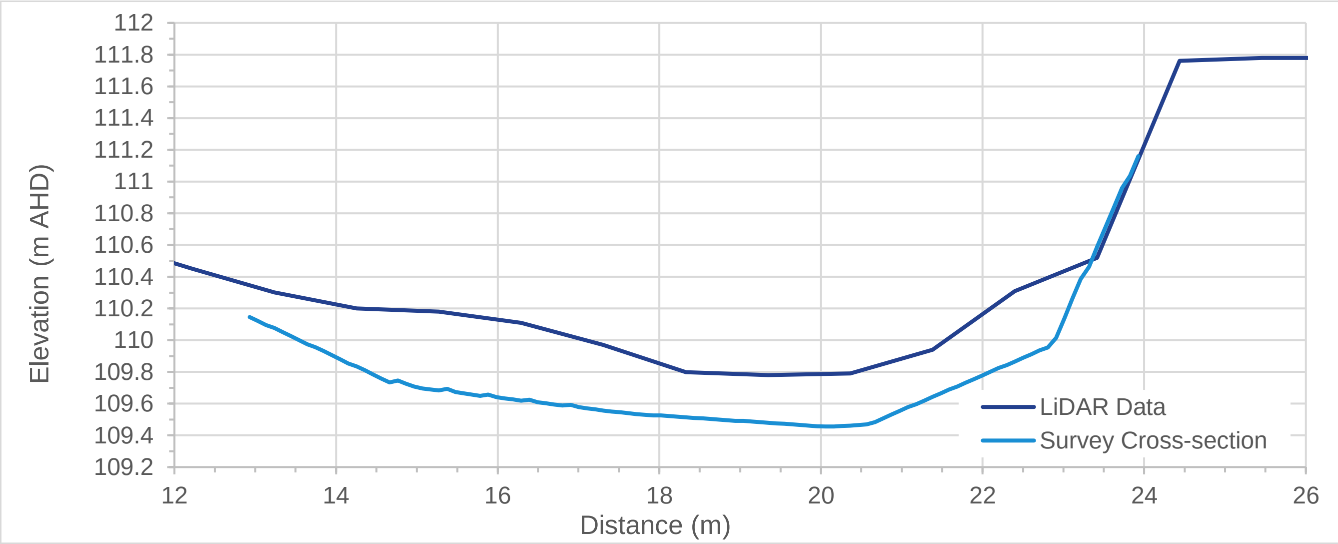
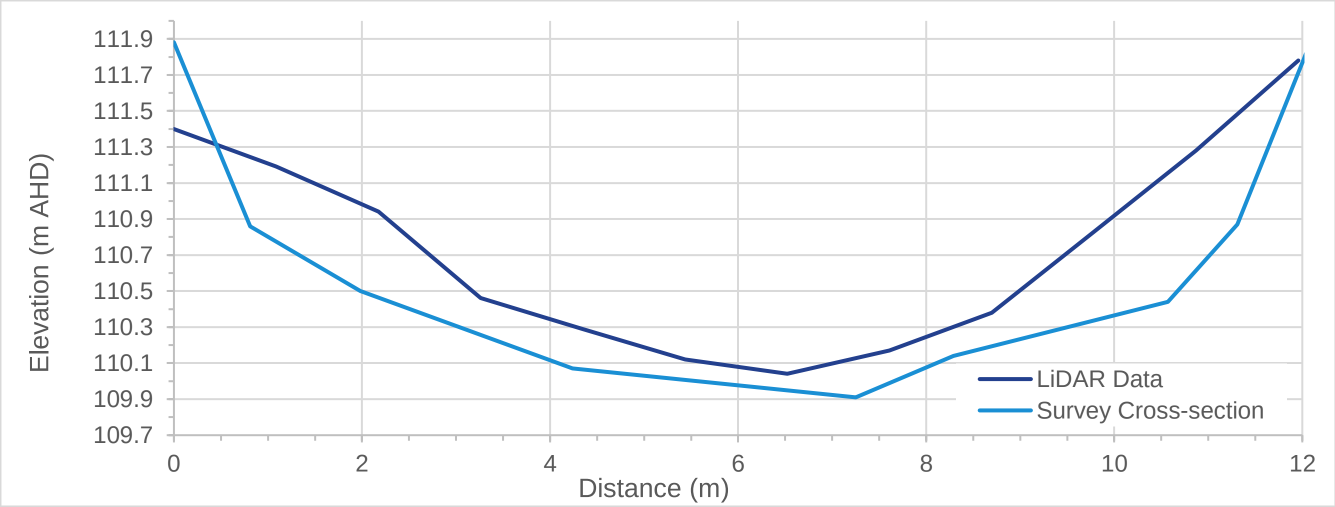


Figure 4.7: Comparison of Survey Cross-Sections to LiDAR data for Unnamed Tributary at Location 4



4.3.5 Surface Roughness

The hydraulic model includes a land use (materials) layer that reflects the surface roughness (Manning's 'n') throughout the catchment. The surface roughness defines how much resistance there is to runoff / overland flow passing over different land use types. For instance, high surface roughness values are found in residential properties due to the presence of buildings, fences and other structures that impede the flow of water, while flow through a paddock will have a lower surface roughness value.

Table 4.1 summarises the roughness values applied to the hydraulic model. These values are based on industry guidelines and were verified during site visits and from aerial photographs. The outcomes of the September 2016 Validation run were also utilised to inform the roughness values particularly along the Atkin Creek and the Unnamed Tributary where higher roughness values were adopted after iterative modelling to appropriately represent the areas of thick / high density vegetation in order to ensure the modelled flood levels account for the resistance. The results of the sensitivity analysis undertaken for the September 2016 event and influence of thick vegetation on the flood levels is discussed and included within Section 4.3.9.

Table 4.1: Hydraulic Model Surface Roughness Values

Land Use	Manning's n
Low density residential property	0.20
Remainder of parcel (residential)	0.10
Commercial or industrial / Building footprints	0.50
Parks, Recreational, Public Conservation and Resource Zone	0.035
Waterway / Parks – grass, some weeds	0.035
Waterway / Parks – minor density vegetation	0.06
Waterway / Parks – medium density vegetation	0.09
Waterway / Parks – high density vegetation	0.12
Car parks and roads (RDZ1, RDZ2)	0.02

Figure 4.8 and Figure 4.9 displays two areas where high Manning's roughness values of 0.12 were adopted along Atkin Creek immediately upstream of Warncoort-Birregurra Road and downstream of Anderson Street.

Figure 4.8: Photo of High-Density Vegetation within Atkin Creek Downstream of Warncoort-Birregurra Road

Figure 4.9: Photo of High-Density Vegetation within Atkin Creek Downstream of Anderson St

4.3.6 Boundary Conditions and Model Inflows

The TUFLOW model includes a series of boundary conditions to control points where flow enters or leaves the model. A HQ (head versus discharge) boundary was drawn to allow flows from the Barwon River floodplain to exit the model. This boundary uses a water surface slope of 0.01 m/m or 1 % to represent the minimal grade and permit the calculation of the stage-discharge relationship.

A series of QT (flow versus time) boundaries were also placed at the upstream extents of the model in order to represent the inflows from Atkin Creek, Unnamed Tributary and Barwon River. These relationships were set up to reference the plot outputs of flow versus time results from the RORB hydrological models discussed in Section 3 and enabled the TUFLOW model extent to be reduced to focus on the study area / township.

The TUFLOW design ensemble simulations used to define flooding within the local township (not associated with the waterway flooding) involved the application of inflows for the 10 minute to 2-hour storm durations with front, rear and mid loaded temporal patterns. The 1 % AEP hydraulic modelling results found the following mid-loaded temporal patterns to result in the median flood levels for each modelled duration:

- 10 minute – tp26.
- 15 minute - tp28.
- 30 minute – tp28.
- 1 hour – tp28.
- 2 hour – tp25.
- 3 hour – tp28.

Rainfall excess hydrographs were also applied as 2-D source areas onto the ground surface covering the sub-catchments within the township.

4.3.7 Barwon River Influence

An assessment of the interaction between the Barwon River and the local Atkin Creek and Unnamed Tributary flows was undertaken for the 1 % AEP event. The following scenarios were modelled and compared:

- Scenario1: 12-hour duration hydrographs for the Atkin Creek and Unnamed Tributary (critical duration for these waterways) with the 24-hour duration hydrograph for the Barwon River (critical duration for the Barwon River at Birregurra). The peak of the Barwon River 24-hour duration hydrograph was shifted to coincide with the peak of the 12-hour duration hydrographs for the Atkin Creek and Unnamed Tributary.
- Scenario 2: 12-hour duration hydrographs for Atkin Creek, Unnamed Tributary and Barwon River. No shifting of the peak flow for the Barwon River was accounted for in this scenario.

Figure 4.10 displays the resultant hydrographs near the Atkin Creek and Unnamed Tributary outlet to the Barwon River floodplain in addition to the Barwon River hydrograph for each of the relevant critical 1 % AEP storm durations. The figure also annotates the significant difference in volumes between the scenarios of 4000 ML prior to the local Atkin Creek peak flow occurring.

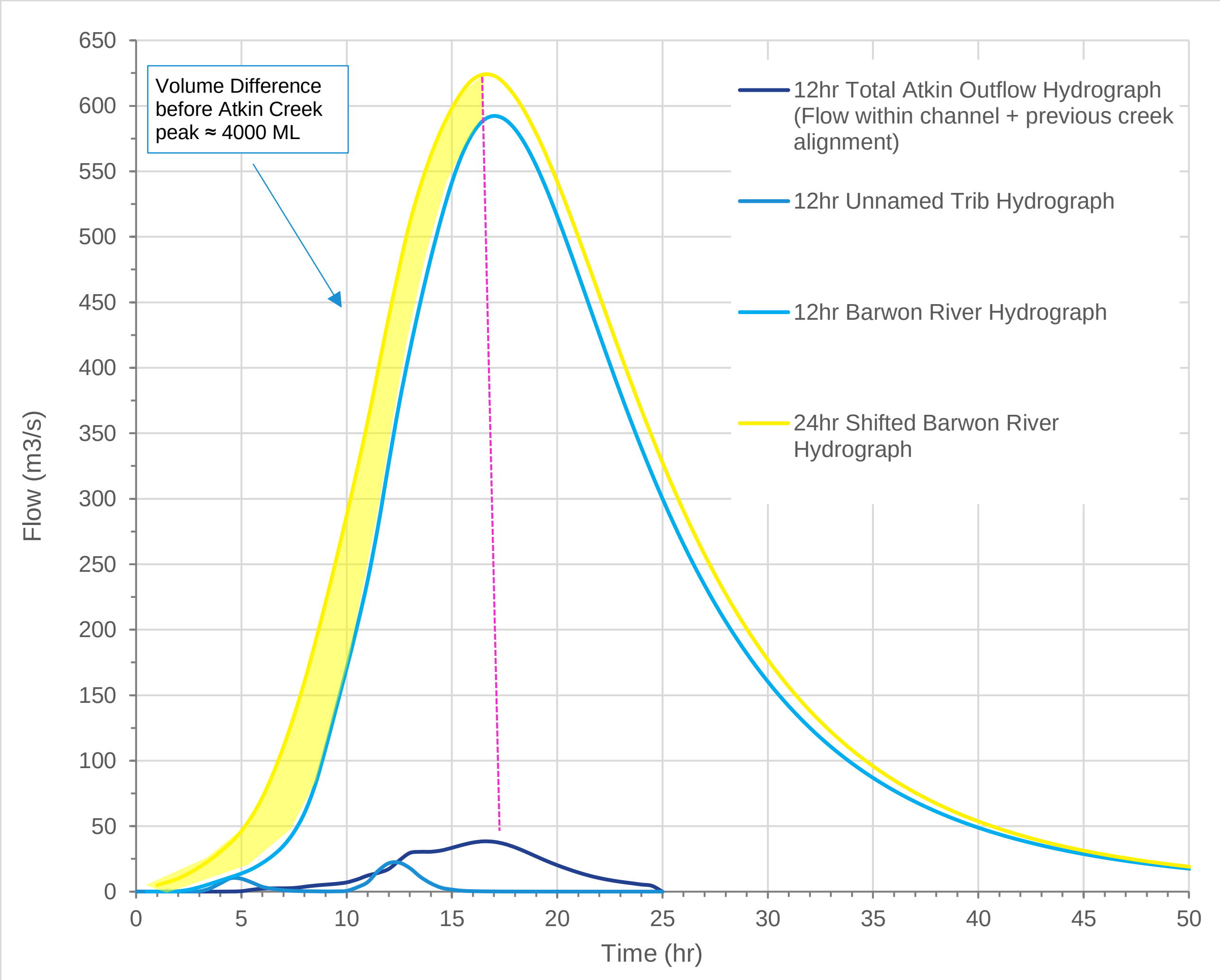
Figure 4.11 displays the corresponding flood depths and Barwon River area of influence for each of the scenarios modelled. As displayed the Barwon River area of influence is limited to the downstream end of the township where the same number of properties are predicted to be impacted regardless of the modelled scenario. The figure also displays the flood depth afflux, highlighting that there would generally be less than 30 mm of flood level difference within the area of influence.

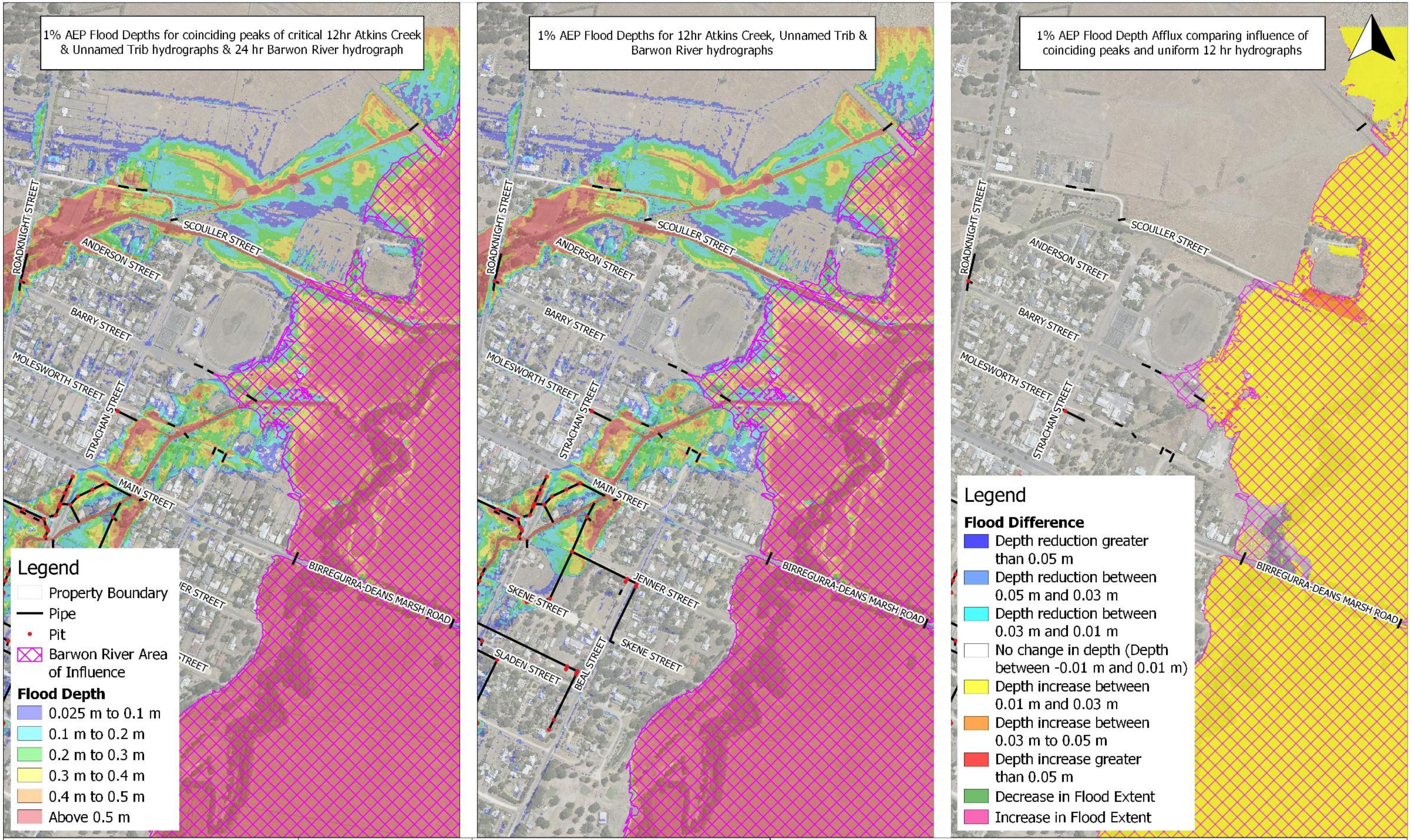
As a result of this analysis it was considered appropriate that for each design storm duration modelled the corresponding Barwon River storm duration inflow would be applied for design events. This allows for a conservative representation of the downstream Barwon River flood levels while noting:

- The design hydraulic model is not intended to run long enough to capture the peak flood levels within the Barwon River. It is also not focused on running the critical 24-hour duration since defining the Barwon River floodplain extent is not required from this study.
- If the peak flow for the Barwon River at Birregurra from the critical 24 hour duration event (considered to be the township's highest tailwater boundary condition) was to coincide with the peak flow from the waterways within the township for a 12hour

critical duration, the difference in flood levels would be less than 30 mm when compared to a scenario whereby the 12 hour rainfall event fell consistently across the Barwon River, Atkin Creek and Unnamed Tributary catchments. The modelling undertaken also indicates this flood depth difference is limited to the downstream end of the township. This confirms that even though the difference in hydrograph volumes is significant (4000 ML) the resultant influence on flood levels and tailwater levels for the Birregurra township was considered minor.

Figure 4.10: Comparisons of Peak 1 % AEP Atkin Creek, Unnamed Tributary and Barwon River Hydrographs





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ENGENY WATER MANAGEMENT

Colac Otway SHIRE

170 0 170 m

Scale in metres (1:5000 @ A3)

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

Birregurra Flood Study

Figure 4.11

Barwon River Interaction with local Township watercourses

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 29/7/2020

4.3.8 Blockage Considerations

ARR 2019 provides a framework to assess blockage risk of culverts and bridges. The guidelines recommend this assessment be undertaken, to determine the potential for the blockage of structures and the likely impact to flood behaviour. Engeny has assessed the blockage risk of six key structures located along Atkin Creek and the Unnamed Tributary within the township for the 1 % AEP. The locations of these structures are shown on Figure 4.12.

Figure 4.12: Location of Culverts and Bridges Assessed for Blockage Potential

In line with the ARR 2019 guidelines, the risk of blockage is informed by several factors including the structures opening flow area and the availability, mobility and transportability of debris and sediment at the inlet and through the bridge/ barrel respectively.

The structures assessed within the township assumed a consistent debris risk potential due to the similarities in land use and waterway slopes. By adopting this approach an inlet (debris) and barrel (sediment) blockage risk of medium to low was determined for all structures. This was based on the following underlying assumptions:

- Medium to Low Debris and Sediment Availability due to:
  - Catchment consisting of rural lands and grazed paddocks.
  - Moderate average bed slopes of 2.5 %.
- Medium Debris and Sediment Mobility due to:

- Moderate rainfall intensities.
- Moderately sloped catchment areas of 2.5 %.

- Medium Debris and Sediment Transportability due to:
  - Moderate bed slopes of 2.5 %.
  - Comparable stream size width to expected debris load dimension.

This medium to low blockage risk corresponds to the 1 % AEP blockage percentages shown in Table 4.2 for each structure analysed.

Table 4.2: Predicted 1 % AEP Blockage Percentages for Each Structure

Location	Structure Type	% Blockage
1	Bridge	15 %
2	Bridge	15 %
3	Culvert	50 %
4	Bridge	15 %
5	Box culvert	15 %
6	Culvert	50 %

The 1 % AEP design event was run with these calculated percentages for each bridge and culvert structure to assess the impacts on flood behaviour. Figure 4.13 displays the 1 % AEP flood depth afflux results from this 1 % AEP blockage sensitivity scenario. As displayed by assuming blockage to the key structures within Birregurra a combination of both increases and decreases in flood depths were identified. These changes to flood depth are generally within + / - 100 mm with the exception of blockage to the culvert structure at Main Street (location 3) where flood depths increase up to 150 mm at the intersection of Main Street and Strachan Street in addition to upstream of the culvert structure. These differences do not however result in an increase to the 1 % AEP flood extent. The flood risk changes at this location were also assessed.

Figure 4.14 presents a comparison of the ARR 2019 flood hazard values without and with blockage at the Main Street structure. As shown, no significant changes to the flood risk were identified except for the changes immediately upstream of the Main Street culvert structure within the Council owned reserve. Due to these sensitivity results, blockage was not accounted for in the simulation of design events.

Figure 4.13: 1 % AEP Blockage Sensitivity Scenario Flood Depth Difference

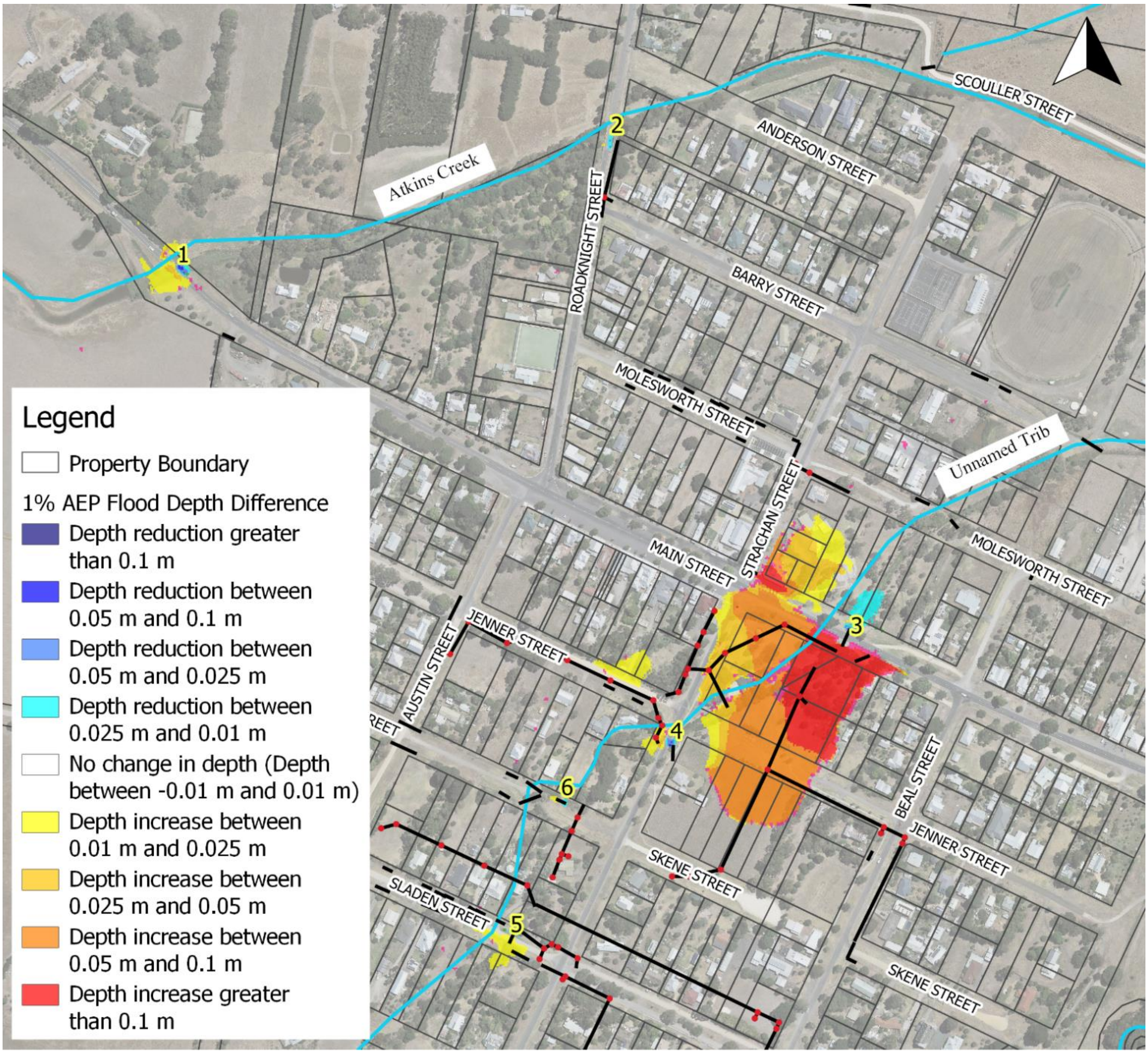
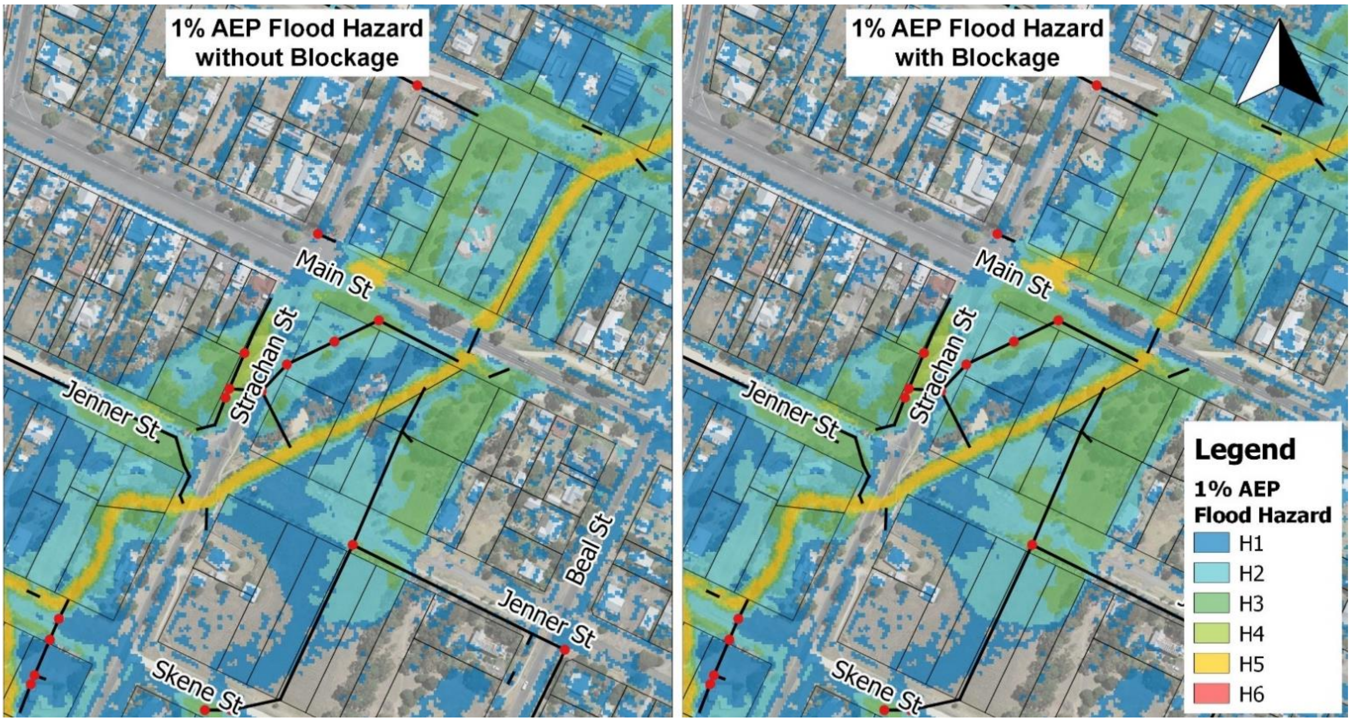


Figure 4.14: 1 % AEP Blockage Sensitivity Scenario Flood Hazard Comparison

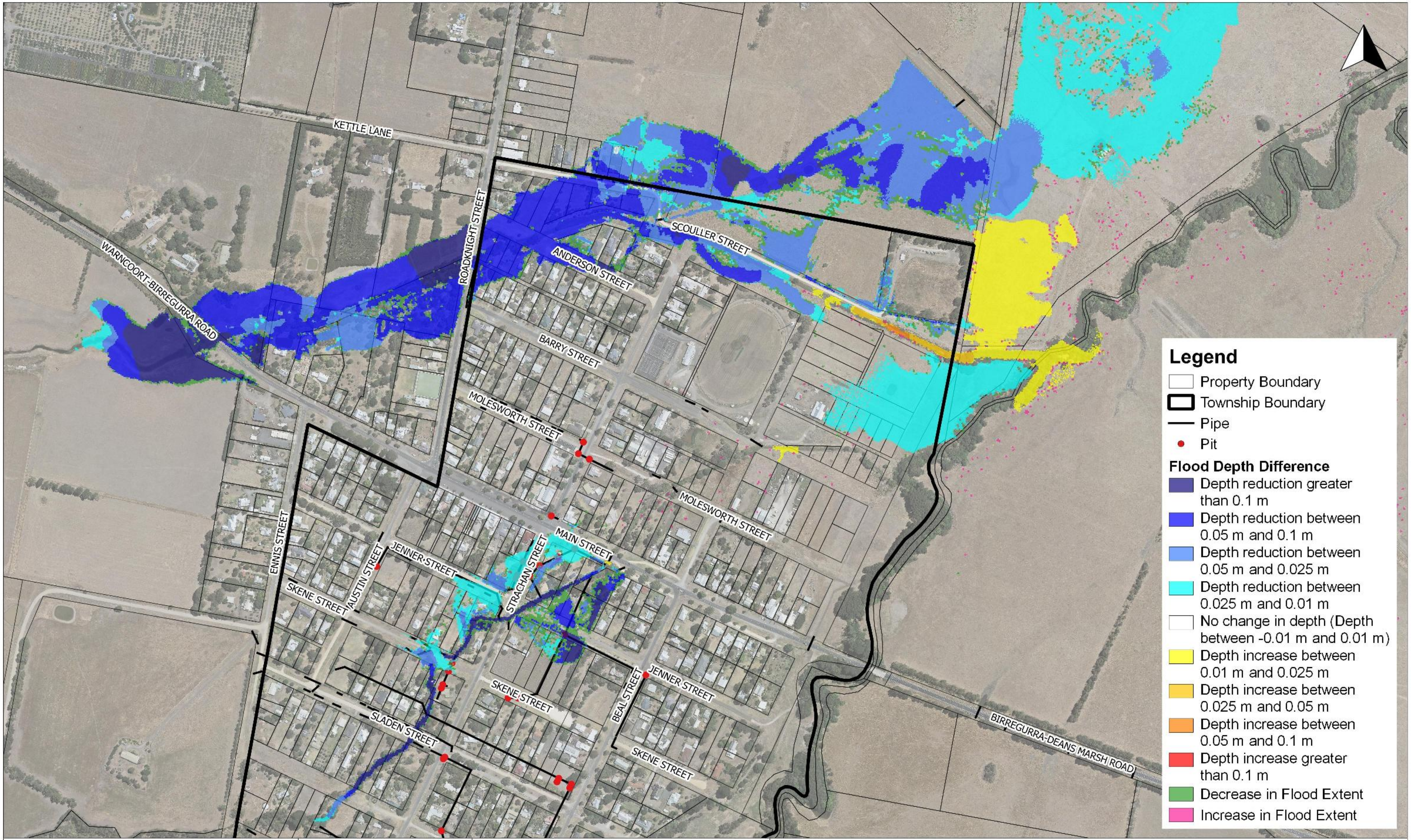


4.3.9 Waterway Vegetation Considerations

An investigation into the influence of thick vegetation within Atkin Creek and the Unnamed Tributary on the resultant flood levels was undertaken using the September 2016 rainfall event. Thick vegetation, as observed within Atkin Creek and the Unnamed Tributary can often be perceived as having a significant negative impact on the conveyance of flows. To understand this degree of influence, the September 2016 rainfall event was simulated with lower surface roughness values along Atkin Creek and the Unnamed Tributary. A maximum surface roughness value of 0.06 was adopted within the waterways. This value does not represent fully maintained waterways with all vegetation removed as this would not be realistic or desirable but instead, aims to represent a thorough trimming of vegetation.

Figure 4.15 displays the resultant flood depth afflux for the September 2016 event from the thorough trimming of vegetation. The plan highlights reductions of up to 100 mm along the waterways with an overall average reduction of 60 mm along Atkin Creek downstream of Warncoort-Birregurra Road. This flood depth difference is not significant and would not have contributed to a change in the number of dwellings affected by above floor level flooding during the September 2016 flood event.

Section 6.3 provides further discussion related to the feasibility of trimming vegetation within Atkin Creek and the Unnamed Tributary as a potential flood mitigation measure given the findings of this assessment and the highlighted minor changes to flood depths. Section 6.3 also discusses the importance of vegetation within waterways from an environmental perspective in stabilizing banks and reducing sediment runoff and erosion in addition to the flora and fauna significance.



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ENGENY WATER MANAGEMENT

Colac Otway SHIRE

40 0 40 80 120 160 m

Scale in metres (1:5600 @ A3)

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

Birregurra Flood Study

Figure 4.15

September 2016 Flood Depth Afflux from trimming of vegetation within Atkins Creek and Unnamed Tributary (Sensitivity Scenario)

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 30/11/2020

4.3.10 Simulation Parameters

The hydraulic model has been simulated with a minimum 1-D time step of 0.2 seconds. As the model was run with the HPC solver adaptive timesteps were applied.

4.4 SEPTEMBER 2016 EVENT MODEL CALIBRATION

4.4.1 Approach

The September 2016 inflow hydrographs were applied to the hydraulic TUFLOW model to represent the flood levels across the township. Iterative modelling was undertaken with modifications to the following parameters:

- **Continuing Loss –** As discussed in Section 3.5.8, after a few iterations a lower continuing loss value was confirmed to provide a closer match to the September 2016 surveyed flood levels.
- **Manning's roughness values –** Application of higher roughness values (within values specified in industry guidelines) within Atkin Creek and the Unnamed Tributary to represent densely vegetated sections indicated that flood levels generally increased by less than 100 mm providing a marginally closer match to the September 2016 surveyed flood levels. These values were also applied to the base case design event hydraulic modelling simulations.
- **Refinement of terrain along the waterways** – following an initial model simulation some differences between the modelled flood levels and the September 2016 flood levels were identified within waterways and near key structures. Survey data was captured and the resultant outputs were used to refine the terrain along waterways and at structures. These refinements were also applied to the base case design event hydraulic modelling simulations.

4.4.2 Results

The TUFLOW model's resultant September 2016 event flows along the waterways are summarised in Table 4.3.

Table 4.3: September 2016 Event TUFLOW Flows Across Township

Location	September 2016 Event Flow
Atkin Creek - Upstream of Warncoort-Birregurra Road	16.0 m^3/s
Atkin Creek - Upstream of Roadknight Street	16.0 m^3/s
Atkin Creek – Downstream of Strachan Street	7.8 m^3/s
Overbank flows from Atkin Creek along previous creek alignment	8..2 m^3/s
Unnamed Tributary – Upstream of Sladen Street	5.8 m^3/s
Unnamed Tributary – Upstream of Skene Street	6.4 m^3/s
Unnamed Tributary – Upstream of Strachan Street	6.5 m^3/s
Unnamed Tributary – Upstream of Main Street	6.7 m^3/s
Unnamed Tributary – Upstream of Barry Street	6.9 m^3/s

Table 4.4 provides a comparison of the surveyed flood levels with the modelled flood levels. As displayed the similarity in results provides confidence in the hydraulic model input parameters.

However, it was noted that the surveyed flood mark at location 9 was up to 400 mm higher than the modelled flood level. In some instances, differences between surveyed and modelled flood levels could be attributed to the blockage of structures during the given storm event noting that blockage generally occurs at the upstream end of structures. In this instance if the Sladen Street structure was blocked during the September 2016 event it would result in a lower modelled flood level at the structures downstream end where the surveyed mark was captured. Alternatively, blockage at the downstream Skene Street structure may result in some banking up and subsequent higher flood levels at Sladen Street, however the modelling suggests that there is already a close match between surveyed and modelled flood levels here (locations 6, 7 and 8). As such, the accuracy of the survey flood level at location 9 was considered questionable.

The location of the surveyed flood marks which matched closely to the modelled flood levels and the questionable survey mark at location 9 are displayed within Figure 4.16.

Table 4.4: Comparison of Surveyed to Modelled Flood Levels for September 2016 Event

Location	Description	Surveyed Flood Level	Modelled Flood Level
1	Warncoort-Birregurra Rd (Fence line)	113.44	113.3
2	Roadknight Street	111.61	111.6
3	Scouller St (Side of Shed)	Unable to access property (approx. 200 mm from shed base @ Lidar level 110.4 m AHD)	110.63
4	Scouller St (Sewer pit)	110.49	110.34
5	Anderson St (Fence post)	111.3	111.12
6	Main Street (US left bank bridge abutment)	109.89	109.98
7	Skene St (Top of crossing)	112.4	112.3
8	Skene St (Base of letter box)	112.63	112.65
9	Bridge abutment (DS Right bank)	114.3	113.94

Figure 4.16: Location of September 2016 Event Surveyed Flood Marks

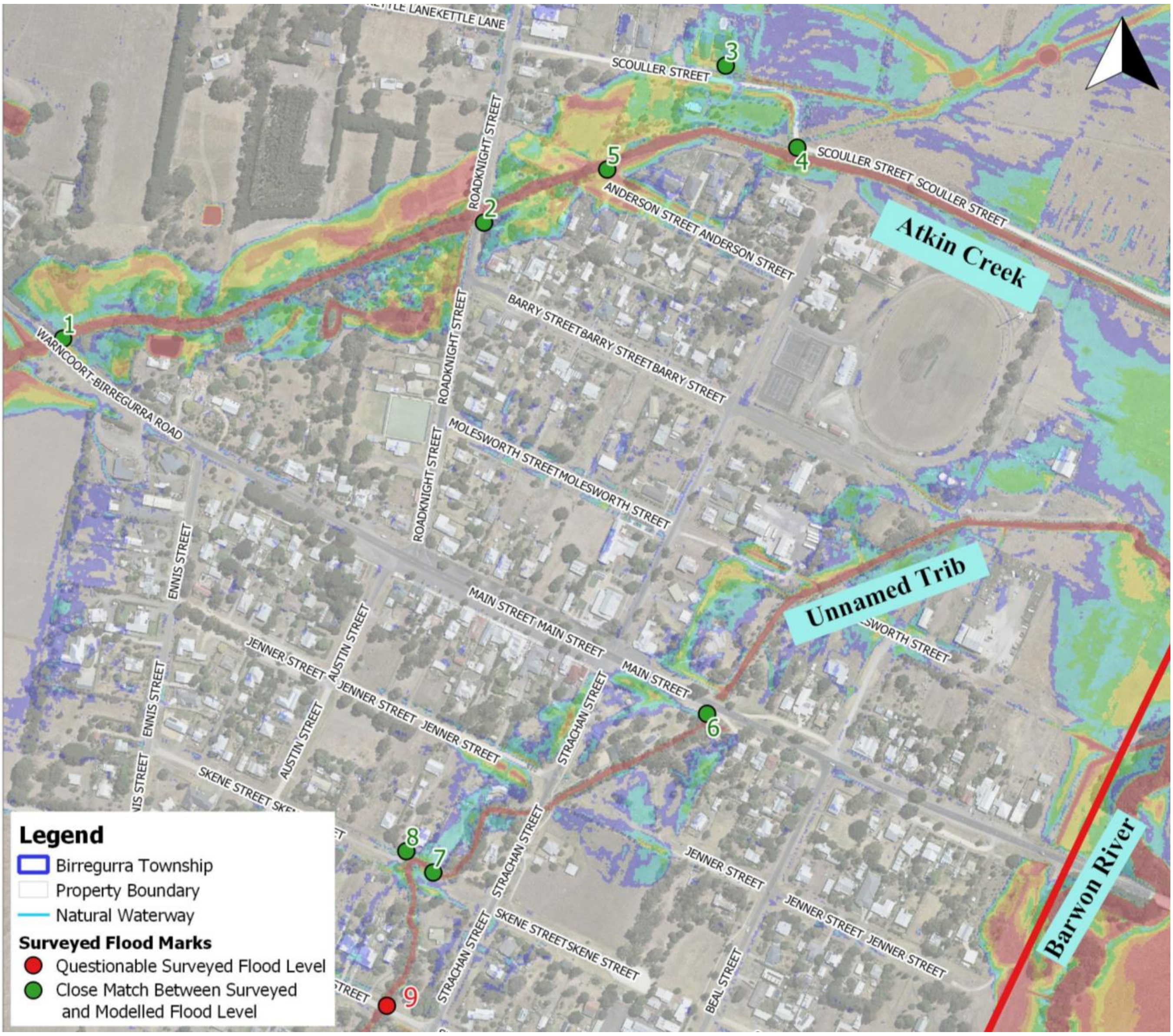
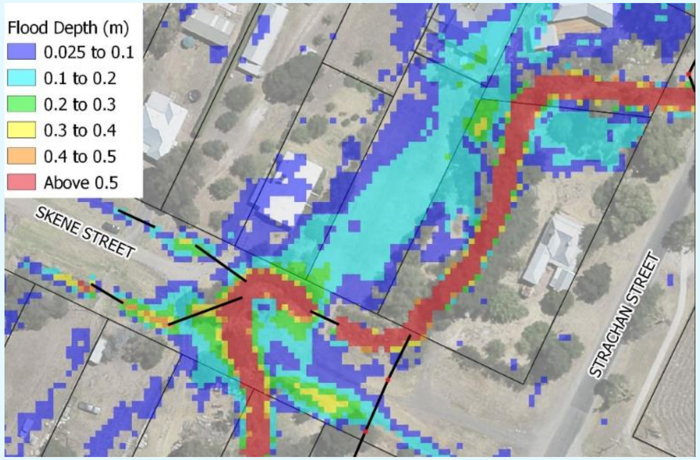
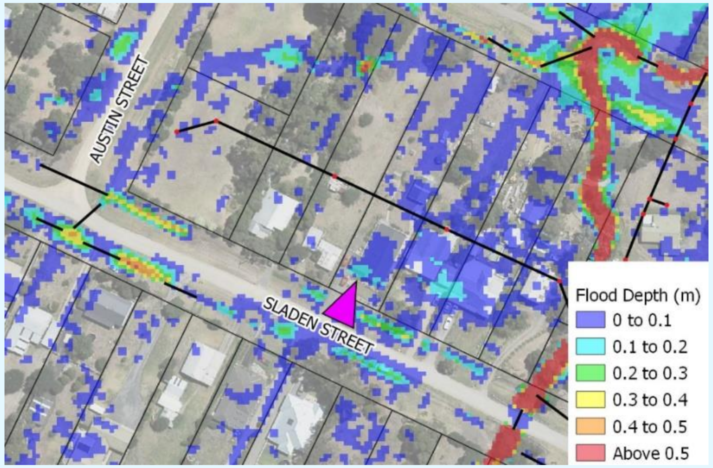


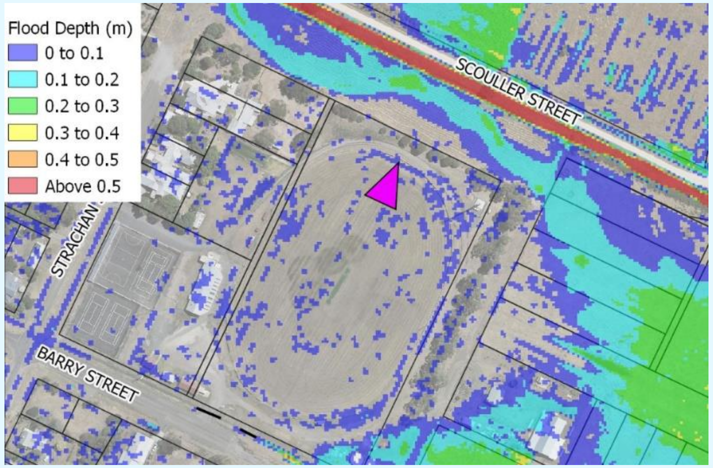
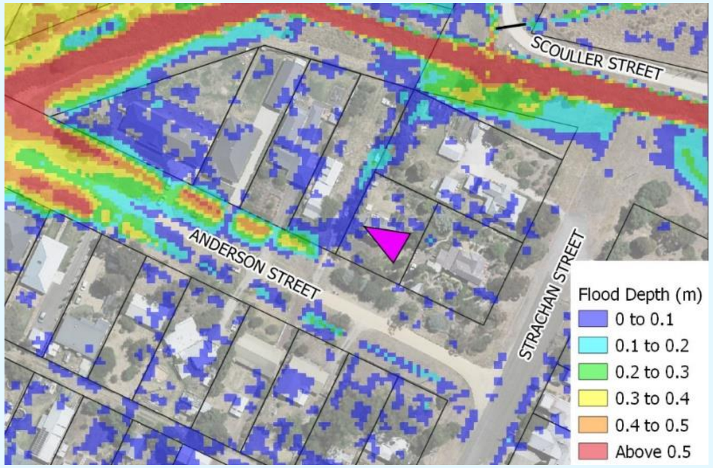
Table 4.5 provides a comparison of the modelled flood depths to photographs and anecdotal evidence collated for the September 2016 event. Comparisons of anecdotal evidence and photographs has provided further confidence that the hydraulic modelling results for the September 2016 event are a good match to those reported by residents across the township.

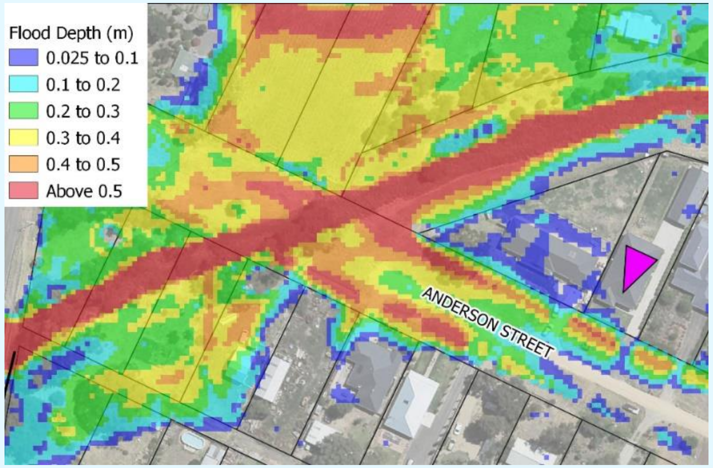
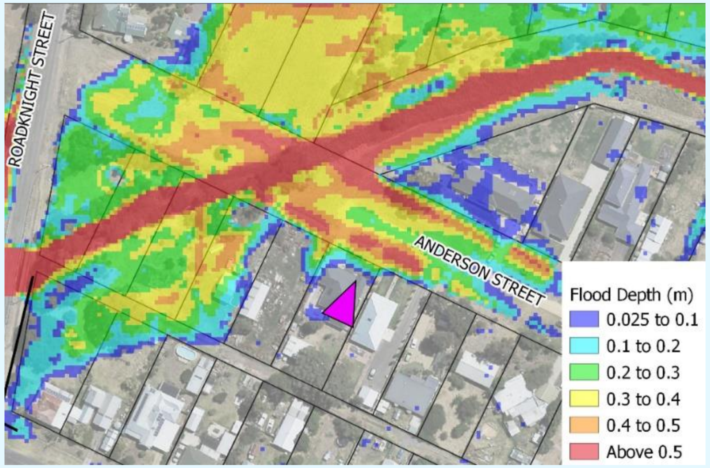
Information obtained from the targeted community engagement sessions conducted in April 2020 to obtain feedback of the results of draft calibration for the September 2016 event also provided support for the results produced with participants having witnessed flooding at key locations across the entire study area.

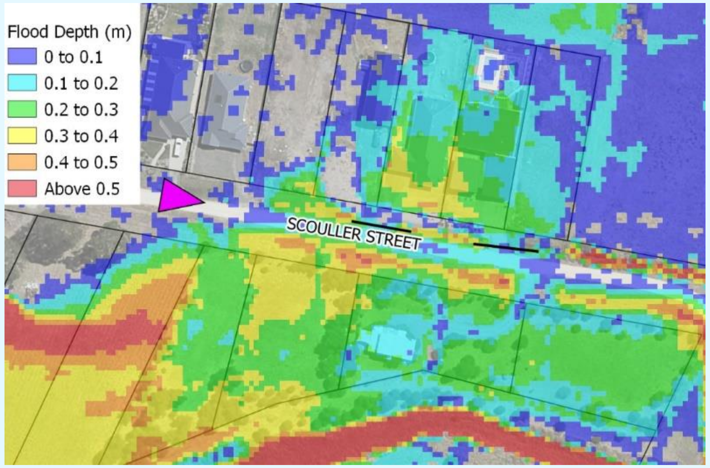
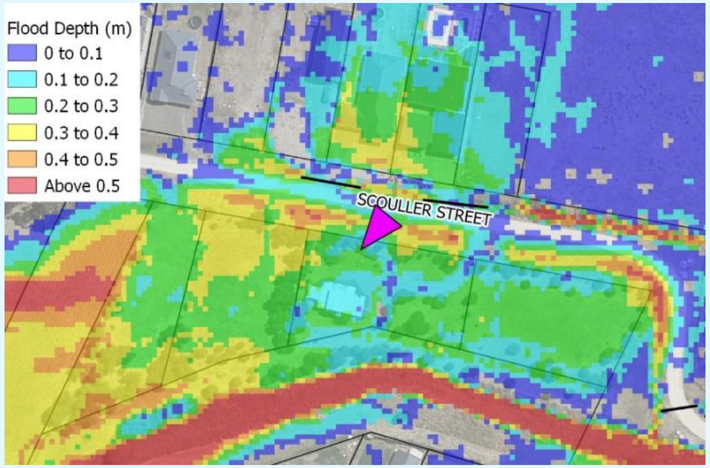
Appendix E displays the resultant flood depth layout plan for the September 2016 flood event.

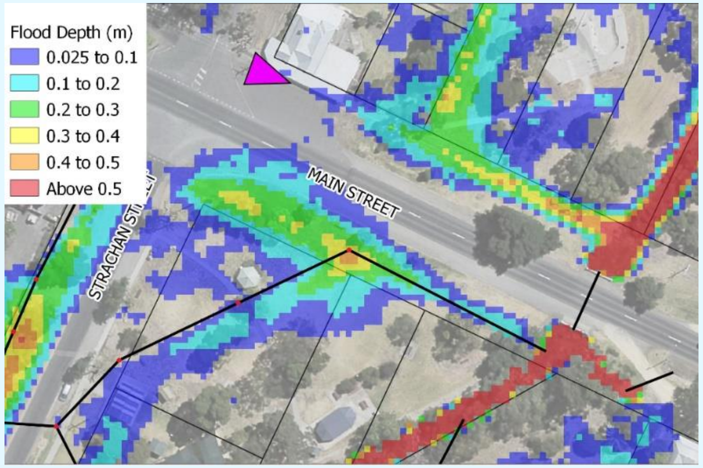
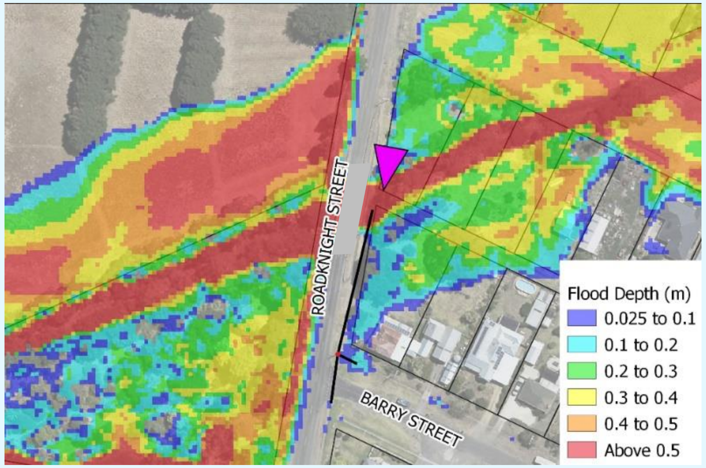
Table 4.5: Comparison of September 2016 Event Photograph / Anecdotal Evidence to Modelled Flood Extent

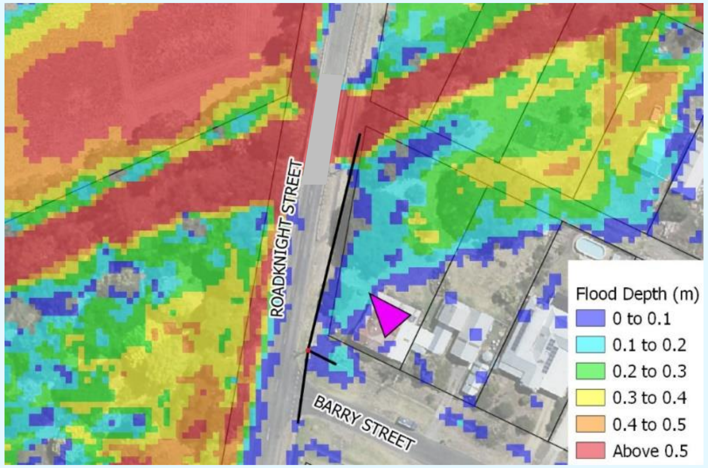
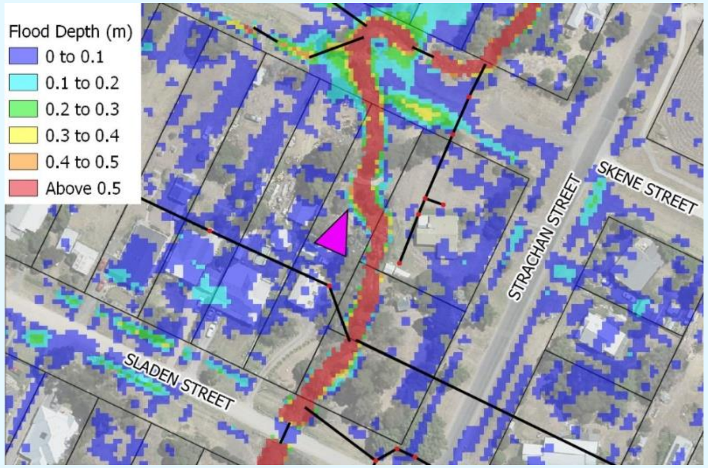
Location	Photograph / Anecdotal Evidence	Modelled Flood Extent
50 Skene Street		
42 Sladen Street	Resident noted: • House did not flood above floor level in 2016. • Water reached the bottom of the weepholes in the brick work. • Considers that the water is backing up the swale because the cross over pipes are not big enough. • Shed floods regularly. • Skene Street and Strachan Street provide overspill point in 2016 near the creek bend.	

Location	Photograph / Anecdotal Evidence	Modelled Flood Extent
Football Oval	Resident noted that '2016 flood reached the northern boundary of the football oval"	
6 Anderson Street	Resident noted that '2016 flood reached their western boundary"	

Location	Photograph / Anecdotal Evidence	Modelled Flood Extent
12 Anderson Street		
17 Anderson Street	 Resident noted that flood waters did not reach above floor level but were over garage floor in 2016	

Location	Photograph / Anecdotal Evidence	Modelled Flood Extent
18-24 Scouller Street		
22 Scouller Street	Resident noted "waters entered house and reached 300 mm above floor level". Following photo provided where modelled flood depths were between 250 to 300 mm. 	

Location	Photograph / Anecdotal Evidence	Modelled Flood Extent
Main Street looking east towards Unnamed Tributary		
Roadknight Road looking south towards Main Street		

Location	Photograph / Anecdotal Evidence	Modelled Flood Extent
43 Roadknight Street	Resident noted: • House didn't flood in 2016 • Flood waters reached bearers of the dwelling	
36 Sladen Street	Resident noted that house didn't flood in 2016	
64 Strachan Street	Resident noted that "block didn't flood – water stayed within its banks"	Consistent with Modelled September 2016 Event Results
71 Jenner Street and 19 Ennis Street	Resident noted that "House didn't flood in 2016" and that the subsoil was saturated	Consistent with Modelled September 2016 Event Results

4.5 DESIGN EVENT FLOOD MAPPING

4.5.1 BASE CASE / EXISTING CONDITIONS

Appendix F provides the resultant flood depth layout plans for all modelled design storm events for existing base case climate conditions. These results were produced with the combination of the maximum grids generated from the following:

- Monte Carlo simulation (representing the flooding along the Atkin Creek and Unnamed Tributary) for the given critical storm durations.
- Ensemble simulations for the 10 minute to 2 hour storm durations (representing flooding within the local township) for the defined mid-loaded temporal patterns.

Table 4.6 provides a summary of the peak 1 % AEP to 20 % AEP flows at road crossings along Atkin Creek and the Unnamed Tributary.

Table 4.6: Design TUFLOW Flows Across the township

Location	39.35 % AEP Flow (m³/s)	20 % AEP Flow (m³/s)	10 % AEP Flow (m³/s)	5 % AEP Flow (m³/s)	2 % AEP Flow (m³/s)	1 % AEP Flow (m³/s)
Atkin Creek - Upstream of Warncoort-Birregurra Road	5.89	10.69	15.12	19.33	28.70	36.30
Atkin Creek - Upstream of Roadknight Street	5.79	10.73	15.21	19.30	28.70	36.31
Atkin Creek – Downstream of Strachan Street	5.22	6.47	7.39	8.32	10.56	12.33
Overbank flows from Atkin Creek along previous creek alignment	1.56	4.30	7.71	10.73	16.94	22.11
Unnamed Tributary – Upstream of Sladen Street	3.96	6.82	10.77	13.23	20.26	22.57
Unnamed Tributary – Upstream of Skene Street	4.40	7.34	11.64	14.13	21.61	24.09
Unnamed Tributary – Upstream of Strachan Street	4.24	7.40	11.64	14.13	21.61	24.09
Unnamed Tributary – Upstream of Main Street	4.29	7.68	11.94	14.69	22.03	25.00

4.5.2 CLIMATE CHANGE CONDITIONS

Modelling of climate change for the 1 % and 10 % AEP storm events consisted of an increase in rainfall intensity based on the forecasted year 2100 and representative concentration pathway (RCP) 8.5 percentage of 18.5 %. This increase was applied via the IFD within the hydrological model (detailed within **Appendix C** and **Appendix D** for both the Barwon River and Atkin/Unnamed Tributary hydrology models).

Appendix G provides the resultant Flood Depth Layout Plans produced as part of the Climate Change Conditions modelling for the 1 % and 10 % AEP storm events: **Appendix H** provides the associated Flood Depth Afflux Plan when compared to existing base climate conditions.

As displayed within these layout plans, an increase of 18.5 % to rainfall intensity increases flood depths, on average, by up to 100 mm in most areas along Atkin Creek and the Unnamed Tributary particularly where the flow path is wider and consists of greater flood storage. In contrast the Unnamed Tributary upstream of Sladen Street is narrow and well incised and as such average flood depth increases of up to 500 mm were noted.

Although these flood depth increases are evident, the resultant flood extent has not significantly changed when compared to existing / base climate conditions.

Appendix I provides a comparison of the changes to the ARR 2019 Flood Hazard criteria values for the 1 % AEP storm event between existing climate conditions and the predicted future climate change conditions. As noted above, although the flood extent does not significantly change when compared to existing conditions, some differences to the flood risk were noted. This would in turn contribute to changes to the proposed planning overlays. Some areas assigned a Land Subject to Inundation Overlay (LSIO) under existing climate conditions, would be assigned a Floodway Overlay if climate change conditions was considered. Based on this comparison, consideration of climate change conditions may be required for the development of the planning overlays. Further discussion is provided in Section 8.

4.6 EXTERNAL INDEPENDENT PEER REVIEW

The hydrological and hydraulic modelling analysis was independently reviewed to ensure the models and their outputs were fit for purpose. The Quality Assurance (QA) review considered the modelling methodology, assumptions and model input parameters. This phase identified the need to include all underlying assumptions and discussion on the limitations related to the data available (rainfall and calibration data) within the study report but also highlighted the overall suitability of the modelling parameters adopted in producing the resultant close match between the surveyed and modelled flood levels presented in Section 4.4.

5 FLOOD DAMAGES

5.1 BACKGROUND

The Average Annual Damages (AAD) assessment estimates the average probable tangible flood damages expected in a year for residential, commercial and industrial property land use types, as well as major, minor and unsealed roadways. The AAD was calculated using Melbourne Water's 2020 AAD spreadsheet which utilises the flood mapping results from a range of storm events including the 20 %, 10 %, 5 %, 2 %, and 1 % AEP.

A flood damages assessment for existing flooding conditions is useful in understanding whether the cost of structural mitigation works is justified. Section 6 presents the mitigation assessment undertaken and also provides a comparison of the mitigation work's resultant AAD value to that presented in this section for base case.

The following provides a summary of the key steps and assumptions made as part of the calculation:

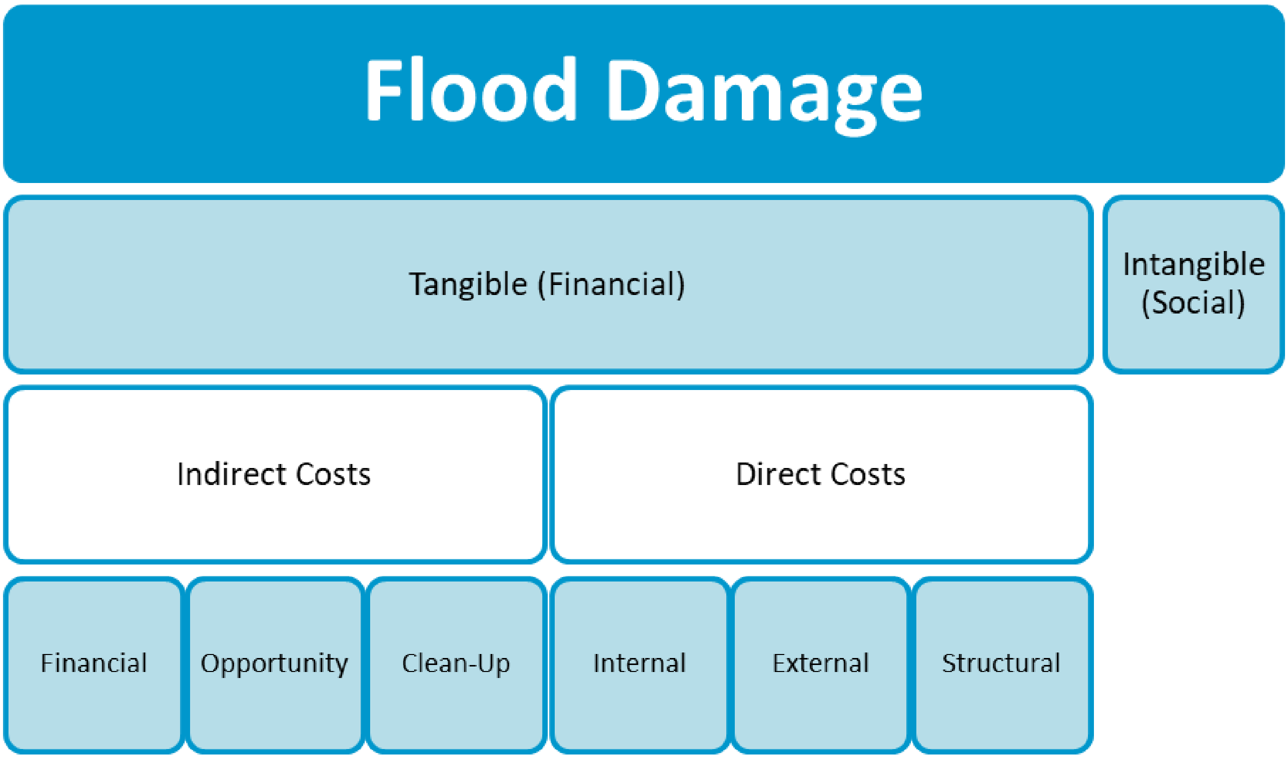
- A building footprint layer digitised using aerial imagery and surveyed floor levels was utilised to determine the maximum water surface level within each flood affected building footprint for the various flood events.
- An up to date property parcel layer obtained from the Department of Environment, Land, Water and Planning (DELWP) was utilised to determine the total area within each property affected by flooding.
- Melbourne Water's AAD spreadsheet contains stage-damage curves that were utilised to inform the damages estimates. These stage-damage curves are not intended to represent the full financial impact caused by flood damage. The damage estimation methodology for residential and commercial / industrial properties utilises a combination of the following methods:
  - The Department of Natural Resources & Mines methodology (DNRM, 2002), which is based on the stage-discharge curves developed by ANUFLOOD (Smith & Greenway, 1988). This methodology was adopted for commercial / industrial properties and uses both building size and contents value to inform the costs associated with the stage-damage curve.
  - The Department of Environment and Climate Change Residential Flood Damages Guidelines as documented in the Floodplain Risk Management Guideline: Residential Flood Damages (DECCW, 2007). This methodology was used to inform the flood damage costs associated with residential properties.
- Indirect damage costs, which represents inconveniences such as emergency assistance, community support and temporary relocation, are assumed to be 30 % of the direct damage costs.
- The AAD assessment does not consider depth or safety in roads but does consider the area of roads that are inundated.
- Calculation of event damages has been undertaken for all surveyed building footprints and roadways within the 2D code boundary delineated for the extent of the TUFLOW flood model.

5.2 FLOOD DAMAGE TYPES

5.2.1 Actual vs Potential

Various types of flood damage may occur and can be measured in different ways. Figure 5.1 presents a summary of the various categories of flood damages, where each type can be either an 'actual' or 'potential' damage. Actual damages are a direct result of a flood event whereas, potential damages are the probable damages that could occur from a flood event. Both types of damages can be minimised or in some cases prevented by community awareness and structural or behavioural measures such as flood mitigation works and flood warning procedures.

Figure 5.1: Flood Damage Categories



5.2.2 Tangible vs Intangible

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

5.2.3 Direct vs Indirect

As presented in Figure 5.1 tangible damages can be further classified as either direct or indirect flood damages. Direct damages include flood waters contacting a structure or its contents and causing damage due to either high velocities or above floor level flooding. Typical methods for assessing flood damages estimate costs differently for various land use types. This investigation has separated costs between residential and commercial / industrial land uses as well as roadways.

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

5.2.4 Average Annual Damage (AAD)

The AAD assessment has considered the potential damage to roads and buildings based on the existing conditions flood modelling for storm events between the 20 % AEP and 1 % AEP.

With regards to buildings considered in the AAD assessment:

- Buildings are included in the assessment if they intersect the proposed flood overlays including the LSIO, FO and SBO extents (based on the 1 % AEP existing conditions flood mapping results). This captured 60 buildings.
- The AAD is then calculated by subtracting the maximum flood level within the building footprint to the surveyed floor level.
- Increased damages are assigned proportional to the difference between flood level and floor level.
- Of the 60 buildings considered at risk of flooding for the 1 % AEP base case scenario (existing conditions), 26 buildings were determined to be flooded above floor level based on the surveyed floor levels and detailed interrogation of the modelling outputs.

- These 26 buildings ‘flooded above floor level’ were assigned higher damage costs comparative to the remaining buildings ‘at risk of flooding’ but not flooded above floor level.
- If the flood level was below the surveyed floor level a flat rate of $12,261 was applied to capture the potential flood damage to the overall property surrounding the dwelling.

In order to determine the number of dwellings affected by above floor level flooding, the interrogation of the modelling outputs was considered essential to ensure dwellings most likely affected were included only. This was particularly important given the influence higher dwelling counts would have on potentially unrealistically inflating the benefits of mitigation works when comparing the AAD to existing conditions. The interrogation of the dwelling counts informed by the raw modelling results included the removal of dwellings initially identified as affected by flooding if:

- The dwelling had high flood depths as a result of the model’s grid cell representation of steep terrain slopes and subsequent interpolation within model outputs (grid results).
- The dwelling had high flood depths as a result of the model’s applied higher manning’s roughness value whilst flood depths surrounding the dwelling were shallow / insignificant.
- Google Street View identified a step up to the dwellings floor level as such indicating a minor discrepancy between the surveyed floor level and the dwellings surround natural ground levels particularly if flood depths above floor level were minor.

Table 5.1 provides a summary of the number of dwellings identified as most likely affected by above floor level flooding under existing conditions for each modelled storm event following the detailed interrogation of raw modelling results. These dwelling counts differ from those presented within Section 0 as the flood warning and MFEP assessments have focused on conservatively ensuring all dwellings with a potential for above floor level flooding are considered. As such the counts presented within this later section of the report consists of a greater overall count as they have been based on the raw flood mapping results.

Table 5.1: Number of Dwellings Most Likely Affected by Above Floor Level Flooding

AEP	Number of Dwellings	Number of Properties
20 %	5	14
10 %	7	27
5 %	9	34
2 %	23	44
1 %	26	47

Table 5.2 provides a summary of the calculated damages for each AEP event. The total AAD of **$746,741 / year** is also displayed which captures the contribution of each AEP’s calculated flood damage when considering the likelihood of the flood event. As an example, the 1 % AEP contribution to AAD is generally less than the 10 % AEP due to the lesser likelihood of occurrence, despite the 1 % AEP event predicting a larger number of buildings / larger extent of the roadways at risk of flooding.

Table 5.2: Existing Conditions AAD Summary

AEP	Calculated Damages
20 %	$1,316,613
10 %	$2,543,329
5 %	$3,662,597
2 %	$5,664,210
1 %	$6,576,244
Total AAD	$746,741 / year

6 FLOOD MITIGATION

6.1 INTRODUCTION

This phase of the study has focused on conceptually identifying and assessing structural flood mitigation measures which aim to balance:

- The extent and cost of works.
- The flood mitigation benefits focused on reducing the number of dwellings affected by above floor level flooding.
- The impacts to surrounding properties as a result of the mitigation works ensuring works do not cause adverse flooding impacts to adjacent / downstream private properties.

As noted within Section 1.3, while the strategy has a focus on flood management it is important to note the importance of waterways in relation to broader ecological, cultural and aesthetic values. Therefore prior to progressing with any conceptual options outlined within this section, outcomes from the following investigations / assessments need to be considered:

- Environmental flora and fauna impact assessment highlighting the ecological values within the mitigation locations and potential impacts, particularly to endangered species.
- Cultural and heritage assessment with further engagement with the traditional owners.
- Geotechnical assessment which identifies the potential erosion and degraded bank stability risks as a result of the mitigation works.
- Aesthetic and recreational values assessment.

This mitigation assessment has consisted of:

1. The identification of mitigation options which could be implemented to address the known flooding hotspots.
2. Selection of five (5) preferred mitigation options. These were selected following discussions with Council and CCMA and high-level consideration of the feasibility / practicality of each option.
3. Mitigation modelling of the selected mitigation works for the 20 % to 1 % AEP storm events and analysis of the resultant flood depth differences when compared to existing flooding conditions.
4. AAD assessment for the selected mitigation works and comparison to the damage's values calculated for existing conditions.
5. High-level cost estimate for the selected mitigation works.
6. High-level multi criteria assessment which summarises the estimated cost of works and AAD in addition to other qualitative factors for each selected option.

6.2 FLOODING HOTSPOTS

From the existing conditions modelling results several flooding hotspots were identified within Birregurra including:

1. The overtopping of Atkin Creek downstream of Roadknight Street caused from the creek's lack of conveyance capacity particularly along the channelised section south of Scouller Street. This affects a number of properties on Scouller Street, Anderson Street and Roadknight Street.
2. The overtopping of the Unnamed Tributary downstream of Sladen Street caused by the creek's lack of conveyance capacity and constriction of the Skene Street driveway culvert structure. This affects a number of properties adjacent to the Unnamed Tributary down to the Barwon River confluence.
3. Overland flow path from Prime Street to Sladen Street caused by the underground drainage system's lack of conveyance capacity. This flow path affects a few properties prior to connecting with the Unnamed Tributary.
4. Overland flow path along Sladen Street originating from the rural farmland east of Ennis Street caused by the road-side channel's lack of conveyance capacity. This results in sheet flows overtopping towards the northern side of Sladen Street and passing through several residential properties.

6.3 IDENTIFIED MITIGATION OPTIONS

Table 2.1 summarises each of the mitigation options identified (Listed A to H) with a description of the works involved and the considerations made to determine whether the option was worth pursuing. To inform this decision making and the works effectiveness in mitigating flooding impacts and overall feasibility, some of these options were assessed in the hydraulic TUFLOW model for the 1 % AEP storm event only. The table clearly notes the options which were selected for further assessment within Section 6.4.

Table 6.1: Summary of Mitigation Options Identified

Mitigation Option	Description	Considerations	Selected for Further Assessment in Section 6.4
A – Atkin Ck Levee	1 metre high levee on northern bank of Atkin Ck, between Roadknight St and Scouller St	1 % AEP modelling results highlighted reduced flood depths to northern residential properties but increases to southern residential properties along Barry Street and Anderson Street. Levee along the southern side of Atkin Creek to maintain flows within waterway was not considered feasible due to obstruction which would be created for overland flows entering the creek from southern side. Option was not considered feasible due to impacts to existing properties south of Atkin Creek along Anderson Street.	**No**
B Atkin Ck Waterway Widening	Widened Atkin Ck waterway, from Roadknight Street to Barwon river confluence.	Proposed channel works contained to Council owned land Sized to convey a majority of the 1 % AEP Atkin Creek flow from Roadknight Street. Requires the removal of vegetation for widening works and as noted above if progressed there will be a need to undertake several investigations including flora and fauna impact assessments, cultural heritage assessment and geotechnical assessment.	**Yes**
C Scouller Street Culverts	Upgrade of existing 375 mm diameter culvert crossing Scouller Street to allow conveyance of flows along previous Atkin Creek alignment towards now abandoned rail embankment	Need to maintain full access along Scouller Street and maintain minimum required road cover (600 mm) for vehicles. Flood modelling results indicate the flood depth reductions would be limited to the areas immediately surrounding the upgraded culverts and would not reduce flooding for properties along Anderson Street or Scouller Street. This option would also result in an increase to flood depths on the farmland immediately north of the culverts.	**No**
D1 Atkin Creek Retarding Basin	Formalise a retarding basin upstream of Warncoort-Birregurra Road for the attenuation of Atkin Creek flows.	Storages sized assuming the existing topography is maintained and an embankment along Warncoort Road is constructed. The required flood storage to attenuate Atkin Creek to the estimated capacity of the existing Atkin Creek is significant. Based on the preliminary hydrological modelling sizing runs it was estimated that even assuming a 4-metre-high embankment, which would provide approximately 158,000 m^3 of flood storage, would not provide sufficient attenuation for flows greater than a 10 % AEP storm event. This option was not considered feasible given the flood storage requirements and minimal associated downstream flooding benefits. Although, consideration could be given to reducing the designated flood storage and pairing this option with additional mitigation works downstream such as the Atkin Creek waterway widening option. A flora and fauna impact assessment, cultural heritage assessment and geotechnical assessment would be required if this option is progressed given the expected changes to flood storage provided upstream of Warncoort-Birregurra Road.	**No**

Mitigation Option	Description	Considerations	Selected for Further Assessment in Section 6.4
D2 Unnamed Tributary Retarding Basin	Formalise a retarding basin upstream of Ennis Street for the attenuation of the Unnamed Tributary flows.	The location of this storage will need to consider future land acquisition which could be considered as part of a Birregurra Structure Plan review. The flood storage has been sized to attenuate the 1 % AEP flow back to the capacity of the Unnamed Tributary at Sladen Street. These works would also require the upgrade of the Skene Street driveway culvert at 48 Skene Street (due to the hydraulic constraint it creates) or alternatively straightening of the Unnamed Tributary at this location (described as Mitigation Option E). The excavation costs associated with these works are significant and the consideration of how and where this storage would lie within the existing steep topography needs to be considered. Nonetheless this option does realise flood reduction benefits to several properties downstream of Sladen Street. A flora and fauna impact assessment, cultural heritage assessment and geotechnical assessment would be required if this option is progressed given the excavation required in order to achieve the flood storage requirements.	**Yes**
E Waterway Straightening of Unnamed Tributary at Skene Street	Modify (straighten) waterway along Unnamed Tributary at Skene Street to improve conveyance from existing meandering alignment.	Required works on upstream end would be within property at Number 36 Skene Street Works are expected to improve conveyance of flows for minor and more frequent storm events however due to the magnitude of flows, particularly in the modelled 1 % AEP event, the works also essentially move flows from one area to another creating localised increases in flood level (afflux). Outcomes from a flora and fauna impact assessment, cultural heritage assessment and geotechnical assessment would be need to be considered if this option is progressed.	**No**
F Hopkins Street Pipe Diversion	1500 mm pipe draining Unnamed Tributary to Barwon River along Hopkins Street	Design to convey medium / high flows only, maintain baseflow and low flow environmental requirements Works would require the need for pipe jacking the last pipe section due to the excessive trench depths (10 metres) and adding significantly to the capital costs. This mitigation option is however expected to have significant benefits for several downstream properties. A flora and fauna impact assessment, cultural heritage assessment and geotechnical assessment would be required if this option is progressed given the size of the proposed diversion pipe and the significant trench depths.	**Yes**
G Drainage Upgrades along Sladen Street	Additional pits within swale and increased pipe capacity along the southern side of Sladen Street to improve conveyance of overland flows originating from rural farmland west of Ennis Street.	In major storm events the ability for pipes to freely drain is restricted downstream tailwater levels in the Unnamed Tributary. Increased pipe and pit capacity have potential to worsen flooding through residential properties if pipes cannot drain freely and / or pits are surcharging during rare storm events.	**Yes**
H Drainage Upgrades between Prime & Sladen Street	Construct large grated inlet pits at low point of Prime Street and Hopkins Street to allow greater inlet capacity and maximise capacity of underground drain	Inflow to existing 600 mm drainage is limited by inlet pit capacities running between Prime Street and Hopkins Street Grated pits located within low points ensures underground stormwater conveyance is maximised.	Yes

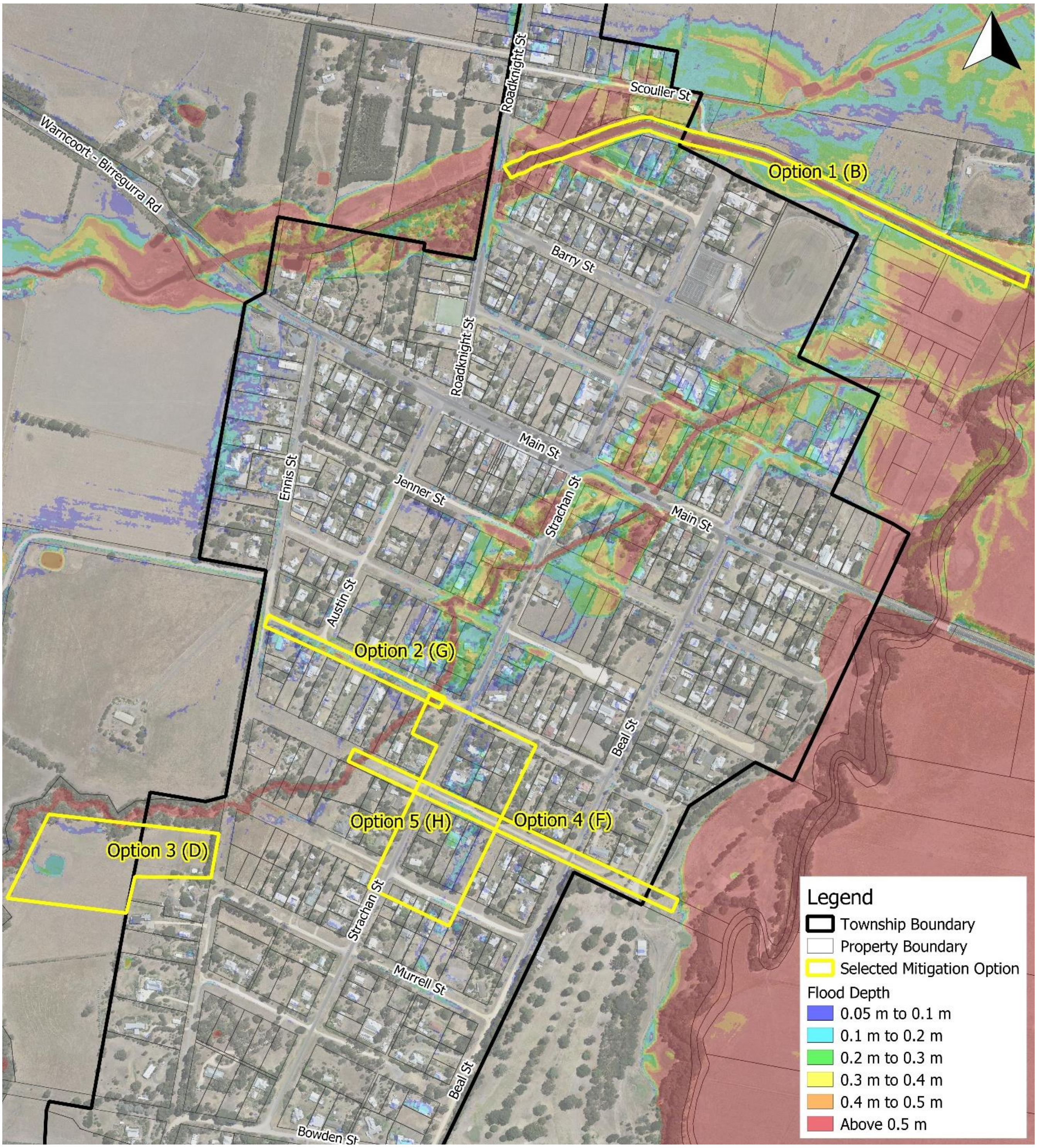
Mitigation Option	Description	Considerations	Selected for Further Assessment in Section 6.4
I Vegetation Removal from Atkin Creek and the Unnamed Tributary	Thorough Trimming of vegetation within Atkin Creek and Unnamed Tributary (downstream of Warncoort-Birregurra Road and Ennis Street respectively)	Dense vegetation (as is the case within Atkin Creek and the Unnamed Trib) can often be perceived as having a significant negative impact on the conveyance of flows. Due to this, vegetation removal can sometimes be considered a potential flood mitigation measure. However, as discussed within Section 4.3.9, following the modelling of the September 2016 sensitivity scenario which assessed the difference in flood depths as a result of thorough vegetation trimming within the waterways, the reductions to flood depths were not considered extensive (typically achieving reductions of up to 100 mm only). The cost of wide-spread vegetation trimming would be a significant ongoing maintenance cost for Council. Consideration of the subsequent impacts to the waterway's ecological values would also need to be investigated to determine whether this option is feasible. This would consist of a flora and fauna impact assessment as well as a cultural heritage assessment.	No

6.4 ASSESSED MITIGATION OPTIONS

Following discussions with Council and Corangamite CMA and consideration of the above listed notes, five (5) mitigation options were selected for further assessment. These options are displayed in Figure 6.1 below.

The following sections provide a summary on the assumptions, considerations, and the required works for each mitigation option and where relevant references are made to the resultant flood depth afflux results provided within **Appendix J**.

Figure 6.1: Location of Selected Mitigation Options (1 % AEP Flood Depth)



6.4.1 Option 1 – Atkin Creek Waterway Widening (B)

The key objective for mitigation Option 1 is to improve the conveyance of flows within Atkin Creek from Roadknight Street to the Barwon River confluence. This option aims to reduce the overtopping of flows which currently result in the flooding of adjacent properties particularly along Scouller Street and Anderson Street.

A widened trapezoidal channel has been included within the hydraulic TUFLOW model between Roadknight Road and the Barwon River confluence. This channel's widened flow area and resultant conveyance capacity was maximised by making the following assumptions:

- No changes to the existing waterway's invert level (to ensure conveyance into the Barwon River is still possible).
- Base width of 8 meters.
- 1 in 3 side slopes.
- Maximum top width of 20 meters which would ensure the widened channel can be accommodated within constrained areas particularly downstream of Strachan Street where based on the road reserve width would only have 20 meters available south of Scouller Street. The total width upstream of Strachan Street is however 30 meters which allows for a small buffer between the widened channel's top of bank and property boundaries.

Based on the modelling undertaken, it is predicted that this widened channel would be able to convey approximately 35 m^3/s. Given the 1 % AEP flow upstream of Roadknight Street is 36.5 m^3/s, assuming limited tailwater impacts, the proposed channel would be capable of conveying the majority of the 1 % AEP flows in contrast to its current capacity of less than 20 m^3/s.

The mitigation modelling results indicate that flows in excess of the widened channel's capacity will impact adjacent properties as is the case in existing conditions, however the reduction in overtopping flows is predicted to result in flood depth decreases of up to 200 mm within properties along Scouller Street and Anderson Street. Minor localised raising of the channel's northern bank between Roadknight Road and Anderson Street could also be considered as part of future works to reduce the magnitude of shallow sheet flows overtopping the Atkin Creek bank.

Appendix J displays the 1 % AEP flood depth afflux highlighting the significant reduction to flood depths. The plan also shows the subsequent increase to flood depths (up to 150 mm). However, this is limited to farmland areas within the Barwon River floodplain.

This is a significant intervention to the waterway and will require further investigation in relation to flora and fauna, cultural heritage and geotechnical considerations to determine whether it is feasible and acceptable in relation to wider legislative requirements.

6.4.2 Option 2 – Drainage Upgrades along Sladen Street (G)

The current drainage system along Sladen Street consists of grassed roadside swales and generally 300 mm driveway culvert crossings. These existing swales and driveway culverts aim to convey runoff originating from the farmland west of Ennis Street to the Unnamed Tributary. However, due to the relatively flat grade and channel flow area, flows overtop Sladen Street in existing conditions and pass through properties on the northern side of the street.

Mitigation Option 2 includes the addition of a drainage line beginning at the corner of Ennis Street and Sladen Street and continuing east along the southern side of Sladen Street and out falling into the Unnamed Tributary. The proposed pipe includes three grated inlet pits located at low points within the existing grass swale to capture overland flows which would have previously overtopped Sladen Street. The following provides a summary of the drainage works and assumptions included in the mitigation modelling undertaken for Option 2:

- 450 mm pipe from Ennis Street to Number 49 Sladen Street.
- 525 mm pipe from Number 49 Sladen Street to discharge at Unnamed Tributary.
- 1 in 80 longitudinal pipe slopes.
- Minimum 600 mm cover on all pipes.
- Three 600 x 600 (length x width) grated pits providing 0.45 m^3/s inlet capacity at ponding depths of up to 500 mm.

Following the modelling of this option for all storm events from the 20 % AEP to the 1 % AEP and closer analysis of the receiving Unnamed Tributary peak flood levels the following was identified:

- A flood depth reduction of less than 25 mm to properties north of Sladen street during a 1 % AEP event.
- The flood mitigation benefits in the 1 % AEP event were limited by the Unnamed Tributary's peak flood level.
- For small to moderate flood events, where the mitigation works would be less inhibited by the downstream peak flood level, the flooding impacts to properties north of Sladen Street were less critical.

As a result of these modelling outcomes, the value provided by this option was considered insignificant and as such disregarded from further assessments presented within this section.

6.4.3 Option 3 – Unnamed Tributary Retarding Basin Upstream Ennis Street (D2)

Option 3 consists of a retarding basin west of Ennis Street, intended to attenuate the peak flows along the Unnamed Tributary prior to entering the Birregurra township. These works would include the design of an inlet and outlet which allows low flows to bypass the storage and high flows to become attenuated respectively. Although the storage has been conceptually located within farmland, the feasibility of this option could be further considered as part of the township's review of the Birregurra Structure Plan. It is however important to note that due to the steep topography west of Ennis Street further design and terrain modelling would need to be undertaken to determine the exact land take requirements. The area presented within this report has excluded the additional land take required for matching the top of bank of the storage to existing ground levels and as such the total asset footprint is expected to be larger than the storage area presented below.

The proposed retarding basin was modelled in RORB with the storage outflow hydrograph applied to the hydraulic TUFLOW model. The following provides details of the retarding basin size and relevance to the 1 % AEP storm event:

- Top of Bank Area = 33,900 m^2.
- 1 in 5 side slopes.
- 1 % AEP Peak Outflow = 7.6 m^3/s (attenuated from 1 % AEP inflow of 20 m^3/s).
- 1 % AEP Storage Depth = 4.33 meters.
- 1 % AEP Peak Flood Storage Volume = 109 ML.

The modelling also identified a constraint caused by the existing driveway crossing at Skene Street. The results indicated the existing 1200 mm diameter culvert had a capacity of approximately 3 m^3/s where the majority of the excess flows would continue north and not within the Unnamed Tributary. As such, the storage works should also consider the need to upgrade this driveway culvert by adding at least 2 additional 1200 mm diameter pipes.

With these works combined, the flood mitigation benefits are significant for all events from the 20 % AEP to the 1 % AEP. **Appendix J** displays the resultant 1 % AEP flood depth afflux plan highlighting reductions of up to 200 mm along the Unnamed Tributary. The plan also indicates that at the Barwon River confluence a marginal increase to flood depths (11-15 mm) is predicted occur. This is likely as a result of the Skene Street culvert upgrade and the improved conveyance of flows within the Unnamed Tributary. As this afflux is limited to the Barwon River floodplain and does not affect existing dwellings, it was considered acceptable.

Should Council determine to pursue investigation of this option, the cultural heritage values will need to be determined with an assessment including field work before confirming the location for this asset.

6.4.4 Option 4 – Hopkins Street Pipe Diversion (F)

Option 4 consists of a 1500 mm drainage pipe diverting water from the Unnamed Tributary at Hopkins Street east towards the Barwon River. The goal of this diversion pipe is to convey medium – high flows which exceed the waterway's capacity downstream and contribute to the overbank flooding under existing conditions. The Unnamed Tributary offtake would be configured to allow low flows to continue within the Unnamed Tributary and high flows to enter the 1500 mm diameter pipe via a large grated pit. The 1500 mm drainage pipe is capable of conveying 6 $m^{3/}$s in the 1 % AEP and assumes:

- 1 in 250 longitudinal slope.
- Minimum 600 mm cover.
- There is a need for pipe jacking for some sections of the alignment when depths to invert are as much as 10 meters.

Appendix J displays the resultant flood depth afflux with the implementation of this pipe diversion. As shown, consistent flood depth decreases of up to 100 mm are predicted to be achieved along the Unnamed Tributary.

6.4.5 Option 5 – Drainage Upgrades between Prime & Sladen Street (H)

The TUFLOW hydraulic model indicates that the existing 600 mm drainage pipes between Prime and Hopkins Street are approximately 50 % full for the 1 % AEP event. To achieve full pipe capacity and reduce flood impact / damage to residential properties in the area, an upgrade to the inlet pits capacity is proposed south of Prime Street and Hopkins Street between Beal Street and Strachan Street. Pits have been sized to provided sufficient inlet capacity to the 600 mm drainage pipes such that the system is flowing full for a 1 % AEP event.

The following provides a summary of the pit upgrades, considerations, and key assumptions for mitigation option 5:

- Upgrade pit inlet at low point of grassed swale fronting 11 Prime Street.
- Upgrade pit inlet at low point in grassed swale along the southern side of Hopkins street fronting 23 Hopkins Street.

Following initial model iterations, the modelling results identified:

- Increases to flood depth within private property in the 1 % AEP north east of the Strachan Street and Sladen Street intersection. This was due to an increase in flows surcharging from the pit immediately upstream of the Strachan Street pipe crossing.
- Approximately 0.6 m^3/s of overland flows remains downstream of the pit upgrade in Prime Street in a 1 % AEP event.

Due to these findings new 750 mm / 900 mm diameter drainage pipes were included in the model to divert the flows in excess of the existing drainage system's capacity to the Unnamed Tributary at Sladen Street. These drainage upgrades assumed:

- Minimum 600 mm cover.
- Minimum 1 in 200 longitudinal grade, steepening to 1 in 30 at the intersection of Prime and Strachan Street to match the grade of Strachan Street.
- Only minor Council road works trenching, and traffic management required.

The resultant 1 % AEP flood depth afflux plan is displayed within **Appendix J**. As shown minor flood depth reductions up to 25 mm were obtained.

6.5 COST ESTIMATE OF MITIGATION OPTIONS

Table 6.2 presents high-level cost estimates for each of the selected mitigation works (excluding the Sladen Street Works). Direct construction cost estimates were derived from Melbourne Water's Development Services Scheme (DSS) costing spreadsheet (2019). The total capital costs have made an allowance for the indirect costs that are likely to be incurred by each option in addition to an overall 20 % contingency rate applied to the sum of the direct and indirect costs. The indirect cost was calculated with an allowance for the following items, presented as a percentage of the total direct cost:

- Site establishment, preparation & reinstatement costs, site supervision and administration fees (~16 % of direct cost).
- Site environmental and traffic management plans (~5 % of direct cost).
- Engineering / consultancy design fees (~15 % of direct cost).

These cost estimates and associated contingencies have not made an allowance for the outcomes which may arise following the completion of further investigations such as flora and fauna impact assessments, cultural heritage assessments and geotechnical assessments. The findings from these assessments may highlight the need for additional approvals and / or changes to the conceptual mitigation options presented and as such alterations to the cost estimates presented below would be required.

Table 6.2: Cost Estimate Mitigation Options

Mitigation ID	Description	Direct Cost	Indirect Cost	Total Capital Cost (Direct + Indirect) + 20 % Contingency)
1	Atkin Creek Waterway Widening	$800,000	$268,000	$1,282,000[6]

[6] Estimated capital cost has used standard typical rates for channel works. They are indicative only and subject to further investigation with consideration of the specific site's characteristics and constraints.

Mitigation ID	Description	Direct Cost	Indirect Cost	Total Capital Cost (Direct + Indirect) + 20 % Contingency)
3	Unnamed Tributary Retarding Basin Upstream Ennis Street	$4,100,000	$1,374,000	$6,569,000
4	Hopkins Street Pipe Diversion	$2,262,000	$758,000	$3,624,000
5	Drainage Upgrade Between Prime & Sladen Street	$861,000	$289,000	$1,380,000

6.6 AVERAGE ANNUAL DAMAGES COMPARISON

Table 6.3 provides a summary of the calculated damages for each event and modelling scenario. Table 6.4 presents the number of buildings flooded above floor level. Option 3 show the greatest reduction in flood damages and number of buildings flooded above floor level for the rare storm events (5 %, 2 %, and 1 % AEP) while Options 1 presents more benefit for frequent storm events (20 % AEP).

Table 6.3: Summary of Calculated Event Damages per Modelling Scenario and AEP Event

Scenario	AEP Event				
	20 %	10 %	5 %	2 %	1 %
Existing Conditions	1,316,613	2,543,329	$3,662,597	$5,664,210	$6,576,244
Mitigation Option 1 – Atkin Creek Waterway Widening	$840,426	$2,111,347	$3,165,858	$4,774,976	$5,652,573
Mitigation Option 3 – Unnamed Tributary Retarding Basin Upstream Ennis Street	$1,128,227	$2,035,684	$2,871,438	$4,208,873	$5,015,312
Mitigation Option 4 – Hopkins Street Pipe Diversion	$1,124,668	$2,086,476	$3,013,181	$5,044,947	$5,868,252
Mitigation Option 5 –Drainage Upgrade Between Prime & Sladen Street	$1,294,050	$2,543,329	$3,335,470	$5,660,166	$6,521,980

Table 6.4: Number of Buildings Flooded Above Floor Level per Modelling Scenario and AEP Event

Scenario	AEP Event				
	20 %	10 %	5 %	2 %	1 %
Existing Conditions	5	7	9	23	26
Mitigation Option 1 – Atkin Creek Waterway Widening	2	4	7	20	22
Mitigation Option 3 – Unnamed Tributary Retarding Basin Upstream Ennis Street	4	5	6	13	17
Mitigation Option 4 – Hopkins Street Pipe Diversion	4	5	7	14	20
Mitigation Option 5 –Drainage Upgrade Between Prime & Sladen Street	4	7	8	23	25

Calculation of the contribution of each AEP to the total AAD for each modelled scenario was then undertaken via consideration of the calculated event damage and the likelihood of the flood event. As a result of this, the 1 % AEP contribution to AAD is generally less than the 10 % AEP, despite the 1 % AEP event predicting a larger number of buildings / larger extent of the roadways at risk of flooding. The total AAD per each modelling scenario was then calculated as the summation of each AEP's contribution to the AAD. Table 6.5 provides a summary of the calculated AAD for each modelled scenario.

The Atkin Creek water widening option (Option 1) presents the largest cost savings, approximately $170,000 / year, followed by the Unnamed Tributary Retarding Basin option (Option 3) at approx. $144,000 / year. The Hopkins Street pipe diversion (Option 4) presents moderate AAD benefits, approx. $115,000 / year, and the drainage upgrades between Prime and Sladen Street (Option 5) shows only minor benefits, approx. $18,000 / year.

Table 6.5: Estimated AAD per Model Scenario

Scenario	AAD ($ / year)	Reduction in AAD ($ / year)
Existing Conditions	$746,741	-
Mitigation Option 1 – Atkin Creek Waterway Widening	$576,833	$169,908
Mitigation Option 3 – Unnamed Tributary Retarding Basin Upstream Ennis Street	$602,433	$144,308
Mitigation Option 4 – Hopkins Street Pipe Diversion	$632,187	$114,554
Mitigation Option 5 –Drainage Upgrade Between Prime & Sladen Street	$728,792	$17,949

6.7 HIGHLEVEL MULTI-CRITERIA ASSESSMENT

Table 6.5 presents the high-level multi-criteria assessment for each mitigation option considering the tangible criteria such as the calculated AAD result and the capital cost in addition to the following non-tangible considerations for each option:

- Social impacts / benefits including:
  - Disruption to private properties / public open spaces.
  - Disruption to major / minor roads.
  - changes to flooding for vulnerable properties.
- Environmental impacts / benefits including:
  - Vegetation removal / potential disturbance to habitats.
  - Stormwater harvesting opportunity.
- Constructability considerations including:
  - Existing services.
  - Land acquisition requirements.
- Risks including:
  - Risk of worsening flooding conditions.
  - Propensity for ongoing maintenance / design issues.

Table 6.6: Multi-Criteria Assessment for Selected Mitigation Options

Mitigation ID	Description	AAD Result ($ / year)	AAD Reduction ($ / year)	Total Capital Cost	Social and Cultural Impact / Benefit	Environmental Impact / Benefit	Constructability	Risks
1	Atkin Creek Waterway Widening	$576,833	$169,908	$1,282,000	• Medium disruption to public open spaces as works are maintained within Council owned land or road reserve. Some disruption to Scouller Street likely. • Benefits several properties currently subject to above floor level flooding in all storm events between 20 % to 1 % AEP • Potential impact to areas of cultural heritage significance – Cultural Heritage Management Plan (CHMP) would be required	• Disruption to existing environmental values provided by vegetation within Atkin Creek • Habitat disturbance and potential impact to vulnerable species within waterway. • A flora and fauna impact assessment would need to be conducted prior to any works to understand feasibility • Potential for the vegetation removed to be reinstated / carefully established with appropriate management plans	• Widening works do not include the deepening of the existing Atkin Creek invert and as such clashes with existing underground services is reduced. • No additional land acquisition required	• Increase to flood depths identified however afflux area is contained to the Barwon River Floodplain where no existing dwellings are present.
3	Unnamed Tributary Retarding Basin Upstream Ennis Street	$602,433	$144,308	$6,569,000	• Disruption limited to farmland and driveway upgrade at 48 Skene Street • Potential impact to areas of cultural heritage significance – Cultural Heritage Management Plan would be required	• Opportunity to incorporate wetland / stormwater harvesting system within base of RB • A flora and fauna impact assessment would be required	• Land acquisition required	• Dependent on further investigations into design arrangement, RB likely to have inherent risk such as embankment failure.
4	Hopkins Street Pipe Diversion	$632,187	$114,554	$3,624,000	• Disruption to use of Hopkins Street and access to properties • Potential impact to areas of cultural heritage significance – CHMP would be required	• Removal of vegetation required within the Unnamed Tributary offtake location in addition to Barwon River outlet. • Potential for habitat disturbance with vegetation removal • A flora and fauna impact assessment would be required •	• Depth of Trenching and need to bore a section of the 1500 mm diameter pipe	• Potential maintenance burden associated with pipe offtake and weir pit arrangement within the Unnamed Tributary to ensure low flow bypass functions as intended.
5	Drainage Upgrade Between Prime & Sladen Street	$728,792	$17,949	$1,380,000	• Disruption to use of Prime Street and along Strachan Street • Potential impact to areas of cultural heritage significance – CHMP would be required	-	-	-

7 STORMWATER TREATMENT ASSESSMENT

7.1 PURPOSE

Future development of Birregurra (informed by the Birregurra Structure Plan) poses potential risks to the environmental values of receiving waterways (Atkin Creek, Unnamed Tributary and Barwon River) if the stormwater quality from new developments is not appropriately considered and managed. There is also an opportunity to improve the stormwater quality from existing development to enhance the health of the Barwon River and local waterways.

Due to a new development's increased impervious fraction, additional pollutant loads are generated. Under legislative requirements, new developments are required to implement Water Sensitive Urban Design (WSUD) assets which treat the stormwater generated to meet a set of pollutant load reduction targets. These are referred to in the Commonwealth Scientific and Industrial Research (CSIRO) Urban Stormwater Guidelines (CSIRO, 1999) as the Best Practice Environmental Management Guidelines (BPEMG) targets and consist of an:

- 80 % reduction of Total Suspended Solids (TSS).
- 45 % reduction of Total Phosphorus (TP).
- 45 % reduction of Total Nitrogen (TN).
- 70 % reduction of Gross Pollutants (GP).
- Retention of flows to pre-development 1.5 year Average Recurrence interval (ARI) pre-development.

Birregurra is an established regional residential town with few vacant lots but significant opportunity for subdivision and densification as identified in the Birregurra Structure Plan. Due to these characteristics, the current planning of WSUD assets is challenging due to the need to retrofit drainage assets and the associated physical land constraints. Although the exact location of WSUD assets is uncertain, Engeny has undertaken this stormwater treatment assessment to provide Council with initial guidance on the type / extent of WSUD assets which could be considered given the predicted increase in stormwater runoff. The outcomes of this investigation could be used to inform the future planning for growth and could also be considered in the next revision of the Birregurra Structure Plan. The assessment has specifically:

- Identified the wetland asset footprint area which would be required to meet the pollutant load removal targets for the predicted increase in impervious area from future development.
- Assessed the benefits and practicality of incorporating street-scale bio-retention basins and lot-scale rainwater tanks.
- Assessed the benefits of sealing the roads within Birregurra.

7.2 METHODOLOGY

Model for Urban Stormwater Improvement Conceptualisation (MUSIC) software has been used to assess the pollutant loads generated from the Birregurra township and the resultant removal rates achieved through the implementation of various WSUD treatment assets. The following provides a summary of the methodology and assumptions adopted:

1. Calculate the increased impervious area for future developed conditions considering the zoning, classification areas and associated minimum lot sizes outlined within the Birregurra Structure Plan (discussed Section 7.3).
2. Include these areas as 'Urban Source Nodes in the MUSIC model to estimate the pollutant loads generated (Total Suspended Solids, Total Nitrogen, Total Phosphorus and Gross Pollutants) from the predicted total additional impervious area.
3. Calculate the pollutant loads (kg / year) which need to be removed to achieve the BPEMG targets.
4. Add a wetland treatment node assuming it is located at the downstream end of the Unnamed Tributary within the Barwon River floodplain with its catchment being the entire Birregurra township.
5. Size wetland to achieve BPEMG targets for the additional impervious area (calculated in Step 3).
6. Assess additional pollutant loads which would be removed through the implementation of 3 KL rainwater tanks.
7. Assess the pollutant load removal benefits which would be achieved through the implementation of a street-scale bioretention basin and factor up to determine the total treatment area which would be required to meet BPEMG targets.

8. Assess pollutant loads generated from unsealed road surfaces and the reduction of pollutants which could be achieved by sealing the roads within the township.

The water quality modelling has been undertaken in accordance with Melbourne Water's updated *MUSIC Guidelines* (2018) where the following parameters and assumptions were adopted in the general model set-up:

- 10-year 6-minute rainfall data (2000-2010) from the Winchelsea (post office) station dataset was extracted from the eWater online portal. This data contained an Average Annual Rainfall of 410 mm.
- Average annual Potential Evapotranspiration (PET) of 1059 mm extracted.
- Soil Storage = 120 mm and Field Capacity = 50 mm.
- Fraction Impervious values displayed in Table 7.1 for each land use.

These fraction impervious values were informed by the typical recommended ranges provided within Melbourne Water's MUSIC guidelines (2018). Due to the regional residential characteristics of Birregurra the road fraction impervious was assumed to be slightly lower than the standard range of 0.5-0.8 which are more representative of a paved kerb and channel road arrangement. The lower density residential areas have also been classified into allotment sizes to achieve a better representation of existing conditions. These values were interrogated against the township's aerial photography. Although the Infrastructure Design Manual (IDM) is Council's engineering guide, it only outlines recommended runoff coefficients for the various lot sizes which is calculated using both the fraction impervious and rainfall insensitivity. Given the rainfall intensity can vary when undertaking MUSIC modelling, the MUSIC guidelines and interrogation of aerial photography was considered an appropriate approach.

Table 7.1: Fraction Impervious Values Adopted in MUSIC Model

Land Use	Allotment Size (m^2)	Adopted Fraction Impervious	MUSIC Guidelines Recommended Fraction Impervious Range
Road	-	0.45	0.50 – 0.80
Open Space	-	0.05	0.00 – 0.20
Commercial	-	0.80	0.70 – 0.90
General Residential	300 - 600 m^2	0.75	0.70 – 0.80
	600 - 1,000 m^2	0.60	0.50 – 0.80
Low Density Residential	1,000 - 1,200 m^2	0.55	0.10 – 0.30
	1,200 - 1,400 m^2	0.50	0.10 – 0.30
	1,400 - 1,600 m^2	0.45	0.10 – 0.30
	1,600 - 2,100 m^2	0.40	0.10 – 0.30
	2,100 - 8,000 m^2	0.20	0.10 – 0.30
	> 8,000 m^2	0.15	0.10 – 0.30

7.3 PREDICTED FUTURE DEVELOPMENT AREA

Assumptions were made to estimate the predicted increase in impervious area as a result of future development within Birregurra. This was required in order to determine the target pollutant loads which should be removed to achieve the BPEMG targets.

The Birregurra Structure Plan outlines the identified character areas and associated minimum single and multi-unit dwelling lot sizes for each character area as displayed in Figure 7.1 and Table 7.2 respectively. In conjunction with this information the following assumptions were also used to estimate the increased impervious area:

- Existing developed lots within Birregurra were summed for each character area and assumed to subdivide into the relevant single dwelling lot size value for each relevant character area.
- Existing undeveloped lots within Birregurra were summed for each character area and assumed to develop into the relevant minimum multi-unit lot size value (except character areas D and E where the single dwelling lot size value was used). For character areas D and E some increase in impervious fraction is possible given that the existing level of development is below guideline values.
- Existing undeveloped lots zoned with a commercial land use were assumed to develop with an 80 % impervious fraction under future developed conditions. This lies within MUSIC's recommended range and aims to more closely reflect the level of development which would be likely within the regional residential town of Birregurra based on aerial photography.

Figure 7.1: Birregurra Structure Plan Preferred Character Areas

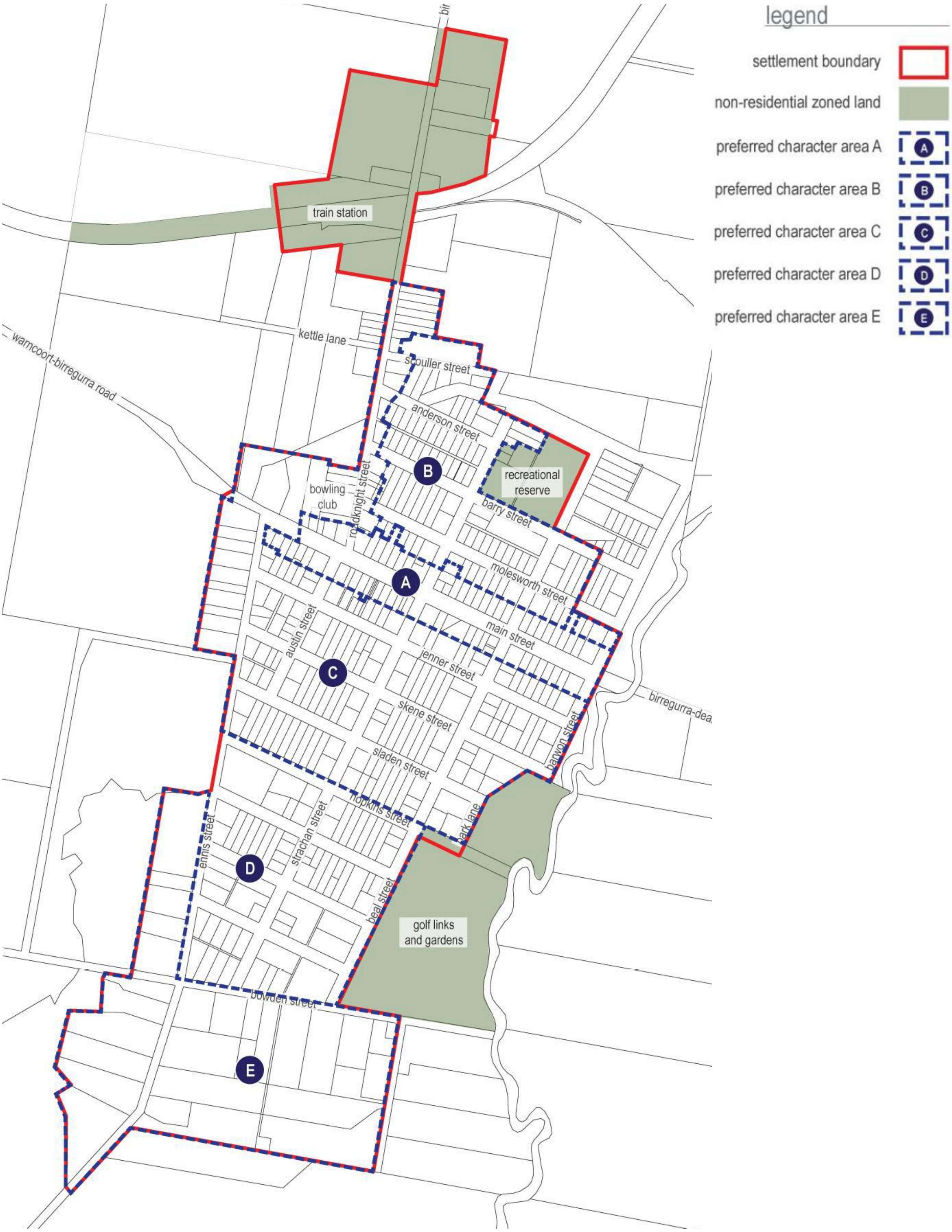


Table 7.2: Proposed Subdivision for Preferred Character Areas

Character Area	Min. lot size single dwelling (m^2)	Min. lot size multi-unit dwelling (m^2)
A	1,000	500
B	700	500
C	1,000	600
D	1,000	discouraged
E	4,000	discouraged

Table 7.3 summarises the estimated increased impervious areas for Birregurra based on the assumptions made under the predicted fully developed conditions. The table also displays the percentage increase from existing conditions.

Table 7.3: Predicted Increase in Impervious Area from Future Development

	Increase in Impervious Area (ha)			% Impervious Area Increase from Existing Conditions		
Character Area	Existing Developed Residential	Existing Undeveloped Residential	Existing Undeveloped Commercial	Existing Developed Residential	Existing Undeveloped Residential	Existing Undeveloped Commercial
A	0.28	0.22	0.08	6.9 %	70.0 %	4 %
B	0.95	2.08	0.00	10.8 %	64.3 %	0 %
C	5.21	5.53	0.60	22.0 %	70.0 %	33 %
D	3.18	2.52	0.00	26.6 %	55.0 %	0 %
E	0.89	1.23	0.00	3.5 %	15.0 %	0 %
Total	**10.51**	**11.58**	**0.68**	**14.3 %**	**47.8 %**	**16.0 %**

7.4 POLLUTANT REMOVAL TARGETS

The increased residential and commercial impervious areas presented in Table 7.3 were modelled in MUSIC to determine the resultant mean pollutant loads generated. Table 7.4 summarises these pollutant loads in addition to the target pollutant removal loads required to meet the BPEMG reduction targets.

Table 7.4: Pollutant Removal Targets for Birregurra Township

Pollutant	Pollutant Load generated from Increased Impervious Area (kg / year)	Target Pollutant Load requiring removal to achieve BPEMG Target (kg / year)	% BPEMG Pollutant Reduction Target
Total Suspended Solids (TSS)	13,590.0	10,872.0	80 %
Total Phosphorus (TP)	21.8	9.8	45 %
Total Nitrogen (TN)	161.0	72.4	45 %
Gross Pollutants (GP)	2,968.5	2,078.0	70 %

7.5 WETLAND ASSET FOOTPRINT

End of drainage line WSUD treatment assets such as wetlands reduce Council's long-term maintenance cost. Following discussions with Council, a consolidated wetland at the Unnamed Tributary's confluence to the Barwon River was modelled and sized. At this location it is noted that the land where the wetland is indicatively positioned is flood prone and as such future residential development is constrained and limited. The location also provides an opportunity to integrate a stormwater harvesting system which could provide an alternative water source for the irrigation of the oval located on the west.

The following assumptions were made during the sizing of the wetland asset in relation to its function and size:

- Contributing catchment area from the Unnamed Tributary consisting of:
  - township Area = 113.8 ha (Weighted Fraction Impervious = 0.44).
  - Upstream Agricultural Area = 417.3 ha (Weighted Fraction Impervious = 0.05).

  Given its current assumed location there is also an opportunity for the wetland asset to receive some low flows from Atkin Creek if required. Although, future development within the contributing Atkin Creek catchment, is expected to be somewhat minor when compared to the Unnamed Tributary's catchment.
- Wetland Treatment Area = 9,000 m^2.
- Wetland Permanent Pool Volume (PPV) = 3,600 m^3.
- Sediment Inlet Pond Area = 1,600 m^2.
- Sediment Inlet Pond Volume = 1,450 m^3.
- Sediment Drying Area = 1,785 m^2.
- Extended Detention Depth = 0.35 m.
- Low Flow Bypass = 0.7 m^3/s (50 % Q3-month remains within creek).
- High Flow Bypass = 6.9 m^3/s (flows in excess of 20 % AEP bypass into creek).

The total wetland asset footprint was estimated at approximately 22,500 m^2. This area considers:

- The wetland and sediment inlet pond treatment areas and associated 1 in 5 battering.
- The predicted sediment drying area.
- A 25 % increase to allow for the terrain shaping associated with the wetland's bathymetry.
- A 10-metre buffer surrounding the total treatment and drying area to allow for a maintenance access track and associated 1 in 5 battering.

This estimated wetland footprint and part of its contributing catchment area is displayed below in Figure 7.2.

Based on these inputs, the MUSIC results shown in Table 7.5 were obtained. As shown when considering the pollutant source generated from the additional impervious area only and the total pollutant removed with the wetland asset, the BPEMG reduction targets are achieved.

Table 7.5: MUSIC Treatment Effectiveness of Wetland Asset

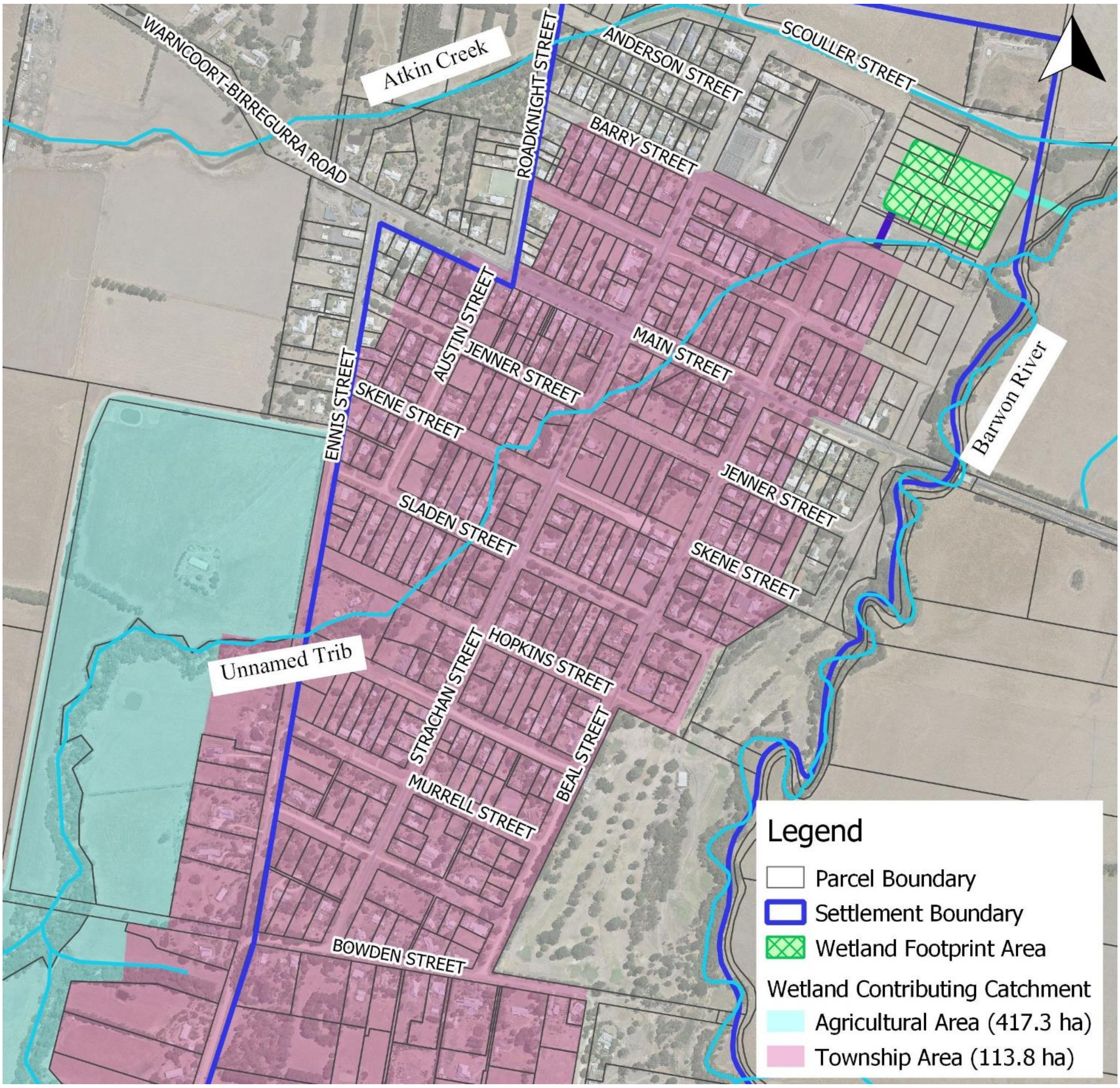
Pollutant	Pollutant Source from Additional Impervious Area	Pollutant Load Removed with Wetland Asset	% Reduction Achieved
Total Suspended Solids (kg/yr)	13,590.0	17,900.0	> 100 %
Total Phosphorus (kg/yr)	21.8	16.1	74.0 %
Total Nitrogen (kg/yr)	161.0	87.0	54.0 %
Gross Pollutants (kg/yr)	2,968.5	2,240.0	75.5 %

It is important to note that if the location of the wetland asset is not deemed suitable through the future planning and revision of the Birregurra Structure Plan, in order to achieve the treatment effectiveness required the following needs to be ensured:

- The wetland cannot be located at the upstream end of the township and should at least have a contributing 20-hectare township catchment area.

- Modifications to the low flow bypass in addition to the high flow bypass should be considered.
- MUSIC modelling should be revised with the updated contributing catchment area to confirm the resultant treatment effectiveness.

Figure 7.2: Wetland Footprint and Contributing Catchment Area



7.6 BENEFITS OF LOT-SCALE RAINWATER TANKS

Rainwater tanks are a lot-scale, at source stormwater quality treatment measure. They can provide multiple benefits including reducing the mean annual load of pollutants discharging into receiving environments and providing a valuable reuse alternative to potable water for toilet flushing, use in laundries and garden irrigation.

A MUSIC model was developed to quantify the additional pollutant load reductions that could be achieved with the installation of rainwater tanks in conjunction with the wetland asset sized above.

The following outlines the assumptions adopted within the MUSIC model:

- The calculated sum of the identified undeveloped lots for each character area was divided by the relevant minimum multi-unit single dwelling lot size to calculate the number of lots. Each of these lot's roof areas was assumed to connect to 3KL rainwater tank. Although Section 7.3 also predicts the existing developed residential areas could also be further developed and subdivided into the identified minimum single dwelling lot size, these developments were not assumed to have connected rainwater tanks.
- Each lot's roof area was assumed to equal 80 % of the lot's impervious area (this percentage of roof area assumes the additional 20 % of imperviousness would be associated with driveways and paved areas).
- Daily reuse demand per person = 20 L/person/day (sourced from the Australian Government's Your Home online resource for Toilet Flushing demand).
- Number of people per household = 2.4 (sourced from the 2016 Census Data).

By adopting these assumptions for each character area within the previously sized wetland's contributing area, the MUSIC results presented within Table 7.6 were obtained. As shown, this would increase the % reduction achieved when compared to the scenario without rainwater tanks and potentially justify the reduction in the wetland area required to meet the BPEMG targets.

Table 7.6: MUSIC Treatment Effectiveness of 3KL Rainwater Tanks

Pollutant	Pollutant Source from Additional Impervious Area	Pollutant Load Removed with Wetland Asset and 3KL Rainwater Tanks	% Reduction Achieved
Total Suspended Solids (kg/yr)	13,590.0	18,119.0	> 100 %
Total Phosphorus (kg/yr)	21.8	16.8	77.0 %
Total Nitrogen (kg/yr)	161.0	96.7	60.1 %
Gross Pollutants (kg/yr)	2,968.5	3,228.0	> 100 %

Based on the results presented within this section, Council could consider the implementation of planning provisions/ subdivision policies to mandate the need for a rainwater tank particularly given the likely reduction to the required wetland asset footprint. Given that most of the town is already developed, other incentive schemes could be considered with Barwon Water to explore opportunities to encourage property owners to install water tanks.

7.7 BENEFITS OF STREET-SCALE BIORETENTION ASSETS

The treatment effectiveness of a single street-scale bioretention asset was assessed. The following was assumed:

- Single Bioretention Treatment Area = 100 m^2.
- Extended Detention Depth = 0.35 m.
- Filter Media Depth = 0.5 m.
- Contributing Catchment Area = 1.35 ha.
- Contributing Catchment Weighted Fraction Impervious = 0.6.

With a single asset and contributing catchment area of this size, the MUSIC treatment effectiveness displayed within Table 7.7 was obtained.

Table 7.7: MUSIC Treatment Effectiveness of Single Bioretention Asset

Pollutant	Pollutant Source from Single Bioretention Asset Contributing Catchment Area	Pollutant Load Removed with Single 100 m² Bioretention Asset	% Reduction Achieved
Total Suspended Solids (kg/yr)	1,980.0	1,890.1	95.5
Total Phosphorus (kg/yr)	1.3	0.9	67.6
Total Nitrogen (kg/yr)	6.8	4.2	61.0
Gross Pollutants (kg/yr)	140.0	140.0	100.0

The asset area was factored up to estimate the treatment area required to meet the township's BPEMG targets assuming the same contributing catchment area characteristics. This resulted in the following areas in order to achieve the treatment effectiveness summarised in Table 7.8:

- Estimated Total Bioretention Treatment Area = 1740 m².
- Estimated Total Contributing Catchment Area = 23.66 ha.

Although this arrangement would meet the BPEMG targets, the following factors should also be considered:

- Although a bioretention treatment area greater than 100 m² could be implemented, guidelines recommend the contributing catchment area should be less than 5 hectares.
- If approximately 17 assets with treatment areas of 100 m² each are implemented an increased reliance on maintenance would be required.

Table 7.8: MUSIC Treatment Effectiveness of Bioretention Assets

Pollutant	Pollutant Source from Additional Impervious Area	Pollutant Load Removed with multiplied Bioretention Assets	% Reduction Achieved
Total Suspended Solids (kg/yr)	13,590.0	32,887.7	> 100 %
Total Phosphorus (kg/yr)	21.8	14.9	68.6 %
Total Nitrogen (kg/yr)	161.0	72.6	45.1 %
Gross Pollutants (kg/yr)	2,968.5	2,436.0	82.1 %

7.8 BENEFITS OF SEALED ROADS

The Birregurra township consists mostly of unsealed roads which can result in the generation of increased sediment and pollutant loads. MUSIC enables users to simulate the difference in pollutants generated from sealed versus unsealed roads to identify the benefits of potentially formalising the road network. Table 7.9 presents this comparison when assuming all roads within Birregurra become sealed. The results highlight that the sealing of roads reduces the TSS load by up to 73 % with minor decreases to the nutrient load as well.

Table 7.9: MUSIC Treatment Effectiveness of Sealed Roads

Pollutant	Pollutant Source from Unsealed Roads	Pollutant Source from Sealed Roads	% Reduction Achieved
Total Suspended Solids (kg/yr)	56,300.0	15,000.0	73.4 %
Total Phosphorus (kg/yr)	25.6	25.5	0.4 %
Total Nitrogen (kg/yr)	107.0	104.0	2.8 %
Gross Pollutants (kg/yr)	2,190.0	2,190.0	0.0 %

7.9 OTHER CONSIDERATIONS

Other treatment measures which could also be considered are Gross Pollutant Traps (GPT). They are considered a primary treatment measure which can remove TSS and GPs. They can be installed to:

- Treat wetland asset inflows to reduce Council's long-term maintenance requirements in the wetland asset.
- Treat otherwise untreated outflows to the waterways to ensure the receiving waterways are protected from excessive sediment and gross pollutant loads.

These have not been included in the modelling undertaken as GPT's cannot claim nitrogen removal which is typically the pollutant which dictates the treatment areas required. It is also worth noting the GPTs have their own maintenance requirements and are ineffective if not maintained regularly.

7.10 COST ESTIMATE OF WSUD ASSETS

Standard rates sourced from Melbourne Water's DSS spreadsheet were used to inform the estimated capital cost of the wetland asset and bioretention assets discussed above. The following contingencies were applied to the capital cost estimates summarised within Table 7.10:

- Indirect costs calculated based on:
  - Site establishment, preparation & reinstatement costs, site supervision and administration fees (~16 % of direct cost).
  - Site environmental and traffic management plans (~2.5 % of direct cost).
  - Engineering / consultancy design fees (~15 % of direct cost).
- Additional 20 % contingency applied to the sum of Direct and Indirect Costs to account for potential changes during detailed/ construction phase.

Although these contingencies have made some allowance for uncertainties in the design of the proposed WSUD further investigations including flora, fauna, geotechnical and cultural heritage assessments will be required to confirm the feasibility and approvals required. These investigations and their outcomes may significantly increase the cost estimates presented in Table 7.10.

The table below also provides an estimate of the ongoing maintenance costs utilising the standard rates provided within the WSUD Life Cycle Costing Data Analysis Report prepared by Parsons Brinckerhoff for Melbourne Water (2013).

Table 7.10: WSUD Asset Cost Summary

Item Allowance	Cost
WETLAND CAPITAL COST	
Planting and Earthworks (Sediment Inlet Pond & Wetland Treatment Area)	$1,666,700
Litter Trap / GPT	$71,500
High flow Bypass	$6,800
Outlet Control Structure	$70,500
Total Direct Cost	$1,816,000
Total Indirect Cost	$609,000
TOTAL (including direct and indirect cost) + 20 % contingency	*$2,910,000*
WETLAND ONGOING MAINTENANCE COST	*$20,000 / year*
BIORETENTION CAPITAL COST	*$2,180,000*
BIORETENTION ONGOING MAINTENANCE COST	$26,000 / year

8 PLANNING OVERLAYS AND CONTROLS

8.1 BACKGROUND

Flood related planning controls are applied in Council's Planning Scheme through the use of designated planning overlays. These are used to ensure flood risks are appropriately considered as part of any development of flood prone land. The strategy has identified that the existing flood planning controls in the Colac Otway Planning Scheme for Birregurra do not sufficiently identify flood prone land and therefore are not effectively informing decisions about development. In contrast to the construction of structural mitigation works, planning controls are one of the most cost-effective means of reducing the community's flood risk by:

- Encouraging people to, where possible, avoid development on flood-prone land.
- Minimising the potential impacts on existing flood-prone developments by raising floor levels of proposed habitable buildings and ensuring the development does not increase the risk of flooding on other properties.

As part of this study planning controls for a series of flood overlays were developed using the design 1 % AEP flood mapping outputs. Draft planning maps and associated schedule documentation has been prepared and is suitable for amendments to the Colac Otway Planning Scheme, to update and replace the existing flood controls currently covering parts of the Birregurra township.

There are three main planning controls to identify flood prone land within the Victorian Planning Provisions: the Floodway Overlay (FO), the Land Subject to Inundation Overlay (LSIO); and the Special Building Overlay (SBO). Their purpose reflects different levels of flood risk. Details of the relevant overlays proposed, and their significance is provided within the sections below. Refer to **Appendix K** for the associated parent clause which should be read in conjunction with the details provided below and the draft planning schedule documentation included as **Appendix L**.

8.1.1 Floodway Overlay (FO)

The FO applies to active flood paths including waterways, significant depressions and areas associated with high hazard. The FO can sometimes be identified as land conveying active flood flows or the high hazard portion of the floodplain and as such new development in these areas is quite restricted. The purpose of the FO is as follows:

- To identify waterways, major flood paths, drainage depressions and high hazard areas which have the greatest risk and frequency of being affected by flooding.
- To ensure that any development maintains the free passage and temporary storage of floodwater, minimizes flood damage and is compatible with flood hazard, local drainage conditions and the minimization of soil erosion, sedimentation, and silting.
- To reflect any declarations under Division 4 of Part 10 of the Water Act, 1989 if a declaration has been made.
- To protect water quality and waterways as natural resources in accordance with the provisions of relevant State Environment Protection Policies, and particularly in accordance with Clauses 33 and 35 of the State Environment Protection Policy (Waters of Victoria).
- To ensure that development maintains or improves river and wetland health, waterway protection and floodplain health.

8.1.2 Land Subject to Inundation Overlay (LSIO)

The LSIO identifies land which is flood affected by overland flow, areas contributing to the floodplains storage or areas fringing a FO. Development and works proposed within an LSIO require a planning permit where the subsequent planning controls are imposed which are intended to ensure the development:

- Maintains unobstructed passage of floodwaters.
- Maintains flood storage.
- Minimises flood damage to proposed building footprints.
- Considers flood hazard and local drainage conditions.
- Does not increase flood levels or velocities on surrounding properties.

The LSIO planning controls imposed through planning permits are similar to those imposed with Special Building Overlays (SBOs). The key difference is the mechanism of flooding and the LSIO and FO directly relate to flooding associated with waterways or runoff from rural land.

The LSIO produced for Birregurra covers flooding along the Atkin Creek and Unnamed Tributary waterways in addition to local minor tributaries which originate from the rural farmland west of the township boundary. The purpose of the overlay is to:

- To identify land in a flood storage or flood fringe area affected by the 1 in 100-year flood or any other area determined by the floodplain management authority.
- To ensure that development maintains the free passage and temporary storage of floodwaters, minimizes flood damage, is compatible with the flood hazard and local drainage conditions and will not cause any significant rise in flood level or flow velocity.
- To reflect any declaration under Division 4 of Part 10 of the Water Act, 1989 where a declaration has been made.
- To protect water quality in accordance with the provisions of relevant State Environment Protection Policies, particularly in accordance with Clauses 33 and 35 of the State Environment Protection Policy (Waters of Victoria).
- To ensure that development maintains or improves river and wetland health, waterway protection and floodplain health.

8.1.3 Special Building Overlay (SBO)

The proposed draft planning overlays produced for Birregurra include two key flow paths that have been included in the SBO extent as these areas are located within urbanized areas of the township where flooding is attributed to the lack of capacity in the underground drainage system to convey stormwater.

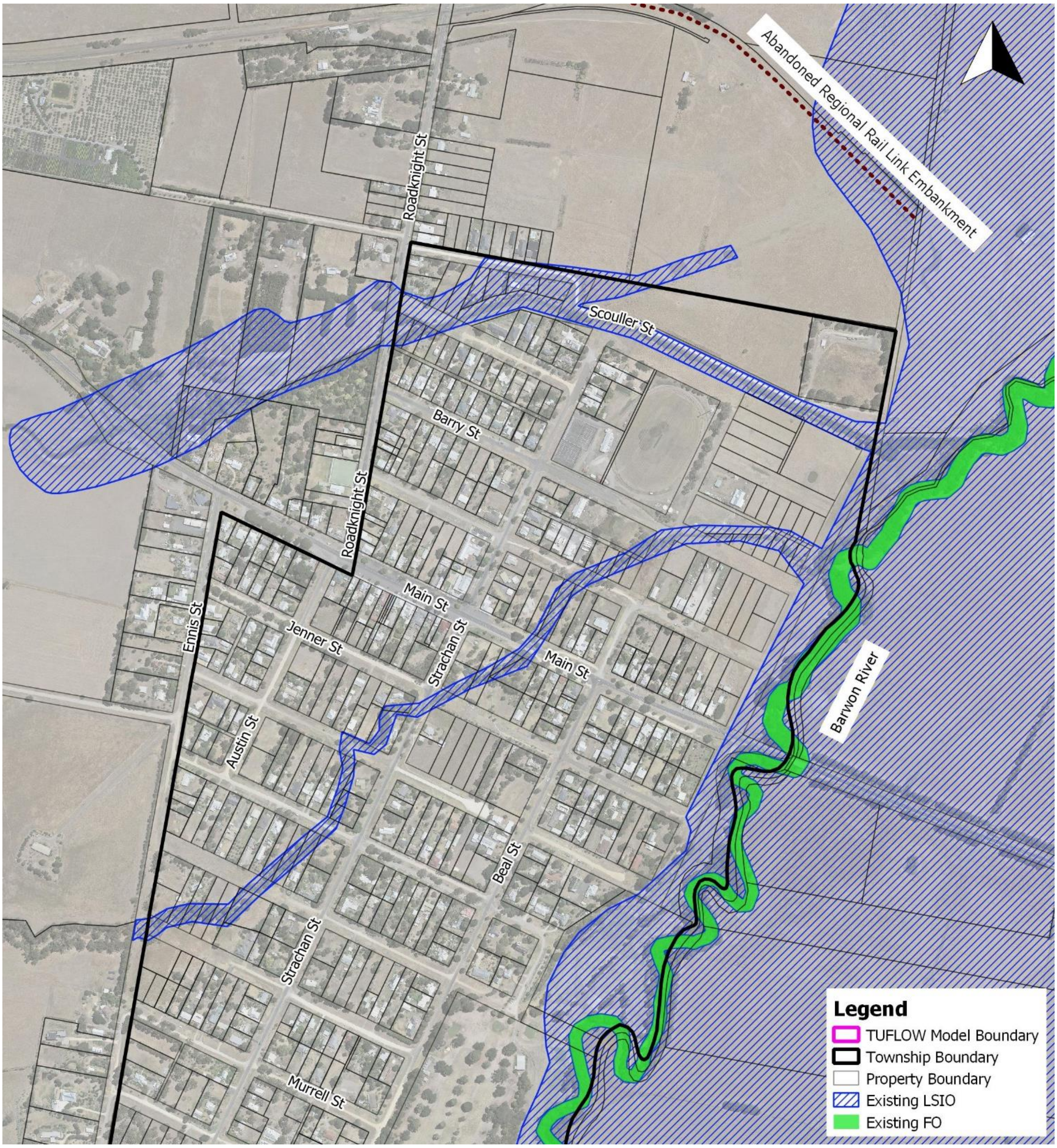
Current industry practice requires the consideration of both major and minor stormwater flows where in addition to conveying minor flows within underground drains, new developments also need to consider the conveyance of major flows resulting from the 1 % AEP event and in excess of the underground drainage capacity (gap flow). These flows are typically conveyed within road reserves and easements. In areas which are well established, such as Birregurra this allowance within development areas and drainage infrastructure has not been made due to differences in the now outdated industry standards and drainage guidelines. Many developments pre-date the introduction of industry standards or the drainage guidelines of the time did not adequately consider the conveyance of overland major flows. The SBO is a way to identify areas where overland flow paths exist. The defined SBO flow paths are included to ensure future developments covered by the overlay consider the flow path and meet the planning controls to manage flood risk.

8.2 EXISTING OVERLAYS AND PLANNING CONTROLS

In the Colac Otway Planning Scheme, an existing LSIO covers sections of Atkin Creek and the Unnamed Tributary waterways in addition to the Barwon River floodplain. An existing FO covers the Barwon River waterway. These overlay extents are proposed to be replaced with the 1 % AEP extents delineated as part of this study and discussed within Section 8.3. Figure 8.1 displays the existing overlays which will be replaced on the west of the Barwon River FO and south of the abandoned regional rail link embankment.

Suggested amendments to the existing planning controls for the LSIO and FO have also been provided as part of this study's scope.

Figure 8.1: Existing Birregurra Overlays



8.3 DRAFT OVERLAY DELINEATION

Figure 8.2 displays the study's proposed draft overlays. The following sections provide a summary of the criteria and approach used to define the extent of each overlay type which have been discussed and agreed upon with Council and CCMA.

8.3.1 FO Delineation

The following approach was adopted to define the draft FO extent within the Birregurra township:

1. The vehicle hazard criterion derived from ARR's 'Project 10: Stage 2 Appropriate Safety Criteria for Vehicles' report (ARR, 2011) was adopted. It was used as the initial cutoff and was applied directly to the relevant 1 % AEP Monte Carlo flood mapping output grids used to define critical flooding along Atkin Creek and the Unnamed Tributary;
   a) Depth greater than 0.3 m.
   b) Velocity greater than 3 m/s.
   c) Hazard (Depth times Velocity) greater than 0.3 m^2/s.
2. The extent was smoothed using the Feature Manipulation Engine (FME).
3. Judgement calls to exclude isolated areas of flooding from the FO not within the main flow path were made with areas less than 1000 m^2 and transferred to the LSIO layer discussed below.
4. Small 'high' islands within the flood extent were included within the FO. Even though these areas are dry they still represent a significant flood hazard with the loss of safe access and egress.

8.3.2 LSIO Delineation

The following approach was adopted to define the draft LSIO extent within the Birregurra township:

1. The 1 % AEP Monte Carlo flood depth and critical durations source grid was used to inform the initial flood extent associated to flooding from the waterways only.
2. This extent was smoothed using the Feature Manipulation Engine (FME) with no flood depth filter applied.
3. Manual manipulation was undertaken to ensure the delineation of the smoothed LSIO focused on flooding associated to the waterways and rural flow paths only. This manipulation was informed by velocity vectors, flood level contours and engineering judgement calls including:
   a) Removal of isolated areas of flooding less than 100 m^2.
   b) Filling in of small 'high' islands within the flood extent. Even though these areas are dry they still represent a flood hazard with the loss of safe access and egress.
   c) Joining of flow paths particularly where flows overtop roads to capture very shallow sheet flows which were originally filtered out through results processing functions.
   d) Judgement calls to remove portions of the LSIO extent which cover less than 2 % of a property parcel where appropriate.
4. Removal of designated FO extent from LSIO extent.

8.3.3 SBO Delineation

The following approach was adopted to define the draft SBO extent within the Birregurra township:

1. A 50 mm filter was applied to the raw 1 % AEP flood depth grid.
2. The filtered extent was smoothed using the Feature Manipulation Engine (FME).
3. The SBO flow paths were manually manipulated using velocity vectors and flood level contours to ensure continuous flow paths. This included:
   a) Removal of isolated areas of flooding less than 100 m^2.
   b) Filling in of small elevated dry islands within the flood extent.
   c) Joining of flow paths particularly where flows overtop roads to capture very shallow sheet flows which were originally interpolated out through results processing functions.

d) Judgement call to remove portions of the LSIO extent which cover less than 2 % of a parcel where appropriate.

4. Connection of SBO flow paths into the associated waterway / LSIO extent.

8.3.4 Additional Adjustments to Overlays

Following a review by Council of the overlays produced in line with the above criteria, it was noted that there were numerous examples where small areas of land titles were partially impacted by the proposed FO, LSIO or SBO extents. Meetings between the CCMA and Council established a framework where these slivers of overlays could be removed. These included:

- where the overlays encroached into less than 20 m² of a property,
- where the overlay was located at the corner / edge of the front boundary of a property, and access to that property did not require access into a roadway that was abutting a Flood Overlay (to ensure safe escape routes and emergency response access).

The entire FO, LSIO and SBO mapping extents were examined in detail using these parameters, and a conservative approach was taken in reducing the overlay extent. Where land was removed from the FO mapping, it was replaced with the LSIO.

8.4 OVERLAY DOCUMENTATION

The following planning schedules are proposed as part of this study:

- Introduction of new SBO with schedule.
- Adoption of LSIO and FO schedules for Birregurra which are the same as the current C90 planning scheme amendment for Colac.

The defined 1 % AEP flood levels and other modelling outputs have also been provided to Council in order to inform development advice particularly the declaration of flood levels following the implementation of the proposed planning scheme amendment.

The draft overlays documentation is contained within **Appendix L.**

8.5 CLIMATE CHANGE CONSIDERATIONS

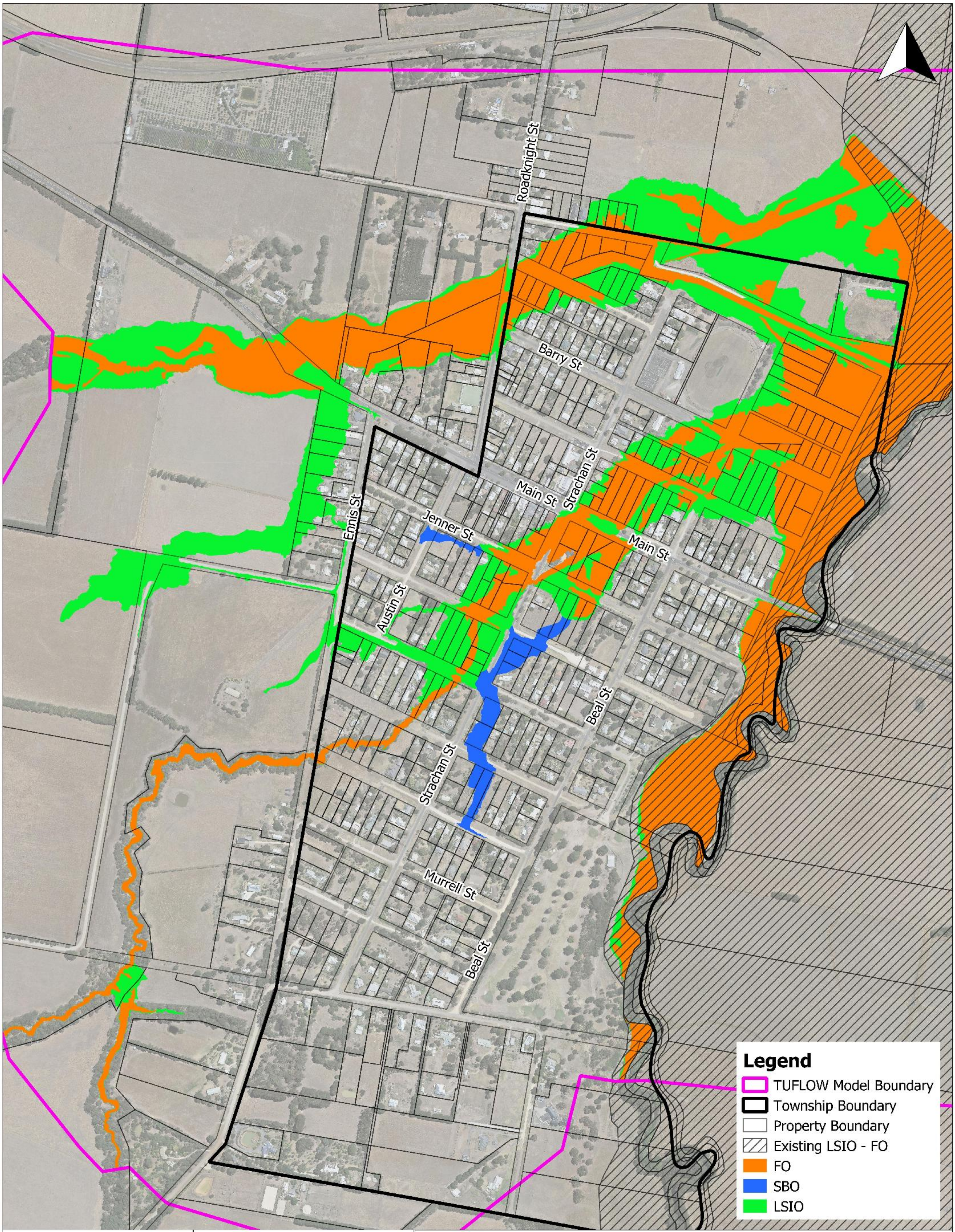
Following the 1 % AEP climate change mapping and discussion presented within Section 4.5.2, an assessment was undertaken to determine how the delineated planning overlays would differ if these climate change mapping outputs were utilised.

Figure 8.3 displays the planning overlays based on the 1 % AEP climate change outputs. Table 8.1 provides a comparison of the number of properties covered by each of the proposed overlays when current and future climate change conditions are considered. This identified that the key difference would be the delineation of the FO extent and the subsequent increase to the number of properties covered by both the LSIO and FO extents. Table 8.1 provides a comparison of the number of properties covered by each of the proposed overlays when current and future climate change conditions are considered. Given these differences were not considered significant and to maintain consistency with current State Government policy on riverine flooding and the recently produced Colac township overlays, the final Birregurra overlays have been based on current climate conditions.

The table also highlights the number of properties captured by the existing overlays and how this insufficiently captures all properties affected by flooding due to the now outdated but previously best available data and modelling approaches.

Table 8.1: Summary of property counts captured by existing and proposed planning overlays

Overlay	Existing Overlays	Proposed Overlays based on current climate conditions	Proposed Overlays based on climate change conditions
SBO only	-	12	12
LSIO only	45	35	20
FO only	-	9	4
LSIO & FO	-	60	84
SBO, LSIO & FO	-	1	1
Total	**45**	**117**	**121**



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ENGENY

Colac Otway SHIRE

150 0 150 m

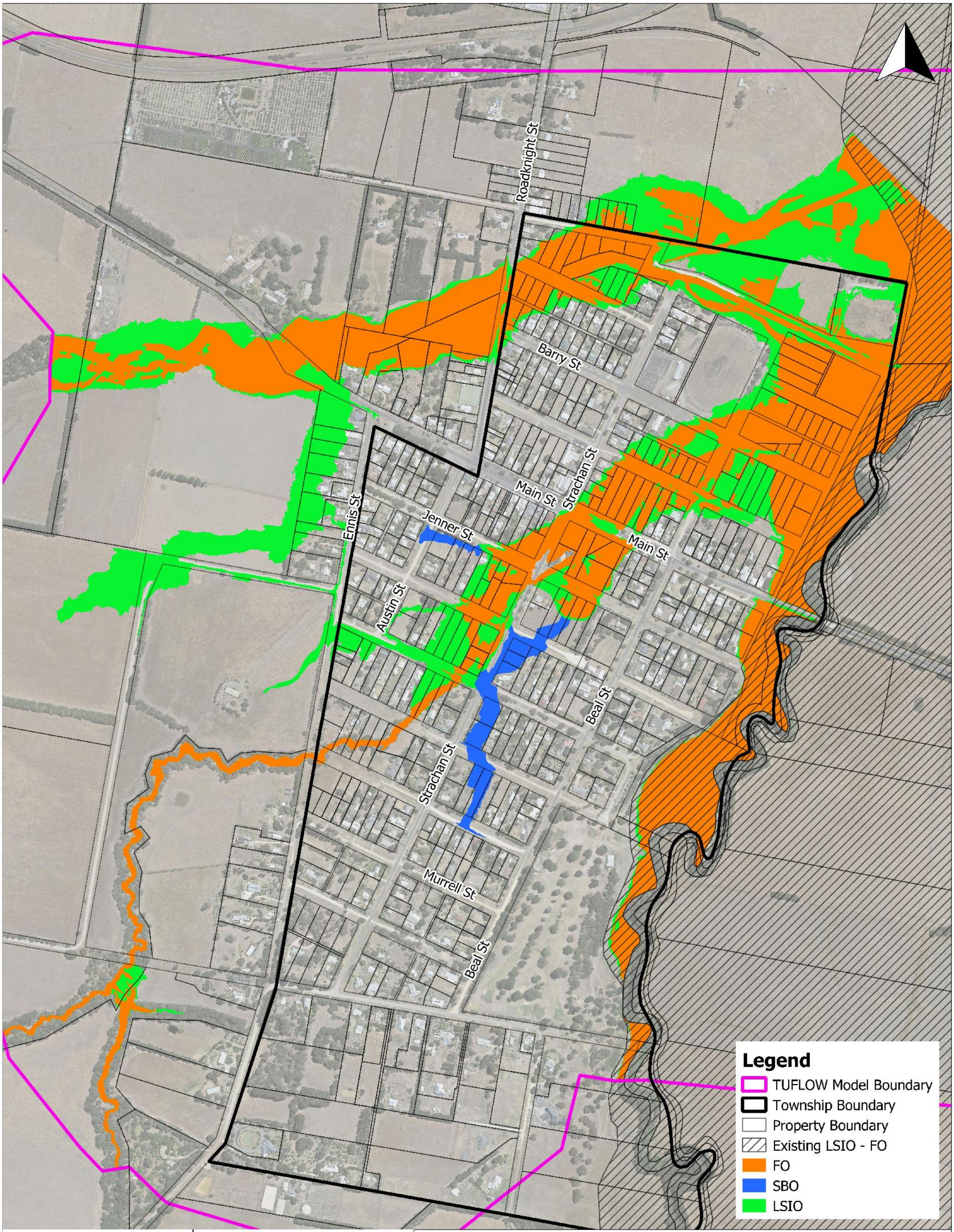
Scale in metres (1:6800 @ A3)

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

Birregurra Flood Study

Figure 8.2
Birregurra Draft Planning Overlays

Job Number: 2013_007
Revision: 1
Drawn: AN
Checked: MM & SD
Date: 30/11/2020



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ENGENY WATER MANAGEMENT

Colac Otway SHIRE

150 0 150 m

Scale in metres (1:6800 @ A3)

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

Birregurra Flood Study

Figure 8.3

Birregurra Draft Planning Overlays
Climate Change Scenario

Job Number: 2013_007
Revision: 1
Drawn: AN
Checked: MM & SD
Date: 30/11/2020

9 FLOOD WARNING ASSESSMENT

9.1 OVERVIEW

A flood warning or alerting system does not currently exist for Birregurra. Essential building blocks (elements) of a Total Flood Warning System (TFWS) have, however, been delivered via other outputs from the Birregurra Flood and Drainage Strategy (i.e. this study). These include:

- Updated flood inundation and related mapping[7].
- An updated Municipal Flood Emergency Plan (MFEP) with Birregurra-centric flood consequence information.
- An indicative flood guidance tool.
- Information suitable for inclusion in a Local Flood Guide (LFG).

This section of the report builds on other study outputs by documenting a flood warning feasibility assessment for Birregurra. It identifies feasible options for improving local capability to act in a timely manner and improving future response to impending floods in Atkin Creek and the Unnamed Tributary that both flow through Birregurra, thereby potentially reducing future impacts and costs. The identified options range from making better use of existing rainfall information in conjunction with deliverables from the Birregurra Flood and Drainage Strategy (i.e. no / low cost options) through to investment in a monitoring and messaging system with automated system elements, that if implemented, could lead to more reliable and substantive outcomes (i.e. an option requiring more substantial investment of time and money to set up and maintain). Guidance is provided as to how such a system may operate.

Where necessary this report draws on the earlier stages of the study. Reports on the work supporting those stages should therefore be read in conjunction with this section of the report.

9.2 ESTIMATED EFFECTIVE FLOOD WARNING TIME

Noting that in general floods develop quicker on wetter catchments (i.e. runoff is generated quicker and there is more of it), that big floods tend to travel faster than small floods (due to greater stream energy), and that a flood on a 'wet' watercourse will generally travel quicker than a flood on a 'dry' watercourse (e.g. the first flood after a dry period will travel more slowly than the second flood in a series of floods), the response time[8] for a major flood through Birregurra is estimated at around 6 to 7 hours under wet antecedent conditions. Response time is estimated to be a little longer for smaller floods and somewhat longer again when the catchment is dry. This places Birregurra within the flash flood category as per Bureau of Meteorology definitions[9] in BoM (1996) and as discussed in VFWCC (2001) and BoM (2020).

[7] While only key maps have been included in the MFEP, all mapping delivered by this study (together with the reports) is expected to be loaded to FloodZoom and also be available from both CCMA and Colac Otway Shire Council. It is further expected that during a flood, CMA and Council officers will have direct access to copies of the original model results in GIS format along with the corresponding reports through respective agency hosting arrangements.

[8] Time between start of heavy rain and the creeks beginning to rise at Birregurra.

[9] Flooding within 6 hours of causal rain.

Under severe flood conditions and having regard for the current consequences of flooding at Birregurra[10], the effective flood warning time[11] for Atkin Creek and the Unnamed Tributary creek is currently (i.e. no flood warning system elements in place) estimated to be around 3 to 5 hours.

With the benefit of the indicative flood guidance tool provided in Appendix C2 of the Colac Otway Shire Council (COSC) Municipal Flood Emergency Plan (MFEP) in concert with the flood intelligence and mapping delivered by this study, it is estimated that effective flood warning time could be extended for the Unnamed Tributary and Atkin Creek by at least 3 hours. The indicative flood guidance tool is included herein as Figure 9.4.

In view of the estimated effective flood warning time, emergency services driven flood response actions within Birregurra in the lead up to flooding are currently likely to be severely limited. There is insufficient time available to mobilise emergency services and for them to prepare the dwellings most at risk of being flooded over-floor (e.g. relocate or lift valuables and household items, sandbag the dwelling, etc). Even with the benefit of the deliverables and additional available time that could result from this study, it is suggested that with due regard for other regional flooding issues and the need to prioritise calls for assistance, there would be limited opportunity to mobilise emergency services to assist local flood response (i.e. damage reducing) activities. Local residents however, armed with the indicative flood tool and with access to rain data from the gauge at Ricketts Marsh, may be able to lay sufficient sandbags during a small flood and raise / move valuable items in the event of a large flood, provided that a supply of sandbags was at hand and / or help was immediately available from neighbours to assist with valuable items. Key to this is awareness of the flood risk, recognition of the likelihood and scale of imminent flooding, and knowing what to do to reduce damage.

While not canvassed with VICSES, EMV or BoM, it is suggested that there may also be opportunities in the context of successful proof of concept trials at Natimuk (see Section 9.4.2) and following successful implementation of protocols and some adjustments to how data from the Ricketts Marsh gauge is managed, for a Vic Emergency warning of likely flooding to be issued for Birregurra during severe rain events. This could be augmented by an Emergency Alert if it was assessed that there was a risk to life.

9.3 FLOOD WARNING SYSTEMS

9.3.1 Introduction

Flood warning is an effective and credible non-structural flood mitigation or flood risk reduction measure. Successful system implementation requires attention to all system elements as well as the striking of a balance between each of those elements appropriate for the community it will serve. A “one size fits all” or standard approach is not appropriate. What works for one community may not necessarily be appropriate for another.

In relation to Birregurra, any system established must meet the needs of the at-risk community with appropriate emphasis on the various system elements while also accounting for the constraints imposed by the effective flood warning time. Consideration of the benefit to cost ratio is also important. This is because in order to secure funding support at State and Commonwealth level, the benefits of establishing a flood warning system need to outweigh costs.

9.3.2 Aim and Function

Put simply, flood warning systems provide:

- A means of gathering information about impending floods.
- Communicating that information to those who need it (those at risk).

[10] Out of bank flows occur along Atkin Creek and the unnamed tributary through Birregurra for events more frequent than the 1 in 2 year ARI flood. There are 35 buildings (excluding sheds but including the CFA shed) identified as being inundated over-floor by the 20 % AEP (5-year ARI) flood. The number of floors wetted rises as flood severity increases.

[11] The time available after receiving advice of an impending flood before flood water prevents appropriate flood response action.

- Facilitating an effective and timely response.

Thus, flood warning systems aim to enable and persuade people and organisations to take timely action to increase personal safety and to reduce the damage caused by flooding[12]. Key to this for those at risk is:

- The availability of information about flood risk.
- Easy access to relevant and timely real time rainfall and water level data / information.
- Knowing what needs to be done in the lead up to and during a flood event.

Flood warning systems (and investments in their implementation) that over-emphasise the collection of input data and / or the production of (highly accurate) flood forecasts relative to the attention given to other elements, often fail to fully meet the needs of the at-risk communities they have been set up to serve. Put another way, it is essential that those parts of the flood warning system that work to build resilience within a community while also increasing warning lead time are given due emphasis and attention.

9.3.3 The Total Flood Warning System Concept

In 1995 the Australian Emergency Management Institute published a best-practice manual entitled Flood Warning: an Australian Guide (AEMI, 1995), and in so doing, introduced the concept of the 'Total Flood Warning System' (TFWS). While the original manual has been updated and republished as Manual 21 of the Australian Disaster Resilience Handbook Collection (AIDR, 2009), the concepts, practices and key messages from the original manual endure.

The Victorian Floodplain Management Strategy (DELWP, 2016) also promotes the TFWS concept and provides clarification on roles and responsibilities for system development and operation in Victoria.

9.3.4 Total Flood Warning System Building Blocks

An effective flood warning system is made up of several building blocks. Each building block represents an element of the Total Flood Warning System (TFWS).

Figure 9.1: Elements of the Total Flood Warning System (source: VFMS)

[12] More generally, the objective of early warning is to empower individuals and communities, threatened by natural or similar hazards, to act in sufficient time and in an appropriate manner so as to reduce the possibility of personal injury, loss of life and damage to property, or nearby and fragile environments (UN, 1997).

Experience shows that flood warning systems that are not designed in an integrated manner and that over-emphasise one element of the warning system at the expense of others inevitably fail to elicit appropriate responses within the at-risk community. An appropriately developed and integrated system considers not only the production of a timely and informative alert[13] of a potential flood, but also the efficient dissemination of that alert to those who need to respond in an appropriate manner, most important of whom are the threatened community. A community that is informed, flood aware and prepared (i.e. flood resilient) is more likely to receive the full benefits of a warning system.

It follows that actions to improve flood response and community flood awareness using technically sound data (such as that produced by the Birregurra Flood and Drainage Strategy) will by themselves result in some reduction in flood losses.

9.3.5 FLARE

As identified in Section 9.2, Birregurra is subject to flash flooding. While BoM does not currently provide flash flood warning services, it has developed FLARE, the national flash flood warning advisory resource. It acts as a repository of technical information and guidance in relation to flash flood warning systems (FFWS). It provides:

- Historical information on flash flooding;
- An overview of some of the systems operating in Australia (i.e. case studies);
- Details of BoM services available to support flash flood warning systems;
- Some suggestions on flash flood warning system elements;
- Advice on relevant standards and guidelines (e.g. on data sensing and measurement, telemetry, data collection systems, metadata management, etc); and
- An office hour help line to respond to questions.

A guide to flash flood warning system considerations and design is also provided, as a supplement to jurisdictional approaches and methods. The guide steps the user through the use of the FLARE resources as part of system design (refer Figure 9.2).

Figure 9.2: Guide to FFWS Design (source: FLARE)

[13] An alert may take the form of access to real-time data, an SMS or message via social media from a credible source, a forecast of expected flood conditions, advice of indicative flood conditions, etc.

9.4 THE TASK FOR BIRREGURRA

9.4.1 Context

The Corangamite Regional Floodplain Management Strategy (RFMS) (CCMA, 2017) characterises Birregurra as a priority flood risk area and cites the September 2016 flooding as an indication that the then current flood data for the area was inaccurate. Consistent with that characterisation, the current study (Engeny, 2020) has shown that flood damages at Birregurra are quite high, with Average Annual Damage (AAD) calculated as being approximately $747K. The study has also shown that out-of-bank flows, flooding of roads and over-floor flooding of dwellings commences during quite frequent floods (i.e. less than the 20 % AEP[14] event). While depths and velocities within the creek channel do present an extreme hazard during those quite frequent events, flood depths and velocities within the overbank floodplain (including through the town) are in general, low hazard.

The Corangamite RFMS proposes a strategic direction that articulates the need for community and regional resilience as a key and sustainable response to flood risk. This is consistent with State and Federal Government policy. This report and the suggested approach to flood warning for the Birregurra community is similarly consistent. It is aimed at a system that will provide information to enable individuals to make informed decisions about risk and what they need to do. The emphasis is therefore on "what works best for Birregurra" with due regard for flood risk, available flood warning and response times, available rain and creek level data, and the funding and other responsibilities associated with implementing and maintaining elements of a (flash) flood warning system.

9.4.2 Policy and Strategy Considerations

The division of responsibilities associated with the establishment, maintenance and operation of flood warning systems as documented in VFWCC (2001) have been endorsed by the relevant Ministers at both State and Federal level. More recent developments have seen the BoM establish a Service Level Specification (SLS) that identifies the flood forecast and warning service it will provide for specific locations across the State (BoM, 2020). BoM is currently moving to establish a fee-for-service approach to the development (on a priority basis) of flood forecasting tools for locations not included in the SLS. In relation to flash flood warning services, BoM will continue to provide generalised warnings of weather conditions likely to lead to flash flooding but it will not currently provide flash flood warnings for specific creeks or locations.

The Victorian Floodplain Management Strategy (DELWP, 2016) provides clarification on roles and responsibilities for TFWS development and operation in Victoria. Policy 16a is directed at flood warning in general while Policy 16d is directed specifically at flash flooding (see below).

VFMS – Policies 16a and 16d

Policy 16a *outlines the future arrangements for flood warnings in Victoria:*

- *The Bureau of Meteorology (BoM) will develop new flood prediction services using a cost-recovery model that involves DELWP covering the capital cost of initial model development and BoM the cost of operating, maintaining and continually improving those models.*
- *Existing flood prediction services will continue to be operated, maintained and improved by BoM.*
- *Where a flood study identifies the need for new rain or stream monitoring gauges to support a TFWS for a community within Melbourne Water's region, Melbourne Water will cover the capital and maintenance costs of those gauges.*
- *Where a flood study or regional floodplain management strategy outside Melbourne Water's region identifies the need for a TFWS and that service has community support, the capital costs for new rain or stream monitoring gauges will be shared between the Victorian and Australian Governments. The local community, through its LGA, will fund ongoing maintenance costs for the gauges.*

[14] Annual exceedance probability (AEP) is the inverse of Average Recurrence Interval (ARI): the 20 % AEP event is equivalent to the 5-year ARI event.

- *Where existing rain and stream monitoring gauges are providing flood warning services, the Victorian Government expects existing cost-sharing arrangements to continue until a regional floodplain management strategy or local flood study assesses the need for a TFWS service.*
- *Where existing gauges are assessed as being an essential component of a TFWS, the costs of maintaining those gauges will be shared between the LGA and the CMA if it is also used for water quality monitoring, or with a water corporation if it is also used for water resource assessments. In some cases, the costs may be shared between all three agencies.*

Policy 16d

- *The CMAs and Melbourne Water, with the support of VICSES and LGAs, will progressively identify areas with a history of flash flooding and include them in their Regional Floodplain Management Strategies and implementation plans.*
- *Cost-sharing arrangements for flash flood warnings will be the same as for riverine flooding (Policy 16a).*

Local government has a more prominent role in flash flood warning than for other flood warning systems while the role of the BoM, as outlined above, is substantially diminished[15].

Looking ahead and as an out-working from the Services Standardisation Project, BoM has been working in Victoria with Emergency Management Victoria (EMV) and VICSES on scoping and trialling an Automated Alerting Project. The project involves BoM systems automatically identifying exceedance of critical levels on data ingested from selected telemetered rain and river gauges and alerting of that exceedance to EMV. It is understood that those alerts then generate warnings of potential or actual river level rises as a push to the VicEmergency website and App and as more formal public issue warnings from VICSES. The work offers exciting potential to alert and warn at-risk communities of developing (flash) flood events. While it is not suggested that the project offers a ready-made solution for Birregurra, subject to further development and adoption following completion of proof of concept trials with the Natimuk community, the future potential for benefits to the Birregurra and similar communities is evident.

There are a number of decisions required in relation to how each of the TFWS elements can be developed and implemented for Birregurra. Regardless, the main messages from the 2005 Flood Warning Service Development Plan for Victoria (VFWCC, 2005) remain valid. Those applicable to Birregurra include:

- Making existing data and information / flood intelligence easily accessible to the at-risk community.
- Assisting at-risk communities use that data and intelligence (for example, personalised "what does it mean for me" letters, pamphlets and related information).
- Developing / providing tools that add value to or drag value from available data and intelligence (e.g. indicative flood guidance tools).
- Developing a (local) means of providing an indication of likely flooding with some lead time for the many communities for which the BoM does not currently provide a flood warning service.
- Driving maximum value from flood mapping and other study outputs for local community benefit.
- Focussing on delivering and / or making available those things that will achieve a reduction in damages (i.e. focussing on facilitating the availability of relevant information with some lead-time and a degree of accuracy and consistency).
- Providing the data, information and tools to enable at-risk communities build resilience.

[15] A flood warning system established for a stream or location considered to be subject to flash flooding is, in general terms, the responsibility of the local Council. This includes the installation, operation and maintenance of the technical elements. BoM will maintain delivery of existing severe weather and riverine flood warning related services. Delivery on other TFWS elements including alerting / warning, the development and application of flood response plans as well as (flash) flood education and awareness programs, is a shared state and local government responsibility.

9.4.3 The Challenge for Birregurra

In view of what TFWS elements have been delivered by the current study (see Section 9.1 above), the key issue for Birregurra (given the short effective flood warning time) is how a potential flood will be detected ahead of the onset of flooding within the town and how the at-risk community will be alerted, ideally with sufficient lead time to enable completion of effective response actions.

A range of systems, equipment and approaches are available. The dilemma is "which of these are appropriate and sufficient" given that with a wet catchment, the time between the beginning of heavy rain and the start of creek level rises is estimated (see Section 9.2) at around 6 to 7 hours, with the peak occurring at Birregurra in Atkin Creek and the Unnamed Tributary creek around 12 to 15 hours later. However, it should be noted that over-floor flooding of the first house affected begins well before the peak of a big flood is reached: around 8 hours after the start of rise. In this situation under current conditions as discussed in Section 9.2, the effective flood warning time for Atkin Creek and the Unnamed Tributary creek is estimated to be around 3 to 5 hours.

Allowing time for information to be made available to the community through a flood warning system and for event severity to become evident (say half way through a heavy rain event) plus time required by the community to confirm that information[16], the time available to respond (i.e. lift furniture and other household goods off the floor, move vehicles and other assets to dry ground and relocate, noting that the first floor in town is flooded at a little below the 20 % AEP flood level) is estimated to increase from between 3 and 5 hours out to 8 hours or more during a large flood and a couple of hours longer for a small flood. With such a short effective warning time and the increase in time estimated to be achievable with a flood warning system, it is apparent that delivery of information to the local community as quickly as possible is paramount.

9.4.4 A TFWS for Birregurra

Having regard for first level achievements only, gives rise to the following functional requirements:

- Monitoring of rainfall (and perhaps also creek level), possibly for exceedance of triggers that indicate that flooding may occur.
- Ready public access to raw rainfall data[17].
- Alerting the community, VICSES and the Colac Otway Shire Council (COSC) to potential flooding as quickly as possible.
- Ready public access to flood intelligence (i.e. mapping perhaps as soft copies or through an interactive GIS hosted by Council and / or CCMA, flood information card, etc) so that the community can determine likely impacts and individual consequences and initiate appropriate response actions.
- Low setup and operating costs with (ideally) a positive benefit-cost ratio.
- Acknowledgement and acceptance that a formal flood warning service is unlikely to be provided for Birregurra.

Most of the above can be achieved with minimal cost. Opportunities do exist for local government to seek and secure Commonwealth and State funding to assist with system set up. Operational and on-going costs remain a local government responsibility as outlined in Section 9.4.2.

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[16] The need for recipients of flood warnings or information that indicates they are in danger from flooding to verify the warning or information and assess it in their own context is discussed at length in the risk communication literature. The time taken for this part of the response process varies based to a large extent on prior experience. It is assumed for Birregurra to be of order 1 to 2 hours.

[17] Easy and timely access to data is important for communities at risk from flash flooding. Data maps and tables available through the BoM website provide one such avenue. Commitment is required from BoM that rain data from existing sites will be available every 15 minutes (minimum) through the tables and maps (as appropriate). Three-hourly data is not ideal for Birregurra due to the short window between event identification and flood consequences.

9.5 FLASH FLOOD WARNING SYSTEM CONSIDERATIONS

9.5.1 Introduction

It is suggested that consideration of a flash flood warning system for Birregurra should have regard for the:

- Potential for rapid development and progress of floods within the Atkin Creek catchment and the limited lead time available between heavy rain and stream rises.
- Character of the flood risk (i.e. rapid onset, high likelihood of over-floor flooding from a little below the 20 % AEP flood level).
- The benefits achievable through the implementation of structural flood mitigation works aimed at reducing flood impacts within the town.
- Economic metrics (i.e. likely benefit-cost based on consideration of the contribution of avoidable damages to the value of average annual damages).

The following sections outline how each of the TFWS elements could be addressed in order to implement an effective, low maintenance, scalable flash flood warning system that has some utility to the Birregurra community, at minimal cost.

9.5.2 Data Collection and Collation

There is a wide range of equipment that will variously collect, collate and / or undertake assessments on rain and / or creek level data and make it available to a single entity or to a group of entities. Data can be pushed either directly from the equipment at site, through a post box or website, or following delivery to a predetermined digital address. The focus here is on what is best for Birregurra. Capital and on-going costs are therefore a consideration as (given Birregurra is subject to flash flooding) they are a local responsibility.

Both Atkin Creek and the Unnamed Tributary are ungauged – there are no formal stream or rain gauges in the catchment.

A permanent fully operational telemetered rain and stream gauge is in place on the Barwon River at Ricketts Marsh (Station No 233224: Barwon River @ Ricketts Marsh). Three-hourly data is publicly available from the BoM website.

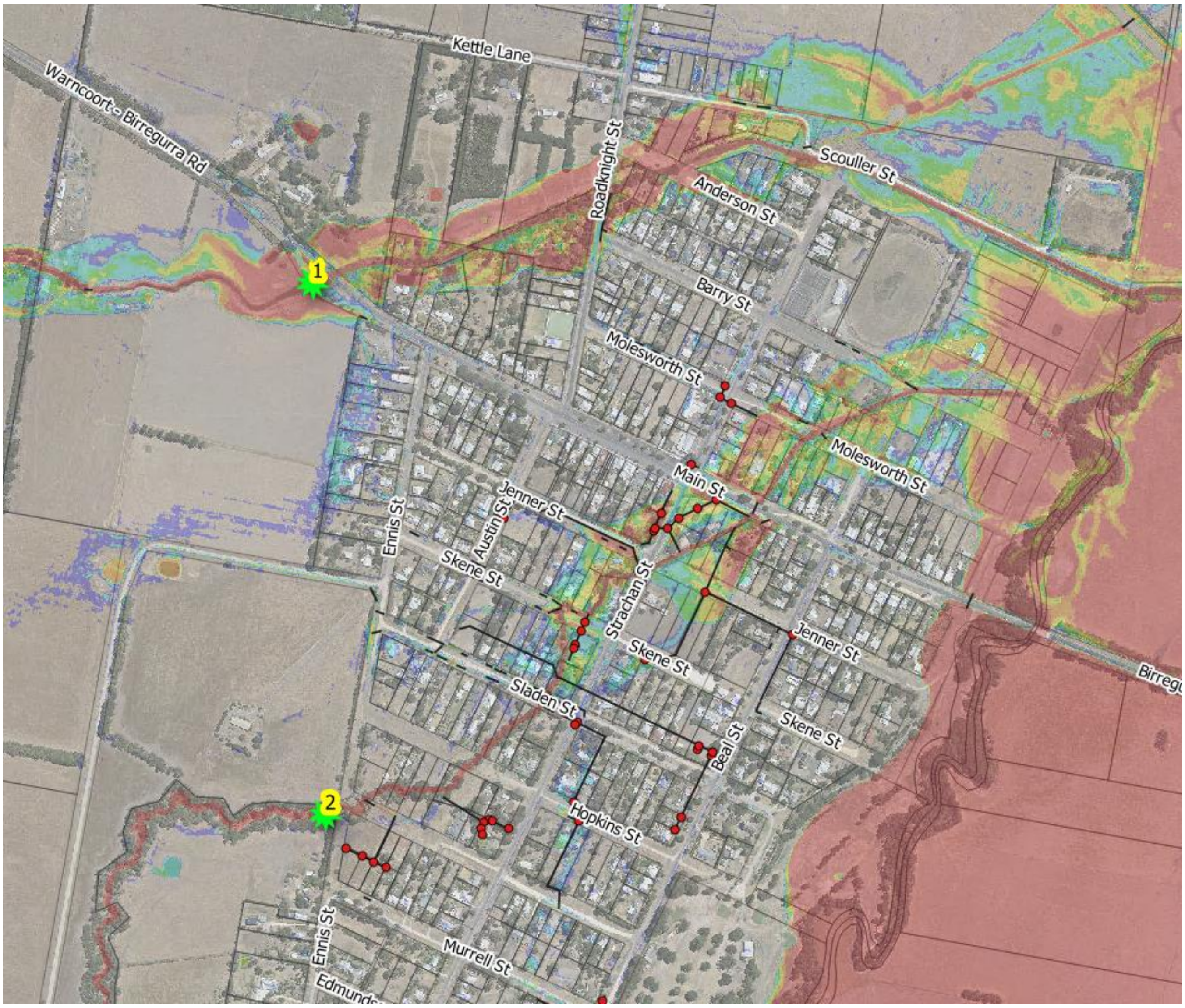
A rain gauge is also in place at the CCMA's office in Colac. However, it is not telemetered. Data only becomes available around the end of each month for the previous month.

It is suggested that with near real-time access to rainfall data from the Ricketts Marsh gauge and an indicative flood guidance tool (see Section 9.5.3), a basis exists for a local community-based flash flood warning system. However, data from the Ricketts Marsh gauge would need to be made publicly available in near real-time (say updated every 15 minutes). The BoM website is an obvious choice to achieve this.

It is suggested that Council:

- Approach BoM (with support from VICSES, CCMA and DELWP) to request necessary changes to enable near real-time public access to rain data from the Ricketts Marsh gauge via the BoM website (e.g. 15 minute updates).
- Alternatively, approach CCMA to request that telemetry be added to the Colac rain gauge and that BoM be requested to enable near real-time public access to rain data from that gauge via the BoM website (e.g. 15 minute updates).
- Arrange for the installation of a set of staff gauges on the upstream side of the Warncoort-Birregurra Road Bridge (Atkin Creek) and on the upstream side of the Ennis Street crossing of the Unnamed Tributary. They should be installed such that the gauge boards can be read from the road for small and larger (i.e. 1 % AEP) floods so that Birregurra residents and emergency services can confirm water levels and rates of rise in the creeks (see Figure 9.3).
- Following a successful approach to the BoM regarding data accessibility, consider providing guidance to the local community (through a locally focussed flood awareness brochure or similar) on how to access and interpret data from the Ricketts Marsh gauge together with instruction on its use with the indicative flood guidance tool. Information about other elements of the flood warning system and how it will assist in reducing risk could also be included.
- Consider developing and maintaining a website (and potentially social media) presence for the FFWS. As a minimum, this website could contain the indicative flood guidance tool and the associated flood mapping and intelligence outputs from this study.

Figure 9.3: Suggested Gauge Locations



If a greater degree of confidence in the likelihood of flooding is required, it is suggested that Council consider:

- As a first step, purchase of an ERTS rain gauge and its installation in the mid reaches of the Atkin Creek catchment close to the shared boundary with the Unnamed Tributary. At the same time, Council with support from VICSES, CCMA and DELWP, would need to approach BoM to provide near real-time public access to data from that gauge via its website.
- As a second step, purchase of two ERTS river (or rain-river) gauges and their installation on the upstream side of the Warncoort-Birregurra Road Bridge (Atkin Creek) and on the upstream side of the Ennis Street crossing of the Unnamed Tributary. As above, Council with support from VICSES, CCMA and DELWP, would need to approach BoM to provide near real-time public access to data from those gauges via its website.

- Alternatively and instead of ERTS equipment, arranging purchase and installation of different commercially available rain and / or rain-river monitoring equipment[18] (e.g. such as DipStik[19]) in the locations described in the above two bullets and identified in Figure 9.3.
- The addition of "sirens and / or flashing lights" options (triggered by exceedance of pre-set rainfall rates and depths, and creek levels and rates of rise) for the automated gauges installed at the creek crossings as an alternative or additional means of alerting the community to imminent flooding.
- As appropriate and dependent on the monitoring and alerting equipment installed, invite Birregurra residents, along with VICSES, local CFA and Police, to opt-in to receive SMS alert messages direct from installed equipment.
- Provide guidance to the local community (through a locally focussed flood awareness brochure and website) on how to interpret and use available rain and creek level data and the indicative flood guidance tool, along with information about the flood warning system and how it will assist in reducing risk.

A decision would need to be made on whether to establish any proposed creek level gauges to local datum or to AHD.

While there is the possibility that the two sites identified in Figure 9.3 could be used as PALS[20] installation sites, catchment response times indicate that in most situations there would be insufficient time to install the equipment ahead of a likely flood. Further, while the PALS would provide useful data for post-event analyses, there are restrictions to public access to the real-time data they provide. Local access to data is key to effective flood warning for Birregurra. There is also no certainty that PALS would be available when needed as there are a limited number of the units available across the state.

9.5.3 Flood Detection & Prediction – Indicative Flood Guidance Tool

Capability Following Completion of this Study

The indicative flood guidance tool provided in Appendix C2 of the COSC MFEP (included here as Figure 9.4) provides some guidance on the likelihood and severity of expected flooding at Birregurra with an estimated lead time of 8 hours or more during a large flood on a wet catchment.

Rainfall data from the Ricketts Marsh gauge (or perhaps from the catchment of Atkin Creek and the Unnamed Tributary) should be used to drive the indicative flood guidance tool. However, the tool may not perform to expectations in severe thunderstorm situations, when there are locally heavy falls embedded in more general rain and when the catchment is dry.

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[18] A variety of rain and water level monitoring equipment and systems are available commercially. DipStik is one such example. It is not suggested that any one system is better than another and should be adopted by Council. Equipment or systems should be evaluated by Council and a choice made based on value (e.g. benefit-cost), functional capability and other relevant factors consistent with prevailing procurement and related guidelines and considerations.

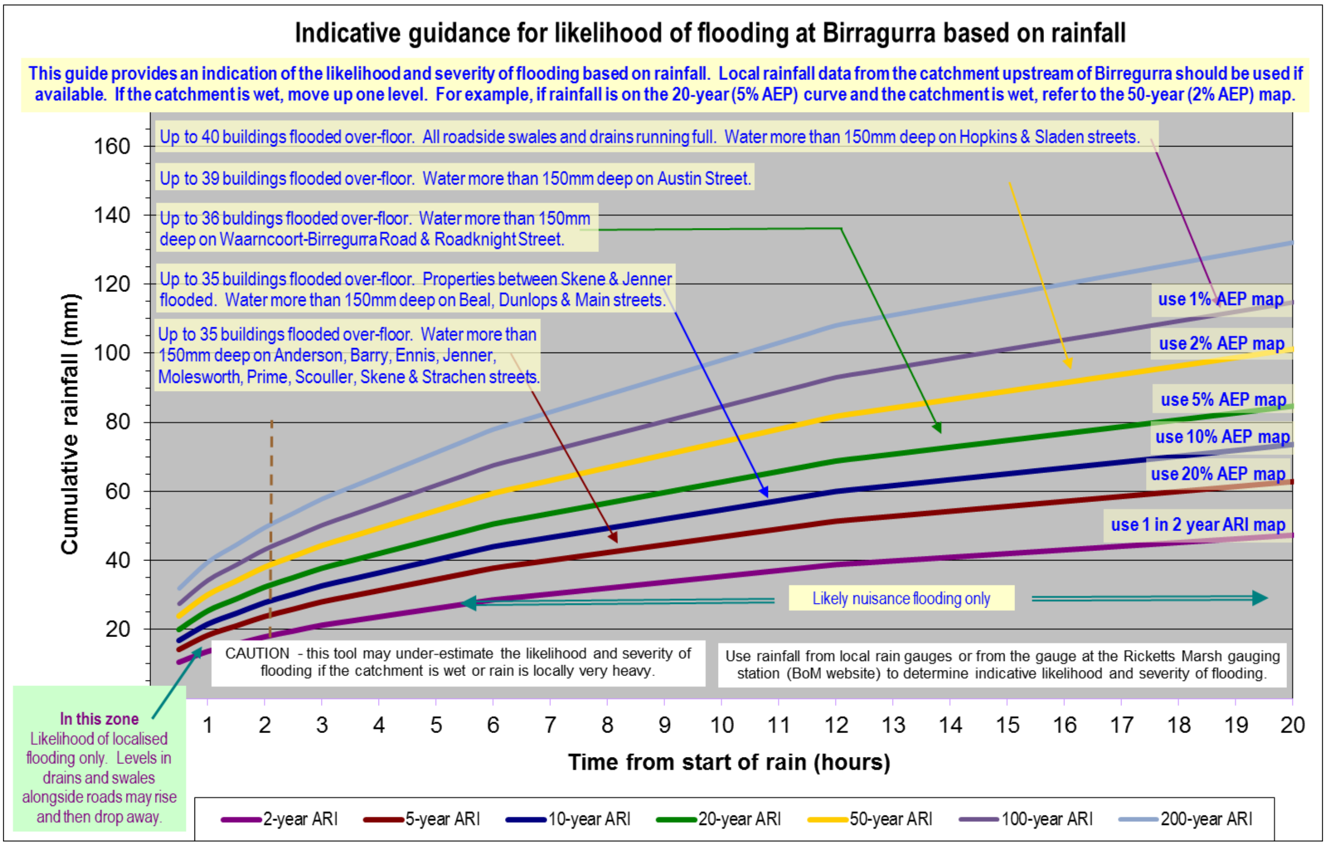
[19] DipStik will continually monitor rainfall and / or water level for potential flood conditions (i.e. exceedance of threshold rainfall amounts and intensities and / or rising water levels). When trigger conditions are met, DipStik sends an SMS alert message, via the mobile phone network, to opted-in recipients. It also sends messages as water levels fall. DipStik maintains a record of maximum flood heights and rate of rise of water levels to help with post-event analyses and future flood mitigation planning. Other functionality including a cloud enabled infrared camera is available. See http://tuftec.com.au/ and particularly the joint NRMA, IAG, LG project in NSW and the Cardinia Shire Council project in Victoria.

Note that cameras are increasingly being added to local gauges in the US in order to keep curious people out of harm's way. Looking at the creek through the cameras is much safer than going to the creek bank to look at it.

[20] PALS continually monitor rainfall and / or water level. Every 15 minutes, the unit transfers data via the mobile phone network to a server for display in near real-time. In addition, the unit can provide simple text alerts when pre-set water level alarm conditions (these are able to be adjusted dynamically by SMS) are triggered. The alerts can be sent to 5 mobile phone numbers (as an SMS) and to 2 email addresses. All data are logged to assist with post-event analyses and future flood mitigation planning.

It is suggested that the indicative flood guidance tool is adopted by VICSES, local CFA and Council for routine use. It is also suggested that the tool and instructions for its use could be shared with the Birregurra community and key community members instructed on use.

Figure 9.4: Indicative Flood Guidance Tool



Potential Capability Pending Investment in Improvements

It is suggested that in the context of State-wide and Regional priorities and the relative scale of flood damages at Birregurra, investment in a more sophisticated and technically demanding forecast tool that would need to be established, operated and maintained by Council (DELWP, 2016 and VFWCC, 2001) is probably not warranted.

With a view to the longer term and subject to the programming of alerts for exceedance of pre-determined rainfall rates and depths at the Ricketts Marsh gauge (and / or additional rain and / or water level monitoring equipment being installed within the creek catchments upstream of Birregurra), the Automated Alerting Project (see Section 9.4.2) appears to offer potential as the basis for a robust initial flood alerting and warning system[21]. It is suggested that Council maintain contact with VICSES on project progress with a view to implementation for Birregurra.

[21] Experience gained in establishing the Natimuk flash flood warning system and proof of concept trials should assist the setting of rainfall and creek level triggers for Birregurra. Warning actions could simply involve issue of a VicEmergency warning of likely flooding and / or in the event of a perceived risk to life, issue of an Emergency Alert.

Flood Class Levels

Flood class levels determined against standard definitions[22], are used to establish a degree of consistency in the categorisation of floods. In order to assist the flood warning process and increase awareness of flooding within the community, it is suggested that Council give consideration to establishing flood class levels for Birregurra at the Warncoort-Birregurra Road Bridge (Atkin Creek) and at the Ennis Street crossing of the Unnamed Tributary. The process would involve coordination between Council, VICSES, CCMA and BoM and is relatively straight-forward. Note however that flood class levels can only be established for locations with a permanent water level gauge.

9.5.4 Interpretation

The flood inundation maps and COSC MFEP Appendices developed as part of the Birregurra Flood and Drainage Strategy provide the base information to enable the community and stakeholder agencies to determine the likely effects of a potential flood. This means however that the flood inundation maps and relevant Appendices of the MFEP, and more specifically the flood information card for Birregurra, would need to be readily available to the Birregurra community.

9.5.5 Message Construction and Dissemination

There are a number of alerting and notification tools, technologies and service providers available, some of which both alert (make people aware of an imminent hazard) and notify (provide a warning message). A summary of those that might be suitable for Birregurra has not been included herein as the approach proposed does not include the construction and / or dissemination of formal warning messages, other than as may occur as a result of the Automated Alerting Project (or similar) described in Section 9.4.2. This is because of the short effective flood warning time in combination with the dependencies between the alerting and notification functional requirements and decisions regarding the data collection network equipment and locations to be instrumented.

If a flood was to occur soon after delivery to the Birregurra community of the maps and indicative flood guidance tool arising from this study, it is likely that for most Birregurra residents, the initial alert of likely flooding will be personal (or perhaps from a neighbour within the community) and will come from a combination of environmental indicators (e.g. observance of heavy rain, local runoff, etc) and the resident's consideration of the flood inundation maps in conjunction with the MFEP. If an alternate commercial monitoring system such as DipStik was installed, the initial (or confirming) alert may come from the unit's SMS'ed message and / or siren, as rain and / or creek levels exceeded triggers with the above acting to reinforce and add value to resident's assessments and decision processes. Alternatively, and subject to resolution of VICSES and EMV roles in the initiation and dissemination of flash flood warnings, the initial alert may come via electronic and social media.

If a marginally more formal alerting system was deemed appropriate and viable for Birregurra, regardless of whether additional permanent rain and water level monitoring equipment (e.g. ERTS, DipStik, other) was installed, the Birregurra community could be encouraged to be more involved in the TFWS by sharing information about the (likely or actual) on-set of flooding and to then back this up with information about likely consequences (e.g. from the MFEP and local knowledge / observations). Social media provides a suitable vehicle. A Twitter and / or Facebook account could be established for the Birregurra TFWS. This would require Council (in conjunction with VICSES) to champion the formation of a Birregurra community flood action group (or similar).

Members of this group could play a key role in local flood warning operations and review. In particular, say via the social media group, they could share information initiated within the community and by VICSES (say, following their use of the indicative flood guidance tool) on likely flood severity, impacts and appropriate actions.

9.5.6 Response

The COSC MFEP Appendices have been populated for Atkin Creek and the Unnamed Tributary at Birregurra as part of the Birregurra Flood and Drainage Strategy. Information in the MFEP includes available intelligence relating to flooding from the upstream catchment along with the indicative flood guidance tool provided at Figure 9.4 of this report. Instructions for the tool's

[22] Standard definitions for minor, moderate and major flood class level are available from the BoM website.

use have also been included in the MFEP. Flood inundation extent and depth maps have been added together with a list of areas and roads likely to be flooded. A table of properties and key infrastructure likely to be flooded along with the likelihood and depth of over-ground and over-floor flooding at each property is also included along with a flood information card for the town.

The availability of this flood intelligence will improve the situational awareness of the emergency service agencies and the Birregurra community while also increasing their potential to respond in a more timely and appropriate manner.

Following (or perhaps in concert with) acceptance of the updated MFEP by Council and VICSES, a program to encourage and assist residents and businesses to develop individual flood response plans should be developed and delivered. A package that assists businesses and individuals is available from VICSES and provides an excellent model for community use.

9.5.7 Community Flood Awareness

As per the project brief, technical text for a Local Flood Guide (LFG) has been provided to Council separately from this report. The text should be forwarded to VICSES to enable production of a LFG for provision to the Birregurra community.

Looking further ahead, it is suggested that VICSES, in partnership with Council, develop activities and materials for the Birregurra community that emphasise personal safety, how available rain and, if available, creek level data can be used, what any warnings / alerts mean and what individuals can do to stay safe and protect their property including how to fill and lay sandbags. This should extend to also making relevant parts of the MFEP publicly available (e.g. Council offices, library, website, etc). Such investments will assist in maintaining and renewing flood awareness within the local community.

9.5.8 Funding Opportunities

Opportunities do exist for local government to seek and secure Commonwealth and State funding to assist with flash flood warning system set up. Generally, the benefits of establishing the system need to outweigh costs in order to secure funding support. Regardless of the support received, operational and on-going costs remain a local government responsibility as outlined in Section 9.4.2.

It is suggested that having determined the desired elements of the flash flood warning system to be established for Birregurra and a timetable for the establishment of each element, Council (with support from CCMA and VICSES) should scope and submit an application for funding under the Commonwealth-State National Partnership Agreement on National Disaster Resilience (i.e. the Natural Disaster Resilience Grants Scheme – NDRGS) or successor funding programs.

9.6 MAIN OUTCOMES FROM THE FEASIBILITY ASSESSMENT

Currently achievable response actions at Birregurra, as outlined above and without regard for time of day or night, are limited to what residents are able to achieve.

It is suggested that an “accurate” forecast is not the key to achieving an increase to personal safety and flood damage reduction in Birregurra. Rather it is timely alerting and access to relevant data and easy-to-use indicative tools that, coupled with robust communications systems supported by sound awareness of flooding consequences (i.e. community resilience), provide the information that triggers those at risk to take timely and appropriate actions: to improve local capability and deliver the benefits sought from a flood warning system.

Further to these specific requirements, this assessment identifies feasible options for improving local capability to act in a timely manner and improving future response to impending floods from the creek catchments upstream from Birregurra, thereby potentially reducing future impacts and costs. The identified options range from making better use of existing rainfall monitoring resources (i.e. no / low cost options) through to investment in improved rain and / or river monitoring in conjunction with automated messaging, that if implemented, could lead to more reliable and substantive outcomes (i.e. an option requiring more substantial investment of time and money to set up and maintain). Guidance is provided as to how such a system may operate.

Adopting and making best use of the immediate deliverables from this investigation (i.e. making the indicative flood tool, flood intelligence and flood mapping available to both the emergency agencies and the Birregurra community and being able to make better use of rainfall data that will (hopefully) soon be available in near real-time from BoM), will increase flood awareness and the opportunity for residents to recognise imminent flooding and initiate appropriate response actions. This has been assessed as being achievable in the near term with minimum investment.

With some investment, a telemetered rain gauge could be installed in the mid reaches of the Atkin Creek catchment close to the shared boundary with the Unnamed Tributary and additional measures implemented to increase flood awareness and community engagement. Together, these measures are estimated to give additional confidence in expected flood severity along with an increase in the time available for damage reducing actions by the town's residents (i.e. more reliable and substantive outcomes). This has been assessed as being achievable in the mid-term.

Further increased confidence in the expected severity of a developing flood, along with additional time to undertake damage reducing measures could be achieved if there was investment in additional and more sophisticated instrumentation to monitor rainfall, creek levels and the associated systems to alert emergency services and individuals to the exceedance of trigger values (i.e. improved monitoring and messaging system with automated elements). It is estimated that together these measures would achieve a further increase in effective flood warning time. This has been identified as the fully developed option for Birregurra and assessed as being achievable in the longer term. Implementation would require significant investment.

The above three paragraphs are presented in summary form against the TFWS building blocks as suggested actions aimed at securing a flash flood warning system for Birregurra in **Appendix M**. A reworked version of this table presented in terms of what is achievable now, with a greater level of investment and longer term is also provided in **Appendix M.**

10 MUNICIPAL FLOOD EMERGENCY PLAN (MFEP)

Flood intelligence data was extracted from the study's deliverables. At VICSES's request, the intel has been collated into the updated MFEP template provided by VICSES rather than into the current version of Council's MFEP. The data included within Council's current version has been reviewed and no information relating to Birregurra was found to need correction. The collated intel have been delivered directly to VICSES and Council within the updated template.

11 FLOOD SPATIAL DATA SPECIFICATION

11.1 OVERVIEW

As part of this study a number of outputs were generated compliant with the format outlined within the Flood Spatial Data Specifications (DELWP, 2020). These results were produced utilising the flood mapping results including extents and grid points for each simulated storm event.

The following sections provide details on the various data sets produced.

11.2 RASTER DATA

The following gridded data sets were provided as final deliverables for each modelled design event scenario:

- Maximum depth.
- Maximum velocity.
- Maximum water surface level.
- Maximum velocity x depth.
- Flood Hazard using the ARR 2019 Flood Hazard Curves Criteria.

11.3 VECTOR DATA

The following vector data was generated in a SDS compliant format:

- Study area (defined by the 1 % AEP flood extent).
- Flood extents (for all modelled scenarios/AEPs).
- Flood level contours (for all modelled scenarios/AEPs).
- Mapping limits.
- Proposed FO, LSIO and SBO extents.
- Flood affected properties.
- Surveyed Floor Levels.

11.4 MAPS

A map was produced for each design flood event which included the following vector and grid GIS layers:

- Flood extents.
- Flood level contours at 1 m intervals.
- Flood depths.
- Identification of essential services.
- Road labels.
- township cadastre.

12 CONCLUSIONS AND RECOMMENDATIONS

12.1 CONCLUSIONS

The investigations undertaken as part of this study highlight the following key outcomes:

- Several dwellings within the 1 % AEP design event flood extent (approximately 78) of which 26 dwellings are affected by above floor level flooding.
- The key flooding hotspots are associated with:
  - Atkin Creek downstream of Roadknight Street due to the existing channel's limited capacity.
  - Unnamed Tributary downstream of Sladen Street due to the existing waterway's limited capacity.
  - Council's existing underground drainage capacity between Prime to Sladen Street and along Sladen Street from Ennis Street.
- The September 2016 flood event modelling and the resultant close match between the surveyed and modelled flood levels provide confidence in the selected input parameters.
- The mitigation assessment undertaken identified 4 key structural mitigation works which could be implemented to reduce flooding impacts to dwellings, subject to securing an appropriate funding source. The high-level multicriteria assessment considering both tangible (capital cost and average annual damage reduction) in addition to intangible factors (such as environmental and social impacts and constructability and risks) were assessed.
  - Detailed assessments have not been considered including in relation to flora and fauna (biodiversity), cultural heritage values, or geotechnical matters. These will need to be examined before any mitigation option is pursued in addition to approvals processes.
- The stormwater quality assessment identified the wetland footprint area which would be required to ensure the predicted future development / increase in impervious area meet the BPEMG targets. Although further investigations would be required to confirm its feasibility, the asset could be funded through developer contributions. The assessment also highlighted the benefits of rainwater tanks and sealing roads within Birregurra and the practicality of implementing bioretention assets to meet the targets.
- The strategy highlighted the importance of updating the existing overlays with the extents delineated and implementation of planning scheme amendments that include schedules for the developed FO, LSIO and SBO with the relevant planning controls.
- The flood warning assessment identified the effective food warning time relevant to Birregurra in addition to highlighting the essential building blocks of a Total Flood Warning System (TFWS) which have been delivered via the outputs of this study including:
  - Updated flood inundation and related mapping.
  - An updated Municipal Flood Emergency Plan (MFEP) with Birregurra-centric flood consequence information.
  - An indicative flood guidance tool.
  - Information suitable for inclusion in a Local Flood Guide (LFG).
- As part of the flood warning assessment a feasibility assessment was also undertaken into how the effective flood warning time could be further extended through improved alerting and warning systems. The identified options range from making better use of existing rainfall monitoring resources (i.e. minimum investment achievable in the near term) through to the improved rain and / or river monitoring with automated messaging (i.e. moderate to significant investment achievable in the mid to longer term).
- Flood intelligence data was extracted from the study deliverables and collated into the updated Municipal Flood Emergency Plan template. This separate working document has been delivered to Council and VicSES directly and aims to provide guidance on the approximate relationship between food magnitude and flood consequences so that appropriate actions can be taken.

12.2 RECOMMENDATIONS

Based on the study's outcomes, the following recommendations relevant to each stakeholder were identified:

1. Colac Otway Shire Council:
    a) Seek internal endorsement of the flood study and undertake public exhibition to ensure the Birregurra community has the opportunity to comment and provide feedback.
    b) Update the planning scheme to incorporate the findings of this study.
    c) Consider the outcomes of the high level multicriteria assessment and findings of additional investigations and consider options which may progress to further feasibility assessments, subject to funding requirements.
    d) Reference the provided flood modelling outputs, in particular the flood level information, to provide advice on recommended minimum floor levels for new developments for which Council is the responsible authority.
    e) Review the Municipal Flood Emergency Plan with input from VICSES and adopt revised document.
2. Corangamite CMA:
    a) Seek internal endorsement of the flood study and use mapping outputs to manage floodplain risk and inform development advice to ensure risks are minimised.
    b) Reference the provided flood modelling outputs, in particular the flood level information, to provide advice on recommended minimum floor levels for new developments for which CCMA is the responsible authority.
    c) Add the produced Flood Spatial Data Specification (SDS) outputs and other relevant mapping outputs to FloodZoom.
3. Victorian State Emergency Services
    a) Continue to engage with the community to increase their awareness of flood related risks.
    b) Review and discuss the updated MFEP.

13 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) The strategy is based on best available information at the time and is subject to an exhibition period which may include minor updates.

c) 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.

d) During the exhibition period, 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.

   Once the document has been adopted and included in the planning scheme it can no longer be amended and a new version would need to be issued.

e) 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.

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.

14 REFERENCES

Australian Emergency Management Institute (AEMI) (1995): *Flood Warning: An Australian Guide*.

Australian Institute for Disaster Resilience (AIDR) (2009): *Manual 21: Flood Warning*.

Bureau of Meteorology (1996): *Bureau of Meteorology Policy on the Provision of the Flash Flood Warning Service.* May 1996.

Bureau of Meteorology (2020): *Service Level Specification for Flood Forecasting and Warning Services for Victoria – Version 3.2.* August 2020.

Commonwealth Scientific and Industrial Research (CSIRO) (1999): *Urban Stormwater Guidelines: Best Practive Environmental Management Guidelines*

Corangamite Catchment Management Authority (CCMA) (2017): *Corangamite Regional Floodplain Management Strategy, 2017-2027*.

Department of Environment Land Water & Planning (2016): *Victorian Floodplain Management Strategy*. April 2016.

Michael Cawood & Associates for the Victorian Flood Warning Consultative Committee (VFWCC) (2005): *Flood Warning Service Development Plan for Victoria: Review of Flood Warning System Development Priorities within Victoria*. October 2005.

United Nations (UN) (1997): *Guiding Principles for Effective Early Warning*. Prepared by the Convenors of the International Expert Groups on Early Warning of the Secretariat of the International Decade for Natural Disaster Reduction, IDNDR Early Warning Programme, October 1997, Geneva, Switzerland.

Victorian Flood Warning Consultative Committee (VFWCC) (2001): *Arrangements for Flood Warning Services in Victoria*. February 2001.

Appendix A:
Site Visit Photos

Appendix Figure A. 1: Atkin Creek Bridge at Warncoort-Birregurra Road

Appendix Figure A. 2: Atkin Creek Bridge at Roadknight Street

Appendix Figure A. 3: Box culverts crossing Sladen Street at Unnamed Tributary

Appendix Figure A. 4: Unnamed Tributary east of Barry Street looking towards Barwon River Confluence

Appendix Figure A. 5: Barwon River Bridge crossing at Birregurra-Deans Marsh Road

Appendix B:
Summary of Findings from Community Engagement Sessions

Appendix Table B. 1: Summary of findings from Community Engagement Sessions

Location	Address	Resident Comment
1	17 Anderson Street	• Flood waters did not reach above floor level but were over garage floor in 2016 • They were pumping water all day • The flood data transfer 1 % extent looked about right for this property. • Road drainage in Anderson Street is an issue. Drains at different levels / grades, water doesn't get away.
2	15 Anderson Street	• The 2016 flood came half way up the front yard.
3	Football Oval	• 2016 flood reached the northern boundary of the football oval.
4	6 Anderson Street	• 2016 flood reached their western boundary.
5	18-24 Scouller Street	• Sewer line is creating a ditch where water is collecting • Sewer line construction blocked off drain at end of Scouller Street • Drain in Scouller Street needs maintenance • Opening of extra drain • Photos provided • $40,000 of flood damage • Waters entered house and reached 300 mm above floor level
6	43 Roadknight Street	• House did not flood in 2016 • Flood waters reached bearers • Contends there are issues with reeds in Atkin Creek near its junction with Barwon River which are impeding the flow of flood waters • Roadknight Street is acting as a levy bank • Suggest contacting Barwon Water about the depression created from sewer line construction • Suggest that Atkin Creek should be inspected for obstructions • Many noted obstructions in waterway at the Atkin Ck bridge on Birregurra Warncoort Road down to Roadknight Street and from Anderson Street to the Barwon River. • Resident suggests creek should be cleared with machinery
7	2 Ennis Street	• Atkin Creek does not flood upstream of this property. The only flood waters on the property come from water backing up at the main road bridge. • Resident suggests creek would benefit from clearing of vegetation • 8 inches deep at Colac / western entrance in 2016 • Channel dug around property • Channel was full in 2016, before that, yearly • Hasn't been full since 2016
8	42 Sladen Street	• Didn't flood above floor level in 2016 • Water reached the bottom of the weepholes in the brick work • Considers that the water is backing up the swale because the cross over pipes are not big enough • Also thinks the farming practices on nearby farmland have changed and there is more run-off coming off the land • Shed floods regularly • Skene Street and Strachan Street provide overspill point in 2016 near the creek bend • Swales need to be cleaned out because of sediment build up in Sladen Street • Austin Street has no swale at the moment • Suggest diverting some water down Austin Street and building swale to split some of the runoff load • Area also to be inspected by council officers
9	36 Sladen Street	• House didn't flood in 2016
10	71 Jenner Street and 19 Ennis Street	• Didn't flood in 2016 • Saturated subsoil
11	40 Sladen Street	• Farmland overflow water draining to north side of Sladen Street • Could be split down Sladen and Skene Street • In 2016 neighbours were pumping water all day
12	64 Strachan Street	• Has had difficulties in obtaining approval for building despite location of house being at high point • In 2016 when floods happened at block didn't flood – water stayed within its banks

Location	Address	Resident Comment
13	14 Anderson Street	• In 2011? – came up to the bridge • Different levels in the swale drains, no constant flow in Anderson Street • Survey height checks required in Atkin Creek between Barwon River and Roadknight Street • Always water at the back of their properties • Doesn’t look like the creek is flowing potentially due to lack of grade • Swale on west side of skate park always full of water

Appendix C:
Barwon River Hydrological Modelling Details

C.1 INTENSITY-FREQUENCY-DURATION (IFD) DATA

C.1.1 Base Conditions

Intensity-Frequency-Duration (IFD) data for each sub-catchment's geographic centroid was sourced from the Bureau of Meteorology. The data was assessed as part of the spatial variation analysis discussed in Section B.2 where a representative subarea (Subarea X) was selected and weighted IFD depths specifically re-defined for the 1 % AEP. The input IFD data is shown in Appendix Table C. 1. This data was used as the basis for the application of Areal Reduction Factor (ARF) where required.

Appendix Table C. 1: IFD Table for Barwon River RORB Model

Duration	Average rainfall depth (mm)							
	39.35 %	20 %	10 %	5 %	2 %	1 %	1 in 200	1 in 500
10 min	7.6	9.2	11.0	12.9	15.6	17.8	20.5	24.0
15 min	9.1	11.1	13.3	15.5	18.9	21.6	24.8	29.1
30 min	12.1	14.7	17.5	20.5	24.8	28.3	32.4	38.0
1 hour	15.8	19.1	22.8	26.6	32.0	36.3	41.4	48.5
2 hour	21.0	25.6	30.4	35.4	42.3	47.9	54.7	64.1
3 hour	25.2	30.9	36.7	42.7	51.0	57.7	65.9	77.4
6 hour	35.2	43.6	52.1	60.6	72.7	82.4	94.5	111.0
12 hour	48.9	61.7	74.2	86.9	105.0	120.0	137.0	162.0
24 hour	65.1	83.5	102.0	120.0	146.0	167.0	191.0	224.0
48 hour	80.7	104.0	128.0	153.0	185.0	210.0	239.0	278.0
72 hour	88.7	114.0	139.0	167.0	200.0	227.0	253.0	291.0

C.1.2 Climate Change Conditions

Appendix Table C. 2 displays the IFD data which was used for the climate change modelling of the 1 % AEP and 10 % AEP storm events.

Appendix Table C. 2: Climate Change IFD Table for Barwon River RORB Model

Duration	Average rainfall depth (mm)							
	39.35 %	20 %	10 %	5 %	2 %	1 %	1 in 200	1 in 500
10 min	6.8	9.2	11	12.9	15.6	17.6	20.5	24
15 min	8.21	11.1	13.3	15.5	18.9	21.3	24.8	29.1
30 min	10.9	14.7	17.5	20.5	24.8	28	32.4	38
1 hour	14.2	19.1	22.8	26.6	32	36.2	41.4	48.5
2 hour	18.9	25.6	30.4	35.4	42.3	48.2	54.7	64.1
3 hour	22.7	30.9	36.7	42.7	51	58.2	65.9	77.4
6 hour	31.7	43.6	52.1	60.6	72.7	83	94.5	111

Duration	Average rainfall depth (mm)							
	39.35 %	20 %	10 %	5 %	2 %	1 %	1 in 200	1 in 500
12 hour	44	61.7	74.2	86.9	105	120	137	162
24 hour	58.6	83.5	102	120	146	164	191	224
48 hour	72.7	104	128	153	185	203	239	278
72 hour	79.9	114	139	167	200	218	253	291

C.2 SPATIAL RAINFALL PATTERNS

The modelled Barwon River catchment exceeds 20 km², and as such a single non-uniform spatial pattern was applied to all modelled design storm events for each of the given storm durations.

As a key objective of the flood study is to produce planning scheme overlays based on the 1 % AEP storm event, the single non-spatial pattern was derived from the 1 % AEP IFD data. The resultant pattern was then compared to the resultant pattern derived from the 20 % AEP IFD data as a sensitivity check to confirm minimal variability. The following provides further details on the creation of the single non-uniform spatial pattern:

1. Download IFD data for the centroid of each Barwon River RORB model sub-catchment.
2. Calculate the volume of rainfall for each sub-catchment for the given duration utilising the design rainfall depth and area.
3. Calculate the weighted rainfall depth average for each duration by dividing the sum of sub-catchment rainfall volumes for each duration (calculated in Step 2) by the total catchment area.
4. Calculate the percentage of rainfall variation for the given duration and sub-catchment by multiplying the weighted average (calculated in Step 3) by the IFD rainfall depth obtained for each sub-catchment and duration (Step 1).
5. Undertake the above steps for the 20 % AEP to compare and confirm the minimal variability between the generated 1 % AEP pattern.
6. Apply the 1 % AEP non-uniform pattern as an input to the Barwon River RORB model.
7. Adopt the weighted rainfall depths (calculated as part of Step 3) to represent the 1 % AEP IFD input with the other AEP design rainfall depths defined by the depths identified as the catchment's representative subarea (Subarea X).

C.3 PRE-BURST RAINFALL DEPTHS

The rural initial losses obtained from the ARR Data Hub corresponds to complete storms (abbreviated as IL_s), however the IFD data provided by the Bureau of Meteorology is associated to rainfall bursts only. To account for this difference, ARR 2019 recommends reducing the rural initial loss (storm) to represent the initial burst loss (IL_b).

- $IL_{Burst} = IL_{STORM} - Preburst\ rainfall\ depth\ (mm)$

Whilst undertaking the Monte Carlo calibration of the Barwon River RORB model to the FFA curves, the initial burst losses were applied in RORB utilising the in-built default pre-burst distribution patterns for each storm duration and the median pre-burst depths sourced from the ARR Data Hub and displayed within Appendix Table C. 3. As the Data Hub does not provide pre-burst depths for durations less than 60 minutes, these durations have adopted the 60-minute pre-burst depths in line with current industry recommendations.

Appendix Table C. 3: Barwon River ARR Data Hub Median Pre-burst Depths

min	hr	20 % AEP	10 % AEP	5 % AEP	2 % AEP	1 % AEP
10	-	1.8	1.7	1.7	1.9	2.1
15	-	1.8	1.7	1.7	1.9	2.1

min	hr	20 % AEP	10 % AEP	5 % AEP	2 % AEP	1 % AEP
30	-	1.8	1.7	1.7	1.9	2.1
60	1	1.8	1.7	1.7	1.9	2.1
120	2	2.1	2.4	2.8	2.6	2.4
180	3	1.7	2.4	3	2.4	2
360	6	2.9	2.6	2.3	1.8	1.5
720	12	2.3	3.4	4.5	4	3.7
1440	24	0.9	1.4	2	3	3.8
2880	48	0	0	0	0.9	1.6
4320	72	0	0	0	0	0.1

For the simulations which defined the Barwon River inflows to the hydraulic TUFLOW model (at Node ID R4), initial burst losses were considered with the application of duration factors for each given storm event. This duration factor was calculated by subtracting the median pre-burst depth of each storm duration from the rural storm initial loss (IL_{storm}) divided by the rural storm initial loss. The duration factors applied to the rural initial loss are summarised in Appendix Table C. 4.

Appendix Table C. 4: Barwon River ARR Initial Loss Duration Factors

min	hr	20 % AEP	10 % AEP	5 % AEP	2 % AEP	1 % AEP
10	-	0.88	0.89	0.89	0.87	0.86
15	-	0.88	0.89	0.89	0.87	0.86
30	-	0.88	0.89	0.89	0.87	0.86
60	1	0.88	0.89	0.89	0.87	0.86
120	2	0.89	0.84	0.80	0.84	0.87
180	3	0.81	0.83	0.85	0.88	0.90
360	6	0.85	0.77	0.70	0.73	0.75
720	12	0.91	0.87	0.83	0.59	0.41
1440	24	1.00	1.00	1.00	1.00	0.99
2880	48	0.88	0.89	0.89	0.87	0.86
4320	72	0.88	0.89	0.89	0.87	0.86

The ARR Data Hub does not provide median pre-burst depths for events greater than the 1 % AEP. A study undertaken by Jordan et al. (2005) has estimated the pre-burst depth to be 3.2 % of the total burst depth. Given the total burst depths are quite large for these rarer events where the pre-burst would not have a significant influence on the peak runoff volume or flow rate, this approach was considered appropriate and adopted for the 0.5 % AEP, 0.2 % AEP and the PMF storm events.

C.4 TEMPORAL PATTERNS

Temporal patterns were obtained from the ARR Data Hub for the modelled Barwon River's catchment centroid. As the catchment is greater than 75 km², areal temporal patterns were adopted. Temporal patterns were derived from the Southern Slopes Mainland Increment data set.

C.5 AREAL REDUCTION FACTOR

The IFD data provided by the BoM is applicable for rainfall in small catchments. As catchment size increases, the chance of that average intensity of rainfall occurring over the entire catchment decreases. To address this issue an Areal Reduction Factor (ARF) can be applied to account for the larger catchment area.

ARR 2019 provides procedures for the calculation of ARFs for catchments up to 30,000 km² and durations up to and including 7 days. The ARF to be applied to the design rainfall is a function of the total area of the catchment, the duration of the design rainfall event and its AEP.

During the assessment of modelled flows at the gauging station / model outlet, the ARF was applied through the RORB interface allowing the consideration of the total catchment area for the given AEP and storm duration.

In contrast for the generation of inflow hydrographs (at Node ID 'R4') for application into the hydraulic TUFLOW model, the ARF was applied to the IFD input data. The relevant procedure and equations described within ARR 2019 for a catchment area between 10 to 1000 km² were utilised. As an example, for the Barwon inflow location (Node ID 'R4') which consists of an upstream catchment area of approximately 432 km² and for a storm duration of 12 hours and 1 % AEP event, an ARF of 0.865 was applied to the relevant IFD rainfall depth. Appendix Table C. 5 provides a summary of the ARF factors applied to generate the Barwon River flows at location 'R4' for the various storm events modelled to date.

Appendix Table C. 5: ARF Factors applied to the Barwon River 'R4' Inflow Location

Duration	20 % AEP	1 % AEP
720 min (12 hr)	0.891	0.865
1440 min (24 hr)	0.936	0.943
2880 min (48 hr)	0.950	0.958

Appendix D:
Atkin Creek & Unnamed Tributary Hydrological Modelling Details

D.1 INTENSITY-FREQUENCY-DURATION (IFD) DATA

D.1.1 Base Case / Existing Conditions

Intensity-Frequency-Duration (IFD) data for each sub-catchment's geographic centroid was sourced from the Bureau of Meteorology. The data was assessed as part of the spatial variation analysis discussed below in Section D.2 where a representative subarea (Subarea AK) was selected and weighted IFD depths specifically re-defined for the 1 % AEP. The input IFD data is shown in Appendix Table D. 1. This data was used as the basis for the application of Areal Reduction Factor (ARF) where required.

Appendix Table D. 1: IFD Table for Atkin Creek and Unnamed Tributary RORB Model

Duration	Average rainfall depth (mm)							
	39.35 %	20 %	10 %	5 %	2 %	1 %	1 in 200	1 in 500
10 min	7.1	8.8	10.6	12.4	15.1	17.2	20.2	23.8
15 min	8.6	10.6	12.8	15.0	18.3	20.9	24.5	29.0
30 min	11.4	14.0	16.8	19.7	23.8	27.2	31.7	37.4
1 hour	14.8	18.0	21.4	25.0	29.8	33.9	39.2	46.0
2 hour	19.2	23.2	27.4	31.7	37.6	42.6	49.0	57.6
3 hour	22.6	27.2	32.0	36.9	43.6	49.4	57.0	67.1
6 hour	30.0	36.2	42.6	49.0	58.0	66.0	76.4	90.5
12 hour	39.6	48.3	57.1	65.8	78.8	90.0	105.0	124.0
24 hour	50.5	62.5	74.5	86.7	105.0	119.6	138.0	163.0
48 hour	61.1	76.1	91.5	107.0	129.0	146.9	167.0	195.0
72 hour	66.9	82.7	99.3	117.0	140.0	157.7	176.0	202.0

D.1.2 Climate Change Conditions

Appendix Table D. 2 displays the IFD data which was used for the climate change modelling of the 1 % AEP and 10 % AEP storm events. This data was also used as the basis for the application of ARFs where relevant.

Appendix Table D. 2: IFD Table for Barwon River RORB Model

Duration	Average rainfall depth (mm)							
	39.35 %	20 %	10 %	5 %	2 %	1 %	1 in 200	1 in 500
10 min	8.4	10.4	12.6	14.7	17.9	20.4	23.9	28.2
15 min	10.2	12.6	15.2	17.8	21.7	24.8	29.0	34.4
30 min	13.5	16.6	19.9	23.3	28.2	32.2	37.6	44.3
1 hour	17.5	21.3	25.4	29.6	35.3	40.2	46.5	54.5
2 hour	22.8	27.5	32.5	37.6	44.6	50.4	58.1	68.3
3 hour	26.8	32.2	37.9	43.7	51.7	58.6	67.5	79.5

Duration	Average rainfall depth (mm)							
	39.35 %	20 %	10 %	5 %	2 %	1 %	1 in 200	1 in 500
6 hour	35.6	42.9	50.5	58.1	68.7	78.2	90.5	107.2
12 hour	46.9	57.2	67.7	78.0	93.4	106.6	124.4	146.9
24 hour	59.8	74.1	88.3	102.7	124.4	141.8	163.5	193.2
48 hour	72.4	90.2	108.4	126.8	152.9	174.1	197.9	231.1
72 hour	79.3	98.0	117.7	138.6	165.9	186.9	208.6	239.4

D.2 SPATIAL RAINFALL PATTERNS

The modelled Atkin Creek and Unnamed Tributary catchment exceeds 20 km², and as such a single non-uniform spatial pattern was applied to all modelled design storm events for each of the given storm durations.

As a key objective of the flood study is to produce planning scheme overlays based on the 1 % AEP storm event, the single non-spatial pattern was derived from the 1 % AEP IFD data. The resultant pattern was then compared to the resultant pattern derived from the 20 % AEP IFD data as a sensitivity check to confirm minimal variability. The creation of a single non-uniform spatial pattern was undertaken using the same approach documented in Section 3.4.6.

D.3 PRE-BURST RAINFALL DEPTHS

The rural initial losses obtained from the ARR Data Hub corresponds to complete storms (abbreviated as ILs), however the IFD data provided by the Bureau of Meteorology is associated to rainfall bursts only. To account for this difference, ARR 2019 recommends reducing the rural initial loss (storm) to represent the initial burst loss (IL_b).

- $IL_{Burst} = IL_{STORM} - Preburst\ rainfall\ depth\ (mm)$

The ensemble and Monte Carlo simulations for the Atkin Creek and Unnamed Tributary RORB model accounted for pre-burst losses by applying loss duration factors for each given storm event. This duration factor was calculated by subtracting the median pre-burst depth of each storm duration from the rural storm initial loss (IL storm) divided by the rural storm initial loss.

Appendix Table D. 3 displays the median pre-burst depths obtained from the ARR Data Hub for the Atkin Creek and Unnamed Tributary catchment centroid with

Appendix Table D. 4 displaying the resultant pre-burst duration factors applied to the rural initial loss for each storm event and duration.

Appendix Table D. 3: Atkin Creek and Unnamed Tributary ARR Data Hub Median Pre-burst Depths

Duration	20 % AEP	10 % AEP	5 % AEP	2 % AEP	1 % AEP
10 min	1.7	1.6	1.5	1.8	1.9
15 min	1.7	1.6	1.5	1.8	1.9
30 min	1.7	1.6	1.5	1.8	1.9
1 hour	1.7	1.6	1.5	1.8	1.9
2 hour	2.8	3	3.2	2.6	2.2
3 hour	2.7	2.8	2.8	2.7	2.7

Duration	20 % AEP	10 % AEP	5 % AEP	2 % AEP	1 % AEP
6 hour	1.7	2.1	2.5	2.9	3.3
12 hour	0.8	1.4	1.9	3.9	5.4
24 hour	0	0	0	0.4	0.6
48 hour	0	0	0	0	0
72 hour	0	0	0	0	0

Appendix Table D. 4: Atkin Creek and Unnamed Tributary ARR Data Hub Initial Loss Depth Duration Factors

Duration	20 % AEP	10 % AEP	5 % AEP	2 % AEP	1 % AEP
10 min	0.89	0.89	0.90	0.88	0.87
15 min	0.89	0.89	0.90	0.88	0.87
30 min	0.89	0.89	0.90	0.88	0.87
1 hour	0.89	0.89	0.90	0.88	0.87
2 hour	0.81	0.80	0.79	0.83	0.85
3 hour	0.82	0.81	0.81	0.82	0.82
6 hour	0.89	0.86	0.83	0.81	0.78
12 hour	0.95	0.91	0.87	0.74	0.64
24 hour	1.00	1.00	1.00	0.97	0.96
48 hour	1.00	1.00	1.00	1.00	1.00
72 hour	1.00	1.00	1.00	1.00	1.00

The ARR Data Hub does not provide median pre-burst depths for events greater than the 1 % AEP. A study undertaken by Jordan et al. (2005) has estimated the pre-burst depth to be 3.2 % of the total burst depth. Given the total burst depths are quite large for these rarer events where the pre-burst would not have a significant influence on the peak runoff volume or flow rate, this approach was considered appropriate and adopted for the 0.5 % AEP, 0.2 % AEP and the PMF storm events.

D.4 TEMPORAL PATTERNS

Temporal patterns were obtained from the ARR Data Hub for the modelled Atkin Creek and Unnamed Tributary RORB model catchment centroid. As the catchment is less than 75 km² point temporal patterns were adopted. Temporal patterns were derived from the Southern Slopes Mainland Increment data set.

D.5 AREAL REDUCTION FACTOR

The IFD data provided by the BoM is applicable for rainfall in small catchments. As catchment size increases, the chance of that average intensity of rainfall occurring over the entire catchment decreases. To address this issue an Areal Reduction Factor (ARF) can be applied to the IFD data to account for the larger catchment area.

ARR 2019 provides procedures for the calculation of ARFs for catchments up to 30,000 km² and durations up to and including 7 days. The ARF to be applied to the design rainfall is a function of the total area of the catchment, the duration of the design rainfall event and its AEP.

The ARF was computed using the relevant procedure described in ARR 2019 for the Monte Carlo simulations focussing on the township's watercourses utilising the short duration ARF equation. Due to the small area of the local township catchment, an ARF of 1 was applied to the ensemble simulations.

Appendix Table D. 5 displays the ARF applied to the Atkin Creek and Unnamed Tributary inflow locations for the AEP events and durations simulated to date. These ARF's were calculated based on the following catchment areas upstream of the relevant node locations:

- 'CA2' on Atkin Creek – 22.7 km^2
- 'CV2' on the Unnamed Tributary – 4.6 km^2

These node locations and associated upstream catchment areas were mid-way along the waterways within the township to allow for the averaged effects of the ARF between the inflow locations and downstream Barwon River confluence of both the Atkin Creek and Unnamed Tributary.

Appendix Table D. 5: ARF Factors applied to the Atkin Creek and Unnamed Tributary inflow locations

Duration	20 % AEP		1 % AEP	
	Inflows to Atkin Creek (BP1 & BS2)	Inflows to Unnamed Tributary (CM2 & CR2)	Inflows to Atkin Creek (BP1 & BS2)	Inflows to Unnamed Tributary (CM2 & CR2)
720 min (12 hr)	0.968	0.991	0.955	0.981
1440 min (24 hr)	0.985	0.999	0.998	1
2880 min (48 hr)	0.990	1	1	1

D.6 PMF MODELLING APPROACH

The Probable Maximum Flood (PMF) is the flow generated from the theoretical peak maximum precipitation (PMP) for a given duration under current climate conditions. Procedures for estimating PMP rainfall depths have been developed by the Bureau of Meteorology (BoM) for different locations and durations. For durations up to 6 hours and areas up to 1000 km^2 the Generalised Short Duration Method (GSDM) is applicable for all of Australia.

The following provides a summary of the approach undertaken and assumptions adopted for calculating the PMF for the Unnamed Tributary and Atkin Creek waterways.

Key Assumptions (used as inputs to the GSDM calculation)

- Elevation Adjustment Factor = 1
- Moisture Adjustment Factor = 0.53
- Proportion of Catchment Rough = 100 %
- Proportion of Catchment Smooth = 0 %

GSDM Methodology

1. Estimate the PMP depth (nearest 10 mm) using the GSDM inputs (above) and the PMP value equation and depth-duration-area curves presented in *The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method* (BoM, 2003)
2. Manually adjust the 4-12 hour PMP estimates to achieve a better fit to the rainfall-duration curve
3. Finalise estimates of the PMP (Appendix Table D. 6)
4. Calculate the depth per time increment for each event duration using the design temporal distribution pattern derived by the BoM (Appendix Table D. 7).

5. Calculate the design spatial distribution of the PMP for each event duration up to the 6 hour event over the catchment using the methodology recommended within the BoM guidelines which includes the use of ellipses (BoM, 2003):
6. Calculate the proportion of each RORB subarea inside each ellipse
7. Calculate the PMP depth applied to each subarea by summing the product of the proportion of each RORB subarea inside each ellipse (calculated in Step 6) by the mean rainfall depth for the ellipse (calculated in Step 5)
8. Generate RORB storm files using the subarea spatial distribution calculated in Step 7 for each event duration to represent the PMF
9. Output the required RORB hydrographs for application to the TUFLOW hydraulic model.

Appendix Table D. 6: Total PMP for Event Duration for the Unnamed Tributary and Atkin Creek Waterways

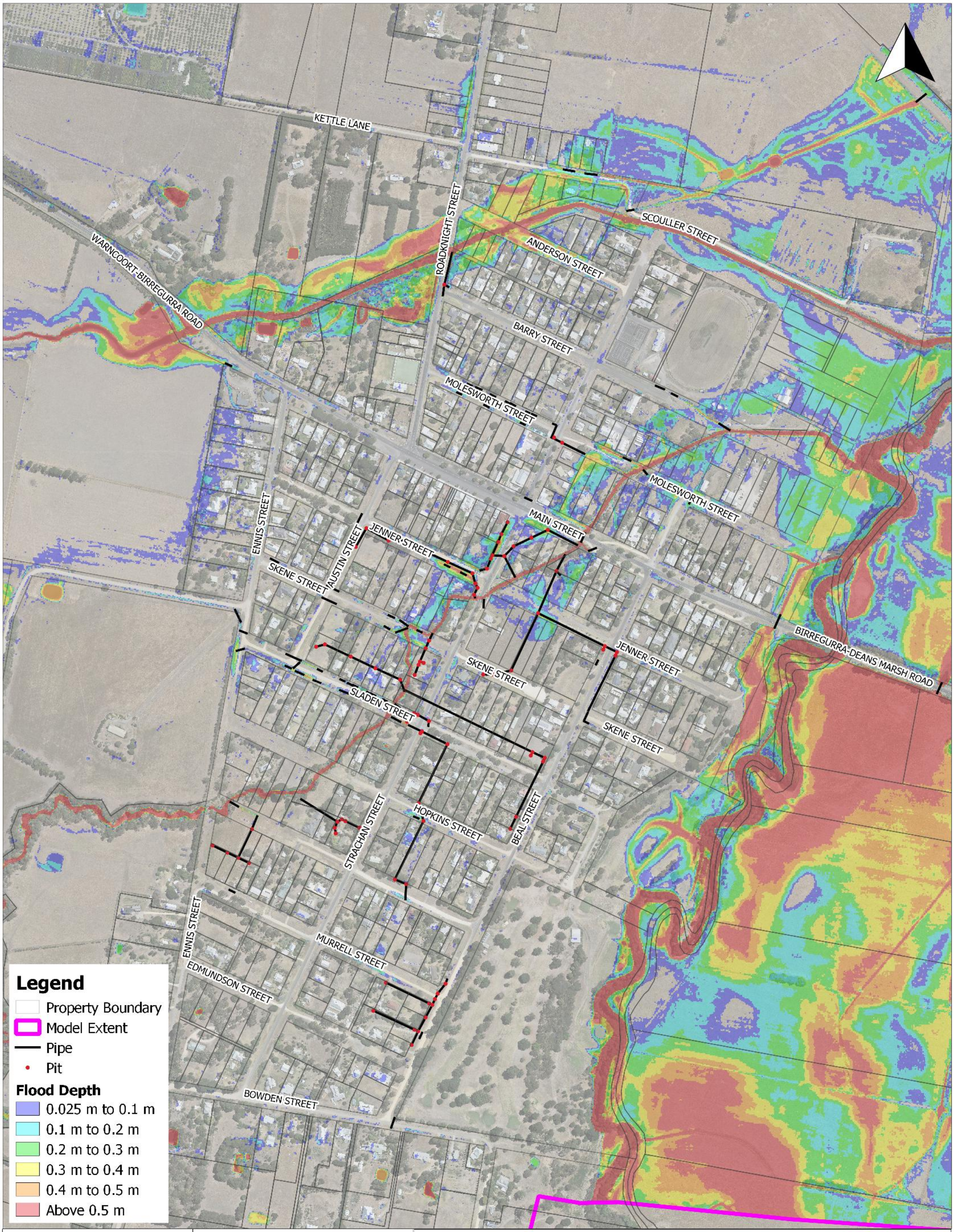
Event Duration	Unnamed Tributary (mm)	Atkin Creek (mm)
15 minute	120	110
30 minute	170	160
1 hour	260	230
2 hour	390	350
3 hour	470	420
4 hour	560	510
6 hour	565	560

Appendix Table D. 7: Design Temporal Distribution of Short Duration PMP (taken from BoM, 2003)

% of time	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	5
% of PMP	4	10	18	25	32	39	46	52	59	64	70	75	80	85	89	92	95	97	99	100	4

Appendix E:

September 2016 Calibration Flood Depth Layout Plan



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Colac Otway SHIRE

110 0 110 m

Scale in metres (1:5600 @ A3)

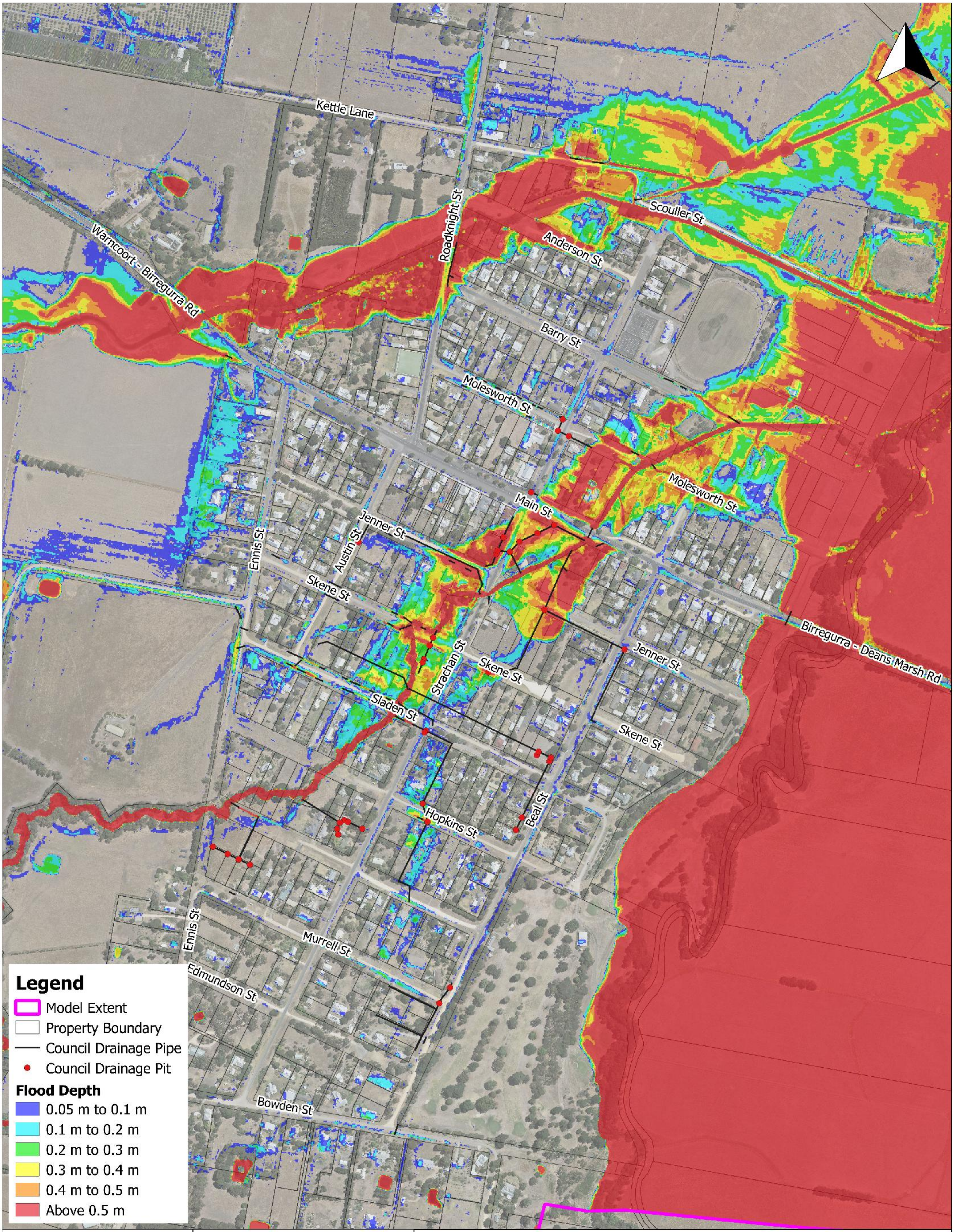
Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 54

Birregurra Flood Study

September 2016 Calibration Event
Flood Depth Layout Plan

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 2/11/2020

Appendix F:
Design Flood Depth Layout Plans



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110 0 110 m

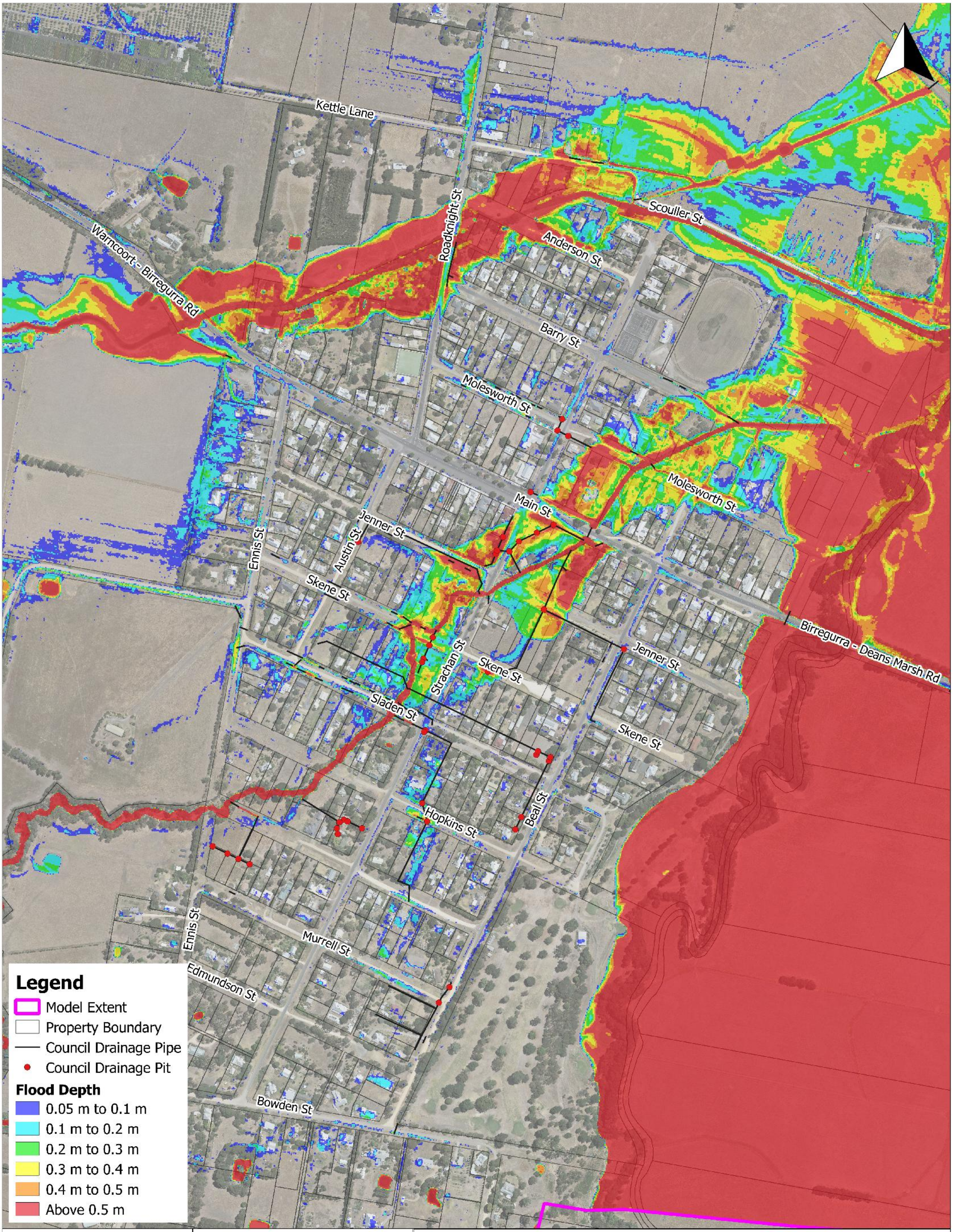
Scale in metres (1:5500 @ A3)

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

Birregurra Flood Study

Flood Depth - 0.2% AEP

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 30/10/2020



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110 0 110 m

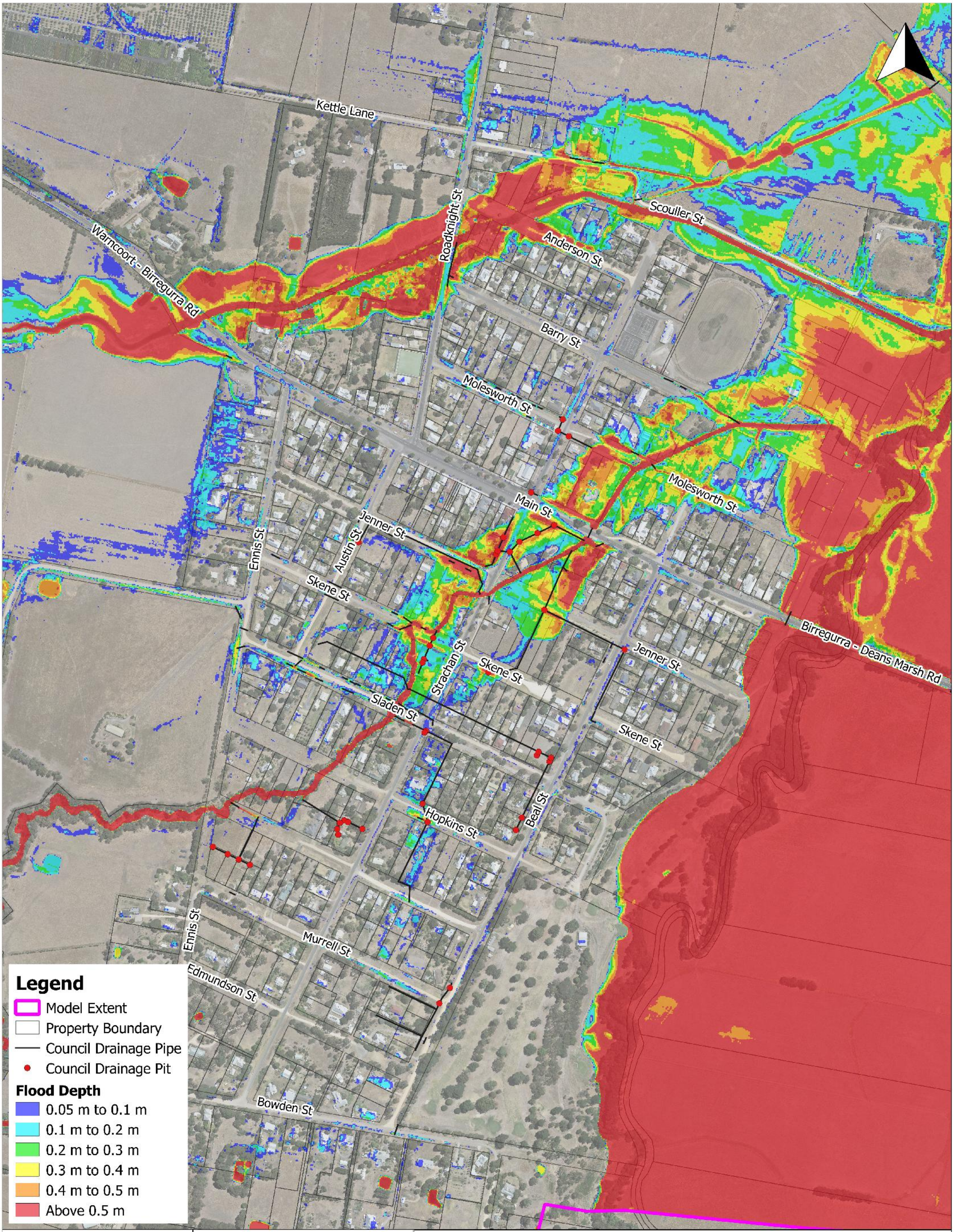
Scale in metres (1:5500 @ A3)

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

Birregurra Flood Study

Flood Depth - 0.5% AEP

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 30/10/2020



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110 0 110 m

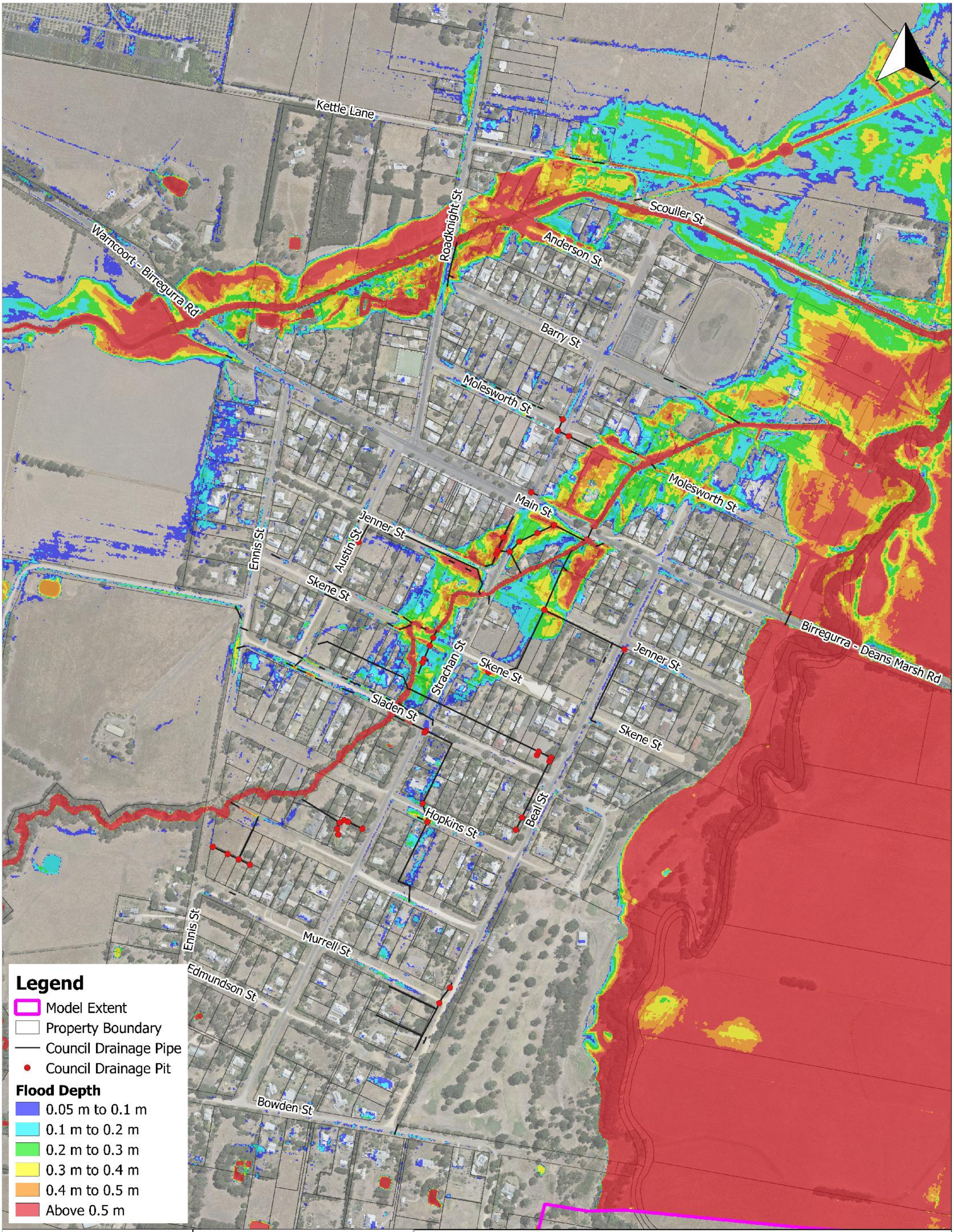
Scale in metres (1:5500 @ A3)

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

Birregurra Flood Study

Flood Depth - 1% AEP

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 30/10/2020



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110 0 110 m

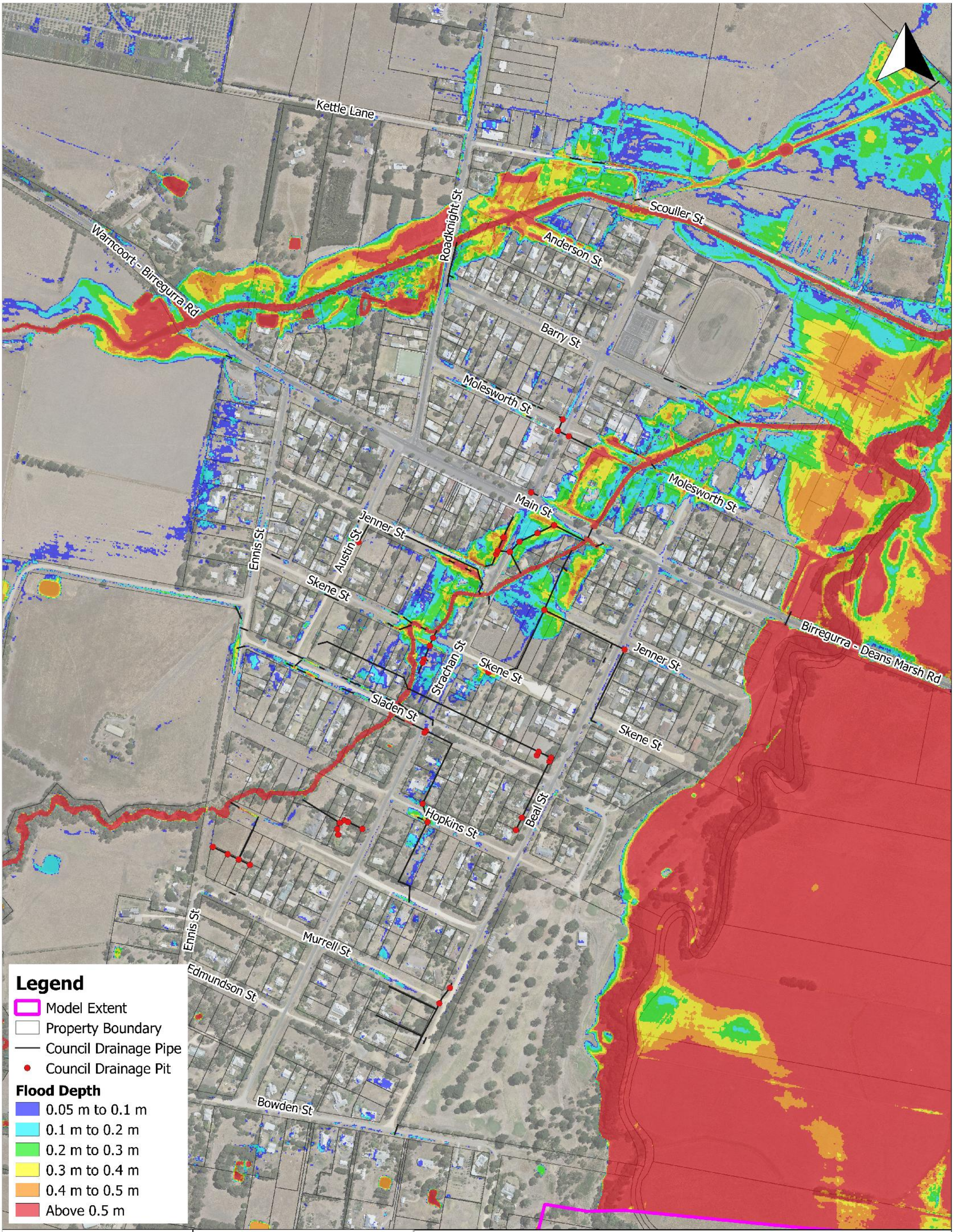
Scale in metres (1:5500 @ A3)

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

Birregurra Flood Study

Flood Depth - 2% AEP

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 30/10/2020



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110 0 110 m

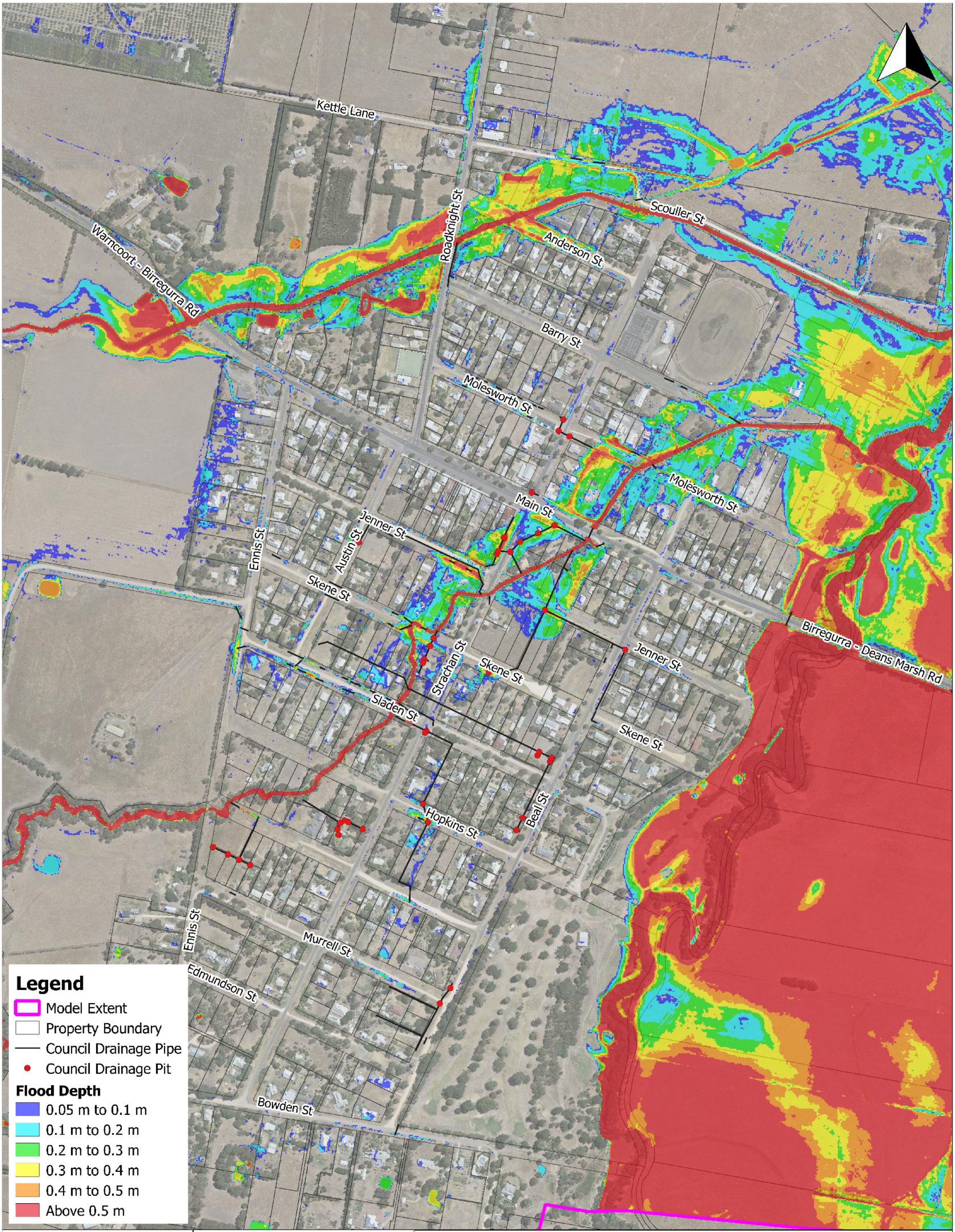
Scale in metres (1:5500 @ A3)

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

Birregurra Flood Study

Flood Depth - 5% AEP

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 30/10/2020



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110 0 110 m

Scale in metres (1:5500 @ A3)

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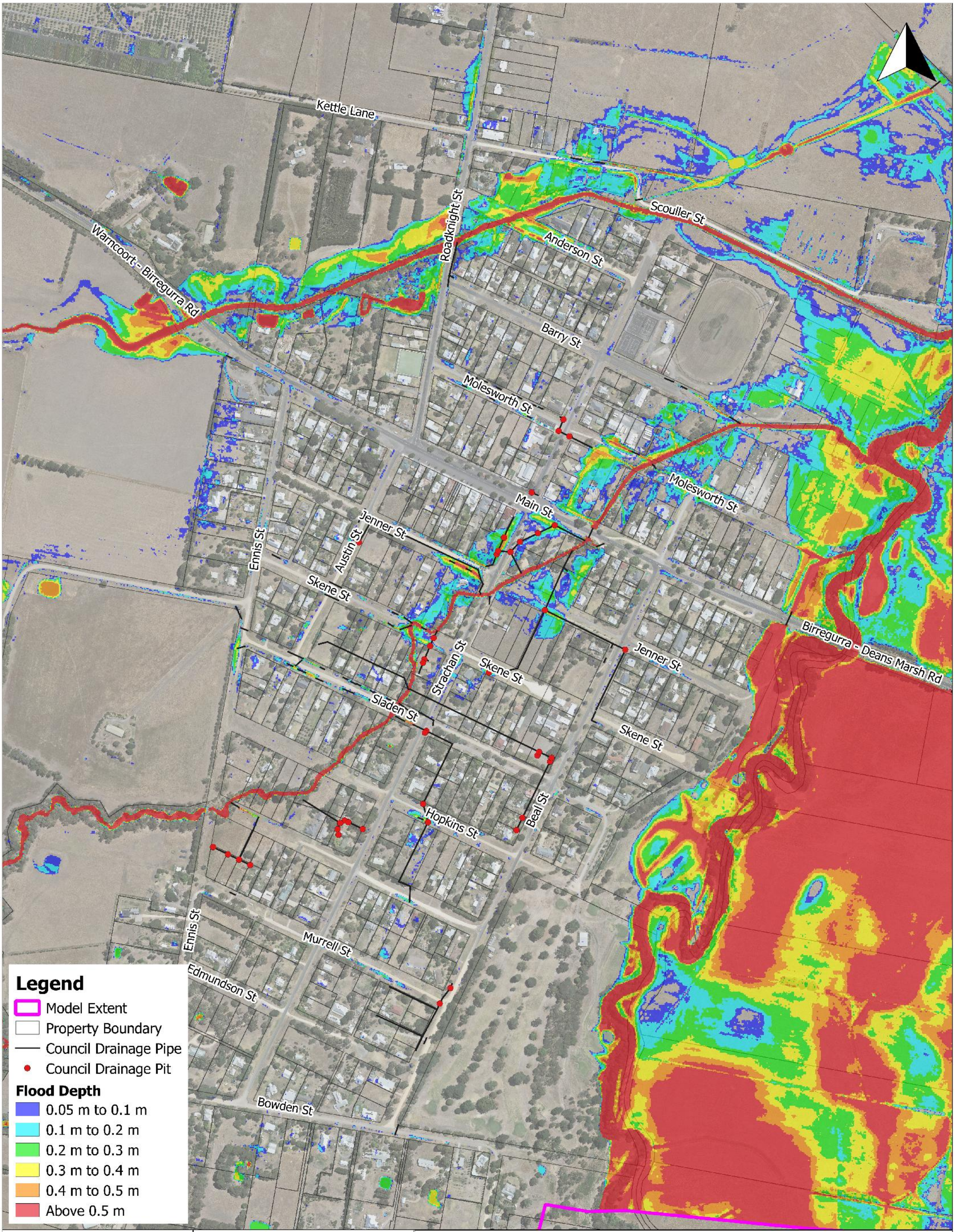
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Birregurra Flood Study

Flood Depth - 10% AEP

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 30/10/2020



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110 0 110 m

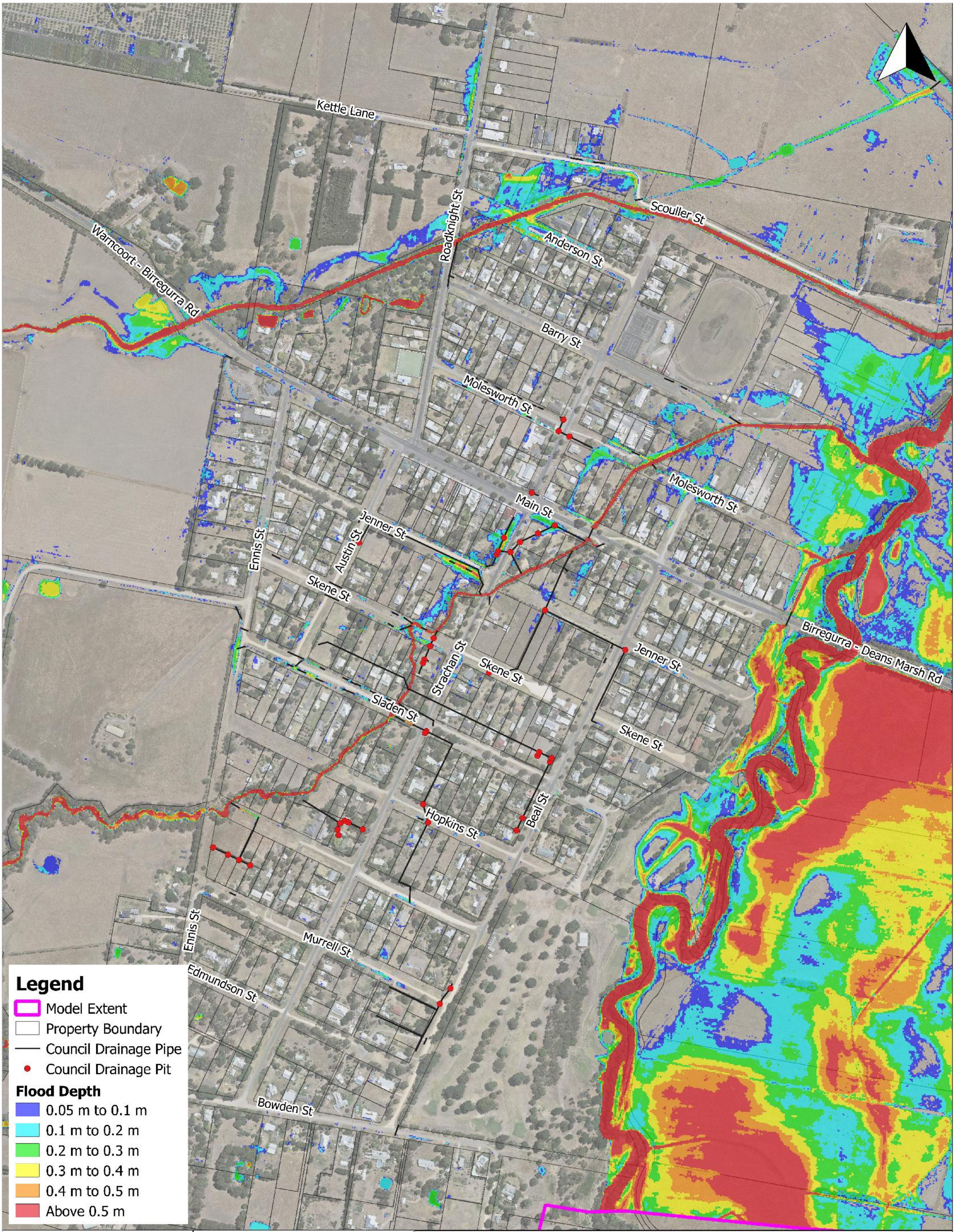
Scale in metres (1:5500 @ A3)

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

Birregurra Flood Study

Flood Depth - 20% AEP

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 30/10/2020



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Colac Otway SHIRE

110 0 110 m

Scale in metres (1:5500 @ A3)

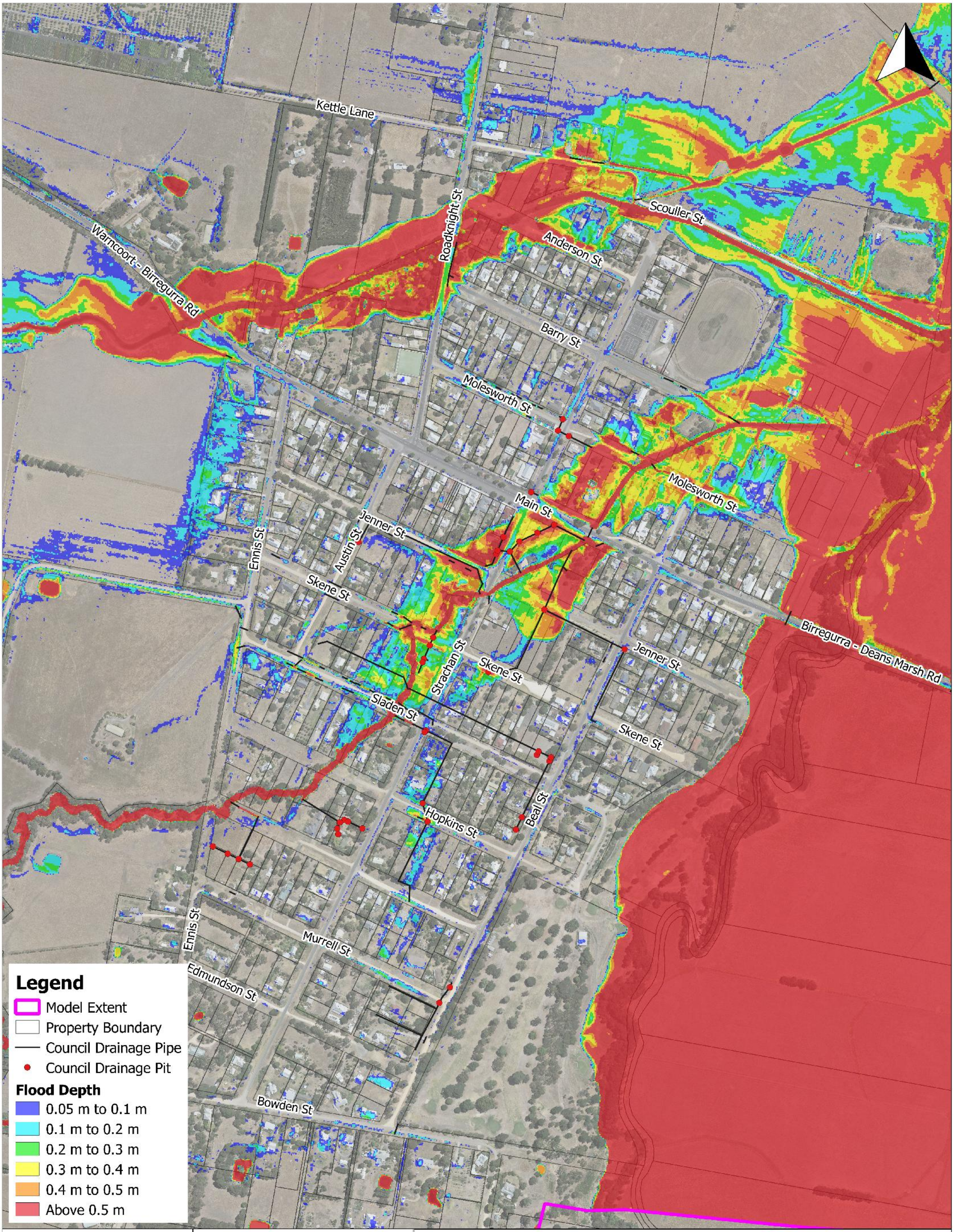
Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Birregurra Flood Study

Flood Depth - 39.35% AEP

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 30/10/2020

Appendix G:
Climate Change Flood Depth Layout Plans



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ENGENY WATER MANAGEMENT

Colac Otway SHIRE

110 0 110 m

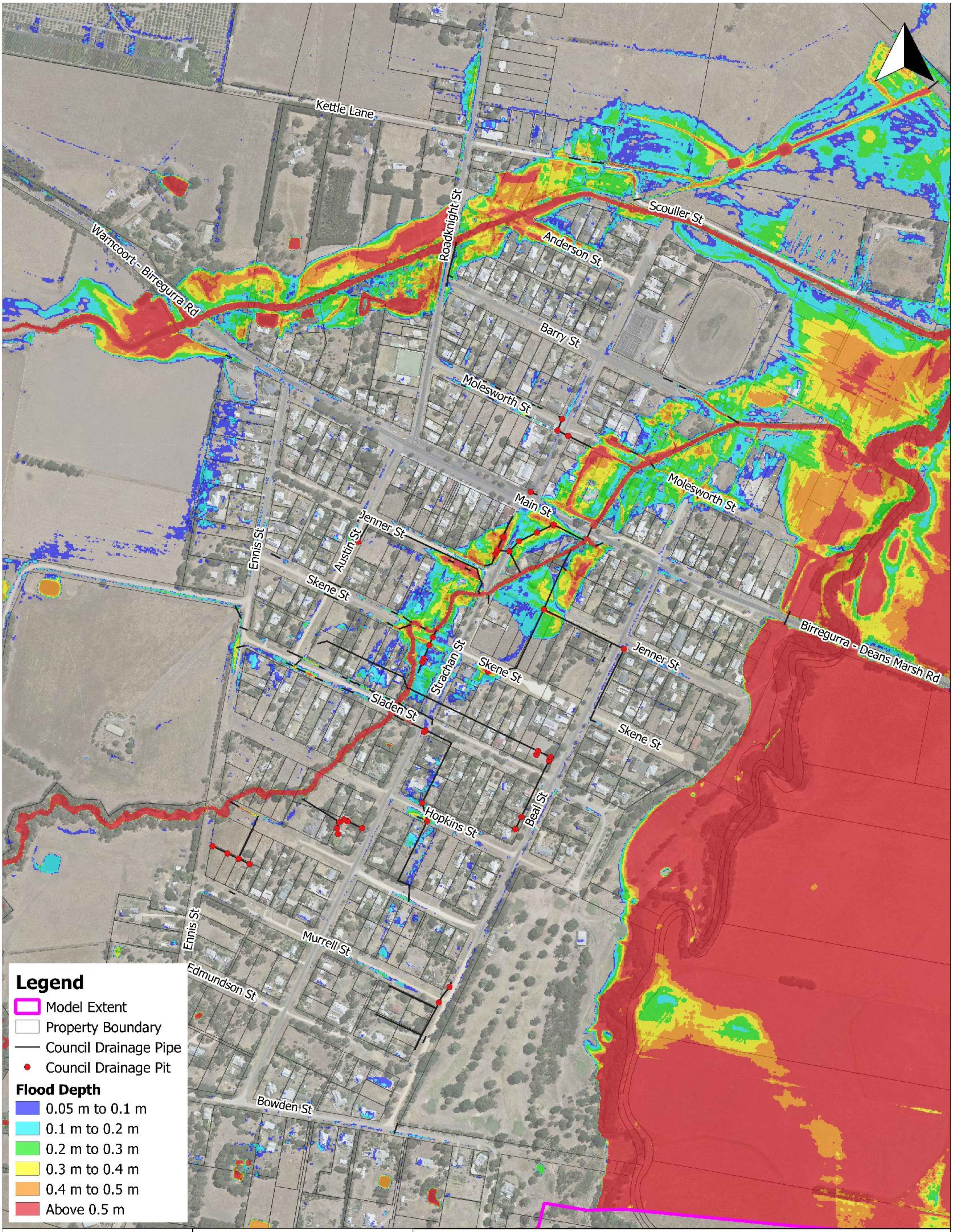
Scale in metres (1:5500 @ A3)

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

Birregurra Flood Study

Flood Depth - 1% AEP Climate Change

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 30/10/2020



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ENGENY

Colac Otway SHIRE

110 0 110 m

Scale in metres (1:5500 @ A3)

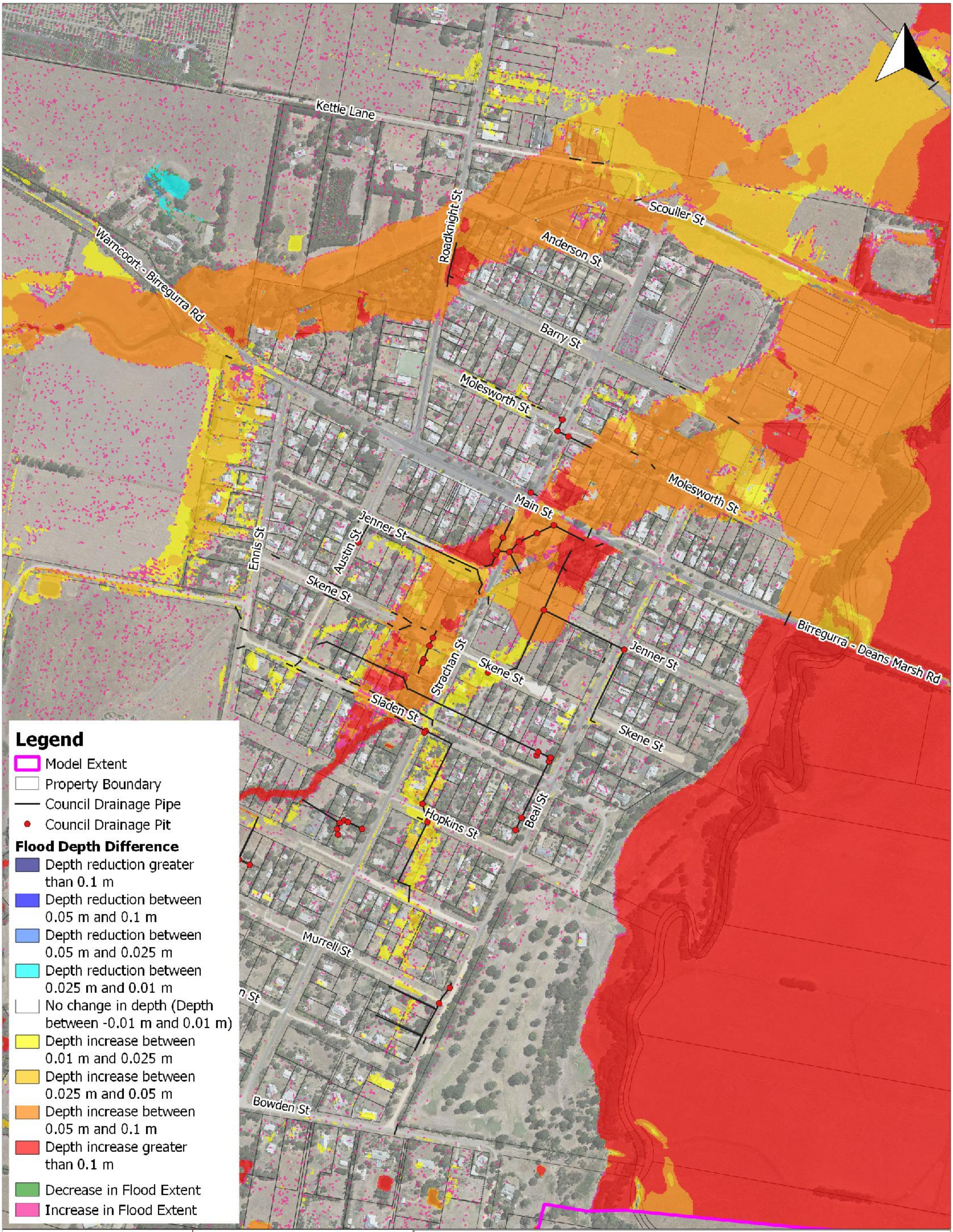
Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Birregurra Flood Study

Flood Depth - 10% AEP Climate Change

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 30/10/2020

Appendix H:
Climate Change Flood Depth Afflux Layout Plans



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ENGENY

Colac Otway SHIRE

110 0 110 m

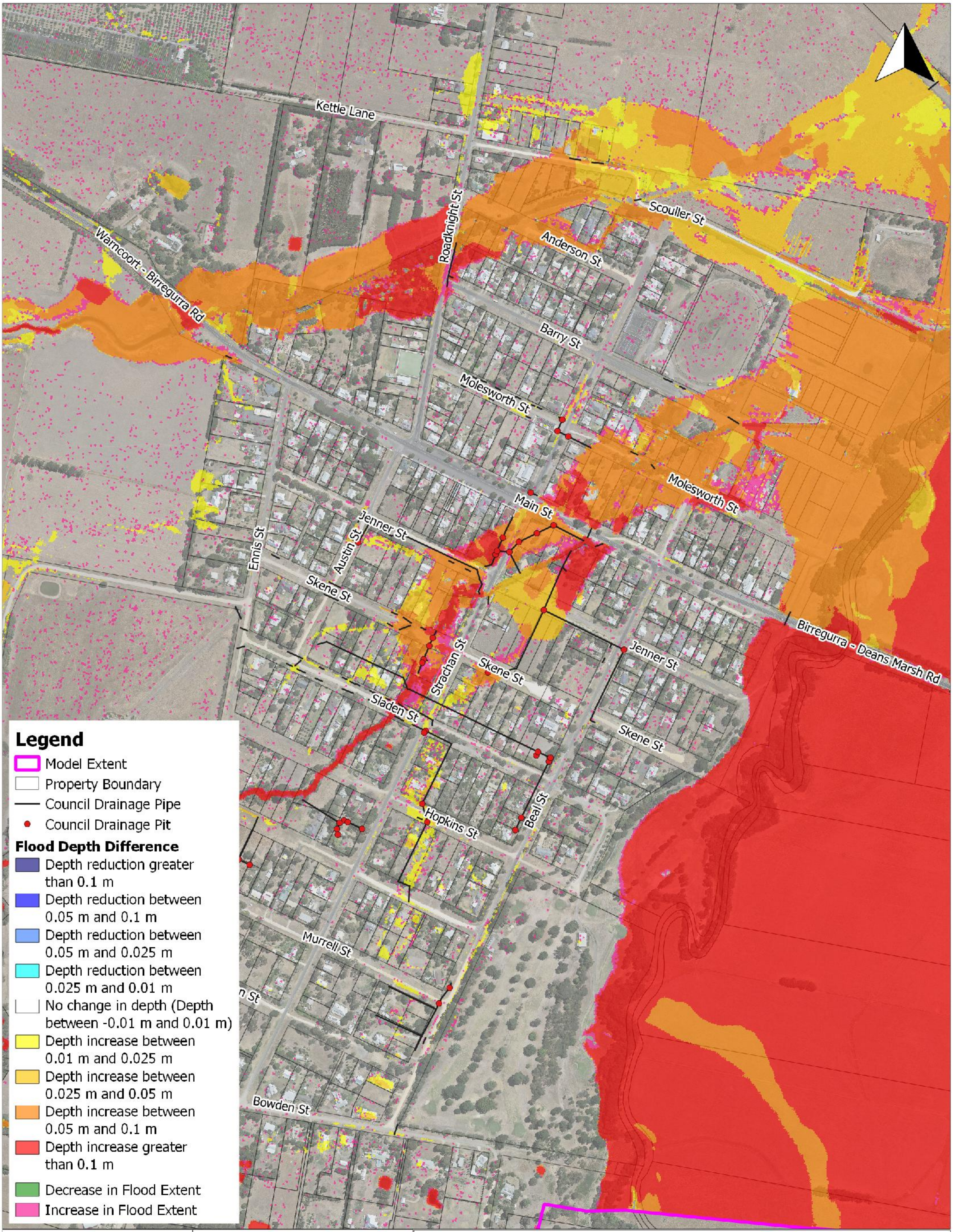
Scale in metres (1:5500 @ A3)

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

Birregurra Flood Study

Flood Depth Afflux -
1% AEP Climate Change

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 2/11/2020



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F: 03 9830 2601
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110 0 110 m

Scale in metres (1:5500 @ A3)

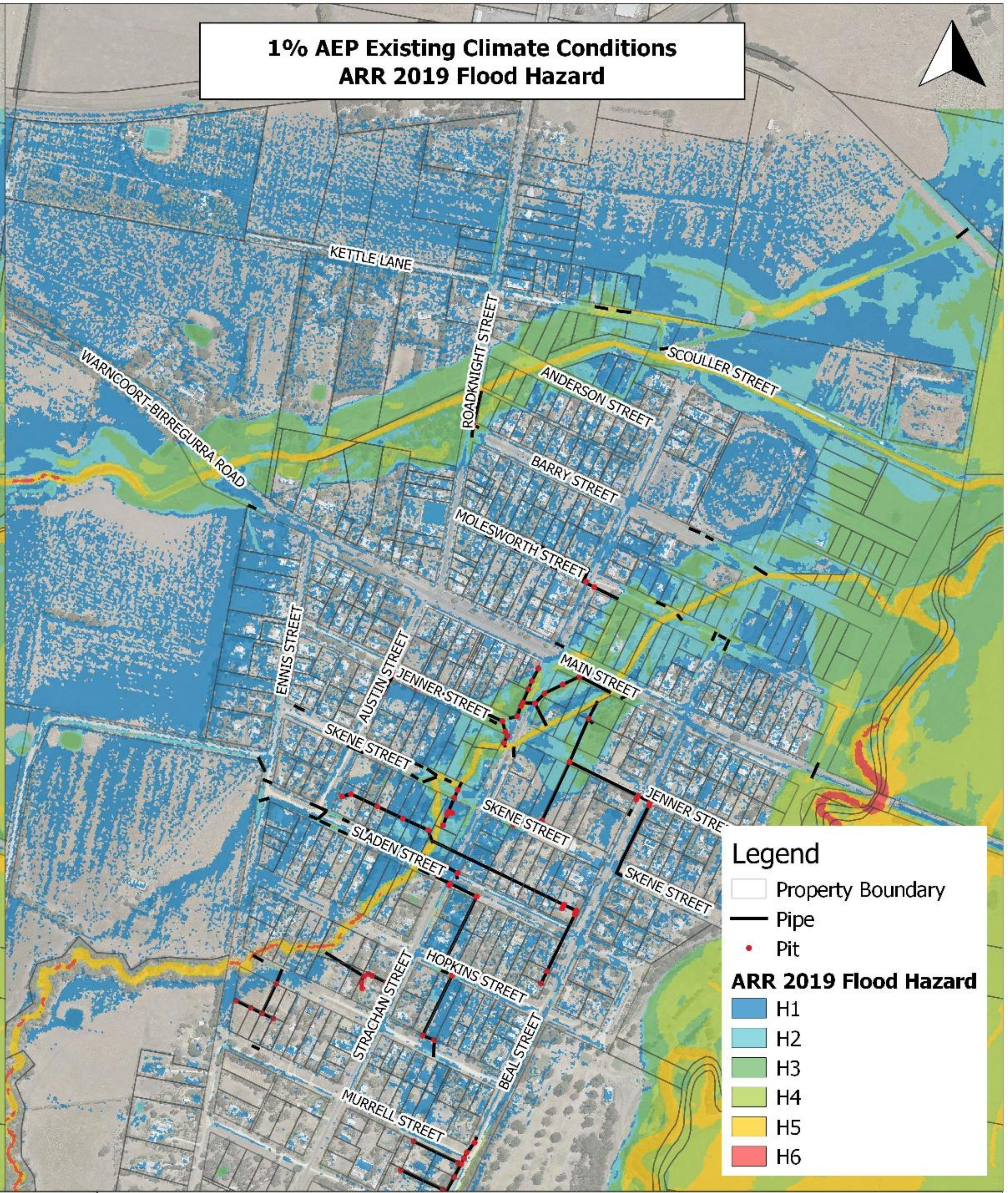
Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 55

Birregurra Flood Study

Flood Depth Afflux -
10% AEP Climate Change

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 2/11/2020

Appendix I:
Climate Change Flood Hazard Comparison Layout Plan



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ENGENY WATER MANAGEMENT

Colac Otway SHIRE

190 0 190 m

Scale in metres (1:5000 @ A3)

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

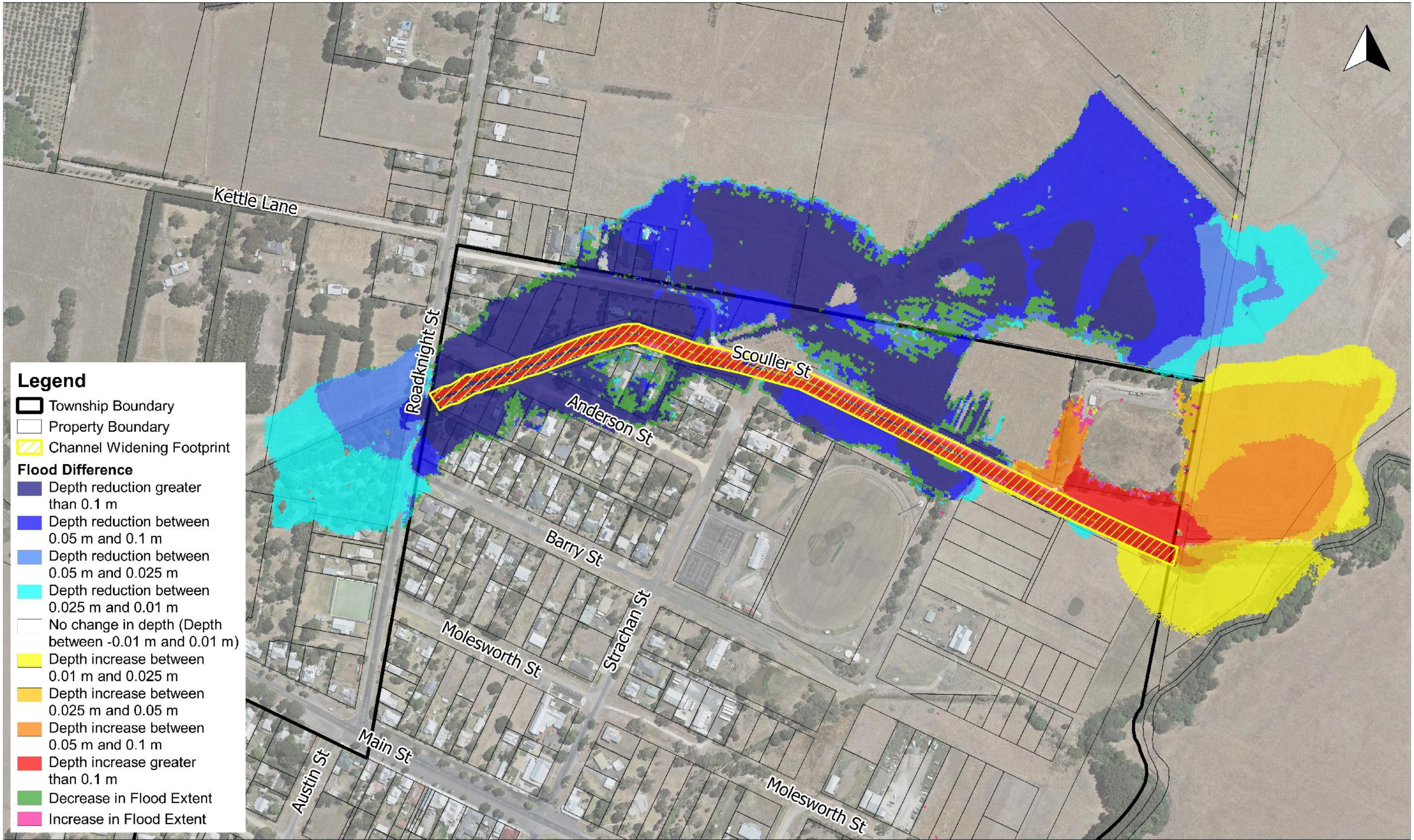
Birregurra Flood Study

1% AEP Climate Change Flood Hazard Comparison
Layout Plan

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 30/11/2020

Appendix J:

Mitigation Modelling Flood Depth Afflux Layout Plans



Legend

- Township Boundary
- Property Boundary
- Channel Widening Footprint

Flood Difference

- Depth reduction greater than 0.1 m
- Depth reduction between 0.05 m and 0.1 m
- Depth reduction between 0.05 m and 0.025 m
- Depth reduction between 0.025 m and 0.01 m
- No change in depth (Depth between -0.01 m and 0.01 m)
- Depth increase between 0.01 m and 0.025 m
- Depth increase between 0.025 m and 0.05 m
- Depth increase between 0.05 m and 0.1 m
- Depth increase greater than 0.1 m
- Decrease in Flood Extent
- Increase in Flood Extent

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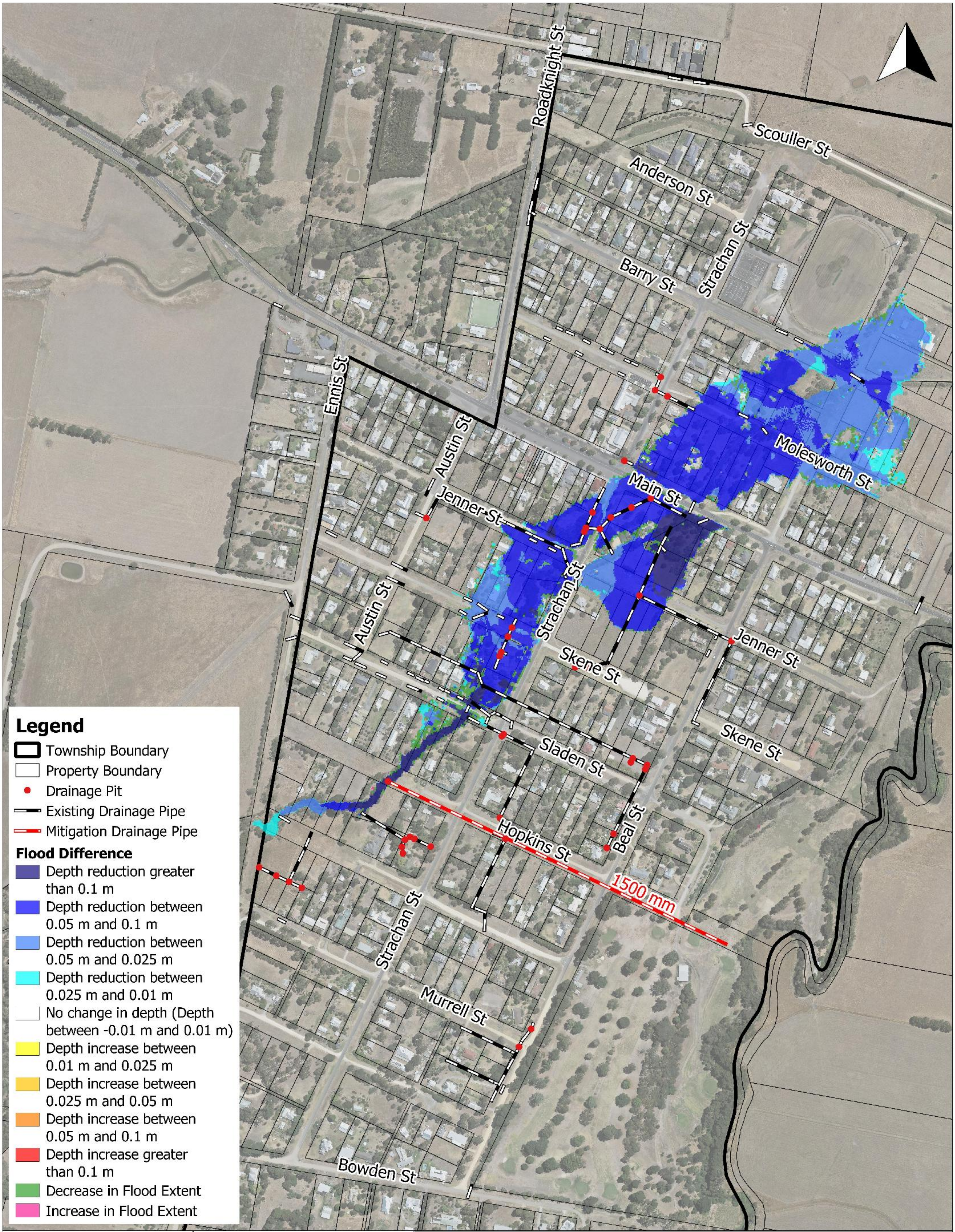
ENGENY WATER MANAGEMENT

Colac Otway SHIRE

Birregurra Flood Study

Mitigation Option 1- Atkins Creek Waterway Widening
1 % AEP Flood Depth Afflux

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 30/11/2020



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ENGENY

Colac Otway SHIRE

100 0 100 m

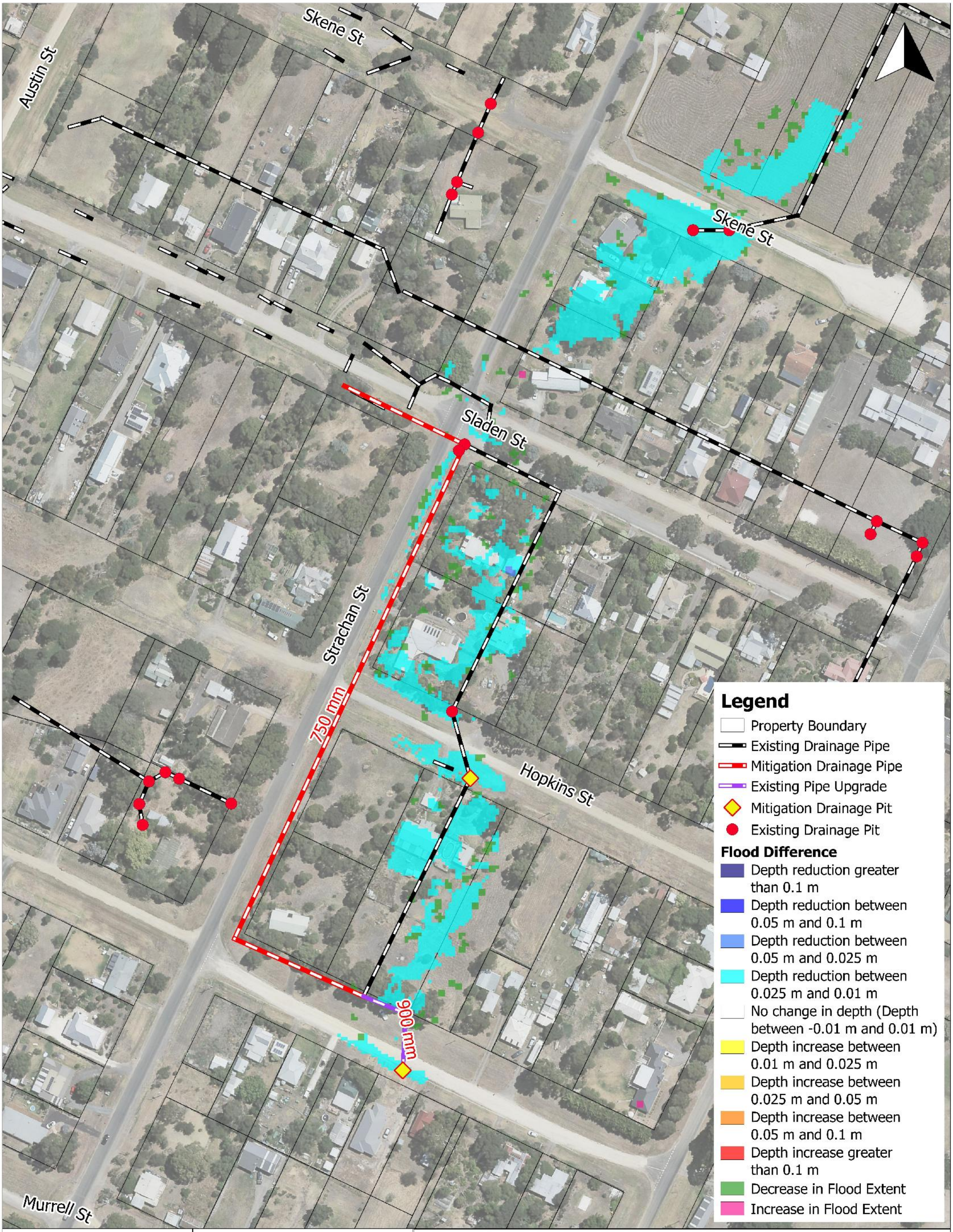
Scale in metres (1:4800 @ A3)

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

Birregurra Flood Study

Mitigation Option 4 - Hopkins Street Pipe Diversion
1 % AEP Flood Depth Afflux

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 30/11/2020



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ENGENY

Colac Otway SHIRE

30 0 30 m

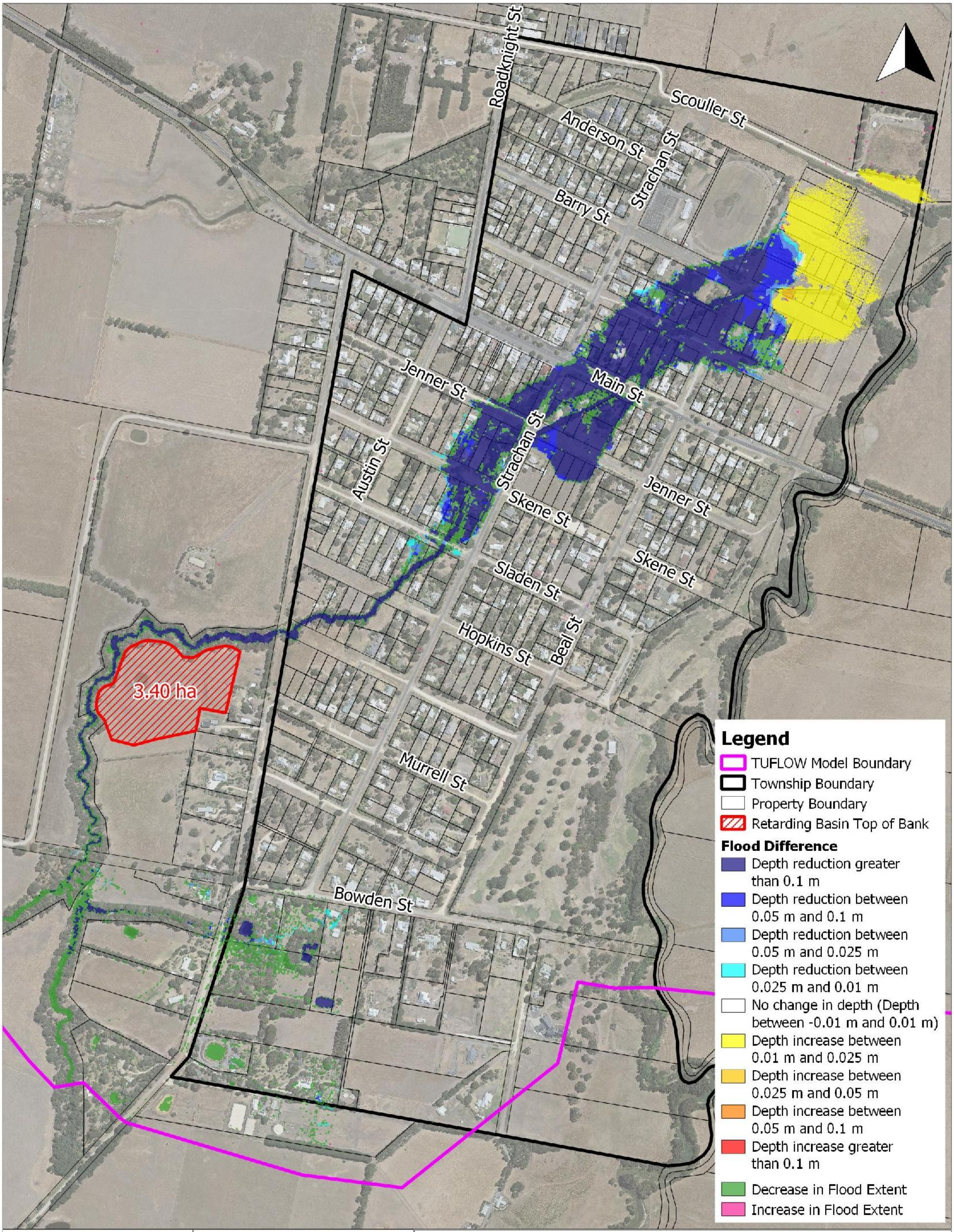
Scale in metres (1:1500 @ A3)

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

Birregurra Flood Study

Mitigation Option 5 - Drainage Upgrades Between Prime & Sladen Street
1 % AEP Flood Depth Afflux

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 30/11/2020



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ENGENY

Colac Otway SHIRE

150 0 150 m

Scale in metres (1:6200 @ A3)

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

Birregurra Flood Study

Mitigation Option 3 - Unnamed Trib Retarding Basin
1 % AEP Flood Depth Afflux

Job Number: V2013_007
Revision: 0
Drawn: AN
Checked: MM
Date: 21/12/2020

Appendix K:
Planning Overlays Parent Clauses

44.03 FLOODWAY OVERLAY

31/07/2018
VC148

Shown on the planning scheme map as **FO** or **RFO** with a number (if shown).

Purpose

To implement the Municipal Planning Strategy and the Planning Policy Framework.

To identify waterways, major floodpaths, drainage depressions and high hazard areas which have the greatest risk and frequency of being affected by flooding.

To ensure that any development maintains the free passage and temporary storage of floodwater, minimises flood damage and is compatible with flood hazard, local drainage conditions and the minimisation of soil erosion, sedimentation and silting.

To reflect any declarations under Division 4 of Part 10 of the *Water Act, 1989* if a declaration has been made.

To protect water quality and waterways as natural resources in accordance with the provisions of relevant State Environment Protection Policies, and particularly in accordance with Clauses 33 and 35 of the State Environment Protection Policy (Waters of Victoria).

To ensure that development maintains or improves river and wetland health, waterway protection and flood plain health.

44.03-1 Floodway objectives and statement of risk

31/07/2018
VC148

A schedule to this overlay may contain:

- Floodway management objectives to be achieved.
- A statement of risk.

44.03-2 Buildings and works

24/01/2020
VC160

A permit is required to construct a building or to construct or carry out works, including:

- A fence.
- Roadworks, if the water flow path is redirected or obstructed.
- Bicycle pathways and trails.
- Public toilets.
- A domestic swimming pool or spa and associated mechanical and safety equipment if associated with one dwelling on a lot.
- Rainwater tank with a capacity of not more than 10,000 litres.
- A pergola or verandah, including an open-sided pergola or verandah to a dwelling with a finished floor level not more than 800mm above ground level and a maximum building height of 3 metres above ground level.
- A deck, including a deck to a dwelling with a finished floor level not more than 800mm above ground level.
- A non-domestic disabled access ramp.
- A dependent person’s unit.

This does not apply:

- If a schedule to this overlay specifically states that a permit is not required.
- To flood mitigation works carried out by the responsible authority or floodplain management authority.

- To the following works in accordance with plans prepared to the satisfaction of the responsible authority:
  - The laying of underground sewerage, water and gas mains, oil pipelines, underground telephone lines and underground power lines provided they do not alter the topography of the land.
  - The erection of telephone or power lines provided they do not involve the construction of towers or poles.
- To post and wire and post and rail fencing.

44.03-3 Subdivision

31/07/2018
VC148

A permit is required to subdivide land. A permit may only be granted to subdivide land if the following apply:

- The subdivision does not create any new lots, which are entirely within this overlay. This does not apply if the subdivision creates a lot, which by agreement between the owner and the relevant floodplain management authority, is to be transferred to an authority for a public purpose.
- The subdivision is the resubdivision of existing lots and the number of lots is not increased, unless a local floodplain development plan incorporated into this scheme specifically provides otherwise.

44.03-4 Application requirements

31/07/2018
VC148

Local floodplain development plan

If a local floodplain development plan has been developed for the area and has been incorporated into this scheme, an application must be consistent with the plan.

Flood risk report

If a local floodplain development plan for the area has not been incorporated into this scheme, an application must be accompanied by a flood risk report to the satisfaction of the responsible authority, which must consider the following, where applicable:

- The Municipal Planning Strategy and the Planning Policy Framework.
- The existing use and development of the land.
- Whether the proposed use or development could be located on flood-free land or land with a lesser flood hazard outside this overlay.
- The susceptibility of the development to flooding and flood damage.
- The potential flood risk to life, health and safety associated with the development. Flood risk factors to consider include:
  - The frequency, duration, extent, depth and velocity of flooding of the site and accessway.
  - The flood warning time available.
  - The danger to the occupants of the development, other floodplain residents and emergency personnel if the site or accessway is flooded.
- The effect of the development on redirecting or obstructing floodwater, stormwater or drainage water and the effect of the development on reducing flood storage and increasing flood levels and flow velocities.
- The effects of the development on river health values including wetlands, natural habitat, stream stability, erosion, environmental flows, water quality and sites of scientific significance.

- An application must be accompanied by any information specified in a schedule to this overlay.

44.03-5 Exemption from notice and review

31/07/2018
VC148

An application under this overlay is exempt from the notice requirements of section 52(1)(a), (b) and (d), the decision requirements of section 64(1), (2) and (3) and the review rights of section 82(1) of the Act.

44.03-6 Referral of applications

31/07/2018
VC148

An application must be referred to the relevant floodplain management authority under Section 55 of the Act unless in the opinion of the responsible authority the proposal satisfies requirements or conditions previously agreed in writing between the responsible authority and the floodplain management authority.

44.03-7 Decision guidelines

31/07/2018
VC148

Before deciding on an application, in addition to the decision guidelines in Clause 65, the responsible authority must consider, as appropriate:

- The Municipal Planning Strategy and the Planning Policy Framework.
- The local floodplain development plan or flood risk report.
- Any comments of the relevant floodplain management authority.
- The Victorian River Health Strategy (2002) and any relevant regional river health strategy and associated wetland plan.
- Any other matters specified in a schedule to this overlay.

44.04 LAND SUBJECT TO INUNDATION OVERLAY

31/07/2018
VC148

Shown on the planning scheme map as **LSIO** with a number (if shown).

Purpose

To implement the Municipal Planning Strategy and the Planning Policy Framework.

To identify land in a flood storage or flood fringe area affected by the 1 in 100 year flood or any other area determined by the floodplain management authority.

To ensure that development maintains the free passage and temporary storage of floodwaters, minimises flood damage, is compatible with the flood hazard and local drainage conditions and will not cause any significant rise in flood level or flow velocity.

To reflect any declaration under Division 4 of Part 10 of the *Water Act, 1989* where a declaration has been made.

To protect water quality in accordance with the provisions of relevant State Environment Protection Policies, particularly in accordance with Clauses 33 and 35 of the State Environment Protection Policy (Waters of Victoria).

To ensure that development maintains or improves river and wetland health, waterway protection and flood plain health.

44.04-1 Land subject to inundation objectives and statement of risk

24/01/2020
VC160

A schedule to this overlay may contain:

- Land subject to inundation management objectives to be achieved.
- A statement of risk.

44.04-2 Buildings and works

31/07/2018
VC148

A permit is required to construct a building or to construct or carry out works, including:

- A fence.
- Roadworks, if the water flow path is redirected or obstructed.
- Bicycle pathways and trails.
- Public toilets.
- A domestic swimming pool or spa and associated mechanical and safety equipment if associated with one dwelling on a lot.
- Rainwater tank with a capacity of not more than 10,000 litres.
- A pergola or verandah, including an open-sided pergola or verandah to a dwelling with a finished floor level not more than 800mm above ground level and a maximum building height of 3 metres above ground level.
- A deck, including a deck to a dwelling with a finished floor level not more than 800mm above ground level.
- A non-domestic disabled access ramp.
- A dependent person’s unit.

This does not apply:

- If a schedule to this overlay specifically states that a permit is not required.
- To flood mitigation works carried out by the responsible authority or floodplain management authority.

- To the following works in accordance with plans prepared to the satisfaction of the responsible authority:
  - The laying of underground sewerage, water and gas mains, oil pipelines, underground telephone lines and underground power lines provided they do not alter the topography of the land.
  - The erection of telephone or power lines provided they do not involve the construction of towers or poles.
- To post and wire and post and rail fencing.

44.04-3 Subdivision

31/07/2018
VC148

A permit is required to subdivide land.

44.04-4 Application requirements

31/07/2018
VC148

An application must be accompanied by any information specified in a schedule to this overlay.

44.04-5 Local floodplain development plan

31/07/2018
VC148

If a local floodplain development plan has been developed for the area and has been incorporated into this scheme, an application must be consistent with the plan.

44.04-6 Exemption from notice and review

31/07/2018
VC148

An application under this overlay is exempt from the notice requirements of section 52(1)(a), (b) and (d), the decision requirements of section 64(1), (2) and (3) and the review rights of section 82(1) of the Act.

44.04-7 Referral of applications

31/07/2018
VC148

An application must be referred to the relevant floodplain management authority under Section 55 of the Act unless in the opinion of the responsible authority, the proposal satisfies requirements or conditions previously agreed in writing between the responsible authority and the floodplain management authority.

44.04-8 Decision guidelines

24/01/2020
VC160

Before deciding on an application, in addition to the decision guidelines in Clause 65, the responsible authority must consider, as appropriate:

- The Municipal Planning Strategy and the Planning Policy Framework.
- Any local floodplain development plan.
- Any comments from the relevant floodplain management authority.
- The existing use and development of the land.
- Whether the proposed use or development could be located on flood-free land or land with a lesser flood hazard outside this overlay.
- The susceptibility of the development to flooding and flood damage.
- The potential flood risk to life, health and safety associated with the development. Flood risk factors to consider include:
  - The frequency, duration, extent, depth and velocity of flooding of the site and accessway.

  - The flood warning time available.
  - The danger to the occupants of the development, other floodplain residents and emergency personnel if the site or accessway is flooded.
- The effect of the development on redirecting or obstructing floodwater, stormwater or drainage water and the effect of the development on reducing flood storage and increasing flood levels and flow velocities.
- The effect of the development on river health values including wetlands, natural habitat, stream stability, erosion, environmental flows, water quality and sites of scientific significance.
- Any other matters specified in a schedule to this overlay.

44.05 SPECIAL BUILDING OVERLAY

31/07/2018
VC148

Shown on the planning scheme map as **SBO** with a number (if shown).

Purpose

To implement the Municipal Planning Strategy and the Planning Policy Framework.

To identify land in urban areas liable to inundation by overland flows from the urban drainage system as determined by, or in consultation with, the floodplain management authority.

To ensure that development maintains the free passage and temporary storage of floodwaters, minimises flood damage, is compatible with the flood hazard and local drainage conditions and will not cause any significant rise in flood level or flow velocity.

To protect water quality in accordance with the provisions of relevant State Environment Protection Policies, particularly in accordance with Clauses 33 and 35 of the State Environment Protection Policy (Waters of Victoria).

44.05-1 Flooding management objectives and statement of risk

31/07/2018
VC148

A schedule to this overlay may contain:

- Flooding management objectives to be achieved.
- A statement of risk.

44.05-2 Buildings and works

31/07/2018
VC148

A permit is required to construct a building or to construct or carry out works, including:

- A fence.
- Roadworks, if the water flow path is redirected or obstructed.
- Bicycle pathways and trails.
- Public toilets.
- A domestic swimming pool or spa and associated mechanical and safety equipment if associated with one dwelling on a lot.
- A rainwater tank with a capacity of not more than 10,000 litres.
- A pergola or verandah, including an open-sided pergola or verandah to a dwelling with a finished floor level not more than 800mm above ground level and a maximum building height of 3 metres above ground level.
- A deck, including a deck to a dwelling with a finished floor level not more than 800mm above ground level.
- A non-domestic disabled access ramp.
- A dependent person’s unit.

This does not apply:

- If a schedule to this overlay specifically states that a permit is not required.
- To flood mitigation works carried out by the responsible authority or floodplain management authority.
- To the following works in accordance with plans prepared to the satisfaction of the responsible authority:
  - The laying of underground sewerage, water and gas mains, oil pipelines, underground telephone lines and underground power lines provided they do not alter the topography of the land.

- The erection of telephone or power lines provided they do not involve the construction of towers or poles designed to operate at more than 66,000 volts.

- To landscaping, driveways, vehicle cross overs, footpaths or bicycle paths if there is no significant change to existing surface levels, or if the relevant floodplain management authority has agreed in writing that the flowpath is not obstructed.
- To an extension of less than 20 square metres in floor area to an existing building (not including an out-building), where the floor levels are constructed to at least 300mm above the flood level or if the relevant floodplain management authority has agreed in writing that the flowpath is not obstructed.
- To an upper storey extension to an existing building.
- To an alteration to an existing building where the original building footprint remains the same and floor levels are constructed to at least 300mm above flood level.
- To an out-building (including replacement of an existing building) if the out-building is less than 10 square metres in floor area and constructed to at least 150mm above the flood level or the relevant floodplain management authority has agreed in writing that the flowpath is not obstructed.
- To a replacement building (not including an out-building) if it is constructed to at least 300mm above the flood level and the original building footprint remains the same. The responsible authority may require evidence of the existing building envelope.
- To fencing with at least 25% openings and with the plinth at least 300mm above the flood level.
- To a replacement fence in the same location and of the same type and materials as the existing fence.
- To a pergola or an open deck area with unenclosed foundations.
- To a carport constructed over an existing carspace.
- To an in-ground swimming pool and associated security fencing, where the perimeter edging of the pool is constructed at natural surface levels and excavated material is removed from the flowpath.
- To a tennis court at existing surface level with fencing designed to minimise obstruction to flows.
- To an aviary or other enclosure for a domestic animal if it is less than 10 square metres in floor area at ground level.
- To open sided verandahs, open sided picnic shelters, barbeques and park furniture (excluding playground equipment) if there is less than 30mm change to existing surface levels.
- To radio masts, light poles or signs on posts or attached to buildings.

VicSmart applications

Subject to Clause 71.06, an application under this clause for a development specified in Column 1 is a class of VicSmart application and must be assessed against the provision specified in Column 2.

Class of application	Information requirements and decision guidelines
Construct a building or construct or carry out works.	Clause 59.08

44.05-3 Subdivision

31/07/2018
VC148

A permit is required to subdivide land.

VicSmart applications

Subject to Clause 71.06, an application under this clause for a development specified in Column 1 is a class of VicSmart application and must be assessed against the provision specified in Column 2.

Class of application	Information requirements and decision guidelines
Any of the following classes of subdivision: ▪ Subdivide land to realign the common boundary between 2 lots where the area of either lot is reduced by less than 15 percent and the general direction of the common boundary does not change. ▪ Subdivide land into lots each containing an existing building or car parking space where: – The buildings or car parking spaces have been constructed in accordance with the provisions of this scheme or a permit issued under this scheme. – An occupancy permit or a certificate of final inspection has been issued under the Building Regulations in relation to the buildings within 5 years prior to the application for a permit for subdivision. ▪ Subdivide land into 2 lots if: – The construction of a building or the construction or carrying out of works on the land is approved under this scheme or by a permit issued under this scheme and the permit has not expired. – The construction or carrying out of the approved building or works on the land has started lawfully. – The subdivision does not create a vacant lot.	Clause 59.08

44.05-4 Application requirements

31/07/2018
VC148

Unless otherwise agreed in writing by the relevant floodplain management authority, an application to construct a building or construct or carry out works must be accompanied by a site plan which shows, as appropriate:

- The boundaries and dimensions of the site.
- Relevant existing and proposed ground levels, to Australian Height Datum, taken by or under the direction or supervision of a licensed land surveyor.
- The layout, size and use of existing and proposed buildings and works, including vehicle parking areas.
- Floor levels of any existing and proposed buildings to Australian Height Datum.
- Cross sectional details of any basement entry ramps and other basement entries to Australian Height Datum, showing floor levels of entry and exit areas and drainage details.
- Any other application requirements specified in a schedule to this overlay.

Local floodplain development plan

If a local floodplain development plan has been developed for the area and has been incorporated into this scheme, an application must be consistent with the plan.

44.05-5 Exemption from notice and review

31/07/2018
VC148

An application under this overlay is exempt from the notice requirements of section 52(1)(a), (b) and (d), the decision requirements of section 64(1), (2) and (3) and the review rights of section 82(1) of the Act.

44.05-6 Referral of applications

31/07/2018
VC148

An application must be referred to the relevant floodplain management authority under Section 55 of the Act unless in the opinion of the responsible authority, the proposal satisfies requirements or conditions previously agreed to in writing between the responsible authority and the floodplain management authority.

44.05-7 Decision guidelines

31/07/2018
VC148

Before deciding on an application, in addition to the decision guidelines in Clause 65, the responsible authority must consider, as appropriate:

- The Municipal Planning Strategy and the Planning Policy Framework.
- Any local floodplain development plan.
- Any comments from the relevant floodplain management authority.
- The existing use and development of the land.
- Whether the proposed use or development could be located on flood-free land or land with a lesser flood hazard outside this overlay.
- The susceptibility of the development to flooding and flood damage.
- Flood risk factors to consider include:
  - The frequency, duration, extent, depth and velocity of flooding of the site and accessway.
  - The flood warning time available.
  - The danger to the occupants of the development, other floodplain residents and emergency personnel if the site or accessway is flooded.
- The effect of the development on redirecting or obstructing floodwater, stormwater or drainage water and the effect of the development on reducing flood storage and increasing flood levels and flow velocities.
- Any other matters specified in a schedule to this overlay.

Appendix L:
Draft Birregurra Planning Schedules

DRAFT SCHEDULE 1 TO CLAUSE 44.04 LAND SUBJECT TO INUNDATION OVERLAY

Shown on the planning scheme map as **LSIO1.**

LAND SUBJECT TO INUNDATION OVERLAY SCHEDULE 1

1.0 Land subject to inundation objectives to be achieved

None specified.

2.0 Statement of risk

None specified.

3.0 Permit requirement

A permit is not required for the following:

New buildings, including extensions

- If the floor level of the building is finished at least 300mm above the 100 year ARI flood level and meets the safety hazard of FMA, and
- If the new building is constructed on stumps (or piers) and bearers, and
- Cladding to the sub floor structure of the extension has openings or is of an open style (such as spaced timber boards) to allow automatic entry and exit of flood water for all floods up to the 1 per cent AEP event, and
- Earthworks including any driveways, paths or services that do not alter the natural ground level.

External alterations to existing buildings

- If the original building footprint remains the same

Repairs and routine maintenance of existing fences

- If the fence design and material remains the same.

New or replacement fence

- A post and wire fence with:
  - Post spacing no less than three metres apart
  - Single wires spaced no more than one horizontal strand per 200mm.
- A post and rail fence with:
  - Post spacing no less than three metres apart
  - Rails no more than 150mm wide
  - Rails spaced no less than 200mm apart
  - Bottom rail no less than 150mm off the ground.
- Tubular steel/pool fencing.

Other buildings and works

- A building which is open on all sides including a pergola, carport, domestic shed, animal enclosure outbuildings, stockyard or agricultural sheds with unenclosed foundations.
- A ramp, verandah or decking and similar structures with a floor raised on stumps or piers and with unenclosed foundations

- Road works or works including footpath/shared paths, bicycle path, car parks, access ways, pathways or driveways (public or private) that do not change the natural ground level
- A mast, antenna, satellite dish, power pole, light pole, or telecommunication tower
- An outdoor advertising sign/structure provided it does not alter flood flows or floodplain storage capacity
- Repairs and routine maintenance that do not affect the height, length, width or location of a levee or embankment
- A rainwater tank with a capacity of not more than 5000 litres
- A shed of 20sqm or less gross floor area
- An in-ground domestic swimming pool or spa, and associated mechanical and safety equipment, providing that:
  - The excavated spoil is removed from within the 100 year ARI floodplain; and
  - The perimeter edging of the pool is finished at natural ground level; and
  - Security pool fencing is of an open style.
- A sportsground, racecourse or recreation area, pathways and trails constructed at general natural surface elevation, playground, open picnic shelter, picnic table, drinking tap, rubbish bin, barbecue and or similar works associated with a park, recreation area and or public places.

4.0 Application requirements

None specified.

5.0 Decision guidelines

None specified.

DRAFT SCHEDULE 1 TO CLAUSE 44.05 SPECIAL BUILDING OVERLAY

Shown on the planning scheme map as **SBO1.**

SPECIAL BUILDING OVERLAY SCHEDULE 1

1.0 Flooding management objectives to be achieved

None specified.

2.0 Statement of risk

None specified.

3.0 Permit requirement

A permit is not required for the following:

New buildings, including extensions

- If the floor level of the building is finished at least 300mm above the 100 year ARI flood level and meets the safety hazard of FMA, and
- If the new building is constructed on stumps (or piers) and bearers, and
- Cladding to the sub floor structure of the extension has openings or is of an open style (such as spaced timber boards) to allow automatic entry and exit of flood water for all floods up to the 1 per cent AEP event, and
- Earthworks including any driveways, paths or services that do not alter the natural ground level.

Other buildings and works

- A building which is open on all sides including a domestic shed, stockyard or agricultural sheds with unenclosed foundations.
- A ramp, verandah or decking and similar structures with a floor raised on stumps or piers and with unenclosed foundations
- An antenna, satellite dish, power pole, or telecommunication tower
- Repairs and routine maintenance that do not affect the height, length, width or location of a levee or embankment
- A rainwater tank with a capacity of not more than 5000 litres
- A shed of 20sqm or less gross floor area
- An in-ground domestic swimming pool or spa, and associated mechanical and safety equipment, providing that:
  - The excavated spoil is removed from within the 100 year ARI floodplain; and
  - The perimeter edging of the pool is finished at natural ground level; and
  - Security pool fencing is of an open style.
- A sportsground, racecourse or recreation area, pathways and trails constructed at general natural surface elevation, playground, picnic table, drinking tap, rubbish bin, and or similar works associated with a park, recreation area or public places.

4.0 Application requirements

None specified.

5.0 Decision guidelines

None specified.

DRAFT SCHEDULE 1 TO CLAUSE 44.03 FLOODWAY OVERLAY

Shown on the planning scheme map as **FO1**.

FLOODWAY OVERLAY SCHEDULE 1

1.0 Floodway objectives to be achieved

None specified.

2.0 Statement of risk

None specified

3.0 Permit requirement

A permit is not required for the following:

Replacement buildings

- If the footprint of the replacement building(s) is the same or less than the original building(s), and
- If the floor level of the building is finished at least 300 mm above the 100 year ARI flood level, and
- If the replacement building is constructed on stumps (or piers) and bearers, and
- Cladding to the subfloor structure of the extension has openings or is of an open style (such as spaced timber boards) to allow automatic entry and exit of flood water for all floods up to the 1 per cent AEP event.

External alterations to existing buildings

- If the original building footprint remains the same

Ground level extensions to existing buildings

- If the floor level of the extension is at least 300mm above the applicable 100 year ARI flood level, and
- The extension of the building is constructed on stumps (or piers) and bearers, and
- Cladding to the subfloor structure of the extension has openings or is of an open style (such as spaced timber boards) to allow automatic entry and exit of flood water for all floods up to the 1 per cent AEP event.
- If the floor level of the extension is not lower than the existing floor level and the combined ground floor area of extensions since 31 December 2018 is no greater than 20sqm.

Upper level extensions to existing buildings

- If there is no increase in the ground floor building footprint other than the floor area exempted above and except for any additions or alterations to the footings to support the extensions to the upper level.

Repairs and routine maintenance of existing fences

- If the fence design and material remains the same.

New or replacement fence

- A post and wire fence with:
  - Post spacing no less than three metres apart
  - Single wires spaced no more than one horizontal strand per 200mm.

- A post and rail fence with:
  - Post spacing no less than three metres apart
  - Rails no more than 150mm wide
  - Rails spaced no less than 200mm apart
  - Bottom rail no less than 150mm off the ground.
- Tubular steel/pool fencing.

Other buildings and works

- A building which is open on all sides including a pergola, carport, domestic shed, animal enclosure outbuildings, stockyard or agricultural sheds with unenclosed foundations.
- A ramp, verandah or decking and similar structures with a floor raised on stumps or piers and with unenclosed foundations
- Road works or works including footpath/shared paths, bicycle path, car parks, access ways or driveways (public or private) that do not change the natural ground level
- A mast, antenna, satellite dish, power pole, light pole, or telecommunication tower
- An outdoor advertising sign/structure provided it does not alter flood flows or floodplain storage capacity
- Repairs and routine maintenance that do not affect the height, length, width or location of a levee or embankment
- A rainwater tank with a capacity of not more than 5000 litres
- A shed of 20sqm or less gross floor area
- An in-ground domestic swimming pool or spa, and associated mechanical and safety equipment, providing that:
  - The excavated spoil is removed from within the 100 year ARI floodplain; and
  - The perimeter edging of the pool is finished at natural ground level; and
  - Security pool fencing is of an open style.
- A sportsground, racecourse or recreation area, pathways and trails constructed at general natural surface elevation, playground, open picnic shelter, picnic table, drinking tap, rubbish bin, barbecue and or similar works associated with a park, recreation area and or public places.

4.0 Application requirements

None specified.

5.0 Decision guidelines

None specified.

Appendix M:
Summary of TFWS Building Blocks and Suggested Actions

Appendix Table M. 1: TFWS Building Blocks and Suggested Actions for Birregurra with due regard for the EMMV, Commonwealth-State arrangements for flood warning service provision VFWCC (2001), AIDR (2009) and DELWP (2016)

FFWS Building Blocks	Potential Improvement Actions for Birregurra
DATA COLLECTION & COLLATION	COSC to approach BoM (with support from VICSES, CCMA and DELWP) to request necessary changes to enable near real-time public access to rain data from the Ricketts Marsh gauge via the BoM website (e.g. 15 minute updates). Alternatively, COSC to approach CCMA to request that telemetry be added to the Colac rain gauge and that BoM be requested to enable near real-time public access to rai data from that gauge via the BoM website (e.g. 15 minute updates). COSC to arrange for the installation of a set of staff gauges on the upstream side of the Warncoort-Birregurra Road Bridge (Atkin Creek) and on the upstream side of the Ennis Street crossing of the unnamed creek. They should be installed such that the gauge boards can be read from the road for small and larger (i.e. 1 % AEP) floods. If a greater degree of confidence in the likelihood of flooding is required, it is suggested that COSC: • As a first step, arrange installation of an ERTS rain gauge in the mid reaches of the Atkin Creek catchment close to the shared boundary with the unnamed creek. At the same time, COSC with support from VICSES, CCMA and DELWP, to approach BoM to provide near real-time public access to data from that gauge via its website. • As a second step, arrange installation of two ERTS rain (or rain-river) gauges on the upstream side of the Warncoort-Birregurra Road Bridge (Atkin Creek) and on the upstream side of the Ennis Street crossing of the unnamed creek. As above, COSC with support from VICSES, CCMA and DELWP, to approach BoM to provide near real-time public access to data from those gauges via its website. • Alternatively and instead of ERTS equipment, arrange installation of different commercially available equipment (e.g. DipStik) to monitor (and alert on) rainfall and / or water level in the creeks at the locations described in the above two bullets and identified in Figure 9.3. • As appropriate and depending on the monitoring and alerting equipment installed, invite Birregurra residents, along with VICSES, local CFA and Police, to opt-in to receive SMS alert messages direct from installed equipment. • Consider the addition of “sirens and / or flashing lights” options (triggered by exceedance of pre-set rainfall rates and depths, and creek levels and rates of rise) for the automated gauge installed at the creek crossings as an alternative or additional means of alerting the community to imminent flooding. As part of all of the above: • Provide guidance to the local community (through a locally focussed flood awareness brochure and website) on how to interpret and use available rain and creek level data and the indicative flood guidance tool, along with information about the flood warning system and how it will assist in reducing risk; and • Develop and maintain a website (and social media?) presence for the FFWS that includes the above guidance along with (a link to) flood mapping and intelligence outputs from the Birregurra Flood and Drainage Strategy. COSC in consultation with CCMA to decide on the datum to be used for any new creek level gauges: AHD or local.
DETECTION & PREDICTION (i.e. Forecasting)	COSC to provide the indicative flood guidance tool and instructions for its use to COSC staff, VICSES and local CFA for routine use. Provide training in use as appropriate. COSC and VICSES to agree who will maintain the tool and how. COSC to lead the determination of flood class levels for Birregurra. Will involve coordination between Council, VICSES, CCMA and BoM and is a relatively straight-forward process. COSC to maintain contact with VICSES on progress with the Automated Alerting Project with a view to implementation for Birregurra.

FFWS Building Blocks	Potential Improvement Actions for Birregurra
INTERPRETATION (i.e. an ability to answer the question "what does this mean for me - will I be flooded and to what depth".	Mapping and intelligence from the Birregurra Flood and Drainage Strategy has been captured to the MFEP. The indicative flood guidance tool together with the MFEP enable those at risk to determine the likely effects of a potential flood with some lead time. COSC to ensure flood inundation maps and relevant Appendices of the MFEP along with the flood information card for Birregurra are readily available to the Birregurra community. If local datum has been chosen for water level gauges, COSC to lead update of the MFEP and indicative flood guidance tool. This will assist local interpretation and the determination of likely flood impacts during future events.
MESSAGE CONSTRUCTION	The initial alert of likely flooding is likely to come from a combination of environmental indicators (e.g. observance of heavy rain) and from consideration of rain data, the flood inundation maps, the indicative flood guidance tool and the flood intelligence in the MFEP and / or from observing a rise in the level of the creeks. If monitoring equipment with SMS capability is installed, the initial (or confirming) alert may come from the unit's SMS'ed message as rain and / or creek levels exceed triggers with the above acting to reinforce and add value to resident's assessments and decision processes. Alternatively, and subject to resolution of VICSES and EMV roles in the initiation and dissemination of flash flood warnings, the initial alert may come via electronic and social media. If a marginally more formal alerting system is deemed appropriate for Birregurra, COSC in conjunction with VICSES to: • Champion formation of a Birregurra community flood action group (or similar); and • Lead establishment of a Twitter and / or Facebook account for the Birregurra TFWS so that information can be shared within the community and by VICSES (say, following use of the indicative flood guidance tool) on likely flood severity, impacts and appropriate actions.
MESSAGE DISSEMINATION (i.e. Communication and Alerting)	Establish a COSC championed community flash flood action group. Use social media. A role remains for the Emergency Alert (EA) during a severe flood event. If an SMS enabled gauge is active, COSC to identify / nominate key community members (in addition to VICSES and perhaps CFA) to receive SMS or email alerts on exceedance of alarm trigger values. If alternate commercially available water level (and rain) monitoring equipment is installed, COSC to establish and maintain an opt-in system that must be heavily community driven.
RESPONSE	Initiate a community engagement program to communicate how the FFWS will work. Following (or perhaps in concert with) acceptance of the MFEP by COSC and VICSES, encourage and assist residents to develop individual flood response plans. A package that assists businesses and individuals is available from VICSES and provides an excellent model for community use.
REVIEW	Review and update of local flood intelligence (i.e. flood characteristics, impacts, etc), local alerting arrangements, response plans, local flood awareness material, etc (initially) after every flood that triggers a response. Best driven by COSC with input from VICSES, CCMA, CFA and the Council championed community flash flood action group. COSC to develop review and update protocols => who does what when and process to be followed to update material consistently across all parts of the flash flood warning and response system, including the MFEP.

FFWS Building Blocks	Potential Improvement Actions for Birregurra
AWARENESS	VICSES to complete the draft LFG then print and make it available to the Birregurra community. Make relevant parts of the MFEP publicly available (e.g. Council offices, library, website). Develop, maintain and renew flood awareness through activities and materials that emphasise personal safety, where data is available, how that data can be used, what any warnings / alerts mean and what individuals should do to stay safe and protect their property including filling and laying sandbags. COSC and VICSES to: • Load and maintain material including the MFEP to the COSC and VICSES websites with appropriate links to relevant useful sites; • Routinely revisit and update awareness material to accommodate lessons learnt, additional or improved material and to reflect advances in good practice; and Routinely repeat distribution of awareness material and consider other measures.

Appendix Table M. 2: TFWS Building Blocks and Staged Suggested Actions for Birregurra with due regard for Appendix Table M. 1

FWS Building Blocks	Potential Improvement Actions for Birregurra
Achievable in the near term with minimum investment	
DATA COLLECTION & COLLATION	COSC to approach BoM (with support from VICSES, CCMA and DELWP) to request necessary changes to enable near real-time public access to rain data from the Ricketts Marsh gauge via the BoM website (e.g. 15 minute updates). Alternatively, COSC to approach CCMA to request that telemetry be added to the Colac rain gauge and that BoM be requested to enable near real-time public access to rai data from that gauge via the BoM website (e.g. 15 minute updates). Provide guidance to the local community (through a locally focussed flood awareness brochure and website) on how to interpret and use available rain data and the indicative flood guidance tool, along with information about the flood warning system and how it will assist in reducing risk.
DETECTION & PREDICTION (i.e. Forecasting)	COSC to provide the indicative flood guidance tool and instructions for its use to COSC staff, VICSES and local CFA for routine use. Provide training in use as appropriate. COSC and VICSES to agree who will maintain the tool and how.
INTERPRETATION (i.e. an ability to answer the question “what does this mean for me - will I be flooded and to what depth”.	Mapping and intelligence from the Birregurra Flood and Drainage Strategy has been captured in the MFEP. The indicative flood guidance tool together with the MFEP enable those at risk to determine the likely effects of a potential flood with some lead time. COSC to ensure flood inundation maps and relevant Appendices of the MFEP along with the flood information card for Birregurra are readily available to the Birregurra community.
MESSAGE CONSTRUCTION	The initial alert of likely flooding is likely to come from a combination of environmental indicators (e.g. observance of heavy rain) and from consideration of rain data, the flood inundation maps, the indicative flood guidance tool and the flood intelligence in the MFEP and / or from observing a rise in the level of the creeks.

FWS Building Blocks	Potential Improvement Actions for Birregurra
MESSAGE DISSEMINATION (i.e. Communication and Alerting)	Establish a COSC championed community flash flood action group. Use social media. A role remains for the Emergency Alert (EA) during a severe flood event.
RESPONSE	Following (or perhaps in concert with) acceptance of the MFEP by COSC and VICSES, encourage and assist residents to develop individual flood response plans. A package that assists businesses and individuals is available from VICSES and provides an excellent model for community use.
REVIEW	Review and update of local flood intelligence (i.e. flood characteristics, impacts, etc), local alerting arrangements, response plans, local flood awareness material, etc (initially) after every flood that triggers a response. Best driven by COSC with input from VICSES, CCMA, CFA and the Council championed community flash flood action group. COSC to develop review and update protocols => who does what when and process to be followed to update material consistently across all parts of the flash flood warning and response system, including the MFEP.
AWARENESS	VICSES to complete the draft LFG then print and make it available to the Birregurra community. Make relevant parts of the MFEP publicly available (e.g. Council offices, library, website). COSC and VICSES to: • Load and maintain material including the MFEP to the COSC and VICSES websites with appropriate links to relevant useful sites; • Routinely revisit and update awareness material to accommodate lessons learnt, additional or improved material and to reflect advances in good practice; and • Routinely repeat distribution of awareness material and consider other measures.
Achievable in the mid-term with a greater level of investment	
DATA COLLECTION & COLLATION	In addition to the above: • COSC to arrange for the installation of a set of staff gauges on the upstream side of the Warncoort-Birregurra Road Bridge (Atkin Creek) and on the upstream side of the Ennis Street crossing of the unnamed creek. They should be installed such that the gauge boards can be read from the road for small and larger (i.e. 1 % AEP) floods. • Develop and maintain a website (and social media?) presence for the FFWS that includes guidance from the previously prepared locally focussed flood awareness brochure (see above) along with (a link to) flood mapping outputs from the Birregurra Flood and Drainage Strategy. • COSC in consultation with CCMA to decide on the datum to be used for any new creek level gauges: AHD or local.
DETECTION & PREDICTION (i.e. Forecasting)	In addition to the above: • COSC to lead the determination of flood class levels for Birregurra. Will involve coordination between Council, VICSES, CCMA and BoM and is a relatively straight-forward process. • COSC to maintain contact with VICSES on progress with the Automated Alerting Project with a view to implementation for Birregurra.

FWS Building Blocks	Potential Improvement Actions for Birregurra
INTERPRETATION (i.e. an ability to answer the question "what does this mean for me - will I be flooded and to what depth".	In addition to the above: • If local datum has been chosen for water level gauges, COSC to lead update of the MFEP and indicative flood guidance tool. This will assist local interpretation and the determination of likely flood impacts during future events.
MESSAGE CONSTRUCTION	In addition to the above: • If monitoring equipment with SMS capability is installed, the initial (or confirming) alert may come from the unit's SMS'ed message as rain and / or creek levels exceed triggers with the above acting to reinforce and add value to resident's assessments and decision processes. Alternatively and subject to resolution of VICSES and EMV roles in the initiation and dissemination of flash flood warnings, the initial alert may come via electronic and social media. • If a marginally more formal alerting system is deemed appropriate for Birregurra, COSC in conjunction with VICSES to: – Champion formation of a Birregurra community flood action group (or similar); and – Lead establishment of a Twitter and / or Facebook account for the Birregurra TFWS so that information can be shared within the community and by VICSES (say, following use of the indicative flood guidance tool) on likely flood severity, impacts and appropriate actions.
MESSAGE DISSEMINATION (i.e. Communication and Alerting)	In addition to the above: • If an SMS enabled gauge is active, COSC to identify / nominate key community members (in addition to VICSES and perhaps CFA) to receive SMS or email alerts on exceedance of alarm trigger values.
RESPONSE	In addition to the above: • Initiate a community engagement program to communicate how the FFWS will work.
REVIEW	As above:
AWARENESS	In addition to the above: • Develop, maintain and renew flood awareness through activities and materials that emphasise personal safety, where data is available, how that data can be used, what any warnings / alerts mean and what individuals should do to stay safe and protect their property including filling and laying sandbags.
Achievable longer term – fully developed option requiring significant investment	
DATA COLLECTION & COLLATION	In addition to the above: • COSC to arrange installation of an ERTS rain gauge in the mid reaches of the Atkin Creek catchment close to the shared boundary with the unnamed creek. At the same time, COSC with support from VICSES, CCMA and DELWP, to approach BoM to provide near real-time public access to data from that gauge via its website. • COSC to arrange installation of two ERTS rain (or rain-river) gauges on the upstream side of the Warncoort-Birregurra Road Bridge (Atkin Creek) and on the upstream side of the Ennis Street crossing of the unnamed creek. As above, COSC with support from VICSES, CCMA and DELWP, to approach BoM to provide near real-time public access to data from those gauges via its website.

FWS Building Blocks	Potential Improvement Actions for Birregurra
	• Alternatively and instead of the ERTS equipment, COSC to arrange installation of different commercially available equipment (e.g. DipStik) to monitor (and alert on) rainfall and / or water level in the creeks at the locations described in the above two bullets and identified in Figure 9.3. • As appropriate and depending on the monitoring and alerting equipment installed, COSC to invite Birregurra residents, along with VICSES, local CFA and Police, to opt-in to receive SMS or other alert messages direct from the installed equipment. • COSC to consider the addition of “sirens and / or flashing lights” options (triggered by exceedance of pre-set rainfall rates and depths, and creek levels and rates of rise) for the automated gauge installed at the creek crossings as an alternative or additional means of alerting the community to imminent flooding.
DETECTION & PREDICTION (i.e. Forecasting)	As above:
INTERPRETATION (i.e. an ability to answer the question “what does this mean for me - will I be flooded and to what depth”.	As above:
MESSAGE CONSTRUCTION	As above:
MESSAGE DISSEMINATION (i.e. Communication and Alerting)	In addition to the above: • If alternate commercially available water level (and rain) monitoring equipment is installed, COSC to establish and maintain an opt-in system that must be heavily community driven.
RESPONSE	As above:
REVIEW	As above:
AWARENESS	As above:

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