in partnership with

South Warrnambool and Dennington Flood Investigation

Summary Report

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Executive Summary

The best available mapping to date for the South Warrnambool and Dennington areas are the 2007 South Warrnambool Flood Study (Water Technology 2007a) and Dennington Flood Study (Water Technology 2007b) and its subsequent updates. Since the completion of the 2007 studies an updated version of Australian Rainfall and Runoff (ARR) (Ball, et al. 2019) was released in 2019 which provides significant progress in the methodologies used to undertake flood modelling and mapping assessments. A major update to the guidance on how to consider climate change in flood investigations was also released in late 2023 (DCCEEW 2023). There has also since been three significant flood events occur, the 2020 riverine flood event and the 2009 and 2014 storm tide flood events.

Warrnambool City Council (Council) in partnership with the Glenelg Hopkins Catchment Management Authority (GHCMA) were successful in gaining funding from Emergency Management Victoria (EMV) to engage Venant Solutions to undertake this Investigation to update existing riverine flood risk modelling and develop new storm tide risk mapping for South Warrnambool and Dennington. Venant Solutions has completed this investigation with support from BMT for the storm tide assessment and PM Design Group for the structural mitigation option assessment.

The Investigation has been undertaken in accordance with the latest guidance and parameters provided in ARR and the Victorian Guideline for Modelling the Interaction of Catchment & Coastal Flooding (Streamology 2022b). The climate change guidance provided by Australian Rainfall and Runoff (DCCEEW 2023), which accounts for the effect of increased and increasing rainfall intensity on flood risk, has also been accounted for. The hydrology and hydraulic model elements of the project including all adopted parameters and assumptions have been independently peer reviewed.

The reliability of the flood model developed to underpin the assessment of flood risk was confirmed through its ability to accurately represent actual flood extents and depths for both riverine and storm tide events that have occurred in the past. For riverine events, facilitated by the availability of a large amount of past flood event data, the October 2020 was replicated as a calibration event and the March 1946 event was replicated, as best as possible with the available information, as a validation event. Two past storm tide events, April 2009 and June 2014, were used as calibration and validation event respectively and the model achieved a good calibration.

A suite of riverine and storm tide design flood event mapping and flood intelligence information has been produced covering the 20%, 10%, 5%, 2%, 1%, 1 in 200, 1 in 500 Annual Exceedance Probability (AEP) events, in addition to an estimate of the probable maximum flood and a Tsunami estimate.

The flood mapping and intelligence information produced for the Investigation includes the flood depth, level, velocity and hazard mapping, identification of inundated properties, buildings and roads, estimation of expected flood travel times and the estimation of monetary flood damages. Current climate (present day at the time of writing this Investigation) 1% AEP flood depth mapping for riverine and storm tide events is presented in Figure 1 to Figure 6. A 1% AEP riverine event is expected to result in the inundation of 379 properties, 25 buildings and 23 roads while a 1% AEP storm tide is expected to result in the inundation of 196 properties, two buildings and five roads.

The riverine event AAD (average annual damages) estimate of $625,000 and storm tide event AAD estimate of $101,000 are based on independent events so there is a combined AAD estimate of $726,000.

The study has also allowed for context to be provided around the level of risk flooding has posed across the study area in the past, in comparison to what can be expected to occur in the present day and into the future as the climate changes.

The 1946 event is by far the largest riverine flood recorded in the Merri River since records began in the mid to late 1800s with an estimated magnitude of approximately a 1 in 150 AEP. Other significant events occurred in 2020 with an estimated magnitude of 6% (1 in 18) AEP and 2001 and 2010 both with an estimated magnitude of 9% (1 in 11) AEP. A relatively limited historical storm tide event dataset was available to identify and quantify the magnitude of storm tides impacting on South Warrnambool but in present day terms, the April 2009 and June 2014 storm tide magnitude is estimated to be 10% (1 in 10) and 5% (1 in 20) AEP events respectively.

Two climate scenarios for the year 2100 have been assessed. These are referred to as Climate Change Scenarios 1 and 2 which represent potential global warming levels (GWLs) of 3.6°C and 4.5°C respectively relative to the baseline period between 1961 to 1990. These scenarios are based on global mean surface temperature projections that stem from the worlds potential greenhouse gas emissions trajectory pathways, as described by the Intergovernmental Panel on Climate Change (IPCC) Shared Socioeconomic Pathway (SSP) modelling. The SSP descriptors for emission trajectory scenarios are conveyed by the IPCC's Sixth Assessment Report. 3.6°C of global warming above the baseline period, occurring between the years 2081 and 2100, is the best estimate (50th percentile) of the SSP3-7.0 high greenhouse gas emissions scenario and the upper limit estimate (95th percentile) of the SSP2-4.5 intermediate greenhouse gas emissions scenario. 4.5°C of global warming above the baseline period is representative of the best estimate (50th percentile) of the SSP5-8.5 very high greenhouse gas emissions scenario. At the time of writing, strong evidence, including the 2024 United Nations Emissions Gap Report (UNEP 2024), indicates that the worlds emissions are continuing to track on the trajectory of upper estimates of greenhouse gas emissions representative of SSP5-8.5 scenario (Climate Change Scenario 2).

Climate change is expected to increase both the intensity of storm rainfalls and mean sea level beyond already observed change in both of these key determinants of flood risk. Increased rainfall intensity will increase the amount of inland catchment rainfall runoff, which affects the magnitude of flood flows in the Merri River. Sea level rise will make storm tide events more severe and will also back water further up the Merri River estuary, progressively increasing the height of riverine flood levels in comparison to flood events of the past.

Climate Change Scenario 2, selected as the climate scenario for draft planning scheme mapping, represents a 41% increase in rainfall intensity and 1.2 m of sea level rise. This results in 1% AEP riverine water levels approximately 0.6 m higher than current climate conditions at Dennington. This is the equivalent of a 1 in 350 AEP event under current climate conditions or an event which is currently expected only to have a 20% chance of occurring in an 80 year lifespan increasing to a 55% chance of occurring. To provide further context of the influence of climate change on riverine flooding, based on a baseline period between 1961 to 1990 the 1946 event would have an estimated flood magnitude of approximately 1 in 300 AEP, which is reduced to 1 in 150 AEP under current climate conditions and 1 in 60 AEP in 2100.

Increases in flood level for storm tide events for the climate change scenarios are consistent with the magnitude of sea level rise.

The feasibility of three structural mitigation options were assessed in the flood model. The options assessed had the aim of mitigating riverine flooding in the urban area of South Warrnambool downstream of Swinton Street. The assessment showed that restricting flow through Swinton Street either by reducing the flow area under the Swinton Street bridge (one option) or by installing flood gates (another option) would significantly reduce flood levels and the number of houses with above floor flooding. The benefits were greater than a third option investigated which was to increase the flow capacity of the Merri River Cutting. However, the option to restrict flow through Swinton Street would increase upstream flood levels. To manage the increases in flood level significant works are required in Kelly Swamp and Saltwater Swamp to allow more flow to pass through Rutledges Cutting. These works include extensive excavation with a very high capital cost resulting in low benefit-cost ratios and the potential to have detrimental environmental and cultural heritage impact on the nationally significant Lower Merri River Wetlands.

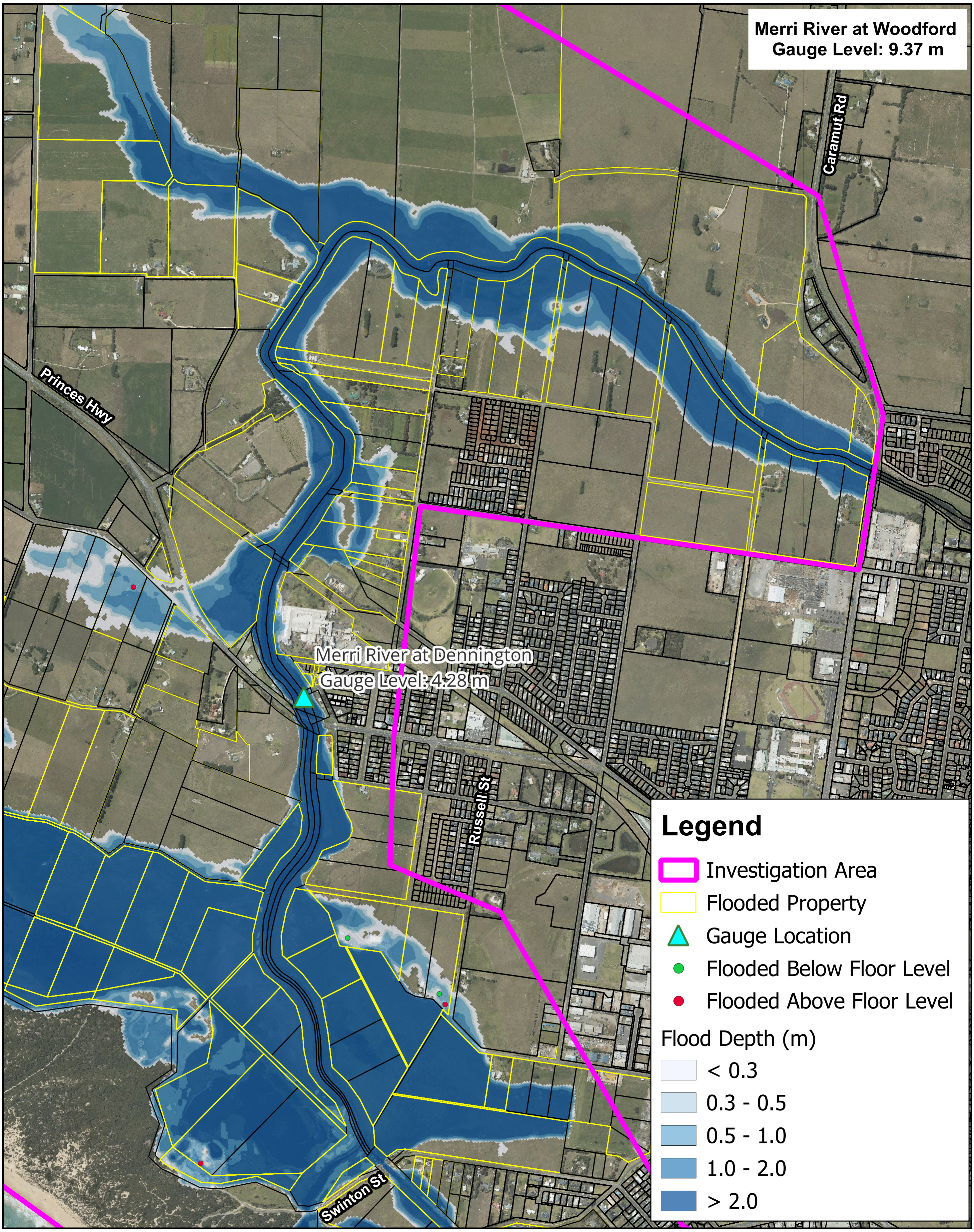
There are currently a number flood risk related planning controls in place for Dennington and South Warrnambool including Urban Flood Zone (UFZ), Floodway Overlays (FO) and Land Subject to Inundation Overlay (LSIO). In South Warrnambool the planning controls were first implemented in the mid-1990s. In the mid-2010s the planning controls were updated north-west of Block Street and extended to include Dennington based on the South Warrnambool Flood Study (Water Technology 2007a) and Dennington Flood Study (2007b). The flood risk mapping produced by this Investigation provides the foundation for updating the Warrnambool Planning Scheme. For South Warrnambool and Dennington this will be achieved through application of the Land Subject to Inundation (LSIO) and Floodway (FO) overlay to the flood prone land in and around both townships and will represent the best available flood modelling and climate science at the time of the Investigation.

The Investigation has involved assessment of the feasibility of improving flood forecasting and warning arrangements for South Warrnambool and Dennington as well as providing tools to aid this process. The outputs of this Study can also be used to improve the communities' and emergency response agencies' abilities to plan for and respond to flood events. This mainly involves updating the Warrnambool City Council Flood Emergency Plan (MFEP) to include flood intelligence or warning information along with improving interpretation and communication of flood risk to the community. Fifteen recommendations are made with priorities assigned.

In light of the outcomes of the Investigation summarised above, the key outcomes are:

- Thorough documentation of the history of flooding across the Investigation Area based on the historical information discovered during the study
- Hydrologic (RORB) and hydraulic (TUFLOW) models that are well calibrated to the available historic flood event data providing confidence that the flood risk mapping and flood emergency response planning (flood intelligence) outputs reflect the likely real world extent, depth and velocity of the modelled flood risk scenarios. The calibrated models have enabled:
  - Provision of knowledge and data around the expected effects of climate change (primarily increase in rainfall intensity and rising mean sea level) on flood risk into the foreseeable future
  - Delineation of appropriate extents for land use and development planning controls for incorporation into the Warrnambool Planning Scheme and mitigation of flood risk via the planning system
  - Development of a range of reliable products to support improvement of flood emergency response procedures and actions, including updating of the Municipal Flood Emergency Plan (MFEP)
- Average annual damage (AAD), which represent the average flood damage in present day monetary terms per year that would occur over a long period of time, estimates of $625,000 for riverine events and $101,000 for storm tide events bringing the total AAD estimate up to $726,000
- The feasibility of three structural mitigation options were assessed in the flood model. The options assessed were broadscale options with the aim of mitigating riverine flooding in the urban area of South Warrnambool downstream of Swinton Street. While these options were successful in mitigating the risk of riverine flooding, they involve extensive excavation with a high capital cost (and in turn a low benefit-cost ratio) and the potential to have detrimental environmental and cultural heritage impact on the nationally significant Lower Merri River Wetlands.
- Demonstrated that the development of a flood warning service operated by the Bureau of Meteorology for the communities of South Warrnambool and Dennington is feasible with much of the infrastructure required already in place. However, there is still significant investment required and the Bureau of Meteorology will prioritise the development of a system across catchments country wide. This

Investigation has provided tools and identified measures that will improve the flood warning arrangements in lieu of a formalised service.



Title:

South Warrnambool and Dennington Flood Investigation - Current Climate
1% AEP Riverine Peak Flood Depth (North)

Figure:	Rev:		This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	By: TL	VENANT SOLUTIONS
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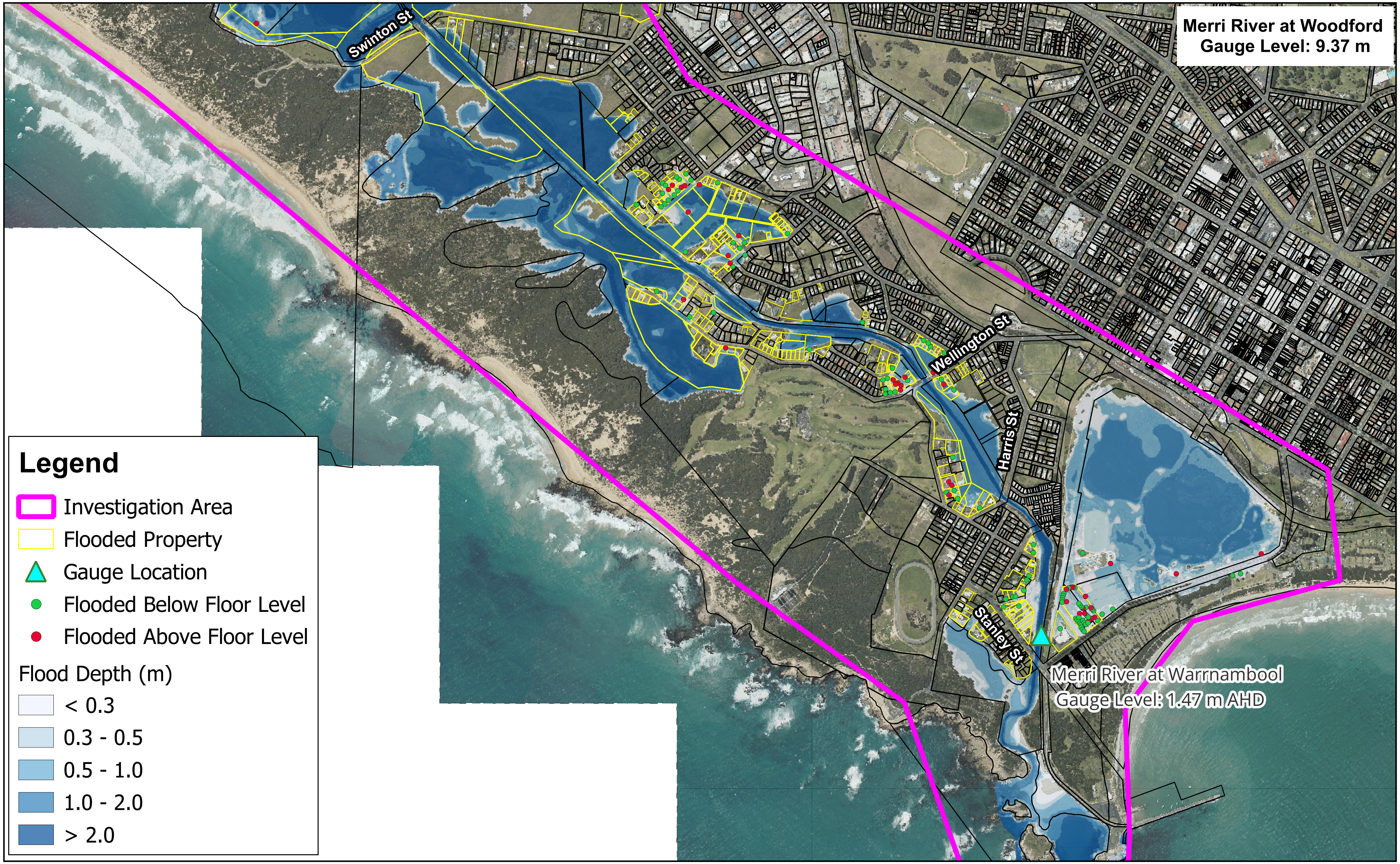

Title: South Warrnambool and Dennington Flood Investigation - Current Climate 1% AEP Riverine Peak Flood Depth (East)	Figure: 2	Rev: A	0 350 700 m	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	VENANT SOLUTIONS
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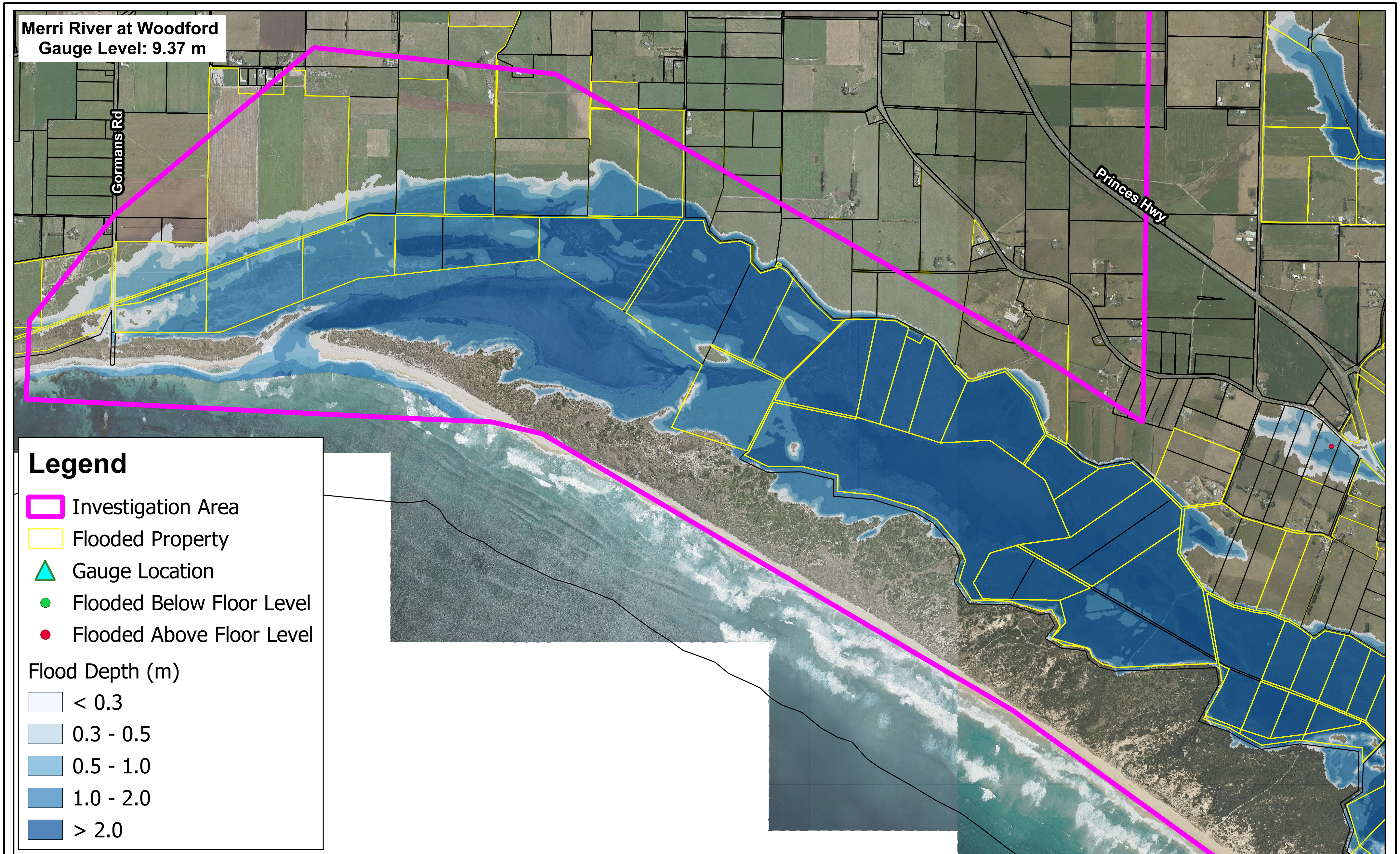

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South Warrnambool and Dennington Flood Investigation - Current Climate
1% AEP Riverine Peak Flood Depth (West)

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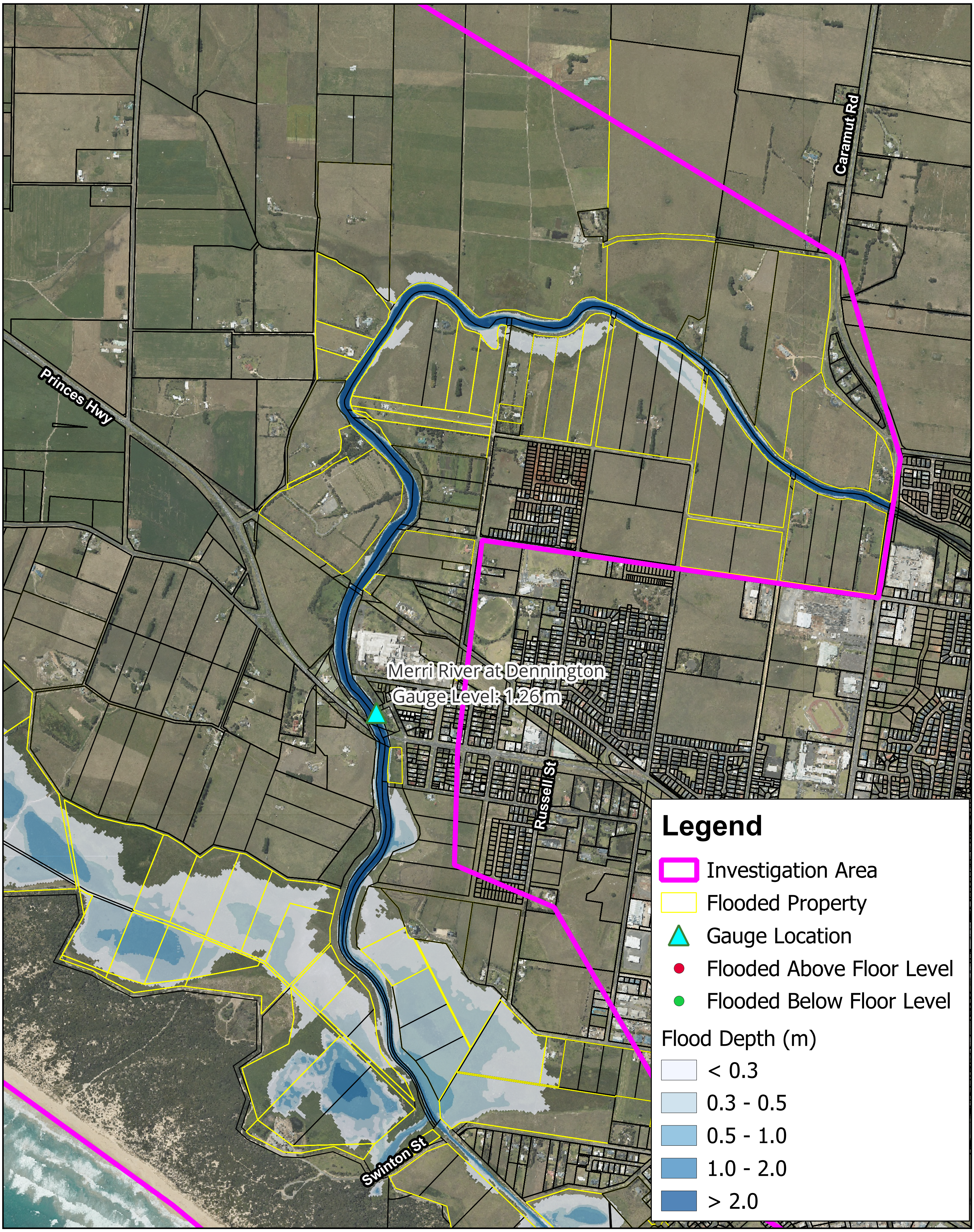

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South Warrnambool and Dennington Flood Investigation - Current Climate
1% AEP Storm Tide Peak Flood Depth (North)

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Title: South Warrnambool and Dennington Flood Investigation - Current Climate
1% AEP Storm Tide Peak Flood Depth (East)

Figure: 5

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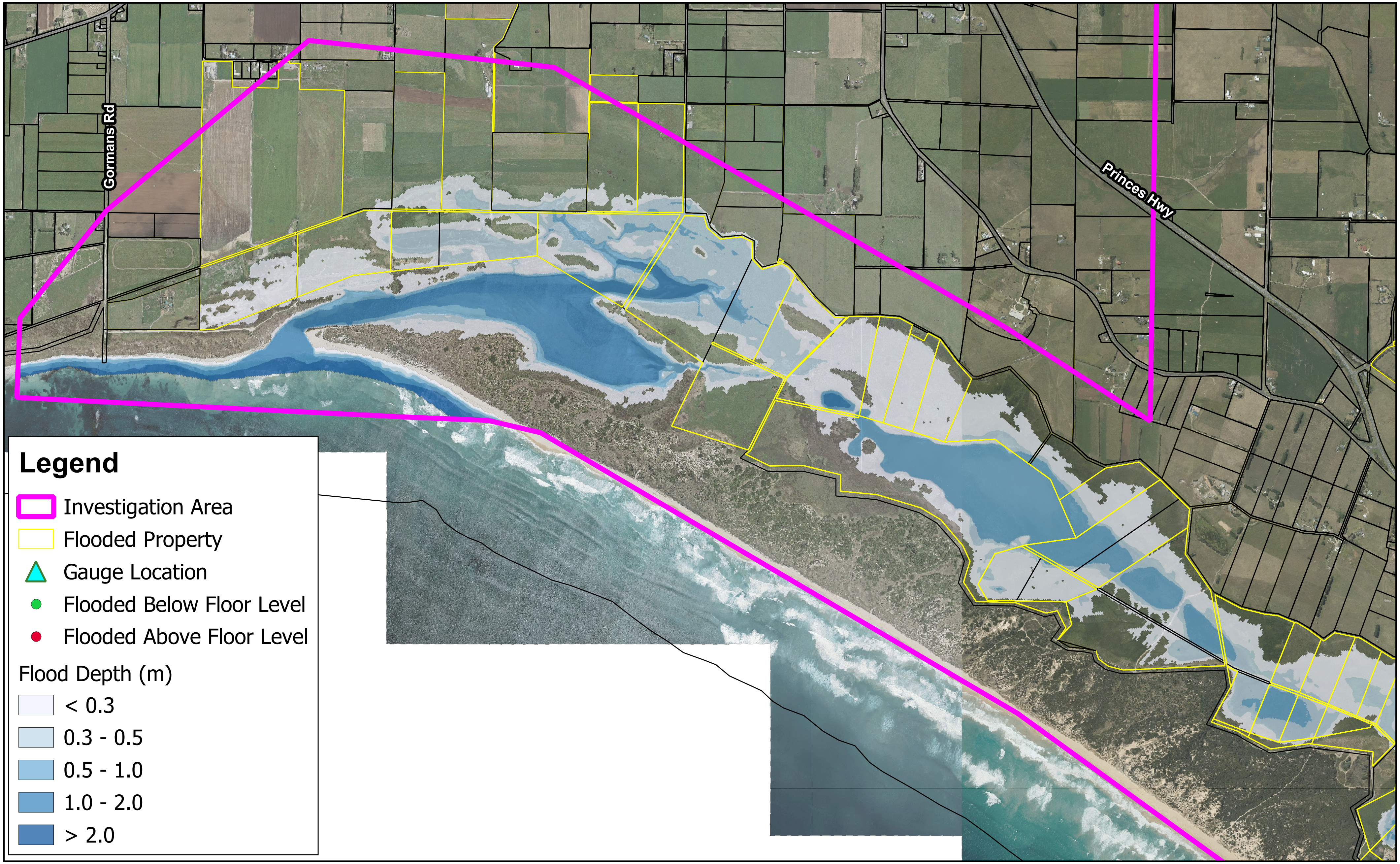

Title:
South Warrnambool and Dennington Flood Investigation - Current Climate
1% AEP Storm Tide Peak Flood Depth (West)

Figure: 6

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By: TL

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Definitions

Annual Exceedance Probability (AEP)	The chance of a flood of a given size (or larger) occurring in any one year, usually expressed as a percentage. For example, if a peak flood level of 8 m has an AEP of 10%, it means that there is a 10% chance (i.e. a 1 in 10 chance) of a peak flood level of 8 m being equalled or exceeded in any one year.
Australian Height Datum (AHD)	National survey datum corresponding to about mean sea level.
Australian Rainfall and Runoff (ARR)	The current (Version 4.1) guidelines for flood modelling in Australia.
Average Annual Damages (AAD)	The average flood damage in monetary terms per year that would occur over a long period of time.
Benefit-Cost Ratio (BCR)	The ratio of the benefits of a project or proposal, expressed in monetary terms, relative to its costs, also expressed in monetary terms. A ratio greater than 1.0 indicates that the benefits are greater than the costs while a ratio less than 1.0 indicates that the costs are greater than the benefits
Catchment	The area of land that drains to a particular point.
Design flood	A theoretical flood representing a specific likelihood of occurrence (for example the 1% AEP flood).
Estuary	The lower sections of rivers where they meet the sea and the fresh river water mixes with the salt water of the ocean.
Flood behaviour	The pattern / characteristics / nature of a flood.
Flood depth	The height or elevation of floodwaters above ground level.
Flood level	The height or elevation of floodwaters relative to a datum (typically the Australian Height Datum).
Flood model	The model developed for this Investigation inclusive of both the RORB hydrologic and TUFLOW hydraulic models
Highest Astronomical Tide	The highest level of water which can be predicted to occur under any combination of astronomical conditions.
Hydraulics	The study of water flow in rivers, estuaries and coastal systems.
Hydrograph	A graph showing how a river or creek's discharge changes with time.
Hydrology	The study of the rainfall-runoff process in catchments.

LiDAR	Remote (aerial) sensing method that uses light in the form of a pulsed laser to measure distance to the Earth. This is used to generate detailed 3D topographical information across an area.
Mean Higher High Water (MWWH)	The mean of the higher of the two daily tide high waters over a period of time.
Probable Maximum Flood	The largest flood that could conceivably be expected to occur at a particular location.
RORB	Rainfall-runoff routing computer model for hydrologic analysis of catchment runoff.
TUFLOW	Fully two-dimensional and one-dimensional unsteady flow hydraulic computer modelling software.
Velocity	The speed at which the floodwaters are moving.

Abbreviations

AAD	Average Annual Damages
AGCD	Australian Gridded Climate Data
AHD	Australian Height Datum
ARR	Australian Rainfall and Runoff (Version 4.1)
BCR	Benefit-Cost Ratio
BoM	Bureau of Meteorology
CFA	Country Fire Authority
Council	Warrnambool City Council
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEECA	Department of Energy, Environment and Climate Action
DEM	Digital Elevation Model
DTP	Department of Transport and Planning
GHCMA	Glenelg Hopkins Catchment Management Authority
EEMSS	Estuary Entrance Management Support System
EMV	Emergency Management Victoria
HAT	Highest Astronomical Tide
IFD	Intensity-Frequency-Duration
IRI	Increased Rainfall Intensity
LFG	Warrnambool Local Flood Guide
MFEP	Warrnambool City Council Flood Emergency Plan
MHHW	Mean Higher High Water
MSL	Mean Sea Level
NSE	Nash Sutcliffe Efficiency
PMF	Probable Maximum Flood
RRV	Regional Roads Victoria
PRG	Project Reference Group
SRWSC	Sate Rivers and Water Supply Commission
SLR	Sea Level Rise
SSP	Shared Socioeconomic Pathway
SWL	Still Water Level
TFWS	Total Flood Warning System
The Investigation	South Warrnambool Flood Investigation

The Catchment	The Merri River catchment to the estuary mouth at Warrnambool
VICSES	Victoria State Emergency Service

1 Introduction

This report provides a summary of the South Warrnambool and Dennington Flood Investigation (the Investigation). This information summarised in this report is detailed in the supporting technical reports:

- Data Review Report (Venant Solutions 2023)
- Flood Modelling Report (Venant Solutions 2024)
- Flood Damages and Mitigation Feasibility Assessment Report (Venant Solutions 2025a)
- Flood Warning Feasibility Assessment Report (Venant Solutions 2025b)

The reporting is supported by investigation deliverables including:

- Calibrated and validated RORB hydrologic and TUFLOW hydraulic models and results
- GIS flood mapping and Spatial Data Specification outputs
- Flood animations
- Draft planning scheme overlay mapping
- Municipal Flood Emergency Plan updates

1.1 Background

Warrnambool is a city of 35,400 people (as of the 2021 Census) and growing. To date the best available mapping for the South Warrnambool and Dennington areas are the 2007 South Warrnambool Flood Study (Water Technology 2007a) and Dennington Flood Study (Water Technology 2007b) and its subsequent updates. Since the completion of the 2007 studies Version 4.1 of Australian Rainfall and Runoff (ARR) (Ball, et al. 2019) was released in 2019 which provides significant progress in the methodologies used to undertake flood modelling and mapping assessments. A major update to the guidance on how to consider climate change in flood investigations was also released in late 2023 (DCCEEW 2023). There has also since been three significant flood events occur, the 2020 riverine flood event and the 2009 and 2014 storm tide flood events.

Warrnambool City Council (Council) in partnership with the Glenelg Hopkins Catchment Management Authority (GHCMA) were successful in gaining funding from Emergency Management Victoria (EMV) to engage Venant Solutions to undertake this Investigation to update existing riverine flood risk modelling and develop new storm tide risk mapping for South Warrnambool. Venant Solutions has completed this investigation with support from consultants BMT for the storm tide assessment and PM Design Group for the structural mitigation option assessment. This information will be used for the following purposes:

- Update knowledge and data around impacts of climate change induced increases in frequency of extreme events, sea level rise and storm tide flooding to enable more effective planning for a worsening flood risk profile for South Warrnambool and Dennington
- Amendment of flood related land use and development controls in the Warrnambool planning scheme
- Assess feasibility for establishing flood alerting/warning arrangements (including for significant storm tide events)
- Provision of flood mapping & intelligence products for the entire project area to inform and develop:
    - Emergency response planning
    - Heightened community flood resilience
- Provision of reliable flood risk information for insurance purposes
- Assessing the feasibility of implementing structural flood mitigation works

A Project Reference Group (PRG) with representatives from the local community, VicSES, Moyne Shire Council, Department of Energy, Environment and Climate Action (DEECA), Eastern Maar Aboriginal

Corporation, Bureau of Meteorology (BoM) and Parks Victoria has been established to provide oversight and local input throughout the Investigation.

1.2 Investigation area and catchment description

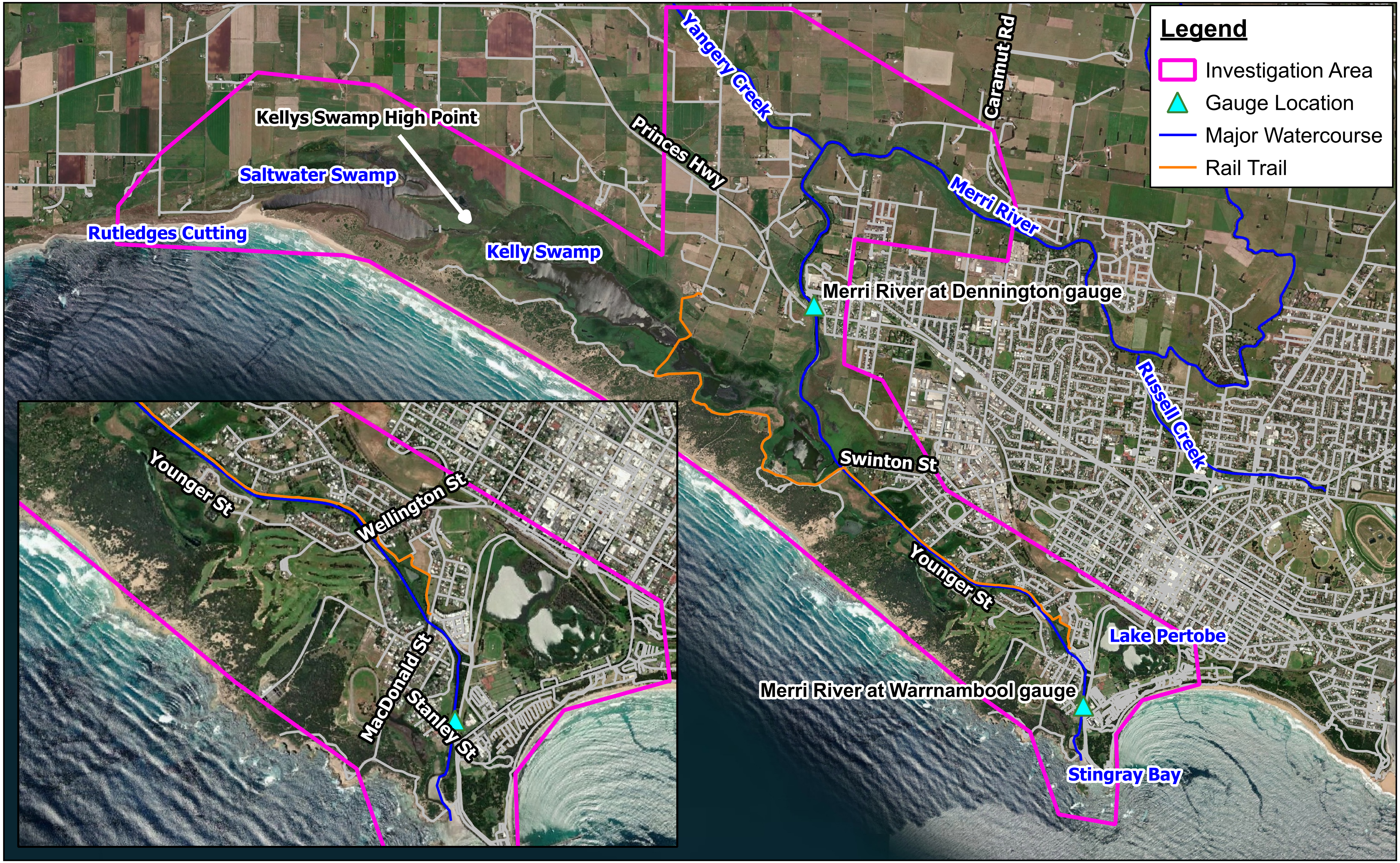
Warrnambool is located approximately 225 km south-west of Melbourne. The city centre and most of its residences are primarily located on the eastern bank of the Merri River (Figure 1-1). The Investigation Area extends from Cassidys Bridge (Caramut Road) at the upstream end, along the Merri River floodplain through Dennington then east past South Warrnambool to the Merri River mouth and west through Kelly and Saltwater Swamps to Rutledges Cutting.

The Eastern Maar are the traditional owners of the South Warrnambool area. Locally the area was inhabited by the Tarerergundidj clan whose name ‘Tarerer’ referred to a large swamp between the Merri River and Tower Hill believed to be what is now known as Kelly Swamp (Clark 1990). The Tarerer Swamp is a significant site as a place where large gatherings of coastal clans occurred when whales were present along the coastline (Clark 1990).

The Merri River catchment (the Catchment) (Figure 1-2) flows in a generally southerly direction. Spring Creek flows through the town of Woolsthorpe upstream of the confluence with Bullanbul Creek, which then becomes the Merri River. Further downstream another major tributary, Drysdale Creek, flows into the Merri River at Grassmere before flowing through Woodford and reaching the coast at Warrnambool. To the downstream extent of the Investigation Area the Catchment has an area of 1,067 km^2. The primary land use within the Catchment beyond the residential and commercial areas of Warrnambool itself is agriculture.

Generally, the waterways and gullies in the Catchment upstream of Dennington are well defined. The main channels of both Spring and Drysdale Creeks are moderately vegetated, while the Merri River main channel is relatively clear, with dense vegetation along the banks. Historically, the Merri River flowed south from the Princes Highway at Dennington to discharge (Gill 1985). Over the past 6000 years coastal processes resulted in the formation of the coastal dune system both forming Kelly Swamp, which was then a bay, and diverting the Merri River eastwards to have its mouth at its current location in Stingray Bay. The Merri River followed a natural river alignment through the South Warrnambool floodplain generally south of the Merri River cutting to discharge into Stingray Bay via the South Warrnambool wetlands. However, since the 1800s there have been significant changes to the South Warrnambool floodplain including the construction of the Merri River cutting to help scour sand deposits in the Warrnambool Harbour, cutting off the natural alignment of the Merri River channel which flowed through the Warrnambool Golf Club and Thunder Point Raceway, and excavation of Rutledges Cutting making it a more permanent connection to the coast. At present during large riverine flood events approximately 80-90% of flow passes through the swamps to Rutledges Cutting while the remaining flow passes through the Merri River cutting to Stingray Bay.

There are three key stream gauges located on the Merri River used in this Investigation, the Merri River at Woodford (236205B) gauge (Figure 1-2) and the Merri River at Dennington (236218B) and Merri River at South Warrnambool gauges (Figure 1-1). At the time of documenting this Investigation the Merri River at Dennington gauge is under construction so gauge records are not yet available, noting that there was previously a stream gauge in Dennington between 1979 and 1985. The Merri River at South Warrnambool gauge is operated by the GHCMA and the gauge records are not publicly assessable.



Title: South Warrnambool and Dennington Flood Investigation
Investigation Area layout

Figure: 1-1

Rev: A

0 0.8 1.6 km

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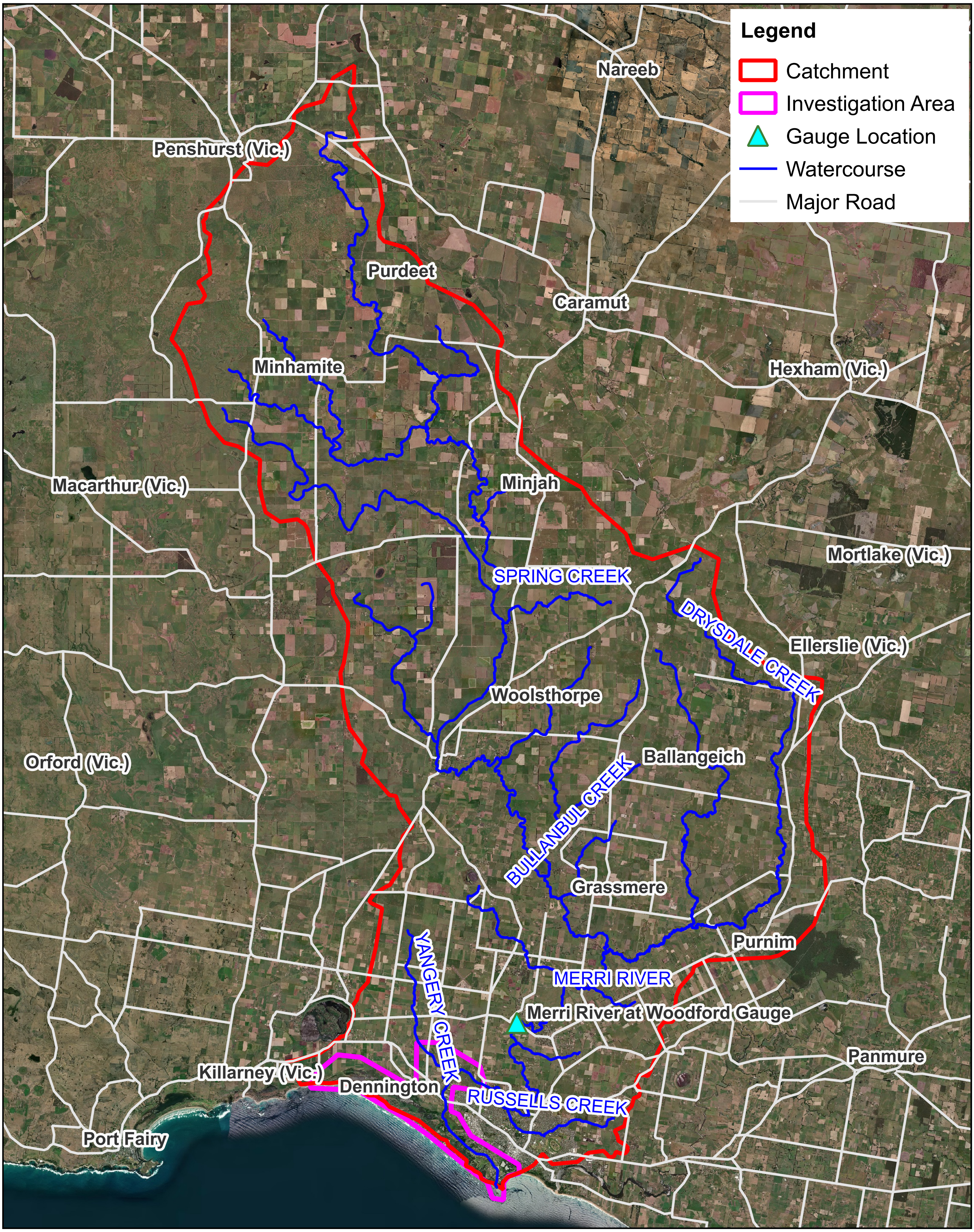

Title:

South Warrnambool and Dennington Flood Investigation
Catchment and Investigation Area Layout

Figure:	Rev:			By: TL	
1-2	A	0 5 10 km	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	Date: Feb 2025	VENANT SOLUTIONS www.venantsolutions.com.au

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1.3 History of flooding in South Warrnambool and Dennington

There is a long and well documented history of flooding in South Warrnambool and Dennington with the earliest reports of flooding in region dating back to 1870 with the first report found specifically mentioning flooding on the Merri River being from 1908 where it was reported that at Woodford water levels were "15 feet above normal level, and 3 feet below the bridge decking" ('Flood at Warrnambool', *Camperdown Chronicle* (5 September 1908), 1).

In March of 1946 the most significant flood event in the south-west region of Victoria since at least 1870 occurred. Following this event the State Rivers and Water Supply Commission prepared a report on the magnitude and impacts of the flood (SRWSC, 1946). Since then many flood studies along the Merri River have assessed the magnitude of this event. In 1948 the Merri River at Woodford stream gauge was installed providing a good record of riverine flooding on the Merri River since then. Figure 1-3 shows the history of flooding at Woodford including an estimate of the 1946 event with the magnitude of design events under current climate conditions shown as a point of comparison. The magnitude of significant riverine events to occur since 1946 in relation to current climate conditions at the Merri River at Woodford gauge are:

- 1946 – 1 in 150 AEP
- 1953 – 14% (1 in 7) AEP
- 1960 – 13% (1 in 8) AEP
- 1978 - 13% (1 in 8) AEP
- 2001 – 9% (1 in 11) AEP
- 2010 – 9% (1 in 11) AEP
- 2016 – 14% (1 in 7) AEP
- 2020 - 6% (1 in 18) AEP

It should be noted that these historic event magnitude estimates shown in Figure 1-3 are based on flow at the Merri River at Woodford gauge and may not represent the magnitude in South Warrnambool or Dennington. This is because if heavy rainfall falls in the lower catchment, flow originating from Russell Creek and Yangery Creek will not be included. Anecdotal information provided by the community indicated that this may have occurred in the 1980s, presumably either in 1983 or 1984 which are approximately 20% AEP events, where it was observed that flood levels were similar to the larger recent events such as in October 2020.

A detailed description of the March 1946 and October 2020 events used in the flood model calibration and validation is provided in the following sections.

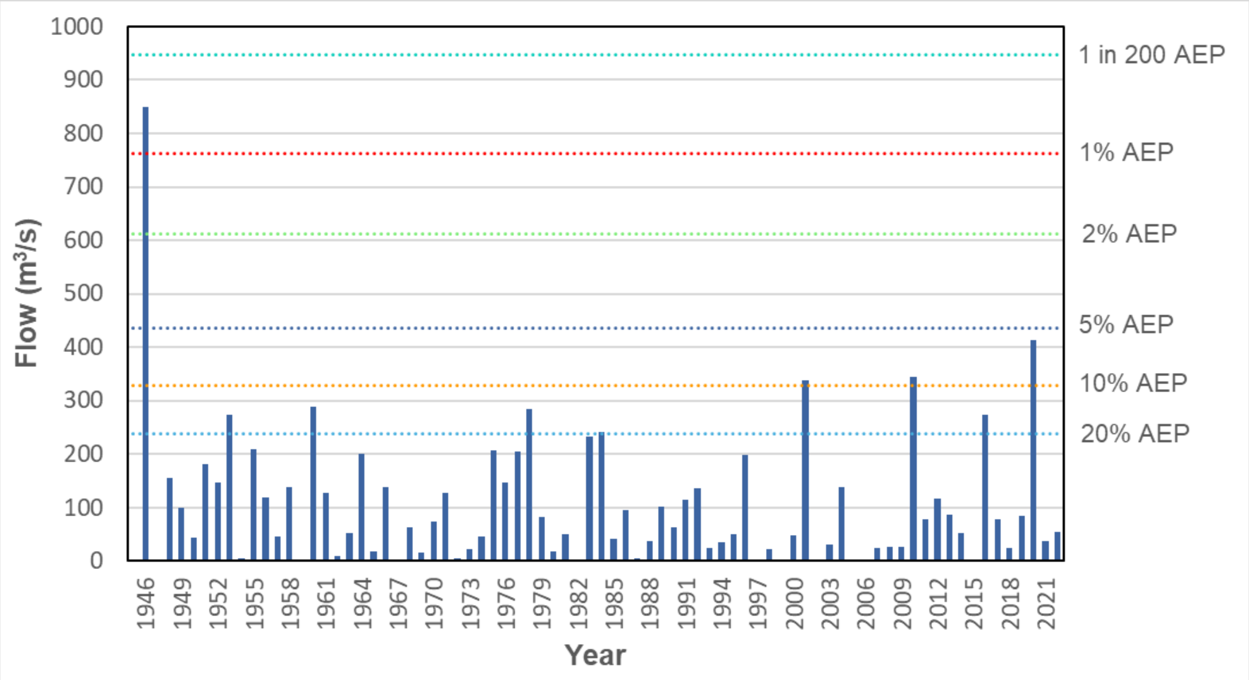


Figure 1-3 History of flooding at Merri River at Woodford gauge

The history of storm tide flooding in South Warrnambool and Dennington is hard to define with offshore ocean height records not always correlating to levels in the Merri River cutting estuary because they do not take into account near shore wave setup (the increase in the mean water level towards the shoreline caused by wave action). It wasn't until 2017 that the stream level gauge at Warrnambool was installed and since then no significant storm tide events have been recorded. This leaves flood photography and surveyed flood levels of the April 2009 and June 2014 events as the only ones with information available and were selected for flood model calibration and validation. The magnitude of the June 2014 and April 2009 storm tide events are equal to approximately the 5% and 10% AEP respectively as shown in Figure 1-4 and a detailed description of the events is provided in the following sections.

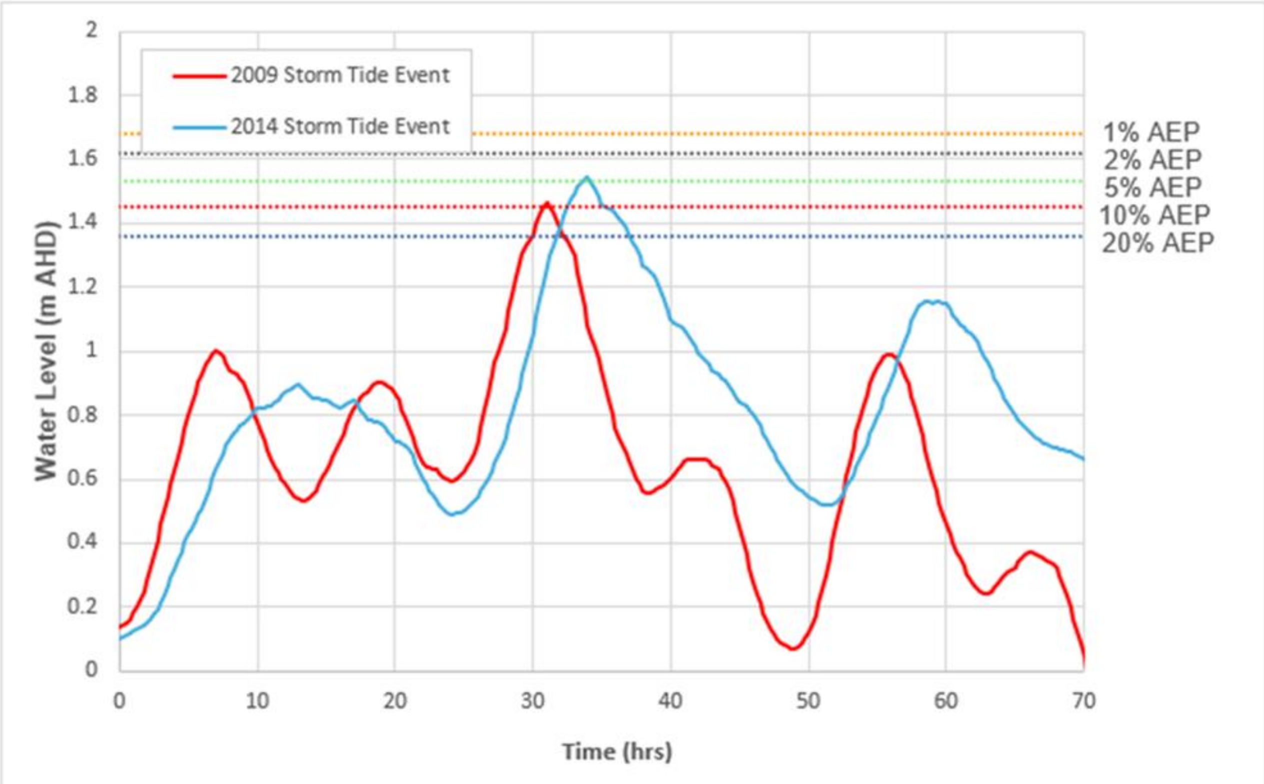


Figure 1-4 Storm tide event magnitudes at the Merri River at Warrnambool gauge

1.3.1 March 1946 riverine event description

The March 1946 riverine flood event is the largest reported on the Merri River since at least 1870. The storm event started on the 15th of March and lasted for three days with most intense period of rainfall occurring over 24 hours from 9:00 am on the 16th of March. Over the three day period a total rainfall of between approximately 140 mm near Ellerslie and 270 mm near the coast fell over the catchment resulting an estimated rainfall magnitude of approximately a 1 in 180 AEP across the catchment. If the rainfall fell in a shorter more intense burst the estimated rainfall magnitude could be higher.

There is limited information available on the impacts of this event in South Warrnambool but further upstream at Dennington a photograph is available of flooding over the old Princess Highway at the Dennington Bowls Club (Figure 1-5), and Cassidys Bridge was washed away (Figure 1-6). It was also observed that at the railway bridge a few hundred yards upstream of the Princes Highway (now removed but the abutments and bridge structure either side of the channel remain) there was a significant difference between the upstream and downstream water levels due to debris blockage and a reported under sizing of the bridge opening (SRWSC 1946). Based on aerial photography captured in 1947 it is estimated that Rutledges Cutting scoured to an opening width of approximately 1 km.

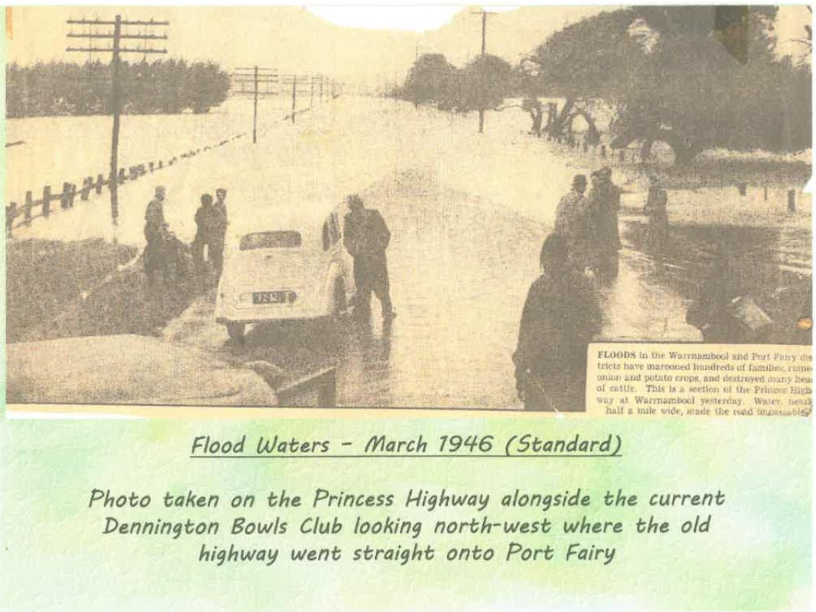


Figure 1-5 Photo of March 1946 event at Dennington (image courtesy of David Skinner)

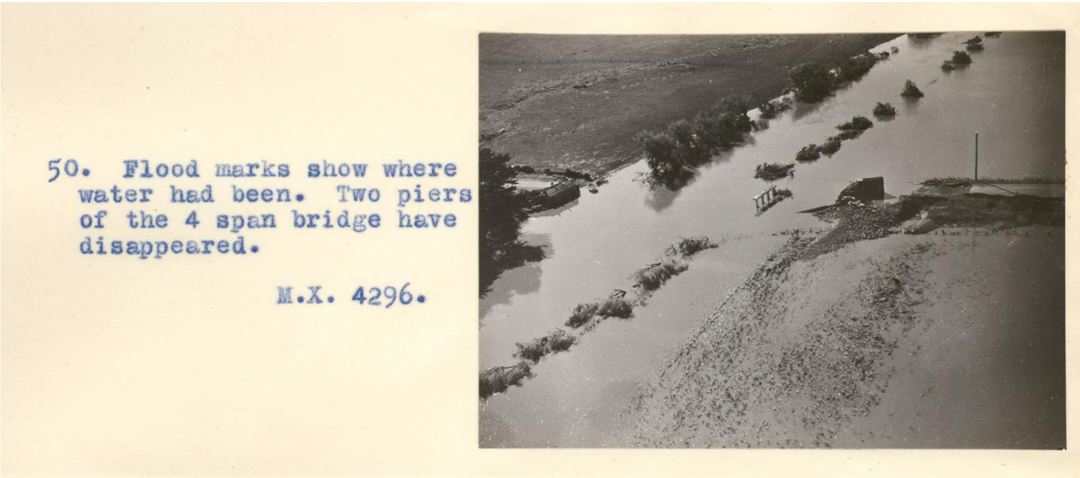


Figure 1-6 Photo of Cassidy's Bridge after the 1946 flood (SRWSC 1946)

At Woodford there is significantly more information available including multiple photos and videos of the event. One of these photos is of flooding of the old police station (Figure 1-7) which is still standing as a house at 233 Bridge Road, Woodford (Figure 1-8). Using survey of the house and assuming that the photograph was taken near the peak of the flood, a minimum flood level of 16.0 m AHD at the front of the house and 15.3 m AHD at the side of the house could be estimated. This allowed for a flow estimate of between 800 m^3/s and 1,100 m^3/s (range due to localised changes in observed water level as flow hits the building) to be derived from the detailed hydraulic model setup to verify the Merri River at Woodford rating curve (Section 3.4.1). This confirmed the peak flow estimate of 850 m^3/s from the North Warrnambool Flood Study (Cardno 2010) which is considered the most robust of the previous peak flow estimates.

Figure 1-7 Woodford during the 1946 flood event (SRWSC 1946)

Figure 1-8 233 Bridge Road, Woodford present day

At Cassidys Bridge the estimated AEP of the event is approximately 1 in 155 AEP. This is slightly rarer than the estimate at Woodford due to high rainfall over the lower catchment. These estimates are significantly lower than some previous estimates of up to a 1 in 1,000 AEP event (Cardno 2010). The higher of these estimates was based on an estimated rainfall of 130 m over 24 hours and outdated design rainfall estimates which under current climate conditions relates to 1 in 80 AEP rainfall event. Regardless, estimating the magnitude of flood events based on a reliable flow estimate to design event flow estimates which represent current climate conditions is considered a more robust approach than estimates made based on rainfall because it takes into account variables such as catchment antecedent conditions “wetness” that influence the conversion of rainfall to flood flows. Flow estimates are also considered more reliable than estimates made on flood level because changes in the physical catchment conditions such as removing the old railway bridge over the Merri River will influence the observed flood levels.

1.3.2 October 2020 riverine event description

The October 2020 riverine flood event is the largest since the Merri River at Woodford stream gauge opened in 1948. The storm event began on the afternoon of the 7th of October and continued into the early morning of the 8th of October with the most intense rainfall falling in the evening of the 7th of October. The rainfall recorded at Warrnambool Airport was approximately equal to a 36 hour 15% AEP event. This resulted in a recorded peak flow of 414 m^3/s at the Merri River at Woodford gauge and an AEP of approximately 6% (1 in 18) at Woodford and Cassidys Bridge.

Flood levels during this event neared those mapped for the 1% AEP event in the 2007 South Warrnambool and Dennington Flood Studies (Water Technology 2007a and 2007b). VICSES records that are documented in the Municipal Flood Emergency Plan show that 13 houses were inundated during this event with flooding threatening 16 more. The Woodford Primary School was closed, the levee protecting the Midfield Meats Rendering Plant failed and several roads were closed including Younger Street, Morse Street, Denman Drive, Obrien Street, Mervue Court, Wellington Street, Northcote Drive, Landmann Street, Wilson Street, Braithwaite Street, and Farnham Road.

A selection of photos taken during the event flood are shown in Figure 1-9 to Figure 1-13.

Figure 1-9 Photo of flooding at the corner of O'Brien and Younger Streets looking south

Figure 1-10 Photo of flood extent taken from near MacDonald Street bridge looking north-west towards Mcgennan Street

Figure 1-11 Photo of flooding at 6 Morse Road

Figure 1-12 Photo of flooding temporary levee at the Midfield Meats Rendering Plant with helicopter dropping sandbag

Figure 1-13 Photo of flooding at the Esplanade looking north-west towards the Dennington Boat Ramp (image courtesy of Graham Conn)

1.3.3 April 2009 storm tide event description

The April 2009 storm tide event occurred from the 25th to the 27th of April with peak storm occurring on the 26th of April. The peak tide level estimate for this event 1.48 m AHD at Warrnambool is approximately a 10% AEP event.

There is little documented on the impacts of this event but there are several sets of photos available as shown in Figure 1-14 to Figure 1-16 that show low lying areas such as MacDonald Street and Ferrier Drive were inundated. Figure 1-14 which was taken looking out over Stingray Bay shows that the large waves breaking over Viaduct Road do not travel up the Merri River estuary

Figure 1-14 Photo of Stingray Bay

Figure 1-15 Photo looking east across inundated MacDonald Street

Figure 1-16 Photo of inundation of Ferrier Street and adjacent properties

1.3.4 June 2014 storm tide event description

The June 2014 storm tide event occurred from the 23rd to the 25th of June with peak storm occurring on the 24th of June. The peak storm tide level estimate for this event is 1.54 m AHD at Warrnambool or approximately a 5% AEP event. The storm tide levels were high enough to overtop the beach berm and open Rutledges Cutting.

As documented in the Municipal Flood Emergency Plan this event inundated more than 35 properties with one house on Ferrier Drive flooded above floor level and several other buildings flooded below floor level on Stanley Street, Edina Street, MacDonald Street, Elliott Street and Ferrier Drive.

A selection of photos taken during the are shown in Figure 1-17 to Figure 1-19

Figure 1-17 Photo at Charles Kane Park playground looking towards the Stanley Street bridge

Figure 1-18 Photo of inundation at MacDonald Street

Figure 1-19 Photo of inundated properties along Denman Drive

1.4 Investigation climate change scenarios

Two climate scenarios for the year 2100 have been assessed, referred to as Climate Change Scenarios 1 and 2 which represent an estimated 3.6°C and 4.5°C of global warming respectively from the baseline period between 1961 to 1990. These scenarios are based on global mean surface temperature projections from the Sixth Assessment Report of the United Nations Intergovernmental Panel on Climate Change Shared Socioeconomic Pathways (SSPs) as accessed via the Interactive Atlas. 3.6°C of global warming between 2081 and 2100 from 1961 to 1990 temperatures is representative of the best estimate (50^{th} percentile) of the SSP3-7.0 high greenhouse gas emissions scenario and the upper limit estimate (95^{th} percentile) of the SSP2-4.5 intermediate greenhouse gas emissions scenario. 4.5°C of global warming between 2081 and 2100 from 1961 to 1990 temperatures is representative of the best estimate (50^{th} percentile) of the SSP5-8.5 very high greenhouse gas emissions scenario.

Increased rainfall intensity has been defined in accordance with the guidance provided in the Draft Update to Climate Change Considerations Chapter in Australian Rainfall and Runoff: A guide to Flood Estimation (DCCEEW 2023). This results in 32% and 41% increase in rainfall intensity from the 1961 to 1990 baseline for Climate Change Scenarios 1 and 2 respectively for storm duration greater than 24 hours.

It should be noted that since the climate change assessment was completed for the Investigation the draft climate change considerations have been incorporated into Version 4.2 of ARR (Version 4.1 was used for this Investigation). Version 4.2 of ARR uses the Summary for Policymakers report (IPCC 2021) as opposed to the Interactive Atlas used in the draft as the source of the global mean surface temperature projections. This has resulted in the global warming levels used in the calculation of increased rainfall intensity reducing from 3.6°C to 3.3°C for Climate Change 1 and from 4.5°C to 4.1°C for Climate Change 2 from the baseline period between 1961 to 1990. This results in the 32% and 41% increased rainfall intensity factors adopted in accordance with (DCCEEW 2023) being 3% and 4% higher for Climate Change Scenarios 1 and 2 respectively. This results in slightly conservative increased rainfall intensity factors been used.

Sea level rise has been defined in accordance with the guidance provided in the Tide Gauge Trigger Levels for Sea Level Rise Adaptation Pathways (Streamology 2022a). In accordance with current Victorian planning policy sea level rise of not less than 0.8 metres by 2100 must be planned for, so 0.8 metres has been adopted for Climate Change Scenario 1. Under Action 3.9 of the Marine and Coastal Strategy (DELWP 2022) the 0.8 m SLR benchmark is currently being reviewed and in the absence of the outcomes of the review Climate Change Scenario 2 uses 1.2 m of SLR representing the upper limit estimate (95^{th} percentile) of the SSP5-8.5 very high greenhouse gas emissions scenario for 2100 (Streamology 2022a).

For brevity reasons only the flood mapping and intelligence outputs for Climate Change Scenario 2 have been presented in this summary report as it has been adopted for the preparation of draft planning overlay mapping. Reasoning for this decision is provided in Section 7.

2 Community engagement

Throughout the course of the Investigation, three community meetings were held at the Merrivale Recreation Reserve, as well an all-day drop-in listening-post style event hosted at the Harbour Pavilion at the beginning of the project. These in-person events were supported by an on-line survey, and updates and draft flood mapping posted via the Council's website. Below are some details on the community engagement activities:

- **Community Listening Post (1st of November 2022)** – This community information drop-in session was held to introduce the community to the Investigation and invite the community to share flood information and images. Attendees at the listening post provided feedback including identifying areas subject to flooding, identifying potential flood level marks for survey, raising concerns over changes to the floodplain which contribute to flooding and the identification of possible structural flood mitigation works. Six attendees also provided photography and videos to support their observations.
- **Community Survey** - To complement the Community Listening Post an on-line survey was provided via Council's website for any community members who wanted to participate, but were not able to attend in-person. The purpose of both the in-person and on-line events was to gain further information regarding the community's past experiences with flooding and the identification of potential mitigation options. In total there were 48 responses to the survey with 11 of the respondents having experienced flooding on their property.
- **Community Meeting (7th of June 2023)** – This community meeting provided an overview of the flood modelling methodology and presented the draft mapping (prior to the release of updated climate change guidelines). Feedback was sought on the accuracy of the mapping following the presentation and via presentation of the mapping on Council's website. The meeting was well attended, with Council staff estimating approximately 30 community members present. The event resulted in several new flood marks as well as additional photography which was used to refine the model.
- **Community Meeting (8th of November 2023)** – Prior to this community meeting a letter was distributed to the South Warrnambool community in late September 2023 asking for the identification of potential structural flood mitigation options. Twenty-five potential structural mitigation options were identified by the community. The meeting was attended by approximately 20 community members. At the community meeting updated flood mapping incorporating additional information provided by the community following the meeting held on the 7th of June 2023 was presented. This was followed by the presentation of six shortlisted structural flood mitigation options including an overview of what each option could entail, the likely effect on flood behaviour and possible "Pros" and "Cons" in relation to flood risk, economic feasibility, and social and environmental considerations. During the meeting each community member was provided with two tokens which they could use to place a vote for the options (Figure 2-1) which they would most like to see further assessed.

Figure 2-1 Photo of the structural options voting

- **Dennington Extension Engagement (July 2024)** - After it was decided to extend the model boundary upstream to better understand flood risk in Illowa and North Dennington, property owners and occupiers in the model extension area were notified via letter and invited to provide flood history information, and to ask questions about the investigation. As a result, further information about past flooding including photographs was gathered to validate the model in the extended area.
- **Community Meeting (11th of December 2023)** – At this community meeting (Figure 2-2) the final flood mapping representing the updated climate change guidelines was presented followed by a presentation of the structural flood mitigation options feasibility assessment and the draft planning scheme control updates. Approximately 50 community members attended this meeting.

Figure 2-2 Community meeting held on the 11th of December 2023

3 Data review

A comprehensive set of data was collected and reviewed for the Investigation from a broad range of resources including Council, GHCMA, DEECA, Department of Transport and Planning (DTP), BoM and publicly available datasets such the Water Measurement Information System (WMIS), Victorian spatial data online portal and the National Library of Australia's Trove newspaper online library. This data was supplemented by information provided by the community (refer to Section 2) captured during the site visits and field survey.

3.1 Previous Studies

There have been several previous flood and other relevant studies completed in the past for the Merri River covering the Investigation area. For this Investigation the three key previous studies are:

- **South Warrnambool Flood Study (Water Technology 2007a)** and **Dennington Flood Study (2007b)** – Detailed flood studies covering the current Investigation area using the methodologies and parameters defined in the now superseded 1987 release of the Australian Rainfall and Runoff Guidelines. Channel and bridge survey captured for these studies was used in the development of the TUFLOW model
- **Design of North Warrnambool Floodplain Management Plan (Cardno 2010)** – This detailed flood study of the North Warrnambool area provided a summary of past March 1946 event Merri River flow estimates and a flow estimate based on a calibrated hydraulic model

3.2 Historic flood data

The following historic flood information has been collected and reviewed in addition to the information provided by the community (Section 2):

- Flood level survey marks from eight past flood events including two marks from the March 1946 riverine event, 34 marks from the June 2014 storm tide event and approximately 400 marks from the October 2020 riverine event. These flood level marks came from several sources including datasets kept by the GHCMA, survey captured for the 2007 study, survey recorded at the Mervue Estate and on Morse Street.
- Spot heights from the Victorian Flood Database (VFD) including 9 levels from the March 1946 event
- Flood photography from nine previous flood events spanning from 2001 to 2020 supplied by the GHCMA. Additional photography was sourced from newspaper articles and other media
- Report on Western District Floods of March 1946 prepared by the State Rivers and Water Supply Commission (SRWSC 1946) included photography and information as summarised in Section 1.3
- The National Library of Australia's Trove newspaper online library (https://trove.nla.gov.au/newspaper/) was searched along with the Google News Archive (https://news.google.com/newspapers) and other media websites with reports of flooding along the Merri River found dating back to 1870

3.3 Topographical data

The following digital elevation models (DEM) and cross-section survey datasets were used in the Investigation:

- **2023 Portland DTV LiDAR**– Captured in 2023 this dataset was used as the primary piece of data to represent the topography of the Merri River floodplain in the hydraulic model
- **South-west Coastal DEM** – Captured between in between 2007 and 2008 this dataset was used to represent the Kellys and Saltwater Swamps floodplain west of the extent of the 2023 Portland DTV LiDAR in the hydraulic model
- **70 Younger Street Design Surface and Mervue Estate Survey** – Topography surfaces of recent developments to ensure they are represented in the hydraulic model

- **2007 cross-section survey** – Cross-section survey captured along the Merri River through the Investigation area for the 2007 studies that was used to represent the Merri River channel bathymetry
- **2017 Warrnambool LiDAR, Victorian Coastal DEM 2021 and Victorian Coastal DEM 2021 – 10 m** – These datasets were used to represent the nearshore bathymetry at Stingray Bay and Rutledges Cutting in the hydraulic model
- **National Intertidal DEM 25 m** – This dataset was used to represent Saltwater Swamp bathymetry in the hydraulic model
- **VicMap Elevation DTM 10m** – A course dataset with limited accuracy used for determining catchment and sub-area boundaries and slopes in the hydrologic model

The accuracy of the LiDAR datasets was verified and it was found they were appropriate for use in detailed hydraulic modelling.

3.4 Stream, reservoir, tide, estuary and rainfall data

The following stream, reservoir, tide, estuary and rainfall datasets were collected to inform the development and calibration of the flood model:

- Stream gauge level and flow data was sourced for four active and closed sites throughout the catchment
- Hourly tide level, including weather data, records were obtained for the Portland tide gauge data from the BoM for the period from 1991 to current. 2022 tide level predictions for Warrnambool, Port Fairy and Portland were obtained from the BoM
- Glenelg River Estuary Entrance Management Support System (EEMSS) records between 2007 and 2022 detailing estuary water levels and mouth opening conditions including berm height survey
- Daily (20 stations) and sub-daily rainfall (21 stations) rainfall data was sourced for active and closed stations in and near the Catchment.

3.4.1 Merri River at Woodford stream gauge rating curve review

Following a site visit and reviewing the published rating curve and flow gaugings (on-site recording of flow velocity to estimate a flow) for the Merri River at Woodford stream gauge potential issues which may influence the rating curve accuracy during high flow (flood) events were identified. These include:

- The highest flow gauging was taken at a level before the flow breaks out of the river banks
- The gauge is located adjacent to a bridge and immediately downstream of a sharp bend in the river likely resulting in complex flow behaviour
- The pully system (Figure 3-1) presumably used during high flow gaugings attaches to the bridge deck itself and does not span the entire channel width
- Inconsistencies between previous flow gaugings

Figure 3-1 Merri River at Woodford gauge pully system

To help resolve these issues and minimise the uncertainty in the flood event flow estimates used in the FFA and model calibration for this Investigation, verification of the rating curve using a hydraulic model was undertaken.

To do this a detailed TUFLOW 2D hydraulic model was developed for Woodford to verify the published rating curve. The results of this model which are presented in Figure 3-2 show that the modelled level-flow series provides a close match to the published rating curve up to a gauge level of approximately 3.5 m. Above this level the model indicates that for a given gauge level there is significantly more flow. This is often found when comparing published rating curves to hydraulic model results due to difficulties in obtaining physical flow gaugings during flood events. However, at the Merri River at Woodford gauge flow gaugings were able to be taken during a relatively high flow event in August 2001 which could result in a higher of level reliability in the rating curve at high gauge levels. As such, before adopting the modelled results for use in this Investigation further verification was undertaken.

An additional TUFLOW model was setup from Woodford to the coast encompassing the Investigation Area to compare flow estimates at the Merri River at Woodford gauge to recorded water levels at the now closed Merri River at Bromfield Weir gauge during for the August 2001 and August 2010 flow events which were the largest to occur while both gauges were operational, noting the weir was in place during these events. This model showed that using the flow inputs from the detailed Woodford TUFLOW model provided a much better match to the recorded flood levels at Bromfield than using those from the published rating curve. As such the rating curve was revised above a gauge level of 3.1 m using the TUFLOW model for use in the FFA and model calibration for this Investigation. The revised rating curve is shown in Figure 3-2.

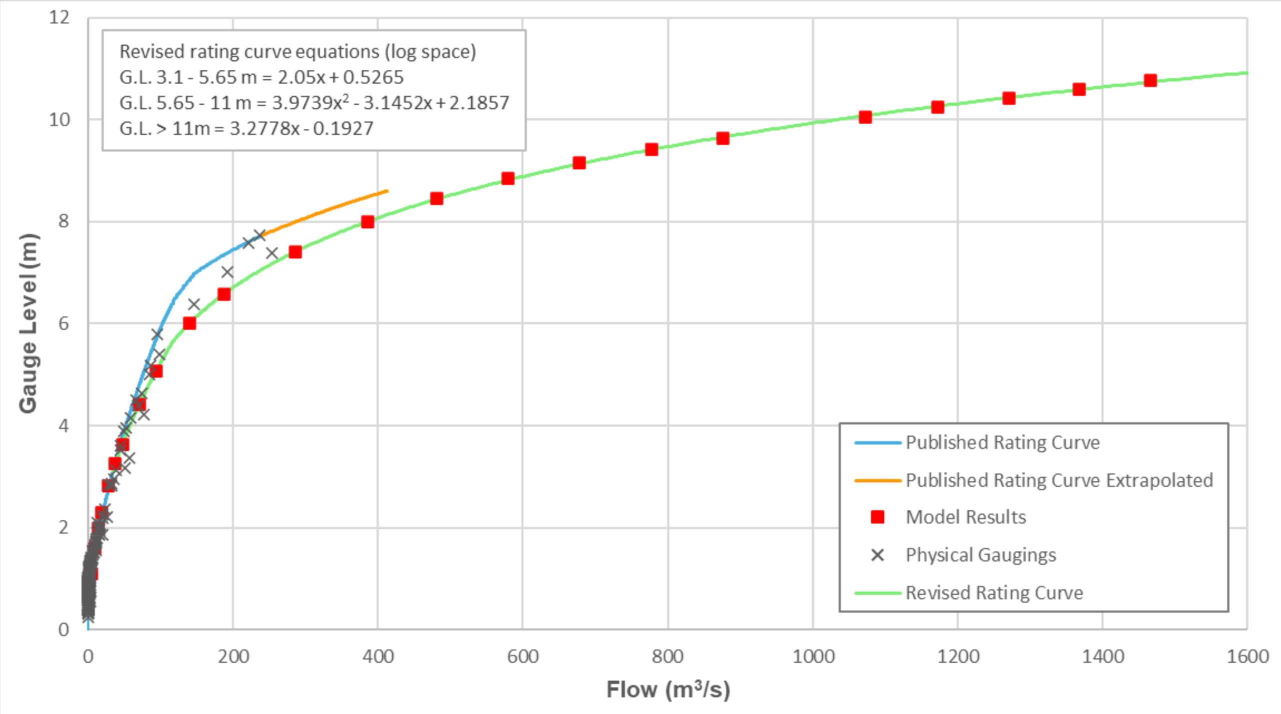


Figure 3-2 Merri River at Woodford rating curve verification

3.5 Bridge data

There are 13 bridges located in the Investigation area that were represented in the hydraulic model. Information on these structures was obtained from Council, DTP, the 2007 flood studies and field survey.

3.6 Site visit

Venant Solutions, accompanied by the GHCMA and Council undertook a site visit on 5 September 2022. Areas of interest were visited including the hydraulic structures along key waterways and roads. These site visits allowed Venant Solutions to gain an understanding of the investigation area, identify structures and measure structures and to obtain a photographic record.

3.7 Field survey

The following field survey was captured for this Investigation:

- 145 spot heights along centre lines at 3 separate long section locations
- Deck level elevations for the Merri River at Bridge Road, Woodford and Merri River at Princes Highway, Dennington bridges
- Dimensions of the Port Fairy – Warrnambool Rail Trail bridge over Kellys Swamp
- Gauge zero level of the Merri River @ Woodford stream gauge
- Ground elevations of the high point between Kelly and Saltwater Swamps
- Bank and channel cross-section survey of the new abutments under the Edwards Street bridge
- Survey of 165 building floor levels and 13 pump stations

4 Flood modelling

4.1 Modelling method summary

A calibrated and validated flood model has been developed for this Investigation using the RORB hydrologic and TUFLOW hydraulic flood modelling packages which are both widely used across Australia. The purpose of the RORB model is to convert rainfall to runoff for a given probability to provide catchment flow rates and timing. The purpose of the TUFLOW model is to represent the physical characteristics of the flow and ocean levels such as flood extent, level and velocity across the Investigation Area. The flood model has been developed in accordance with the guidance and parameters provided in ARR and the Victorian Guideline for Modelling the Interaction of Catchment & Coastal Flooding (Streamology 2022b) for the scenarios and design events listed in Table 4-1.

The calibration and validation of the flood model is a critical process of any detailed investigation. Calibration is the process of developing model parameters that represents observed flood behaviour where validation is the process of confirming these parameters to separate flood events. Best practice model calibration considers all available historic information, which typically could include stream gauge levels, historic flood extents and flood marks, along with other data such as flood photography and community recollections. For this Investigation the calibration and validation took place within a joint calibration framework, where historical estimations from the RORB model were tested in the TUFLOW model, the results checked and both models adjusted as necessary.

The model was calibrated and validated to two riverine flood events and two storm tide flood events:

- October 2020 riverine calibration event
- March 1946 riverine validation event
- June 2014 storm tide calibration event
- April 2009 storm tide validation event

The October 2020 riverine was selected as the riverine calibration event because it is the largest event to occur since the Merri River at Woodford gauge was opened, there is a large of amount of observed data available through Dennington and South Warrnambool, and it generally represents current floodplain conditions except for some recent developments. The March 1946 event was chosen as the riverine validation event because it is the largest event on record and provides a good tool to communicate what extreme events can look like to the community. The June 2014 and April 2009 storm tide events were chosen because they are the two largest storm tide events that have historic data available with the June 2014 event being larger with slightly more data available so was chosen for calibration.

Design flows have been defined by validating Monte Carlo flood frequency analysis results using the BoM 2016 IFDs (1961-1990 baseline period) to the at-site FFA results at the Merri River at Woodford gauge. The validation was achieved by varying the initial and continuing losses. Weighting was given to validating the Monte Carlo FFA analysis results to the FFA results for events between the 10% AEP and 1% AEP event. The 10% AEP event is the most frequent event recommended for the use of FFA based on annual maximum series in ARR and given the length of available gauge records, beyond the 1% AEP event the uncertainty bounds become greater in comparison to rainfall based estimates. This allows for higher reliance on the at-site FFA for events where the uncertainty bounds are smaller, while using a probabilistic method for extreme events.

The storm tide design events were derived using extreme value analysis of the residuals at the Portland tide gauge. The surge heights were then factored by 17% to relate them to Warrnambool and a 7% factor for offshore wave heights was used to represent wave setup.

Table 4-1 Design event scenarios

Riverine Flooding			Storm Tide Flooding		
Climate Scenario	**Riverine Flood**	**Coastal Condition**	**Climate Scenario**	**Storm Tide**	**Riverine Flow**
Current Climate	20% AEP	MHHW	**Current Climate**	20% AEP	Mean flow (May to September)
	10% AEP			10% AEP	
	5% AEP			5% AEP	
	2% AEP			2% AEP	
	1% AEP			1% AEP	
	0.5% AEP			0.5% AEP	
	0.2% AEP			0.2% AEP	
	PMF			Tsunami	NA
Climate Change 1 (CC 1) **(32% IRI + 0.8 m SLR)**	20% AEP	MHHW	**Climate Change 1 (CC 1)** **(0.8 m SLR)**	20% AEP	Mean flow (May to September)
	10% AEP			10% AEP	
	5% AEP			5% AEP	
	2% AEP			2% AEP	
	1% AEP			1% AEP	
	0.5% AEP			0.5% AEP	
	0.2% AEP			0.2% AEP	
Climate Change 2 (CC 2) **(41% IRI + 1.2 m SLR)**	20% AEP	MHHW	**Climate Change 2 (CC 2)** **(1.2 m SLR)**	20% AEP	Mean flow (May to September)
	10% AEP			10% AEP	
	5% AEP			5% AEP	
	2% AEP			2% AEP	
	1% AEP			1% AEP	
	0.5% AEP			0.5% AEP	
	0.2% AEP			0.2% AEP	

4.2 Merri River at Woodford flood frequency analysis

The at-site FFA for the Merri River at Woodford gauge was undertaken in the Flike software package. Streamflow records are available at the gauge from 1948 to the present day allowing for an annual maximum flow series of 76 years including the March 1946 event. Data availability was generally complete since the 1970s but from 1948 through the 1950s and 1960s there were gaps mainly over the summer and autumn periods. It was confirmed that calendar year provides a good representation of water year.

It is believed that the March 1946 flood event was the largest riverine flood event to occur on the Merri River since records of flooding were first identified in 1870. A flow of 850 m^3/s was estimated for this event derived for the North Warrnambool Flood Study (Cardno 2010) with the flow verified to flood levels shown in photography using the TUFLOW hydraulic model developed to revise the Merri River at Woodford rating curve (Section 3.4.1) as described in Section 1.3.1. The 1946 event was included in annual maximum flow series. Censored information was also included in Flike representing the assumption that there were no events larger than the March 1946 event in the 76 year period from 1870 to 1945.

As recommended in ARR, low flows were censored from the dataset to ensure that these did not unduly affect the fit of the flood frequency curve. A better fit to the recorded annual maximum flows was achieved without the use of prior parameter information from a Regional Flood Frequency Estimate (RFFE) to the Bayesian framework in Flike.

The results of the FFA are shown in Table 4-2 and Figure 4-1 with the best fit achieved using the log Pearson Type III probability model without prior parameter information.

The peak flow estimates are significantly higher than those derived for the 2007 South Warrnambool Flood Study (Water Technology 2007a). This is due to several factors including the availability of the Flike software package which supports the Bayesian methods described in Book 3, Chapter 2 of ARR, the additional functionality in Flike to include censored historic flood information and prior parameter information, the use of the multiple Grubbs-Beck test to remove probable influential low flows, the additional annual maximum series length which includes the October 2020 event and the revision of the rating curve. However, mainly it is the inclusion of the March 1946 event which was removed as an outlier in the 2007 study. Sensitivity testing and confirmation of the flow estimates to design rainfall estimates was undertaken to ensure that including the March 1946 flow in the FFA is appropriate.

Table 4-2 FFA Results for Merri River at Woodford gauge

AEP	Expected Flow (m^3/s)	Lower 90% Confidence Limit Flow (m^3/s)	Upper 90% Confidence Limit Flow (m^3/s)
20%	167	132	215
10%	263	207	337
5%	369	288	481
2%	524	398	723
1%	651	480	945
1 in 200	783	559	1,720
1 in 500	965	720	2,175

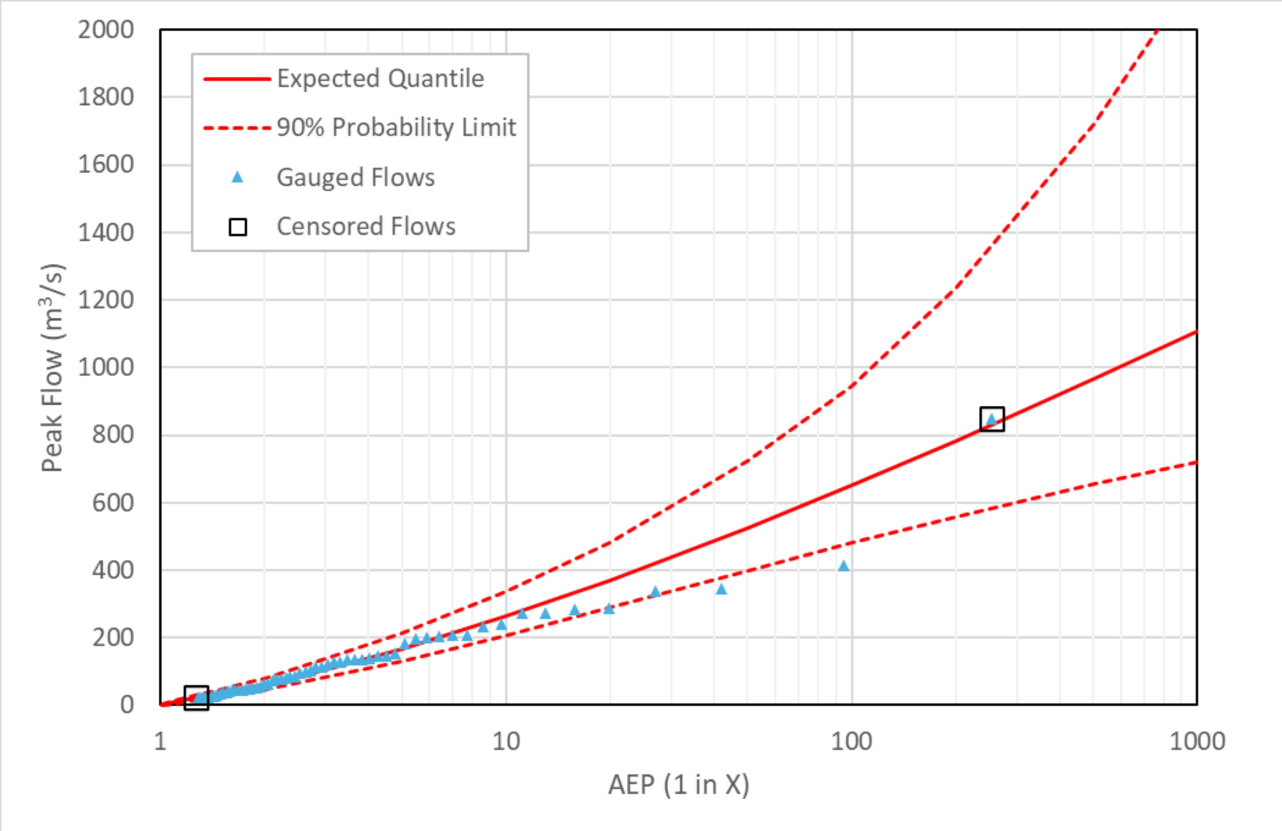


Figure 4-1 Flood Frequency Curve for the Merri River at Woodford gauge

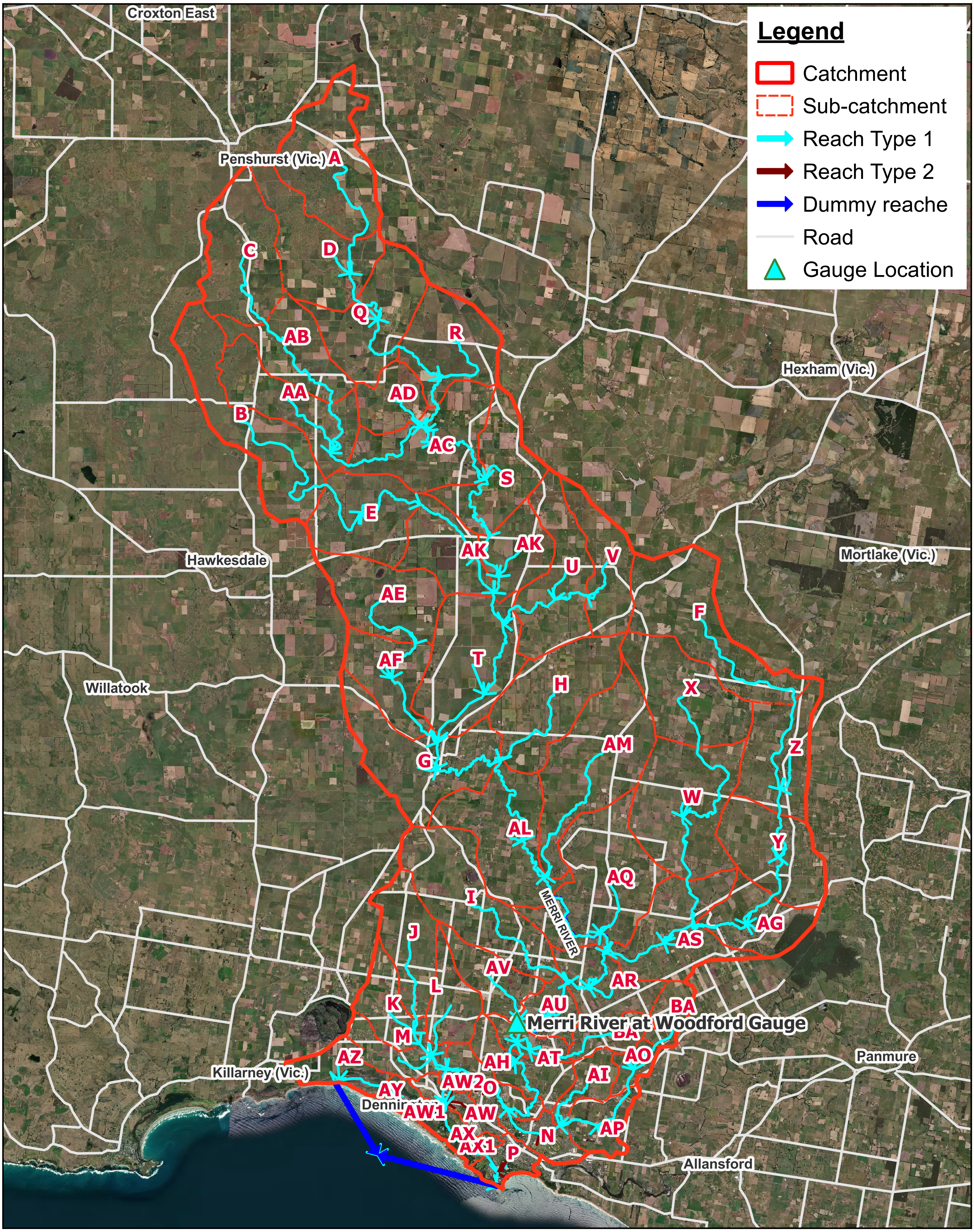
4.3 RORB modelling

4.3.1 RORB model development

As shown in Figure 4-2 the RORB model covers the entire Merri River catchment. For this Investigation delineation into sub-catchments was performed to ensure sufficient sub-catchment representation to provide suitable flow estimates upstream of the Merri River at Woodford stream gauge used in the calibration and validation process.

Flow was routed through the model using RORB Reach Type 1, representing natural channels, throughout the model except for those in the urban areas of Warrnambool where Reach Type 2, representing excavated but unlined channels, were used as faster runoff times are expected.

Upstream of Warrnambool the catchment is primarily rural with small townships and as such was assumed to consist of entirely pervious area. The roads and small towns within this area do not meaningfully increase the catchment runoff. Within Warrnambool the effective impervious area was represented in accordance with the guidance provided in ARR.



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South Warrnambool and Dennington Flood Investigation
RORB Schematisation

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4-2	A	0 5 10 km	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	By: TL Date: Feb 2025	VENANT SOLUTIONS www.venantsolutions.com.au

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4.3.2 RORB model calibration and validation

The October 2020 riverine event calibration achieved a good fit to the recorded flows at the Merri River at Woodford stream gauge using a k_c routing parameter of 71.0 above Woodford and a *m* routing parameter of 0.8.

The peak flow estimate of 850 m^3/s at Woodford for the March 1946 event was matched using storm losses within acceptable bounds confirming that the calibrated routing parameters are appropriate.

4.3.3 Design event rainfall and parameters

The design event rainfall defined by the Intensity-Frequency-Duration (IFD) curves published by the [Bureau of Meteorology] (BoM) were used to generate design rainfall depths for events from 12 hours to 168 hours in duration and from 63.2% AEP to 1 in 2,000 AEP. The BoM IFDs were published in 2016 and best represent the climate period between 1961 and 1990. To represent current climate conditions IFDs were derived via the methodology outlined in the Draft updates to the Climate Change Considerations chapter in Australian Rainfall and Runoff guidelines (DCCEEW 2023). The SSP5-8.5 Current and near-term (2021-2040) scenario was used as it is the climate scenario that best represents emissions to date (Schwalm, et al. 2020) resulting in an increase in rainfall intensity of 12% from the 1961 and 1990 period.

The Generalised Southeast Australia Method (GSAM) (BoM 2003) was used to develop Probable Maximum Precipitation (rainfall event that leads to a Probable Maximum Flood (PMF)) rainfall depth estimates for durations 24 hours to 72 hours.

The Climate Change 1 and 2 scenario IFDs were derived via the methodology outlined in the Draft update to the ARR climate change guidelines (DCCEEW 2023). The resulting increases in rainfall intensity are presented in Table 4-3 from the 1961 and 1990 period.

Initial and continuing losses have been defined through validation to the at-site FFA. For design event modelling the validated losses have been increased to account for the influence of climate which is expected to result in an overall "drying" of catchments change in accordance with DCCEEW (2023). The resulting storm losses are shown in Table 4-3.

Table 4-3 Design event parameter and rainfall inupts

Scenario	Routing Parameters			Storm losses (% increase from calibrated losses)		Increase in rainfall intensity from 2016 IFDs
	k_c (above Woodford)	k_c (below Woodford)	*m*	Initial Loss (mm)	Continuing Loss (mm/hr)	
Current Climate	71	32.8[1]	0.8	16.9 (6%)	0.34 (13%)	12%
Climate Change 1				18.4 (15%)	0.40 (34%)	32%
Climate Change 2				19.0 (19%)	0.43 (44%)	41%

[1.] Constant k_c / d_{av} ratio from Merri River at Woodford gauge interstation area.

4.3.4 Critical events

The critical events (storm duration and temporal pattern) for each AEP were selected using the ensemble modelling approach in RORB and are listed in Table 4-4.

Table 4-4 Critical events

AEP	Current Climate		Climate Change 1		Climate Change 2	
	Critical Duration	Critical Temporal Pattern	Critical Duration	Critical Temporal Pattern	Critical Duration	Critical Temporal Pattern
20%	48 hr	3	48 hr	3	48 hr	3
10%	48 hr	3	48 hr	3	36 hr	9
5%	48 hr	3	48 hr	3	36 hr	9
2%	36 hr	9	36 hr	9	36 hr	9
1%	36 hr	9	36 hr	9	36 hr	9
1 in 200	36 hr	3	36 hr	3	36 hr	3
1 in 500	24 hr	6	24 hr	6	24 hr	6
PMF	24 hr	GSAM	-			

4.4 Storm tide assessment

The southwest Victorian coastline is exposed to strong wave energy from the Indian Ocean. The Merri River opens into Stingray Bay, South Warrnambool, and is provided with partial protection from direct waves by two islands; Merri Island and Middle Island, as well as other undersea features such as rock bommies. Despite this protection, historical storms (e.g., the 2009 and 2014 storm tide events) have shown that attenuated yet significant waves can penetrate the bay causing temporary elevation of water levels due to local wave setup.

Coastal inundation occurs due to extreme sea-levels caused by severe coastal storms. Such storms generate elevated water-levels because of low atmospheric pressure (sometimes referred to as reverse barometric pressure) and strong winds that pile up water towards the coast, with the combined effect referred to as storm surge. Storm surge often coincides with strong waves breaking on the open coast which can also drive increased water-levels at the coastline, known as wave setup. Along with astronomical tide level, these three components make up what is referred to as a storm tide. Figure 4-3 shows a schematic of these processes.

A set of calibrated design storm tide events have been developed to provide boundary conditions to the TUFLOW model in accordance with the guidance provided in the Victorian Guideline for Modelling the Interaction of Catchment & Coastal Flooding (Streamology 2022b).

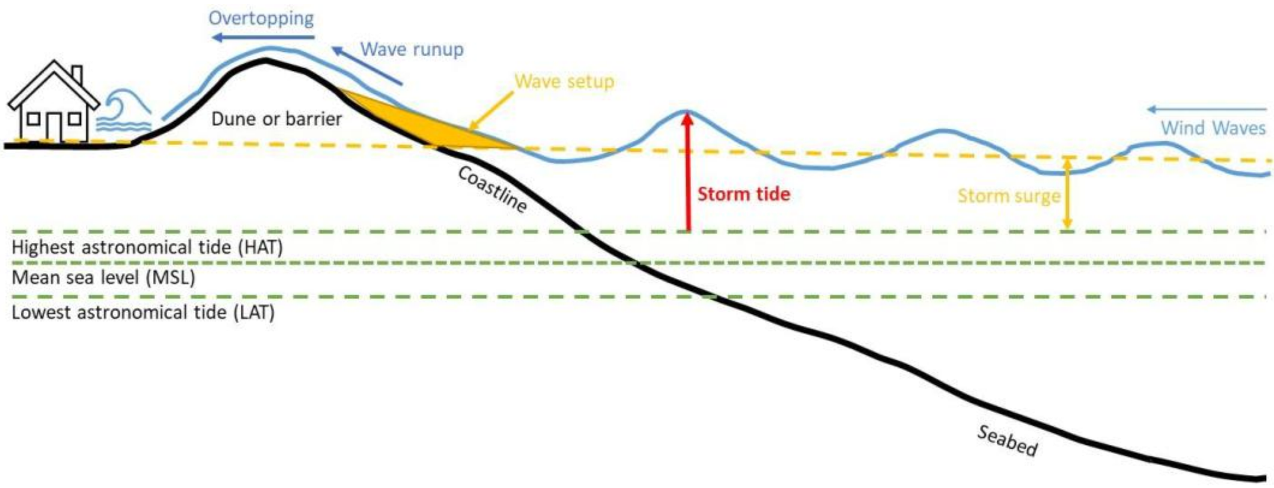


Figure 4-3 Schematic showing the components of a storm tide (Streamology 2022b)

The extreme storm tide levels (and peak wave setup components) that have been prepared for modelling are shown in Table 4-5 with the water-level timeseries for the TUFLOW model shown in Figure 4-4. Calibration to the June 2014 resulted in a wave setup factor of 7% of offshore wave height. This factor was validated to the April 2009.

To estimate worst case storm tide scenario peak, tsunami water levels (maximum stage) from the 2018 Australian Probabilistic Tsunami Hazard Assessment: Hazard from earthquake generated tsunamis (PTHA18) (Davies and Griffin 2018) were used resulting in a tsunami water level estimate of 3.9 m AHD which has been adopted to represent a “worst case” storm tide level for this Study and was applied to the TUFLOW model as static water level, often referred to as the “bathtub” approach. This is because detailed numerical modelling using the offshore maximum-stage heights is required for a detailed tsunami hazard assessment.

Table 4-5 Warrnambool storm tide levels

AEP	Extreme Still Water Level (SWL) (m rel. MSL)	Peak Wave Setup Component (m rel. MSL)	Extreme SWL with Wave Setup (m rel. MSL)
20%	0.85	0.51	1.36
10%	0.92	0.53	1.45
5%	0.98	0.55	1.53
2%	1.05	0.57	1.62
1%	1.10	0.59	1.69
1 in 200	1.14	0.60	1.74
1 in 500	1.19	0.61	1.80

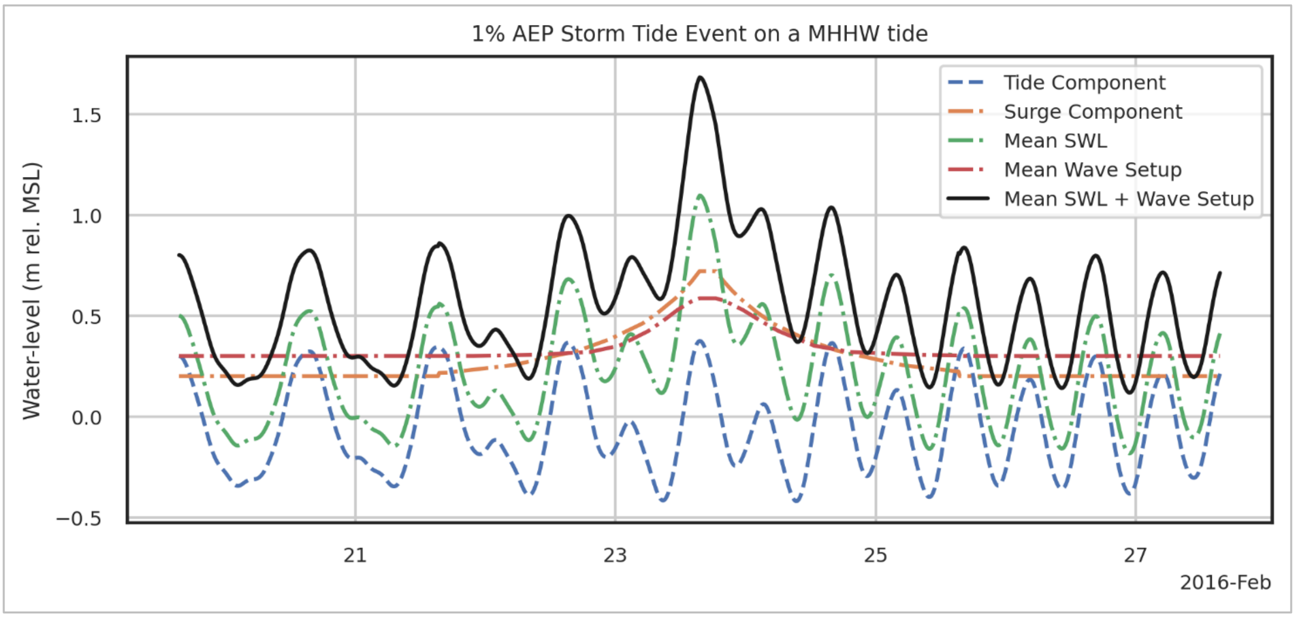


Figure 4-4 1% AEP storm tide time series

4.5 TUFLOW modelling

4.5.1 TUFLOW model development

The TUFLOW model covers the entire Investigation Area extending from upstream of Cassidys Bridge to the coast at Stingray Bay and across Kelly and Salwater Swamps to the coast at Rutledges Cutting. The broad layout of the TUFLOW model can be seen in Figure 4-6.

To ensure accurate representation of flooding within the Investigation Area a grid resolution of 8 metres was adopted for floodplain areas of the model. Along the main Merri River channel and in urban areas quadtree was used to reduce the grid size to 2 metres to increase the fidelity of modelling. These areas can be seen in Figure 4-6. Sub-grid Sampling (SGS) was used with a sample frequency of 9 for the 8 m grid and 7 for the 4 m grid and 5 for the 2 m grids.

The base topography used in the hydraulic model was based on the LiDAR and bathymetry survey DEM datasets as detailed in Section 3.3.

South Warrnambool has two openings to the coast at Stingray Bay and Rutledges Cutting both of which are dynamic being subject to sand deposition and natural and artificial openings resulting in the bathymetry for every riverine or storm tide flood event being unique.

The Merri River mouth at Stingray Bay is primarily open but the bathymetry is dynamic being subject to sand deposition and natural scour which occasionally results in a sand berm closing the mouth. For riverine and storm tide design events the mouth has been modelled under open conditions based on mouth opening conditions representative of the October 2020 flood event.

The Rutledges Cutting opening condition is dynamic being subject to sand deposition resulting in a sand berm that closes the mouth 89% of the time according to Estuary Entrance Management Support System (EEMSS) records. For riverine design events the cutting has been modelled under closed conditions at the start of the event with a berm height of 2.1 m based on the highest berm levels observed in the past. The variable geometry functionality in TUFLOW was used to scour the cutting over a 6 hour period when the berm is overtopped. In the absence of cutting opening bathymetric survey, for design event modelling the scour geometry calibrated for the October 2020 event has been adopted with the scour depths set to the lowest tide level after riverine event flows have overtopped the berm. For storm tide design events the mouth has been modelled under open conditions from the start of the event as occurred in June 2014 to represent a conservative assumption for flood levels through Kelly Swamp. For storm tide events the same opening geometry for riverine events was used with the scour depth set to the lowest tide level in the days prior to the storm surge event.

For the climate change scenarios it was assumed that Merri River mouth geometry remains under current conditions. This is because the mouth is primarily open because of natural flows and artificial openings and if mouth levels were raised commensurate with sea level rise then normal water levels outside of flood events in the estuary could become quite high which is outside the focus of this Investigation. For Rutledges Cutting the berm height was raised commensurate with sea level rise to represent the expected landward and upwards shift of the berm profile as a result of wave runup as schematised in Figure 4-5. The scour depths for future conditions are also commensurate with the level of expected sea level rise with no change in the scour width.

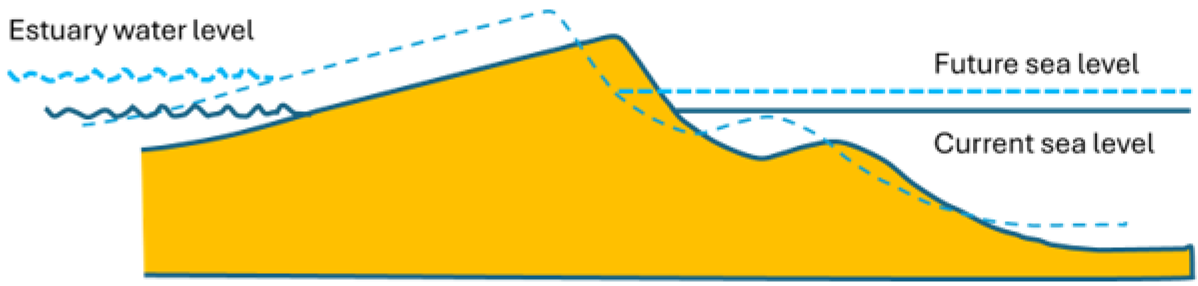


Figure 4-5 Schematic of landward and upward shift in entrance berm profile due to sea level rise (Streamology 2022b)

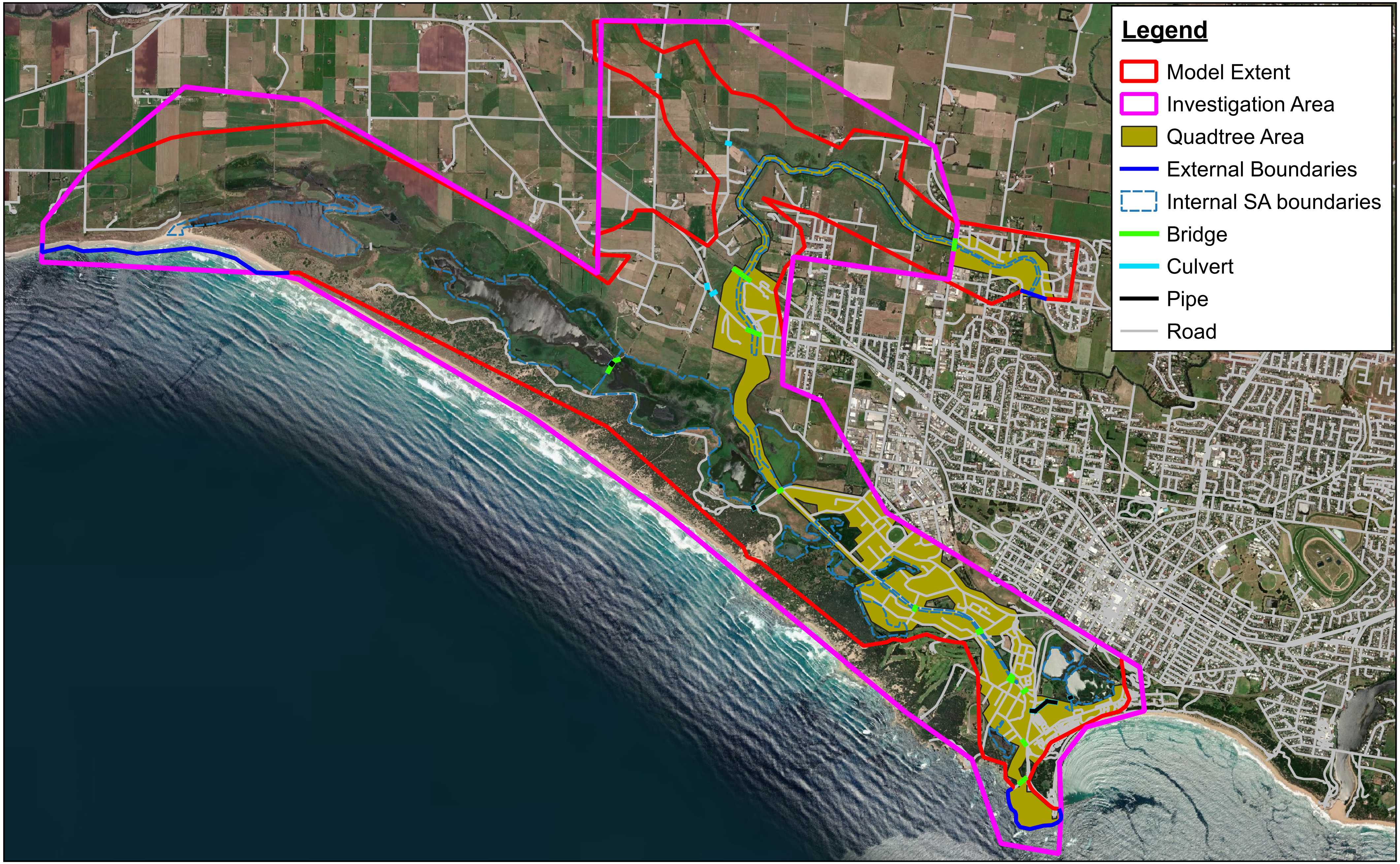
The manning’s ‘n’ surface roughness values for the model were based on areas of different land-use type as indicated in the aerial photography and observed during the site visit. Initially these values were based on standard texts such as Open Channel Hydraulics (Chow 1959) and refined during the calibration process.

Bridge and culvert hydraulic structures along the floodplain were included in the model as shown in Figure 4-6. The bridges were represented in the 2D model domain while culverts were represented as 1D elements embedded in 2D domain.

The TUFLOW model inflow boundaries were determined from the RORB model for the riverine events, and for the storm tide events the adopted riverine inflow boundary represented the mean daily flow between May and September when most storm tides events are expected to occur.

The TUFLOW model outflow boundary was defined by a dynamic tide-height boundaries at Stingray Bay and Rutledges Cutting. For design event modelling the peak tidal level is timed to coincide with the peak of the flood so as to provide a conservative estimate of flood levels by providing a worst case scenario. For the climate change scenarios the whole dynamic tide boundary was raised by the amount of sea level rise being accounted for in each scenario.

Initial water levels in the Merri River were set to the tide boundary height at the start of the simulation. For Kelly and Saltwater Swamps initial water levels were defined by highest level of ponding that could occur in each waterbody before they would drain back to the Merri River. The Lake Pertobe levels were set via advice provided by Council.



Title: South Warrnambool and Dennington Flood Investigation TUFLOW model layout	Figure: 4-6	Rev: A	0 0.8 1.6 km	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	VENANT SOLUTIONS
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4.5.2 TUFLOW model calibration and validation

Historic flood data available to calibrate and validate the TUFLOW model for both riverine and storm tide events includes:

- The recorded water levels at the Merri River at Warrnambool stream gauge (October 2020 event only because the stream gauge has only been operational since 2017)
- Surveyed flood marks (October 2020, March 1946 and June 2014 events)
- Observed flood extents (October 2020, June 2014 and April 2009 events)
- Flood photography captured during the event (all events)
- Estuary Entrance Management Support System (EEMSS) records (October 2020, June 2014 and April 2009 events)

For the October 2020 riverine event the successful calibration achieved confirmed the revised flow estimates at the Merri River at Woodford gauge (refer to Section 3.4.1) that the RORB hydrologic model was calibrated to are appropriate. It also confirmed that the TUFLOW model is appropriate for representing riverine flood events in Dennington and South Warrnambool. The October 2020 calibration also highlighted the sensitivity of the Rutledges Cutting opening geometry on peak flood levels in South Warrnambool.

While it is difficult to draw conclusions from TUFLOW model validation to the March 1946 event because of the more than 70 years that have passed during which time significant changes in catchment topography, hydraulic structures and surface roughness have occurred, it does show the extent of inundation that has occurred in the past and will at some stage happen again.

For the June 2014 riverine calibration event successful calibration confirmed an offshore wave height factor of 7% is appropriate for Warrnambool and that the TUFLOW model is appropriate for representing storm tide events without detailed wave modelling in Stingray Bay. It also showed that the 7% factor is appropriate at Rutledges Cutting. When the standard assumption of 12% was tested it erroneously resulted in flow from Rutledges Cutting through the swamp system and down the Merri River cutting where the EEMSS records documented that flow was travelling up the Merri River cutting into the swamp system. The 7% offshore wave height factor was confirmed by the successful validation of the April 2009 event.

4.6 Treatment of joint probability

Flood risk in South Warrnambool results from a combination of riverine and storm tides. The joint probability (or dependence) of these events occurring separately or simultaneously needs to be assessed.

Book 6, Chapter 5 of ARR provides practical methodologies for assessing the interaction of riverine and storm tide flooding in coastal regions. The first step recommended prior to detailed assessment consists of a pre-screening analysis to determine whether completion of a more complex joint probability assessment is warranted. For the pre-screening analysis, it is required to identify the Joint Probability Zone (JPZ); defined as being a '*region in which the dependence between riverine and ocean processes has the potential to influence the design flood level*'. The concept of the JPZ is illustrated in Figure 4-7.

For this Investigation the JPZ is defined as the area between flood levels of a riverine flood event with a MHHW tide (fluvial-only), a storm tide event with May to September median daily riverine flows (ocean-only) and riverine event with the corresponding occurrence probability storm tide event (complete dependence) above a tolerance of 0.3 m. The primary assumption of this assessment is that peak riverine flood flows at South Warrnambool occur at the same time as the peak storm tide level. This is a conservative assumption as riverine event peaks are unlikely to occur at the same time as the peak storm tide from the same weather event.

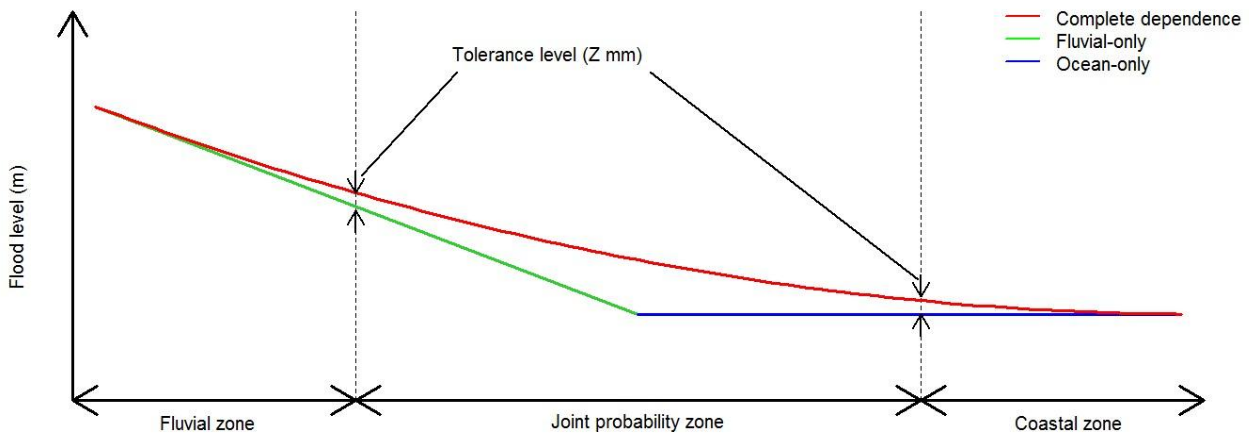


Figure 4-7 Illustration of Joint Probability Zone (Ball, et al. 2019)

The results of the joint probability assessment show that across all modelled climate scenarios and events peak flood levels downstream of MacDonald Street are dominated by storm tides and peak flood levels upstream of Wellington Street are dominated by riverine events with the JPZ between MacDonald Street and Stanley Street. Given the relatively weak dependence between riverine and storm tide flooding and modelling very frequent events (more frequent than 20% AEP) is beyond the scope for this Investigation, for the purposes of creating flood mapping and intelligence information for emergency response and other uses that do not overestimate flood levels, independent riverine and storm tide events have been adopted.

For the purpose of flood planning control levels and extents (Section 7) the joint probability assessment showed that the 1% AEP riverine event a with 20% AEP storm tide boundary provided the closest match to the 1% AEP flood levels in the JPZ.

4.7 Quality assurance and sensitivity testing

The hydrologic and hydraulic modelling was internally reviewed at Venant Solutions by a registered professional engineer in Victoria. The flood modelling was also independently peer reviewed by a third party consultant engaged by the Council and GHCMA. The reviewers' comments regarding modelling methods, setup, parameters, assumptions and results were documented in a Technical Note provided to Venant Solutions, Council and GHCMA and have been addressed in the development of flood modelling presented in this report.

To better understand the level of uncertainty associated with the adopted flood modelling parameters, sensitivity analysis has been undertaken on the following parameters:

- The critical storm duration
- Rainfall temporal patterns
- The spatial rainfall variation across the catchment
- The RORB model routing parameters
- Storm losses (antecedent catchment conditions)
- Adopted surface roughness parameters
- Rutledges Cutting mouth opening geometry
- Rutledges Cutting berm height and scour times
- The adopted storm tide event wave setup factor
- Bridge blockage

5 Flood mapping and intelligence outputs

This section provides a summary of key flood mapping and intelligence information (flood behaviour characteristics that are not represented by flood mapping) that is used to inform the key outputs of the study including:

- Draft planning overlay mapping
- Flood damages assessment
- Flood warning feasibility assessment
- Inputs into the Municipal Flood Emergency Plan (MFEP) and any other subsequent flood intelligence information / documentation

Whilst in this summary report a limited selection of flood mapping and intelligence outputs is presented, these outputs have been developed for all of the design event scenarios presented in Table 4-1. Please note, that as described in Section 1.4 only the inputs and results of Climate Change 2 scenario have been documented in this summary report.

Mapping is limited to the Investigation Area and does not include mapping of local storm water runoff behaviour or drainage systems.

5.1 Flows and hydrographs

The design event peak flows and volumes at Cassidys Bridge for current climate and Climate Change 2 scenario are presented in Table 5-1. Current climate hydrographs are presented in Figure 5-1 and Climate Change 2 comparison hydrographs are presented in Figure 5-2.

Under current conditions in a 1% AEP riverine event approximately 88% of the Merri River flow discharges to the coast via Rutledges Cutting with only 12% of flow discharging to Stingray Bay via the Merri River Cutting.

For the Climate Change 2 scenario peak flows are increased by 34-36%. As shown in Table 5-1 for the Climate Change Scenario 2 more frequent events up to the 5% AEP are equivalent to the next assessed less frequent event peak when compared to current climate. For rarer events the increase is slightly larger. For example, the 1% AEP Climate Change 2 peak flow is similar to the current climate 1 in 250 AEP peak flow. Similar percentage increases in hydrograph volume as for peak flow are observed.

Table 5-1 Flows and volumes at Cassidys Bridge

AEP	Current Climate		Climate Change 2			
	Peak Flow (m^3/s)	Hydrograph Volume (m^3)	Peak Flow (m^3/s)	Peak flow increase	Hydrograph Volume (m^3)	Volume increase
20%	241	4.36×10^7	325	35%	5.63×10^7	29%
10%	335	5.80×10^7	454	36%	7.00×10^7	21%
5%	445	7.44×10^7	600	35%	8.87×10^7	19%
2%	616	9.11×10^7	824	34%	1.17×10^8	28%
1%	765	1.10×10^8	1,017	33%	1.40×10^8	27%
1 in 200	964	1.34×10^8	1,277	32%	1.71×10^8	28%
1 in 500	1,221	1.55×10^8	1,632	34%	1.97×10^8	27%
PMF	5,246	5.36×10^8	-			

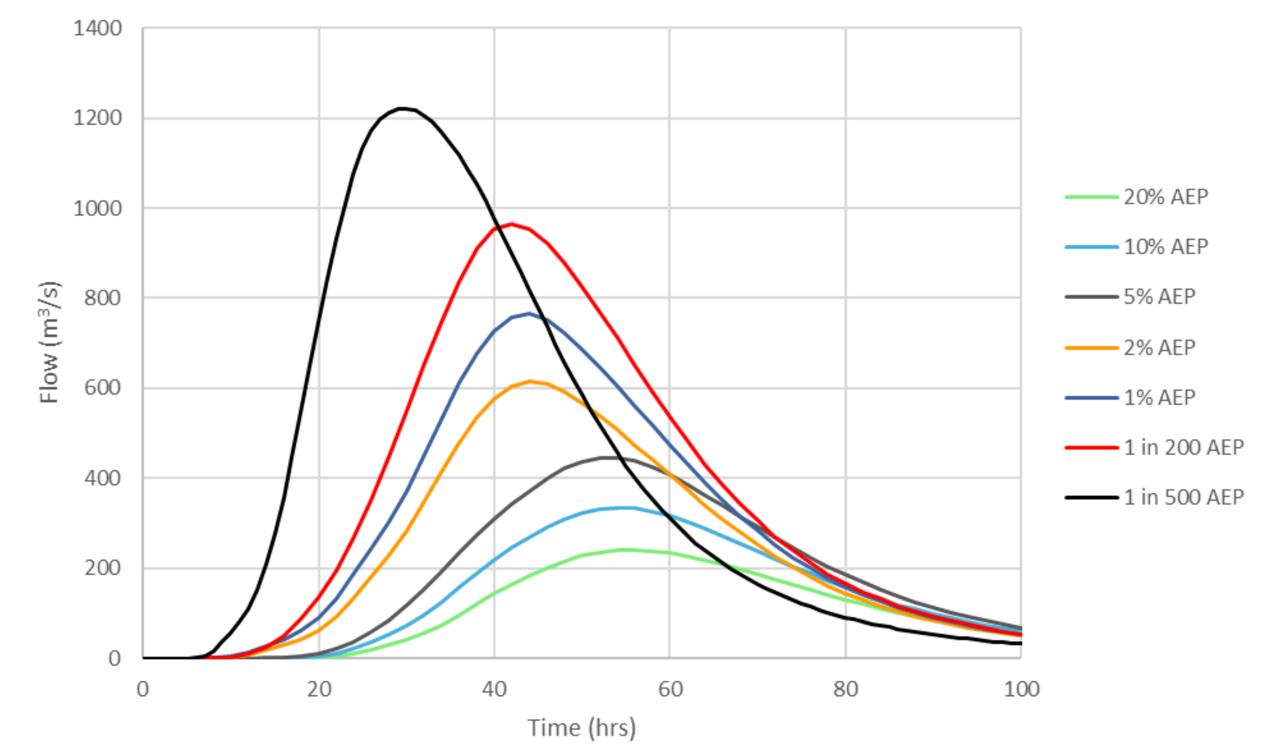


Figure 5-1 Current climate hydrographs at Cassidys Bridge

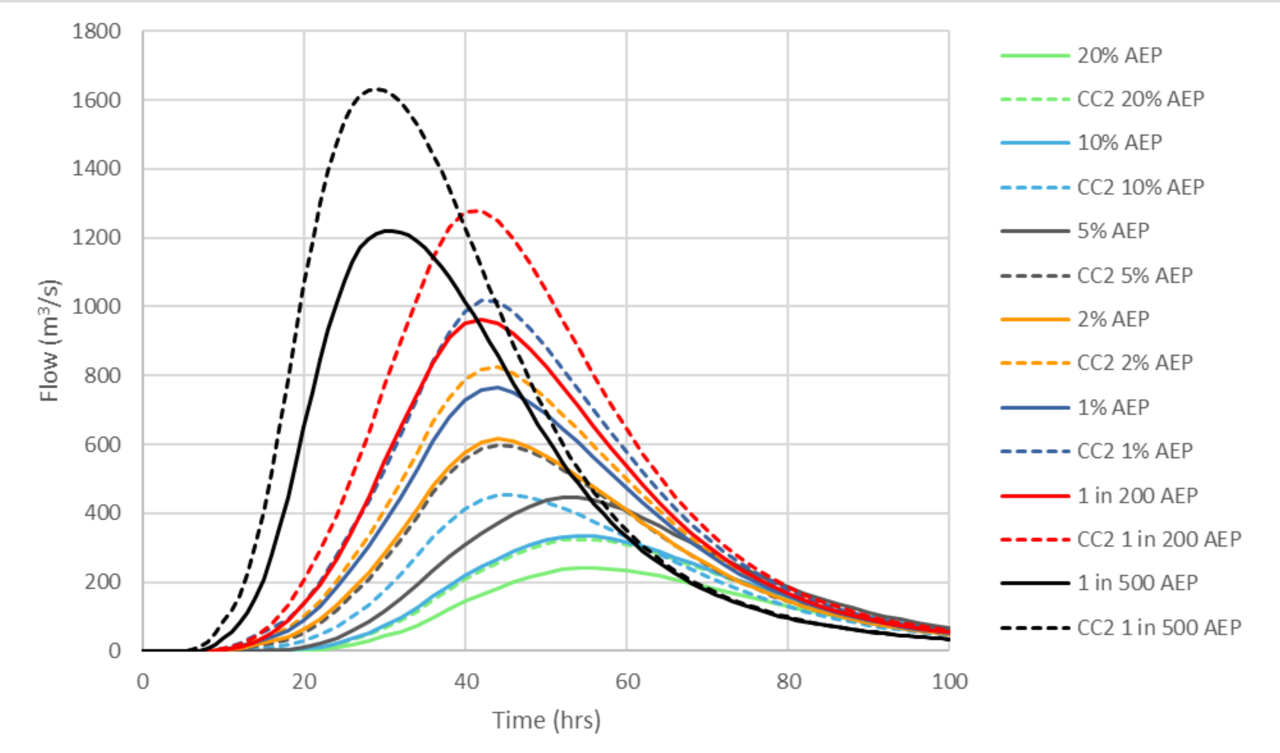


Figure 5-2 Climate Change 2 hydrographs at Cassidys Bridge

5.2 Flood depth mapping

Flood depth mapping is presented in Appendix A for the 1% AEP riverine and storm tide events under Current Climate and Climate Change 2 scenarios. The flood depth mapping shows that inundation throughout South Warrnambool is quite broad but generally restricted to the floodplain reserve areas. However, there are residential areas that are subject to inundation including along Stanley Street and MacDonald Street, near the intersection of Elliott Street and Mcgennan Street, along Wellington Street, Younger Street, Landmann Street and other isolated properties.

5.3 Flood velocity mapping

Flood velocity mapping is presented in Appendix B for the 1% AEP riverine and storm tide events under Current Climate and Climate Change 2 scenarios. In riverine events velocities across the floodplain are generally less than 0.5 m/s. In the Merri River channel velocities are higher and largest where the channel becomes most restricted. At the Princes Highway, MacDonald Street and the Merri River mouth velocities exceed 2.0 m/s. These locations correspond with the locations where the greatest drops in water level are observed as described in Section 5.5. In storm tide events velocities across the floodplain are generally less than 0.5 m/s with the exception of a few limited areas in the Merri River channel.

5.4 Flood hazard mapping (velocity x depth product)

Flood hazard (velocity x depth) mapping is presented in Appendix C for the 1% AEP riverine and storm tide events under Current Climate and Climate Change 2 scenarios. In riverine events velocity x depth upstream of the Princes Highway are generally greater than 0.3 m^2/s which is considered hazardous for vehicles and people. Downstream of the Princes Highway through South Warrnambool higher velocity x depths are restricted to the Merri River channel and areas of greater depth. In storm tide events velocity x depths across the floodplain are generally less than 0.3 m^2/s with the exception Merri River cutting channel downstream of Swinton Street.

5.5 Flood levels

Peak flood levels at the Merri River at Woodford, Merri River at Dennington and Merri River at Warrnambool stream gauges are presented in Table 5-2.

Figure 5-3 shows a long-section of flood levels along the Merri River for riverine events. As shown in Figure 5-3 the water level grade in the riverine events through Dennington is relatively constant before there is a significant drop in water level as the floodplain narrows near the Princes Highway. The water level grade then flattens off as it flows into the South Warrnambool floodplain and Kelly Swamp. Further downstream as the Merri River Cutting flows through several points of constriction the water grade steps down to the Merri River mouth at Stingray Bay with the most notable constriction point been the narrow channel at MacDonald Street.

Figure 5-4 shows a long-section comparison of 1% AEP climate change scenario and previous South Warrnambool (Water Technology 2007a) and Dennington (Water Technology 2007b) flood levels. The 1% AEP current climate levels are approximately 0.5 to 0.8 m higher through South Warrnambool and 0.8 to 1.3 m higher through Dennington than the 2007 studies where the 1% AEP water levels were similar to the October 2020 event that had rainfalls consistent with approximately a 36 hour 15% AEP event. This indicates that flood levels were being underestimated in the 2007 studies. Climate Change 2 riverine event water levels are approximately 0.6 m higher than current climate conditions through South Warrnambool with greater increases upstream of the Princes Highway. This is approximately equivalent to the current conditions 1 in 350 AEP event.

As shown in Figure 5-5 the water levels up the Merri River during storm tide events drop off from the levels at the Stingray Bay as water travels up the Merri River cutting before flattening off upstream of Swinton Street. Increases in 1% AEP Climate Change 2 flood levels (Figure 5-6) is consistent with the amount of sea level rise but higher sea levels mean that water is able to flow through the swamps from Ruteledges Cutting resulting in the drop in water levels along the Merri River cutting not being as pronounced.

Table 5-2 Flood levels (m AHD)

Event (AEP)	Riverine						Storm tide			
	Merri River at Woodford gauge[1]		Merri River at Dennington gauge[1]		Merri River at Warrnambool gauge		Merri River at Dennington gauge[1]		Merri River at Warrnambool gauge	
	Current Climate	Climate Change 2	Current Climate	Climate Change 2	Current Climate	Climate Change 2	Current Climate	Climate Change 2	Current Climate	Climate Change 2
20%	12.90 (7.04)	13.48 (7.62)	2.81 (2.92)	3.56 (3.67)	0.78	1.66	1.04 (1.15)	2.30 (2.41)	1.36	2.53
10%	13.54 (7.68)	14.18 (8.32)	3.12 (3.23)	3.73 (3.84)	0.92	1.68	1.08 (1.19)	2.40 (2.51)	1.45	2.60
Apr 2009							0.99 (1.1)		1.48	
Oct 2020	14.00 (8.14)[2]		3.23 (3.34)		0.97[2]					
5%	14.10 (8 .24)	14.73 (8.87)	3.44 (3.55)	3.95 (4.06)	1.07	1.71	1.10 (1.21)	2.48 (2.59)	1.53	2.65
Jun 2014							1.00		1.56	
2%	14.79 (8.93)	15.38 (9.52)	3.83 (3.94)	4.43 (4.54)	1.23	1.80	1.13 (1.24)	2.57 (2.68)	1.61	2.71
1%	15.23 (9.37)	15.82 (9.96)	4.17 (4.28)	4.81 (4.92)	1.37	1.91	1.15 (1.26)	2.64 (2.75)	1.68	2.75
Mar 1946	15.46 (9.60)		4.21 (4.32)		1.44					
1 in 200	15.68 (9.82)	16.27 (10.41)	4.59 (4.7)	5.28 (5.39)	1.55	2.08	1.17 (1.28)	2.70 (2.81)	1.73	2.79
1 in 500	16.18 (10.32)	16.79 (10.93)	5.04 (5.15)	5.78 (5.89)	1.81	2.29	1.19 (1.30)	2.77 (2.88)	1.8	2.89
PMF (Tsunami)	21.35 (15.49)		9.78 (9.89)		4.06		3.91 (4.02)		3.9	

[1.] Levels in gauge datum presented in parentheses.

[2.] Recorded flood level at stream gauge.

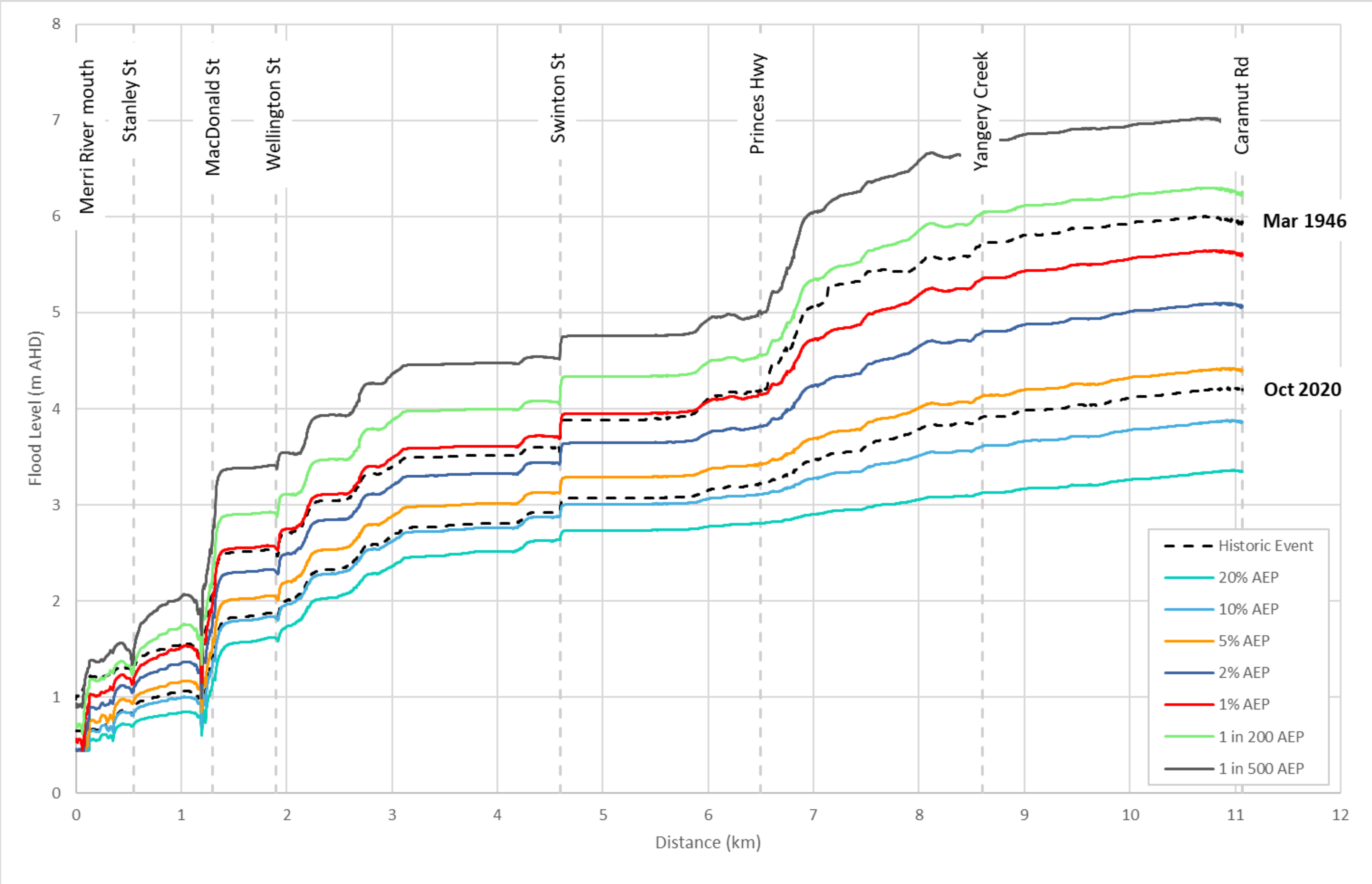


Figure 5-3 Riverine event flood level long-section

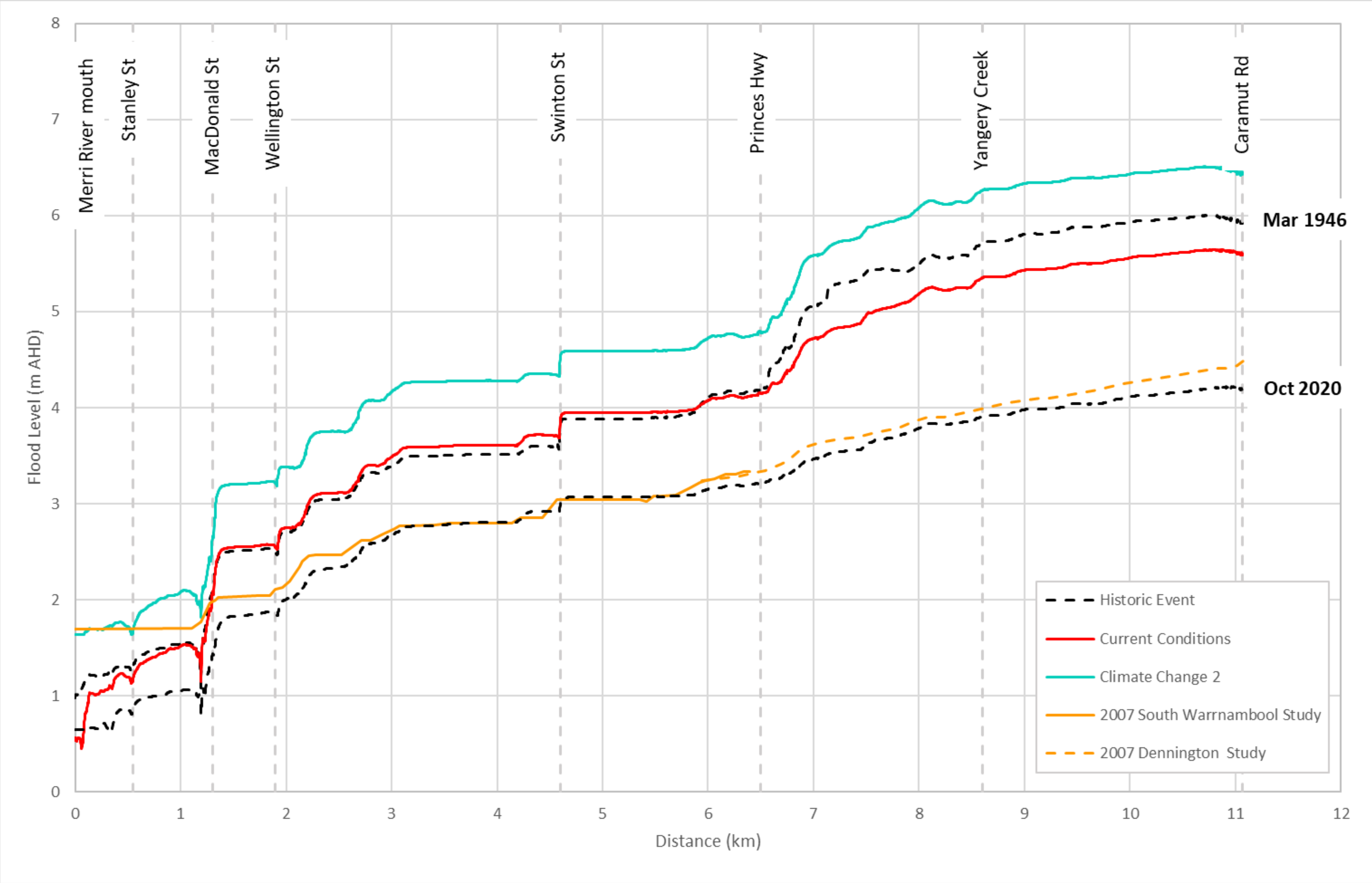


Figure 5-4 Riverine event 1% AEP flood level long-section scenario comparison

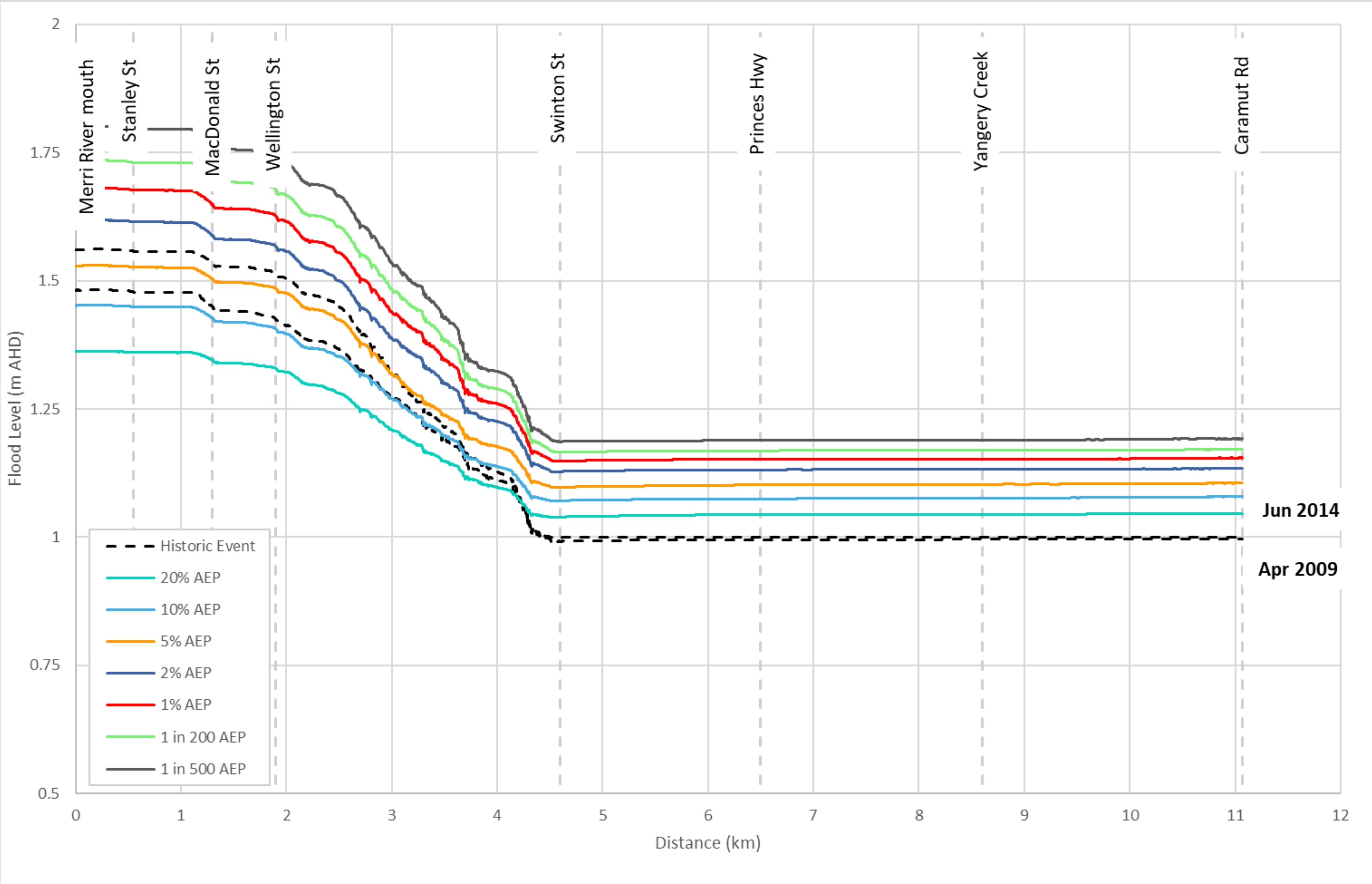


Figure 5-5 Storm tide event flood level long-section

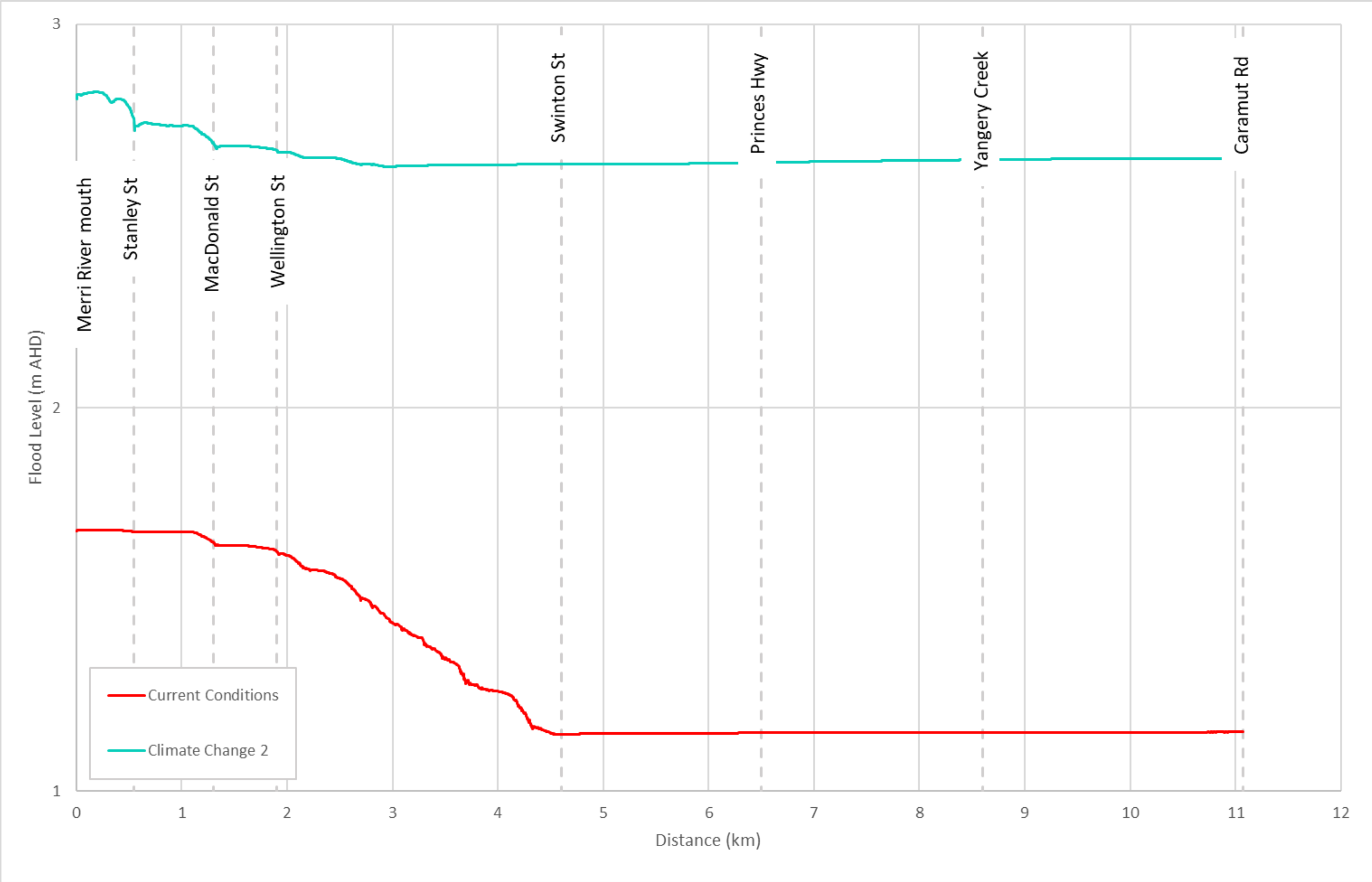


Figure 5-6 **Storm tide event 1% AEP flood level long-section scenario comparison**

5.6 Property and building inundation

Counts of properties with flooding within their boundary and buildings with flooding above the floor level for riverine and storm tide events are shown in Table 5-3. Inundated properties and buildings are also shown in the depth mapping (Appendix A). The inundated buildings include residential buildings and commercial and industrial buildings. Caravan park cabins, sheds and garages associated with residential properties and pump stations are not included in Table 5-3. However, for emergency response purposes the caravan park cabins inundated are shown on the depth mapping.

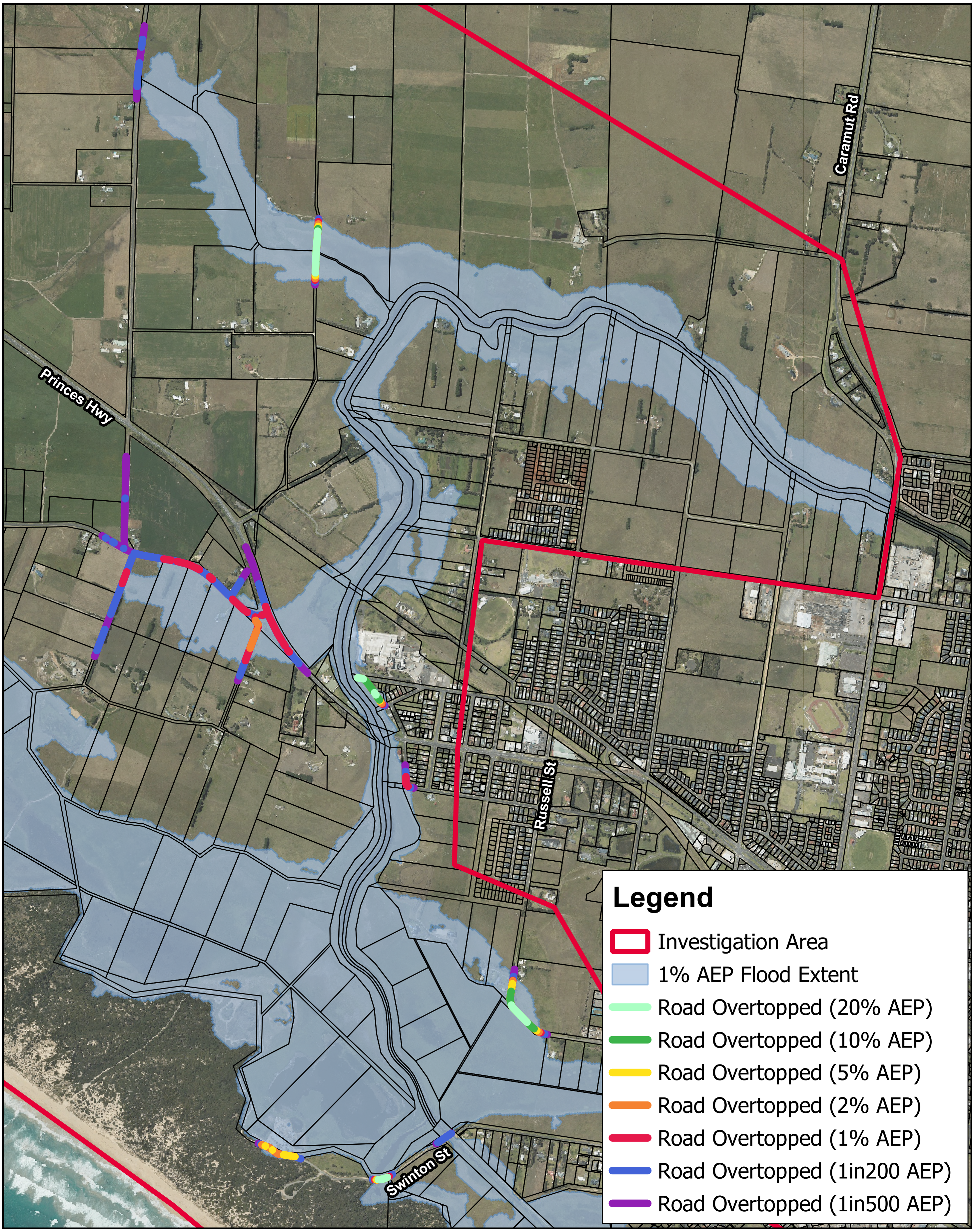
Properties zoned Public Park and Recreation (PPRZ) and Public Conservation and Resource (PCRZ) have been removed from the inundated properties counts. Properties within transport reserves and within the waterways have also been removed.

Table 5-3 Inundated properties and buildings with above floor flooding

Event (AEP)	Current Climate				Climate Change Scenario 2			
	Riverine		Storm Tide		Riverine		Storm Tide	
	Property	Building above floor flooding	Property	Building above floor flooding	Property	Building above floor flooding	Property	Building above floor flooding
20%	220	0	142	0	343	7	318	55
10%	243	0	154	0	362	9	325	58
5%	272	2	169	1	387	20	374	62
2%	336	9	183	2	483	55	396	65
1%	379	25	196	2	560	97	403	68
1 in 200	478	61	200	3	613	137	415	70
1 in 500	569	109	211	3	752	180	426	71
PMF / Tsunami	1093	245	627	122				

5.7 Road inundation

Inundated roads for current climate are shown in Figure 5-7 to Figure 5-12. Road sections are coloured by the smallest event at which overtopping occurs. Inundated roads that are inundated by less than 0.05 m are excluded.



Title:

South Warrnambool and Dennington Flood Investigation - Current Climate
Riverine events inundated roads (North)

Figure:	Rev:			By: TL	
5-7	A	0 0.35 0.7 km	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	Date: Feb 2025	VENANT SOLUTIONS www.venantsolutions.com.au

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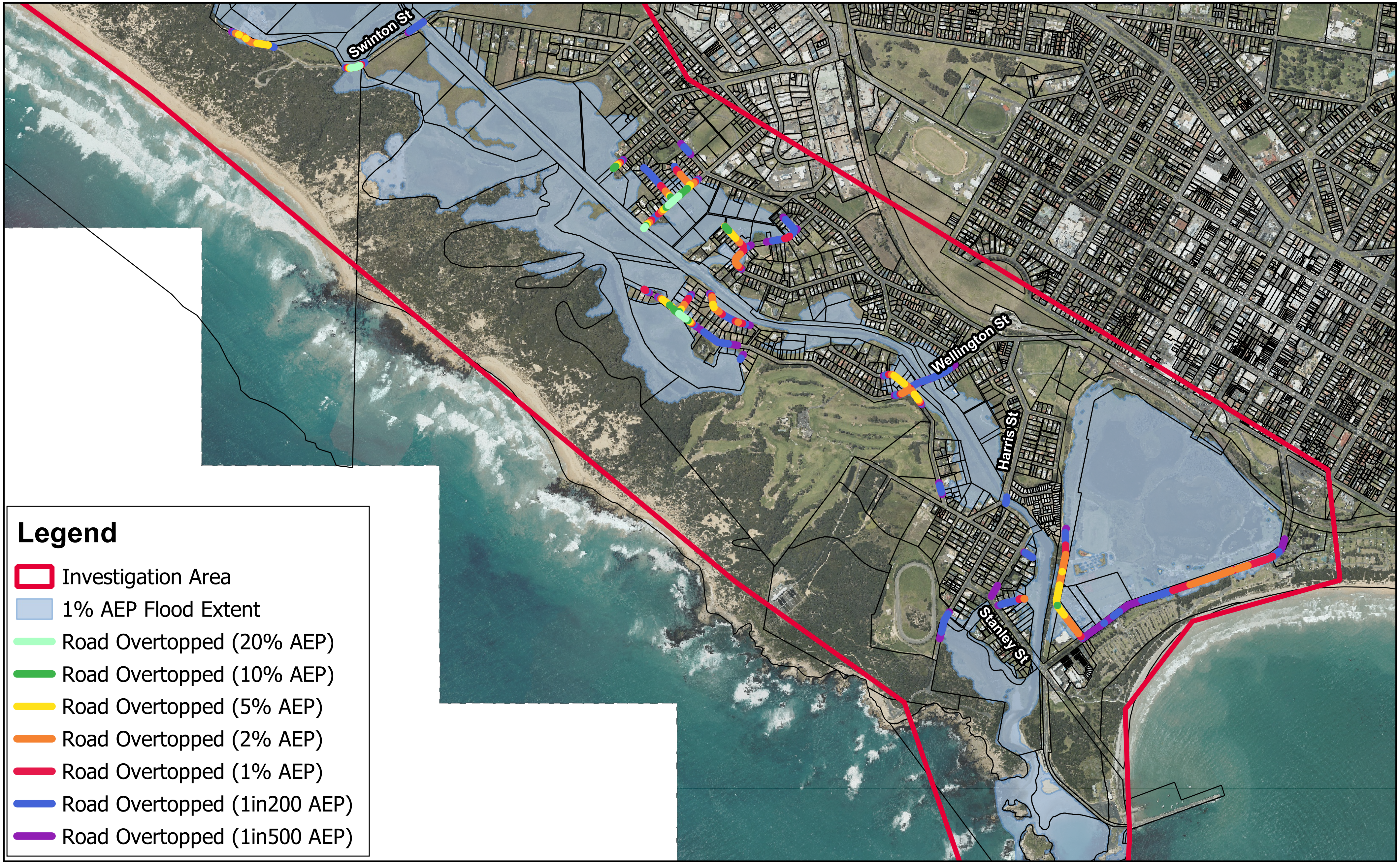

Title:
South Warrnambool and Dennington Flood Investigation - Current Climate
Riverine events inundated roads (East)

Figure: 5-8

Rev: A

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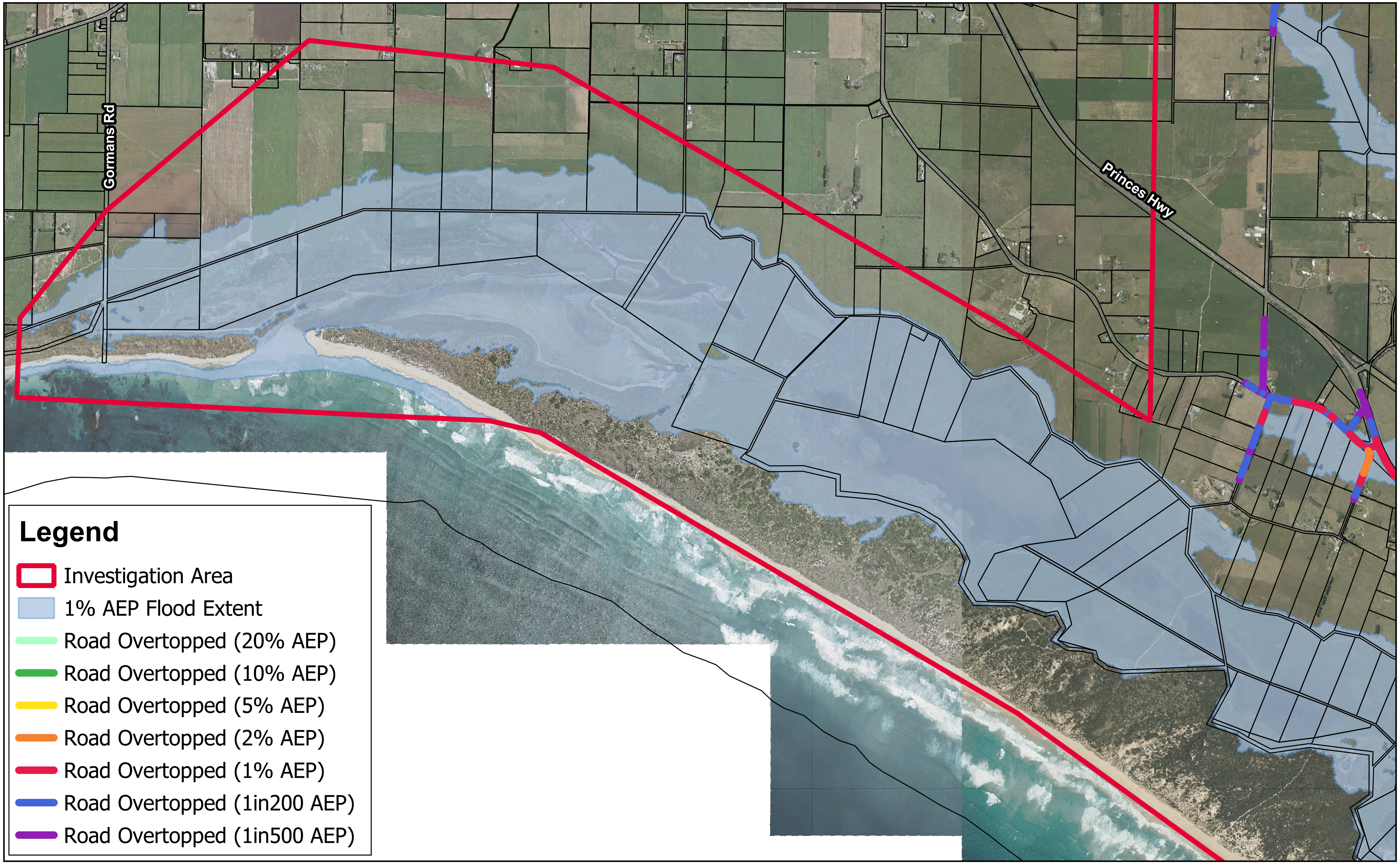
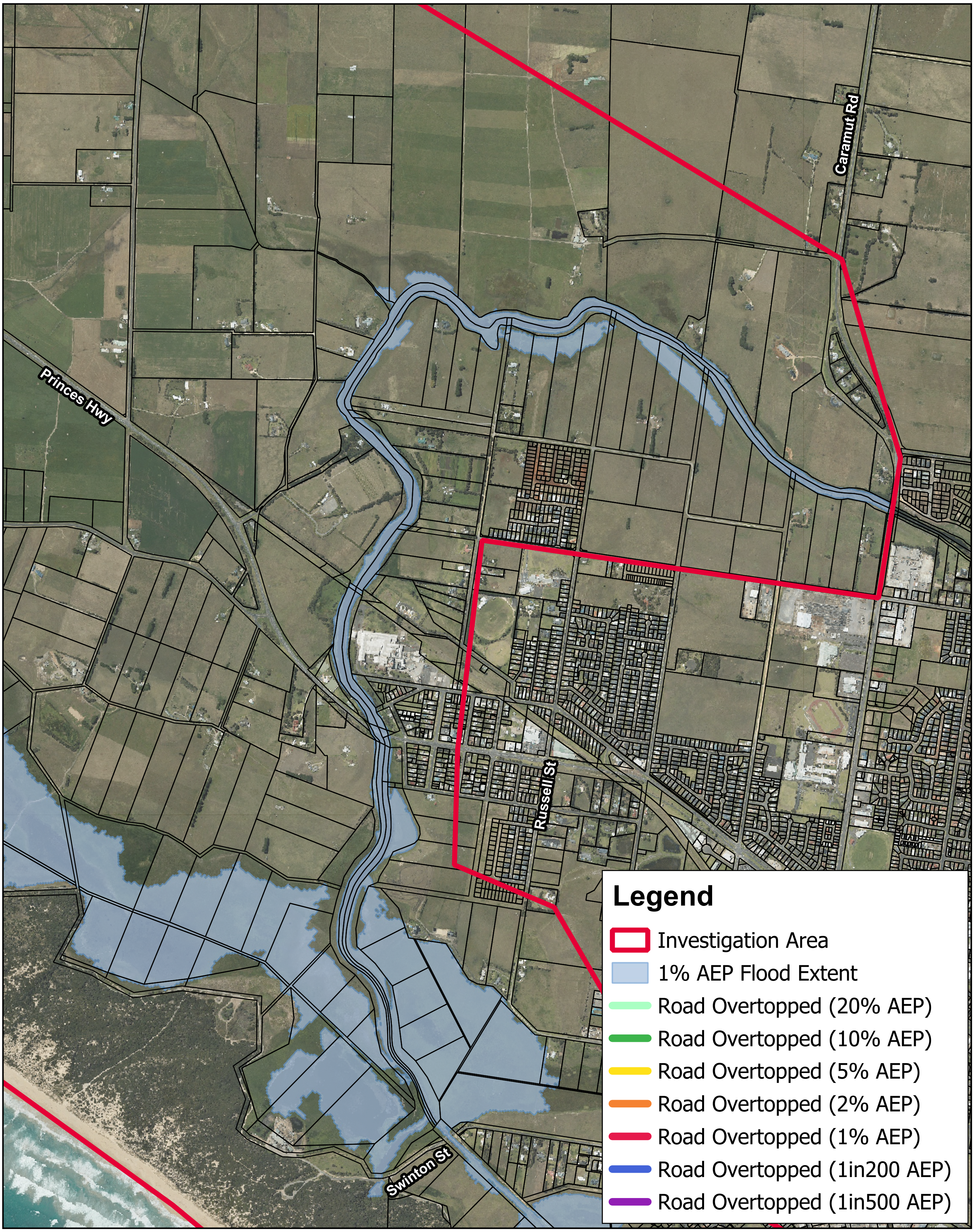


Title: South Warrnambool and Dennington Flood Investigation - Current Climate Riverine events inundated roads (West)	Figure: 5-9	Rev: A	0 400 800 m	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	VENANT SOLUTIONS
Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\Fig5-9_SWFS_RIV_Inundated_Roads_West.qgz				By: TL	Feb 2025 www.VenantSolutions.com.au



Title:

South Warrnambool and Dennington Flood Investigation - Current Climate
Storm Tide events inundated roads (North)

Figure:	Rev:	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	By: TL
5-10	A		Date: Feb 2025

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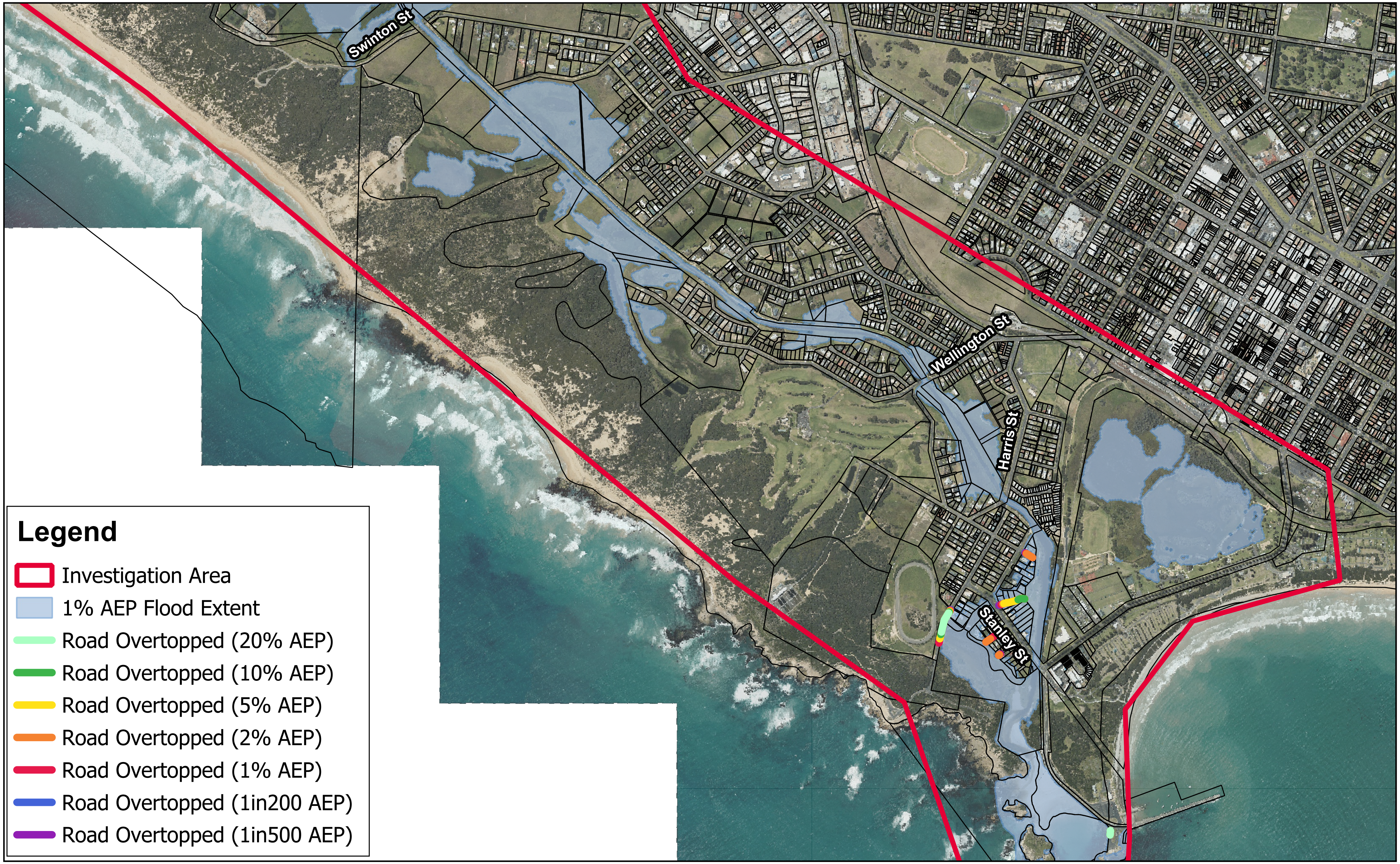

Title: South Warrnambool and Dennington Flood Investigation - Current Climate Storm Tide inundated roads (East)

Figure: 5-11

Rev: A

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

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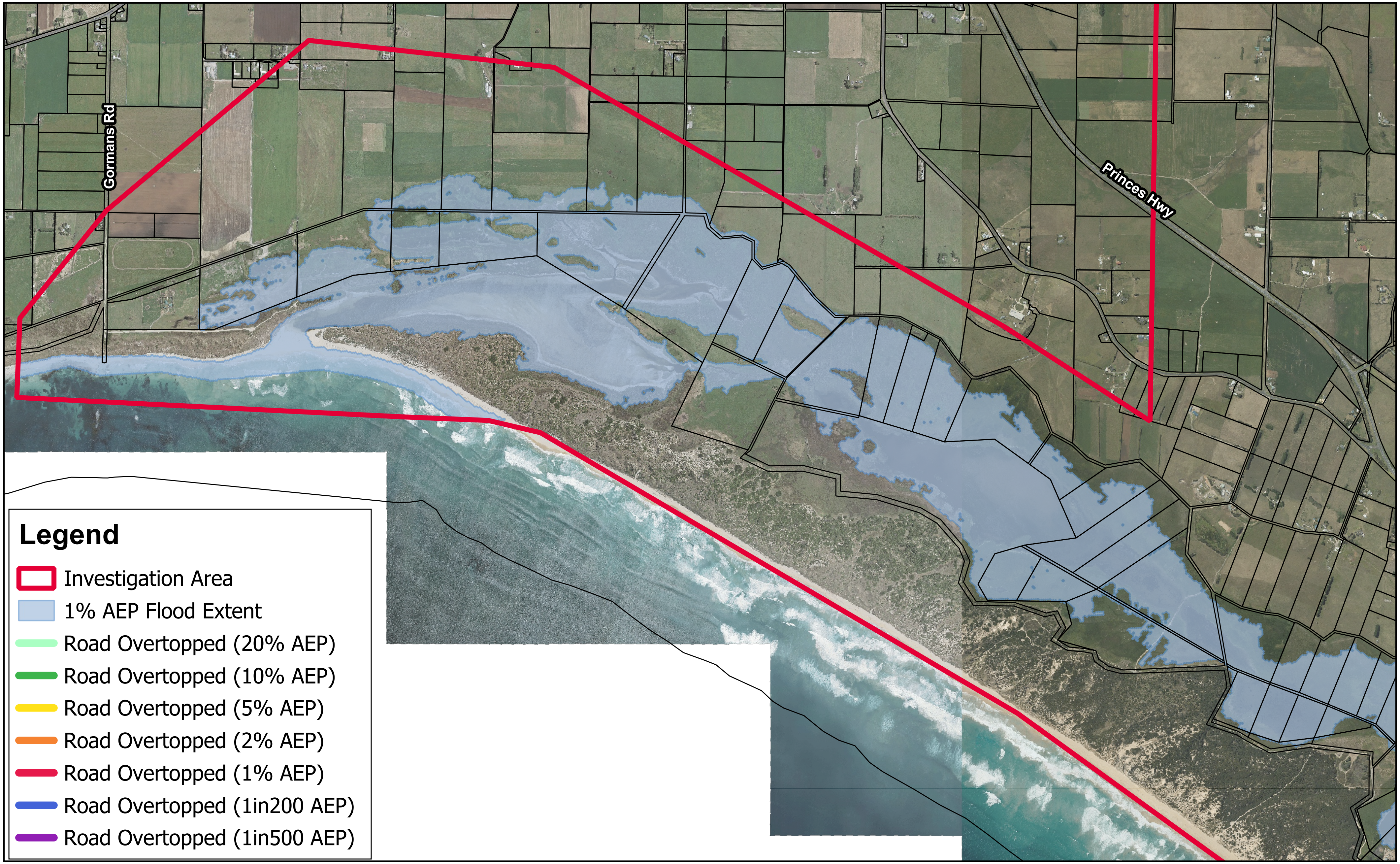

Title: South Warrnambool and Dennington Flood Investigation - Current Climate Storm Tides inundated roads (West)

Figure: 5-12

Rev: A

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

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Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.01\Fig5-12_SWFS_TIDE_Inundated_Roads_West.qgz

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5.8 Travel times

From the start of rainfall it typically takes approximately 10-20 hours for water levels in the Merri River to start rising significantly in Dennington and South Warrnambool. However, this time can be significantly reduced if heavy rainfalls occur over the lower catchment resulting in high flows from tributaries such as Russell Creek and Yangery Creek.

Flood peaks at Woodford typically occur 1-2 days from the start of rainfall in the mid/upper catchment reaching Dennington (Princes Highway) 5-6 hours later and then South Warrnambool (Stanley Street) another 6-10 hours later depending on tide heights.

Table 5-4 presents the estimated travel times relative to start of rainfall in the mid/upper catchment. It should be noted that these travel times are similar to those currently presented in Appendix B of the MFEP.

The travel times can vary significantly for individual flood events as a result of several factors including:

- Antecedent conditions - Catchment antecedent (wetness) conditions (including waterway baseflow) altering the time to convert rainfall to runoff
- Storm durations - Intense short duration storms are likely to result in shorter travel times than longer less intense storms
- Temporal patterns - The time distribution of rainfall within a storm event can alter the travel times
- Spatial patterns - The location of storm in the catchment can alter travel times. For example, a storm centred over the upper catchment is likely to have a longer travel time than a storm centred over the Russell Creek in the lower catchment

Table 5-4 Estimated travels times

Location from	Location to	Typical travel time	Comments	Duration
Start of rainfall (upper catchment)	Woodford	1-2 days	To peak, begins steep rise after 10-20 hours	1-2 days
Woodford	Dennington (Princes Hwy)	5-6 hours	To peak, may begin to rise earlier than 10-20 hours if rainfall over lower catchment results in flooding from Russell Creek	
Dennington (Princes Hwy)	South Warrnambool (Stanley Street)	6-10 hours	To peak, dependent on tide levels	

6 Flood damages assessment

This section summaries the methods used to calculate the Average Annual Damage (AAD) estimate for the Study Area of $625,000 for riverine events and $101,000 for storm tide events resulting in a combined AAD estimate $726,000.

Quantification of flood damages enables floodplain managers and decision makers to gain an understanding of the monetary cost of flooding. For this assessment the flood damages are presented as AAD which is the average flood damage in monetary terms per year that would occur over a long period of time.

As shown in Figure 6-1 flood damages can be categorised as either direct or indirect damages. Direct damages comprise the physical impact of the flood, for example, damages to structure and contents of buildings, agricultural enterprises and regional infrastructure. Indirect damages comprise losses from disruption of normal economic and social activities that arise because of flooding; for example, costs associated with emergency response, clean-up, community support, as well as disruption to transport, employment and commerce.

Further, depending on the difficulty of assigning a monetary value, damages can also be categorised as tangible or intangible. Tangible flood damages are those which can easily be assigned a monetary value such as damages to buildings. Intangible flood damages are those which cannot be easily assigned a monetary value such as environmental and social costs.

Potential flood damages can be reduced by actions taken during the warning time available in response to a flood event referred to as actual damages.

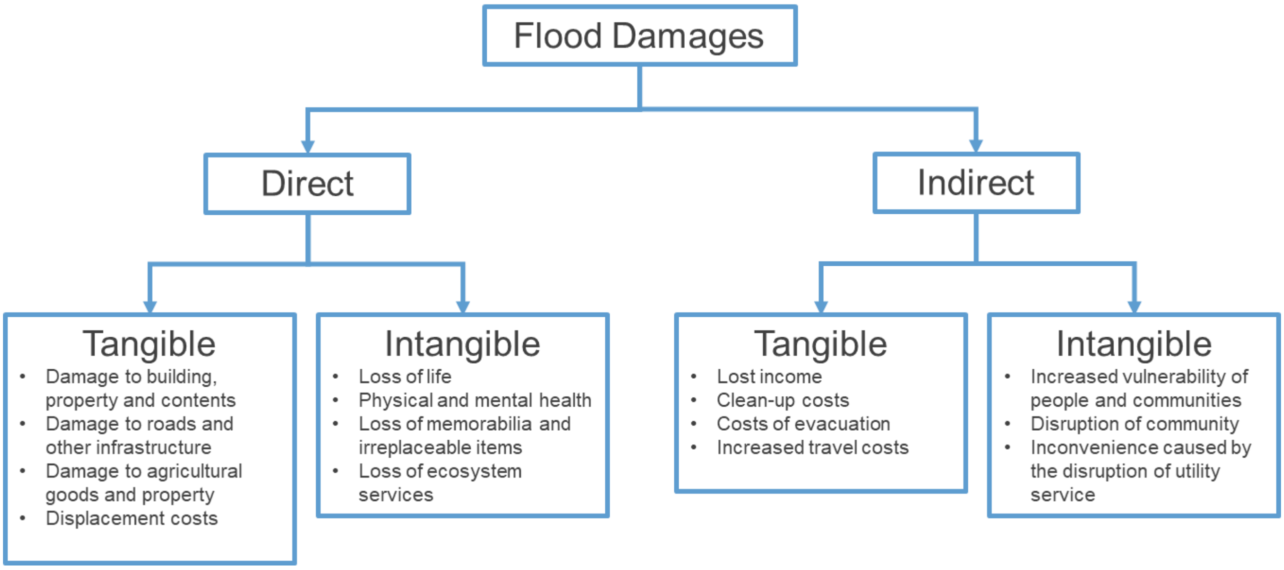


Figure 6-1 Categories of flood damage

6.1 Economic inputs

The following economic input data, indexed to a monetary value relative to that at the end of the September quarter of 2024, were used as inputs into the damage calculations:

- **Building and property damages**
  - **Residential direct damages** – Residential direct damages are comprised of several aspects; structural damage, contents damage, external (property) damage and relocation costs.
    The inundation depth-damage curves for residential buildings which include structural and contents damages were sourced from the NSW Department of Planning and Environment's Flood risk

management measures: Flood risk management guideline MM01 (DPE 2023) factored for the Warrnambool Local Government Area.

External damages were applied to each residential property with a building on it when inundated above 0.3 m as recommended in DPE (2023).

Relocation costs are based on the June 2024 quarter median rental rates for regional Victoria published by the Department of Families, Fairness and Housing applied via an inundation depth-relocation duration curve provided in the Flood Damage Assessment FRM Tool DT01 developed by the NSW Department of Planning and Environment

    - **Commercial and industrial building direct damages** - Commercial and industrial building direct damages are comprised of structural and contents damage. The inundation depth-damage curves for commercial and industrial buildings were sourced from DPE (2023)
    - **Public building damage** - Public building direct damages are comprised of structural and contents damage. The inundation depth-damage curves for public buildings were sourced from DPE (2023) and are classified in three categories; schools, hospitals and other public buildings

- **Road and other infrastructure damages** - Road damages were defined by Rapid Appraisal Method (RAM) for Floodplain Management (DNRE 2000) and include initial road repair, subsequent accelerated deterioration and bridge repair and accelerated deterioration.

  Other infrastructure damages are assumed to be 5% of residential property damages as recommended in the Flood Damage Assessment FRM Tool DT01 developed by the NSW Department of Planning and Environment.
- **Agricultural damages** - The predominant agricultural land use type in the Investigation area is dryland pasture which is not expected to experience plant death during inundation periods of less than five to seven days (DNRE 2000). As such only clean-up costs have been accounted for
- **Indirect damages** - For residential clean-up costs when buildings are inundated above floor level a clean-up cost has been applied as recommended in DPE (2023). Non-residential Indirect damages are assumed to be 30% of total direct damages as recommended in DNRE (2000)
- **Intangible damages** - Intangible damages are assumed to be 100% (Deloitte 2016 and Werritty et al. 2007) of total direct damages. Intangible damages are comprised of non-physical and unpriced damages that result from direct and indirect impacts. These include but are not limited to the following:
    - Physical health (including loss of life)
    - Psychological health impacts (e.g. mental health impacts, trauma, concerns of future floods and loss of confidence in authorities and services)
    - Social impacts (loss of community and irreplaceable societal memorabilia)
    - Cultural and heritage impacts
    - Flora and fauna impacts

6.2 Current climate average annual damages

The riverine event AAD estimate of $625,000 and storm tide event AAD estimate of $101,000 are based on independent events so there is a combined AAD estimate $726,000.

The AAD and the breakdown from each type of damages for riverine and storm tide flooding are presented in Table 6-1 and Table 6-2 respectively. The composition of the type of damage contributing to the AAD for riverine and storm tide flooding are shown in Figure 6-2 and Figure 6-3 respectively. These figures show that except for intangibles, damages to building and property contribute the largest portion of damages, approximately 45%. This is expected given the relative high worth of residential and other use type buildings and property in comparison to road and other infrastructure and agricultural land per unit of area.

Table 6-1 Riverine event current climate damages summary

AEP	Building and property damages	Road and other Infrastructure Damages	Agricultural Damages	Intangible Damages	Total Damages	Contribution to AAD
PMF	$74,354,000	$5,955,000	$44,000	$76,879,000	$157,232,000	**$201,000**
1 in 500	$20,591,000	$1,728,000	$21,000	$21,321,000	$43,661,000	**$102,000**
1 in 200	$11,322,000	$1,031,000	$17,000	$11,750,000	$24,120,000	**$86,000**
1%	$4,757,000	$480,000	$14,000	$4,985,000	$10,236,000	**$72,000**
2%	$1,901,000	$238,000	$11,000	$2,044,000	$4,194,000	**$83,000**
5%	$571,000	$98,000	$9,000	$637,000	$1,315,000	**$46,000**
10%	$216,000	$52,000	$7,000	$258,000	$533,000	**$29,000**
20%	$0	$20,000	$7,000	$20,000	$47,000	**$7,000**
Average Annual Damages						**$625,000**

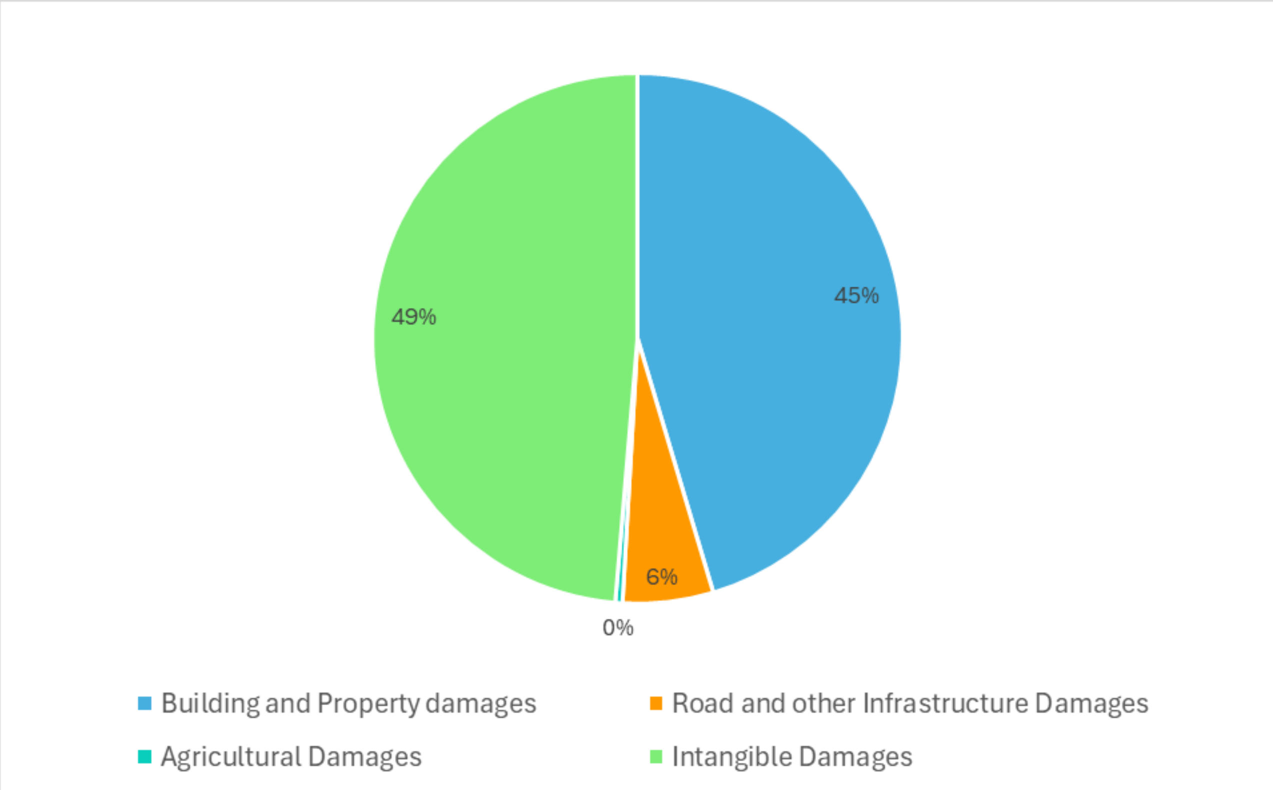


Figure 6-2 Riverine event current climate AAD composition

Table 6-2 Storm tide event current climate damages summary

AEP	Building and property damages	Road and other Infrastructure Damages	Agricultural Damages	Intangible Damages	Total Damages	Contribution to AAD
Tsunami	$37,476,000	$2,796,000	$13,000	$38,103,000	$78,387,000	**$76,000**
1 in 500	$577,000	$56,000	$2,000	$610,000	$1,245,000	**$3,000**
1 in 200	$379,000	$41,000	$2,000	$404,000	$826,000	**$3,000**
1%	$250,000	$32,000	$2,000	$268,000	$552,000	**$4,000**
2%	$138,000	$23,000	$1,000	$153,000	$315,000	**$8,000**
5%	$83,000	$14,000	$1,000	$90,000	$188,000	**$5,000**
10%	$0	$6,000	$1,000	$5,000	$12,000	**$1,000**
20%	$0	$5,000	$1,000	$4,000	$9,000	**$1,000**
Average Annual Damages						**$101,000**

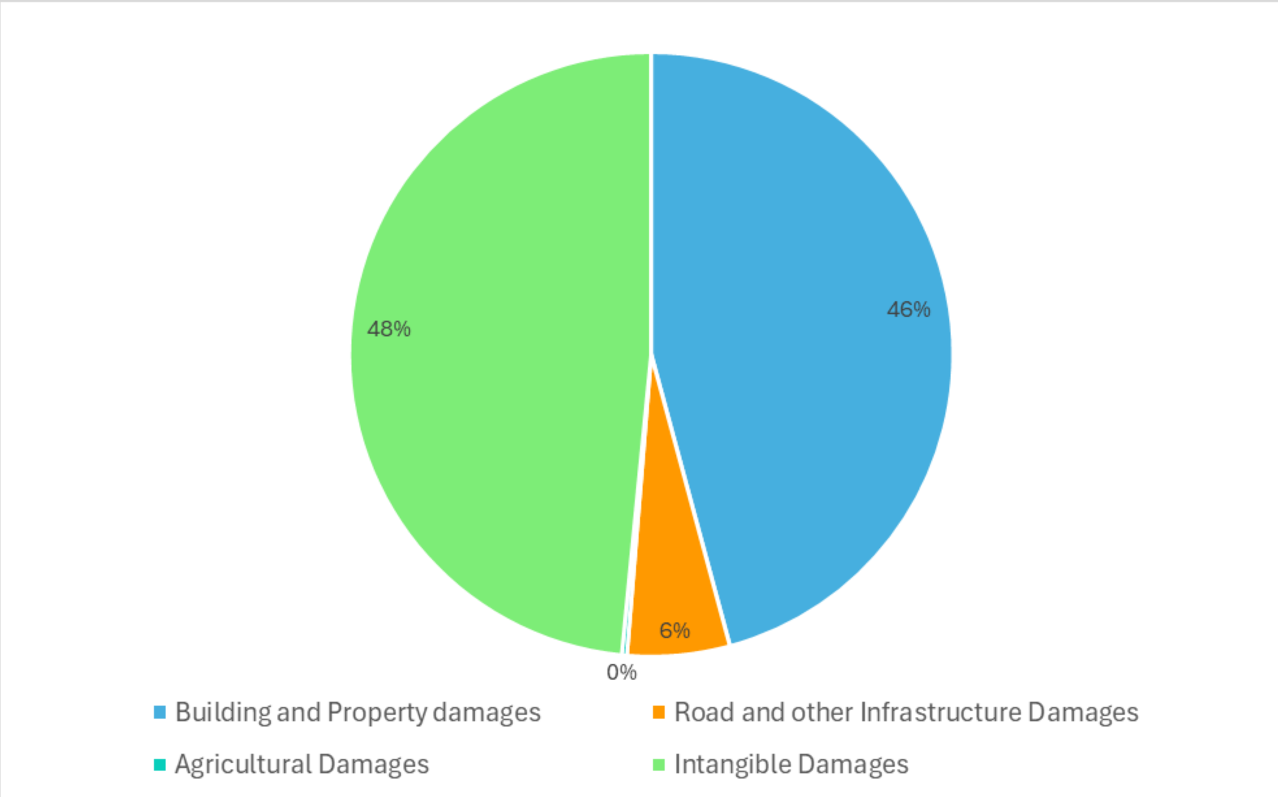


Figure 6-3 Storm tide event current climate AAD composition

7 Draft planning overlay mapping

A key objective of the Victorian Floodplain Management Strategy (DELWP 2016) is "*not making things worse*" and the strategy recognises avoidance and minimisation of flood risk via the Victorian land use and development and building approval systems as key to achieving this objective.

Land use planning controls are one of the most, if not the most, effective instruments available to mitigate the risk of flooding on communities. The objectives of the State and Warrnambool City Council planning policy for floodplain management is to assist the protection of:

- Life, property and community infrastructure from flood hazard, including coastal inundation, riverine and overland flows
- The natural flood carrying capacity of rivers, streams and floodways
- The flood storage function of floodplains and waterways
- Floodplain areas of environmental significance or of importance to river, wetland or coastal health

The strategy to achieve these objectives includes identifying land affected by flooding, including land inundated by 1% AEP or as determined by the floodplain management authority in planning schemes. For this Study the 1% AEP event is defined as a combination of the maximum of 1% AEP riverine (allowing for the influence of joint probability, refer to Section 4.6) and 1% AEP storm tide events.

As shown in Figure 7-1 and Figure 7-2 there are currently a number of flood risk related planning controls in place for Dennington and South Warrnambool including Urban Flood Zone (UFZ), Floodway Overlays (FO) and Land Subject to Inundation Overlay (LSIO). In South Warrnambool the planning controls were first implemented in the mid-1990s. In the mid-2010s the planning controls were updated north-west of Block Street and extended to include Dennington based on the South Warrnambool Flood Study (Water Technology 2007a) and Dennington Flood Study (2007b).

The flood risk mapping produced by this Investigation provides the foundation for updating and providing consistency in the planning controls.

Flood prone land is defined by the 1% AEP and shows where development is generally permissible and is represented by LSIOs. Waterways, major floodpaths, drainage depressions and high hazard areas which have the greatest risk and frequency of being affected by flooding where development should generally not be permitted are represented by UFZs and FOs. For this Investigation these areas have been identified using safety criteria where the 1% AEP flood depth is likely to reach or exceed 0.5 m, and/or land where the 1% AEP flood hazard factor (the product of depth and velocity) is likely to reach or exceed 0.4 m^2/s, and/or water velocity is likely to be 2 m/s or more. This is based on the safety thresholds for children and light building structures as presented in the Guidelines for Development in Flood Affected Areas (DELWP 2019).

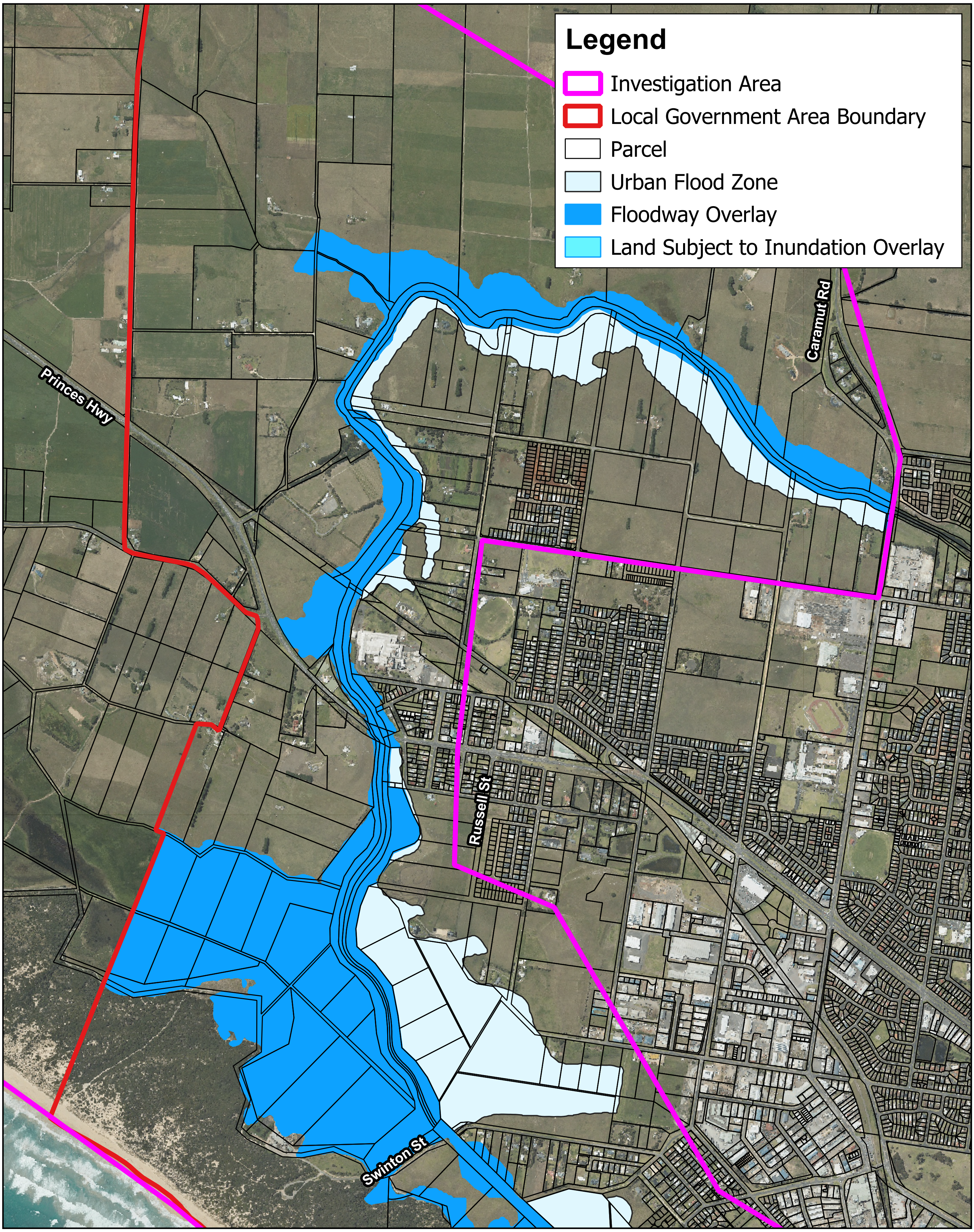
An objective of the State and Warrnambool City planning policy is to minimise the impacts of natural hazards and adapt to the impacts of climate change by identifying at risk areas using the best available data and climate change science. Therefore, the draft planning mapping has been prepared based on the Climate Change 2 scenario, described in detail in Section 1.4, to represent the best available climate science at the time of this Investigation and is widely adopted for land use and development planning purposes in Victoria and throughout Australia.

Increased rainfall intensity has been defined in accordance with the guidance provided in the Draft Update to the Climate Change Considerations Chapter in Australian Rainfall and Runoff: A guide to Flood Estimation (DCCEEW 2023) resulting in a 41% increased rainfall intensity from the 1961 to 1990 baseline. The applied increased rainfall intensity factor accounts for the likely impact of climate change on the amount of inland catchment rainfall runoff, which affects the magnitude of flood flows in the Merri River. Flood risk is also affected by the height of the ocean at the Merri River mouth (Stingray Bay) and Rutledges Cutting. This is because sea level rise results in higher ocean levels making the impact of storm tide events more severe and backs water up the Merri River estuary during riverine flood events.

Victoria's current sea level rise planning policy (Clause 13.01-2s of the Victoria Planning Provisions) is to plan for not less than 0.8 m of sea level rise by the year 2100. It is understood at the time of the Study, that this policy has been reviewed as per Action 3.9 of the Marine and Coastal Strategy (DELWP 2022). It is also understood that this review responds to the IPCCs 6th assessment report finding that the global average increase in mean sea level can be expected to be in the order of up to 1.1 metres by the year 2100, given the current trajectory of greenhouse gas emissions and the potential impact of this trajectory on the future mean surface temperature. Consequently, Victoria's minimum required planning allowance for sea level rise is likely to be revised upward to account for more than 0.8 m of rise in alignment with Climate Change Scenario 2.

A notable decision relating to this and Victoria's adaptive approach to dealing with the sea level rise risk was made by the Minister for Planning in early October 2024. The decision related to amendment C69 of the Moyne Shire planning scheme. The Ministers Decision was to revise the flood risk related planning controls (overlays) covering the coastal and riverine floodplains at Port Fairy to account for up to 1.2 m of sea level rise. The decision accounts for the fact that there is high confidence that sea levels will continue to rise for centuries beyond 2100 due to continuing deep ocean heat uptake and mass loss of glaciers and ice sheets and remain elevated for thousands of years (IPCC 2019). Therefore the 1.2 m sea level rise mapping is an appropriate tool for understanding, planning for and adapting to, future levels of risk.

The resulting draft planning mapping is shown in Figure 7-3 and Figure 7-4. Please note, the mapping presented is likely to be subject to change prior to use in any planning scheme amendment as review of the extents on an individual lot scale is undertaken.



Title:

South Warrnambool and Dennington Flood Investigation
Existing flood related planning controls (North)

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Figure:	Rev:	0.35 0 0.35 km		By: TL
7-1	A		This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	Date: Feb 2025

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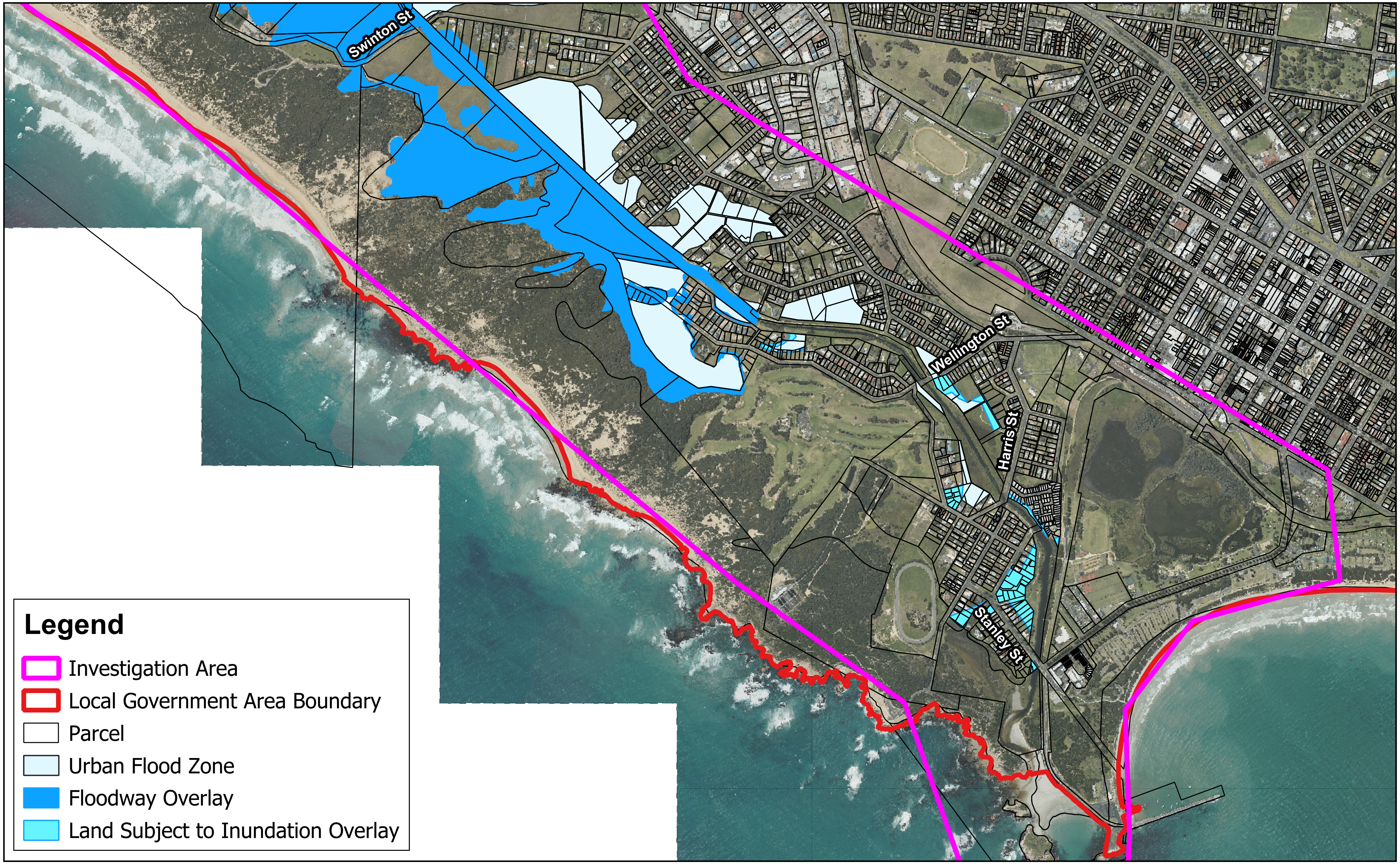

Title: South Warrnambool and Dennington Flood Investigation
Existing flood related planning controls (East)

Figure: 7-2

Rev: A

0 350 700 m

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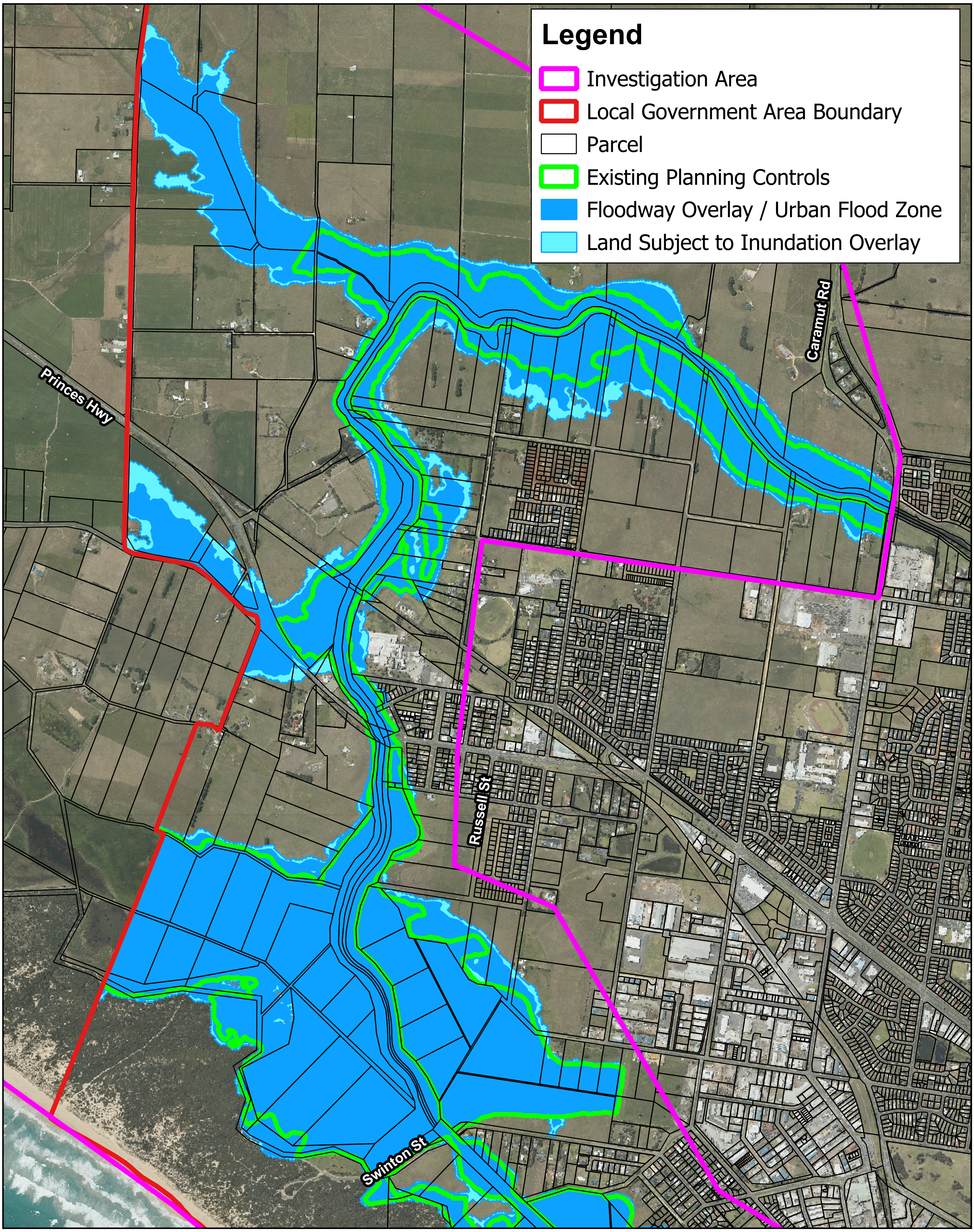

Title:
South Warrnambool and Dennington Flood Investigation - Climate Change 2
Draft Planning Overlay Mapping (North)

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Figure: 7-3

Rev: A

0.35 0 0.35 km

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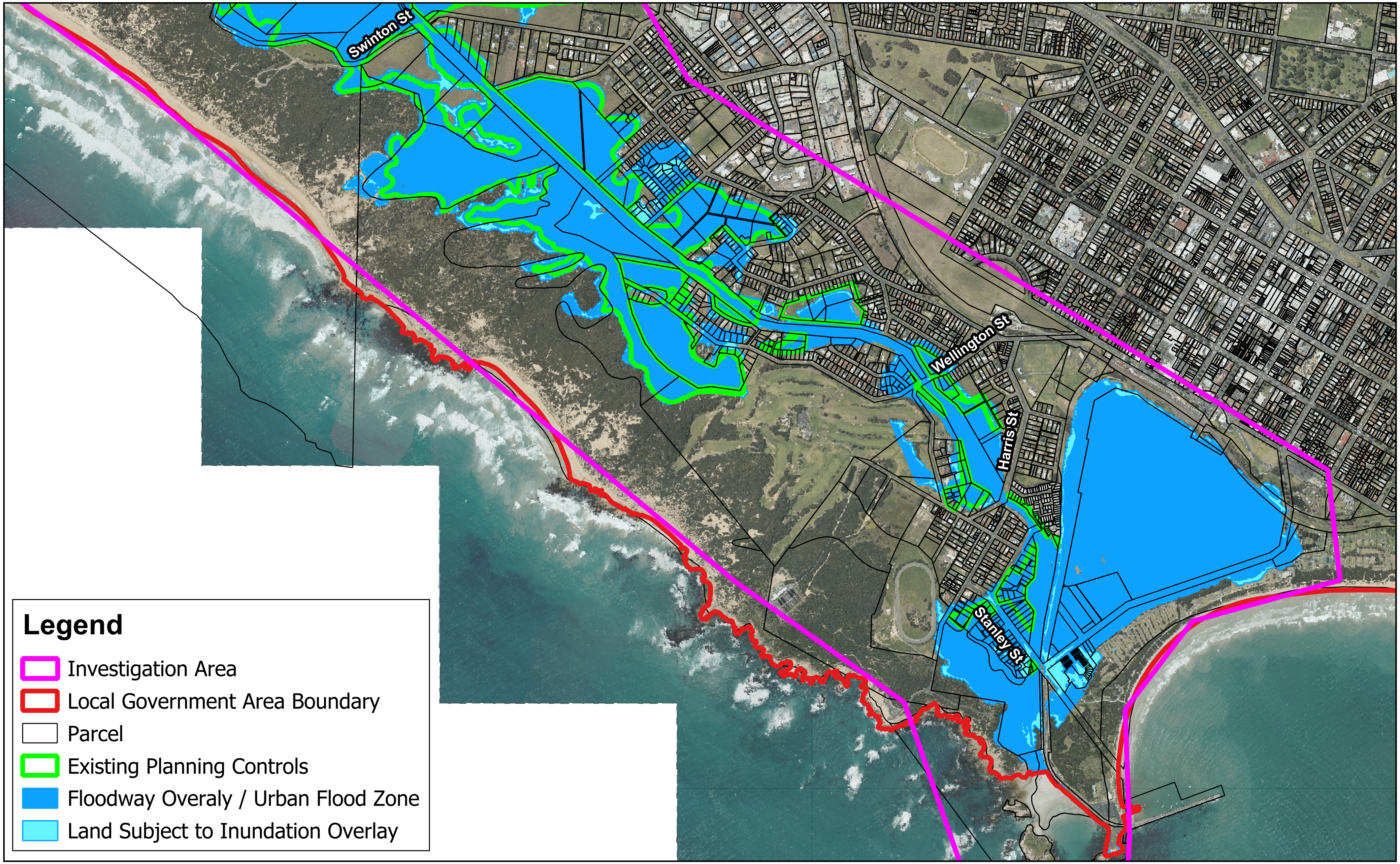

Title: South Warrnambool and Dennington Flood Investigation - Climate Change 2
Draft Planning Overlay Mapping (East)

Figure: 7-4

Rev: A

0 350 700 m

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8 Structural mitigation options feasibility assessment

Structural mitigation measures are physical works to reduce the likelihood of flooding. For this Investigation the feasibility assessment of three structural mitigation options has been assessed.

8.1 Mitigation option selection

A mitigation option selection process was undertaken to identify the structural mitigation options for the feasibility assessment. The mitigation option selection process was undertaken in three stages:

1. Identification of 27 potential structural mitigation options throughout the preceding tasks of the Investigation from the following sources:
    a) Local community from feedback provided prior to the Community Session held on the 8th of November 2023
    b) Project Reference Group (PRG)
    c) Project team (Council, GHCMA and Venant Solutions)
2. Collation and review all the identified potential structural mitigation options to develop a consolidated list of six options listed in Table 8-1 to present to the community at the session held on the 8th of November 2023.
3. Following presentation of the pre-feasibility assessment each community member in attendance at the meeting was provided with two votes which they could use for the option that they wished to be further assessed. The votes were collated and the options selected for the feasibility assessment were confirmed at the PRG meeting held on the 9th of November 2023. The results of the votes are presented in Table 8-1

Table 8-1 Potential structural mitigation option community votes results

Option	Votes	Rank
Merri River Levees	1	6
Creation of an opening at Levys Point	3	5
Restrict flow through Swinton Street Bridge	9	1
Increase capacity of Merri River bridge openings	9	1
High flow bypass into Kellys Swamp	4	5
Improve flow across Kellys Swamp (Boardwalk and Kellys Swamp / Saltwater Swamp high point)	8	3

Following the community vote at the PRG meeting on the 9th of November 2023 the outcomes of the votes were confirmed and three options were developed for feasibility assessment using the flood model:

- Option 1 – Restrict flow across Swinton Street with Kelly Swamp / Saltwater Swamp works
- Option 2 – Excavation of the Merri River Cutting channel under and downstream of the MacDonald Street bridge
- Option 3 – High flow bypass from the Merri River into Kelly Swamp

In the early stages of flood mitigation options feasibility assessment using the flood model it became apparent that Option 2 and 3 would not provide as significant improvements in flood risk as expected.

For Option 2, the flood model showed that excavation of the Merri River Cutting channel under and downstream of the MacDonald Street bridge would provide reductions in peak riverine event flood levels that were primarily limited in extent to between MacDonald Street and Wellington Street where reductions in the 1% AEP riverine peak flood level of -0.4 m are achieved. Further upstream reductions in peak flood level of less than 0.05 m are achieved.

For Option 3, the bypass channel did not show any significant benefit in reducing flow and in turn flood levels downstream of Swinton Street through South Warrnambool.

Therefore, two new options were developed for feasibility assessment using the flood model:

- Option 4 – Excavation of the Merri River Cutting at four locations
- Option 5 – Install flood gates at the Swinton Street bridge with Kelly Swamp / Saltwater Swamp works

The options selected are focused on mitigating the impact of riverine flooding which is of the highest flood risk for the majority of the floodplain as opposed to storm tide flooding.

8.2 Selected mitigation option descriptions

8.2.1 Option 1 - Restrict flow across Swinton Street with Kelly Swamp / Saltwater Swamp works

The aim of Option 1 is to further increase the proportion of flow that discharges via Rutledges Cutting to reduce the flood flows and in turn flood levels in the urbanised area of South Warrnambool.

As shown in Figure 8-1 Option 1 consists of the following works:

- Placement of 200 m^3 of rock reinforcement under the Swinton Street bridge to restrict flows. This narrows the channel width under the bridge by approximately 5 m
- Raising of a 50 m section of Swinton Street at the corner near the quarry entrance to a level of 4.3 m AHD equal to the next lowest point in the road approximately 20 m south-east of the Swinton Street bridge
- Excavation of the higher land between Kelly Swamp and Saltwater Swamp to a level of 0.8 m AHD to allow for more flow to pass towards Rutledges Cutting. This results in an estimated 400,000 m^3 of material been excavated and disposed of offsite
- Clearing of the Spiny Rush that is growing in the swamp system. The GHCMA has estimated that the Spiny Rush currently covers an area of 4.2 ha

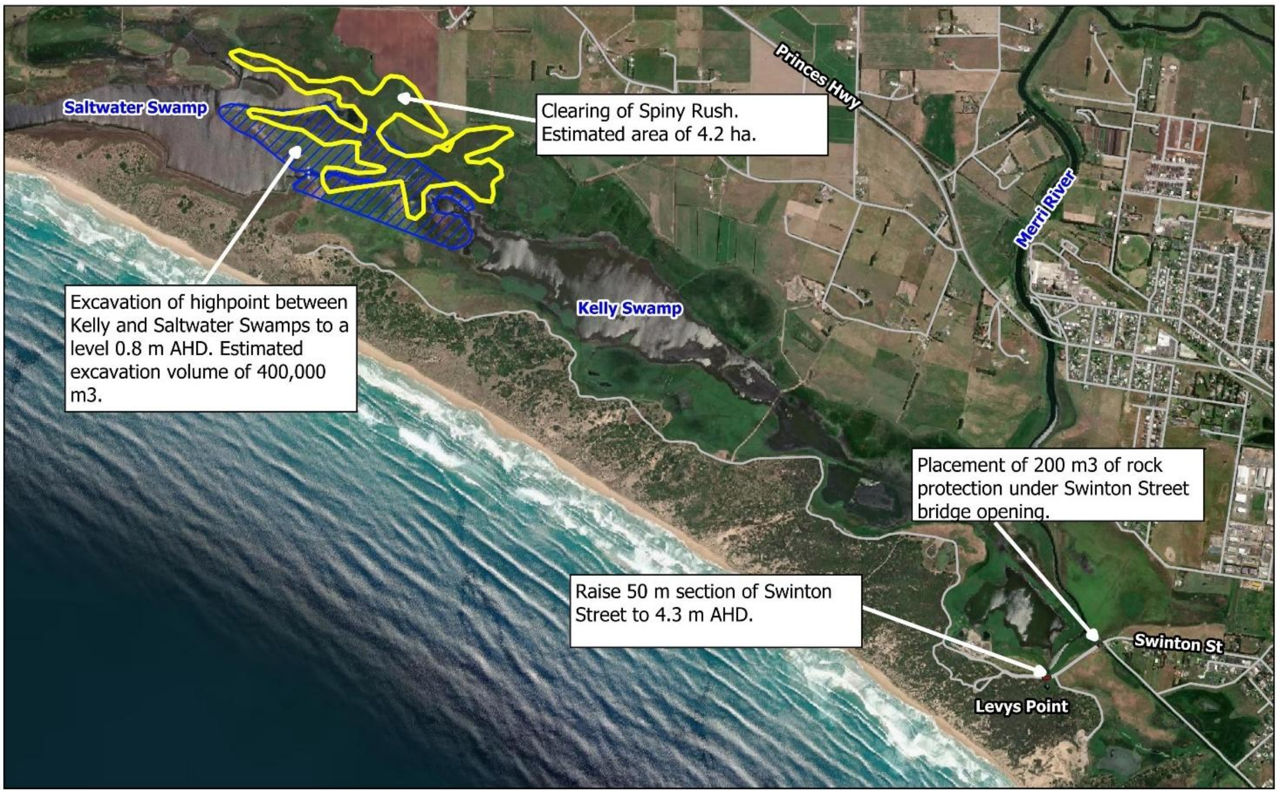


Figure 8-1 Option 1 layout

8.2.2 Option 4 - Excavation of the Merri River Cutting at four locations where the channel narrows

There are several locations along the Merri River Cutting where the channel width narrows restricting the flow capacity to the outlet at Stingray Bay. The aim of Option 4 is to increase the flow capacity of the Merri River Cutting by widening the channel at the narrowest points. To offset the additional flow that passes through the channel downstream of MacDonald Street, ground levels on the west bank of the channel between Stephens Street and Stanley Street need to be raised.

As shown in Figure 8-2 Option 4 consists of the following works:

- Excavation of the Merri River Cutting at four locations with a total excavation volume of 14,300 m3.
- Raise Denman Drive by between 50 mm and 350 mm.
- A 50 to 350 mm high bund with a 0.5 m top width and 1 in 8 batters.

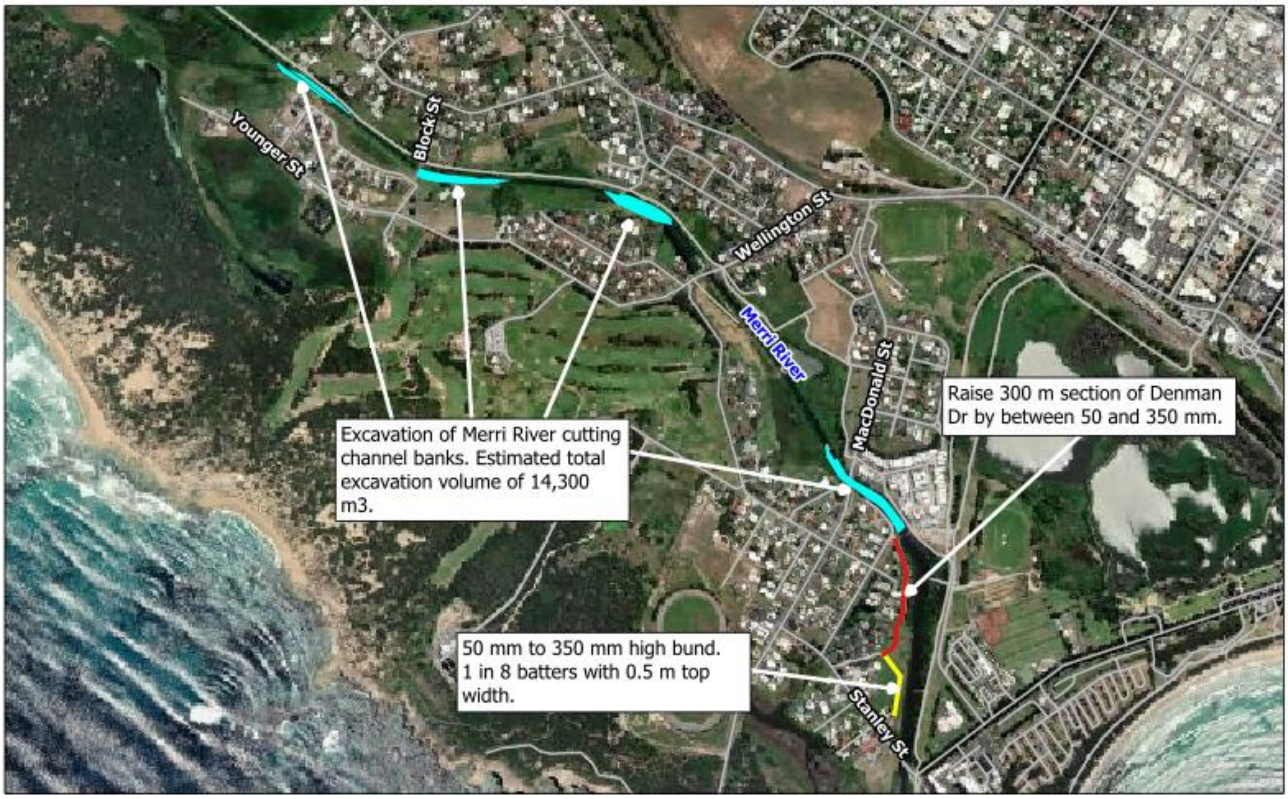


Figure 8-2 Option 4 layout

8.2.3 Option 5 - Install a flood gate at the Swinton Street bridge with Kelly Swamp / Saltwater Swamp works

The aim of Option 5 is to further the concept tested in Option 1 (Section 8.2.1) by completely blocking flow at Swinton Street to a level of 4.3 m AHD or a current climate conditions 1% AEP riverine event. To compensate for the increase in flood level upstream through Dennington, the Kelly and Saltwater Swamp works are required.

As shown in Figure 8-3 Option 5 consists of the following works:

- Install flood gates at Swinton Street involving:
  - Construction of a concrete headwall upstream of Swinton Street to attach the flood gates to
  - Four 4000 mm wide x 2700 mm high penstocks
  - Actuators to raise and lower penstocks
- Raising of a 50 m section of Swinton Street at the corner near the quarry entrance to a level of 4.3 m AHD to equal to the next lowest point in the road approximately 20 m south-east of the Swinton Street bridge
- Install flap valve on the 750 mm culvert under Swinton Street
- Excavation of the higher land between Kelly Swamp and Saltwater Swamp to a level of 0.8 m AHD to allow for more flow to pass towards Rutledges Cutting. This results in an estimated 400,000 m^3 of material been excavated and disposed of offsite
- Clearing of the Spiny Rush that is growing in swamp system. The GHCMA has estimated that the Spiny Rush currently covers an area of 4.2 ha

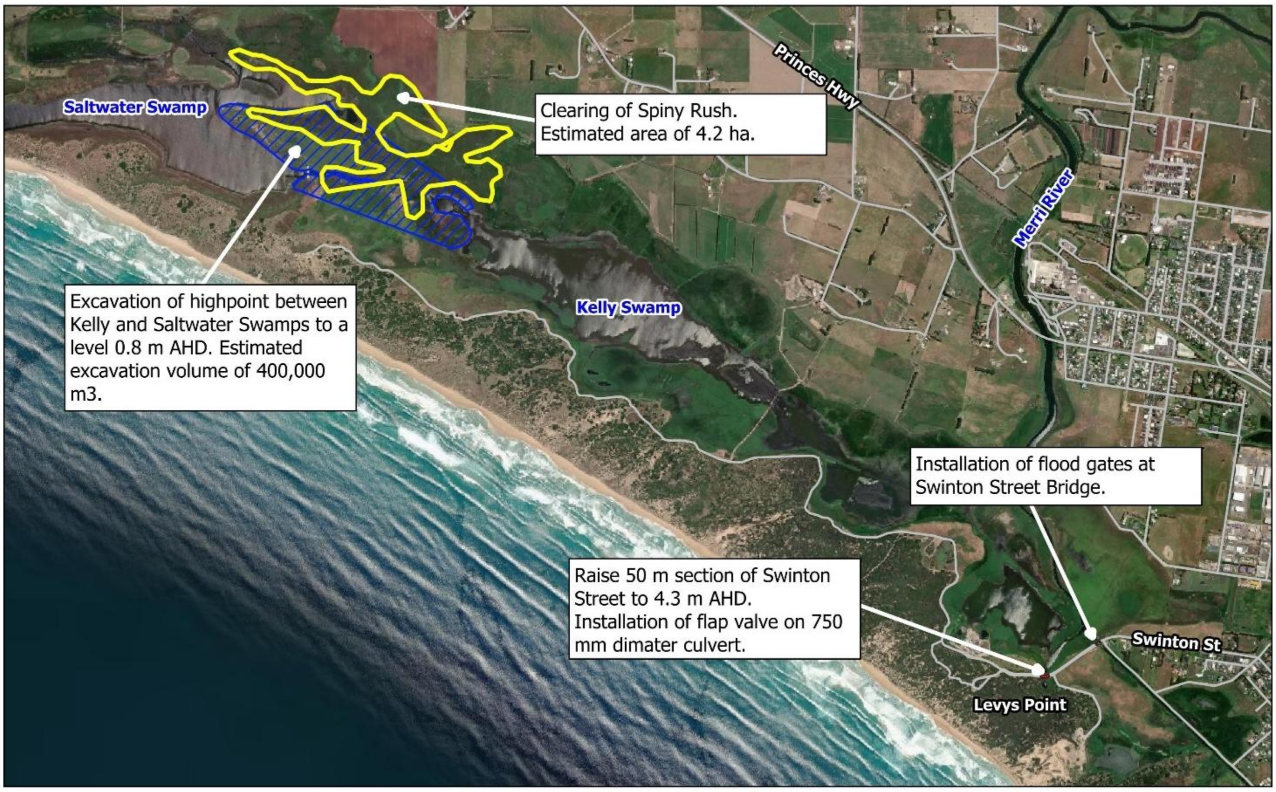


Figure 8-3 Option 5 layout

8.3 Feasibility assessment results

Each structural mitigation option is assessed against the effectiveness in reducing flood levels using the flood model and the economic benefit.

8.3.1 Flood level reductions

To determine the effectiveness of a structural mitigation option in reducing flood risk, flood level impact mapping is used to compare the reduction (or increase) in peak flood levels as a result of the works. The reduction in the number of houses with above floor flooding is also assessed.

The flood level impact mapping for 1% AEP riverine Current Climate and Climate Change 2 scenarios is presented in Appendix D. To interpret flood level impact maps the yellow colour indicates no change in flood level within a +/- 0.05 m tolerance, reductions in flood level are shaded with greens and increases in flood level are shaded with oranges/reds. The magenta colour indicates a region where flooding currently occurs, but would no longer occur if the option was implemented, and the blue colour indicates a region where flooding currently does not occur but would if the option was implemented.

The number of houses with above floor flooding in the Current Climate 1% AEP riverine event are shown in Table 8-2.

The modelling indicates that Option 1 results in the amount of flow discharging to Rutledges Cutting in a 1% AEP riverine event increasing from 88% to 92%. This results in decrease in flood level across the South Warrnambool and Dennington floodplain in all modelled events. In the current climate 1% AEP riverine event these decreases are up to 0.5 m in the Landmann Street area with inundation of the properties on the west side of Landmann Street, Silesia Court and Rentsch Court prevented. Further upstream decreases in current climate 1% AEP riverine event of between 0.05 to 0.1 m up to the Yangery Creek confluence are shown. West of the excavation area increases in peak flood level are limited to below 0.1 m. As shown in Table 8-2 Option 1 is successful in reducing riverine event above floor flooding of houses in South Warrnambool in a 1% AEP riverine flood event from 25 to 5.

For Option 4 in the 1% AEP current climate conditions riverine event the additional flow capacity of the Merri River cutting lowers flood levels in the Landmann Street area by approximately 0.15 m and upstream of the MacDonald Street bridge by 0.3 m. As shown in Table 8-2 Option 4 is successful in reducing riverine event above floor flooding of houses in South Warrnambool in a 1% AEP riverine flood event from 25 to 17.

For Option 5 in events up to and including the current climate 1% AEP event Merri River flow is prevented from crossing Swinton Street with the inundation shown in the flood level impact maps being that from the local rainfall and the tide. As a result, all inundation in these events is confined within the Merri River Cutting channel, wetland areas and flooding from Lake Pertobe. In the current climate 1% AEP (and less frequent events) riverine event the swamp excavation works ensure that there no increases in flood levels upstream through Dennington. As shown in Table 8-2 Option 5 is successful in reducing riverine event above floor flooding of houses in South Warrnambool in a 1% AEP riverine flood event from 25 to 2.

Table 8-2 Current climate 1% AEP riverine event houses flooded above floor level

Existing Conditions	Option 1[1]	Option 4[1]	Option 5[1]
25	5 (20)	17 (8)	2 (23)

[1.] Reductions presented in parentheses.

8.3.2 Economic assessment

The economic viability of a scheme is initially assessed by calculating the monetary benefit-cost ratio (BCR). A benefit-cost ratio of 1.0 indicates that the monetary benefits are equal to the monetary costs. A ratio greater than 1.0 indicates that the benefits are greater than the costs while a ratio less than 1.0 indicates that the costs are greater than the benefits.

Assuming that construction starts in 2026 and that options have a 50 year lifespan the benefit-cost ratio for each option is summarised in Table 8-3. Due to the high capital costs of each option the benefit-cost ratios are well below 1.0.

Table 8-3 Benefit-cost ratio summary

Item	Existing Conditions	Option 1	Option 4	Option 5
AAD (Current Climate Riverine Event without Intangibles)	$321,000	$199,000	$278,000	$183,000
Benefit (per Annum)		$122,000	$43,000	$138,000
Total Benefit (Present Value)		$1,284,480	$1,284,480	$1,926,720
Capital Cost		$26,400,000	$2,550,000	$27,900,000
Total Cost (Present Value)		$21,550,260	$2,081,560	$22,774,710
Benefit-Cost Ratio		**0.06**	**0.23**	**0.08**

8.4 Feasibility assessment outcomes

The feasibility of the three selected structural mitigation options were assessed in the flood model. The options assessed had the aim of mitigating riverine flooding in the urban area of South Warrnambool downstream of Swinton Street. The assessment showed that restricting flow through Swinton Street either by reducing the flow area under the Swinton Street bridge (Option 1) or by installing flood gates (Option 5) provides a great benefit to reducing flood levels and reducing the number of houses with above floor flooding in comparison to increasing the flow capacity of the Merri River Cutting (Option 4). The flood gates (Option 5) perform better and could be left open during storm tide events removing any detrimental impacts. However, to manage the increases in flood level upstream significant works are required in Kelly Swamp and Saltwater Swamp to allow more flow to pass through Rutledges Cutting. These works include extensive excavation with a very high capital cost and the potential to have detrimental environmental and cultural heritage impact on the nationally significant Lower Merri River Wetlands.

Given the high capital cost estimates of all three options the benefit-cost ratios are far lower than one indicating that costs outweigh the financial benefits. However, in floodplain management, a benefit-cost ratio substantially less than 1.0 may still be considered viable because the economic analysis does not include all of the benefits gained by flood mitigation works.

If further assessment of the structural flood mitigation options whose feasibility was assessed in the Investigation or of other structural mitigation options it is recommended that:

- Any further assessment of mitigation options should include:
  - Refinement of design to incorporate design factors such as land ownership, existing utilities, etc
  - Cost estimation commensurate with the level of design
  - Environmental assessments and approvals

  - Cultural heritage assessments and approvals
  - Stakeholder consultation with parties such as landowners, the Eastern Maar Aboriginal Corporation, Parks Victoria and DEECA
- Any further assessment of mitigation options should incorporate climate change into the evaluation of options. This includes how the options perform in relation to flood risk reduction measures (flood level reductions, number of buildings with above floor flooding saved, etc) in the future, incorporation of climate change into the benefit-cost ratio and consideration of what the floodplain characteristics will be in the future allowing for considerations such as sea level rise, expected growth and urban renewal
- Further assessment of mitigation options should consider developing more specific estimates of intangible damages for inclusion in the benefit-cost ratio
- The options assessed for this Investigation are broadscale flood mitigation options with the aim of reducing flood risk across large parts of the floodplain. Consideration should also be given to localised structural flood mitigation options that target specific areas of high risk
- The options assessed for this Investigation are primarily focused on mitigating the impact of riverine flooding which is of the highest flood risk for the majority of the floodplain. Consideration could also be given to flood mitigation options that address the risk of storm tide flooding which affects the lower areas of the floodplain at present and is to create an increasing risk as sea levels rise

9 Flood warning feasibility assessment

A review of the current flood warning arrangements found that for riverine flooding at present the Bureau of Meteorology (BoM) does not offer a flood warning service for the Merri River. Nor is it believed that any other agencies or community groups have established a flood warning system for South Warrnambool or Dennington for riverine flooding. As such flood warnings for riverine flood events are limited to general warnings for the region or VICSES notifications where there is a verified risk to life or property.

For storm tide flooding the BoM does provide Coastal Hazard Warnings for abnormally high tides or storm tides which provides a good indicator of potential storm tide flooding in South Warrnambool but is limited in estimating magnitude accurately as the magnitude of wave setup for any given storm tide event greatly influences the tide flood levels.

The Warrnambool City Council Flood Emergency Plan (MFEP) currently includes a description of riverine and storm tide flooding for the Merri River, flood peak travel times to the Merri River at Woodford gauge and to Warrnambool and has a sub-plan (Appendix C2) for Merri River flooding. The current MFEP provides a good summary of the mechanisms of flooding from the Merri River based on a combination of observed past event information and previous flood studies. However, there is limited detailed information identifying the specific consequences in terms of impacted buildings and inundated roads.

Most of the recommended potential improvement actions are focused on using information, services and systems that are currently in place to communicate and incorporate the information derived from this Investigation. This includes building the community’s resilience to flooding via awareness and education products primarily through making the outcomes of this Investigation publicly available and easily assessable via online web portals(s) and an update of the Local Flood Guide.

Documenting expected consequences of flooding and appropriate response actions in the MFEP will greatly reduce the burden on emergency response agencies in the event of expected flooding in Dennington and South Warrnambool and allow for targeted response actions to be undertaken. The rainfall based indicative flood tool and stream gauge relationships will also greatly aid predicting the magnitude and consequences of an event.

One recommendation that will greatly improve the reliability of flood warning information provided is to install a sub-daily rainfall gauge in the mid or upper catchment. Currently the only gauge located in the catchment is the Warrnambool AWS (90186) in the lower catchment with the next closest gauges been located at Mortlake, Hamilton, Gerrigerrup and Willatook.

There is a good stream gauge network already in place, in particular the Merri River at Woodford and Merri River at Dennington gauges, to allow for the establishment of a formal flood warning system. However, there are considerable cost and time requirements in making and providing a forecast system including setting up and calibrating a new hydrologic model, establishing stream gauge management arrangements (Merri River at Dennington), verifying rating curves which could include survey and or hydraulic modelling, establishing flood class levels, training and coordination with emergency services. As such establishment of any new system by the BoM would be prioritised across catchments country wide. The flood risk outputs of this Investigation provide the basis for comparing the flood risk in Dennington and South Warrnambool to other catchments. It should be noted that other areas not within the scope of this Investigation including North Warrnambool, Woodford and Bushfield would also benefit from this system.

9.1 Flood warning feasibility assessment recommendations

The feasibility of improving flood warning arrangements for Dennington and South Warrnambool have been assessed with the recommended potential improvement actions presented in Table 9-1.

Many of the actions are focused on using information, services and systems that are currently in place to incorporate the information derived from this Investigation. These improvements are achievable and sustainable with relatively little effort and cost, whereas others would require more significant investment. As such each potential improvement action has been assigned a priority based on the following criteria:

High	Actions achievable in the near-term (0 - 1.5 years) using information, services and systems that are currently in place and require minimum investment and will provide the greatest benefit.
Medium	Actions achievable in the mid-term (1.5 – 3 years) requiring a greater level of investment to implement.
Low	Actions achievable in the long-term (+3 years) requiring a greater level of investment to implement but do not provide a significant benefit in comparison to high or medium priority actions.

Table 9-1 Recommended potential improvements

TFWS Element	No.	Potential Improvement Actions for South Warrnambool and Dennington	Lead Agency(s)	Partner Agency(s)
Building community resilience to disasters	**1**	• Continue flood awareness activities that emphasise personal safety and damage reduction. This includes: ○ Provide links to the Final Summary Report (at a minimum), Local Flood Guide and Municipal Flood Emergency Management Plan on Council's and GHCMA's website ○ Upload the flood mapping onto the regional Flood Information Portal hosted by the GHCMA	Council	GHCMA
	2	• Continue to investigate the feasibility of a new web portal (such as the WISER platform) that can be linked to stream gauge levels, present more detailed flood mapping and prepare property specific flood information.	Council	GHCMA
	3	• Update the Warrnambool Local Flood Guide (LFG).	VICSES	Council
	4	• Identify appropriate locations in South Warrnambool and Dennington for the installation of a flood pole(s) to aid in increasing and maintaining the community's and visitor's awareness of flooding and to help visualise the magnitude of past flood events, flood class levels and provide context to the design flood levels developed by this study. The flood pole would also make a suitable location to display flood intelligence products such as posters with links to the LFG.	Council	Relevant landowner / manager of identified location
Monitoring and prediction	**5**	• Incorporate the rainfall based indicative flood tool and gauge level relationships into the Municipal Flood Emergency Management Plan.	VICSES	Council, GHCMA
	6	• Council, GHCMA and VICSES agree who will maintain the gauge level relationships (post event review and update and/or incorporation of updated flood mapping information) and undertake the predictive assessments during an event.	VICSES	Council, GHCMA
	7	• Investigate installing a sub-daily gauge located in the mid to upper catchment such as at Woolsthorpe, Minjah or Minhamite.	Council	DEECA, BoM, GHCMA

	8	• Through the South West Regional Water Monitoring Partnership investigate making the Merri River at Dennington gauge operated by the GHCMA data publicly available (via the Water Management Information System (WMIS) for use by other emergency response agencies for flood forecasting and intelligence. Ideally the live gauge levels would also be made available via BoM's website as a river data location.	Council	DEECA, BoM, GHCMA
	9	• Request BoM to establish a flood warning system for the Merri River. Prior to the development of a flood warning system other actions need to be taken including resolving management of the Merri River at Dennington gauge (preferable warning location for South Warrnambool and Dennington) and establishment of flood class levels.	Council	BoM, DEECA, GHCMA
	10	• In lieu of a BoM flood warning service, an information location can be established for the Merri River at Woodford gauge.	Council	BoM, DEECA, GHCMA
Interpretation	**11**	• Establish flood class levels for the Merri River at Woodford (riverine events), Merri River at Dennington (riverine events) and Merri River at Warrnambool (riverine and storm tide events) gauge.	GHCMA	VICSES, Council
Message construction	**12**	• If specific flood access/egress routes are established messaging should include instructions about the location and use of these routes when constructing flood warnings and bulletins.	VICSES	BoM
Communication	**13**	• In lieu of a BoM flood warning service, an information location can be established for the Merri River at Woodford gauge.	Council	BoM, VICSES
Community Response	**14**	• Confirm and incorporate emergency response actions into the Municipal Flood Emergency Management Plan.	VICSES	GHCMA, Council
Continuous review and improvement	**15**	• Review and update all aspects of the Total Flood Warning System including: ○ Ensuring locations and links to flood information are up to date and accessible to the community ○ Additional flood behaviour information and post response review findings following flood events are incorporated into emergency response documentation and actions ○ Incorporate updated flood mapping and intelligence information if it becomes available	Council	VICSES, GHCMA

		• It is recommended that this review be undertaken periodically or after an event by Council's Emergency Management Unit with input from VICSES, GHCMA and other agencies engaged in emergency response.		

10 Key outcomes

This report provides a summary of the South Warrnambool and Dennington Flood Investigation. For a detailed description of the Investigation inputs, approach and outcomes the accompanying detailed technical reports should be referred to.

The key outcomes of the Investigation are:

- Thorough documentation of the history of flooding across the Investigation Area based on the historical information discovered during the study
- Hydrologic (RORB) and hydraulic (TUFLOW) models that are well calibrated to the available historic flood event data providing confidence that the flood risk mapping and flood emergency response planning (flood intelligence) outputs reflect the likely real world extent, depth and velocity of the modelled flood risk scenarios. The calibrated models have enabled:
    - Provision of knowledge and data around the expected effects of climate change (primarily increase in rainfall intensity and rising mean sea level) on flood risk into the foreseeable future
    - Delineation of appropriate extents for land use and development planning controls for incorporation into the Warrnambool Planning Scheme and mitigation of flood risk via the planning system
    - Development of a range of reliable products to support improvement of flood emergency response procedures and actions, including updating of the Municipal Flood Emergency Plan (MFEP)
- Average annual damage (AAD), which represent the average flood damage in present day monetary terms per year that would occur over a long period of time, estimates of $625,000 for riverine events and $101,000 for storm tide events bringing the total AAD estimate up to $726,000
- The feasibility of three structural mitigation options were assessed in the flood model. The options assessed were broadscale options with the aim of mitigating riverine flooding in the urban area of South Warrnambool downstream of Swinton Street. While these options were successful in mitigating the risk of riverine flooding, they involve extensive excavation with a high capital cost (and in turn a low benefit-cost ratio) and the potential to have detrimental environmental and cultural heritage impact on the nationally significant Lower Merri River Wetlands.
- Demonstrated that the development of a flood warning service operated by the Bureau of Meteorology for the communities of South Warrnambool and Dennington is feasible with much of the infrastructure required already in place. However, there is still significant investment required and the Bureau of Meteorology will prioritise the development of a system across catchments country wide. This Investigation has provided tools and identified measures that will improve the flood warning arrangements in lieu of a formalised service.

11 References

Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I (Ed) (2019), *Australian Rainfall and Runoff: A Guide to Flood Estimation*, Version 4.1, Commonwealth of Australia (Geoscience Australia).

(BoM) Bureau of Meteorology (2003), *Guidebook to the Estimation of Probable Maximum Precipitation: Generalised Southeast Australia Method*, Bureau of Meteorology.

Cardno (2010), *Design of North Warrnambool Floodplain Management Plan – Implementation Works*, Cardno.

Clark I (1990), *Aboriginal Languages and Clans: An Historical Atlas of Western and Central Victoria 1800–1900*, Monash University.

Davies G, Griffin J (2018), *The 2018 Australian probabilistic tsunami hazard assessment: hazard from earthquake generated tsunamis*, Geoscience Australia.

(DCCEEW) Department of Climate Change, Energy, the Environment and Water (2023), *Draft updates to the Climate Change Considerations chapter in Australian Rainfall and Runoff guidelines*, Department of Climate Change, Energy, the Environment and Water.

Deloitte (2016), *The economic cost of the social impact of natural disasters*, Deloitte.

(DELWP) Department of Environment, Land, Water and Planning (2022), *Marine and Coastal Strategy*, Department of Environment, Land, Water and Planning.

(DPE) NSW Department of Planning and Environment (2023), *Flood risk management measures: Flood risk management guideline MM01*, Department of Planning and Environment.

(DNRE) Department of Natural Resources and Environment (2000), *Rapid Appraisal Method (RAM) for Floodplain Management*, Department of Natural Resources and Environment.

Gill E (1985), *Coastal Processes and the Sanding of Warrnambool Harbour*, Warrnambool Institute Press.

(IPCC) International Panel on Climate Change (2019), *Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*, Cambridge University Press.

Schwalm C, Glendon S, Duffy P (2020), 'RCP8.5 tracks cumulative CO2 emissions', *Proceedings of the National Academy of Sciences*, Vol. 117, No. 33.

(SRWSC) State Rivers and Water Supply Commission of Victoria (1990), Victorian Surface Water Information to 1987, State Rivers and Water Supply Commission of Victoria.

Streamology (2022a) *Tide Gauge Trigger Levels for Sea Level Rise Adaptation Pathways.*, Streamology.

Streamology (2022b). *Victorian Guideline for Modelling the Interaction of Catchment & Coastal Flooding. Report for Glenelg Hopkins Catchment Management Authority*, Streamology.

Venant Solutions (2023), *South Warrnambool Flood Investigation Data Review Report*, Venant Solutions, Doc. Ref: R.M00407.001.02.DataReport.

Venant Solutions (2024), *South Warrnambool and Dennington Flood Investigation Flood Modelling Report*, Venant Solutions, Doc. Ref: R.M00407.002.02_FloodModelling.

Venant Solutions (2025a), *South Warrnambool and Dennington Flood Investigation Flood Damages and Mitigation Feasibility Assessment Report*, Venant Solutions, Doc. Ref: R.M00407.003.01_Mitigation.

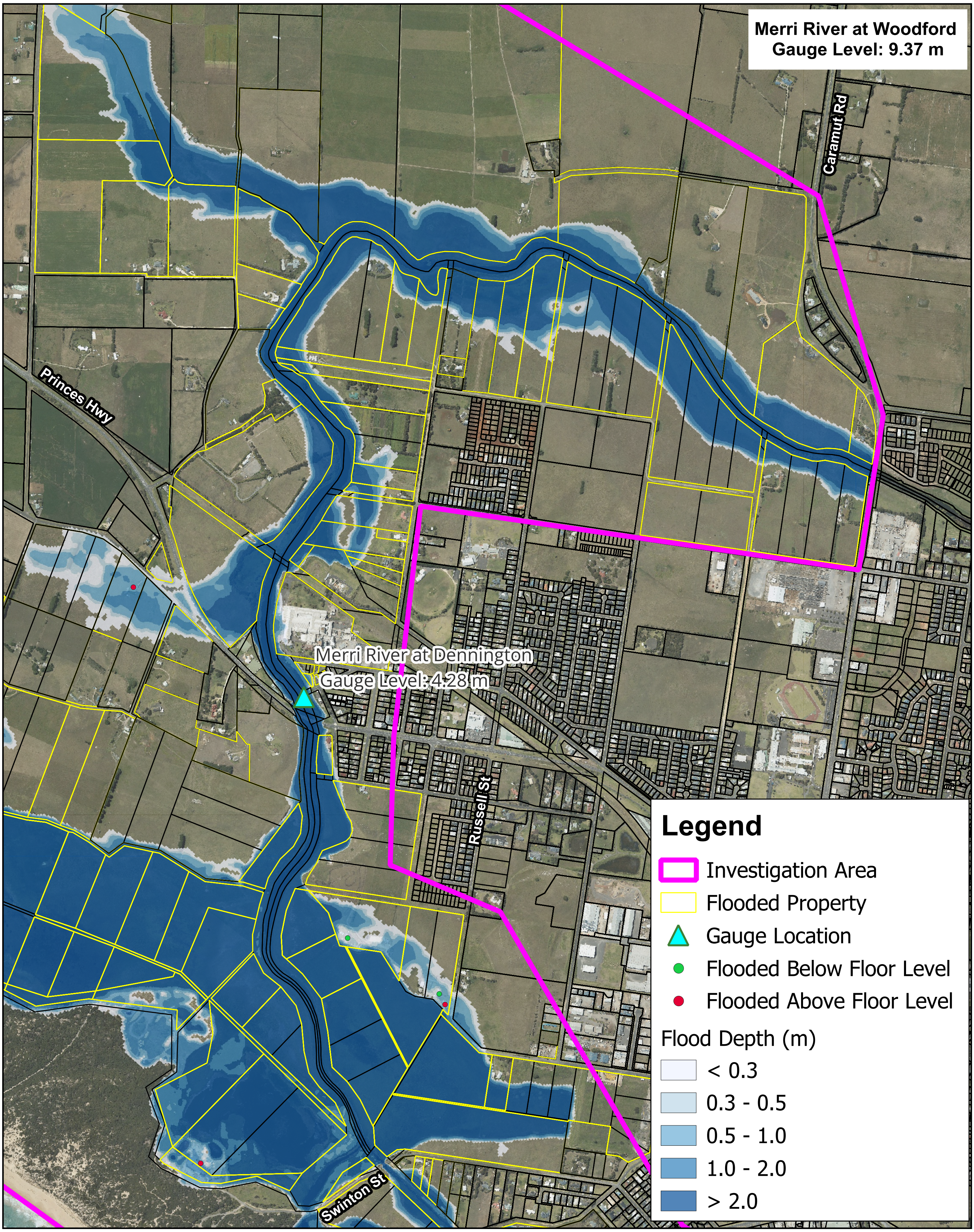
Venant Solutions (2025b), *South Warrnambool and Dennington Flood Investigation Flood Warning Feasibility Assessment Report*, Venant Solutions, Doc. Ref: R.M00407.004.00_Warning.

Water Technology (2007a), *South Warrnambool Flood Study – Study Report*, Water Technology.

Water Technology (2007b), *Dennington Flood Study – Study Report*, Water Technology.

Werritty A, Houston D, Ball T, Tavendale A, Black A (2007), *Exploring the Social Impacts of Flood Risk and Flooding in Scotland*, Scottish Executive Social Research, Scotland.

Appendix A Flood depth mapping



Title:

South Warrnambool and Dennington Flood Investigation - Current Climate
1% AEP Riverine Peak Flood Depth (North)

Figure:	Rev:			By: TL	
A-1	A	0 0.35 0.7 km	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	Date: Feb 2025	VENANT SOLUTIONS www.venantsolutions.com.au

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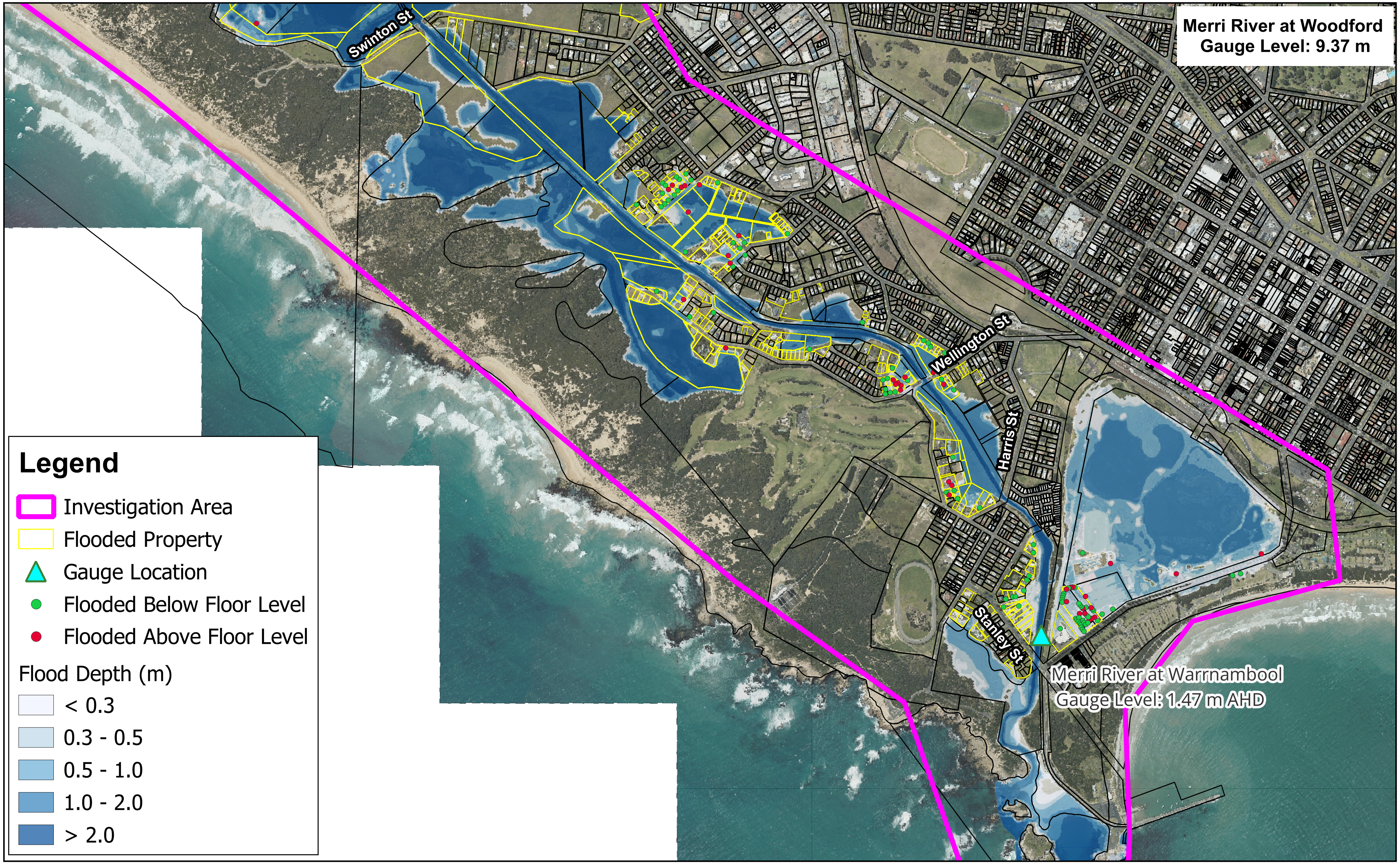

Title: South Warrnambool and Dennington Flood Investigation - Current Climate
1% AEP Riverine Peak Flood Depth (East)

Figure: A-2

Rev: A

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

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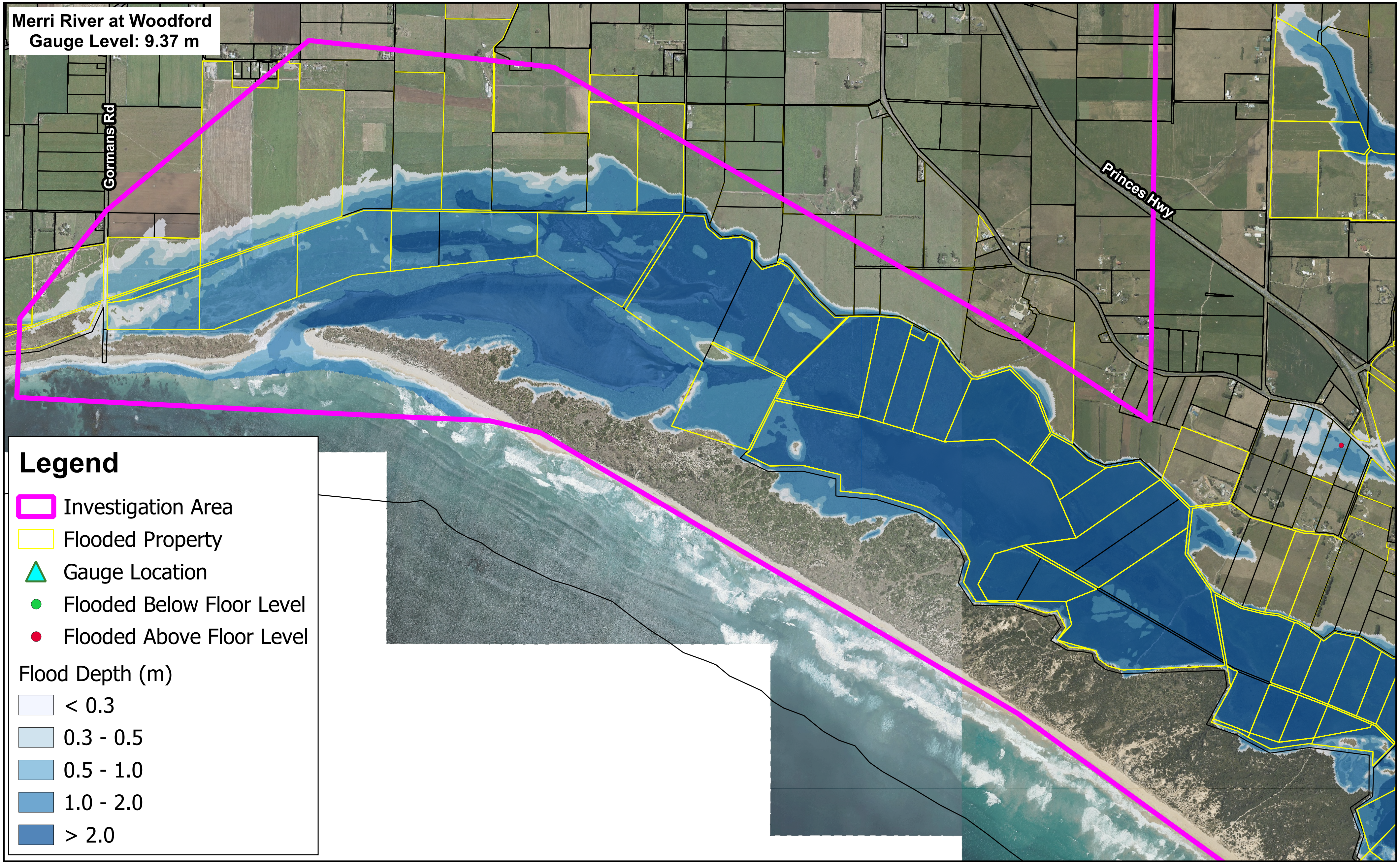
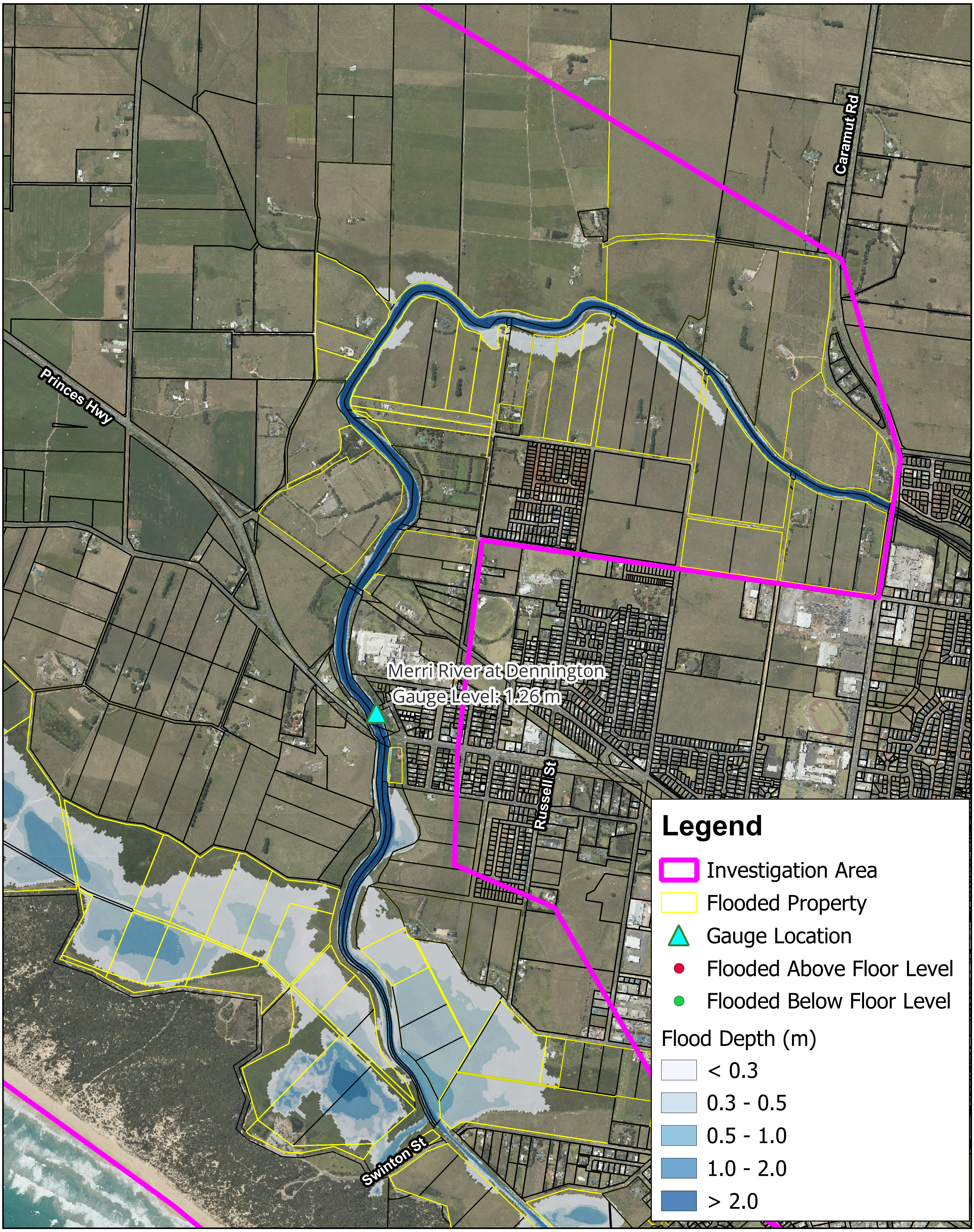


Title: South Warrnambool and Dennington Flood Investigation - Current Climate 1% AEP Riverine Peak Flood Depth (West)	Figure: A-3	Rev: A	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	VENANT SOLUTIONS
Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigA-3_West_SWFS_E01_RIV_RF1pc_36hr_tp9_TH_MHHW_047_d_Max.qgz			By: TL Feb 2025	www.VenantSolutions.com.au



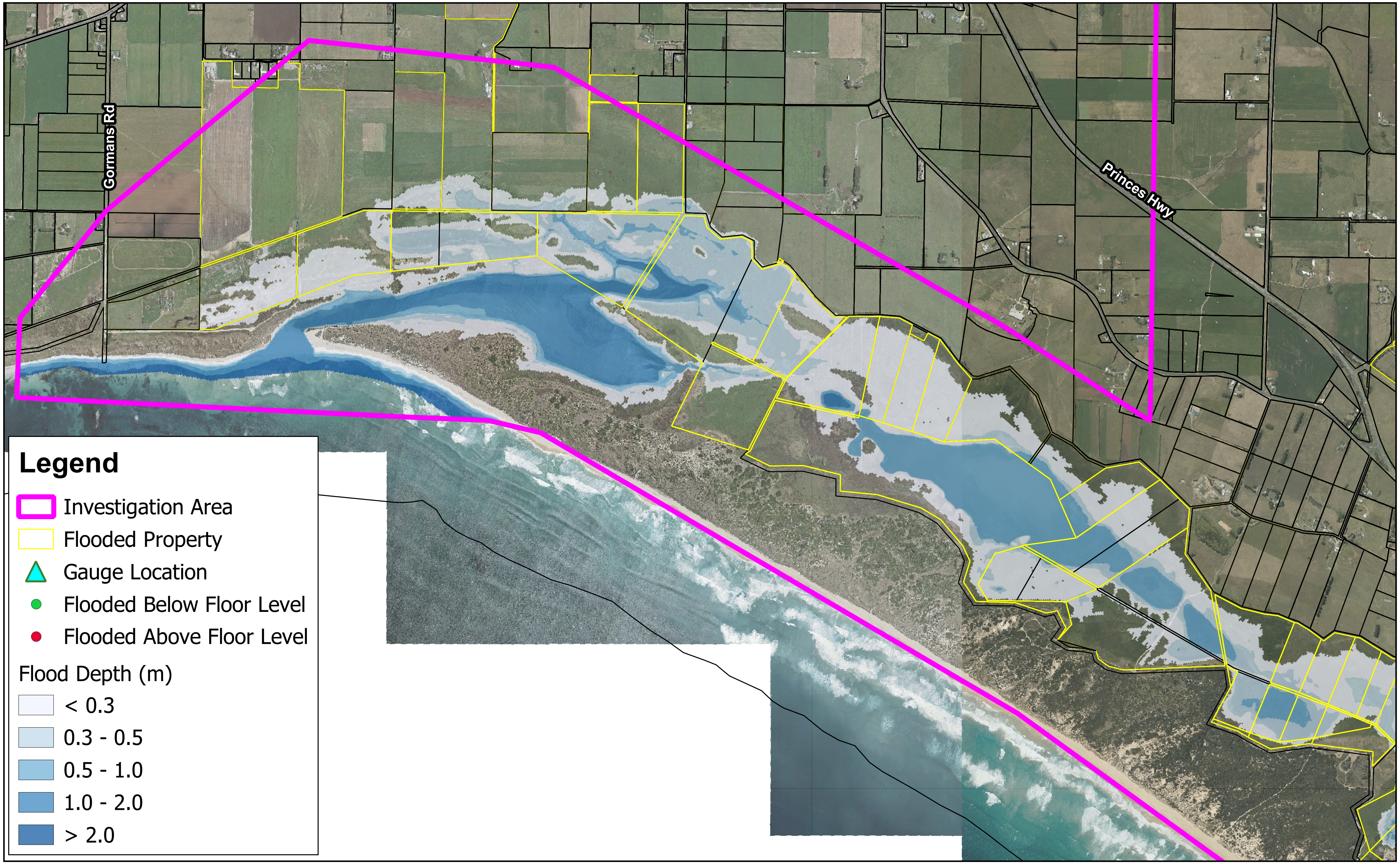
Title:

South Warrnambool and Dennington Flood Investigation - Current Climate
1% AEP Storm Tide Peak Flood Depth (North)

Figure:	Rev:				
A-4	A	0 0.35 0.7 km	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	By: TL Date: Feb 2025	VENANT SOLUTIONS www.venantsolutions.com.au

Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigA-4_North_SWFS_E01_TIDE_RFno_0hr_tp0_TH1pc_047_d_Max.qgz

Title: South Warrnambool and Dennington Flood Investigation - Current Climate 1% AEP Storm Tide Peak Flood Depth (East)	Figure: A-5	Rev: A	0 350 700 m	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	VENANT SOLUTIONS
Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigA-5_East_SWFS_E01_TIDE_RFno_0hr_tp0_TH1pc_047_d_Max.qgz				By: TL Feb 2025	www.VenantSolutions.com.au



Title: South Warrnambool and Dennington Flood Investigation - Current Climate 1% AEP Storm Tide Peak Flood Depth (West)

Figure:	Rev:	
A-6	A	0 400 800 m

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

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Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigA-6_West_SWFS_E01_TIDE_RFno_0hr_tp0_TH1pc_047_d_Max.qgz

By: TL

Feb 2025

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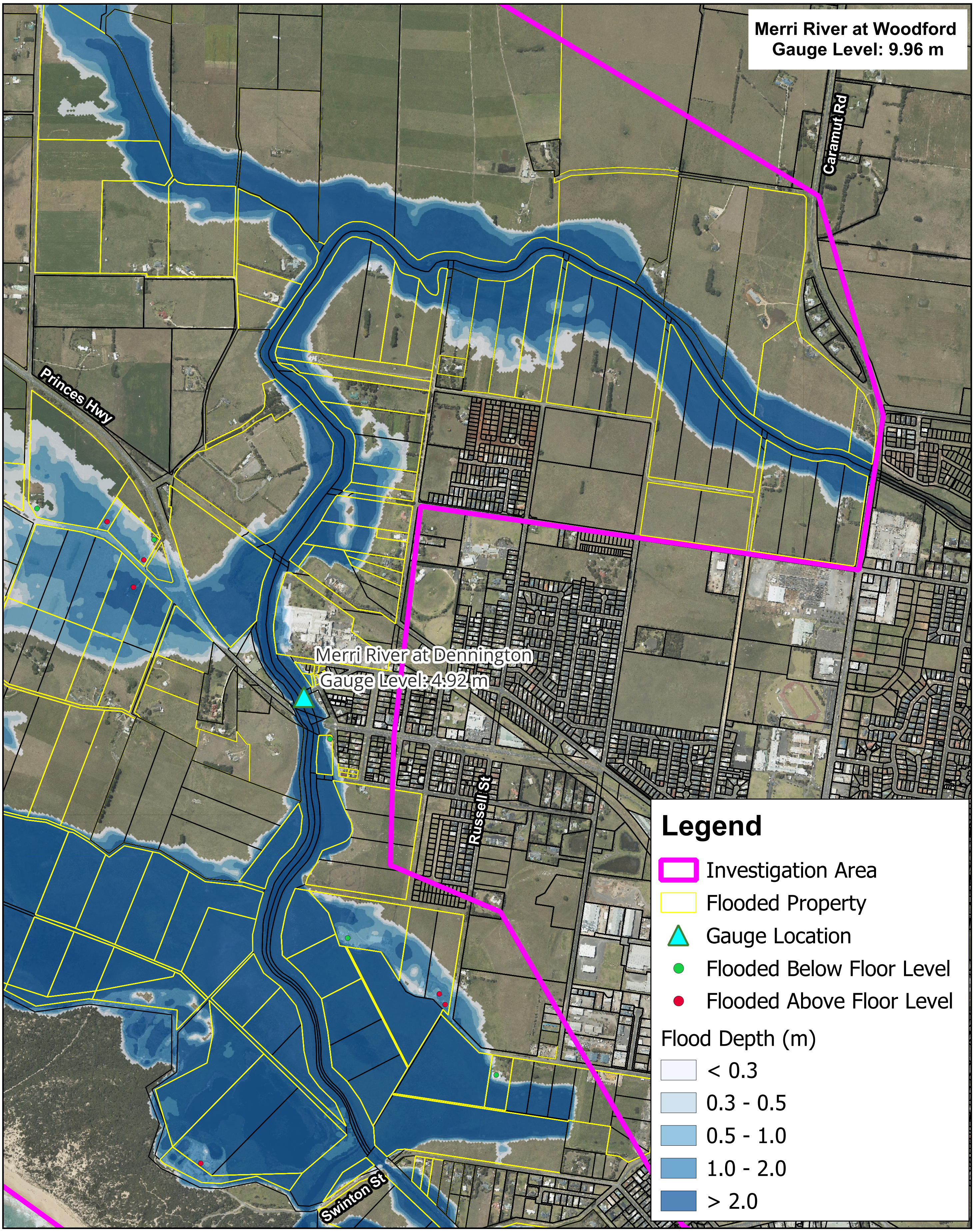
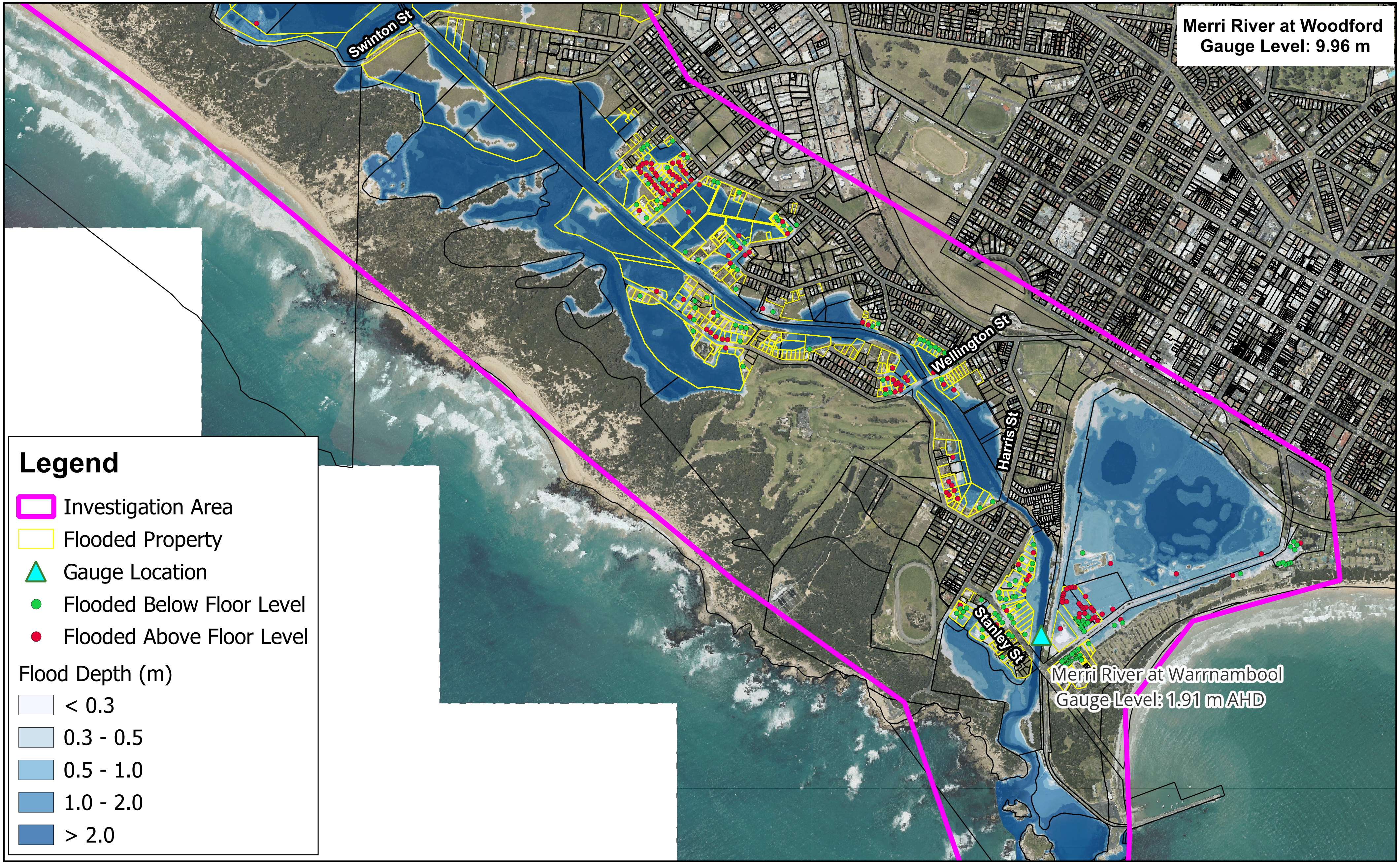


Title:

South Warrnambool and Dennington Flood Investigation - Climate Change 2
1% AEP Riverine Peak Flood Depth (North)

Figure:	Rev:	0 0.35 0.7 km	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	By: TL	VENANT SOLUTIONS
A-7	A			Date: Feb 2025	www.venantsolutions.com.au

Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigA-7_North_SWFS_CC2_RIV_RF1pc_36hr_tp9_TH_MHHW_047_d_Max.qgz



Title: South Warrnambool and Dennington Flood Investigation - Climate Change 2
1% AEP Riverine Peak Flood Depth (East)

Figure: A-8

Rev: A

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

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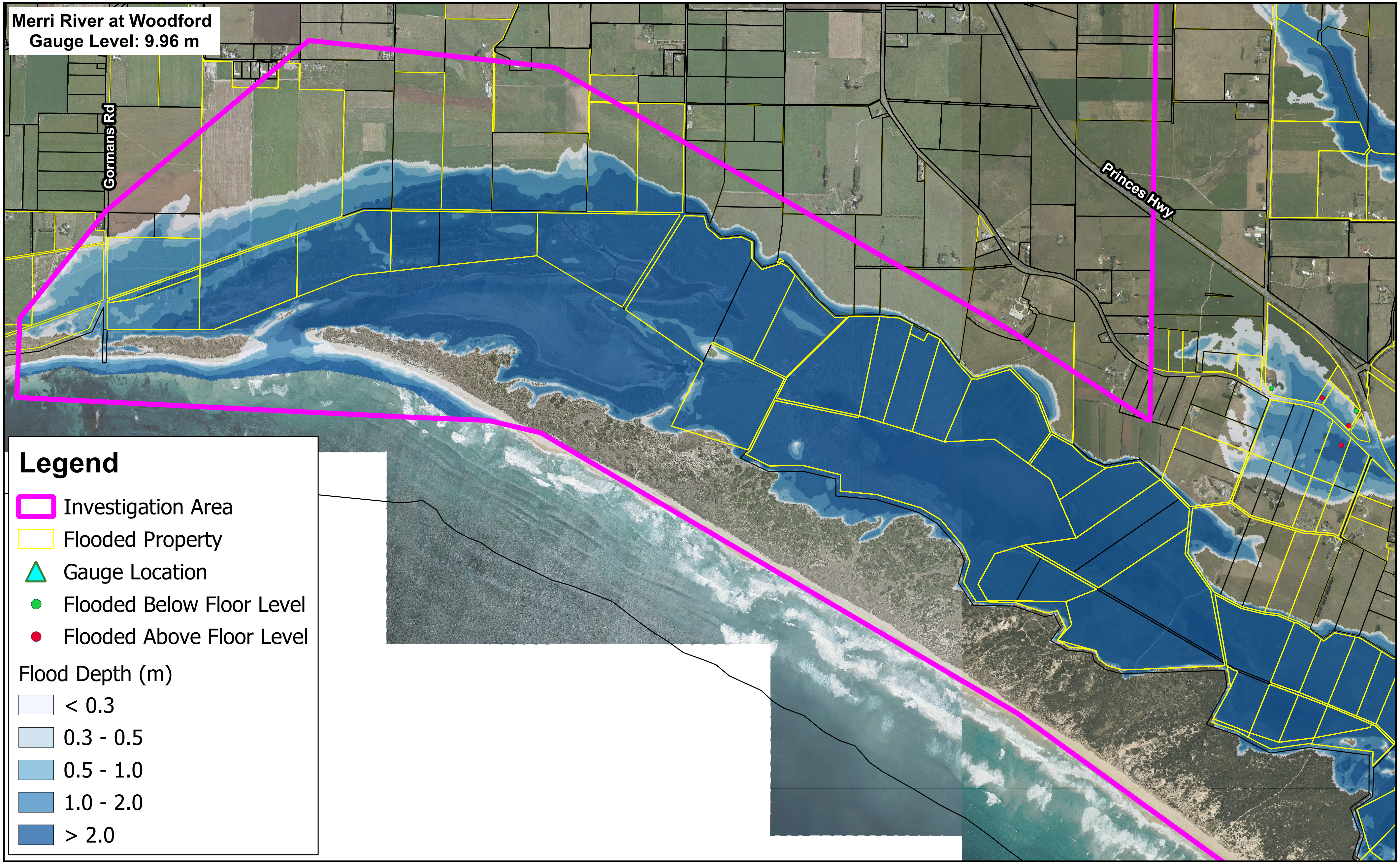
Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigA-8_East_SWFS_CC2_RIV_RF1pc_36hr_tp9_TH_MHHW_047_d_Max.qgz

By: TL

Feb 2025



Title: South Warrnambool and Dennington Flood Investigation - Climate Change 2
1% AEP Riverine Peak Flood Depth (West)

Figure:	Rev:
A-9	A

0 400 800 m

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

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Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigA-9_West_SWFS_CC2_RIV_RF1pc_36hr_tp9_TH_MHHW_047_d_Max.qgz

By: TL | Feb 2025

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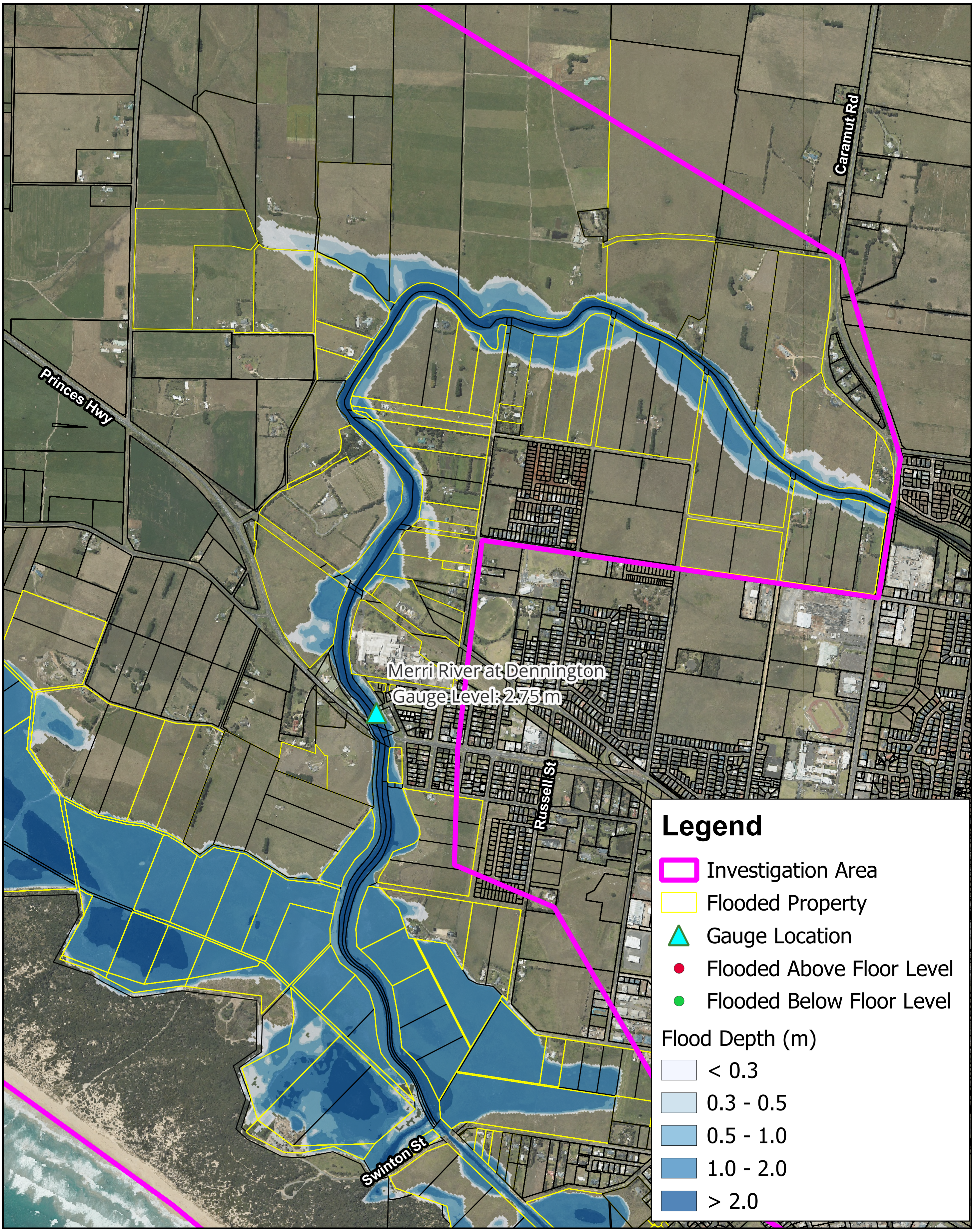

Title:

South Warrnambool and Dennington Flood Investigation - Climate Change 2
1% AEP Storm Tide Peak Flood Depth (North)

Figure:	Rev:	Scale	Disclaimer		
A-10	A	0 0.35 0.7 km	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	By: TL Date: Feb 2025	VENANT SOLUTIONS www.venantsolutions.com.au

Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigA-10_North_SWFS_CC2_TIDE_RFno_0hr_tp0_TH1pc_047_d_Max.qgz

Title: South Warrnambool and Dennington Flood Investigation - Climate Change 2
1% AEP Storm Tide Peak Flood Depth (East)

Figure: A-11

Rev: A

0 350 700 m

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

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Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigA-11_East_SWFS_CC2_TIDE_RFno_0hr_tp0_TH1pc_047_d_Max.qgz

By: TL

Feb 2025

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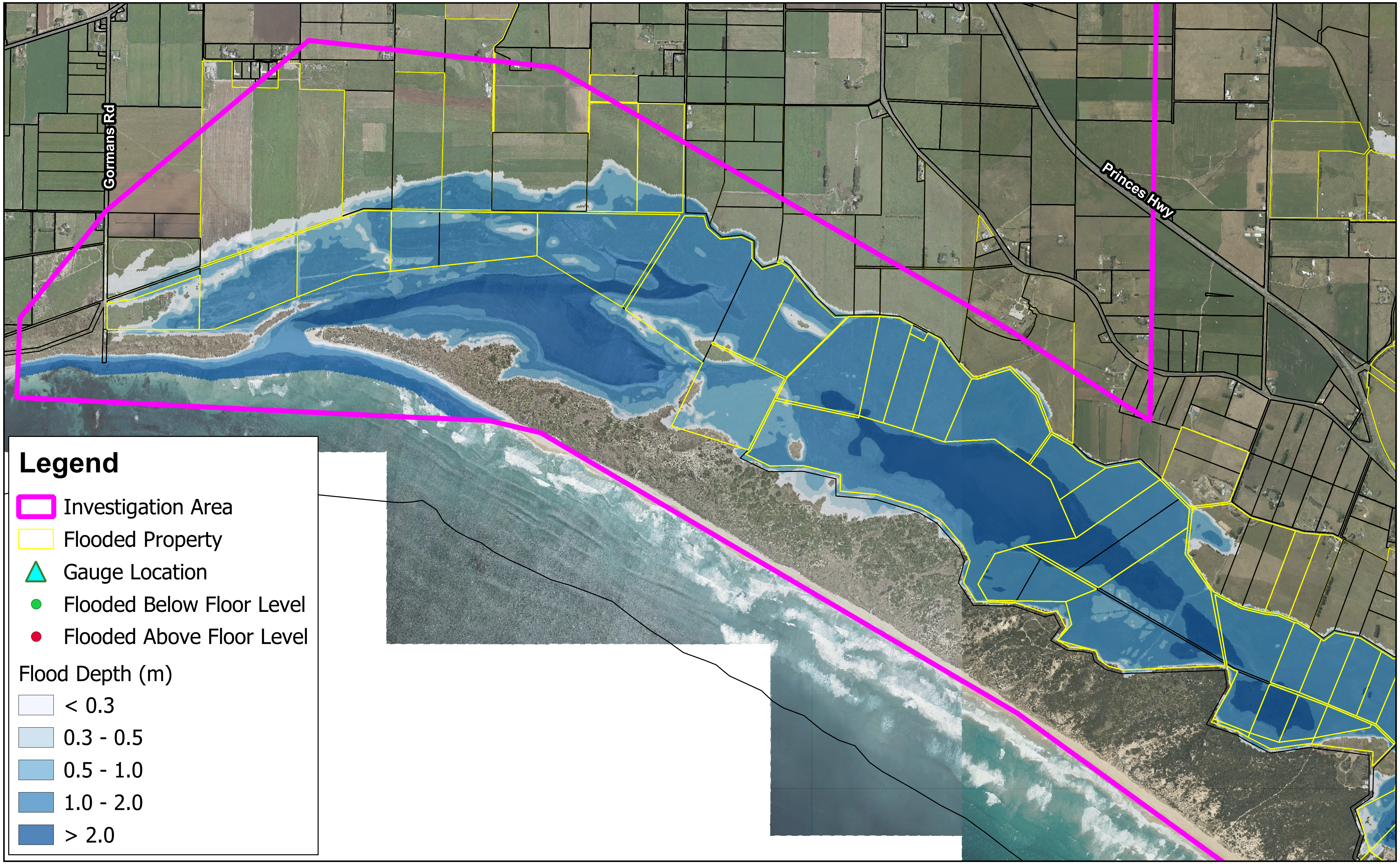

Title:
South Warrnambool and Dennington Flood Investigation - Climate Change 2
1% AEP Storm Tide Peak Flood Depth (West)

Figure: A-12

Rev: A

0 400 800 m

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

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Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigA-12_West_SWFS_CC2_TIDE_RFno_0hr_tp0_TH1pc_047_d_Max.qgz

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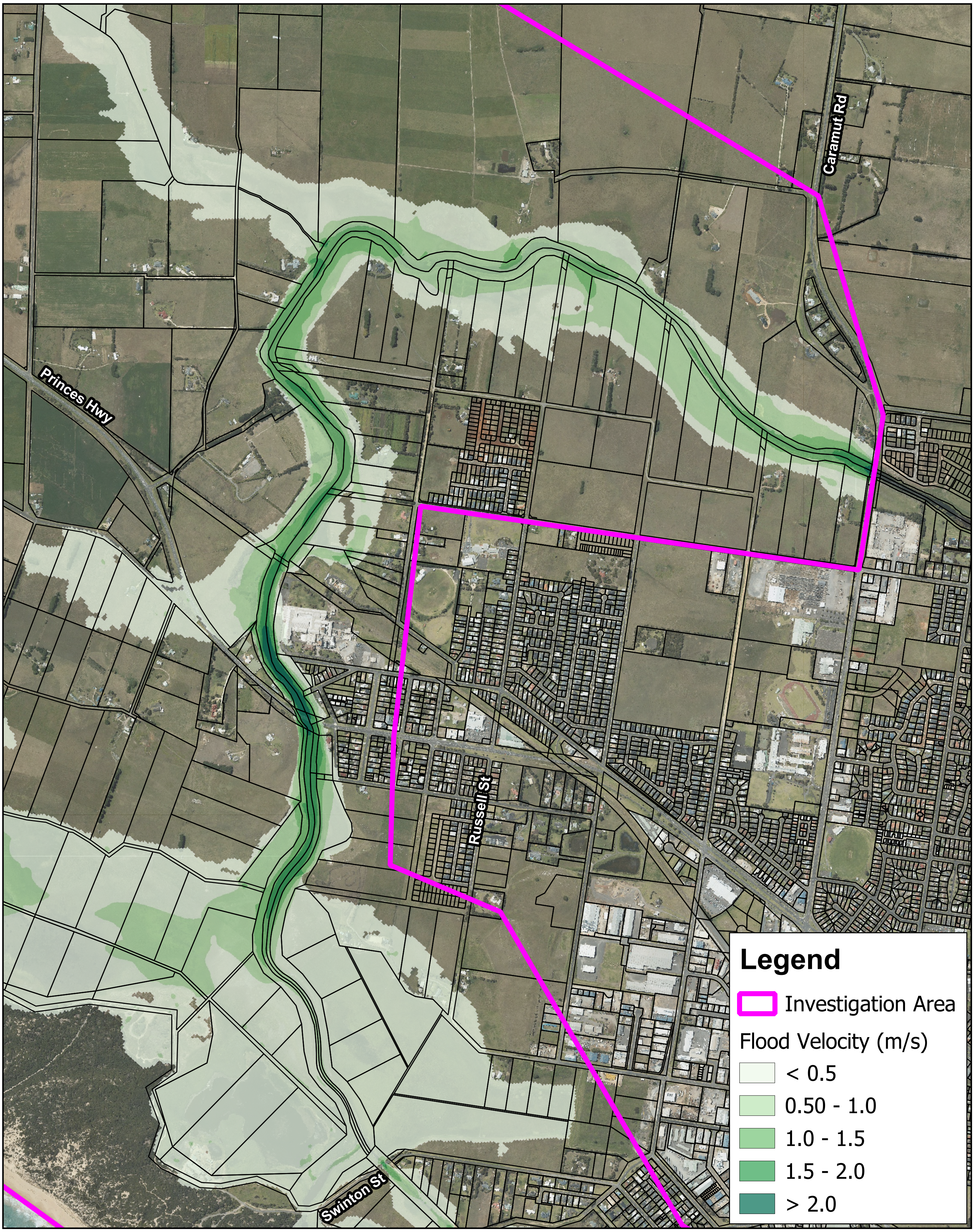
Appendix B Flood velocity mapping



Title:

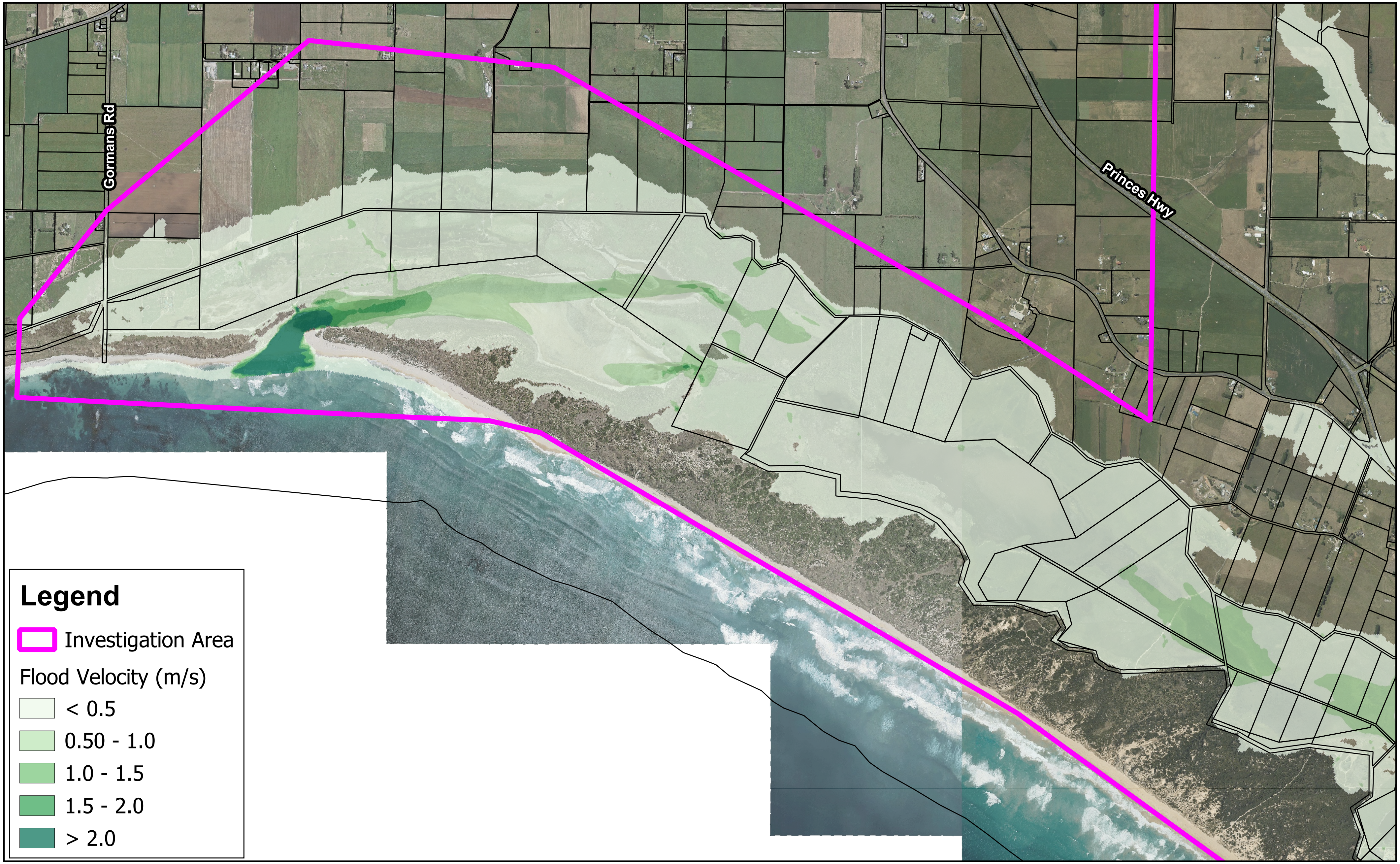
South Warrnambool and Dennington Flood Investigation - Current Climate
1% AEP Riverine Peak Flood Velocity (North)

Figure:	Rev:	0 0.35 0.7 km		By: TL	
B-1	A		This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	Date: Feb 2025	VENANT SOLUTIONS www.venantsolutions.com.au

Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigB-1_North_SWFS_E01_RIV_RF1pc_36hr_tp9_TH_MHHW_047_V_Max.qgz

Title: South Warrnambool and Dennington Flood Investigation - Current Climate 1% AEP Riverine Peak Flood Velocity (East)	Figure: B-2	Rev: A	0 350 700 m	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	VENANT SOLUTIONS www.VenantSolutions.com.au

Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigB-2_East_SWFS_E01_RIV_RF1pc_36hr_tp9_TH_MHHW_047_V_Max.qgz | By: TL | Feb 2025



Title: South Warrnambool and Dennington Flood Investigation - Current Climate
1% AEP Riverine Peak Flood Velocity (West)

Figure: B-3

Rev: A

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

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Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigB-3_West_SWFS_E01_RIV_RF1pc_36hr_tp9_TH_MHHW_047_V_Max.qgz

By: TL

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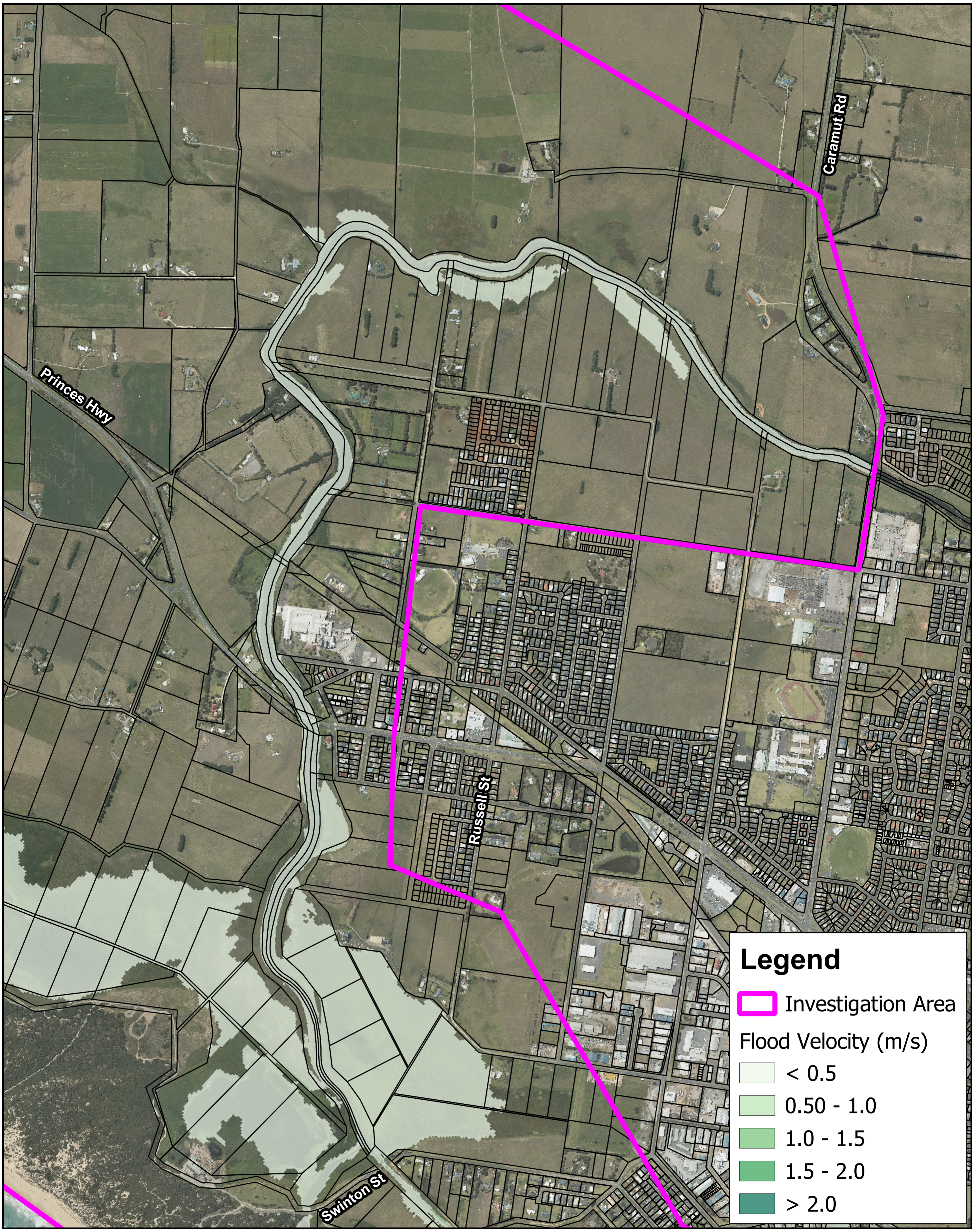

Title:

South Warrnambool and Dennington Flood Investigation - Current Climate
1% AEP Storm Tide Peak Flood Velocity (North)

Figure:	Rev:			By	
B-4	A	0 0.35 0.7 km	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	By: TL Date: Feb 2025	VENANT SOLUTIONS www.venantsolutions.com.au

Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigB-4_North_SWFS_E01_TIDE_RFno_0hr_tp0_TH1pc_047_V_Max.qgz

Title:
South Warrnambool and Dennington Flood Investigation - Current Climate
1% AEP Storm Tide Peak Flood Velocity (East)

Figure: B-5

Rev: A

0 350 700 m

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

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Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigB-5_East_SWFS_E01_TIDE_RFno_0hr_tp0_TH1pc_047_V_Max.qgz

By: TL

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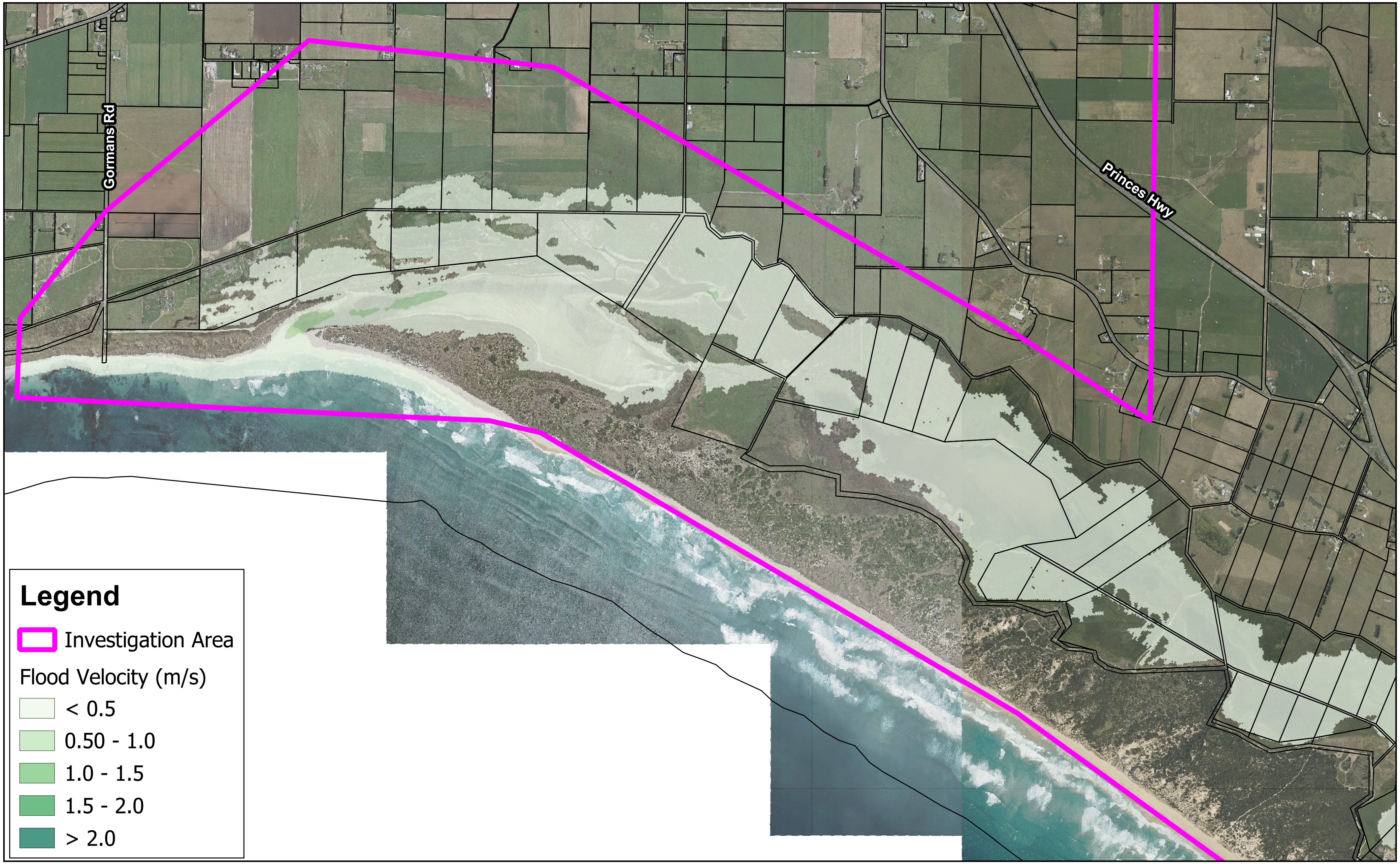

Title: South Warrnambool and Dennington Flood Investigation - Current Climate
1% AEP Storm Tide Peak Flood Velocity (West)

Figure: B-6

Rev: A

0 400 800 m

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

VENANT SOLUTIONS

Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigB-6_West_SWFS_E01_TIDE_RFno_0hr_tp0_TH1pc_047_V_Max.qgz

By: TL | Feb 2025

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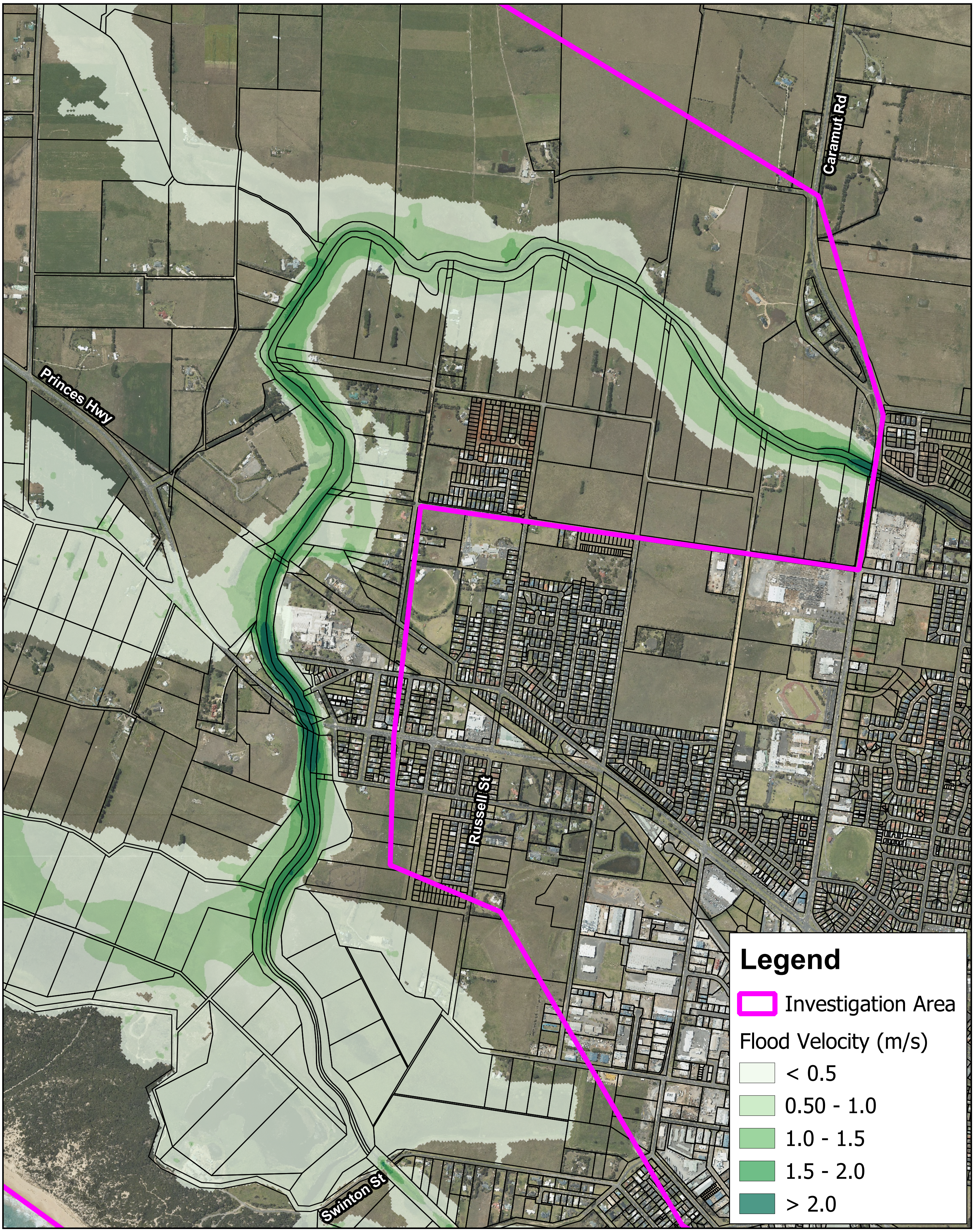

Title:

South Warrnambool and Dennington Flood Investigation - Climate Change 2
1% AEP Riverine Peak Flood Velocity (North)

Figure:	Rev:				
B-7	A	0 0.35 0.7 km	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	By: TL Date: Feb 2025	VENANT SOLUTIONS www.venantsolutions.com.au

Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigB-7_North_SWFS_CC2_RIV_RF1pc_36hr_tp9_TH_MHHW_047_V_Max.qgz

Title: South Warrnambool and Dennington Flood Investigation - Climate Change 2
1% AEP Riverine Peak Flood Velocity (East)

Figure:	Rev:
B-8	A

0 350 700 m

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

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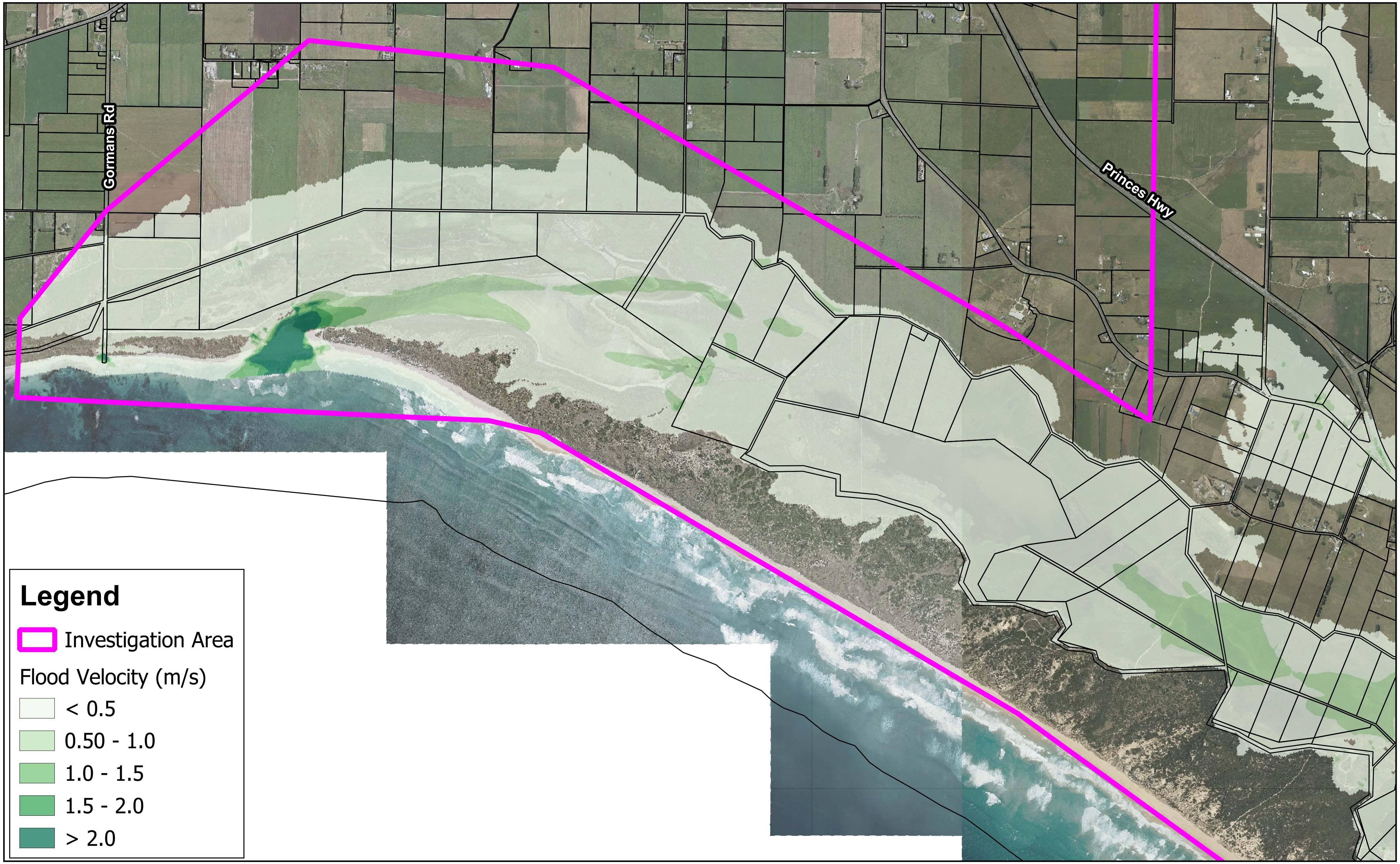
Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigB-8_East_SWFS_CC2_RIV_RF1pc_36hr_tp9_TH_MHHW_047_V_Max.qgz

By: TL | Feb 2025



Title: South Warrnambool and Dennington Flood Investigation - Climate Change 2
1% AEP Riverine Peak Flood Velocity (West)

Figure: B-9

Rev: A

0 400 800 m

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

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Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigB-9_West_SWFS_CC2_RIV_RF1pc_36hr_tp9_TH_MHHW_047_V_Max.qgz

By: TL

Feb 2025

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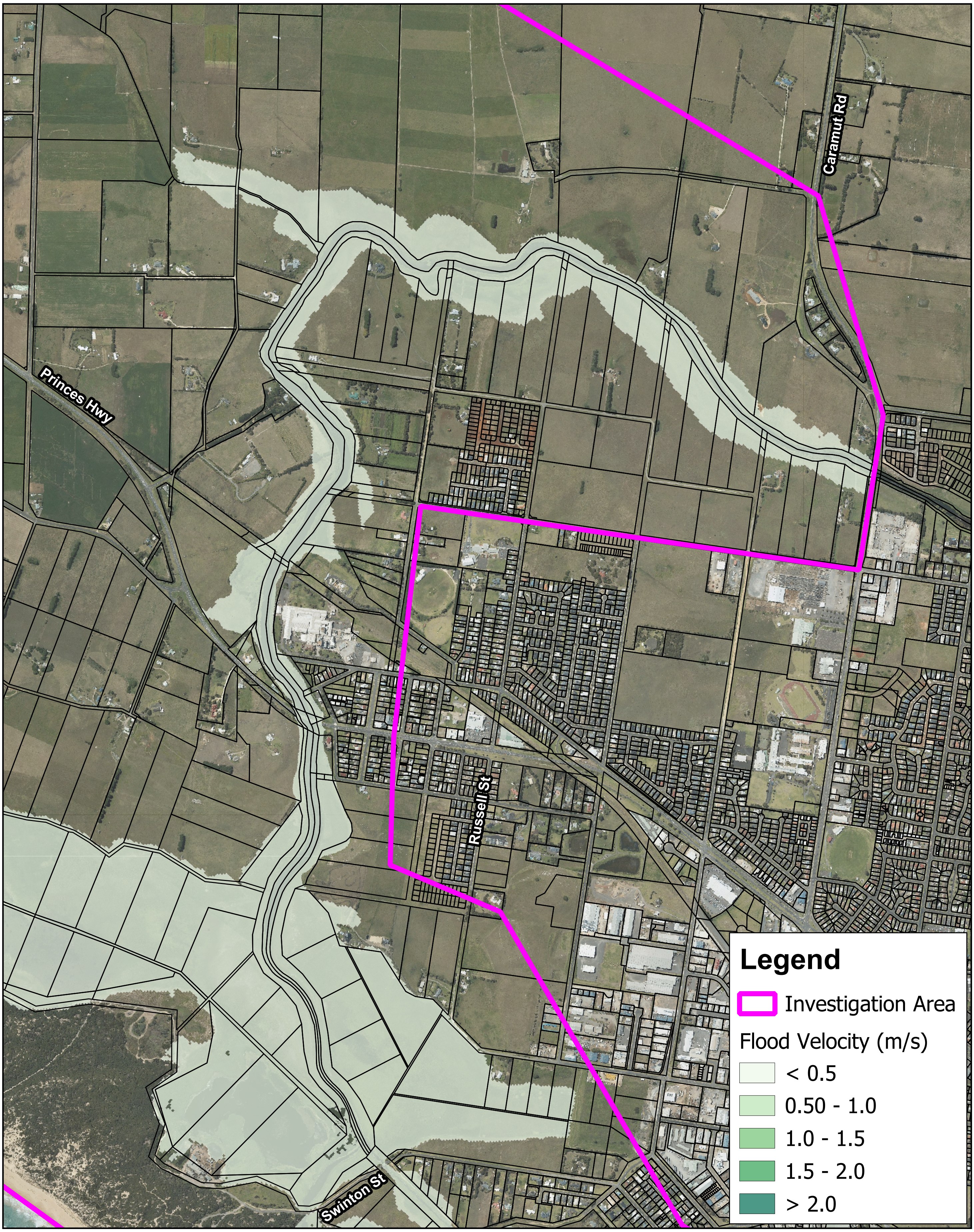

Title: South Warrnambool and Dennington Flood Investigation - Climate Change 2
1% AEP Storm Tide Peak Flood Velocity (North)

Figure:	Rev:	Scale	Disclaimer		
B-10	A	0 0.35 0.7 km	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	By: TL Date: Feb 2025	VENANT SOLUTIONS www.venantsolutions.com.au

Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigB-10_North_SWFS_CC2_TIDE_RFno_0hr_tp0_TH1pc_047_V_Max.qgz

Title: South Warrnambool and Dennington Flood Investigation - Climate Change 2
1% AEP Storm Tide Peak Flood Velocity (East)

Figure: B-11

Rev: A

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

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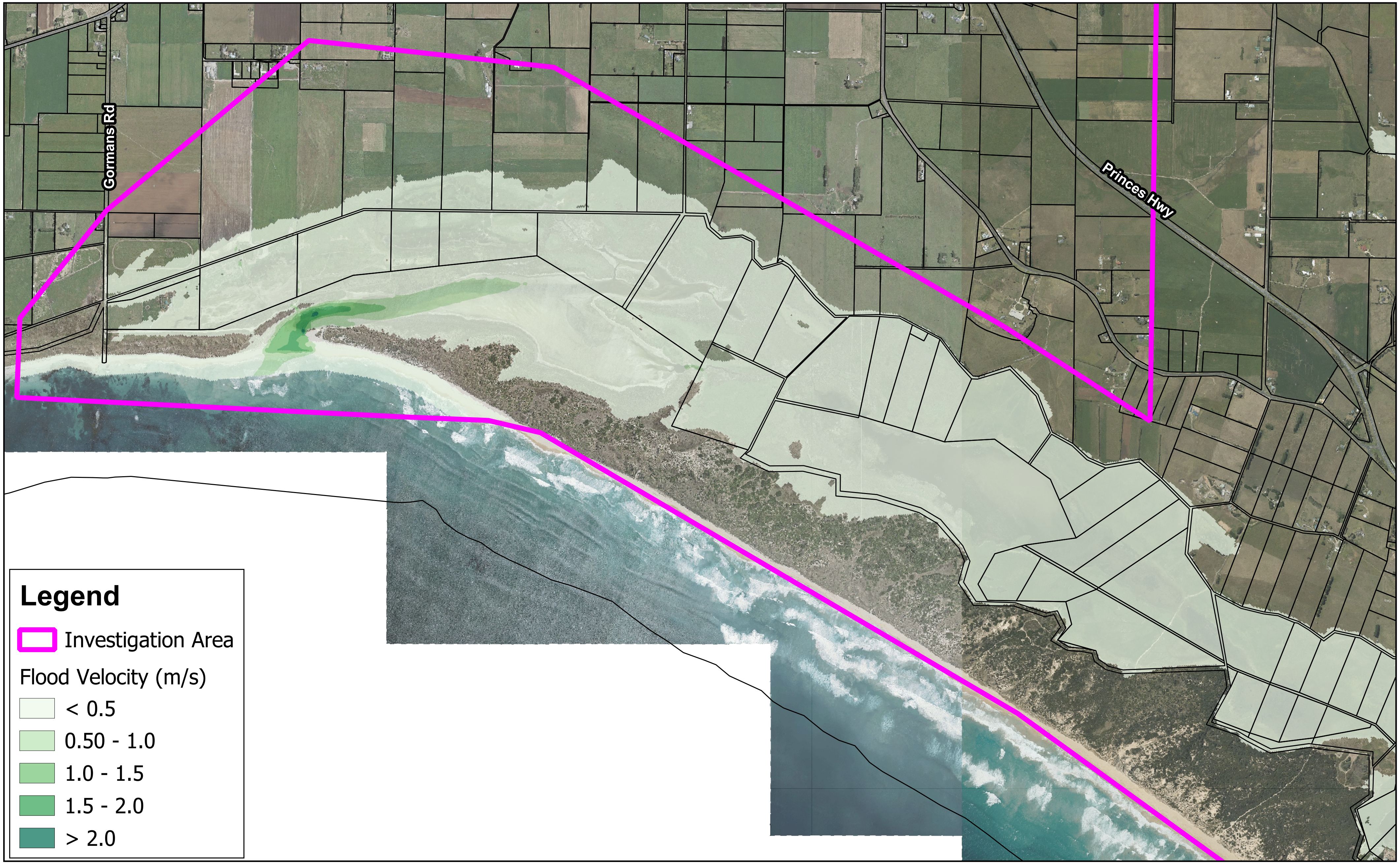
Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigB-11_East_SWFS_CC2_TIDE_RFno_0hr_tp0_TH1pc_047_V_Max.qgz

By: TL

Feb 2025



Title: South Warrnambool and Dennington Flood Investigation - Climate Change 2
1% AEP Storm Tide Peak Flood Velocity (West)

Figure: B-12

Rev: A

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

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Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigB-12_West_SWFS_CC2_TIDE_RFno_0hr_tp0_TH1pc_047_V_Max.qgz

By: TL

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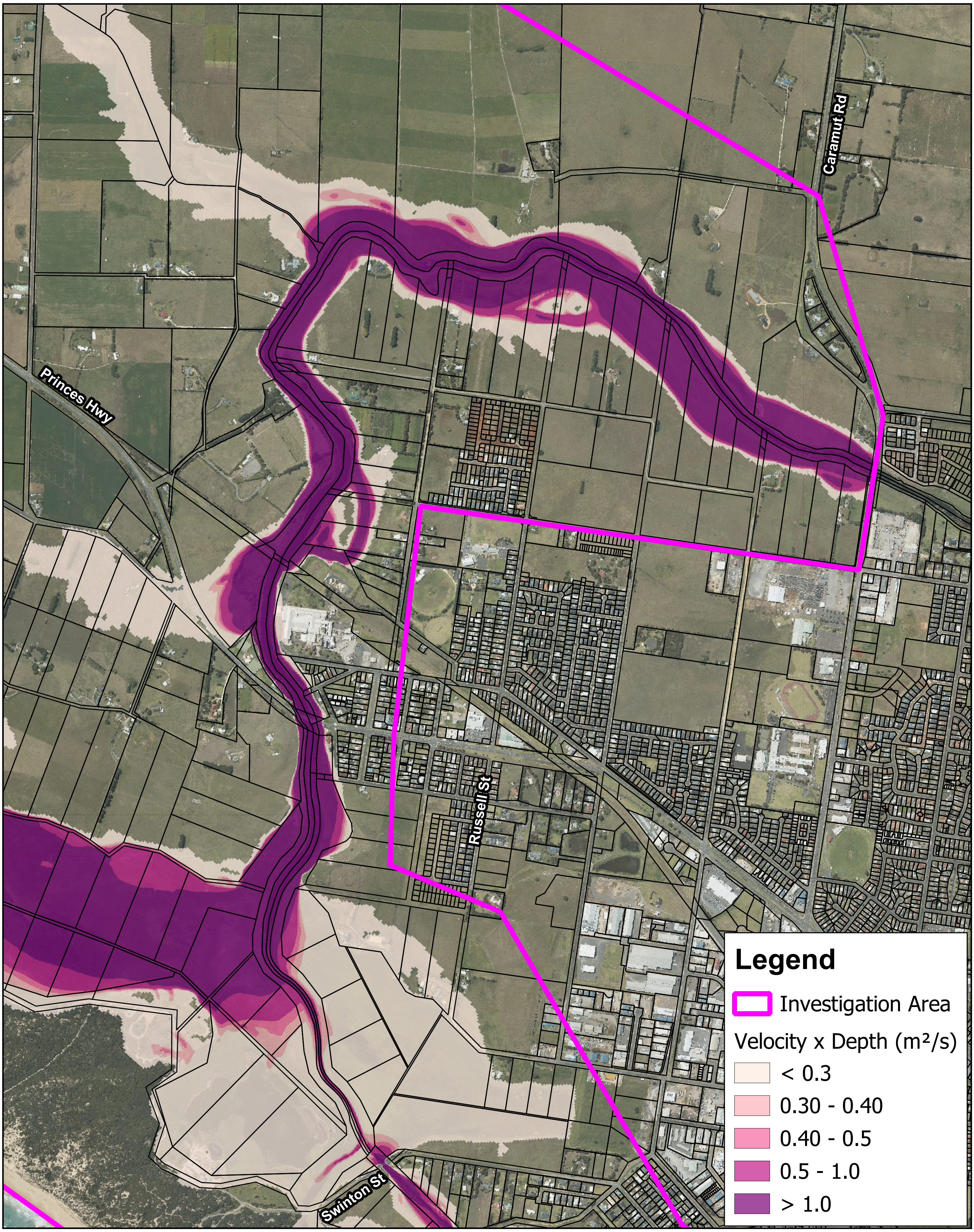
Appendix C Flood velocity x depth mapping

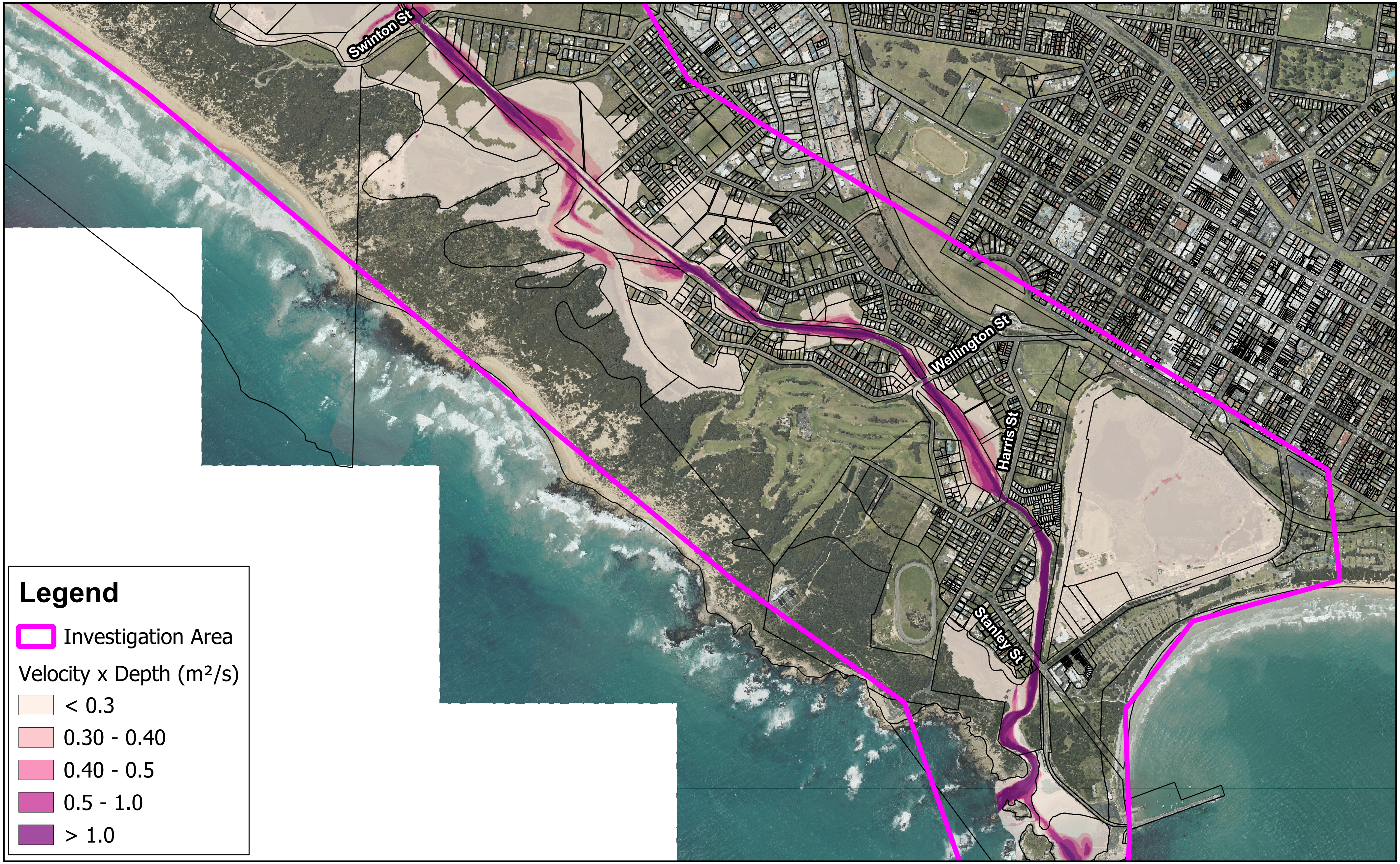


Title:

South Warrnambool and Dennington Flood Investigation - Current Climate
1% AEP Riverine Peak Flood Velocity x Depth (North)

Figure:	Rev:	Scale	Disclaimer	By / Date	
C-1	A	0 0.35 0.7 km	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	By: TL Date: Feb 2025	VENANT SOLUTIONS www.venantsolutions.com.au

Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigC-1_North_SWFS_E01_RIV_RF1pc_36hr_tp9_TH_MHHW_047_Z0_Max.qgz



Title: South Warrnambool and Dennington Flood Investigation - Current Climate 1% AEP Riverine Peak Flood Velocity x Depth (East)

Figure: C-2

Rev: A

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

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Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigC-2_East_SWFS_E01_RIV_RF1pc_36hr_tp9_TH_MHHW_047_Z0_Max.qgz

By: TL

Feb 2025

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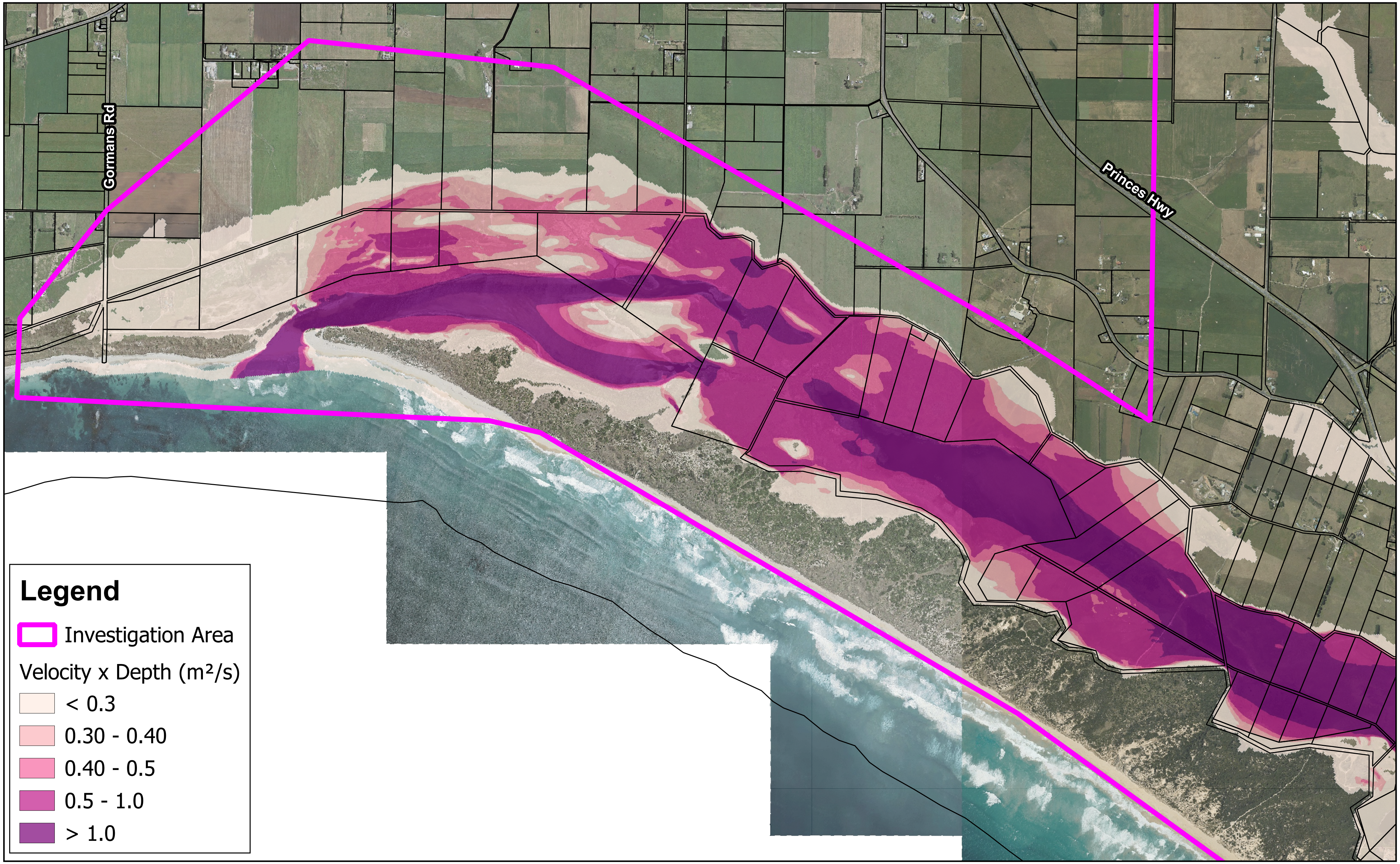

Title:
South Warrnambool and Dennington Flood Investigation - Current Climate
1% AEP Riverine Peak Flood Velocity x Depth (West)

Figure:	Rev:
C-3	A

0 400 800 m

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

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Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigC-3_West_SWFS_E01_RIV_RF1pc_36hr_tp9_TH_MHHW_047_Z0_Max.qgz

By: TL Feb 2025

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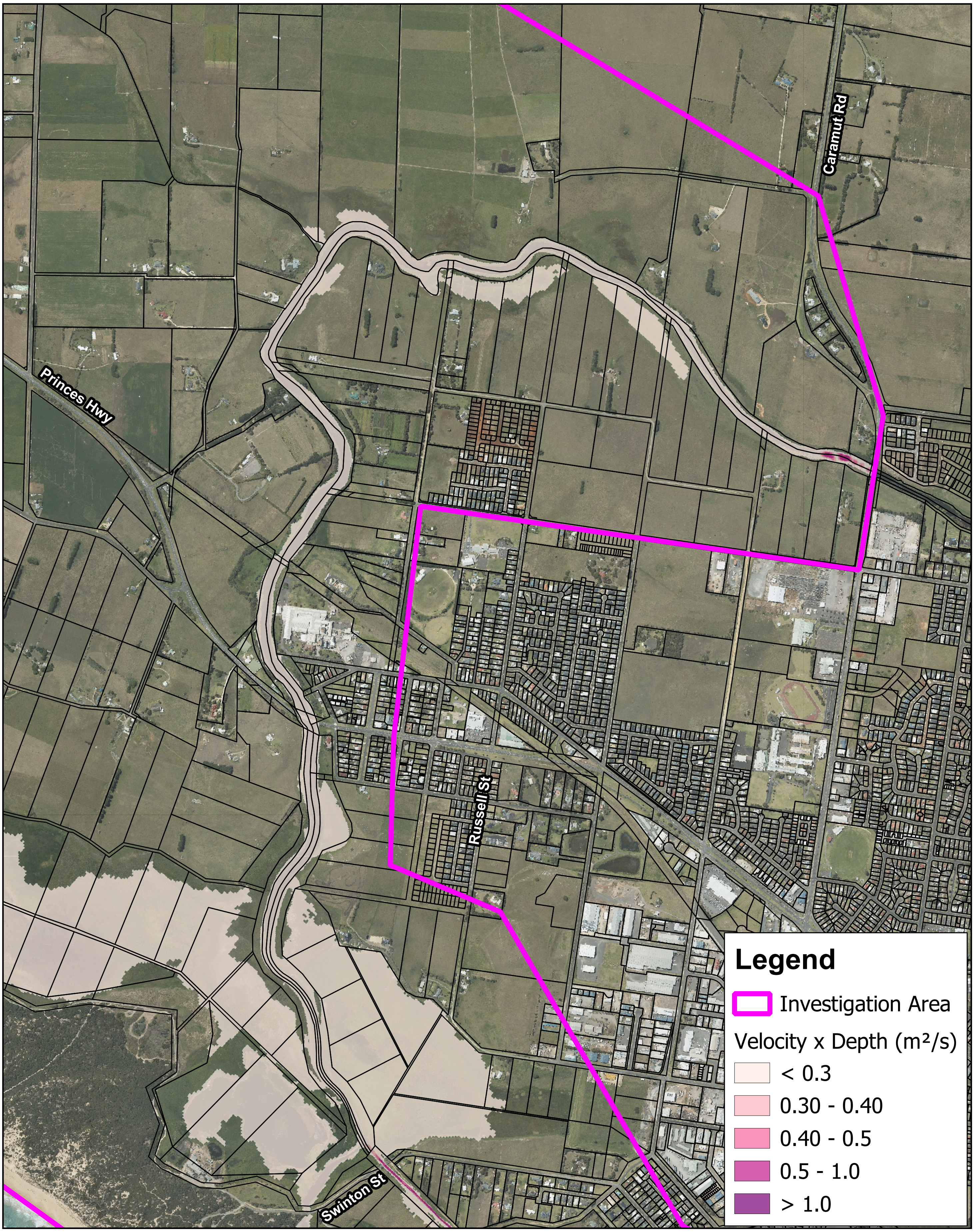

Title:

South Warrnambool and Dennington Flood Investigation - Current Climate
1% AEP Storm Tide Peak Flood Velocity x Depth (North)

Figure:	Rev:			By: TL	
C-4	A	0 0.35 0.7 km	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	Date: Feb 2025	VENANT SOLUTIONS www.venantsolutions.com.au

Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigC-4_North_SWFS_E01_TIDE_RFno_0hr_tp0_TH1pc_047_Z0_Max.qgz

Legend

Investigation Area

Velocity x Depth (m²/s)

- < 0.3
- 0.30 - 0.40
- 0.40 - 0.5
- 0.5 - 1.0
- > 1.0

0 350 700 m

Title: South Warrnambool and Dennington Flood Investigation - Current Climate
1% AEP Storm Tide Peak Flood Velocity x Depth (East)

Figure: C-5

Rev: A

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

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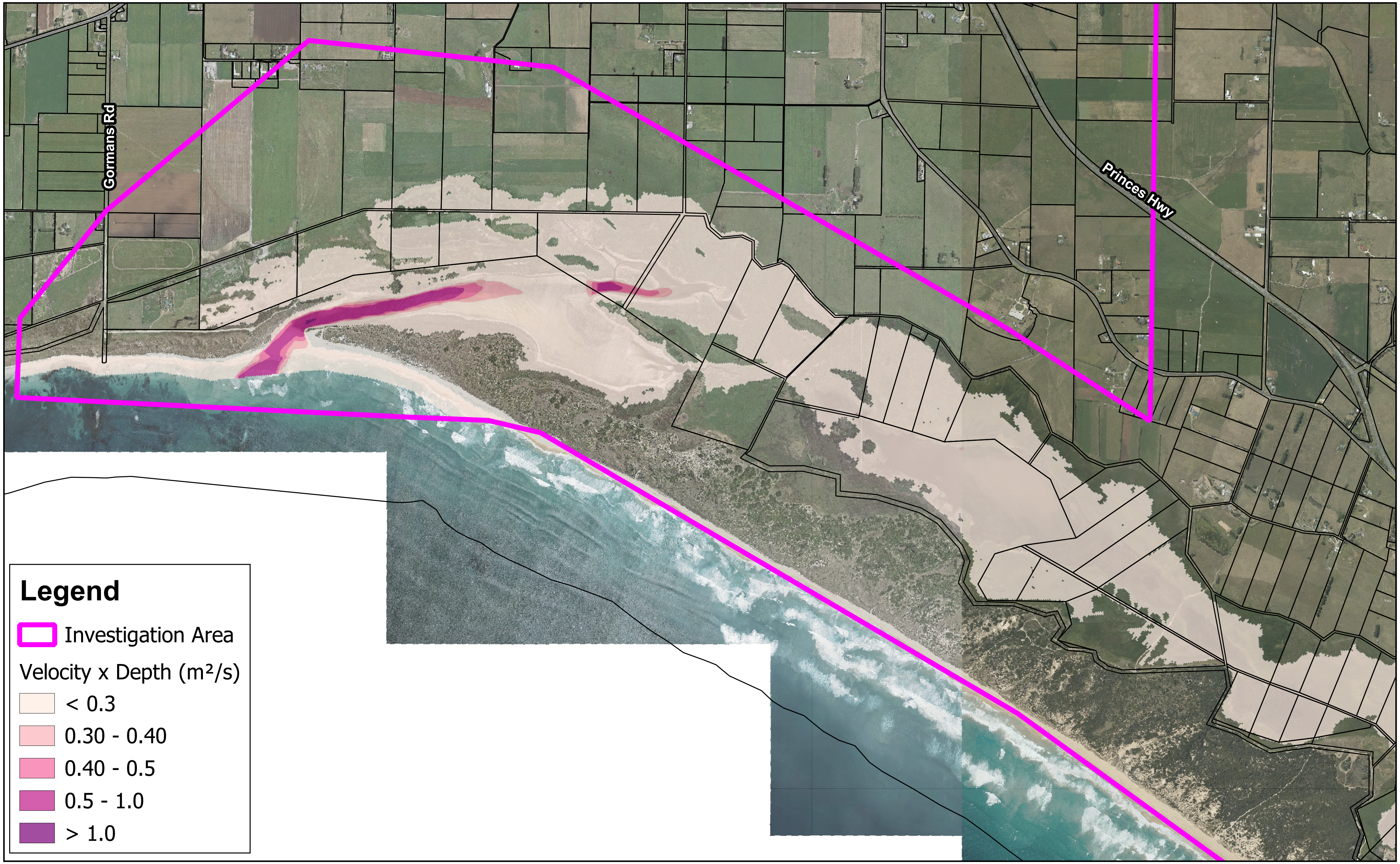
Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigC-5_East_SWFS_E01_TIDE_RFno_0hr_tp0_TH1pc_047_Z0_Max.qgz

By: TL

Feb 2025



Title: South Warrnambool and Dennington Flood Investigation - Current Climate
1% AEP Storm Tide Peak Flood Velocity x Depth (West)

Figure: C-6

Rev: A

0 400 800 m

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

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Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigC-6_West_SWFS_E01_TIDE_RFno_0hr_tp0_TH1pc_047_Z0_Max.qgz

By: TL

Feb 2025

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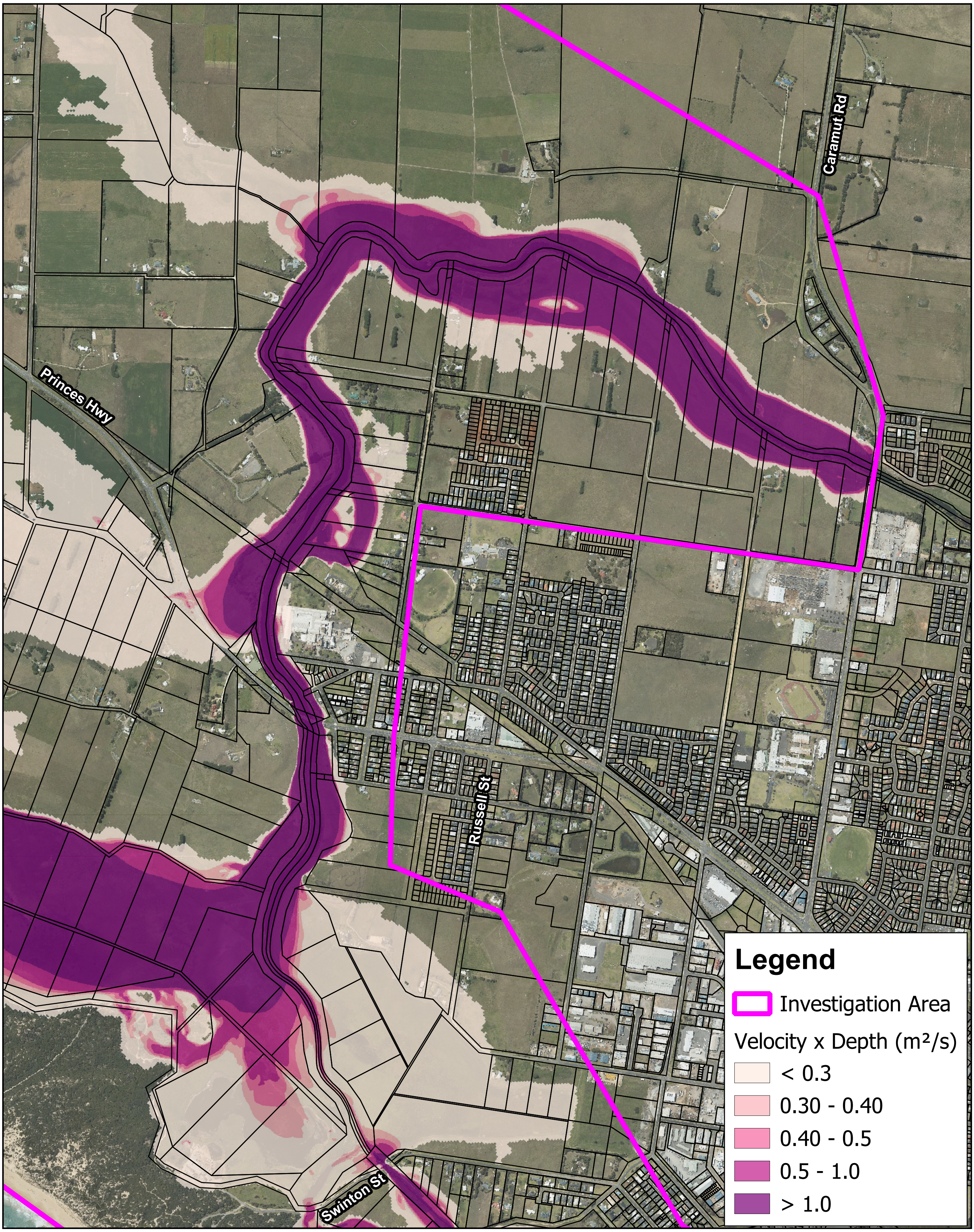
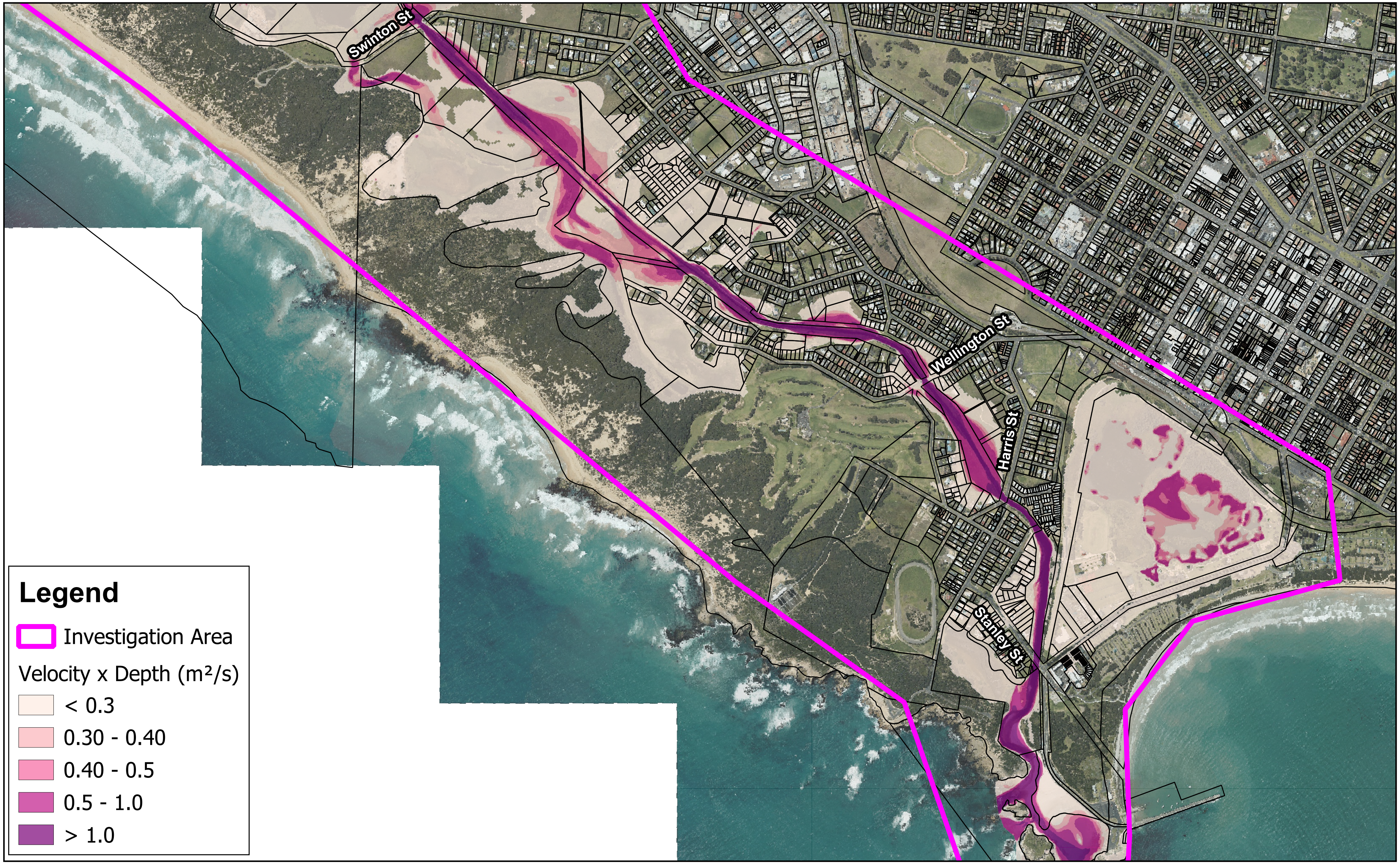


Title:

South Warrnambool and Dennington Flood Investigation - Climate Change 2
1% AEP Riverine Peak Flood Velocity x Depth (North)

Figure:	Rev:			By: TL	
C-7	A	0 0.35 0.7 km	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	Date: Feb 2025	VENANT SOLUTIONS www.venantsolutions.com.au

Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigC-7_North_SWFS_CC2_RIV_RF1pc_36hr_tp9_TH_MHHW_047_Z0_Max.qgz



Title:
South Warrnambool and Dennington Flood Investigation - Climate Change 2
1% AEP Riverine Peak Flood Velocity x Depth (East)

Figure: C-8

Rev: A

0 350 700 m

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

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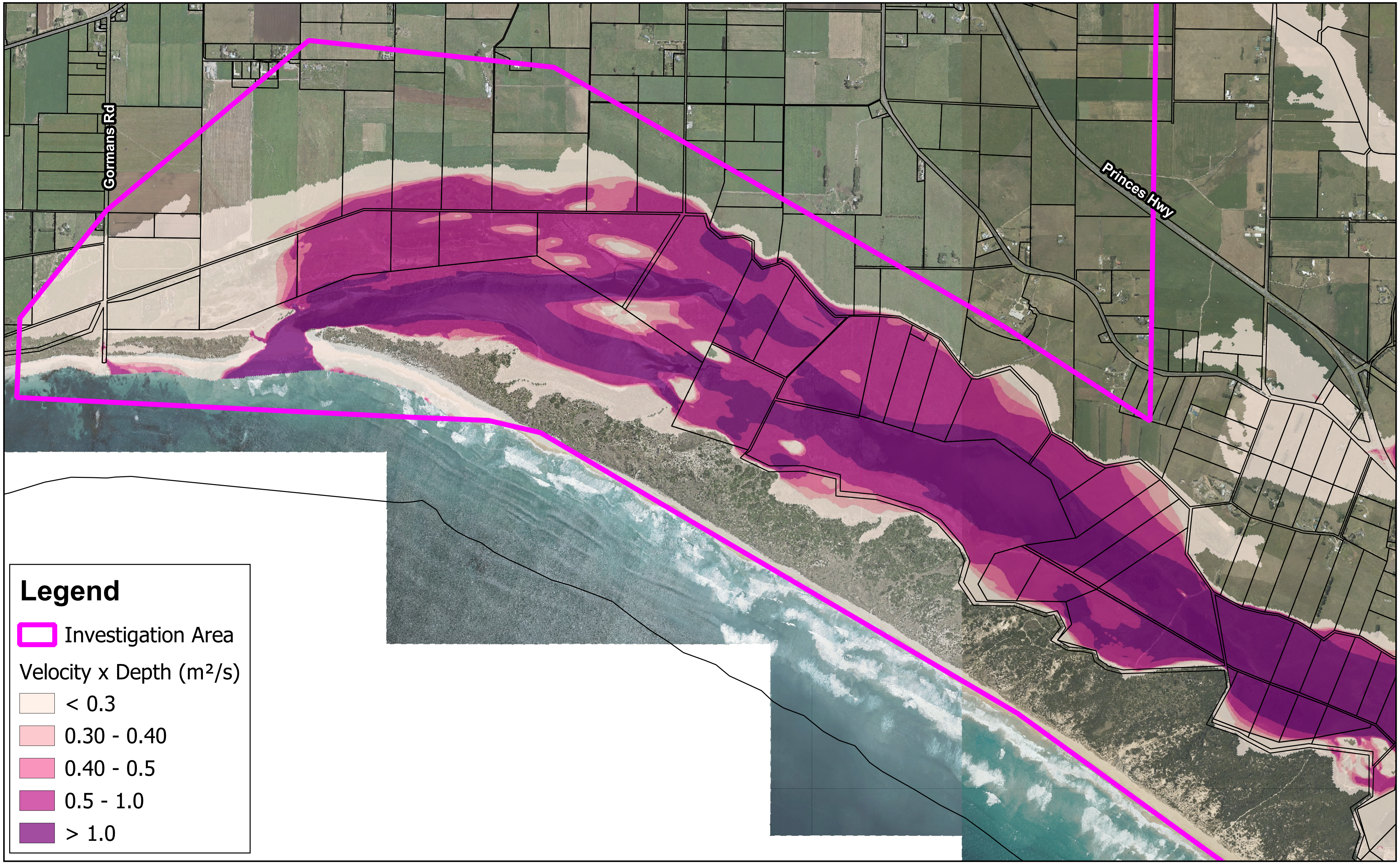
By: TL

Feb 2025



Title: South Warrnambool and Dennington Flood Investigation - Climate Change 2 1% AEP Riverine Peak Flood Velocity x Depth (West)	Figure: C-9	Rev: A	0 400 800 m

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

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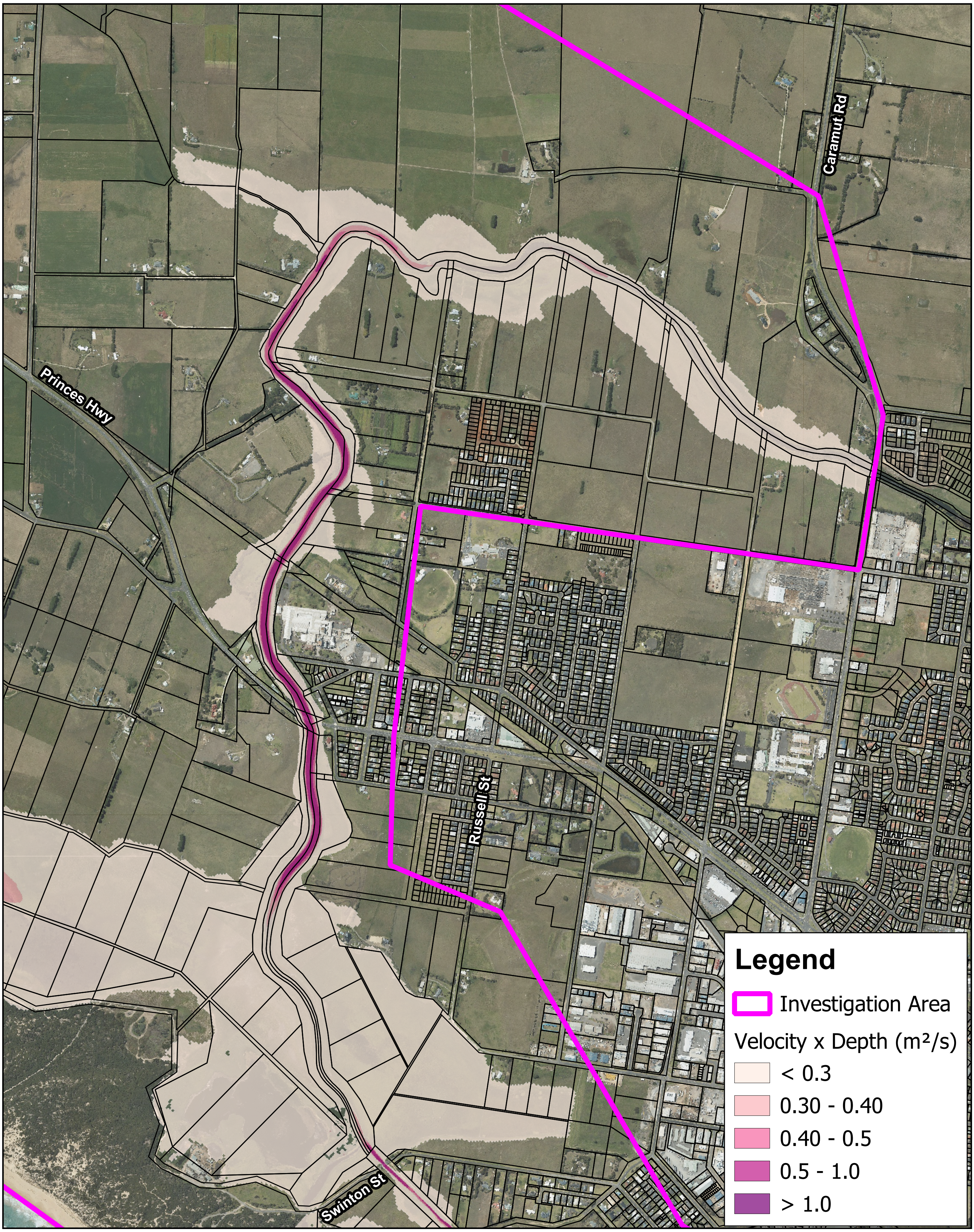
Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigC-9_West_SWFS_CC2_RIV_RF1pc_36hr_tp9_TH_MHHW_047_Z0_Max.qgz

By: TL | Feb 2025

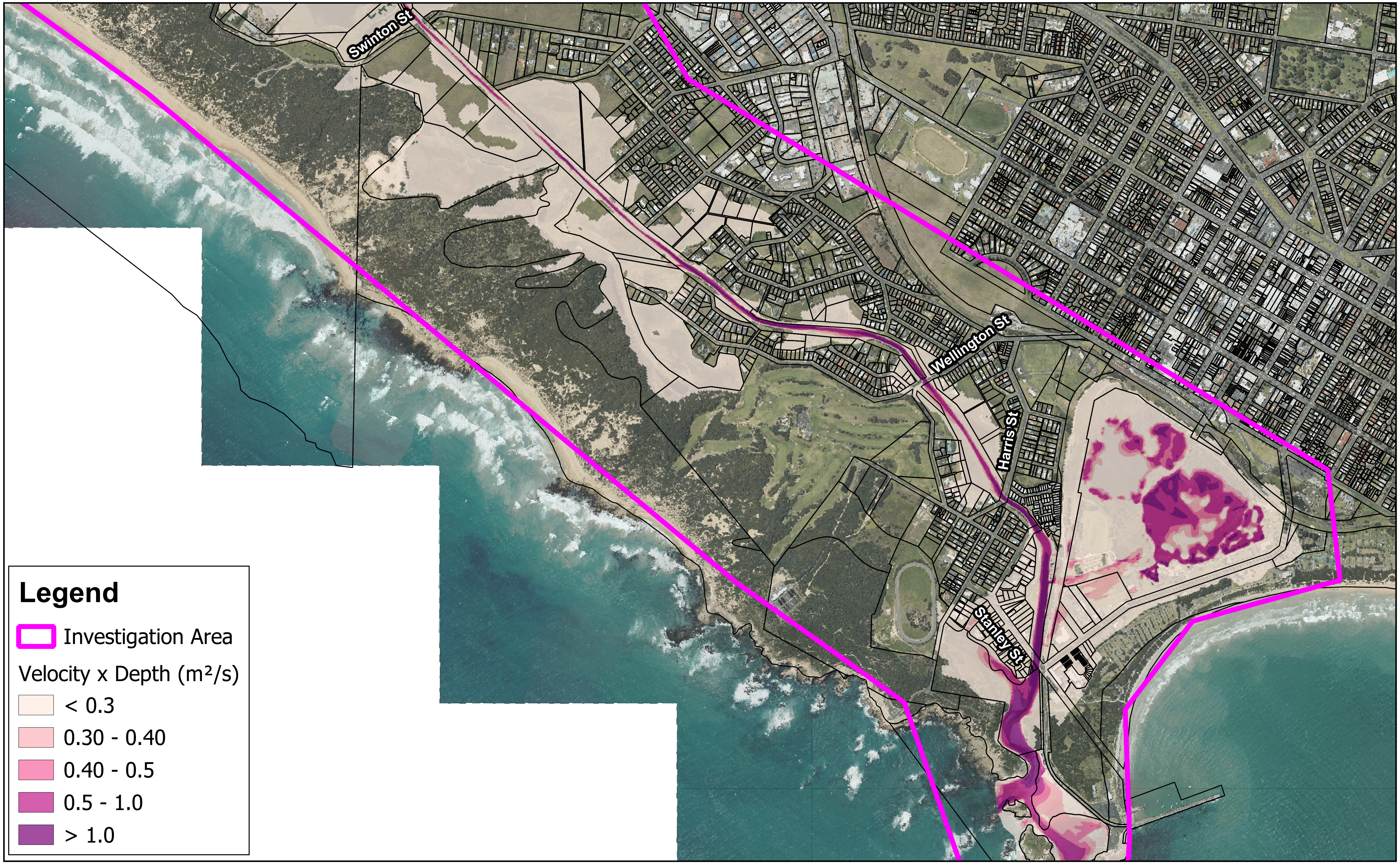


Title:

South Warrnambool and Dennington Flood Investigation - Climate Change 2
1% AEP Storm Tide Peak Flood Velocity x Depth (North)

Figure:	Rev:				
C-10	A	0 0.35 0.7 km	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	By: TL Date: Feb 2025	VENANT SOLUTIONS www.venantsolutions.com.au

Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigC-10_North_SWFS_CC2_TIDE_RFno_0hr_tp0_TH1pc_047_Z0_Max.qgz



Title:
South Warrnambool and Dennington Flood Investigation - Climate Change 2
1% AEP Storm Tide Peak Flood Velocity x Depth (East)

Figure: C-11

Rev: A

0 350 700 m

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

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Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigC-11_East_SWFS_CC2_TIDE_RFno_0hr_tp0_TH1pc_047_Z0_Max.qgz

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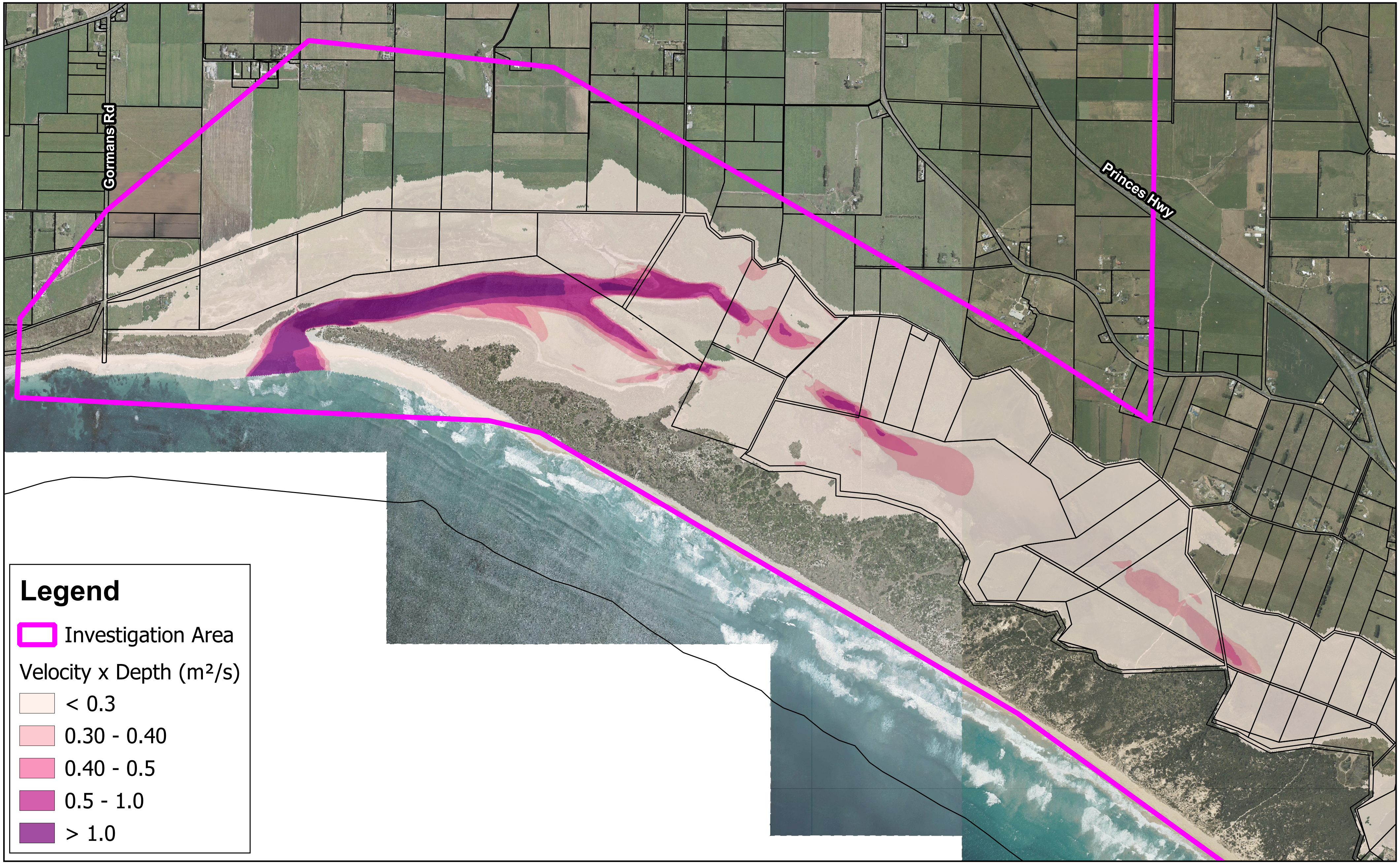

Title: South Warrnambool and Dennington Flood Investigation - Climate Change 2
1% AEP Storm Tide Peak Flood Velocity x Depth (West)

Figure: C-12

Rev: A

0 400 800 m

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Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigC-12_West_SWFS_CC2_TIDE_RFno_0hr_tp0_TH1pc_047_Z0_Max.qgz

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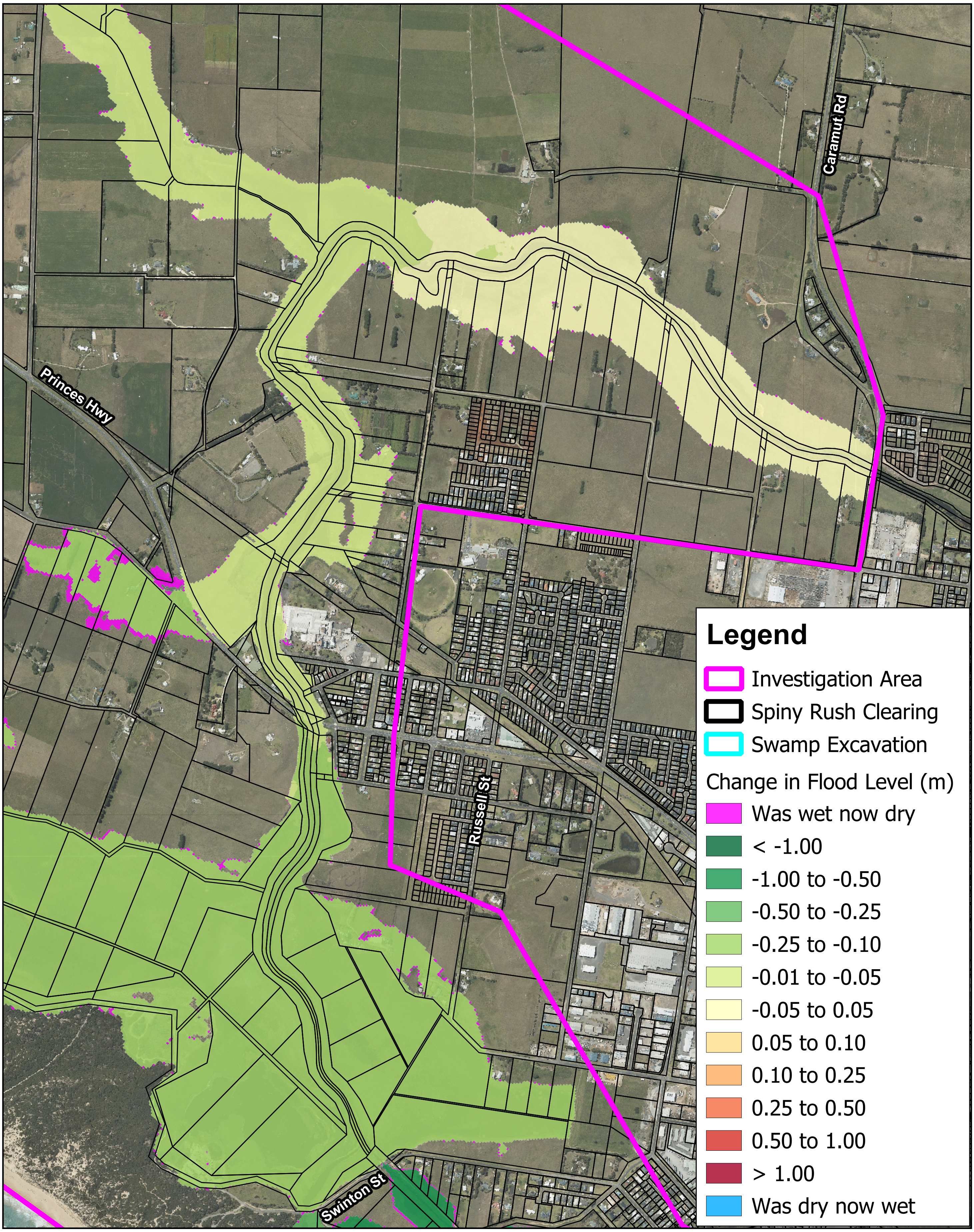
Appendix D Structural mitigation options flood level impact mapping

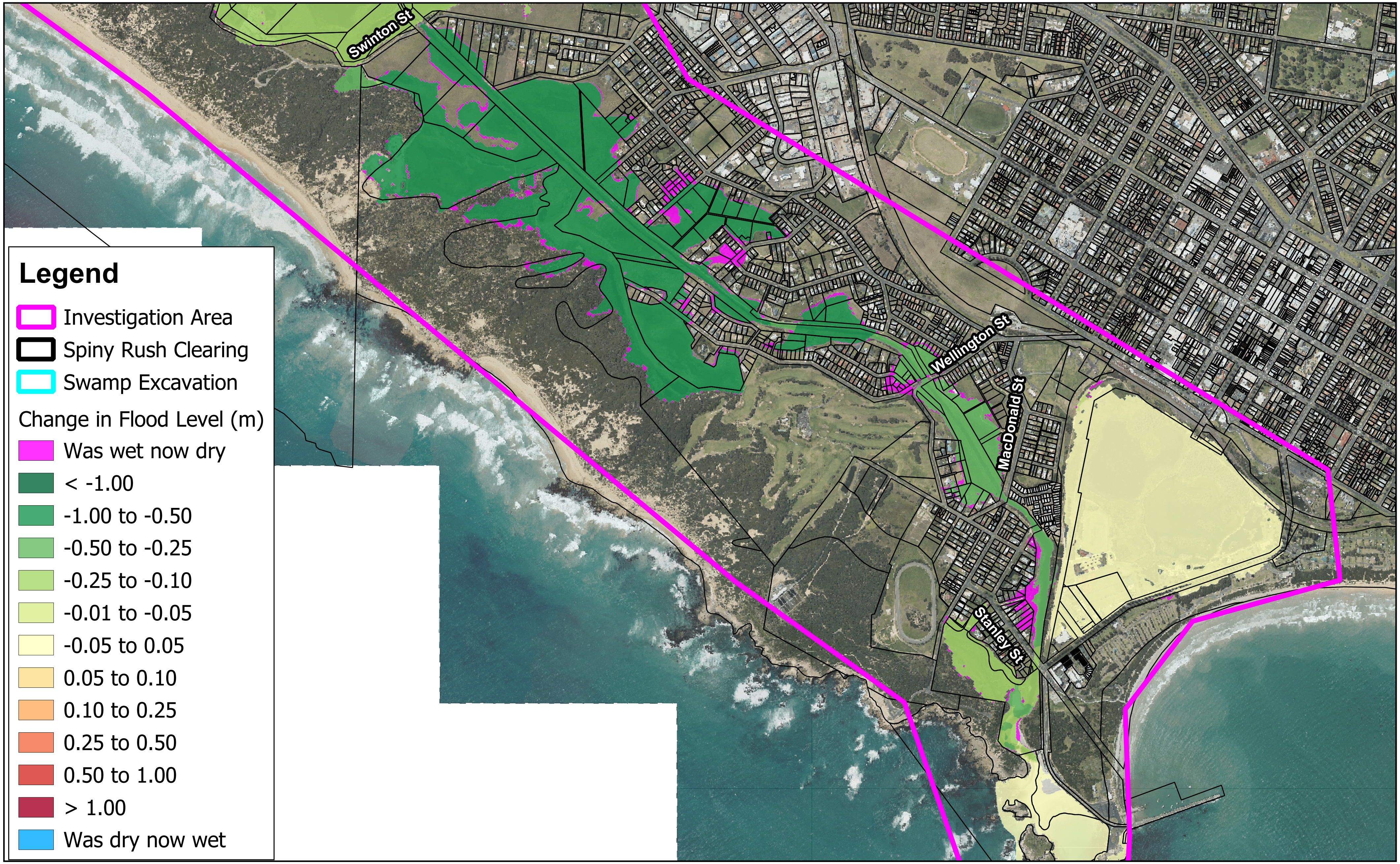


Title:

South Warrnambool and Dennington Flood Investigation - Option 1
Current Climate 1% AEP Riverine Change in Flood Level (North)

Figure:	Rev:			By: TL	
D-1	A	0 0.35 0.7 km	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	Date: Feb 2025	VENANT SOLUTIONS www.venantsolutions.com.au

Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigD-1_Dif_North_SWFS_M01_E01_RIV_RF1pc_36hr_tp9_TH_MHHW_050_047_h_Max.qgz



Title:
South Warrnambool and Dennington Flood Investigation - Option 1
Current Climate 1% AEP Riverine Change in Flood Level (East)

Figure: D-2

Rev: A

0 350 700 m

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

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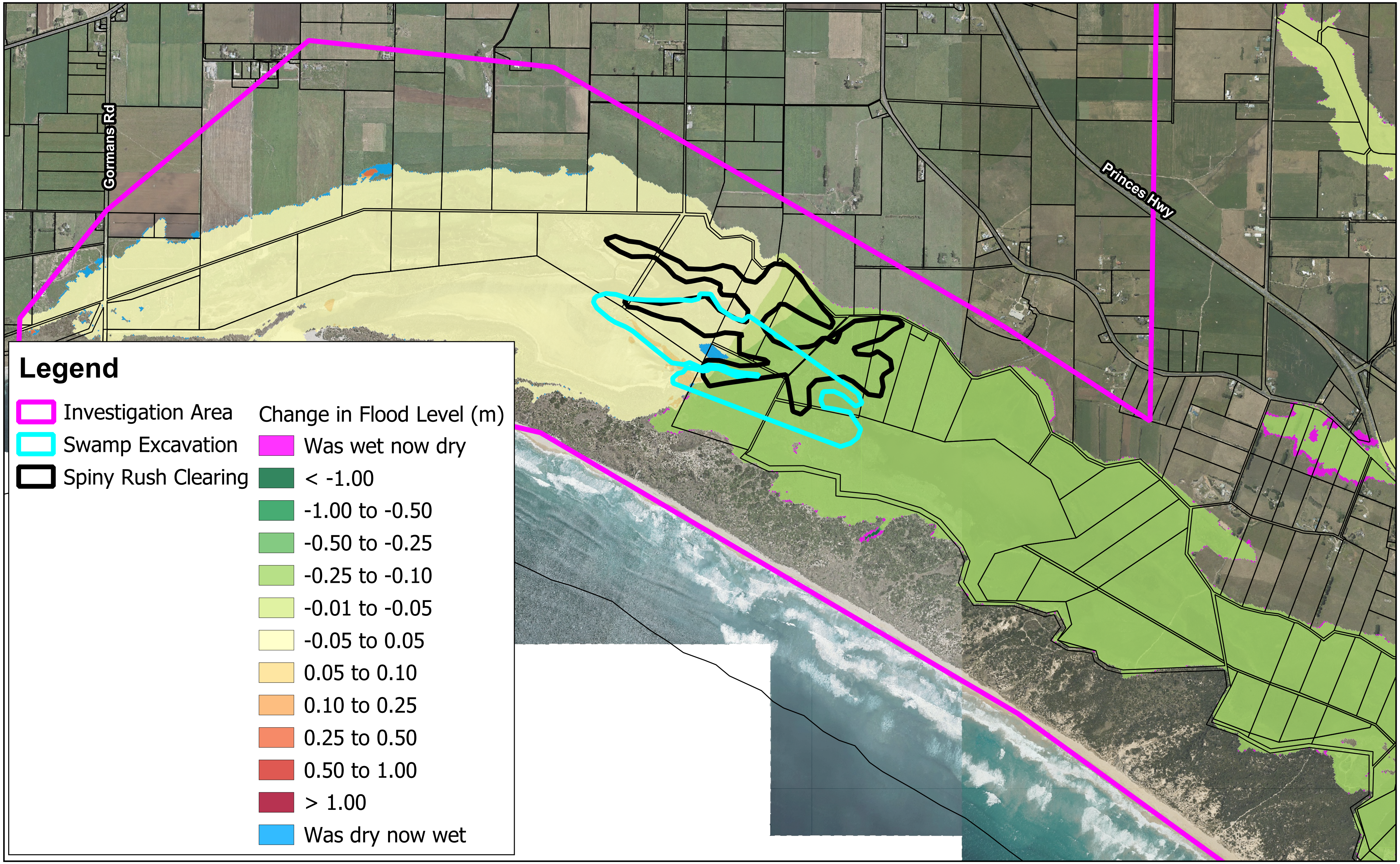
By: TL

Feb 2025



Title: South Warrnambool and Dennington Flood Investigation - Option 1
Current Climate 1% AEP Riverine Change in Flood Level (West)

Figure: D-3

Rev: A

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

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By: TL

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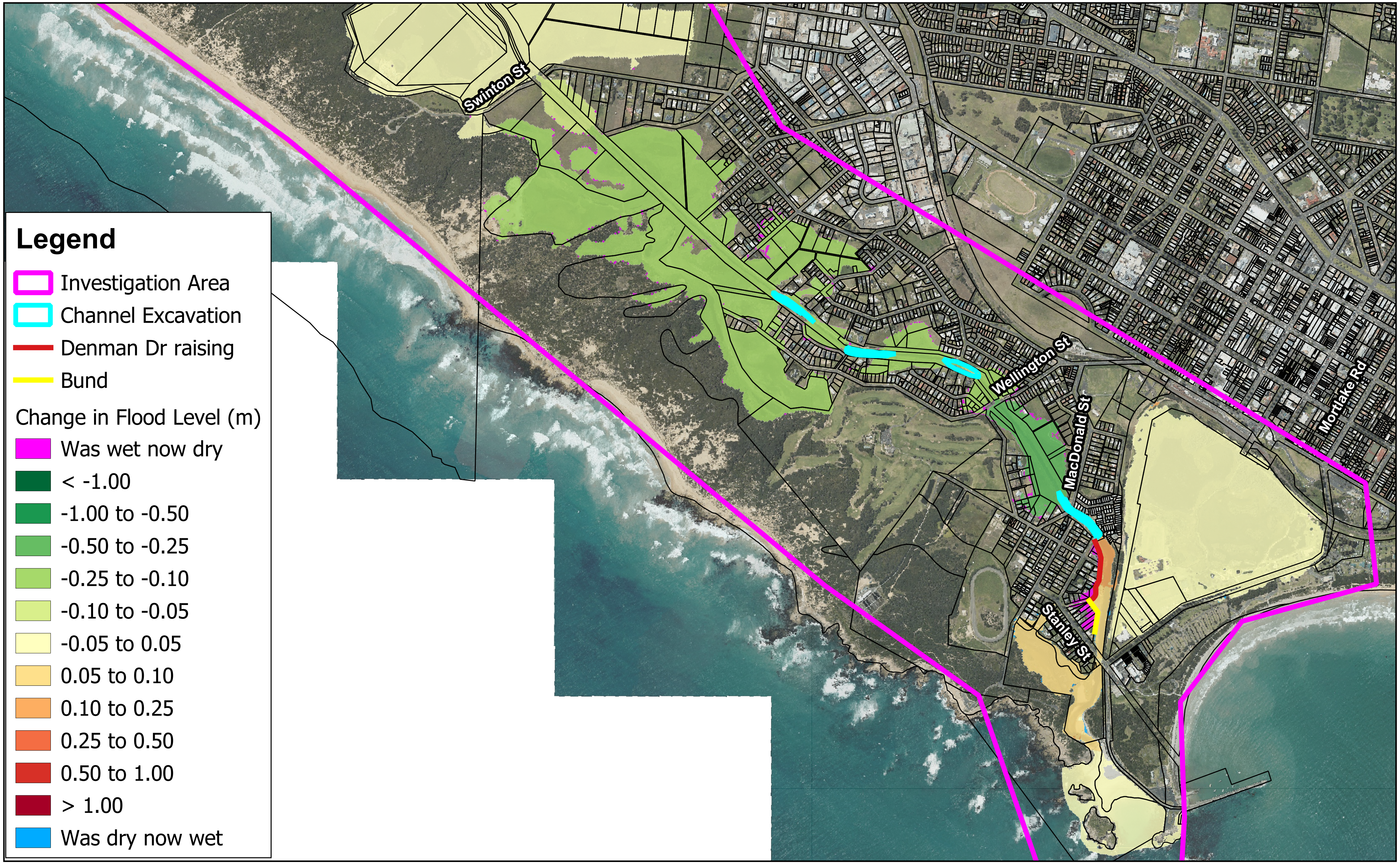

Title: South Warrnambool and Dennington Flood Investigation - Option 4
Current Climate 1% AEP Riverine Change in Flood Level (East)

Figure: D-4

Rev: A

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

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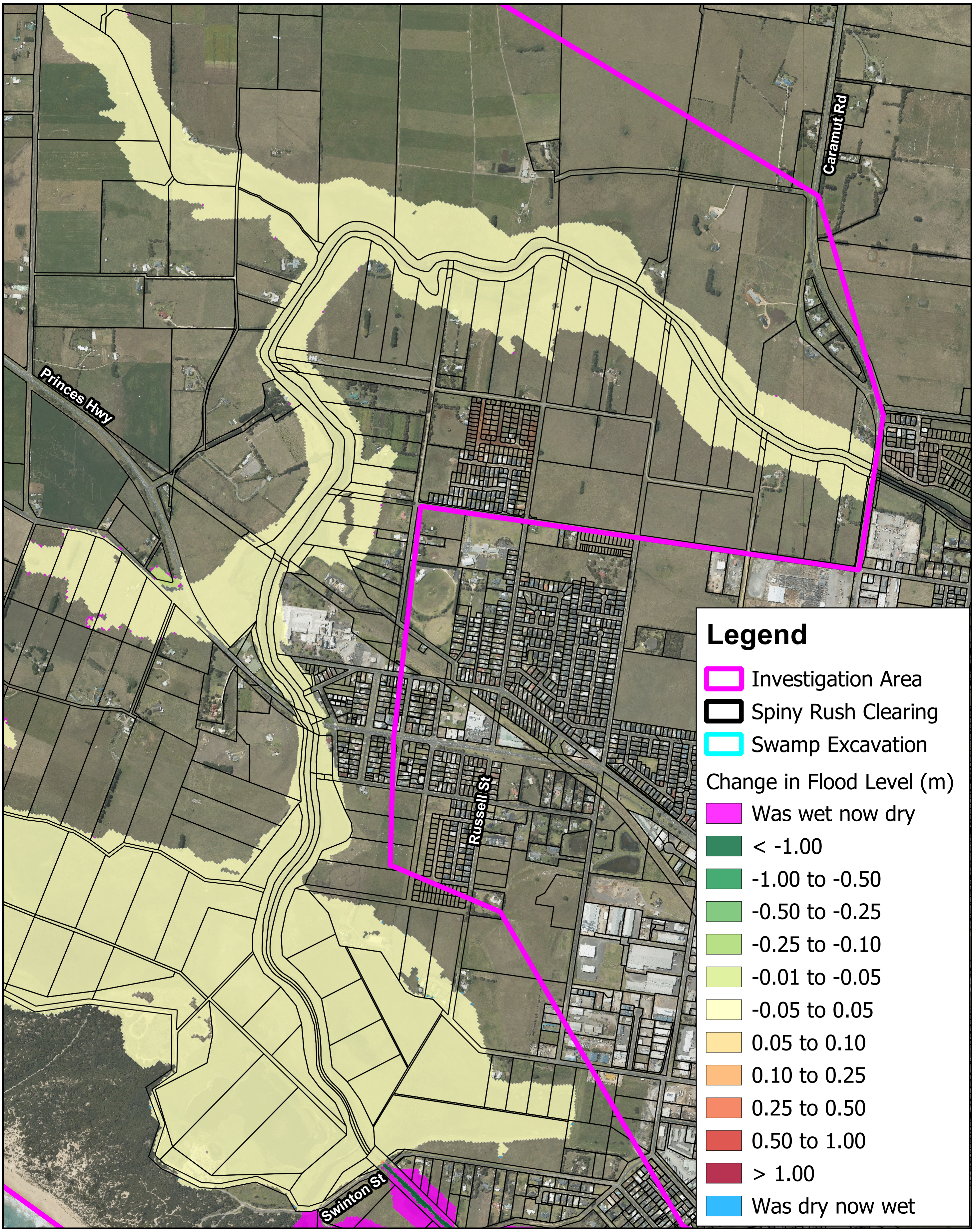
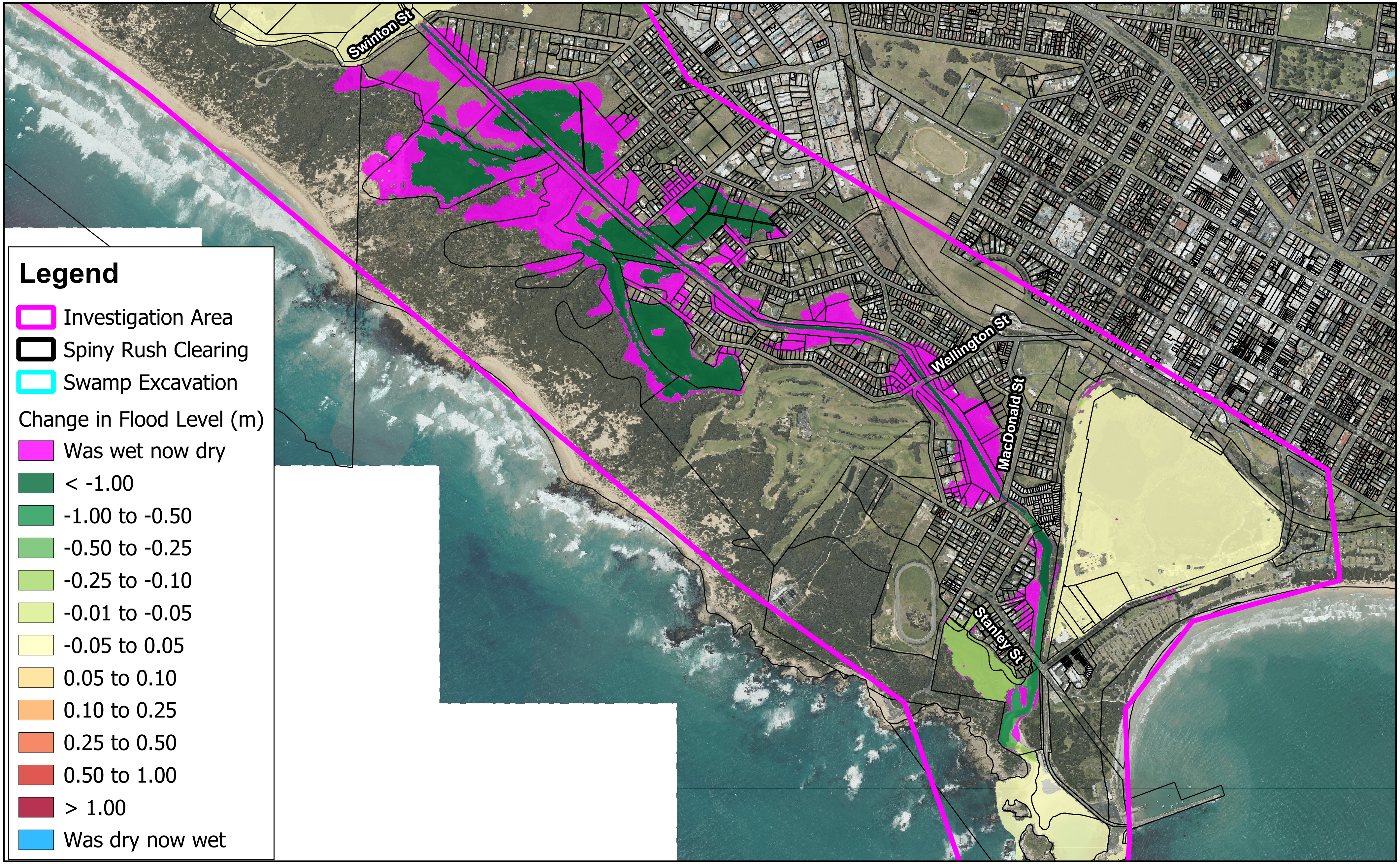


Title:

South Warrnambool and Dennington Flood Investigation - Option 5
Current Climate 1% AEP Riverine Change in Flood Level (North)

Figure:	Rev:			By: TL	
D-5	A	0 0.35 0.7 km	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	Date: Feb 2025	VENANT SOLUTIONS www.venantsolutions.com.au

Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigD-5_Dif_North_SWFS_M05_E01_RIV_RF1pc_36hr_tp9_TH_MHHW_048_047_h_Max.qgz



Title: South Warrnambool and Dennington Flood Investigation - Option 5
Current Climate 1% AEP Riverine Change in Flood Level (East)

Figure: D-6

Rev: A

This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.

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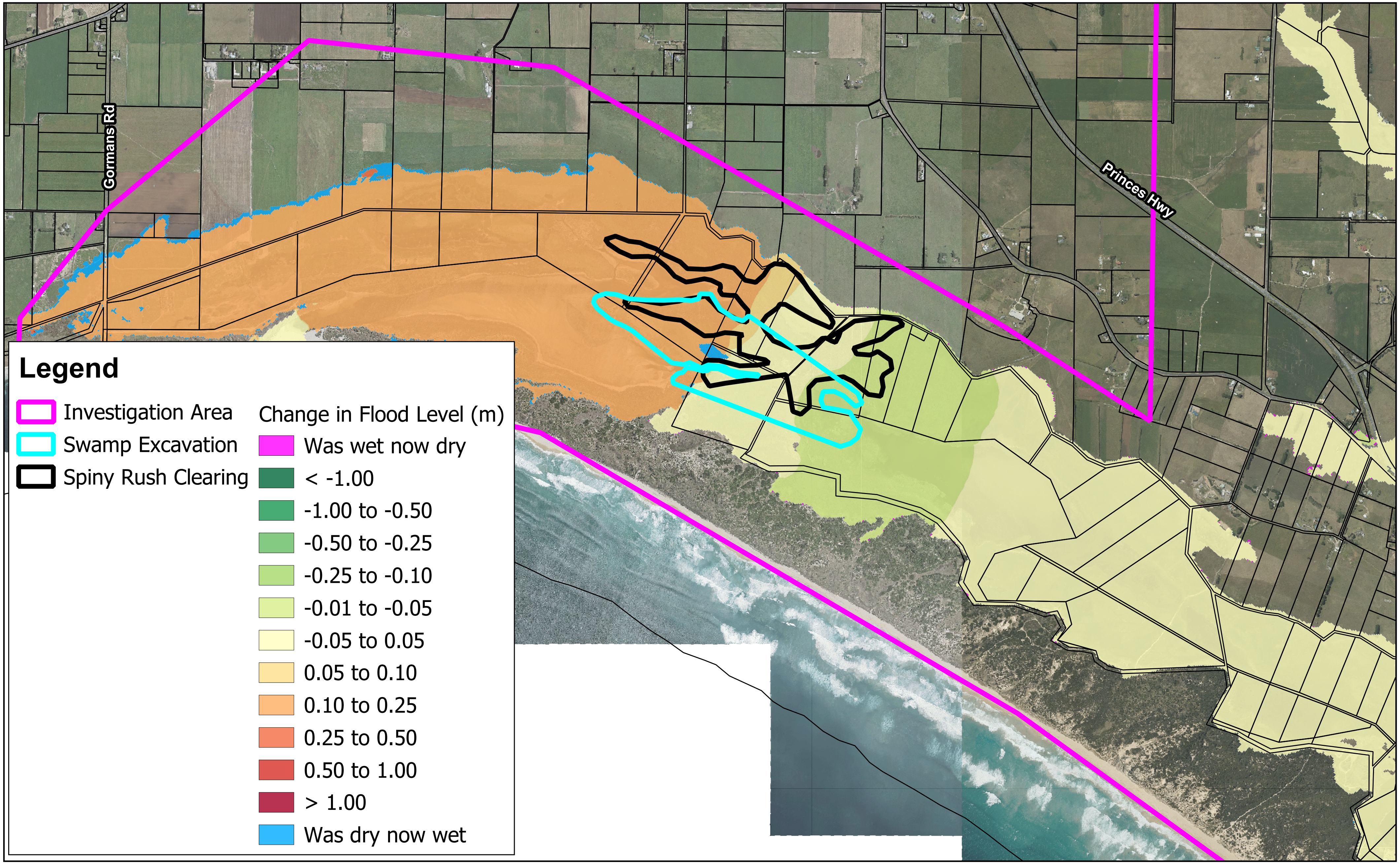
By: TL

Feb 2025



Title: South Warrnambool and Dennington Flood Investigation - Option 5 Current Climate 1% AEP Riverine Change in Flood Level (West)	Figure: D-7	Rev: A	0 400 800 m	This mapping product is based on techniques and data in accordance with the study scope. Users should consider the mapping in the context of the report. No two floods are the same and care should be taken in the use and interpretation of the results presented.	VENANT SOLUTIONS
Filename: S:\Projects\M00407.MS.SouthWarrnamboolFS\GIS\Drawings\R.M00407.005.00\FigD-7_Dif_West_SWFS_M05_E01_RIV_RF1pc_36hr_tp9_TH_MHHW_048_047_h_Max.qgz				By: TL Feb 2025	www.VenantSolutions.com.au