Design Hydrology and Detailed Hydraulic Modelling Report

Lara Flood Study

City of Greater Geelong

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1 INTRODUCTION

This report is one of a series documenting the outcomes of the Lara Flood Study. The Study provides a detailed analysis of the catchments surrounding the township of Lara and the broader Hovells Creek/Lara catchment and part of the Avalon catchment management units[1]. Reporting was broken up into a series of deliverables, this report includes a brief overview of each of the previous reports submitted and the recommendations developed throughout the study. The reporting deliverables were as follows:

- R01 - Preliminary Report (Water Technology 2018)
- R02 – Hydrology/Hydraulic Calibration Report (Water Technology 2019)
- **R03 – Design Hydrology and Detailed Hydraulic Modelling Report (2020a) *This Report***
- R04 – Assess and Treat Risk, Flood Warning and Mitigation (Water Technology 2020b)
- R05 – Flood Warning and Intelligence Report (2020c)
- R06 - Summary Report (Water Technology 2020d)

These reports detail the project methodology, review the available data and present results and recommendations of the Lara Flood Study. The reports are supported by PDF flood maps and digital deliverables to be provided at the completion of the study.

This report summarises the joint model build and model calibration process, including rain-on-grid hydraulic modelling, design parameters adoption, simulations undertaken and the sensitivity analysis of the hydraulic modelling. Results of the modelling are discussed briefly within this report and examples of mapping outputs are also provided. Further information on the hydrology and calibration process are provided in R02 Hydrology/Hydraulic Calibration Report.

1.1 Overview

1.1.1 Project Objectives

The study brief prepared by City of Greater Geelong clearly demonstrates a strong understanding of the area, its floodplain and drainage infrastructure. The objectives of the study are described below.

1 - To produce detailed flood mapping for a range of flood modelling scenarios within the study area.

2 - To undertake definitive flood investigations for the floodplain reaches within the study area; to pool all the available data and, through rigorous analysis determine robust flood levels, velocities, depths and extents.

3 - To build on the previous flood studies undertaken in 2001/02 by the partnership of Corangamite CMA, City of Greater Geelong and a private consultant (Floodplain Management Strategy, April 2002) using baseline data and current technology to update flood data, value add for extra flood events, update of land use changes, update flood intelligence for the City of Greater Geelong Flood Emergency Plan, update flood data in the City of Greater Geelong Planning Scheme, support the preparation of the Planning Scheme Amendment to identify appropriate areas for development that mitigate flood risk.

1.2 Study Area

The study area consists of two major drainage catchments, Hovells Creek/Lara and part of the Avalon catchment management unit[1], as shown in Figure 1-1. The township of Lara was also a key focus area of the study as it is impacted by riverine flooding from Hovells Creek and stormwater inundation from within the urban area. The Hovells Creek/Lara catchment begins near Mount Anakie and flows in a south easterly direction

[1] Stormwater Services Strategy 2020-30, Draft Report. City of Greater Geelong, 2019

through farmland and into the urban area of Lara before flowing into Limeburners Bay, an inlet to Corio Bay. There are several large storages, including farm dams, located throughout the catchment. The Avalon catchment begins just to the south of the Little River township and flows south. There are no named waterways within the catchment; however, is often referred to as the Austins Swamp catchment. Several farm drains have been constructed to drain wetlands and local storage depressions. Flow behaviour in the lower end of the catchment is impacted by a former saltworks located between the Princes Freeway and the Avalon Coastal Reserve (Corio Bay).

The Melbourne-Geelong Railway and Princes Freeway intersect both catchments, crossing Hovells Creek at the lower end of the catchment. The Avalon Road catchment is crossed by the railway line in the mid-upper catchment and the Princes Freeway in the middle of the catchment.

Lara is a residential and commercial town located at the lower end of the Hovells Creek catchment and has a population of just over 16,000[2]. The town has been identified as a growth area for residential, commercial and industrial development. Lara has been subject to inundation from Hovells Creek and stormwater catchments in the past with significant flood events in 1933, 1973, 1983, 1988, 1995, 2005 and 2010. Several flood investigations have been carried out of this area, and flood mitigation work has been proposed along the Elcho Drain. Further work in the Northern Growth Area, to the west of the main township has also been undertaken recently.

Drainage assets in the township range from roadside open swale drains within wide road reserves, to pit and pipe networks within the urban areas. Hovells Creek and the Elcho Drain run through the Lara. Elcho Drain runs through several man-made lake/retarding basin systems and in parts is channelised and has underground low-flow pipes before outfalling to Hovells Creek.

[2] Australian Bureau of Statistics, 2016 Census – Lara Population data

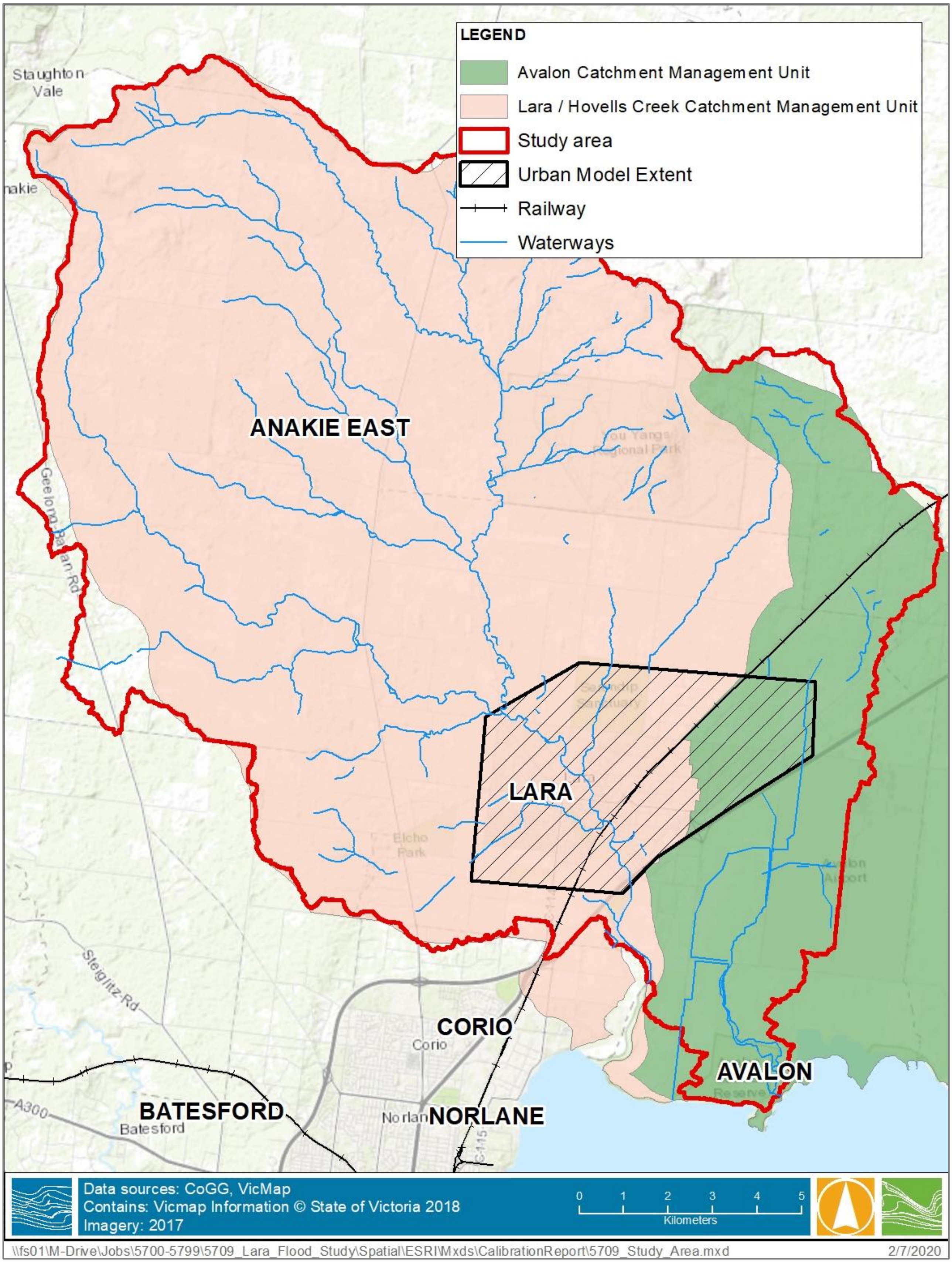

FIGURE 1-1 LARA/ HOVELLS CREEK AND AVALAON CATCHMENTS

2 CATCHMENT DESCRIPTION

Hovells Creek begins at Mount Anakie, flows through farmland and the Lara urban area, of before flowing into Limeburners Bay, an inlet to Corio Bay. Parts of the Hovells Creek catchment are within the Otway Ranges rain shadow, which results in less rainfall than other neighbouring catchments, with a mean annual rainfall of around 450 mm (Figure 2-1). This compares to an average annual rainfall of 538 mm for inner Geelong (Geelong SEC). Further to the north-west (Durdidwarrah) experiences an annual average of 685 mm. Hovells Creek is ephemeral, whilst it is also tidal in its lower reaches. Catchment response times for Hovells Creek and its tributaries from the start of intense rainfall to peak riverine flooding in Lara is generally between 8-12 hours; however, can be as short as 6 hours. Stormwater flooding is likely to impact Lara in a much shorter timeframe as a result of intense storm events.

The majority of the catchment consists of grassed plains rising from an elevation of 400 m AHD in the upper reaches through to sea level at the lower end of the catchment. The main topographical features of the catchment are the You Yangs (347 m AHD) and Mount Anakie (398 m AHD) to the north-west. The combined catchment area of Lara/ Hovells Creek and Avalon is 230 km^2. According to Bureau of Meteorology, there are multiple weather patterns that produce the prolonged heavy rainfall likely to lead to flooding within Lara. Heavy rain typically occurs from a well-developed cloud band associated with a cold front moving from the Great Australian Bight moving in an easterly direction. The area is also subject to isolated thunderstorms which can result in flash flooding within the built-up urban areas.

Land use within Lara is predominantly residential and commercial, with surrounding land to the south occupied by industrial development, most notably the Geelong Ring road Employment Precinct (Heals Road Industrial Area). The Avalon Airport is located to the south-east of Lara with increasing industrial land demand surrounding the airport. Land use within the upper catchments of Hovells Creek is mainly farming with agricultural production varying between poultry, sheep, wool and grain cropping. Lara has been identified as a growth area for residential, commercial and industrial development. Lara has been subject to riverine flooding from Hovells Creek and stormwater flooding in the past, so with Lara designated a growth area, it is important to develop a strong appreciation of the flood risk and plan accordingly.

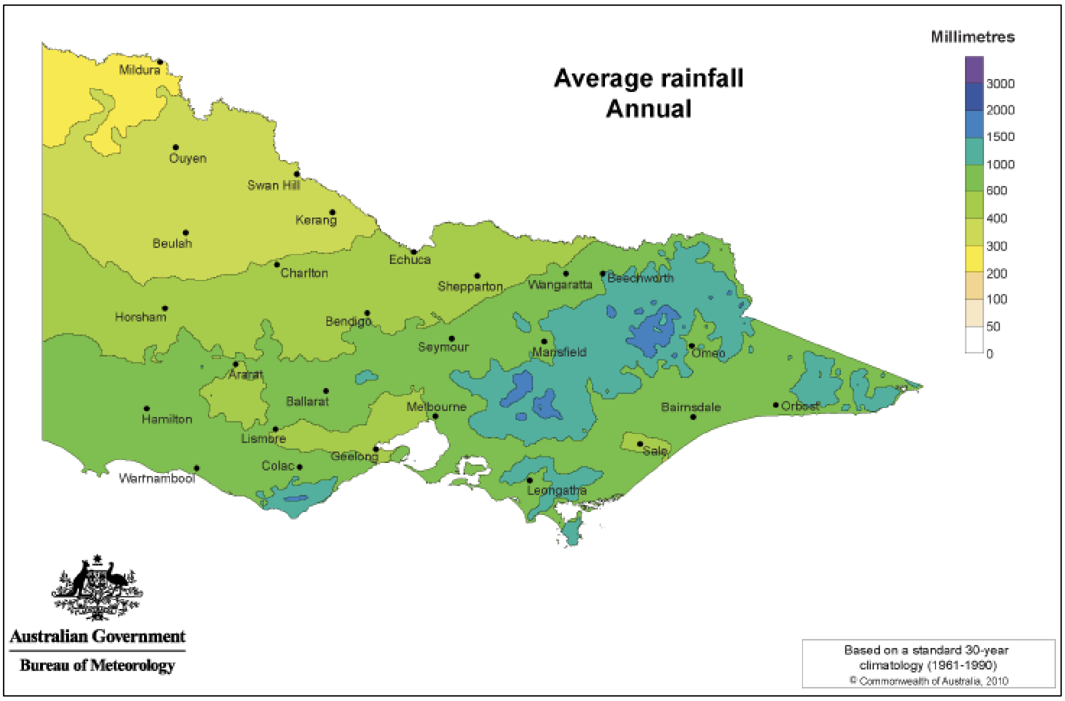

FIGURE 2-1 VICTORIAN MEAN ANNUAL RAINFALL (1961-1990) SOURCE: BOM

3 METHODOLOGY

A joint hydrology/hydraulic calibration approach was adopted for the project due to several determining factors including data limitations. There was little available streamflow information for Hovells Creek, with only a short-term record at the Flinders Avenue and Rennie Street streamflow gauges. Previous flow estimates for two of the four calibration flood events (1973 and 1988) were found in the Shire of Corio's report of the December 1988 floods. The joint calibration approach allowed for uncertainties in both flow estimation and hydraulic behaviour to be combined, with both models jointly evaluated against available flood observations (flood levels, extents, photo and anecdotal reports). The four flood events chosen for the calibration varied in magnitude and cover a number of decades in which changes to land use (urban development of previously open farming space) and changes to topography (levees, roadways and drains) have impacted the movement of water and flood behaviour throughout the study area. Where applicable topographic changes were included, based on what limited information was available (documentation of the levee mitigation scheme in 1985 and levee height increases in 1990, aerial imagery showing the level of urban development, etc.).

Through the calibration phase, storages in the upper catchment, land use changes, topographic change and drainage infrastructure throughout the township were incorporated into both hydrologic and hydraulic models (where applicable). This ensured a good representation of the runoff (hydrology modelling) and the flood behaviour (hydraulic model) for a range of flow events. The approach undertaken was developed to ensure a high degree of confidence in the model results.

The calibration parameters used in both the hydrologic (RORB) and hydraulic model (TUFLOW) were used to inform those adopted during the design modelling. Design mapping produced by this investigation will inform flood intelligence information and planning overlays. The following sections provide an overview of how the modelling was combined to produce final mapping and intelligence outputs.

3.1 Riverine Flooding

The study area consisted of two defined catchments, Lara/ Hovells Creek and the Avalon catchments (Figure 1-1). Inundation across these catchments is generally a result of longer duration storms (6 hours +). A detailed RORB model produced excess runoff hydrographs that were placed in a hydraulic model (TUFLOW). This allowed for the assessment of a range of variables, including antecedent conditions (storage levels within major dams, initial and continuing losses) from the calibration assessment and the selection of appropriate storm events (duration and temporal pattern selection) for the design modelling. The complexity of the flood behaviour and issues within the study area and the lack of long-term streamflow records for both catchments resulted in the approach to develop two distinct hydraulic models.

Post processing of riverine flood results used the maximum output of each of the six durations (per AEP) modelled to produce a combined maximum final set of results for each AEP. This ensured the maximum flood levels for the entire study area were accurately represented. This was an important consideration when assessing large catchments found in the study area (Lara/Hovells Creek and Avalon catchments), as the critical duration varies significantly across the study area. The critical duration for the upper catchment was generally a shorter duration (2-Hour) event with a rapid rise in flowrate, compared to the longer 18-48-Hour durations for the middle to lower parts of the catchments where volume was more significant to the critical duration.

3.2 Urban Stormwater Flooding

The urban stormwater model was developed to provide detailed mapping of the township area. While the township area is prone to flooding from short intense storms, longer duration events also create flooding issues in the broader peri-urban area. Significant areas of flooding around the North East Lara area (which has a relatively short catchment which begins just north of Plains Road) along with Lara West and portions of the Elcho Drain are flooded as a result of overland flow from semi-urban areas.

The stormwater model adopted parameters for land use roughness determined during calibration of the riverine modelling.

3.3 Combined Results

Rain on grid and riverine model results were combined to produce a single set of deliverables for each AEP. In areas impacted by both stormwater inundation and riverine flooding, the higher of the inundation types was adopted for modelling results. To smooth out the process of combining the riverine and rain-on-grid modelling, areas not likely to be impacted from riverine or catchment flooding (outside of the main Hovells Creek or Elcho drain waterway extent) were removed from the riverine model to ensure that any lumped hydrology assumptions do not impact on the flood results in these urban areas. Figure 3-1 highlights the areas where either or both of the model results were used to develop the combined flood results.

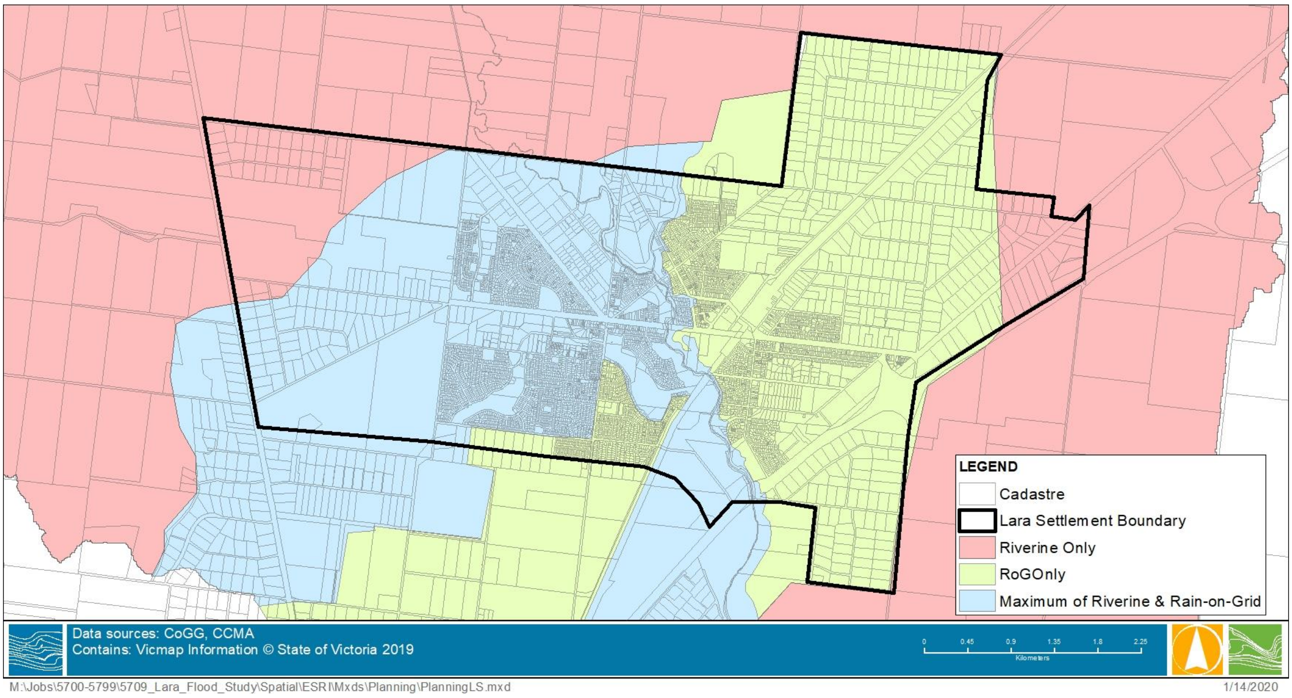

FIGURE 3-1 RESULT SELECTION METHODOLOGY

4 RIVERINE HYDROLOGY MODEL

The appropriate selection of design parameters is critical to ensure the flood mapping is based on the most realistic site specific characteristics, and not skewed by any one factor. Australian Rainfall and Runoff (2016) provides recommended approaches and parameters for use and is considered industry best practice.

Water Technology has adopted the approach of ARR (2016), as outlined in the sections below, for the range of hydrological variables including antecedent conditions (storage levels within major dams, initial and continuing losses) and the selection of appropriate design storm events (duration and temporal patterns).

4.1 Rainfall Depths

Rainfall depths for used for the Hovells Creek and Austins Swamp catchment were derived from Australian Rainfall and Runoff (2016)[3] recommendations. Rainfall depths were sourced from the Bureau of Meteorology (BoM) online IFD tool[4] (Table 4-1). The associated rainfall and datahub files (containing areal reduction factors, loss parameters and temporal pattern information) were sourced for the location at the centre of the catchment.

During the design testing phase, it was identified that the RORB model was producing much lower peak flow rates for Hovells Creek when compared with previous design estimates identified from earlier flood study reports. An assessment of the rainfall compared to the previous rainfall IFD tables from 1987 was undertaken. The results shown in Figure 4-1 highlight a significant reduction in design rainfall depths when compared with the 1987 IFD totals. For example, the rainfall depth for the 24-hour design event has reduced from 122.6 mm to 80.6 mm. The resulting peak flows and flood levels are highly dependent on the design rainfall depths from the IFD data. Testing of the impact on peak flows and design levels is to be carried out during the design modelling stage.

Rainfall data for the 1973, 1988 and 2005 calibration events, when plotted against the 2016 IFD curves, suggest there were parts of the catchment that received rainfall totals in excess of the current 1% AEP design totals during both flood events. This information has been provided upfront to highlight the 1% AEP design flood levels may be lower than the existing 1% AEP flood levels for Hovells Creek at Lara.

TABLE 4-1 BOM 2016 DESIGN RAINFALL DEPTHS (LARA)

DURATION	1 EY	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
10Mins	3.7	5.0	6.9	8.2	10.0	12.6	14.8
20Mins	4.2	5.6	7.7	9.2	11.2	14.1	16.5
30Mins	5.6	7.5	10.3	12.3	14.9	18.7	21.8
1Hr	8.1	10.8	14.7	17.3	20.8	25.9	30.1
2Hrs	9.9	13.1	17.6	20.6	24.7	30.7	35.6
3Hrs	13.1	17.3	23.0	26.9	32.1	39.5	45.6
6Hrs	16.9	22.2	29.2	34.0	40.4	49.6	57.0
12Hrs	19.5	25.5	33.6	38.7	45.9	56.1	64.5
24Hrs	24.6	32.2	42.0	48.5	57.2	69.6	79.8
48Hrs	30.8	40.3	52.4	60.5	71.3	86.6	99.1
72Hrs	37.9	49.7	64.8	74.4	88.1	107.0	122.6

[3] http://data.arr-software.org/
[4] http://www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016

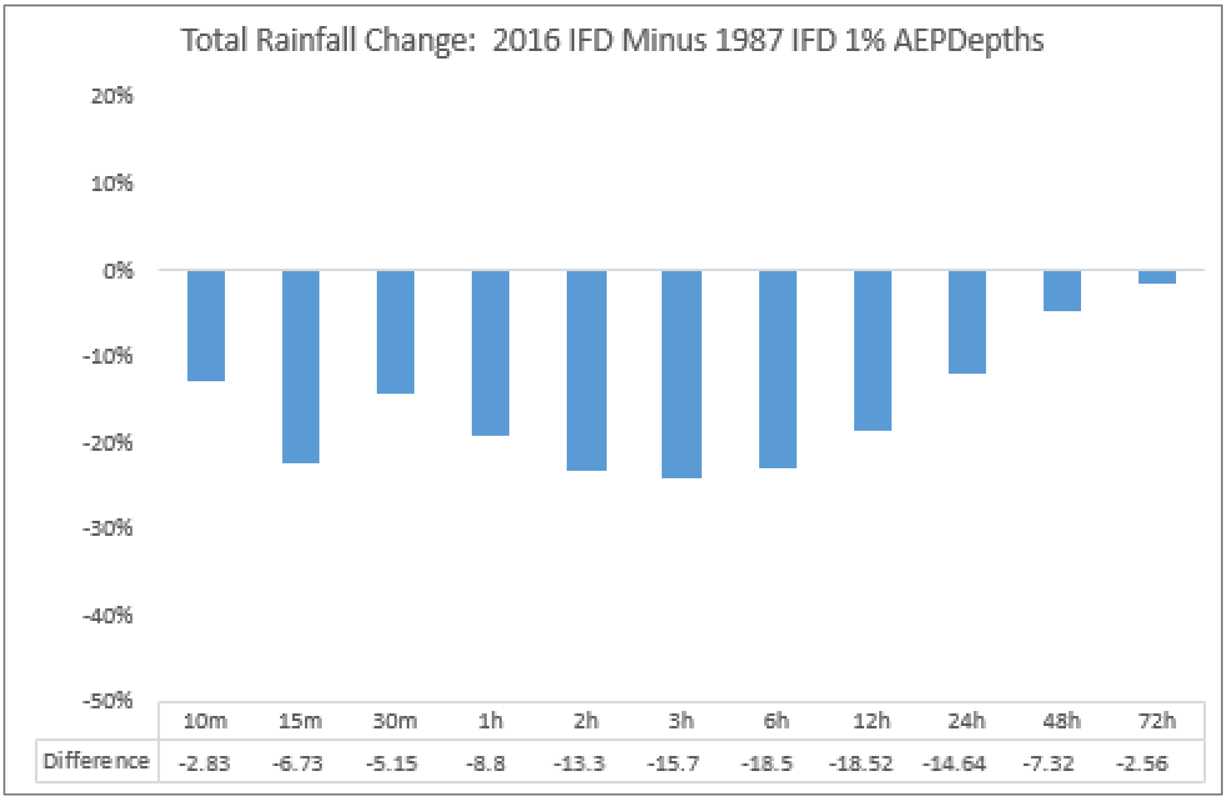

FIGURE 4-1 CHANGE IN 1% AEP DESIGN RAINFALL DEPTHS (2016 IFD COMPARED WITH 1987 IFD)

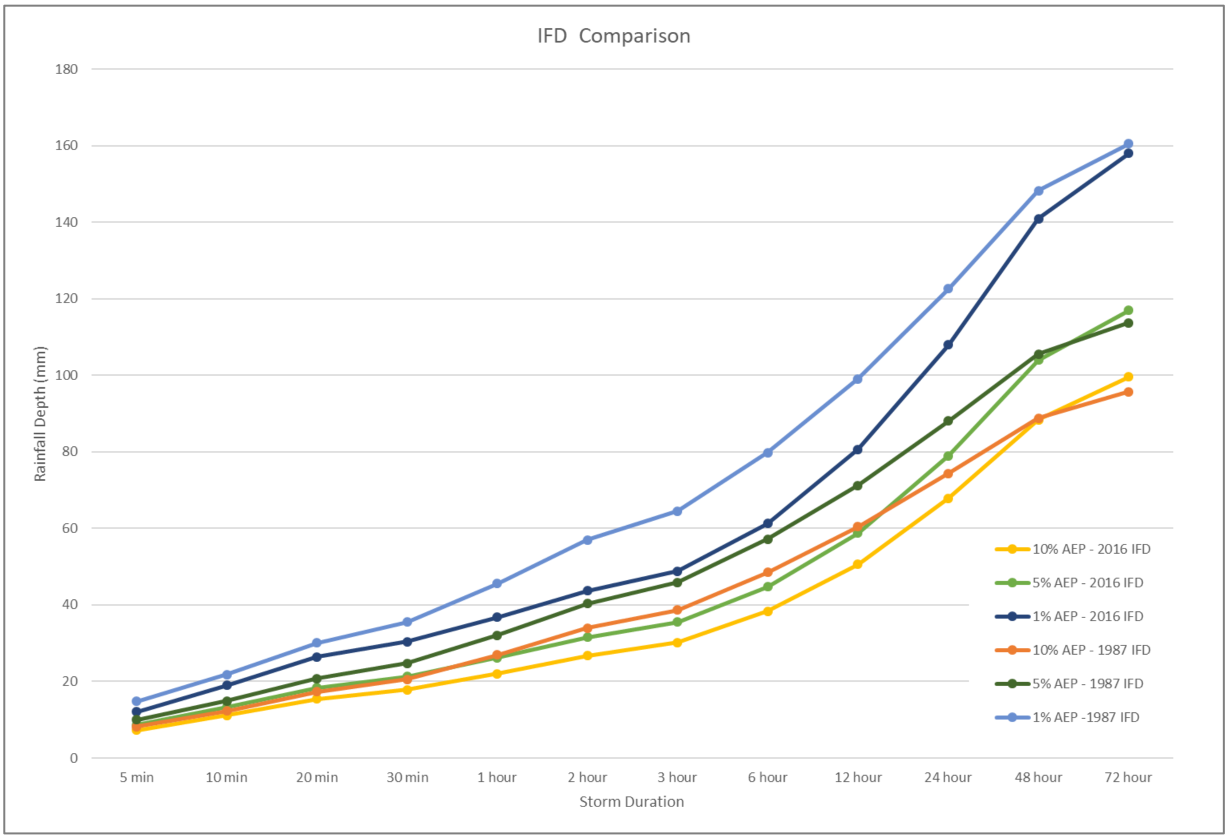

FIGURE 4-2 INTENSITY FREQUENCY DURATION (IFD) RAINFALL DEPTH COMPARISON

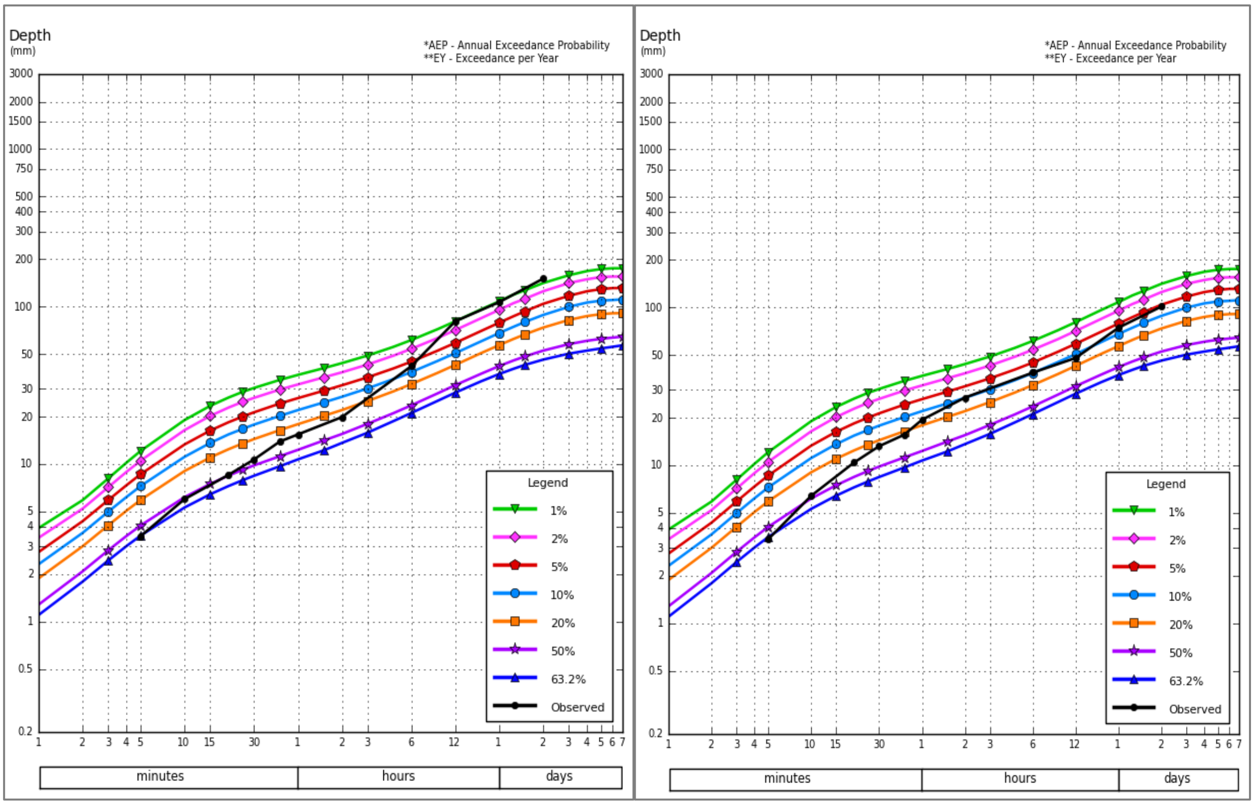

FIGURE 4-3 OBSERVED RAINFALL AT (LEFT) NORTH GEELONG FOR THE 1973 EVENT, AND (RIGHT) AVALON FOR 2005 EVENT, PLOTTED AGAINST CURRENT BOM IFD CURVES

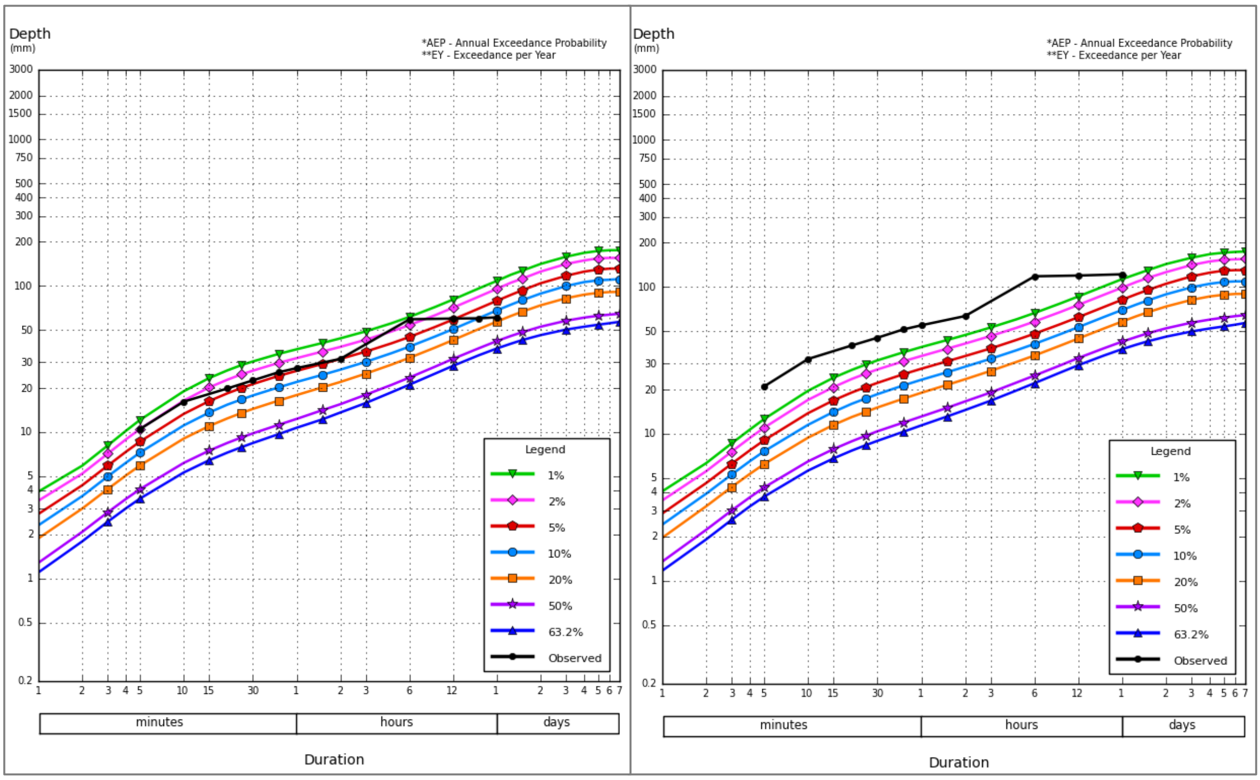

FIGURE 4-4 OBSERVED RAINFALL TOTALS FOR THE 1988 FLOOD EVENT AT (LEFT) NORTH GEELONG, AND (RIGHT) LITTLE RIVER PLOTTED AGAINST CURRENT BOM IFD CURVES

4.2 Storages

Catchment storages have the potential to impact the timing and extent of flooding, depending on their capacity and how full they are prior to a storm event. Seven storages (dams) within the Hovells Creek catchment were considered sufficiently large to warrant inclusion in the RORB and TUFLOW models. The location and estimated storage volumes are shown in Figure 4-5 and Table 4-2. As detailed within **R02- Calibration Report – Lara Flood Study,** the storage volume estimates have been generated through an assessment of LiDAR and interpolated bank profiles.

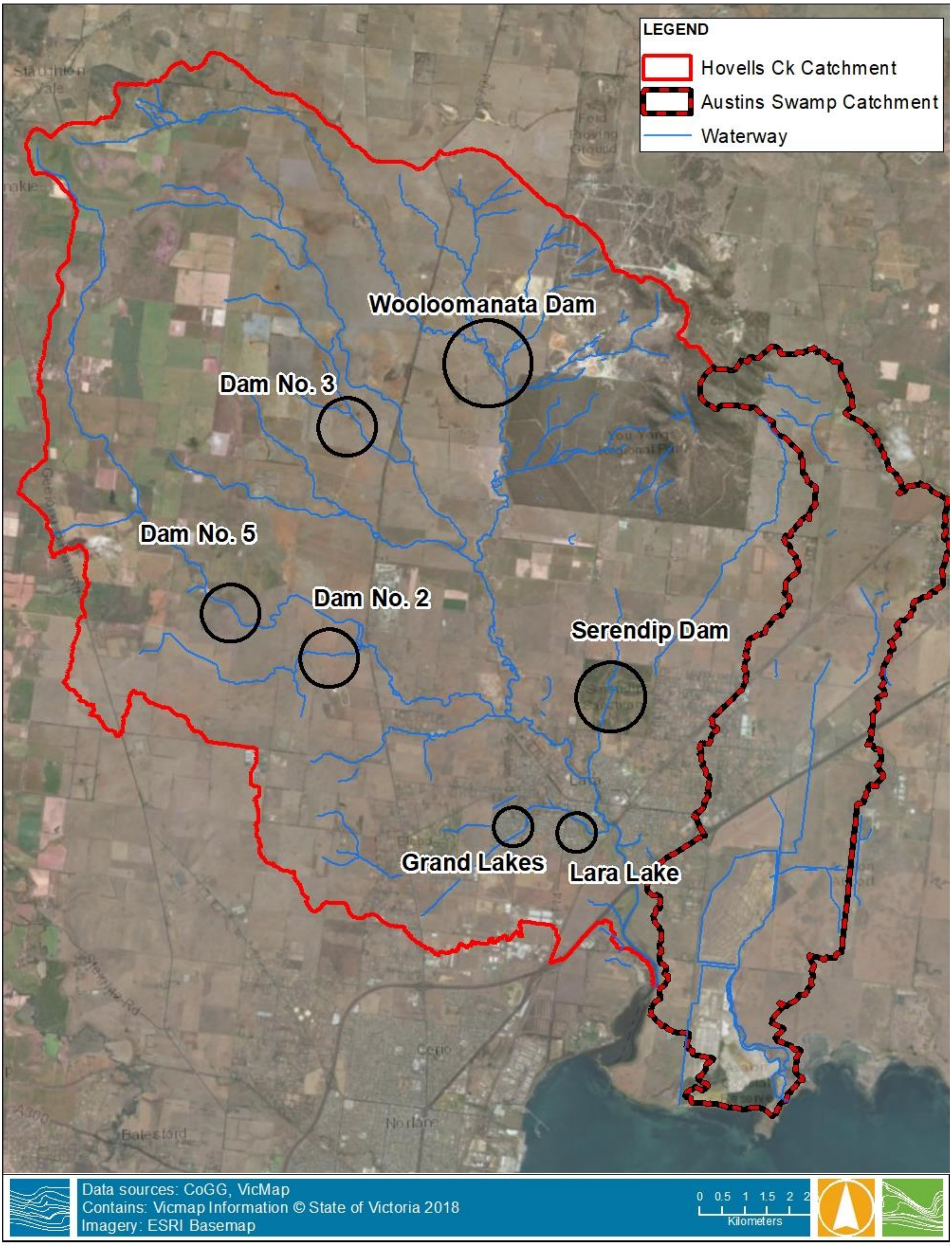

FIGURE 4-5 SIGNIFICANT STORAGES LOCATION

TABLE 4-2 AVAILABLE STORAGE VOLUMES FOR SIGNIFICANT CATCHMENT STORAGES

		Wooloomanata	Dam2	Dam3	Dam5	Serendip	Grand Lakes	Lara Lake
Empty Level (m AHD)		45.3	31.0	49.5	76.0	10.5	8.00	3.25
Initial Spillway level (m AHD)		51.4	35.00	54.5	81.7	12.95	11.00	6.49
Available storage (m^3)	Empty	372,510	75,150	712,760	370,600	370,000	24,900	22,400
	50%	186,255	37,575	356,380	185,300	185,000	12,450	11,200
	Full	0	0	0	0	0	0	0

The level of available storage within these dams during major flood events can impact peak flows and timing downstream (at Lara). The sensitivity of peak flows to dam levels was tested by modelling three scenarios of available storage within the RORB model. The scenarios tested assumed storages were empty, 50% full and 100% full.

A Monte Carlo simulation was used to assess the three scenarios, adopting a fixed initial loss of 15 mm and continuing loss of 2 mm/hr. Summary results are provided in Table 4-3, demonstrating the impact on the 1% AEP peak flows at Flinders Avenue and Rennie Street. The difference in peak flow at these downstream locations, between the seven major dams being assumed to be empty or full being between 35 - 40 m^3/s (around 10-15% of the total peak flow).

TABLE 4-3 1% AEP PEAK FLOW ESTIMATION FOR VARIOUS STORAGE LEVELS

	Empty Storage		50% Capacity		Full	
IL 15 mm & CL 2 mm/hr	Critical Duration	Peak Flow (m^3/s)	Critical Duration	Peak Flow (m3/s)	Critical Duration	Peak Flow (m3/s)
Peak Flow at Flinders	18-Hour	**240.85**	12-Hour	**262.07**	12-Hour	**277.74**
Peak Flow at Rennie St	18-Hour	**275.94**	12-Hour	**292.71**	12-Hour	**311.88**

Based on these findings, it is recommended to adopt an initial storage level in the major dams of the Hovells Creek catchment of 50% capacity. Whilst the RORB modelling has shown the peak 1% AEP flows at Lara are not significantly impacted as a result of storage levels, a predetermined storage level of 50% provides a more realistic scenario whereby the storages within the catchment have some airspace. A sensitivity analysis for the 1% AEP – 18-hour duration event will also be undertaken with the dams 100% full to provide an indication of the impact on flood levels at Lara.

4.3 Losses

Design losses provide a representation of the antecedent conditions within the catchment. In determining appropriate values to use, a review of existing values used in previous studies, regional loss values from the ARR datahub and loss values adopted in the joint calibration process (Table 4-4) was undertaken.

TABLE 4-4 DESIGN LOSSES FROM EXISTING STUDIES AND ARR

Source	Initial Loss (mm)	Continuing Loss (mm/hr)
ARR Datahub	11	2
Figure 5.3.18 and Figure 5.3.19 Book 5 Ch 3 ARR, 2019	20-30	2-4
Table 5.3.5 & Table 5.3.6 Book 5 Ch 3 ARR, 2019	37.21	3.24

Source	Initial Loss (mm)	Continuing Loss (mm/hr)
Water Technology Calibration	25-40	2-3
Hovells Creek (Shore of Corio, 1990)	20	0.5
Hovells Creek (Lawson & Treloar, 2000)	20	1
Hovells Creek (WBM, 2002)	20	0.25
Austins Swamp (Lawson & Treloar, 2000)	20	1

It is recommended that the design losses for the riverine RORB modelling adopt an initial loss of 15 mm and a continuing loss of 1.5 mm/hr. Sensitivity of the impact on flood levels at Lara should be undertaken in the hydraulic modelling phase of the project. These values have been adopted as medium ground between the calibration modelling (which was shown to be following periods of dry antecedent conditions), previous modelling assessments and the ARR datahub loss values.

The sensitivity of the model to these values was assessed, to provide an indication of the potential variance in design floods as a result of different antecedent conditions. Variable design losses were tested in a Monte Carlo simulation for 9-hour up to 72-hour duration events. Storages were assumed to be at 50% capacity. In assessing the impact of initial loss, a continuing loss value of 2 mm/ hr was adopted, with initial loss values of 11 mm, 15 mm and 20 mm (in line with ARR datahub and previous study loss values). The results showed the peak flow at Flinders Avenue varied from 240 m^3/s – 262 m^3/s, around 10% of the estimated peak flow (Figure 4-6).

In assessing the impact of continuing loss, an initial loss of 15 mm/hr was adopted, with continuing loss values of 1 mm/r, 2 mm/hr and 3 mm/hr. The results showed the peak flow values at Flinders Avenue varied from 205 m^3/s to 315 m^3/s (Figure 4-6), indicating the model to be more sensitive to variances in continuing loss compared with initial loss and storage parameters assessed.

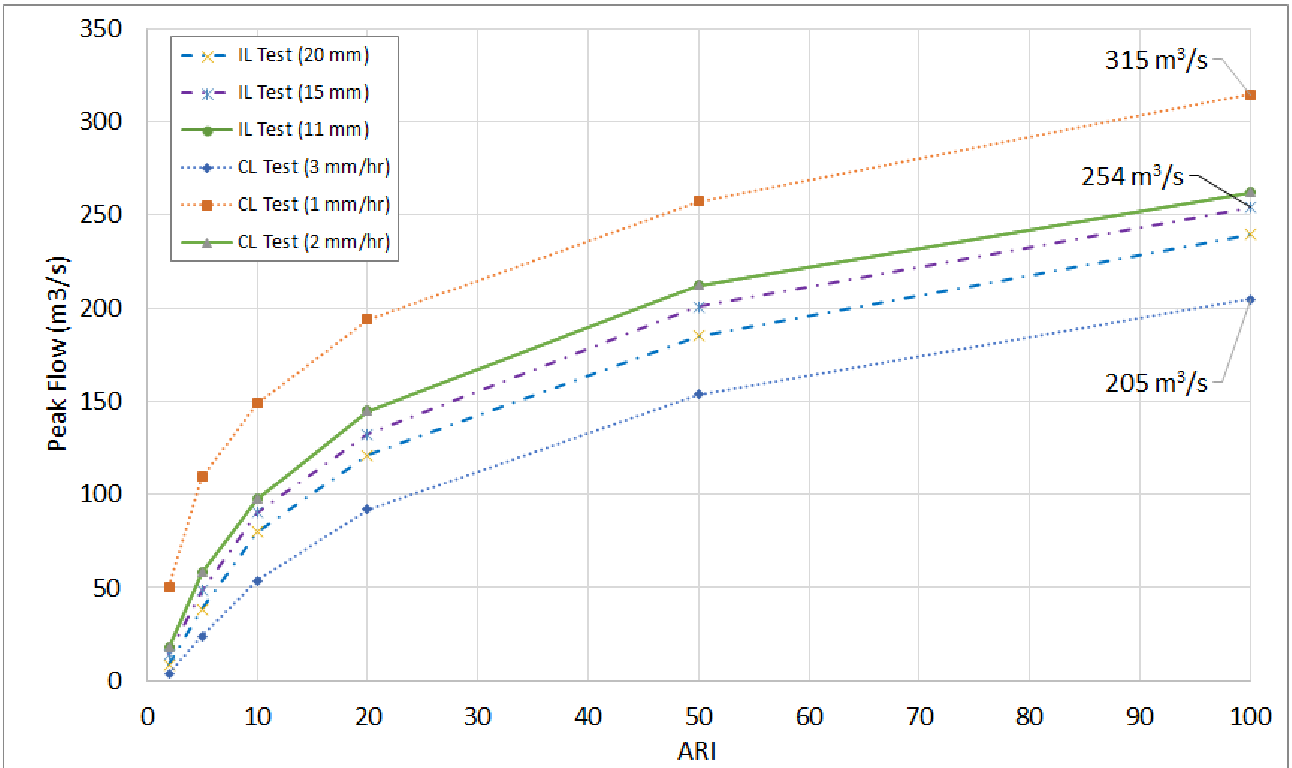

FIGURE 4-6 INITIAL AND CONTINUING LOSS SENSITIVITY TESTING

4.4 Critical Duration

The critical duration at various locations throughout the Hovells Creek and Austins Swamp catchments (Figure 4-7) was assessed, to determine the appropriate design events for modelling. A Monte Carlo simulation for durations of 1 hour up to 72 hours, adopting a fixed continuing loss value of 1.5 mm/hour, and variable initial loss (ranging from 1- 3 mm/hr). The resulting peak flows (Figure 4-8) at each of the seven locations indicate the critical duration ranged from 9 to 18 hours. The peak flow in Hovells Creek at Finders Avenue and Rennie Street was resulted from an 18 hour event.

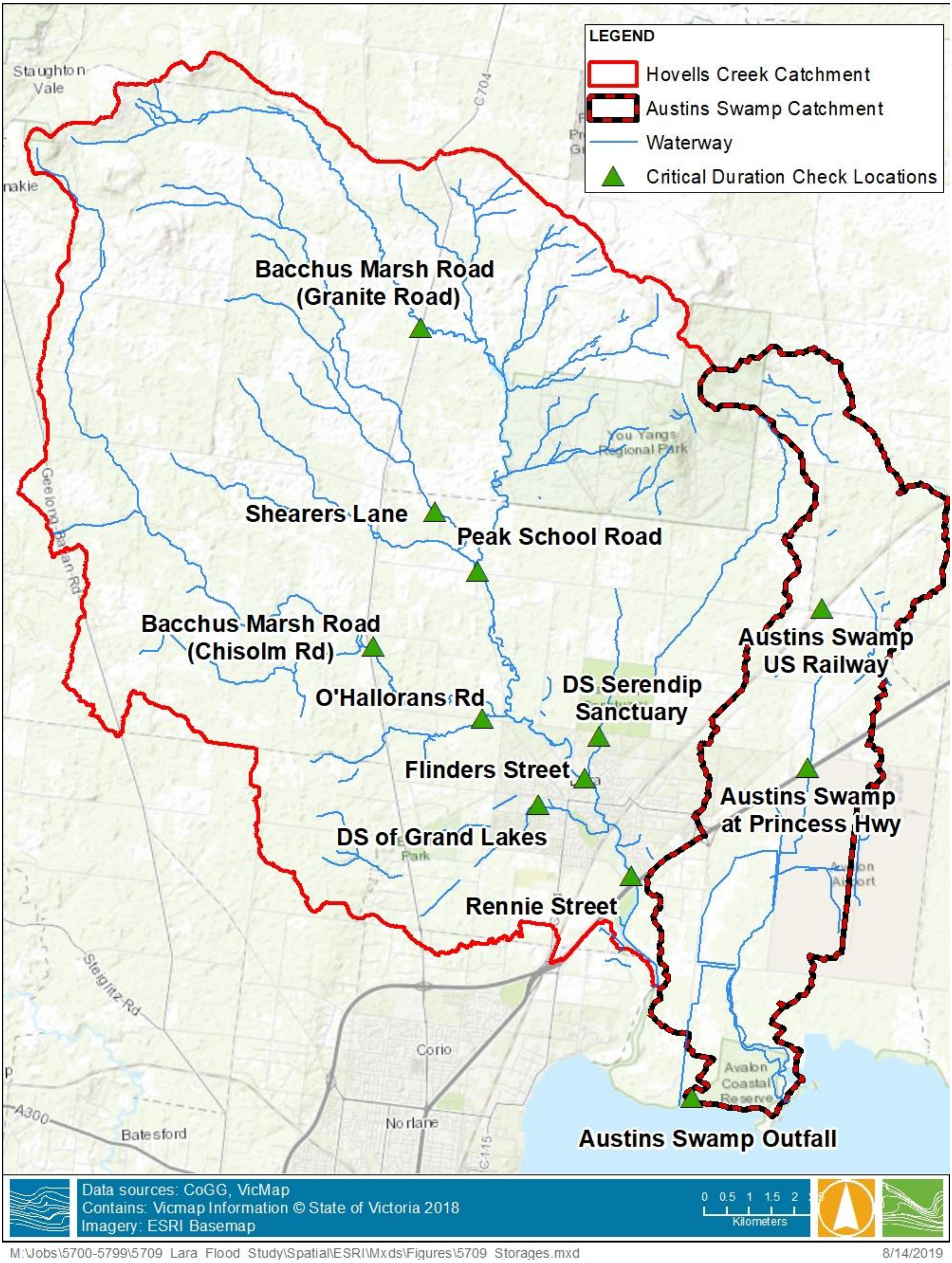

FIGURE 4-7 CRITICAL DURATION CHECK LOCATIONS

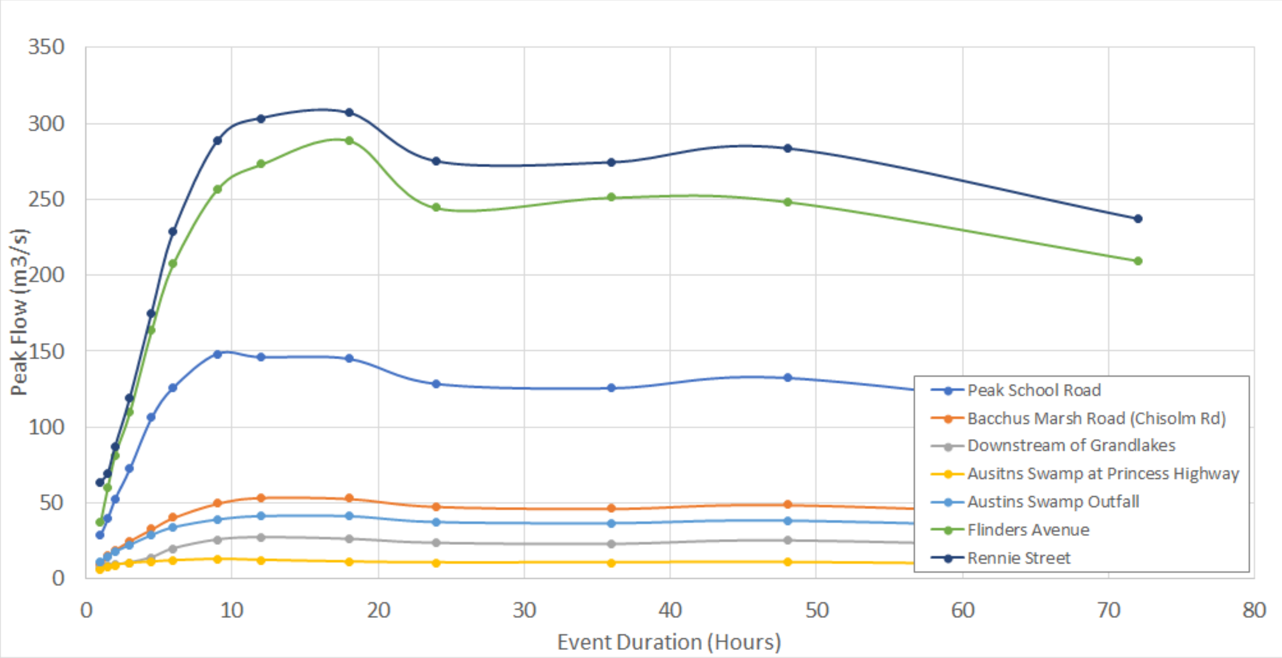

FIGURE 4-8 CRITICAL DURATION ASSESSMENT – 1% AEP RORB SIMULATION

Based on these findings, the design events to be simulated in the hydraulic model will include the 2-hour, 6-hour, 9-hour, 12-hour, 18-hour and 48-hour events. This will ensure the majority of the catchment from the upper reaches of Hovells Creek and Austins Swamp Drain are assessed for the critical duration within each area as well as a longer (48-hour) volume driven event.

4.5 Temporal Pattern

A major change to best practice design hydrology as a result of the ARR2016 (now 2019) release is the change from a single temporal pattern to the analysis of 'real data' storms recorded at nearby pluvio stations. There are 30 pre-determined temporal patterns for most of Australia. These consist of three event characteristics; frequent, intermediate, and rare events, each containing ten temporal patterns. To demonstrate the variation in rainfall timing, ten temporal patterns (from rare events) are plotted in Figure 4-9 for the 1% AEP 18-hour duration storm. The plot shows the cumulative rainfall throughout each of the ten storms, with 'front-loaded' storms producing the bulk of the rainfall within the first half of the storm (dark brown TP8), 'back-ended' storms producing the bulk of the rainfall in the later stages of the storm (dark and light grey TP3 & TP9).

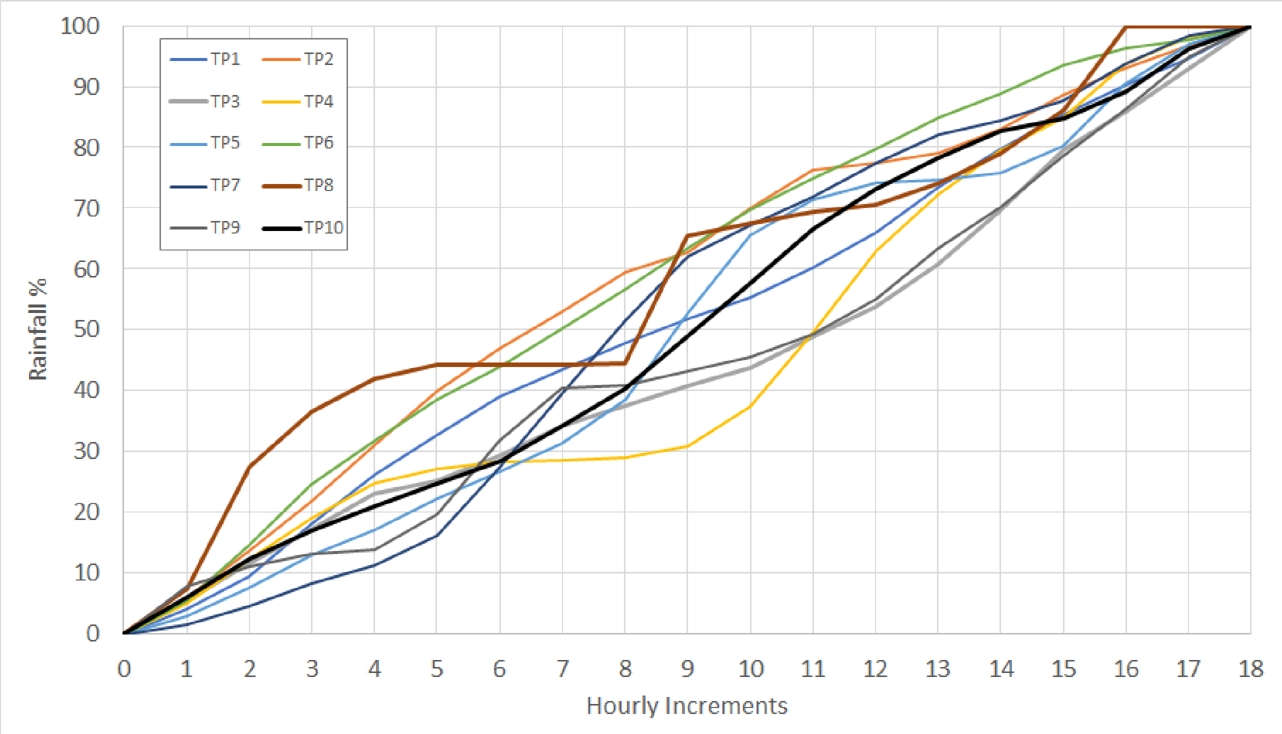

FIGURE 4-9 18-HOUR 'RARE EVENT' TEMPORAL PATTERNS FOR THE STUDY AREA

ARR provides two approaches to selecting an appropriate temporal pattern for the design modelling:

- select the temporal pattern that produces the closest (on the higher side) to the median design flow for each event duration
- Select the temporal pattern closest to the average Monte-Carlo peak flow.

The relevant temporal patterns for Lara, downloaded from ARR 2016 Data Hub[1], were used as input to the RORB model, and run as an ensemble (i.e. run individually, with statistics generated for the 10 events), and as a Monte Carlo simulation.

For the purposes of establishing design conditions, an assessment of peak flows was undertaken at the Flinders Avenue gauge on Hovells Creek. Figure 4-10 shows the ensemble results (as a box plot, and with a separate series for the average), alongside the averages of the Monte-Carlo results for the 1% AEP (1.5 hour to 48 hour duration events). The results show greater variability in the longer duration events (18 to 48 hours), with the mean ensemble flow generally lower than the Monte Carlo peak flow. The peak Monte-Carlo flow at Flinders Avenue was found to be 288 m^3/s for the 18-hour storm event, while the peak mean flow from the ensemble results was found to be 267 m^3/s for the 12-hour duration, with the mean flow for the 18-hour duration slightly lower at 262 m^3/s.

The temporal pattern which produced the closest peak flow (above the median) was adopted. For the 18-hour duration event, this was temporal pattern 10, with a peak flow of 270 m^3/s. This peak flow also best matched the Monte-Carlo flow of 273.9 m^3/s (although slightly lower). For the remaining durations, the same assessment was undertaken for the critical durations at locations of interest determined previously.

A comparison of the peak flows for all temporal patterns with the temporal selected for design modelling was undertaken at number of locations throughout the catchment. This was undertaken to ensure that in selecting a single temporal pattern for each duration, the modelling provided suitable peak flows across the entire catchment. Table 4-5 below summarises the ensemble results at a number of the locations referred to in Figure 4-7 and the corresponding peak flows for the temporal pattern selected for design modelling.

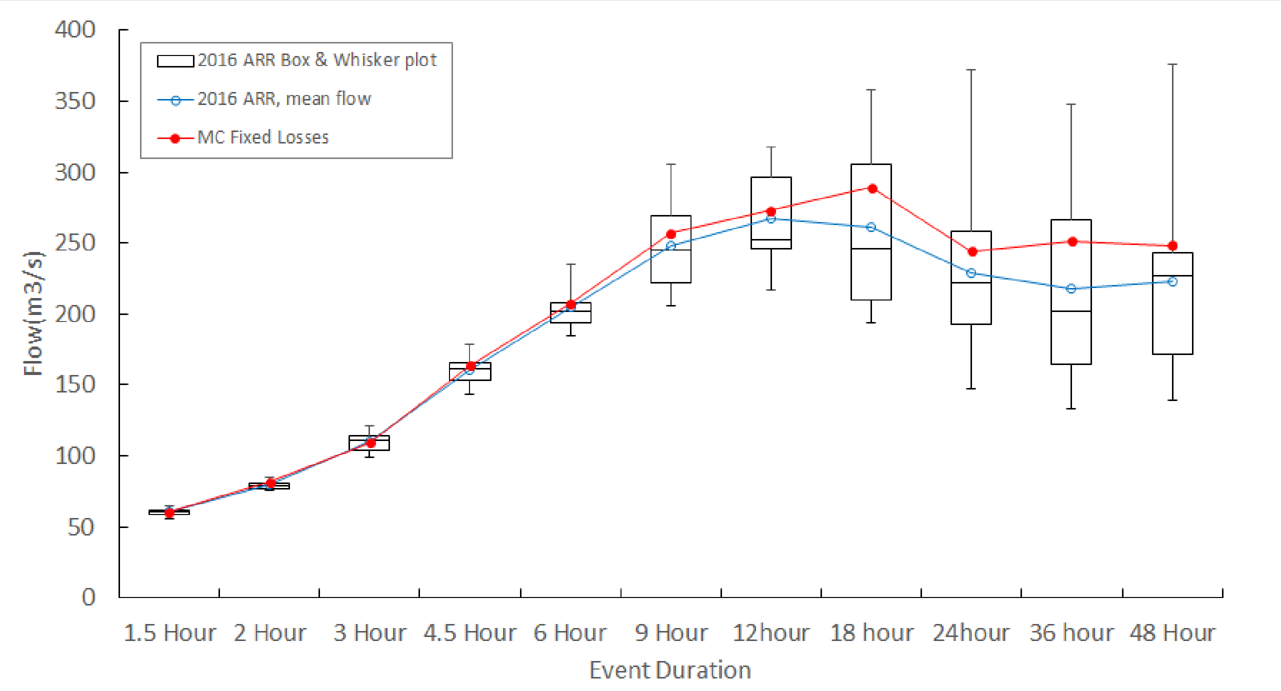

FIGURE 4-10 1% AEP – ENSEMBLE AND MC PLOT (HOVELLS CREEK AT FLINDERS AVENUE)

TABLE 4-5 TEMPORAL PATTERN CHECK FOR ALL DESIGN DURATIONS (1% AEP)

Location	Critical Duration	Mean Flow (m^3/s)	MC Flow (m^3/s)	TP Selected	Selected TP Flow (m^3/s)
Darlington Rd	2-Hour*	29	32	3	30
Bacchus Marsh Road (Granite Rd)	6-Hour	37	41	6	40
Peak School Rd	9-Hour	142	148	1	133
Shearers Lane	12-Hour	36	37	4	37
Bacchus Marsh Rd (Chisolm Rd)	12-Hour	52	54	4	55
O'Hallarons Rd	12-Hour	70	74	4	72
Flinders Av	18-Hour	261	288	10	270
Rennie St	18-Hour	300	307	10	310
Austins Swamp Upstream of Railway	9-Hour	19	20	1	18
Austins Swamp at Princes Hwy	9-Hour	13	13	1	10
Austins Swamp Outfall	12-Hour	41	42	4	42

The recommended temporal pattern for each duration to be used in the design modelling is shown in Table 4-5. Note this is based on a 1% AEP analysis. A similar analysis will be completed for the remaining temporal pattern bins to be adopted for the remaining design magnitude events.

**The critical duration at Darlington Rd was found to be 1-hour event with a MC flow of 34.91 m^3/s compared with the 2-hour MC flow of 31.5 m^3/s. However given its isolation in the upper catchment, the 2-hour duration was likely to provide similar results in this location and a better representation of critical duration throughout other 'upper catchment' areas.*

4.6 Tailwater Boundaries

Two tailwater boundaries were placed at the lower end of the model, where Hovells Creek enters Limeburners Bay and where the Austins Swamp drain outfalls into the Avalon Coastal Reserve. Water Technology have recently undertaken a project on the Avalon Coastal Reserve investigating tidal levels and potential sea level rise. Table 4-6 provides information on the tidal levels for Corio Bay and ultimately the static tailwater conditions used for the hydraulic modelling. A conservative approach was undertaken to the tailwater level with the Highest Astronomical Tide (HAT) level (1.13 m AHD) applied to both tailwater conditions. The tidal influence has little impact on Hovells Creek with the HAT reaching just upstream of Rennie Street.

TABLE 4-6 CORIO BAY/LIMEBURNERS BAY TAILWATER CONDITIONS

Tidal Plane	Level (m AHD)
Lowest Astronomical Tide (LAT)	-0.81
Mean Lower Low Water (MLLW)	-0.48
Mean Higher Low Water (MHLW)	-0.08
Mean Lower High Water (MLHW)	0.12
Mean Higher High Water (MHHW)	0.42
Highest Astronomical Tide (HAT)	1.13

The Highest Astronomical Tide (HAT) has been selected as the static tailwater level for the modelling. As outlined above, the tailwater level has minimal influence on flood level conditions within the area of interest.

5 RIVERINE HYDRAULIC MODEL

5.1 Model Schematisation

The riverine TUFLOW model extent encompassed the Hovells Creek and Austins Swamp catchment areas, through to the outlets at Limeburners Bay and Corio Bay as shown in Figure 1-1. In total, the TUFLOW model extent covered around 290 km^2. The model utilised a 4-metre grid resolution, considered fit for purpose as it provides sufficient detail of the key waterways and hydraulic features without compromising model run time.

The main objective of the riverine model was to provide mapping sufficient to highlight flood hazard and flood intelligence information for the riverine waterways within the study area. The upper reaches of Hovells Creek flow through farmland, transitioning to rural-residential areas and the residential area of Lara in the lower reaches, before outfalling to Limeburners Bay. To ensure the model resolution accurately depicted the channel capacity of Hovells Creek and other waterways within the model, a number of channel profile cross sections of the detailed LiDAR and final model DEM were extracted at key locations within the study area. For much of the study area the waterway cross sections indicated that the capacity of the channels was likely to be exceeded, with flooding spreading out across the floodplain. The main waterway channels in the upper catchment range from 10-15 metres in width, with some larger and deeper channels closer to 15-20 metres wide. Several main drains around Lara are in the order of 8-12 metres wide. The grid resolution selected ensured there were at least 2-3 cells within the main waterway channels. For the smaller drains, the adopted grid size is unlikely to represent the true capacity accurately, but it is understood that in rarer events (such as the 1% AEP event), most flow will be on the floodplain.

More detail on the riverine hydraulic model build can be found in the Calibration Report (**R02)**. Results of the riverine model are provided in Section 7.

5.2 Model Simulations

All riverine model design runs completed in the hydraulic model (including sensitivity and mitigation modelling) are listed in Table 5-1.

TABLE 5-1 HYDRAULIC MODEL SIMULATIONS COMPLETED

Riverine Model	Magnitude	Durations	IL (mm)	CL (mm/hr)	Tailwater
Design Events	PMF	18hr	-	-	1.13m AHD
	0.1% AEP	2hr,6hr,9hr,12hr,18hr,48hr	15	1.5	1.13m AHD
	0.2% AEP	2hr,6hr,9hr,12hr,18hr,48hr	15	1.5	1.13m AHD
	0.5% AEP	2hr,6hr,9hr,12hr,18hr,48hr	15	1.5	1.13m AHD
	1% AEP	2hr,6hr,9hr,12hr,18hr,48hr	15	1.5	1.13m AHD
	2% AEP	2hr,6hr,9hr,12hr,18hr,48hr	15	1.5	1.13m AHD
	5% AEP	2hr,6hr,9hr,12hr,18hr,48hr	15	1.5	1.13m AHD
	10% AEP	2hr,6hr,9hr,12hr,18hr,48hr	15	1.5	1.13m AHD
	20% AEP	2hr,6hr,9hr,12hr,18hr,48hr	15	1.5	1.13m AHD
	50% AEP	2hr,6hr,9hr,12hr,18hr,48hr	15	1.5	1.13m AHD
Sensitivity Analysis	1% AEP - Highest TP	18hr	15	1.5	1.13m AHD
	1% AEP - Full Storage	2hr,6hr,9hr,12hr,18hr,48hr	15	1.5	1.13m AHD
	1% AEP - Roughness Test	12hr,18hr	15	1.5	1.13m AHD
	1% AEP - CC - SLR	12hr	15	1.5	1.93m AHD
	10% AEP - CC - SLR	12hr	15	1.5	1.93m AHD
	1% AEP - CC - Rainfall Intensity - RCP4.5 (2050)	12hr,18hr	15	1.5	1.13m AHD
	1% AEP - CC - Rainfall Intensity - RCP8.5 (2050)	12hr,18hr	15	1.5	1.13m AHD
	1% AEP - CC - Rainfall Intensity - RCP4.5 (2090)	12hr,18hr	15	1.5	1.13m AHD
	1% AEP - CC - Rainfall Intensity - RCP8.5 (2090)	12hr,18hr	15	1.5	1.13m AHD
	Culvert Blockage (Key Structures) 1% & 10%	12hr	15	1.5	1.13m AHD

5.3 Sensitivity Analysis

5.3.1 Overview

A range of parameters were selected for sensitivity analysis within the hydraulic model. These are listed below and described the following sections:

- Climate change.
- Temporal Patterns.
- Storage conditions.
- Waterway Vegetation.
- Structure blockage.

5.3.2 Climate Change

At the time the scope of the project was defined, climate change was incorporated into the project brief as a sensitivity analysis to understand how sensitive the study area is to potential changes in climatic conditions. By gaining an understanding of the catchment sensitivity to these changes, an information gathering exercise for decisions and policy regarding future impacts can be considered. Since the project inception, more information and guidance on managing climate change risk has been developed by DELWP[5]. Council currently have a Climate Change Adaption Strategy[6] which aims to prepare Council and the broader Greater Geelong community for climate change impacts by integrating climate change adaption through its decision-making process.

- **Increased rainfall intensity based on Representative Concentration Pathway (RCP) 4.5 & 8.5 for years 2050 and 2090, undertaken for the 1% AEP 12-hour duration**. The increased rainfall intensity as a result of climate change for the four scenarios modelled was using the IFD data downloaded from BoM. The results showed maximum increases in flood levels along Hovells Creek through Lara ranging from 150 mm (RCP 4.5 for year 2050) through to an increase of 500 mm for RCP 8.5 for the year 2090. Difference plots for the RCP 4.5 Year 2050 and RCP 8.5 Year 2090 scenarios are provided below (Figure 5-2 and Figure 5-3) and are summarised in Table 5-2.

TABLE 5-2 CLIMATE CHANGE SENSITIVITY ANALYSIS SUMMARY

Year	RCP	Increase in Rainfall (1% AEP 12-hour)	Increase in Flood Levels (Flinders Ave)	Increase in Flood Levels (DS Station Lake Road)
2050	4.5	5.4%	0.11	0.19
2050	8.5	7.3%	0.14	0.24
2090	4.5	7.6%	0.15	0.25
2090	8.5	16.3%	0.27	0.44

It should be noted that although the increase in rainfall intensity was modelled, the initial and continuing loss values were maintained as is. While predictions suggest rainfall intensity is likely to increase as a result of climate change, it is also expected that average annual rainfall will decrease[7] (CSIRO, 2015). Based on this prediction, it is likely that the on average, the broader Hovells Creek catchment conditions may be drier and

[5] DELWP – Managing Climate Change Risk – Guidance for Board Members and Executives of Water Corporations and Catchment Management Authorities
[6] City of Greater Geelong – Climate Change Adaptation Strategy
[7] CSIRO – Climate Change in Australia.

an increase in initial loss and potentially continuing loss would be likely. This may reduce the increase in flood levels from riverine flooding somewhat; however, new major infrastructure along the waterway and within the floodplain should be assessed with the impact of climate change considered. Stormwater flooding in urban areas is more likely to be impacted from predicted increase in extreme events, specifically increased rainfall intensity. Given the antecedent conditions of the impervious areas in Lara are relatively static, increased rainfall intensity is likely to result in an increase in design levels throughout the town.

- **10% and 1% AEP 12-hour duration with sea level rise for year 2090 (+0.80m tailwater level).** Flood modelling results showed the increases in flood levels were significant within the lower end of the Avalon Road catchment (and likely to cause significant flooding along the Avalon Foreshore Road (Figure 5-1). It is likely that minimal sea level rise will result in increased frequency and severity of flooding along the foreshore. An increase of 0.80 m along the lower end of Hovells Creek is likely to result in the capacity of the Rennie Street Ford crossing being reduced due to the higher tailwater level. This may reduce the flow rate at which the road is overtopped, increase the frequency at which the road is closed. No significant increase is expected upstream of Rennie Street. The Princes Freeway bridge may experience a higher frequency at which the underside of the bridge is inundated; however, it is not likely that the frequency of overtopping would increase as a result of the modelled sea level rise.

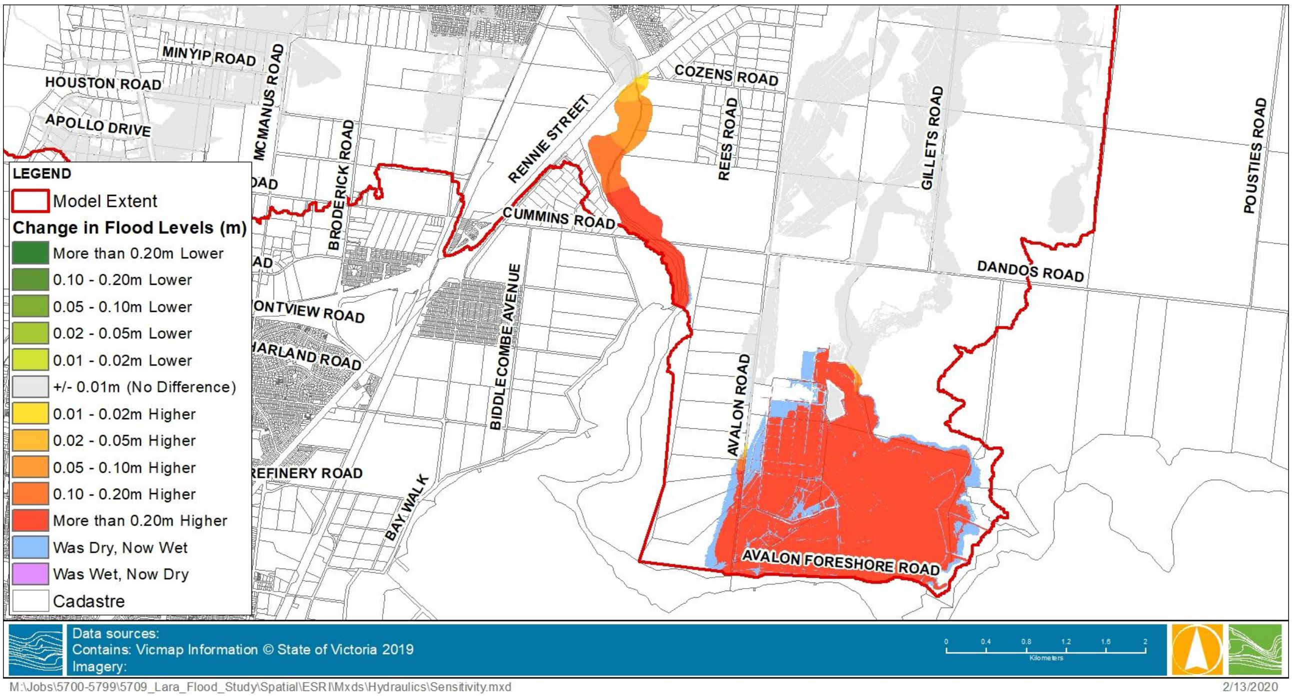

FIGURE 5-1 FLOOD LEVEL DIFFERNCE PLOT – 0.8 METRE SEA LEVEL RISE

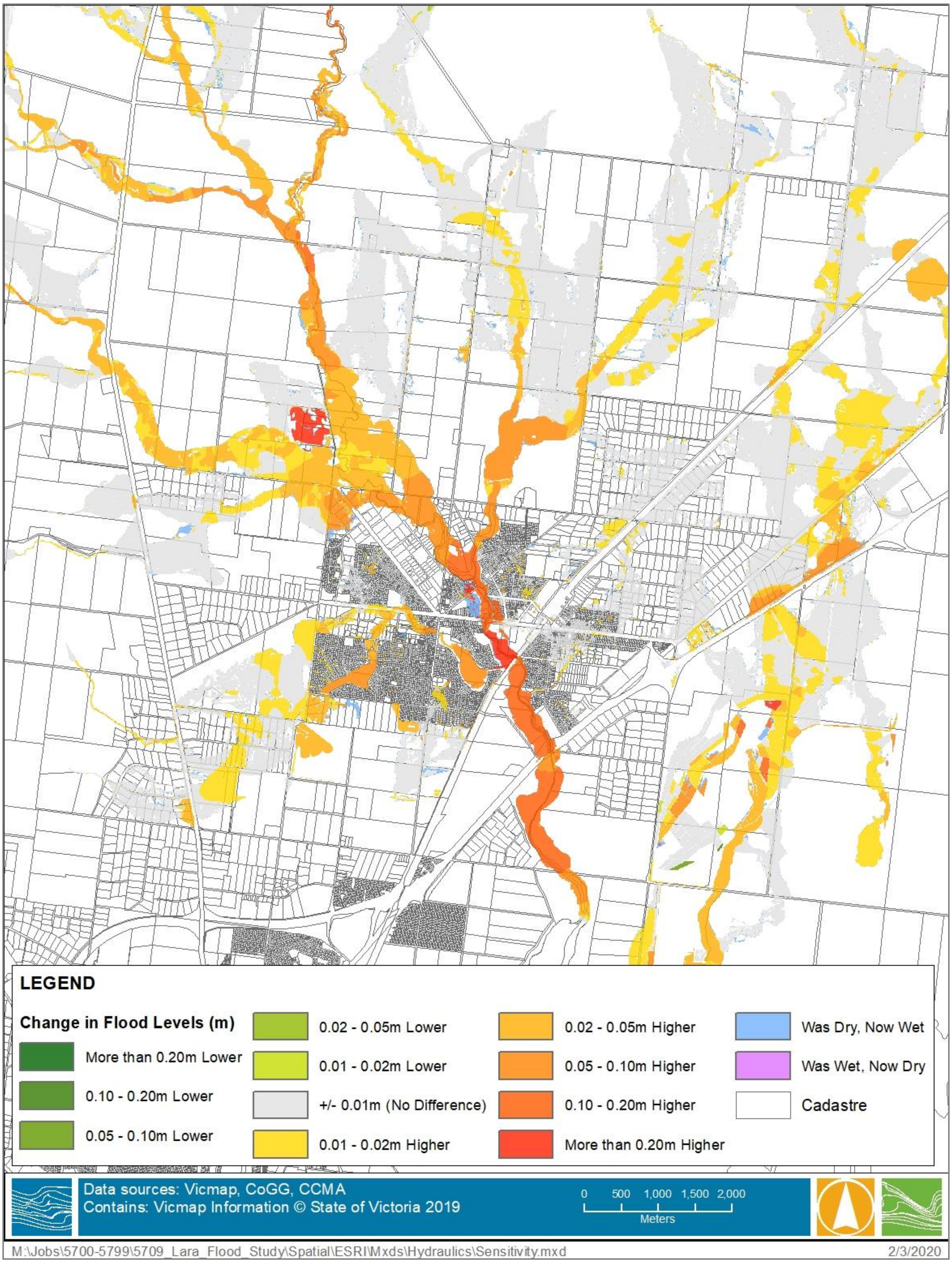

FIGURE 5-2 FLOOD LEVEL DIFFERENCE PLOT RCP4.5 YEAR 2050 AND EXISTING CONDITIONS

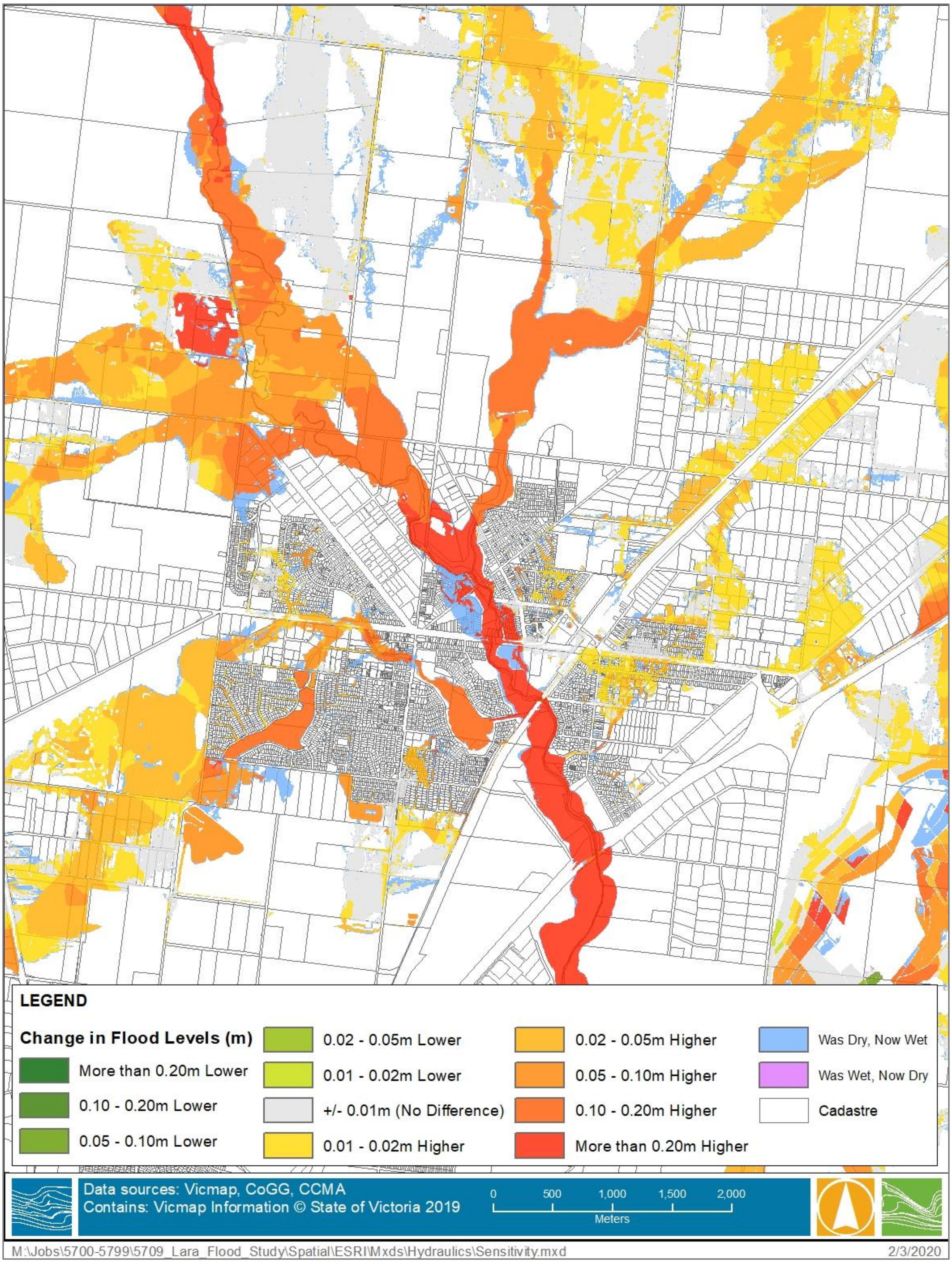

FIGURE 5-3 FLOOD LEVEL DIFFERNCE PLOT RCP8.5 YEAR 2090 AND EXISTING CONDITIONS

5.3.3 Peak Temporal Pattern

When assessing the impact of temporal pattern selection on flows for Hovells Creek at Lara (Flinders Avenue), temporal pattern nine (9) produces the highest peak flow (18-hour duration). This resulted in a higher flow along Hovells Creek at Lara of around 40 m^3/s and increased flood levels through Lara of between 200-300 mm. This is expected and, the temporal pattern selected for design modelling was based on the ARR2019 guidelines. The selection of the temporal pattern closest to the median for design modelling is industry standard.

5.3.4 Storage Conditions

Major Storages within the catchment filled to provide no available storage at the start of the storm event (1% AEP – 6 & 48 Hour Event). This does not show in an increase in peak flood level (or flow) through Lara in the 48-Hour event, but a faster rise in the rising limb. The 6-hour event with the storage removed showed a peak flow increase of 25 m^3/s (Figure 5-4), resulting in an increase in flood levels of around 200 mm along Hovells Creek through Lara. This reflects the impacted modelled in the hydrology assessment. The antecedent conditions can impact on peak flood levels as well as timing for when flooding is likely to start impacting the town as well as the peak flooding in town.

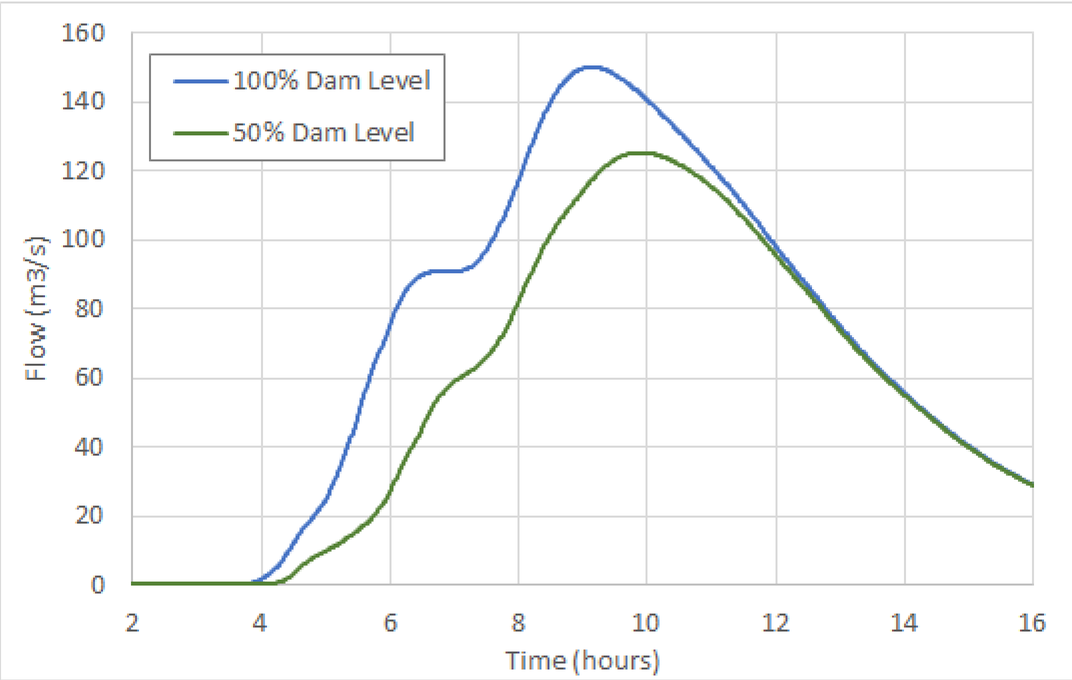

FIGURE 5-4 COMPARISON OF FLOW RATES WITH CATCHMENT STORAGES AT 50% (DESIGN CONDITIONS) AND 100% CAPACITY

5.3.5 Waterway Vegetation

Increasing channel roughness (Manning's 'n') along Hovells Creek by 20% was found to increase levels by 50-100mm with isolated increases downstream of Station Lake Road just above 100mm (Figure 5-5). The assessment also looked at when assessing the impact of scour erosion within Hovells Creek at the Station Lake Road bridge.

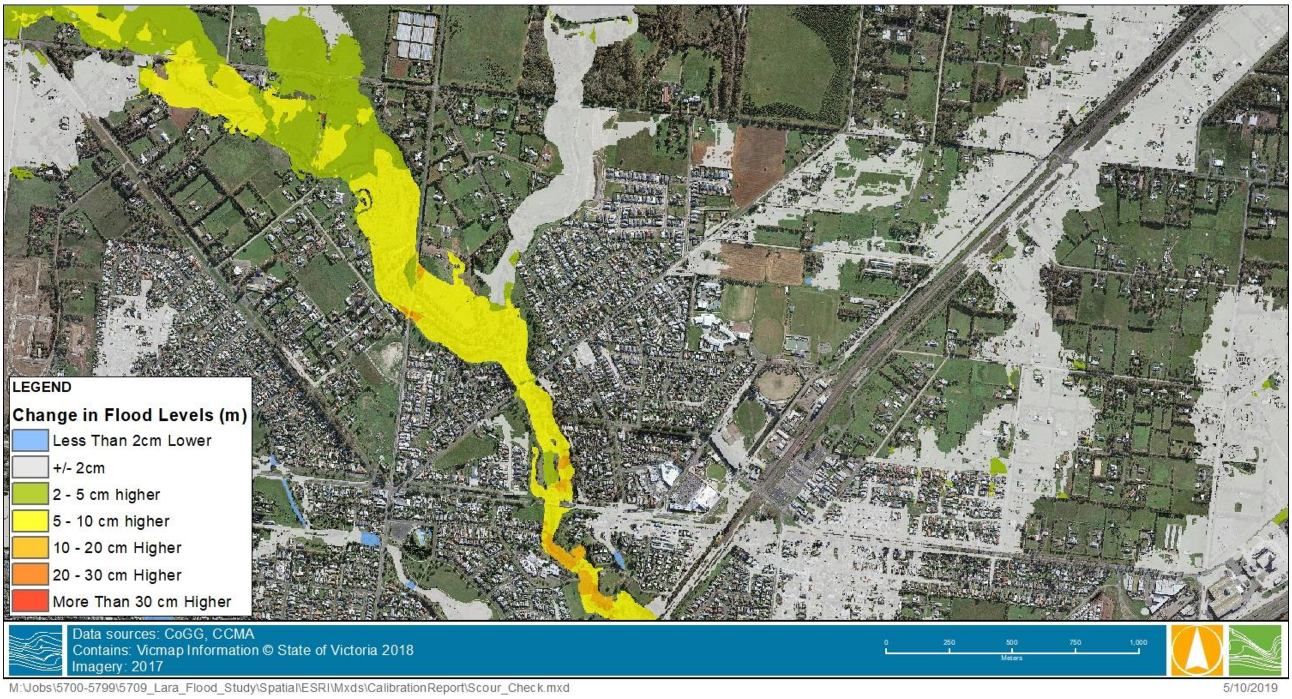

FIGURE 5-5 FLOOD LEVEL DIFFERENCE PLOT - INCREASED WATERWAY ROUGHNESS 1% AEP

5.3.6 Blockage Factors

100% blockage of key structures along major waterways (1% & 10% AEP 18-hour event) showed a significant increase in flood levels along Hovells Creek with isolated increases up to 300 mm (Figure 5-6). These increases were predominately confined to the floodplain; however, and a complete blockage of a major structure is unlikely due to the number of structures along the water and the limited availability of large debris within the catchment to cause a major blockage.

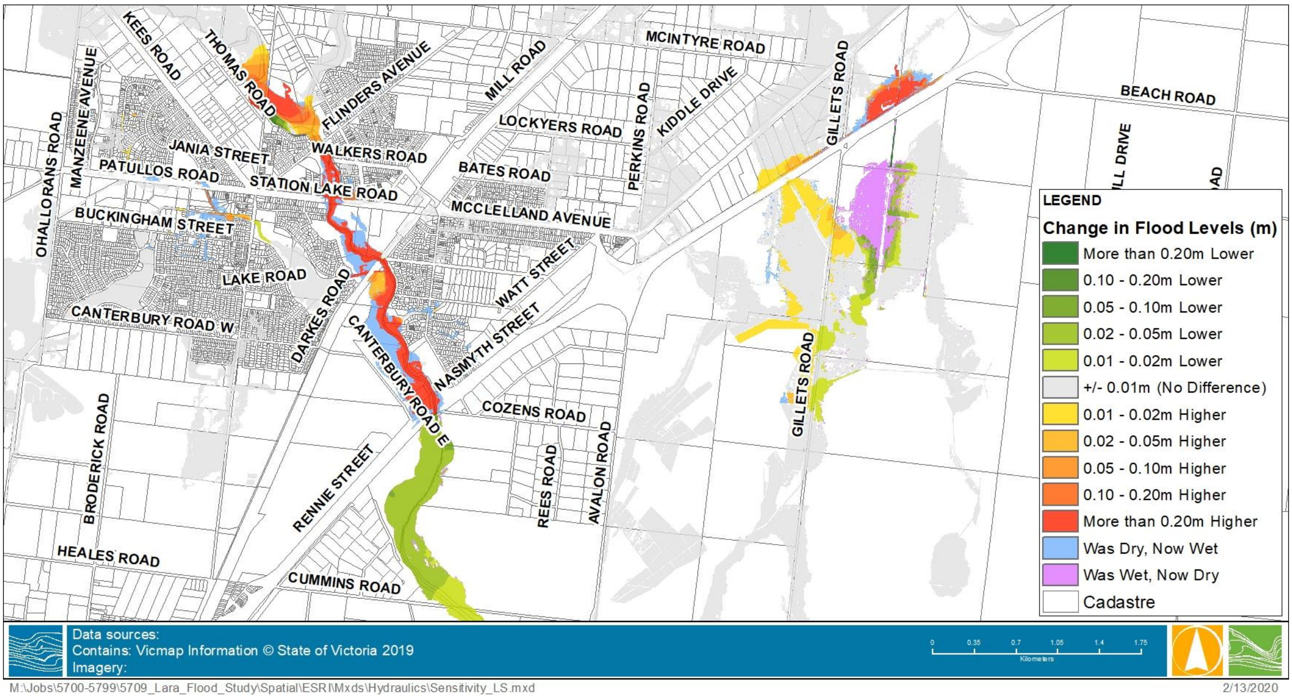

FIGURE 5-6 FLOOD LEVEL DIFFERENCE PLOT - KEY WATEREWAY ASSETS BLOCKED 10%AEP

6 URBAN HYDRAULIC MODEL

6.1 Schematisation

Parameters derived from the riverine hydrology model were used as a starting point to inform the urban stormwater (rain-on-grid) model, the extent of which is shown in Figure 6-1. The TUFLOW rain-on-grid model at 3 metre grid resolution was used to represent these areas. Available pit and pipe information was incorporated into the model and data gaps in the underground drainage network were filled using engineering judgement (ensuring similar cover to other pipes/downstream gradient etc.).

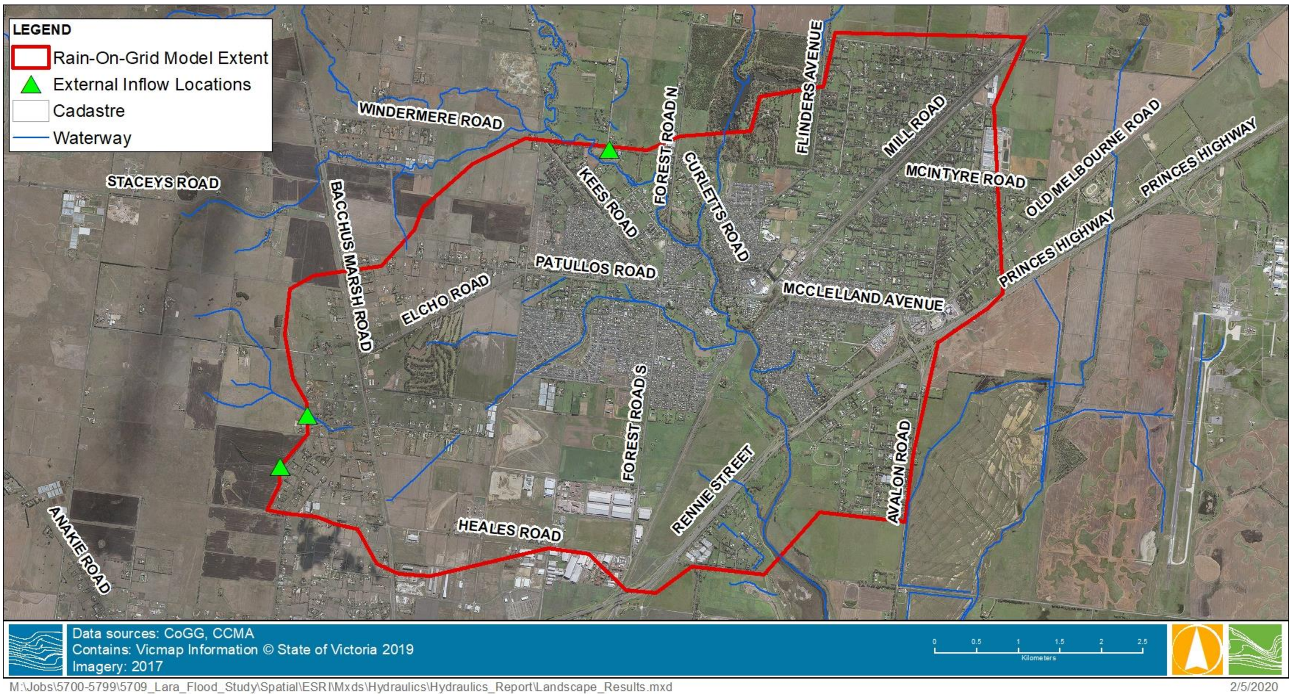

FIGURE 6-1 LARA URBAN STORMWATER MODEL EXTENT

6.2 Rainfall

Rainfall IFDs were extracted from the TUFLOW ARR2016 tool within TUFLOW. The rainfall was extracted from the centre of the urban model. The TUFLOW ARR2016 tool automatically generated rainfall hyetographs for each of the 10 temporal patterns for each AEP/duration combination. As identified in the Calibration Report **(R02)**, the rainfall totals in the 2016 IFD's are considerably lower than the 1987 IFD totals.

6.3 Inflow Boundaries

Three inflow boundaries were incorporated into the rain on grid model. Flows were taken from the RORB model used for the riverine modelling. A 10% AEP design flow was adopted for the Hovells Creek inflow at the northern end of the model area for all design AEPs given the relative catchment sizes. At the western side of the model, the catchment upstream of Bacchus Marsh Road adopted the relevant AEP as an inflow (i.e. for a 20% AEP design event, a 20% AEP inflow was adopted). This inflow was split with 80% of the runoff from RORB placed at the northern inflow and 20% for the southern inflow based on the sub-catchment delineation. No inflow was placed for Serendip Dam as the rain-on-grid modelling looked at relatively short duration storm events.

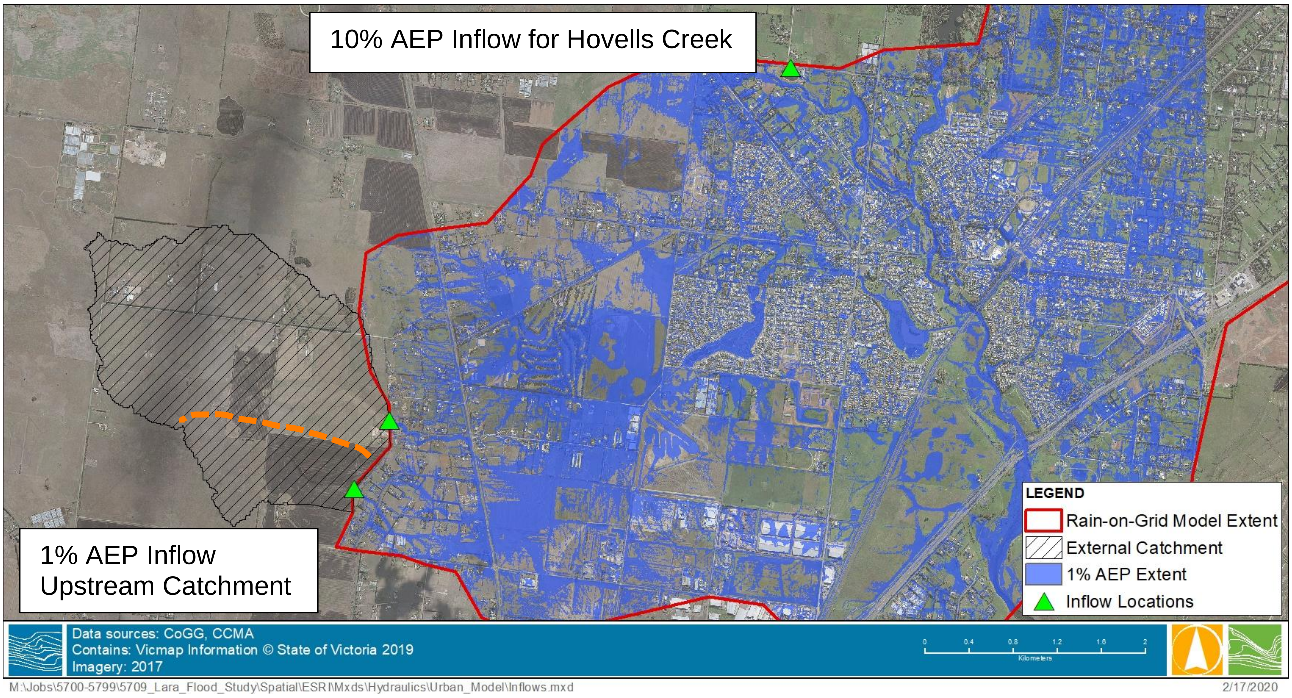

FIGURE 6-2 EXTERNAL INFLOWS FOR RAIN-ON-GRID HYDRAULIC MODEL

6.4 Tailwater Boundaries

Two tailwater boundaries were placed at the lower end of the model; where Hovells Creek enters Limeburners Bay and where the Austins Swamp drain outfalls into the Avalon Coastal Reserve. Water Technology has recently undertaken a project on the Avalon Coastal Reserve investigating tidal levels and potential sea level rise. Table 6-1 provides information on the tidal levels for Corio Bay and ultimately the static tailwater conditions used for the hydraulic modelling. A conservative approach was undertaken to the tailwater level with the Highest Astronomical Tide (HAT) level (1.13 m AHD) applied to both tailwater conditions. The tidal influence has little impact on Hovells Creek with the HAT reaching just upstream of Rennie Street.

TABLE 6-1 CORIO BAY/LIMEBURNERS BAY TAILWATER CONDITIONS

Tidal Plane	Level (m AHD)
Lowest Astronomical Tide (LAT)	-0.81
Mean Lower Low Water (MLLW)	-0.48
Mean Higher Low Water (MHLW)	-0.08
Mean Lower High Water (MLHW)	0.12
Mean Higher High Water (MHHW)	0.42
Highest Astronomical Tide (HAT)	1.13

The Highest Astronomical Tide (HAT) was selected as the static tailwater level for the modelling. As outlined above, the tailwater level has minimal influence on flood level conditions within the area of interest.

6.5 Losses and Material Roughness

Losses for a rain-on-grid model are applied in the material roughness layer. The loss values adopted in the riverine model were used as the basis for loss values within the urban model.

The design losses associated with individual land use types within the urban model were adopted in line with the ARR2019 urban chapter. This considered the impervious area of each parcel based on current zoning and aerial imagery. Design losses reflected the existing land use conditions (as of the beginning of August 2019) and were adjusted for an assessment of 'ultimate development' conditions, as directed by Council. The 'ultimate development' scenario provided an assessment of potential 'worst case' flood conditions, assuming no retention to existing flows from future developments. A summary of initial and continuing losses for different land use types is shown in Table 6-2.

Modelling of building footprints was incorporated using a depth varying roughness parameter that applied a smooth surface for shallow depths (less than 2 cm) and a highly rough surface for depths above 10 cm. This allows for rainfall directly onto building footprints to quickly runoff into the stormwater network, replicating the direct connections of individual properties without the need for complicated pipe and topography alterations. The high roughness for the deeper depths provides resistance, simulating the slower overland flow making its way through the urban areas. While this approach did not represent all building types perfectly, it provided an overall fit for purpose representation of the impact of buildings located within overland flow paths. The high Manning's values of building footprints direct overland flow around the building where there is less resistance.

TABLE 6-2 RAIN ON GRID DESIGN LOSS VALUES

Land use Type	Initial Loss, mm	Continuing Loss, mm/hr	Mannings value
Open Space (minimal vegetation)	15	1.5	0.04
Dense Bush	15	1.5	0.1
Open Space (grassed)	15	1.5	0.035
Open Water (no vegetation)	0	0	0.03
Vegetated Waterway	1	0.5	0.06
Riparian Zone (Dense Vegetation)	5	1.5	0.07
Rural Residential (parcel)	10	1.5	0.1
Urban Residential (parcel)	5	1	0.15

Land use Type	Initial Loss, mm	Continuing Loss, mm/hr	Mannings value
Industrial/Commercial	4	1	0.2
Unsealed Road (Reserve)	6	1.2	0.03
Sealed Road (Reserve)	3	0.6	0.02
Carpark	1	0	0.05
Railway Reserve	8	2	0.05
Building Footprint (roof)	0.5	0.05	Depth Varying: depth < 2cm value is 0.02, depth > 10 cm, value is 0.3

6.6 Catchment Conditions and Pre-Burst Losses

Rain-on-grid modelling of urban catchments can create significant perceived incidental storage, initial rainfall is required to 'pre-fill' or 'wet' the catchment. If the pre-wetting is not accounted for, this can reduce resultant flood levels and peak flow rates.

To ensure this was not an issue in the Lara model pre-burst losses were not removed from the design rainfall. The catchment was pre-wet to remove incidental storage within the catchment. Modelling results matched anecdotal evidence in there being large areas of shallow ponded water on the edge of the urban areas around Lara.

6.7 Temporal Pattern Selection

All 10 temporal patterns were simulated for the 1% AEP events for durations from 15-minute up to 6-hours to represent the critical durations across the urban area. Using post-processing tools, the methodology outlined below was used to produce a filtered set of result grids and flood extents. Following completion of the 1% AEP mapping, the remaining AEP events will be simulated using a single temporal pattern that provided the best representation of the median temporal pattern in the 1% AEP mapping. A visual representation of the process is shown in Figure 6-3.

- Initial and continuing losses were applied via the material (land-use) layer of the hydraulic model. Values varied based on the current land use.
- 10 temporal pattern result grids analysed to produce a grid representing the median water level were developed for each of the durations.
- Temporal pattern selection was based on the temporal pattern which gave the 'median' water level the greatest number of times across the urban model area for each 1% AEP duration event.
- Temporal patterns were selected for the remaining AEPs based on the 1% AEP methodology listed above.

6.7.1 Processing

- Temporal patterns were selected for the remaining AEPs based on the 1% AEP methodology listed above.
- These grids were then be spliced together to generate a 'maximum' water surface grid across the catchment.
- Maximum grids were filtered to remove depths below 30 mm and 'puddles' less than 200 m^2 (this removed low depth 'flooding' that can occur when applying rainfall to the entire catchment).

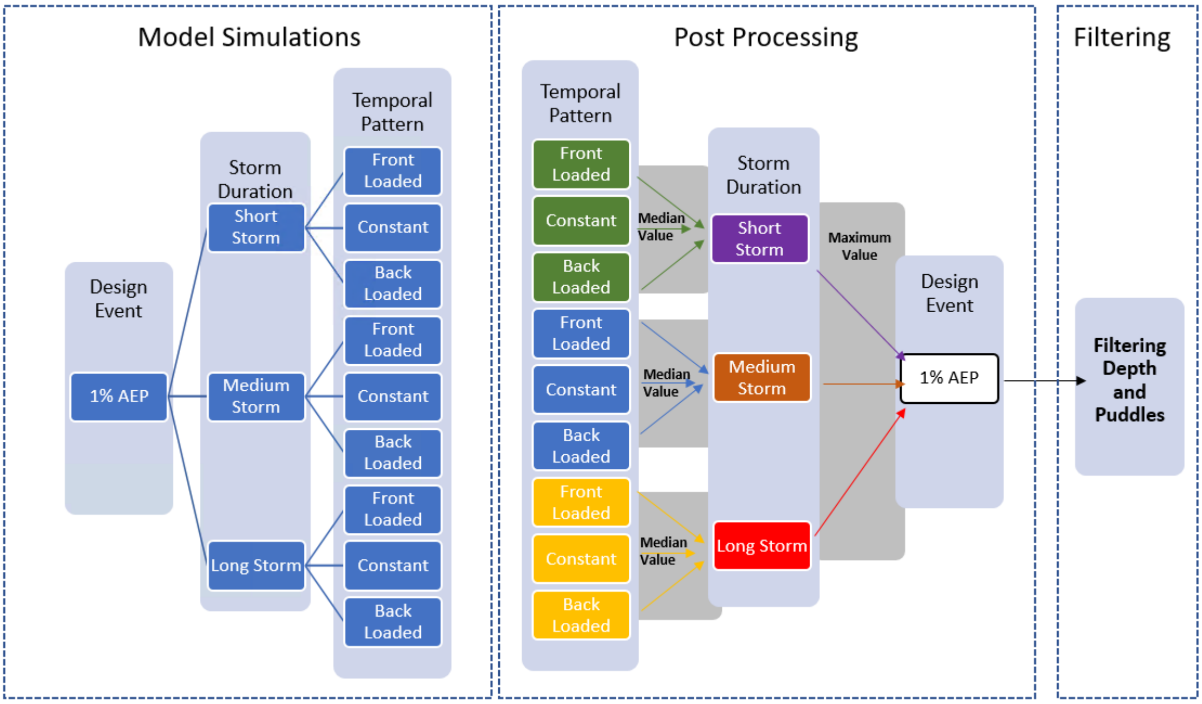

FIGURE 6-3 RAIN-ON-GRID WORKFLOW TO DEVELOP SINGLE SET OF MAPS PER AEP

6.8 Model Simulations

All design runs completed in the urban rain on grid hydraulic model (including sensitivity and mitigation modelling) are listed in the table on the following page.

Urban Model	Magnitude	Durations	IL (mm)	CL (mm/hr)	Tailwater
Design Events	0.1% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	0.2% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	0.5% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	1% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	2% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	5% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	10% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	20% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	50% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
Sensitivity Analysis	1% AEP - CC - Rainfall Intensity - RCP4.5(2050)	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	1% AEP - CC - Rainfall Intensity - RCP8.5(2050)	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	1% AEP - CC - Rainfall Intensity - RCP4.5(2090)	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	1% AEP - CC - Rainfall Intensity - RCP8.5(2090)	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	10% AEP -50% Pit Blockage Scenario	2-hour	15	1.5	10% AEP Flow in Hovells
	1% AEP -50% Pit Blockage Scenario	2-hour	15	1.5	10% AEP Flow in Hovells
	1% AEP - Ultimate Development	2-hour	15	1.5	10% AEP Flow in Hovells
Mitigation Option 1 (Lipson Drive Pipe and Drain Option)	0.1% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	0.2% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	0.5% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	1% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	2% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	5% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	10% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	20% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	50% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
Mitigation Option 2 (Lipson Drive Pipe and Drain Option)	0.1% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	0.2% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	0.5% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	1% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	2% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	5% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	10% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	20% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	50% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
Mitigation Option 3 (Lipson Drive Pipe and Drain Option)	0.1% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	0.2% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	0.5% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	1% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	2% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	5% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	10% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	20% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells
	50% AEP	15min,30min,60min,2-hour, 4.5-hour, 6-hour	15	1.5	10% AEP Flow in Hovells

6.9 Sensitivity Analysis

The urban rain-on-grid hydraulic model run for the following sensitivity tests, in order to understand the impact certain parameters within the model can have on peak flows and flood levels throughout the catchment:

- **50% blockage of all pit inlets in the urban area (1% & 10% AEP 2-hour event).** Increased flood levels were generally isolated, cul-de-sacs where water ponded up were areas that showed increases.
- '**Ultimate development' scenario assuming no retention of flows to pre-developed conditions (1% & 10% AEP 2-Hour event).** The proposed Elcho Drain upgrade was incorporated into the model and showed a widespread decrease in flood levels downstream of Bacchus Marsh Road (150-300mm) and extended further downstream to the Grand Lakes estate where a decrease of 10-20 mm was observed. Increases appeared in the Elcho Road and Patullos Road area, as expected due to increased run-off from development and no inclusion of flow retardation incorporated. Elsewhere, increases were generally less than 20mm.
- Increased rainfall intensity based on Representative Concentration Pathway (RCP) 4.5 & 8.5 for years 2050 and 2090, undertaken for the 1% AEP 12-hour duration. The increased rainfall intensity as a result of climate change for the four scenarios modelled was using the IFD data downloaded from BoM. The results showed maximum increases in flood levels through Lara ranging from 150 mm (RCP 4.5 for year 2050) through to an increase of 500 mm for RCP 8.5 for the year 2090 (within a basin). Difference plots for the RCP 4.5 Year 2050 and RCP 8.5 Year 2090 scenarios are provided below (Figure 5-2 and Figure 5-3) and are summarised in Table 5-2.

TABLE 6-3 CLIMATE CHANGE SENSITIVITY ANALYSIS SUMMARY (STORMWATER)

Year	RCP	Increase in Rainfall (1% AEP 2-hour)
2050	4.5	5.4%
2050	8.5	7.3%
2090	4.5	7.6%
2090	8.5	16.3%

Stormwater flooding in urban areas is more likely to be influenced by the predicted increase in extreme events, specifically increased rainfall intensity. Given the antecedent conditions of the impervious areas in Lara are relatively static, increased rainfall intensity is likely to result in an increase in design levels throughout the town. Areas with higher increases in flood levels tended to be where volume was an important factor in flood behaviour. Generally, throughout residential areas, increases in flood levels did not appear to be significant. Current freeboard requirements for new developments (recommended at 300 mm above the 1% AEP flood level) which appears sufficient to limit above floor flooding for new developments. It is recommended that the City continue to request sensitivity due to climate change be incorporated into design of infrastructure (roads, major culverts and retarding basins).

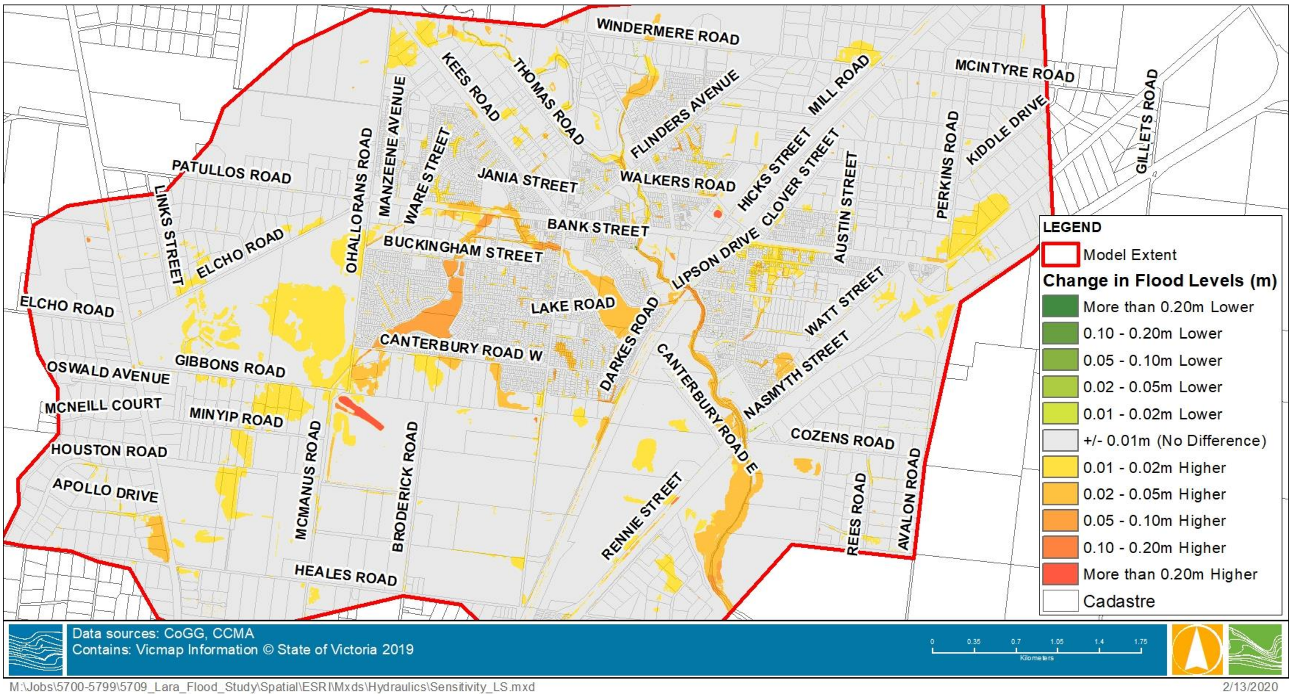

FIGURE 6-4 FLOOD LEVEL DIFFERENCE 1% AEP FLOOD EVENT – YEAR 2050 RCP4.5

7 RESULTS

Results for the riverine and urban models were combined and are presented in this section. Due to the size of the study area, results are more easily viewed in GIS software. Under the 20% AEP there is a relatively large flood extent that extends beyond the floodplain area of the waterways that flows through Lara. The extent impacts land to the south of Elcho Road, along Patullos Road, along Station Lake Road and along Forest Road South.

Existing areas of high flood risk identified during the modelling include several residential properties fronting Hovells Creek between Forest Road North and Station Lake Road. A number of these are inundated in a 1% AEP flood event, including properties on Martain Avenue which is flooded from stormwater accumulating behind the levee. For most areas, the existing levee system offers protection up to the 1% AEP event; however, relies on a series of flood gates, sandbags and pumps to stop flood waters backing up behind the levee.

Stormwater flooding appears to be an issue for several residential and rural living properties north east of Lara, including McClelland Avenue, which acts as a hydraulic control, resulting in around a 200 mm water level drop across the road (Figure 7-1). This combined with the flat terrain of the area and limited drainage network, causes flood levels to extend back up from McClelland Avenue into Kyema Drive and Brownlow Court. This accumulation of water ponding also causes property behind McClelland Avenue to flood. The depth of flooding within Kyema Drive is generally less than 300 mm. A long section showing the existing topography and the 1% AEP water level from Brownlow Court, Kyema Drive, McClelland Avenue through to Brunel Close (Figure 7-2), showing the impact flat terrain and a hydraulic control at McClelland Avenue has on flood behaviour in this high flood risk area.

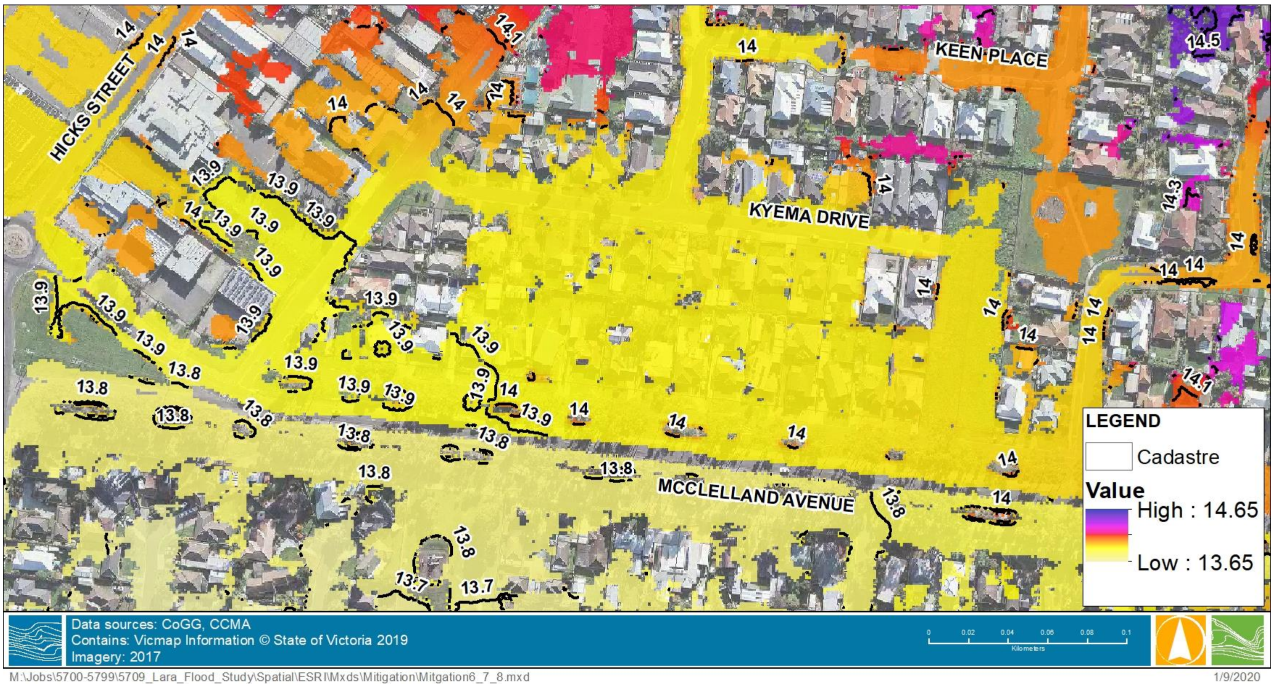

FIGURE 7-1 1% AEP WATER SURFACE LEVELS AT MCCLELLAND AVENUE

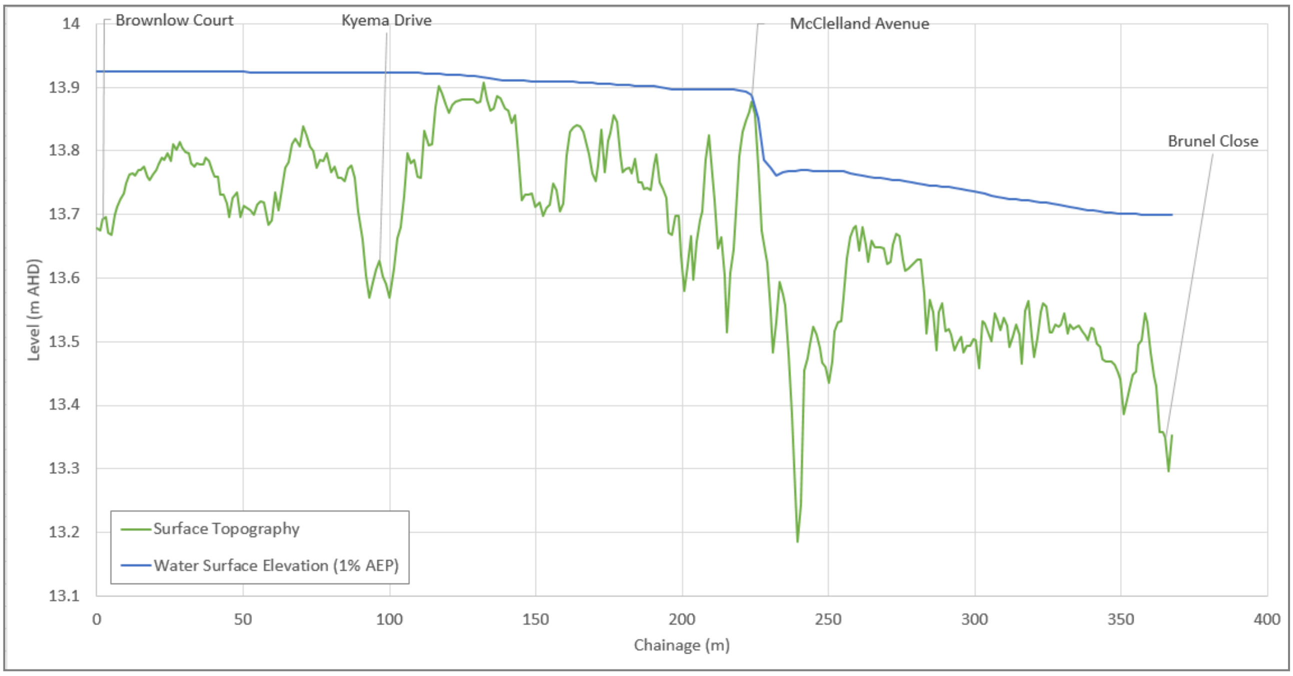

FIGURE 7-2 1% AEP WATER LEVEL AND NATURAL SURFACE ACROSS MCCLELLAND AVENUE

The lower end of the Avalon Road/Austins Swamp catchment has several dwellings located on the Avalon Foreshore Road. Access to these properties is cut during the highest astronomical tide (1.13 m AHD) which was applied to the hydraulic model. Sea Level Rise is a significant issue for these properties. Catchment flows through this system would be highly restricted due to the channels and pits of the former salt works.

Flood extent plots zoomed to areas around Lara are shown in Figure 7-3 to Figure 7-5. Depth, velocity, and surface water maps for the 1% AEP are shown in Appendix A.

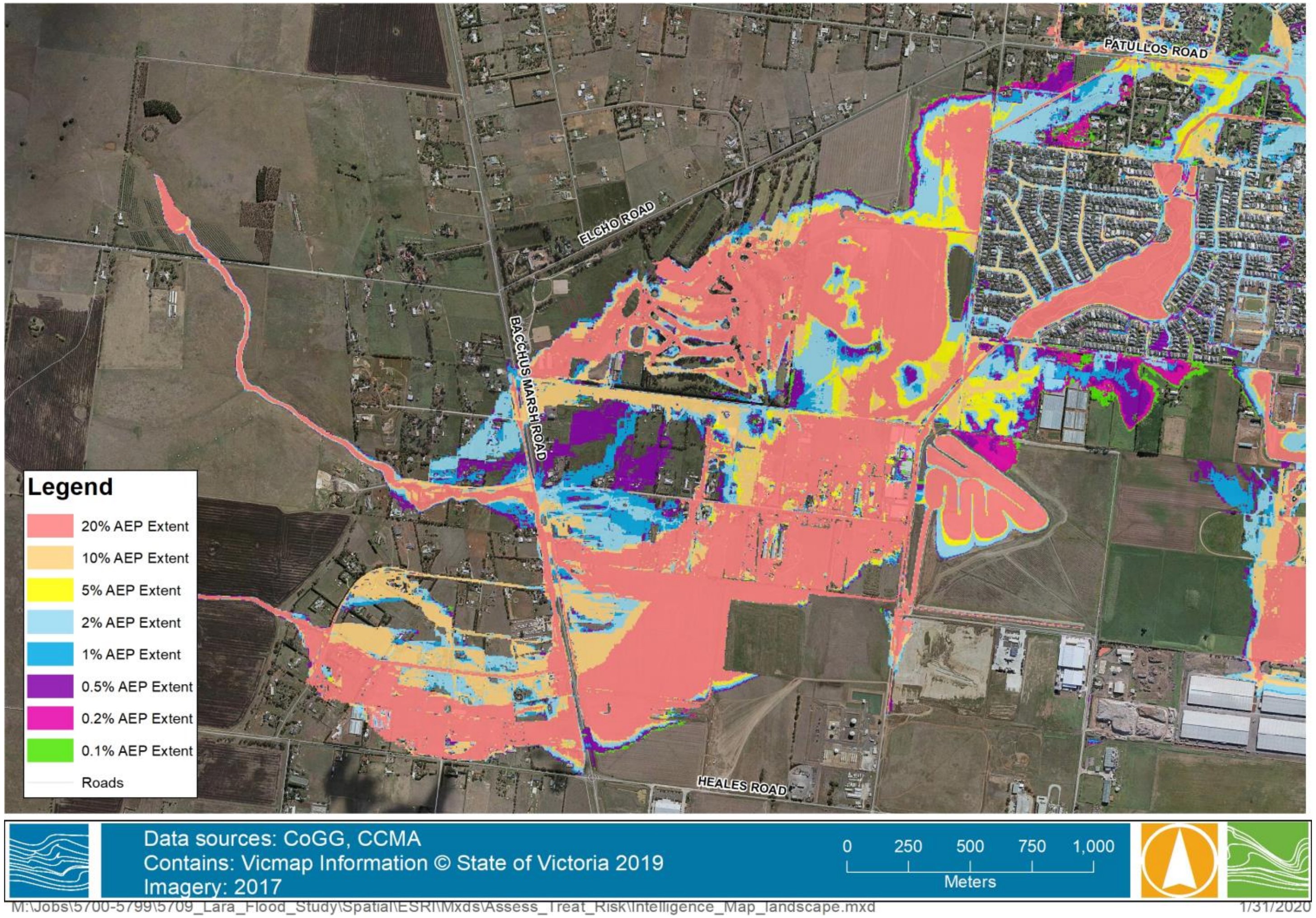

FIGURE 7-3 DESIGN MODELLING – EXTENTS (ELCHO DRAIN & LARA WEST)

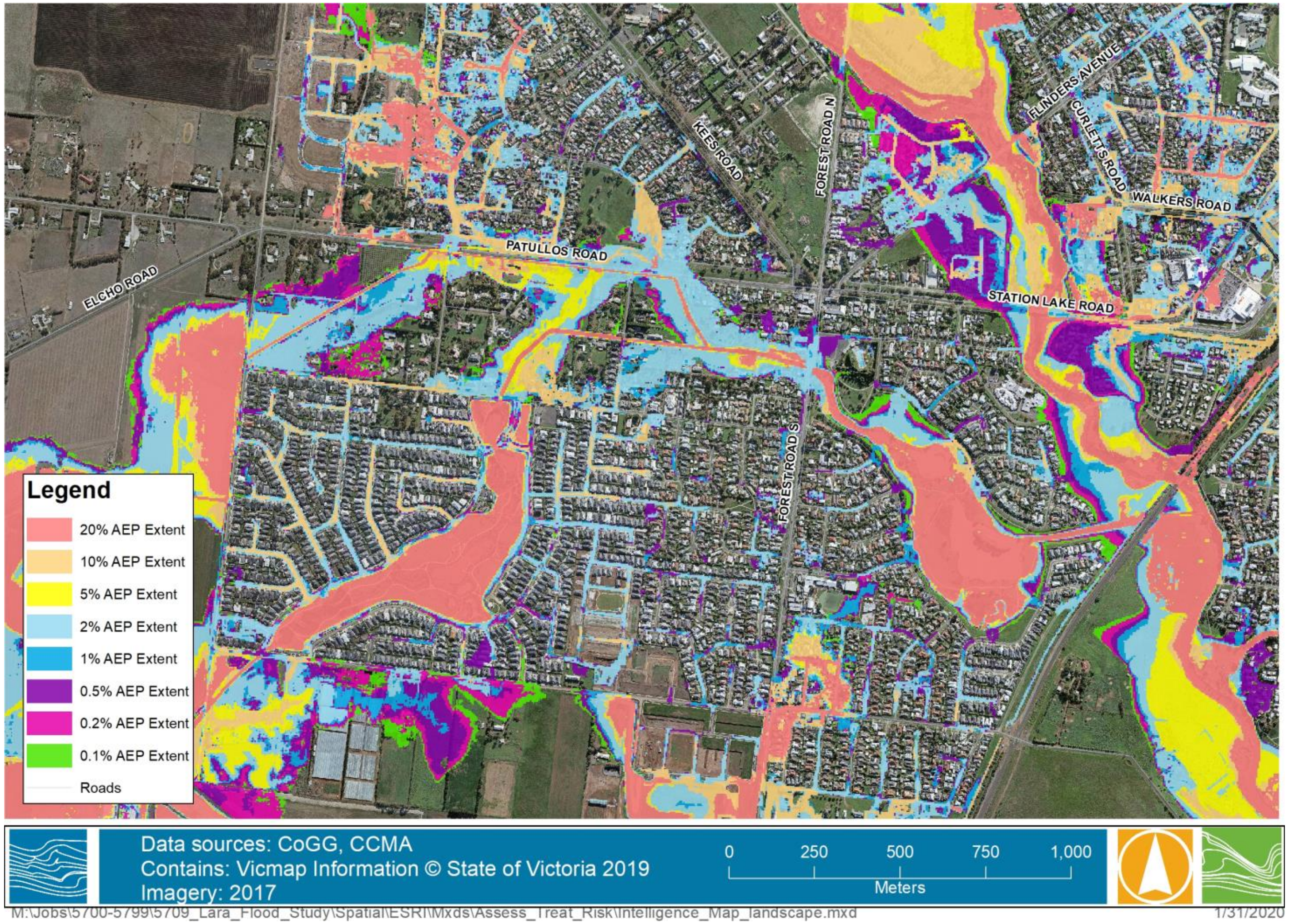

FIGURE 7-4 DESIGN MODELLING EXTENTS – GRAND LAKES & LARA LAKE

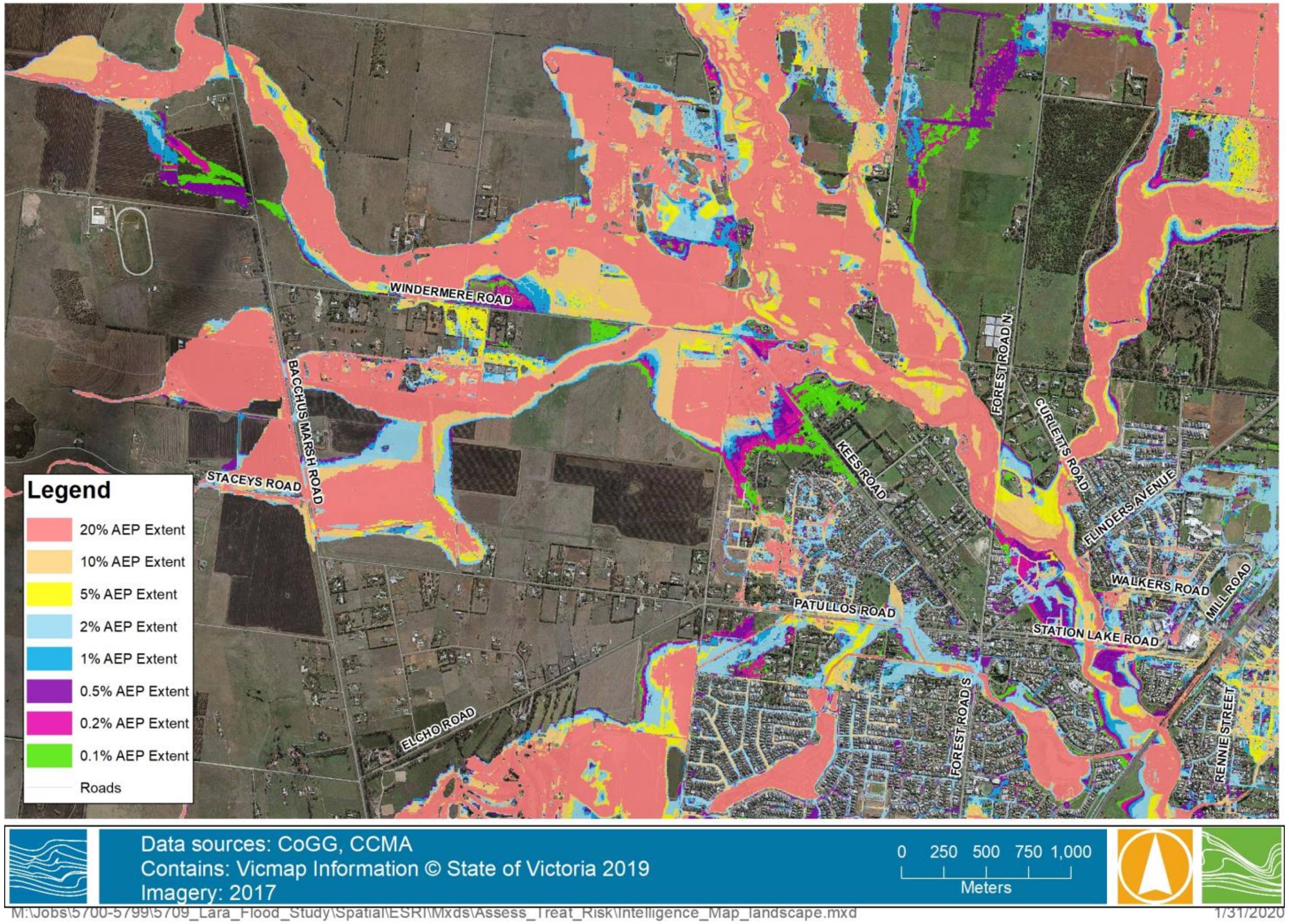

FIGURE 7-5 DESIGN EXTENTS – HOVELS CREEK

7.1 Riverine Flood Behaviour

Flood behaviour and intelligence outputs developed as part of the Lara Flood Study are described in the following section. During significant rainfall events, the catchment to the northwest and north of Lara begins to contribute runoff which accumulates and flows towards Lara. While there is significant flow along Hovells Creek, there is also accumulation of shallow flows across agricultural properties. To appropriately plan for flood response, it is necessary to predict and understand flood behaviour and determine properties and assets which are likely to be inundated.

Existing conditions modelling results indicate that significant portions of the Hovells Creek floodplain and Lara township are inundated even in smaller magnitude events (50 & 20% AEP event). In smaller magnitude events, a large portion of the flood extent is shallow widespread water due to the relatively flat terrain across most of the study area. This is due to a combination of both urban flash flooding and flows from the Hovells Creek breaking out and entering the town.

Flooding throughout the Austins Swamp/Avalon Road catchment is generally widespread and shallow, with deeper flooding through several wetland areas and where waters are backed up behind roadways and the railway line which act as hydraulic controls running perpendicular to the main flow paths. Downstream of the Princes Freeway, flooding from earthen drains spread into the former saltworks.

7.1.1 Flood Impacts

Streamflow gauges are located along Hovells Creek at two locations, both are located upstream of the Princes Freeway at Flinders Avenue and Rennie Street respectively. The Hovells Creek streamflow gauge at Flinders Avenue is located north west of Flinders Avenue within a section of the creek immediately downstream of an unnamed tributary of Hovells Creek entering from Serendip Dam to the north. The Rennie Street streamflow gauge is located upstream of the Rennie Street ford crossing which runs parallel to the Princes Freeway. A summary of the theoretical gauge rating is provided in Table 7-1. A summary of flood impacts for the design events are listed out in bullet points below. Further detailed information on flood intelligence and properties, roads and houses inundated above floor can be found in the Flood Warning and Intelligence Report (R05).

TABLE 7-1 SUMMARY OF DESIGN FLOWS AND PEAK GAUGE HEIGHTS FOR HOVELLS CREEK

Design Event	Hovells Creek at Flinders Avenue		Hovells Creek at Rennie Street	
	Peak Flow (m^3/s)	Gauge height (m)	Peak Flow (m^3/s)	Gauge height (m)
50% AEP	16.2	7.06	17.5	2.58
20% AEP	45.4	7.90	50.0	2.99
10% AEP	93.1	8.49	97.5	3.54
5% AEP	132.6	8.83	142.9	4.08
2% AEP	185.1	9.19	203.5	4.60
1% AEP	228.2	9.42	242.0	4.85
0.5% AEP	256.1	9.63	284.6	5.02
0.2% AEP	339.8	9.82	360.8	5.24
0.1% AEP	406	9.95	424.3	5.38

*Both gauge datums are set to m AHD (i.e. Gauge zero is 0.00 m AHD)

- Under the 50% AEP event some of the flood behaviour reported includes that the floodwaters begin to accumulate across the upper Hovells Creek floodplain, flooding of the Elcho Drain beings to inundate private property and the Elcho Golf Course flooded.

- In a 20% AEP, in the Upper Hovells Creek Floodplain and overland area, flows impact farmlands west of the HM Prison Barwon, north of Windermere Road and west of Blairs Road. In Hovells Creek floodplain & Lara West there is widespread flooding north to the town impacting on farmland, and there are also overland flows at West Gateway impacting on several properties. Whilst in the Avalon Road Catchment (Mill Road to Princes Highway), the floodwater flows across farmland from upstream until Old Melbourne Road and floodwater breaks out of waterways and spread across farmlands south of Princes Highway.
- In a 10% AEP event, in the area of Hovells Creek through Lara, there is a large flood extent upstream of Hovells Creek, north of the town and in Lara East, there is also a large flood extent upstream of Hovells Creek, north of the town. Water overtops Old Melbourne Road and spreads across farmland west of Gillets Road.
- In a 5% AEP, the Upper Hovells Creek floodplain inundation flood extent has no significant difference to the 10% AEP event. More flooding occurs along two sides of Mill Road, north east of the area of Lara East and in Avalon Road catchment, flood breaks out north east of the area and observed extents largely increase between Old Melbourne Road and Princes Highway.
- In a 2% AEP, floodwaters break out of channel at Bridge Street and there is a major flood extent increase north and east of Princes Highway, with the flood level at Princes Highway increasing by up to 0.2m.
- In a 1% AEP, Duggans Lane is overtopped by floodwater spilling out of Hovells Creek; and in the area of Lara West, Elcho Park & Elcho Drain, parcels are now flooded between Gibbons Road and Minyip Road.
- In a 0.5% AEP, there is a minor increase in flood extent compared with 1% AEP event in the upper Hovells Creek floodplain, further residential flooding in Lara East and increasing extent impacts through Lara from Hovells Creek.
- In a 0.2% AEP, overland flow reaches and overtops Manzeene Avenue and floodwater flows to further south at Canterbury Road, but only a minor overall increase in flood extent.
- In a 0.1% AEP, there is flood water flowing along the Kees Road and impacting adjacent properties, private properties in SW of Grand Lakes estate are flooded and there is major flooding across private property between Plains Road, Old Melbourne Road and Princess Highway.

The major roads overtopped under the modelled AEPs are shown in Table 7-2. Generally, roads overtopped at lower magnitude events (20% AEP) are unsealed roads outside of town or smaller service roads. The overtopped classification (where roads become wet) was used to identify access routes likely to be impacted during a flood event. Based on the risk associated with travelling through floodwaters, appropriate consideration should be given of the below table when planning for suitable evacuation routes.

TABLE 7-2 MAJOR ROADS OVERTOPPED

Road	Design Event Overtopped
Rennie Street	> 50% AEP
Flinders Avenue	> 50% AEP
Princes Freeway (Gillets Road)	2% AEP
Princes Freeway (Riordan Grain)	1% AEP
Princes Freeway (Hovells Creek)	20% AEP
Station Lake Road	2% AEP
Peak School Road	20% AEP
Windermere Road (Hovells Creek)	20% AEP

Road	Design Event Overtopped
Windermere Road (O'Hallorans Road)	1% AEP
Forest Road North	10% AEP
Forest Road South (Canterbury Road)	20% AEP
Forest Road South (Elcho Drain)	2% AEP
Old Melbourne Road	20% AEP
O'Hallorans Road	10% AEP
Kees Road	20% AEP
Mill Road	10% AEP
Bacchus Marsh Road (Elcho Drain)	20% AEP
Bacchus Marsh Road (Patullos Road)	10% AEP
Bacchus Marsh Road (West Gateway)	2% AEP
Bacchus Marsh Road (Clifts Culverts/Chisolm Road)	1% AEP
Bacchus Marsh Road (North Peak School Road)	20% AEP
Bacchus Marsh Road (North Shearers Lane)	20% AEP
Bacchus Marsh Road (Hovells Creek)	20% AEP

Results indicate that significant portions of the town are inundated by floodwaters from Hovells Creek in the 1% AEP event. This is due to a combination of both urban flash flooding and flows from the Hovells Creek breaking out and entering the town. Localised urban flooding impacts different parts of the town compared to Hovells Creek riverine flooding. Impacts from both forms of flooding (independently and combined) is summarised in the tables below.

7.2 Urban Stormwater Flood Behaviour

Rain on grid flood behaviour is dominated by widespread shallow flooding across large portions of the study area. Flood extents do not vary significantly throughout the urban area, in comparison to the Elcho Drain and Elcho golf course area where the increases in extents as event magnitude increases are significant. Break out flows from the Elcho drain downstream of the Grand Lakes begin at events greater than 2% AEP. Flows break out along both sides of Patullos Road in events greater a 5% AEP flood event.

8 SUMMARY

The four historic flood events modelled as part of calibration process were February 1973, December 1988, February 2005 and April 2017. These events varied significantly in magnitude with December 1988 regarded as the largest flood in recent memory.

Through the calibration phase, storages in the upper catchment, land use change, topographic change and drainage infrastructure improvements throughout the township were incorporated into the models, providing an accurate representation of the runoff (hydrology) and the flood behaviour (hydraulics) for a range of flow events. The approach undertaken was developed to ensure the design modelling undertaken was done with confidence in the model results. Overall, the joint calibration process ensured accurate results across the catchment for the range of modelled events and demonstrated the models were fit for purpose.

Design modelling consisted of detailed RORB and TUFLOW models, adopting design parameters and modelling a range of scenarios and sensitivity assessments. RORB was used to develop excess runoff hydrographs that were placed in the TUFLOW model. Assessment of several variables within the catchment was undertaken; including antecedent conditions (storage levels within major dams, initial and continuing losses) and the selection of appropriate design storm events (duration and temporal pattern selection). The riverine model was simulated for 2-hour, 6-hour, 9-hour, 18-hour and 48-hour event durations to ensure the range of critical durations were well represented across the model area. Temporal Patterns were selected for each event duration based on median peak flow for Hovells Creek at Lara.

A rain-on-grid hydraulic model was developed for design modelling of urban areas. This ensured small overland flow paths and local depressions provided a higher level of accuracy within the urban environment. The model was simulated for 15-minute, 30-minute, 1-hour, 2-hour, 3-hour and 6-hour duration events to ensure the range of critical durations were well represented across the model area. The temporal pattern selected for the urban model was based on the temporal pattern which gave the 'median' water level the greatest number of times across the urban model area for each 1% AEP duration event.

Sensitivity analysis was undertaken to ensure design parameters selected were appropriate, but to also provide information on Climate Change, antecedent conditions, future development and storm temporal patterns. The sensitivity analysis was useful to provide an insight into a range of scenarios without the need for a new investigation.

Design mapping has been used to develop draft planning controls to be implemented in a proposed planning scheme amendment following completion of this study. Results from the design modelling (specifically the 1% AEP), utilise depth, velocity and flood hazard to develop appropriate planning controls. Flood Hazard classification has followed the ARR2019 recommendations adopting flood hazard categories as outlined by Australian Emergency Management Institute in 2014[8] (Figure 8-1).

Model results were processed to provide a single set of deliverables for each AEP, while stormwater outputs and riverine outputs can also be used independently for both Council and the CMA. PDF maps were provided mapping depth, velocity, water surface elevation and flood hazard as well as GIS deliverables.

[8] https://knowledge.aidr.org.au/resources/handbook-7-managing-the-floodplain/

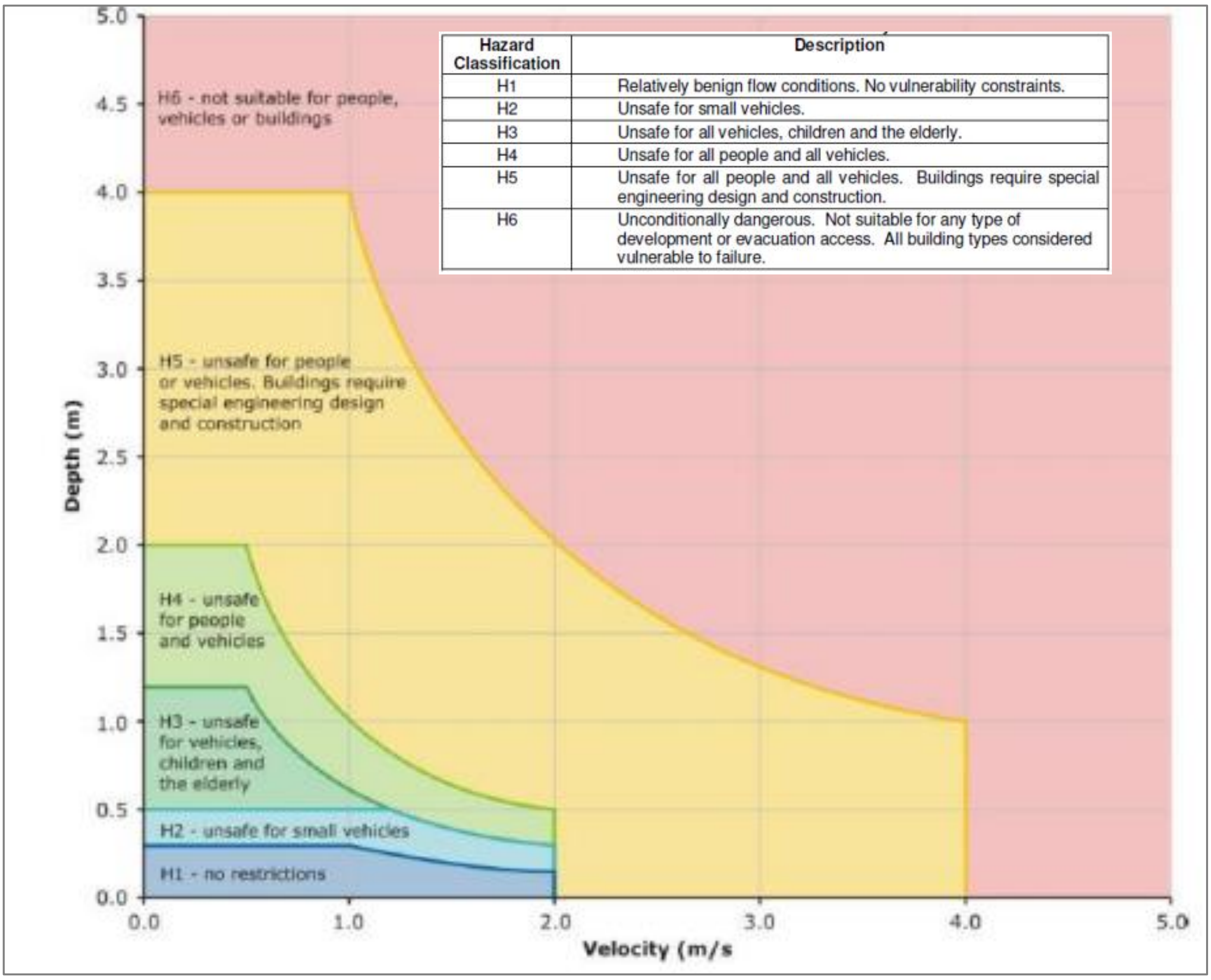

FIGURE 8-1 FLOOD HAZARD CLASSIFICATION

APPENDIX A
FLOOD MAPPING OUTPUTS

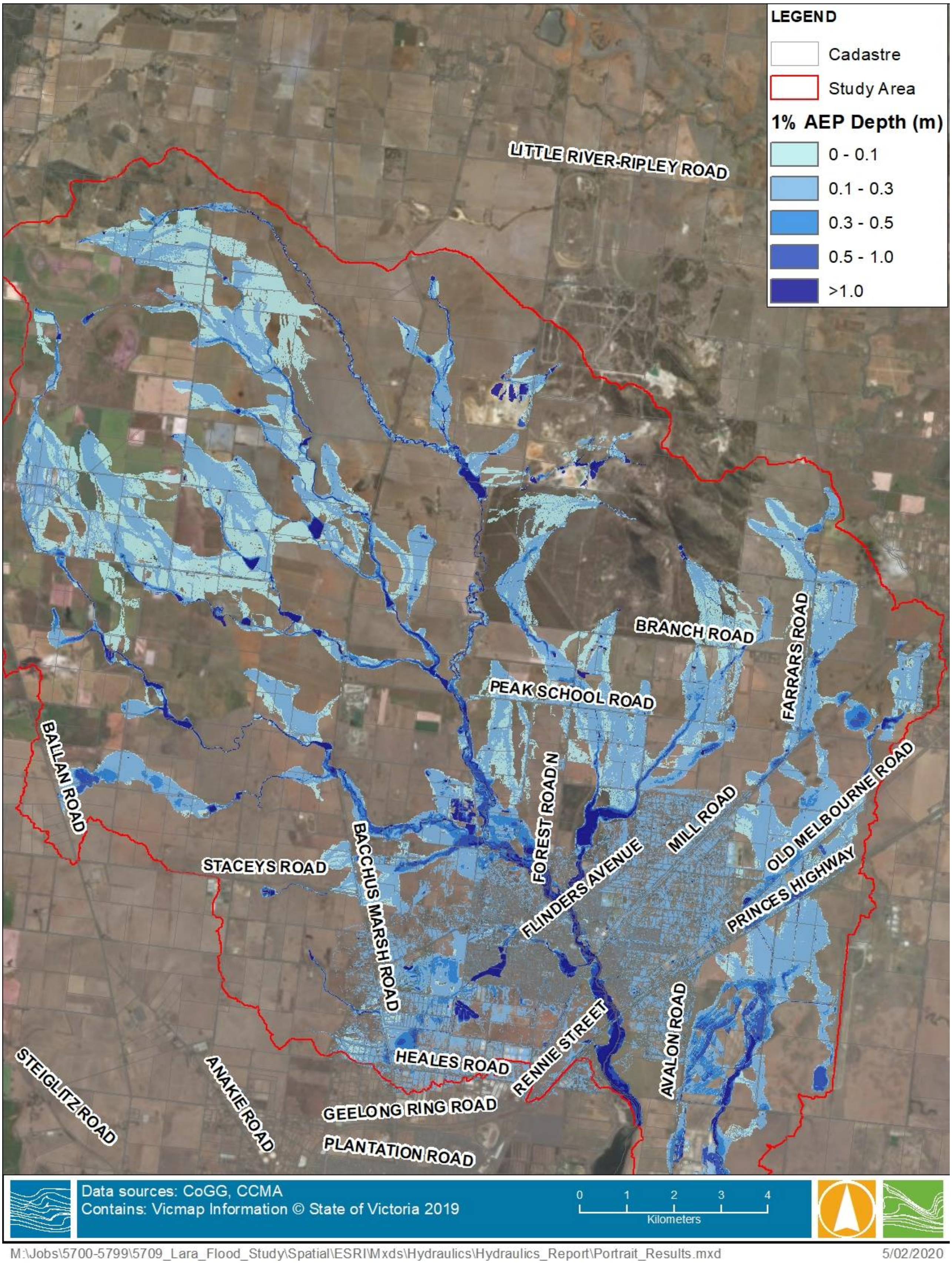

FIGURE 8-2 1% AEP – DEPTH PLOT (STUDY AREA)

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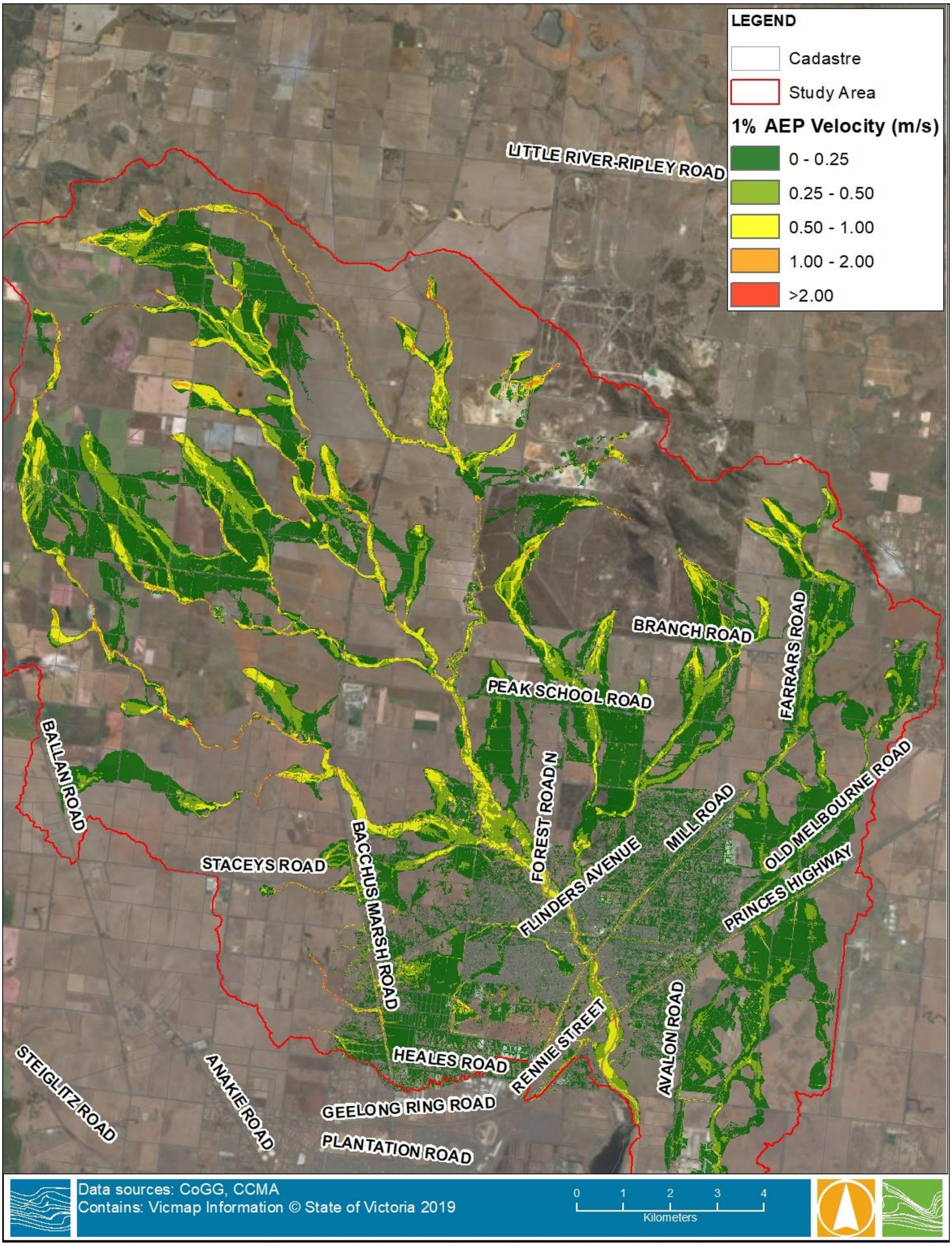

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FIGURE 8-3 1% AEP – VELOCITY PLOT (STUDY AREA)

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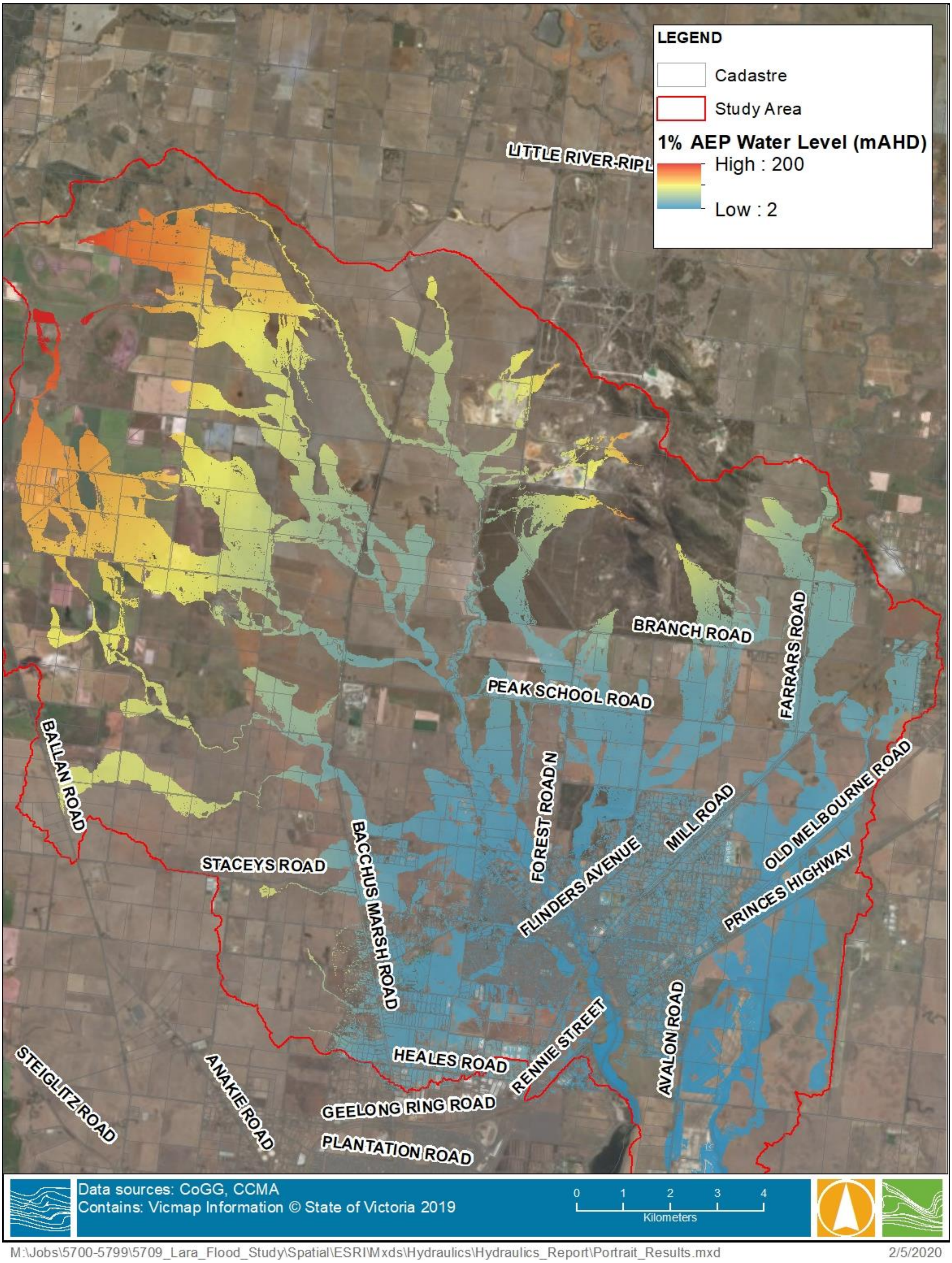

FIGURE 8-4 1% AEP – WATER SURFACE ELEVATION PLOT (STUDY AREA)

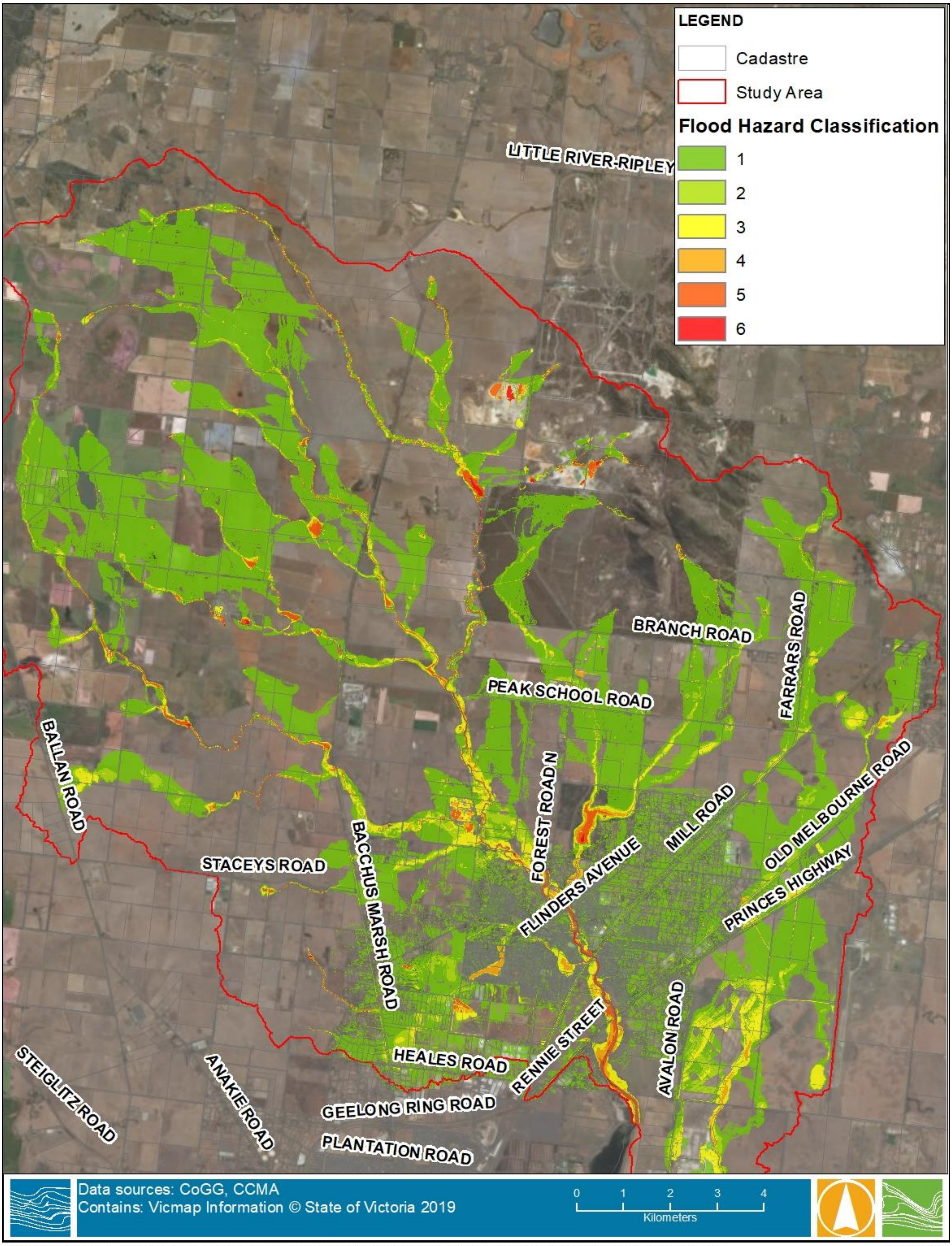

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FIGURE 8-5 1% AEP - FLOOD HAZARD PLOT (STUDY AREA)

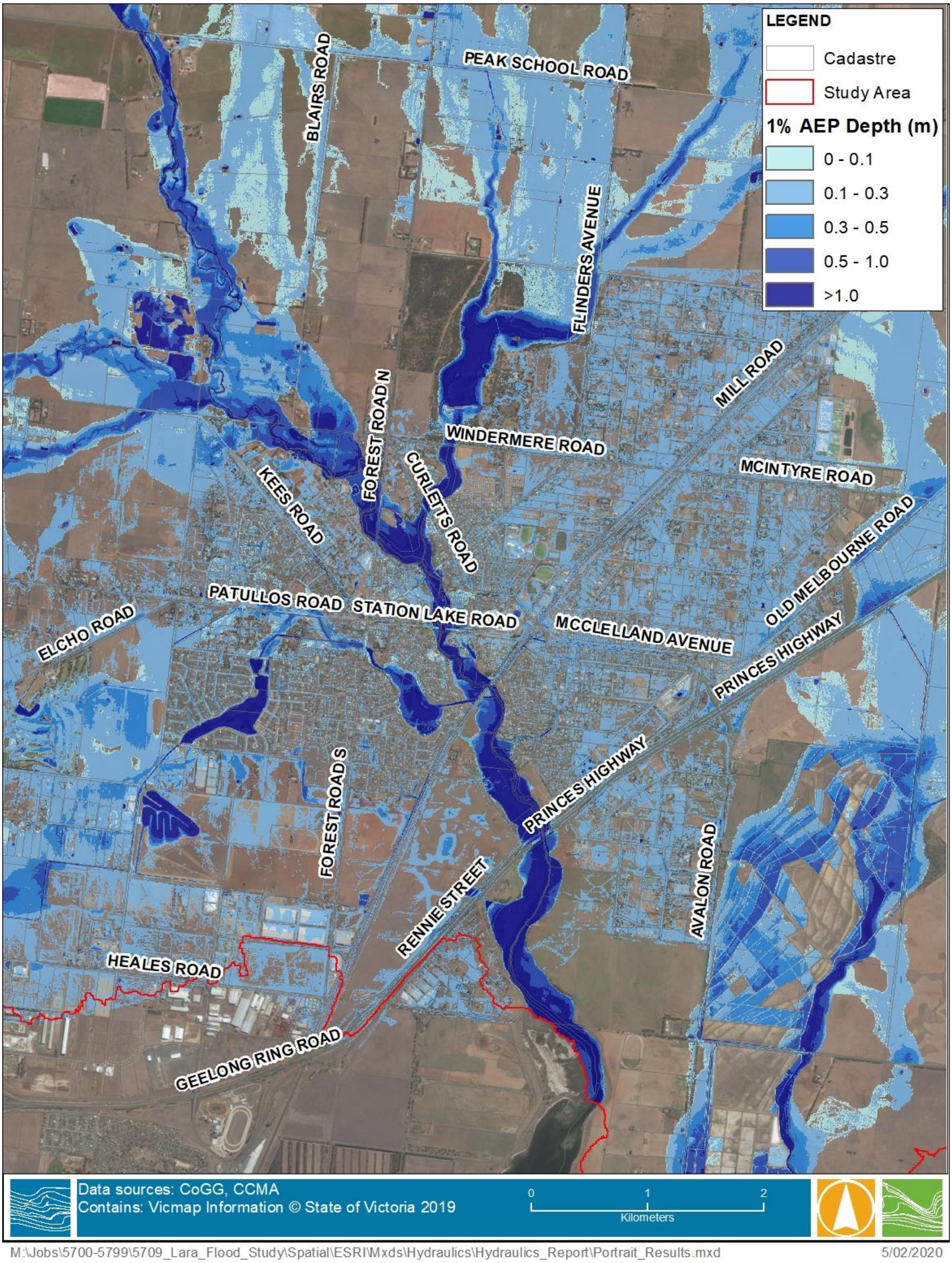

FIGURE 8-6 1% AEP – DEPTH PLOT (LOWER HOVELLS & AVALON ROAD)

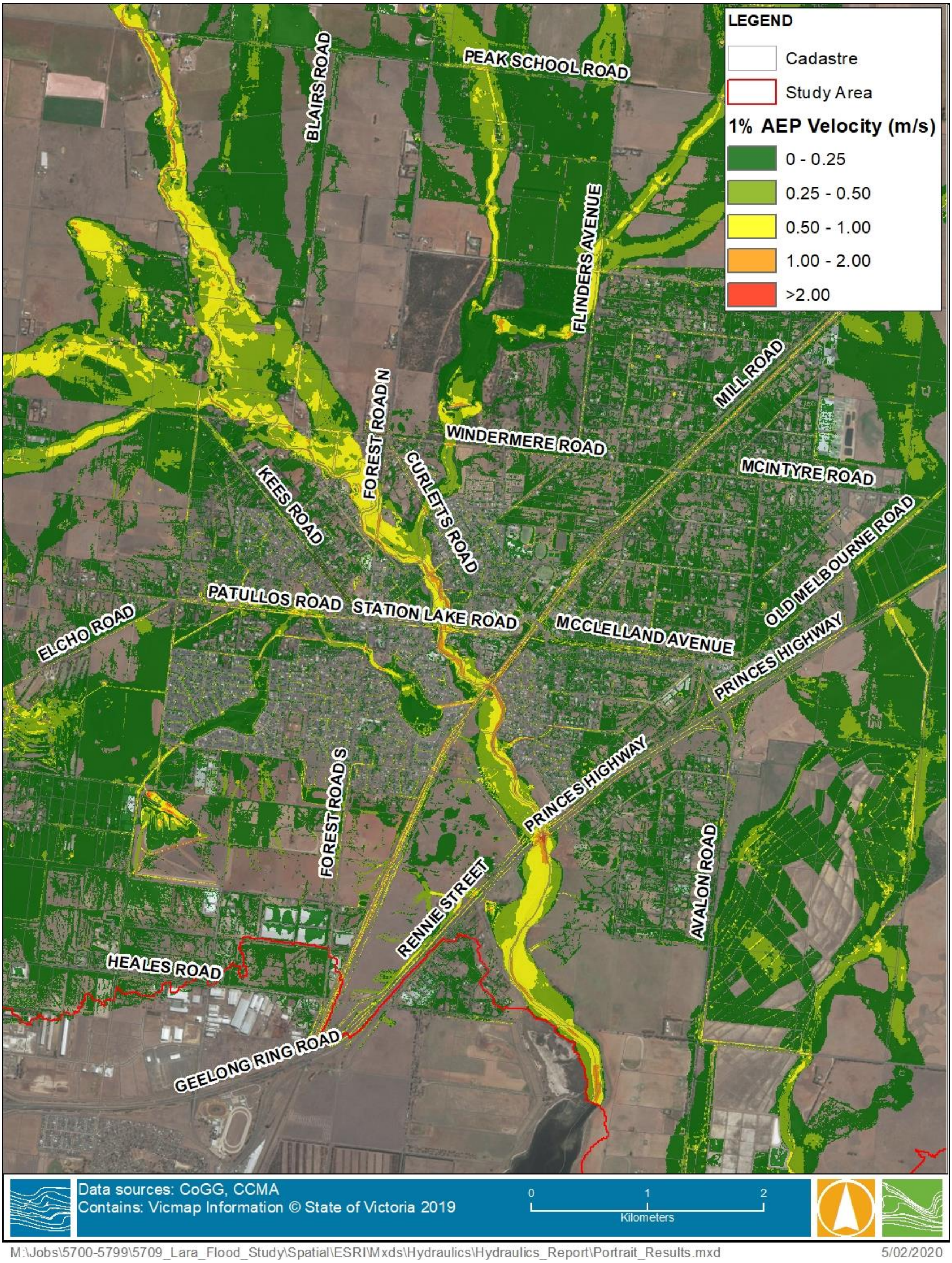

FIGURE 8-7 1% AEP – VELOCITY PLOT (LOWER HOVELLS & AVALON ROAD)

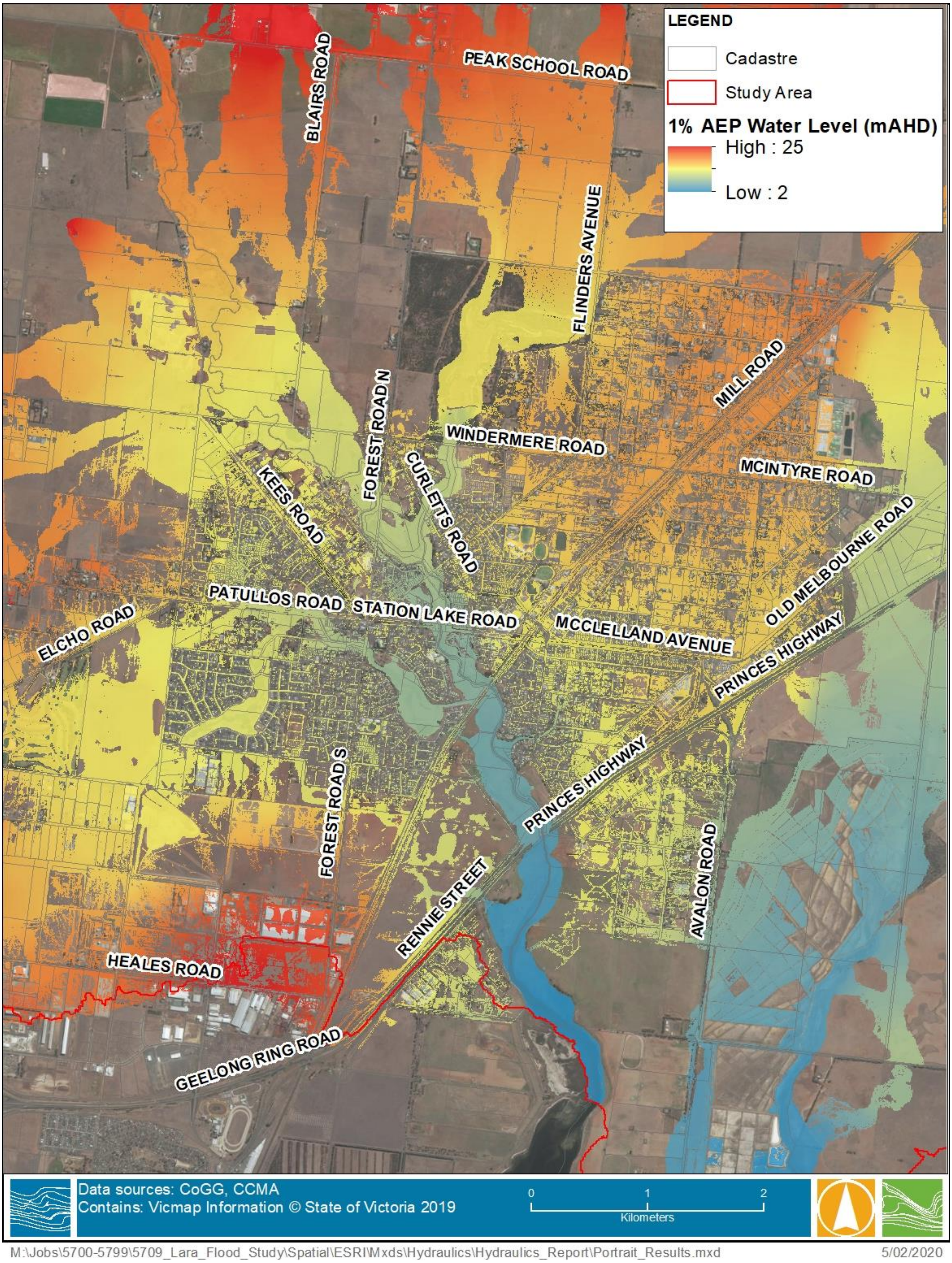

FIGURE 8-8 1% AEP – WATER SURFACE ELEVATION (LOWER HOVELLS & AVALON ROAD)

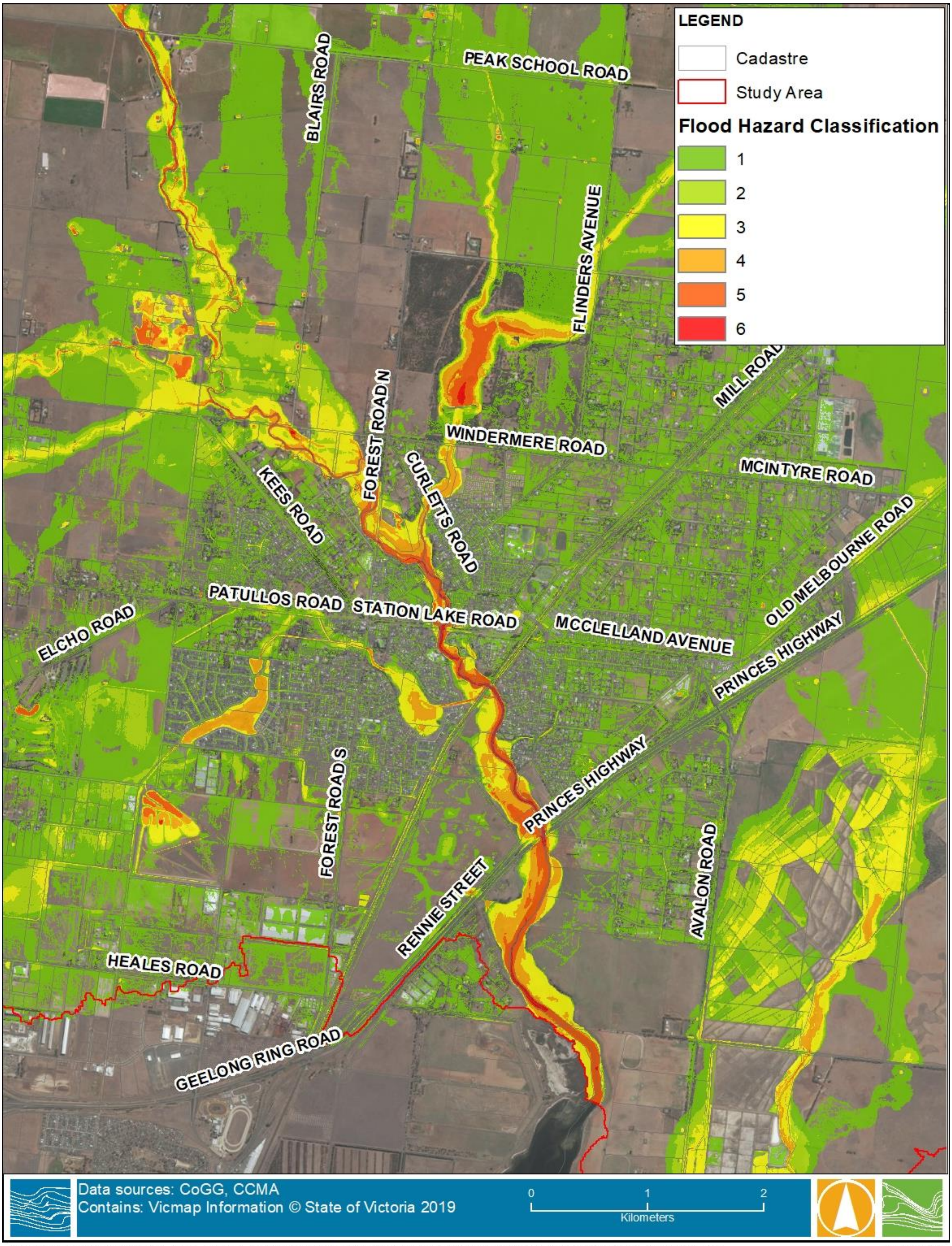

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FIGURE 8-9 1% AEP – FLOOD HAZARD PLOT (LOWER HOVELLS & AVALON ROAD)

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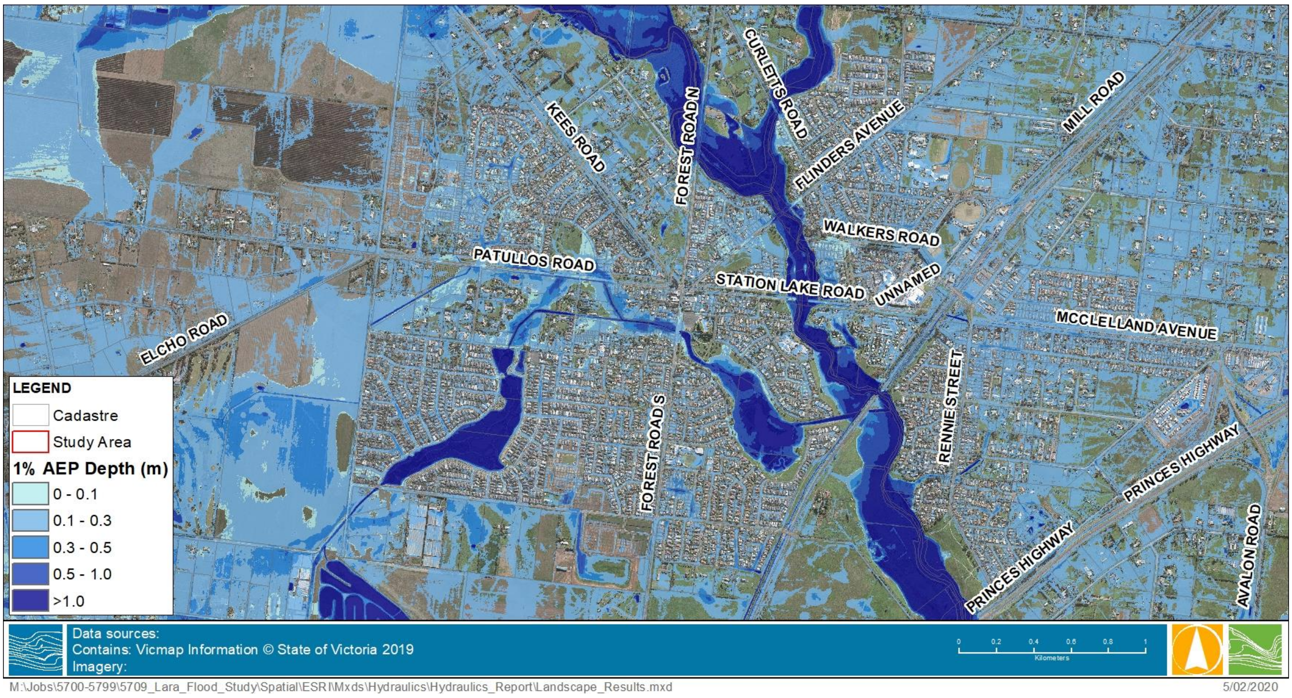

FIGURE 8-10 1% AEP – DEPTH PLOT (TOWNSHIP)

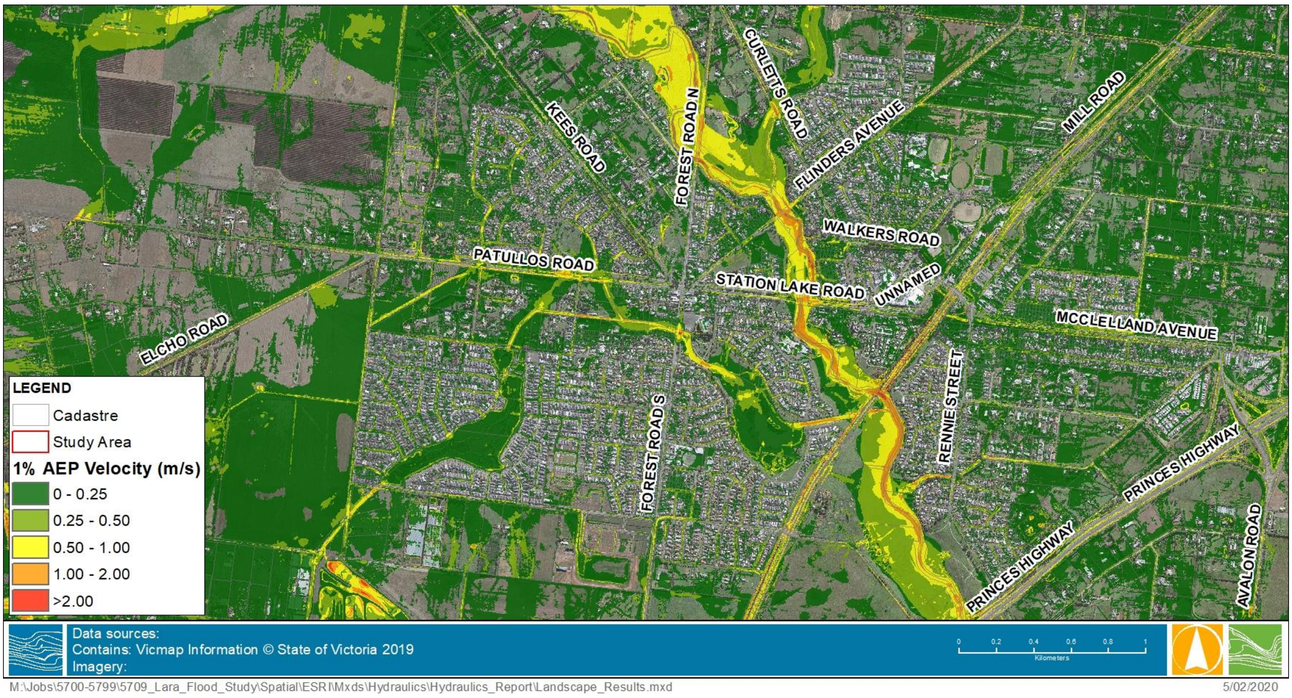

FIGURE 8-11 1% AEP – VELOCITY PLOT (TOWNSHIP)

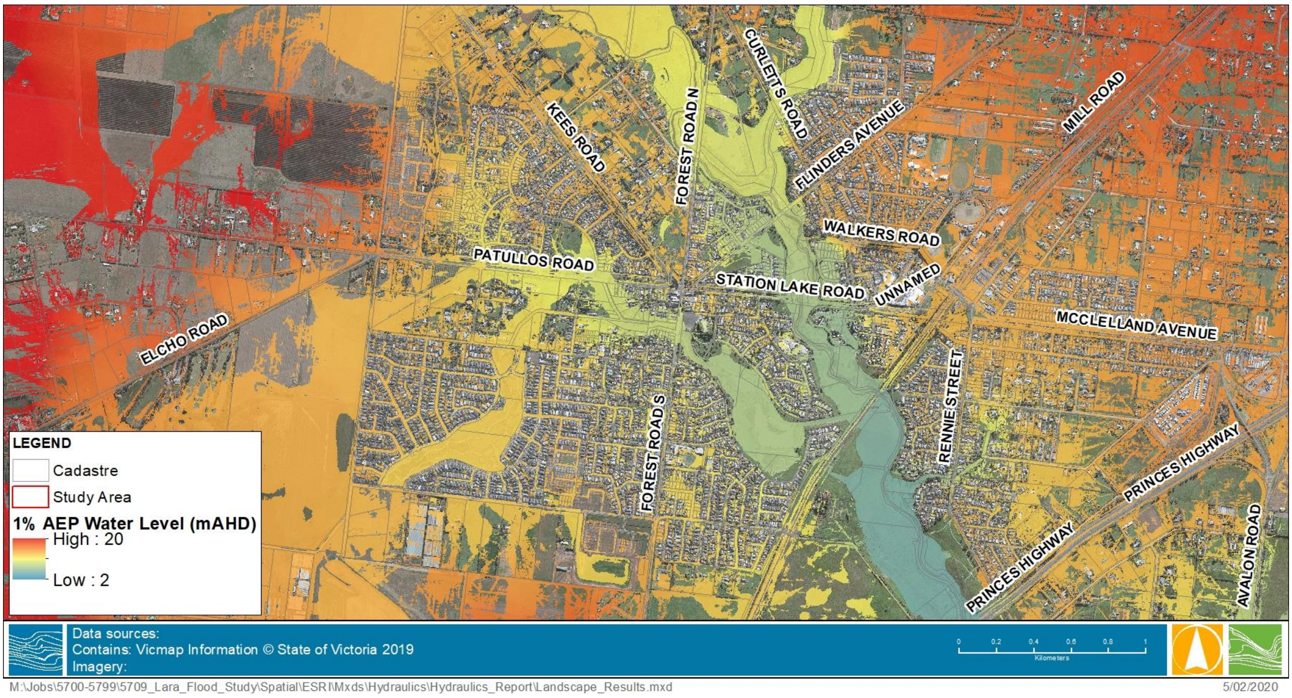

FIGURE 8-12 1% AEP – WATER SURFACE ELEVATION PLOT (TOWNSHIP)

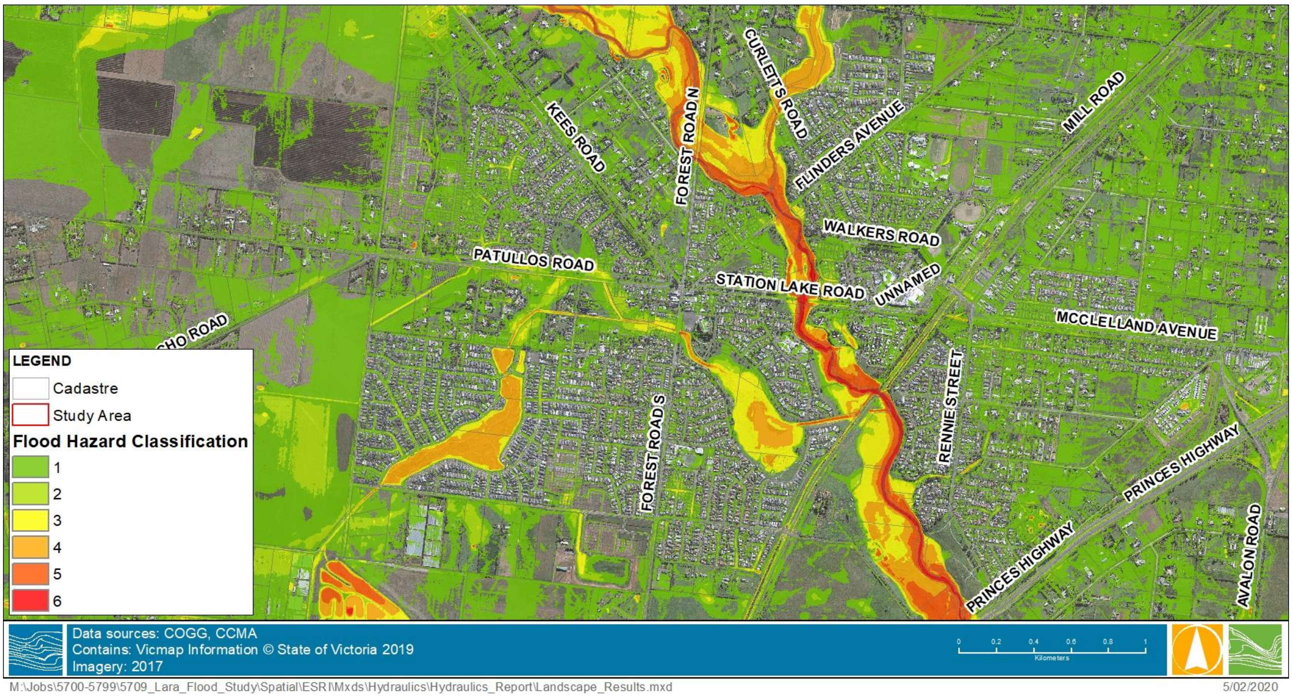

FIGURE 8-13 1% AEP – FLOOD HAZARD PLOT TOWNSHIP

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