Updated Hydrology and Hydraulic Report – ARR2016

Carisbrook Flood Mitigation Modelling

Central Goldfield Shire Council

30 August 2019

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30 August 2019

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Dear Leigh,

Carisbrook Flood Mitigation Modelling

Please see attached the hydrology and hydraulics report of the Carisbrook Flood Mitigation Mapping updated with ARR2016 methodology.

Yours sincerely

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WATER TECHNOLOGY PTY LTD

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1 INTRODUCTION

Carisbrook is a small township, situated 60 km north of Ballarat, 6 km east of Maryborough, in Central Victoria (Figure 1-1). Carisbrook is located at the confluence of McCallum and Tullaroop Creeks, with the waterway through town known locally as Deep Creek. Following the flood events in September 2010 and January 2011, Water Technology completed the Carisbrook Flood and Drainage Management Plan for North Central CMA in 2013.

Following a review by Jacobs (2017) and release of new design rainfall Intensity-Frequency-Duration (IFD) data by the Bureau of Meteorology and the new techniques from the *Australia Rainfall and Runoff (ARR2016)*, Water Technology was approached to update the following:

- Rerun the RORB model to ensure the hydrological analysis is consistent with Australian Rainfall and Runoff 2016 methodology.
- Item 5.3 of Jacobs Review - hydraulic modelling of 1% AEP event for the current floodplain conditions incorporating current mitigation works.
- Item 5.5 of Jacobs Review - hydraulic modelling of 1% AEP event for the proposed ultimate mitigation conditions as per design plans.
- Item 5.7 of Jacobs Review – an explanation regarding the flood impacts of shorter durations and why they were not critical to the levee design.
- Item 5.10 of Jacobs Review – an explanation regarding the requirement to update the FFA.
- Rerunning the full range of design events (20% to 0.5% AEP events) with the revised hydrological input.
- A brief report outlining the modelling methodology and results. The report will include mapping of the mitigation scenarios and difference plots comparing existing to mitigated conditions.
- Provision of digital outputs of the modelling results included gridded data of water depths, velocities, hazard and water surface elevation.

This report outlines the hydrology and hydraulic modelling methodology and results. The hydrology was updated and RORB model was run according to the methodology described in *Australia Rainfall and Runoff (ARR2016)* and presented in Section 2 under Hydrology. This section has also described the process of selection of critical duration from the range of short and long durations and derivation of the critical flow hydrographs for hydraulic modelling. The 1% AEP result is presented in this report. Other AEP result are included in the appendices.

This study uses the previous hydraulic model updated with the new levee and drainage structure for existing conditions modelling. The mitigated option design plan was provided by Central Goldfields Shire Council and the existing condition model was updated for mitigation modelling. The description of the model update and mitigation measures are described in Section 3 under Hydraulic Modelling.

The current existing floodplain condition and modelling results are presented in Section 4.

The ultimate flood mitigation plan and modelling results are presented in Section 5.

FIGURE 1-1 MAJOR WATERWAYS AND RESERVOIR SURROUNDING CARISBROOK

2 HYDROLOGY

2.1 Overview

The hydrological analysis for Carisbrook consisted of updating the hydrologic modelling following the revised *Australian Rainfall Runoff 2016* methodology. The RORB model developed and calibrated during the previous study[1] was adopted for hydrological modelling. In the previous study, the hydrologic RORB model was calibrated to three historic events and parameter sets for design were validated against flood frequency analysis and regional flow estimates.

The hydrological RORB model was used to determine the design flows at the site. The design events were modelled using a Monte-Carlo approach as recommended in ARR 2016[2]. The updated design inflow hydrographs were provided as boundaries to the hydraulic model.

2.2 Catchment Delineation

The total catchment area contributing to the study site is 1,240 km² and was delineated into 421 sub-areas in RORB. The detail regarding the development of the RORB model is outlined in the previous Water Technology (2013)[1] report. The township of Carisbrook lies at the confluence of McCallum Creek and Tullaroop Creek within the Loddon River catchment as shown in Figure 2-1.

A series of nodes and reaches were defined in the RORB model to represent the routing characteristics of the catchment. Paved areas of the catchment (such as roads) make up only a very small portion of this rural catchment and were represented in the RORB model by adjusting the fraction impervious (FI) of the subareas.

[1] Water Technology 2013, Carisbrook Flood and Drainage Management Plan, report prepared for North Central CMA
[2] Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors), 2016, Australian Rainfall and Runoff: A Guide to Flood Estimation, Commonwealth of Australia

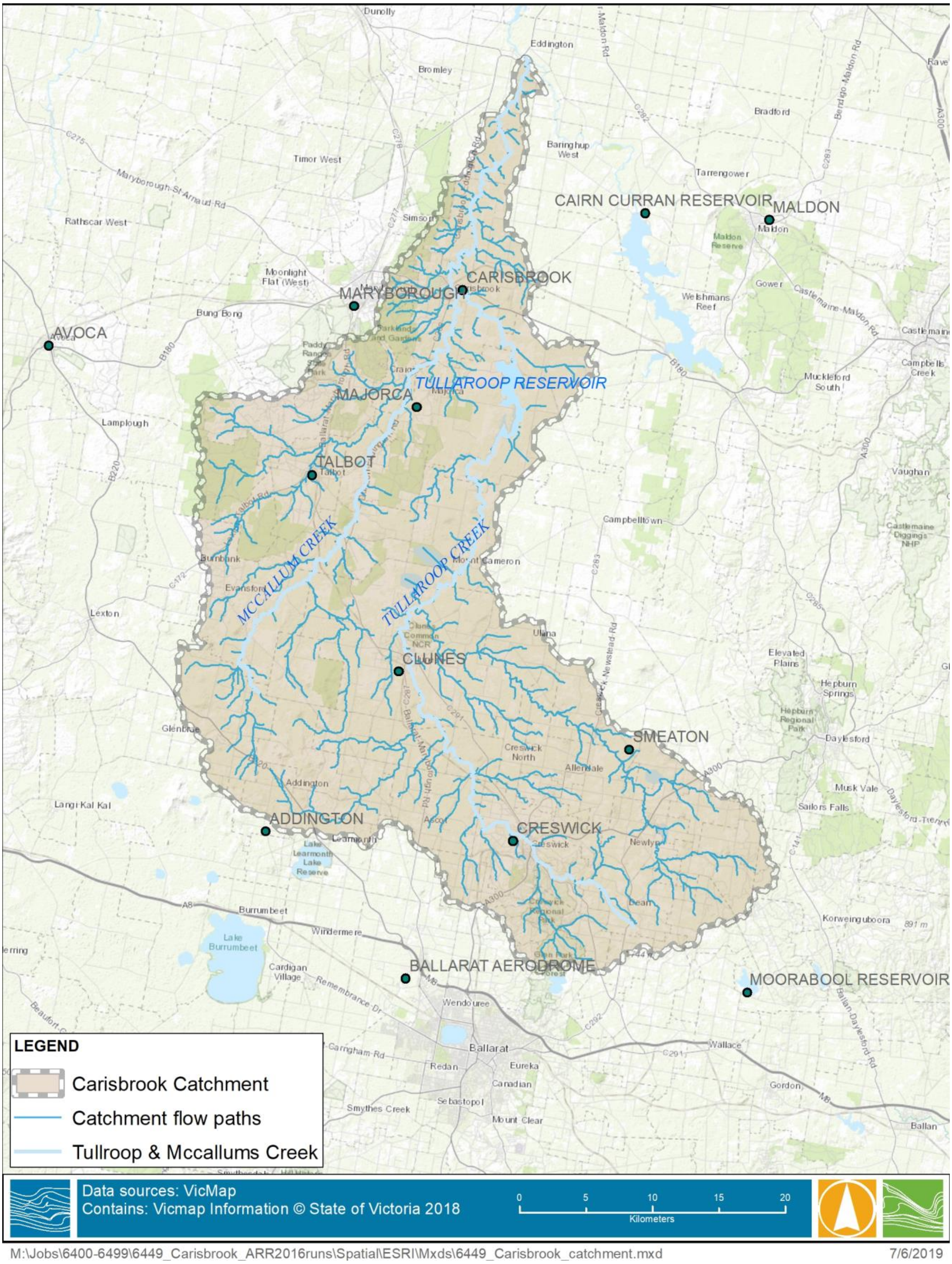

FIGURE 2-1 THE CARISBROOK CATCHMENT AND STUDY AREA

2.3 Storages

The main storage with potential to impact flooding at Carisbrook is Tullaroop Reservoir, situated on Tullaroop Creek approximately 17 km upstream of Carisbrook. Tullaroop Reservoir is a Goulbourn-Murray Water asset. Tullaroop Creek has a catchment area of approximately 730 km^2 upstream of the reservoir. Construction of the reservoir was completed in 1959. The full capacity of the reservoir is 73 GL at a full supply level of 222.8 m AHD. The storage-elevation relationship for Tullaroop Reservoir is shown in Figure 2-2.

Goulburn-Murray Water provided a report by SKM (2012)[3] which included an updated spillway rating curve of Tullaroop Reservoir. The update rating curve was adopted for this study and presented in Figure 2-3 along with the rating curve used in the previous Water Technology (2013)[1] study which was not available at the time of the previous flood study. It is noted that the new rating curve estimates a significantly higher outflow from Tullaroop Reservoir at dam crest level compared to the older rating curve. For context, during the January 2011 event the water level of the Tullaroop Creek Head Gauge reached 225.5 m AHD, at that height there is not much of a difference in the new and old rating curve flows.

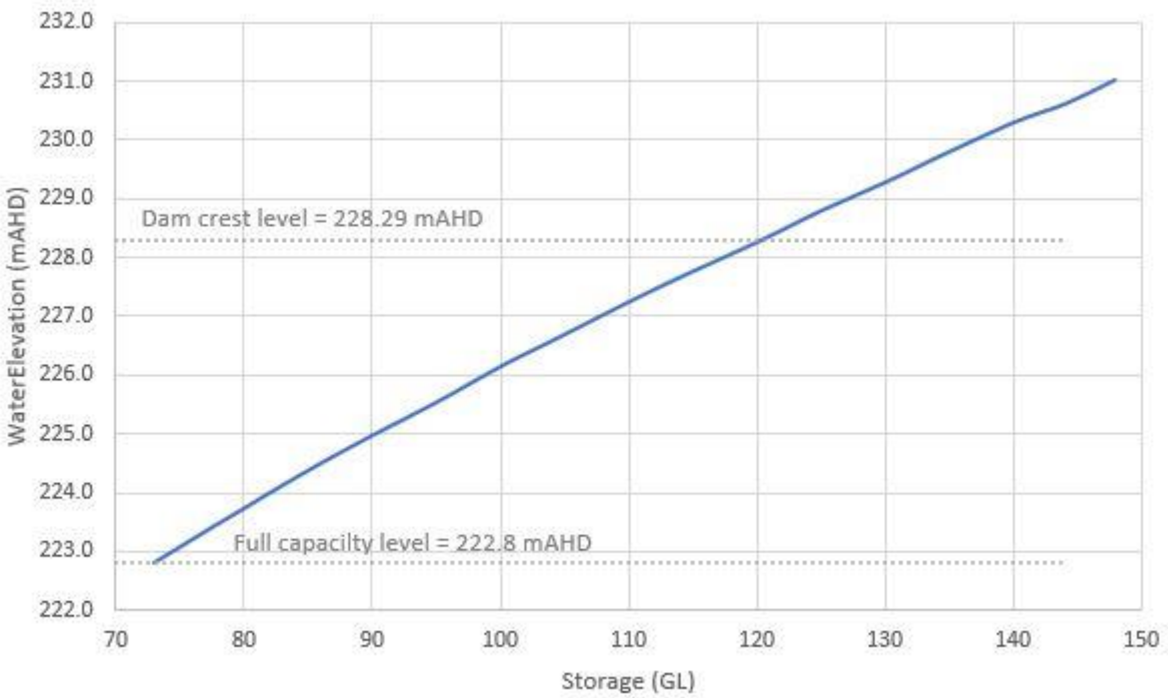

FIGURE 2-2 TULLAROOP STORAGE-ELEVATION RELATIONSHIP

[3] Tullaroop Dam-Flood hydrology update, SKM August 2012

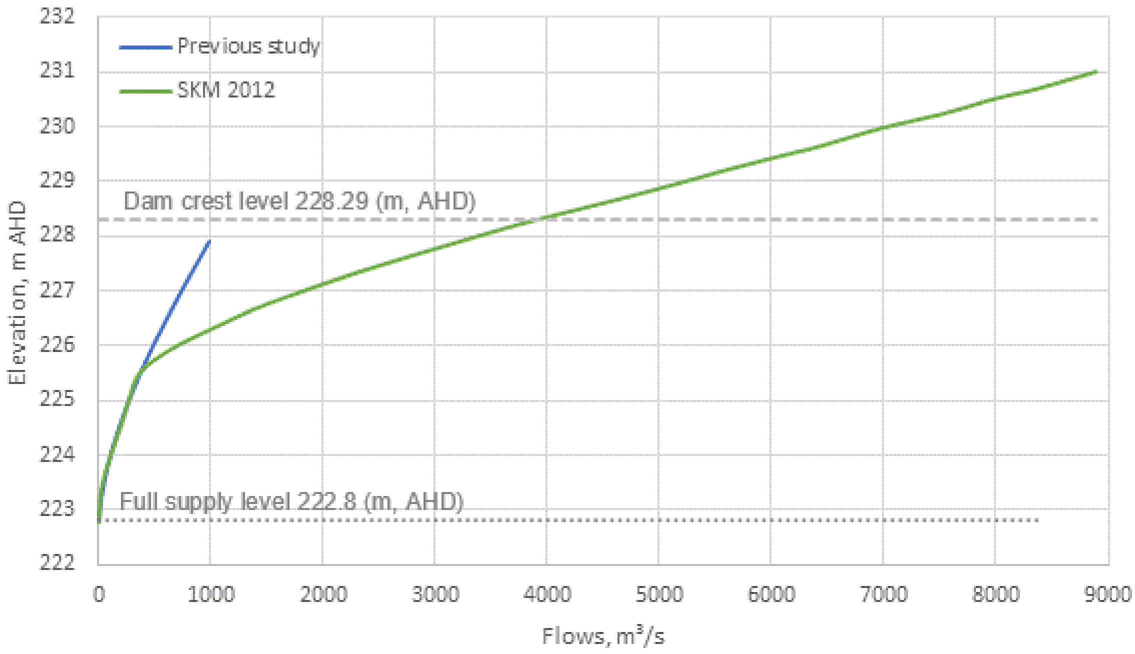

FIGURE 2-3 TULLAROOP RATING CURVES

2.4 Design Parameters

The parameters for the design modelling were adopted from the previous study. A rigorous calibration process and sensitivity analysis has been carried out during the Water Technology (2013) study. A summary table of the adopted design parameters are presented in Table 2-1.

The loss parameters proposed in the ARR 2016 DataHub[4] are an initial loss of 25 mm and a continuing loss of 4.6 mm/hour. This is consistent with the loss parameters adopted in the previous study as presented in Table 2-1.

The initial storage level of Tullaroop Reservoir was assumed to be at full supply level. The results from the previous study indicated that during major flood events the peak flow through the town is dominated by McCallum Creek and that the initial reservoir storage level has a relatively minor impact. The study also concluded that initial water level at full supply level is a conservative approach and was thus adopted for this study.

TABLE 2-1 ADOPTED PARAMETERS FOR DESIGN MODELLING

Parameter	Upper catchment	Lower Catchment
Routing parameter, kc	10.5	4.79
Median Design losses	IL=25 mm, CL = 2.5 mm/h	
Initial storage level, Tullaroop reservoir	Full Supply Level	
m	0.8	

[4] http://data.arr-software.org/

2.5 Design Modelling

2.5.1 Overview

Design modelling was carried out using a Monte Carlo framework in RORB to determine the design peak flows at several key locations within the catchment.

The RORB Monte Carlo analysis was undertaken adopting the losses and k_c value presented in Table 2-1. During the Monte Carlo analysis the RORB model was run for 10,000 different model simulations, sampling from an extensive range of temporal patterns and rainfall initial loss values. This is completed in combination with the other set model parameters of spatial pattern, continuing loss, aerial reduction factors, k_c and m. The model then takes the hydrographs from all model runs and produces a statistical design peak flow at each RORB output location.

Design modelling was carried out through the following steps:

- The design inputs were adopted according to the ARR 2016 methodology. Design inputs are described in Section 2.5.2.
- Monte Carlo simulation to determine the peak flows and critical duration, presented in Section 2.5.3.
- Selection of temporal pattern for design runs to allow generation of design hydrographs, presented in Section 2.5.4

2.5.2 Design Inputs

Design rainfall intensities and durations were calculated for the 10%, 5%, 2%, 1% and 0.5% AEP events according to ARR 2016 recommended methods. Design inputs required for design model runs included:

- Rainfall depth
- Areal Reduction Factor
- Temporal patterns
- Pre-burst temporal pattern
- Spatial pattern
- Losses

Each of these inputs are described below.

Intensity-Frequency-Duration (IFD)

Rainfall burst depths for all the design events were estimated for the centroid of the catchment using the 2016 ARR IFD analysis available from the Bureau of Meteorology[5].

Rainfall depths for rare events (rarer than 0.5% AEP) are only supplied for storm durations greater than 24 hours. Therefore, for estimating design rainfalls for AEPs between 1 in 100 and 1 in 2000 for short duration burst depths, a growth factor was applied according to the ARR 2016[6] guidelines.

The design rainfall versus frequency estimates for the catchment are shown in Table 2-2 and Figure 2-4.

[5] (http://www.bom.gov.au/water/designRainfalls/ifd/).
[6] Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors), 2016, Australian Rainfall and Runoff: A Guide to Flood Estimation, Commonwealth of Australia, Book 8, Chapter 3

TABLE 2-2 DESIGN RAINFALL DEPTHS (MM) FOR VARYING EVENT DURATIONS AND AEP

AEP (1:Y)	2 hr	3 hr	6 hr	9 hr	12 hr	24 hr	36 hr	48 hr	72 hr
5	25.8	29.2	36.8	42.5	47.3	60.6	69.1	75.1	82.8
10	31.5	35.4	44.0	50.5	55.9	71.7	82.3	89.9	99.8
20	37.5	41.9	51.4	58.7	64.8	82.9	95.5	105.0	117.0
50	46.2	51.3	62.0	70.1	77.0	98.2	114.0	125.0	141.0
100	53.4	59.0	70.5	79.3	86.8	110.0	128.0	141.0	161.0
200	60.9	67.3	80.4	90.4	99.0	125.4	145.9	160.7	183.5

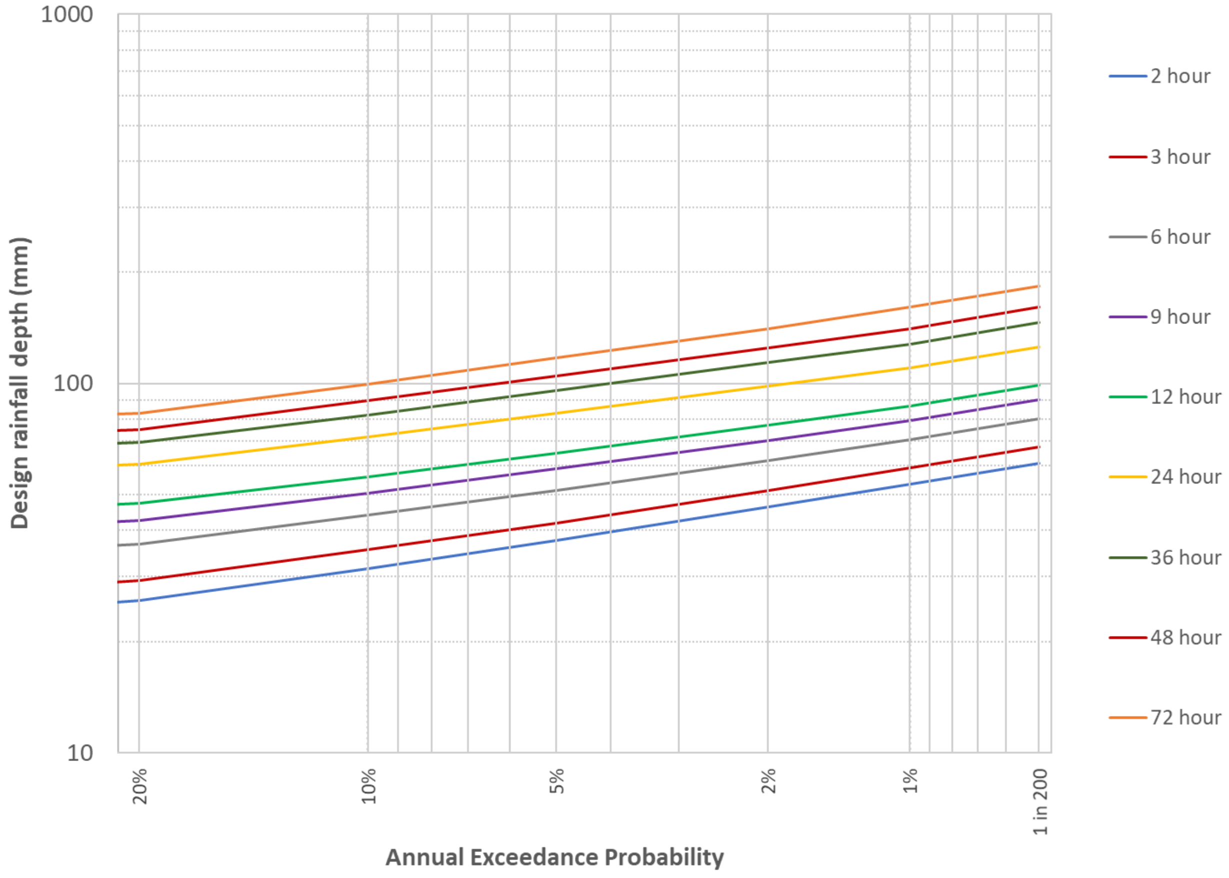

FIGURE 2-4 DESIGN RAINFALL DEPTH ANNUAL EXCEEDANCE PROBABILITY

Areal Reduction Factor

The point rainfall estimates were converted to catchment average values using the areal reduction factors developed for Victoria during the recent revision of ARR2016[7]. The areal reduction factor is included in the datahub data. Conceptually, this factor accounts for the fact that larger catchments are less likely to experience high intensity rainfall over the whole of the catchment.

Temporal Pattern

The 10 temporal patterns as downloaded from ARR 2016 Data Hub[8] were used to simulate the distribution of burst rainfall depth during each storm duration modelled.

For the short duration storms, a sample of 10 Monte-Carlo point temporal patterns downloaded from ARR data hub was used for durations between 1 to 12 hours. A sample of areal temporal patterns available from ARR data hub was also used for long duration design storms.

Before the areal temporal patterns were used, they were smoothed to remove embedded bursts. An embedded burst is a sub-period of rainfall within a given temporal pattern that has a rarer AEP than the actual burst.

The ARR 2016 approach describes two alternative methods to dealing with multiple storm temporal patterns. The first is the Monte Carlo approach described above and the second is an Ensemble approach, which runs the ten provided temporal patterns for each design event and recommends adopting the median peak flow as the design hydrograph. During review of the most common areal temporal patterns it became apparent there were large discrepancies in peak flow between the Monte Carlo and Ensemble approaches for events with a critical duration of 72 hours. For example, at the Tullaroop Creek and McCallum Creek inflow locations to the hydraulic model, RORB 1% AEP Monte Carlo peak flow was 323 m^3/s and 740 m^3/s respectively, whereas using the ensemble approach of temporal patterns resulted in Tullaroop Creek peak flows ranging from 119 to 1,135 m^3/s and McCallum Creek peak flows ranging from 123 to 1,394 m^3/s as shown Table 2-3.

TABLE 2-3 PEAK FLOWS FROM ENSEMBLE METHOD – 72 HOUR DURATION, 1% AEP

Temporal Pattern	Areal Temporal Pattern Number	Peak Flow, Tullaroop Creek outlet	Peak flow, McCallum Creek outlet
1	5827	196	299
2	5828	127	123
3	5829	689	1156
4	5830	397	585
5	5831	179	350
6	5832	119	184
7	5833	355	435
8	5834	251	405
9	5835	216	386
10	5836	1135	1394

[7] Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors), 2016, Australian Rainfall and Runoff: A Guide to Flood Estimation, Commonwealth of Australia, Book2, Chapter 4
[8] http://data.arr-software.org/

To investigate this further, the ten temporal patterns for the relevant catchment area size and 72 hour duration event were plotted together in Figure 2-6. Figure 2-6 shows that Pattern No. 3 (5829) and Pattern No. 10 (5836) stand out with a very intense burst, the largest peak in the patterns implies that 35 to 45% of the 72 hour rainfall occur in a single 3 hour increment. Recent work from Tony Ladson posted on his website[9], indicates that these intense bursts are likely to be due to data measurement errors at the gauges used to construct the temporal patterns and that they represent periods where rainfall has be accumulated over a period of time and reported in one timestep rather than being disaggregated over the true period of the storm.

These temporal patterns are causing an intense embedded burst that produces misleading results. These two temporal patterns for the 72 hour duration were replaced by an adjacent pattern and the Monte Carlo and Ensemble approaches were repeated.

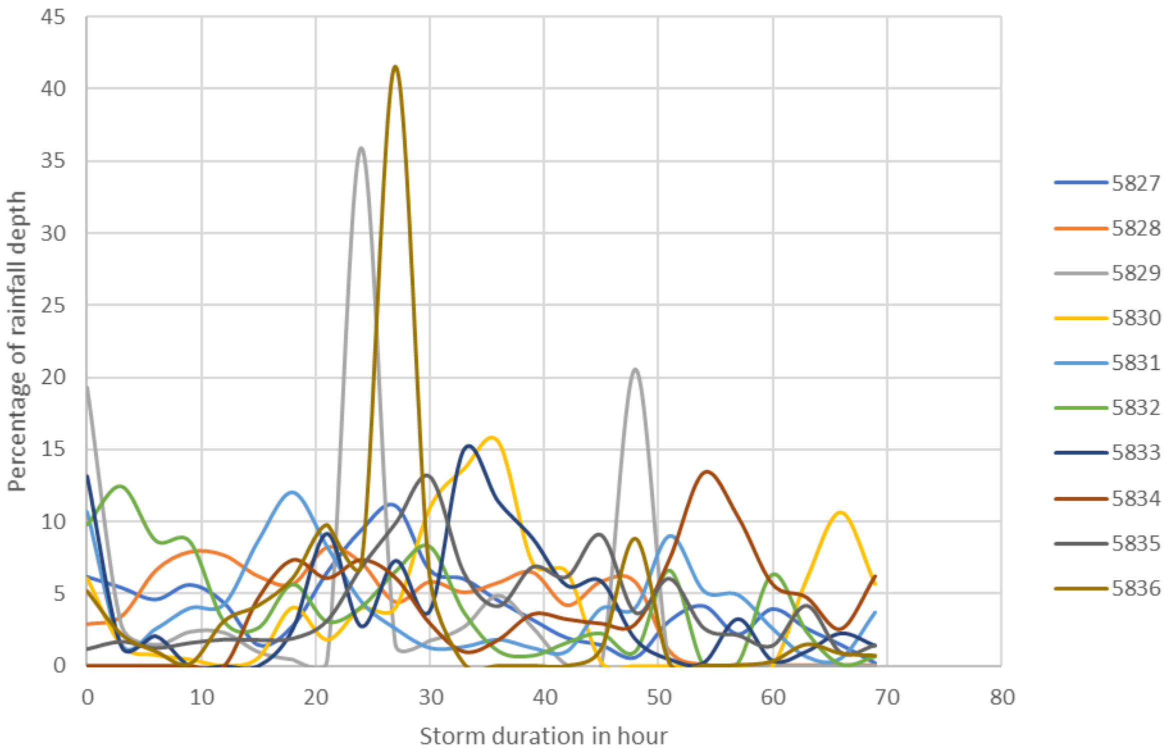

FIGURE 2-5 72 HOUR AREAL TEMPORAL PATTERN FOR CATCHMENT AREA OF 1000 KM²

[9] https://tonyladson.wordpress.com/2019/04/02/check-arr-temporal-patterns-before-you-use-them/

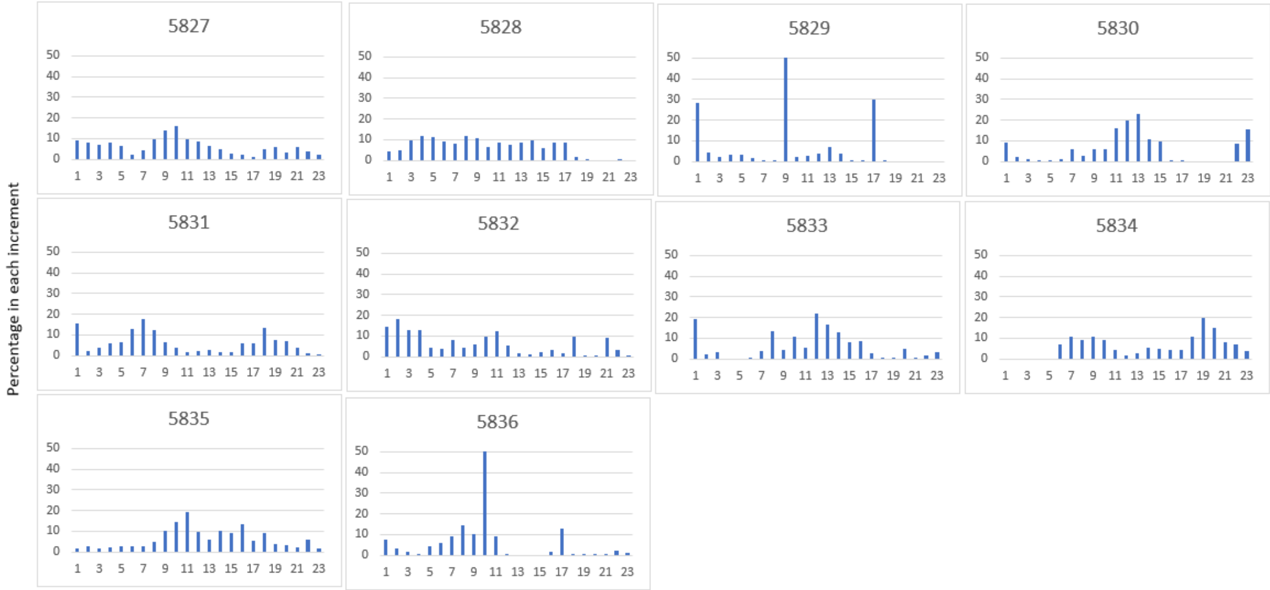

FIGURE 2-6 AREAL TEMPORAL PATTERNS FOR SOUTHERN SLOPES (MAINLAND) FOR 72 HOURS, AND CATCHMENT AREA OF 1000 KM²

Pre-Burst rainfall depth and temporal pattern

Estimates of the total depth of rainfall prior to the main burst were obtained from the ARR data hub. The data hub provides a distribution of pre-burst depths by duration and AEP. The median pre-burst depths for each duration was compared across AEPs, and for the purpose of design flood modelling, it was decided that adopting an average of the median for each duration was appropriate.

Although the ARR data hub provides pre-burst depths, it does not contain information regarding the temporal patterns. Therefore, temporal patterns of rainfall antecedent to the main burst were taken from HRS6 report of BOM[10] and applied to burst durations of 12 hours and longer.

Design Losses

An initial and continuing loss model was applied for the RORB modelling. Losses have been determined based on flood modelling results for a large number for catchments across Australia within the ARR online DataHub[8]. However there has been a significant amount of evidence that continuing loss values contained on the ARR DataHub are overestimates, with a recent paper presented by Mark Babister suggesting that for the NSW region they should be multiplied by 0.4. The adopted losses for this study were 25 mm initial loss and 2.5 mm/hr continuing loss, from the previous study. These loss values are consistent with loss values used across the region.

Spatial Pattern

Spatial patterns for long and short duration storms were derived using the approaches in Section 3 of the GSAM method (BoM, 2006) and Section 6 of the GSDM method (BOM, 2003). For design flood modelling, the spatial pattern selected varied with storm duration. The spatial pattern for long duration and short duration events is presented in Figure 2-7 and Figure 2-8.

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[10] BOM Hydrology report series-HRS6 – Rainfall antecedent to large and extreme rainfall bursts over Southeast Australia

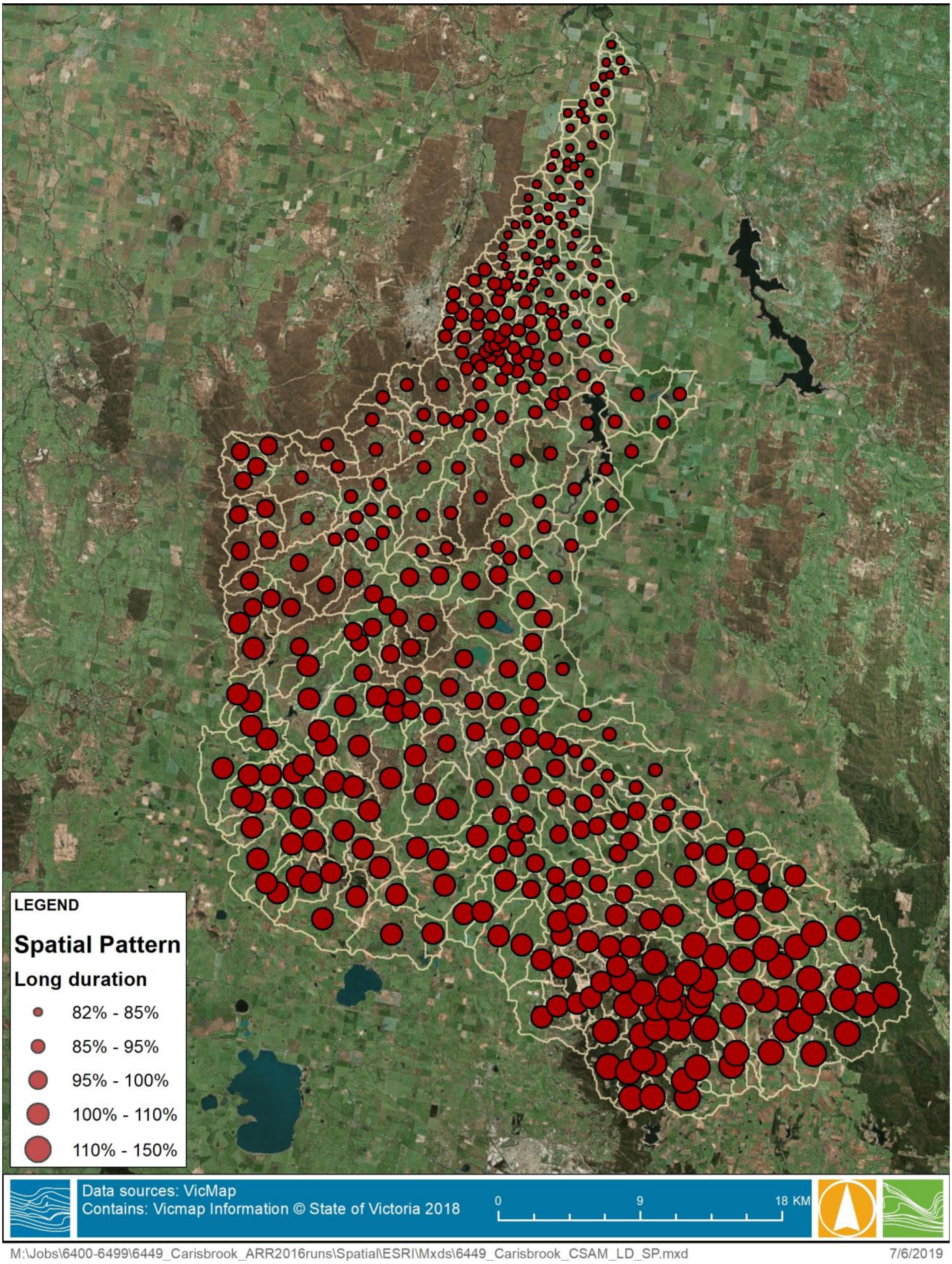

FIGURE 2-7 SPATIAL PATTERN FOR LONG DURATION EVENTS

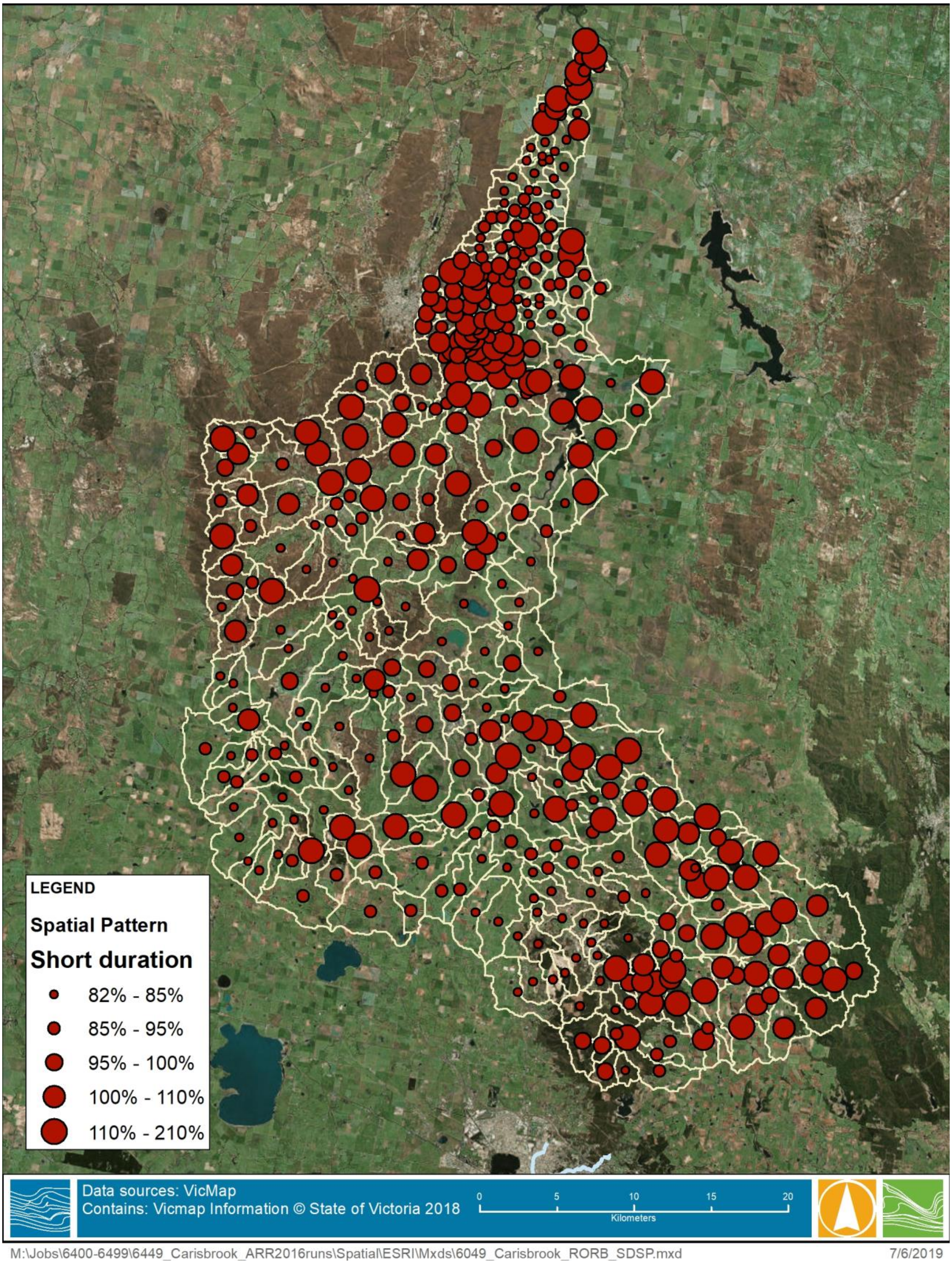

FIGURE 2-8 SPATIAL PATTERN FOR SHORT DURATION EVENTS

2.5.3 Monte Carlo Results

A RORB Monte Carlo analysis was carried to determine the design peak flows at several key locations of the RORB model as presented in Figure 2-9. The 1% AEP peak design peak flow and the critical durations at the key locations are summarised in Table 2-4.

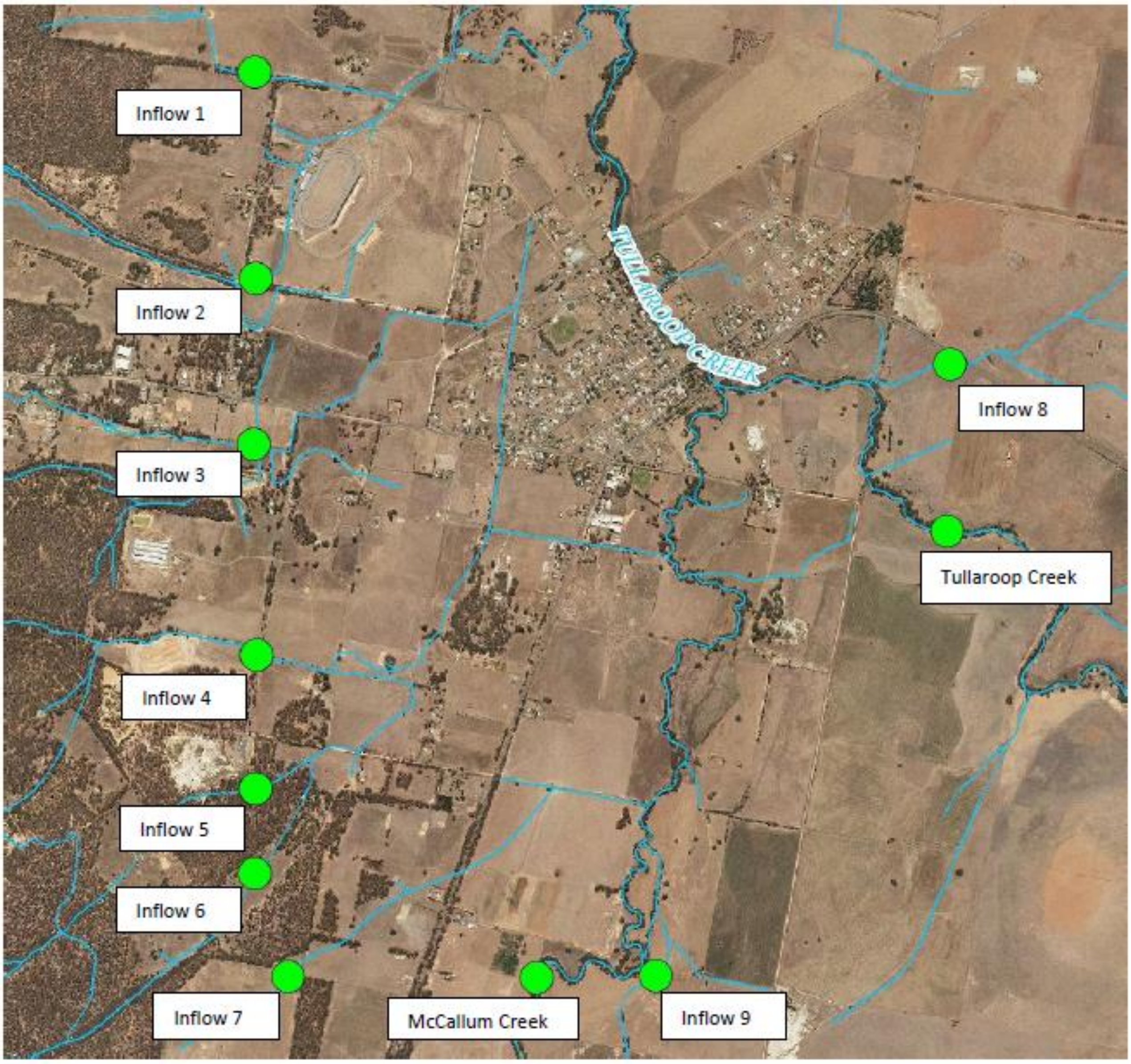

FIGURE 2-9 LOCATION OF RORB EXTRACTED HYDROGRAPHS AROUND CARISBROOK

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TABLE 2-4 PEAK FLOWS AND CRITICAL DURATION AT SELECTED LOCATION, MONTE CARLO SIMULATION

Location	0.5% AEP		1% AEP		2% AEP		5% AEP		10% AEP		20% AEP	
	Flow	Dur	Flow	Dur	Flow	Dur	Flow	Dur	Flow	Dur	Flow	Dur
Inflow1	32.7	6 h	27.9	6 h	22.5	6 h	15.0	6 h	10.7	6 h	6.6	12 h
Inflow2	43.2	6 h	35.8	6 h	27.4	6 h	18.8	2 h	13.2	2 h	8.4	12 h
Inflow3	29.9	6 h	24.3	6 h	19.4	6 h	12.5	6 h	9.5	9 h	5.4	12 h
Inflow4	34.5	6 h	27.6	6 h	21.4	6 h	13.9	6 h	10.1	9 h	5.5	12 h
Inflow5	10.1	6 h	8.5	6 h	6.9	6 h	4.6	6 h	3.2	9 h	1.9	12 h
Inflow6	8.0	6 h	6.6	6 h	5.2	6 h	3.1	6 h	2.3	9 h	1.2	12 h
Inflow7	14.0	6 h	11.3	6 h	9.4	6 h	6.1	2 h	4.2	9 h	2.4	12 h
Inflow8	9.0	2 h	7.3	2 h	5.5	2 h	3.7	2 h	2.4	2 h	1.5	2 h
Inflow9	29.4	6 h	23.9	6 h	19.3	6 h	12.6	6 h	9.3	9 h	5.3	12 h
McCallum Creek	756	12 h	617	12 h	485	12 h	327	12 h	213	12 h	101	12 h
Tullaroop Creek	581	24 h	323	24 h	229	24 h	139	24 h	79	24 h	34	24 h

2.5.4 Temporal pattern selection for design runs

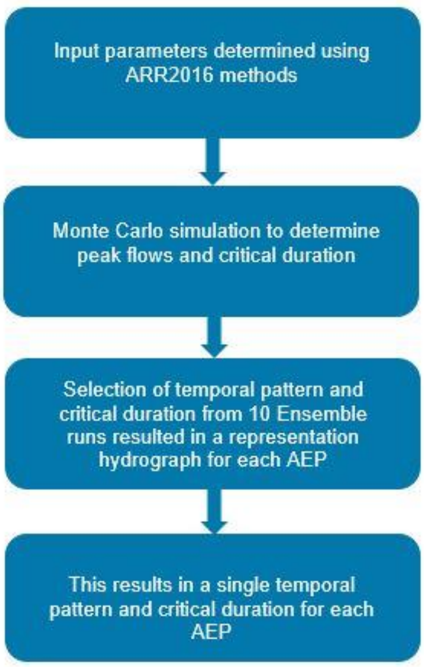

FIGURE 2-10 DESIGN MODELLING FLOW CHART

RORB was run in a Monte-Carlo framework to develop the peak flows at each selected location using the parameters in Table 2-1.

The key locations selected throughout the Carisbrook model were used to determine the suitable temporal patterns for the entire model. These locations are shown in Figure 2-9.

The appropriate temporal patterns were selected by choosing the ensemble temporal pattern that closest matched the Monte Carlo analysis peak flow for the critical duration of each AEP event.

The flow chart outlined in Figure 2-10 demonstrates the process.

The selected temporal patterns and event durations for each location for 1% AEP is shown in Table 2-5.

Based on the results shown in Table 2-5, the 2, 6, 9, 12 and 24 hour durations were run in the hydraulic model. This ensured that the critical durations of both the local and broader catchments were modelled. The resulting flood extents from all the durations were enveloped to form a single AEP event extent.

TABLE 2-5 DURATIONS AND TEMPORAL PATTERNS FOR KEY HYDRAULIC MODEL LOCATIONS

	0.5% AEP		1% AEP		2% AEP		5% AEP		10% AEP		20% AEP	
Location	Dur	TP	Dur	TP	Dur	TP	Dur	TP	Dur	TP	Dur	TP
Inflow 1	6 hr	23	6 hr	23	6 hr	22	6 hr	14	6 hr	14	12 hr	2
Inflow 2	6 hr	23	6 hr	23	6 hr	22	2 hr	17	2 hr	14	2 hr	23
Inflow 3	6 hr	23	6 hr	23	6 hr	22	6 hr	15	9 hr	14	12 hr	6
Inflow 4	6 hr	23	6 hr	23	6 hr	22	9 hr	14	9 hr	14	12 hr	6
Inflow 5	6 hr	23	6 hr	23	6 hr	23	6 hr	14	6 hr	14	12 hr	6
Inflow 6	6 hr	23	6 hr	23	6 hr	22	6 hr	14	9 hr	14	12 hr	6
Inflow 7	6 hr	23	6 hr	23	6 hr	22	2 hr	14	9 hr	14	12 hr	2
Inflow 8	2 hr	23	2 hr	29	2 hr	23	2 hr	14	2 hr	14	2 hr	23
Inflow 9	6 hr	23	6 hr	23	6 hr	23	6 hr	14	9 hr	14	12 hr	6
McCallum Creek	12 hr	4(LD)	12 hr	6(LD)	12 hr	2(LD)	12 hr	9(LD)	12 hr	9(LD)	12 hr	10(LD)
Tullaroop Creek	24 hr	1(LD)	24 hr	6(LD)	24 hr	6(LD)	24 hr	6(LD)	24 hr	6(LD)	24 hr	6(LD)

The LD in the Table 2-5 refers to long duration temporal pattern, rest are from short duration temporal pattern.

The adopted temporal pattern for design modelling is shown in Table 2-6 below.

TABLE 2-6 CHOSEN REPRESENTITIVE TEMPORAL PATTERNS FOR SELECTED DURATION

AEP	2hour	6hour	9hour	12hour	24hour
20%	23	N/A	N/A	6	6
10%	14	N/A	14	9	6
5%	14	14	N/A	9	8
2%	N/A	22	N/A	2	6
1%	29	23	N/A	6	6
0.5%	23	23	N/A	4	1

Modelling of the all the AEPs flood events for five storm durations resulted in 27 simulation runs in the hydraulic model for each floodplain scenario (current conditions and ultimate mitigation scheme). The 1% AEP inflow hydrographs at McCallum Creek and Tullaroop Creek for 12hr and 24hr critical duration is plotted in Figure 2-11.

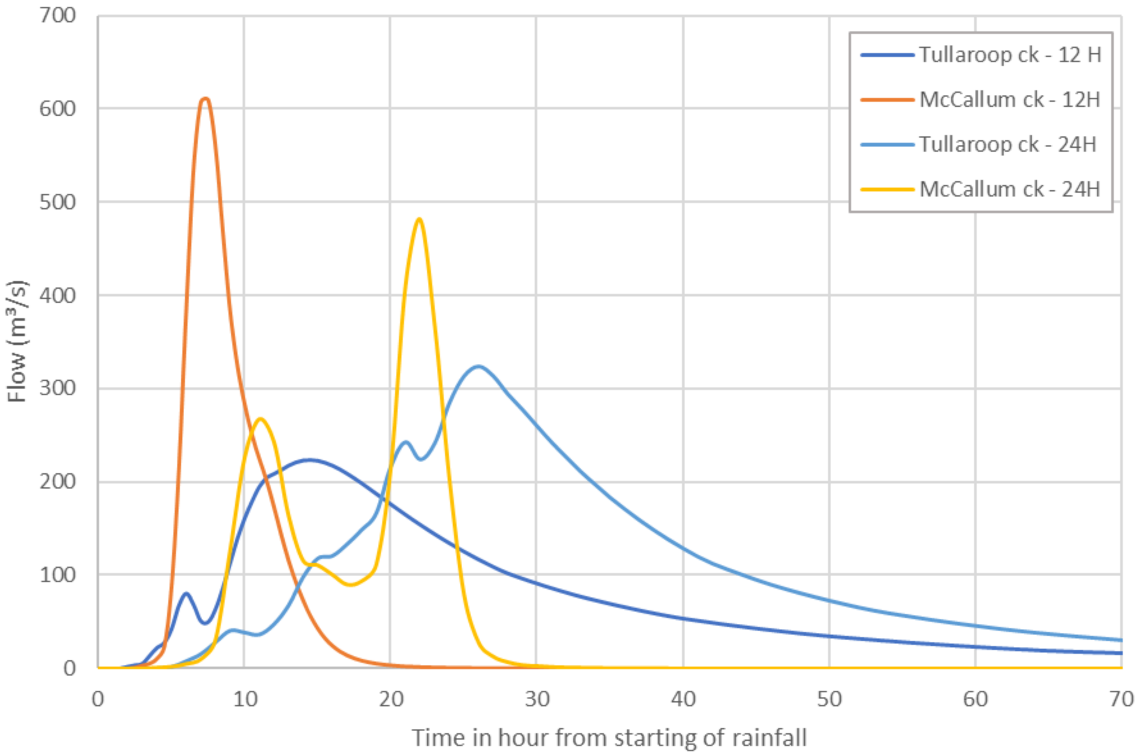

FIGURE 2-11 1% AEP FLOW HYDROGRAPHS AT MCCALLUM CREEK AND TULLAROOP CREEK

2.6 Comparison of hydrology results

Since completion of the Carisbrook Flood and Drainage Management Plan (2013)[1], there have been significant advances in the best practice hydrology approaches recommended in ARR (2016). These advances include Monte-Carlo sampling of rainfall depths, temporal patterns and loss parameters.

In addition to the Monte- Carlo framework, there have been numerous other changes to the design inputs. For Carisbrook, the most significant changes include:

- Updated intensity-frequency-duration (IFD) curves for design rainfalls with AEP up to 1 in 100
- Growth curves for estimating design rainfall depths with an AEP between 1 in 100 and 1 in 2000
- Inclusion of pre-burst temporal patterns
- Updated areal reduction factors for converting estimates of point rainfall depths to catchment average values
- Updated guidance on interpolating rainfall depths between the 1 in 2000 AEP and the PMP
- Short and long duration temporal patterns
- Improved regional flood frequency estimates for verification

Together, these have had a significant impact on the estimation of rare and extreme rainfalls and the corresponding flood flows.

The comparison of the design rainfalls (with areal reduction factors applied) for the ARR 1987 and 2016 values are presented in Figure 2-12. Table 2-7 presents the percentage change in the rainfall depths for various design frequencies and storm durations. The overall impact of the changes in methodology for developing design rainfalls is noticeable. In general, the new rainfall depths are lower for all the AEP's. However, shorter duration rainfall has higher changes than longer duration rainfall.

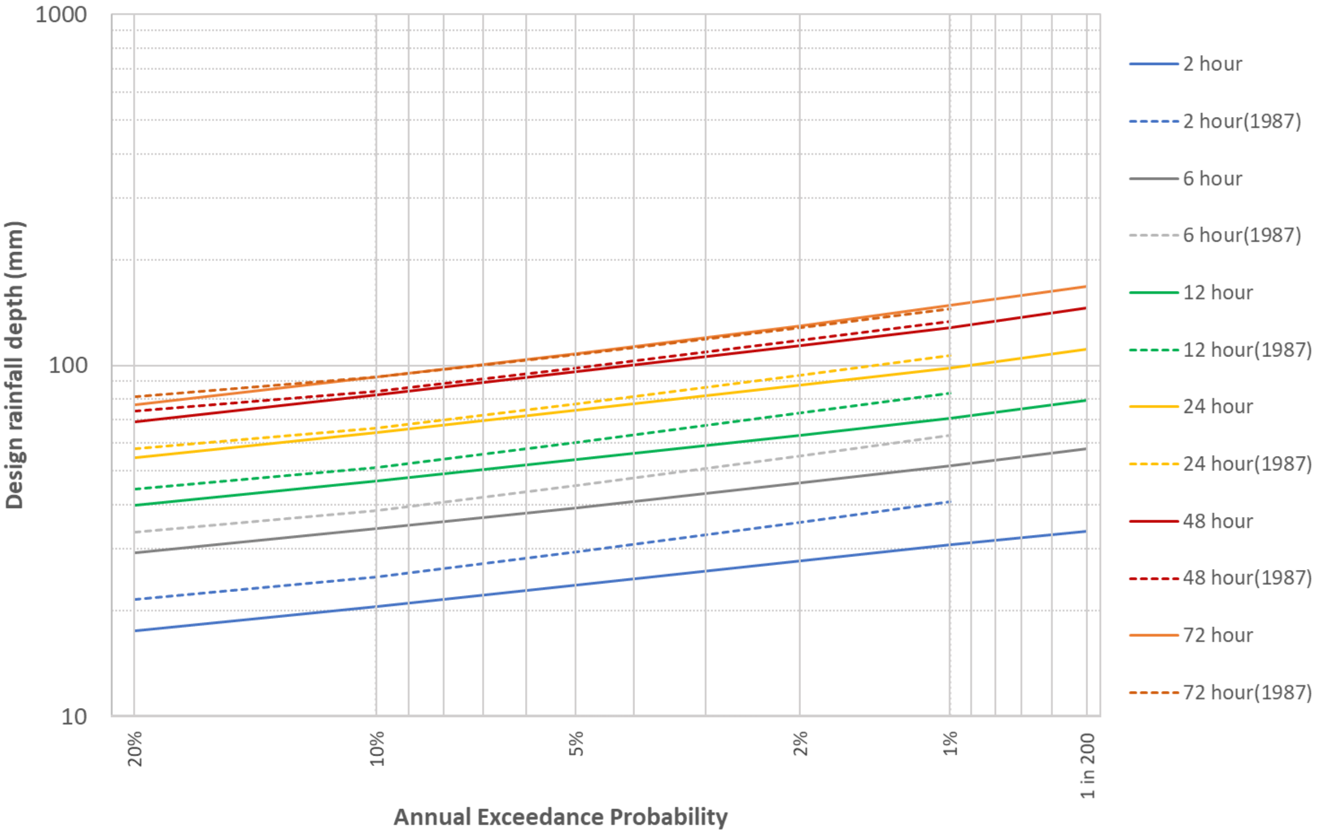

FIGURE 2-12 RAINFALL DEPTH COMPARISON BETWEEN ARR2016 & ARR1987 (ARF APPLIED)

TABLE 2-7 PERCENTAGE CHANGES IN DESIGN RAINFALL DEPTHS FOR CARISBROOK.

AEP (1 in Y)	2hr	3hr	6hr	12hr	24hr	48hr	72hr
5	-19%	-17%	-13%	-10%	-5%	-6%	-5%
10	-17%	-16%	-11%	-8%	-3%	-2%	0%
20	-20%	-19%	-14%	-11%	-5%	-2%	1%
50	-22%	-22%	-16%	-14%	-6%	-3%	1%
100	-25%	-25%	-18%	-15%	-8%	-4%	2%

A comparison of the design flows from the RORB modelling completed in the Carisbrook Flood and Urban Drainage Management Plan (2013) and this update, at selected locations is summarized in Table 2-8. The results show that the 1% AEP peak flow in McCallum Creek from this update study is approximately 617 m^3/s (12-hour critical duration), which is lower than the previous peak flow of 817 m^3/s (6-hour critical duration). However, flow has not decreased similarly for frequent AEP's. In the updated hydrology, a more consistent critical duration for all AEP's is observed in both McCallum Creek and Tullaroop Creek, as would be expected.

For Tullaroop Reservoir, the 1% AEP design outflow is 323 m^3/s (24-hour critical duration). The SKM (2012) study reported the same 24-hour storm duration event resulted in 120 m^3/s peak outflows from the reservoir; this is likely because SKM modelled the effect of reservoir drawdown on flood frequencies, whereas this study assumed the storage was always at its full capacity. The estimated design flow at Tullaroop Creek at Clunes (407222) for a 1% AEP event was reported in SKM (2012) at 700 m^3/s which is very close to the present study's estimate at 670 m^3/s.

While there is an increase and decrease of peak flows at McCallum Creek, the peak flows at Tullaroop Creek are consistently higher than the previous study at all AEP's. Although there are lower rainfall depths observed in ARR 2016, there are other factors which can lead to higher flow, like spatial pattern, temporal pattern, Monte-Carlo selection of initial loss. The sensitivity analysis in the previous study shows that changes in spatial pattern from uniform to non-uniform can reduce the flow by 12% to 15%. The temporal patterns of the ARR 1987 and 2016 methods are plotted in Figure 2-13, showing the significant difference which leads to differences in peak flows from both these methodologies.

The sensitivity on the Tullaroop Reservoir level done in the previous study showed that in a major flood events peak flows through the town are dominated by the McCallum Creek flow, not by Tullaroop Reservoir outflow. The previous study also showed that regardless of the starting storage level, Tullaroop Reservoir causes significant attenuation of the inflow to the dam, reducing the outflow to Carisbrook.

Downstream of the confluence the combined peak flow has been reduced in this update study compared to the Carisbrook Flood and Urban Drainage Management Plan by approximately 18% in the 1% AEP event. The flows at the more frequent events are similar, with no significant changes. These reductions in flow were tested in the hydraulic model and the impact on flood levels is discussed in Section 3.

TABLE 2-8 PEAK FLOW AND CRITICAL DURATION AT SELECTED LOCATIONS, WATER TECHNOLOGY (2013) STUDY VALUES HIGHLIGHTED IN BLUE

AEP	McCallum Creek (above confluence)		Tullaroop Creek (above confluence)		Tullaroop Creek (below confluence)		Local Tributary D/S of Carisbrook Reservoir(Inflow3)	
	Peak flow (m^3/s)	Duration (hrs)	Peak flow (m^3/s)	Duration (hrs)	Peak flow (m^3/s)	Duration (hrs)	Peak flow (m^3/s)	Duration (hrs)
20%	101 (123)	12h (9h)	33 (22)	24h (9h)	113 (129)	12h (9h)	5.4 (3.8)	12h (9h)
10%	212 (204)	12h (18h)	79 (39)	24h (18h)	235 (220)	12h (18h)	9.5 (4.9)	9h (9h)
5%	326 (315)	12h (18h)	139 (109)	24h (72h)	374 (352)	12h (18h)	12.5 (7.1)	6h (3h)
2%	484 (573)	12h (6h)	229 (181)	24h (18h)	555 (617)	12h (6h)	19.4 (12.0)	6h (2h)
1%	617 (817)	12h (6h)	323 (272)	24h (6h)	718 (882)	12h (6h)	24.3 (16.4)	6h (2h)

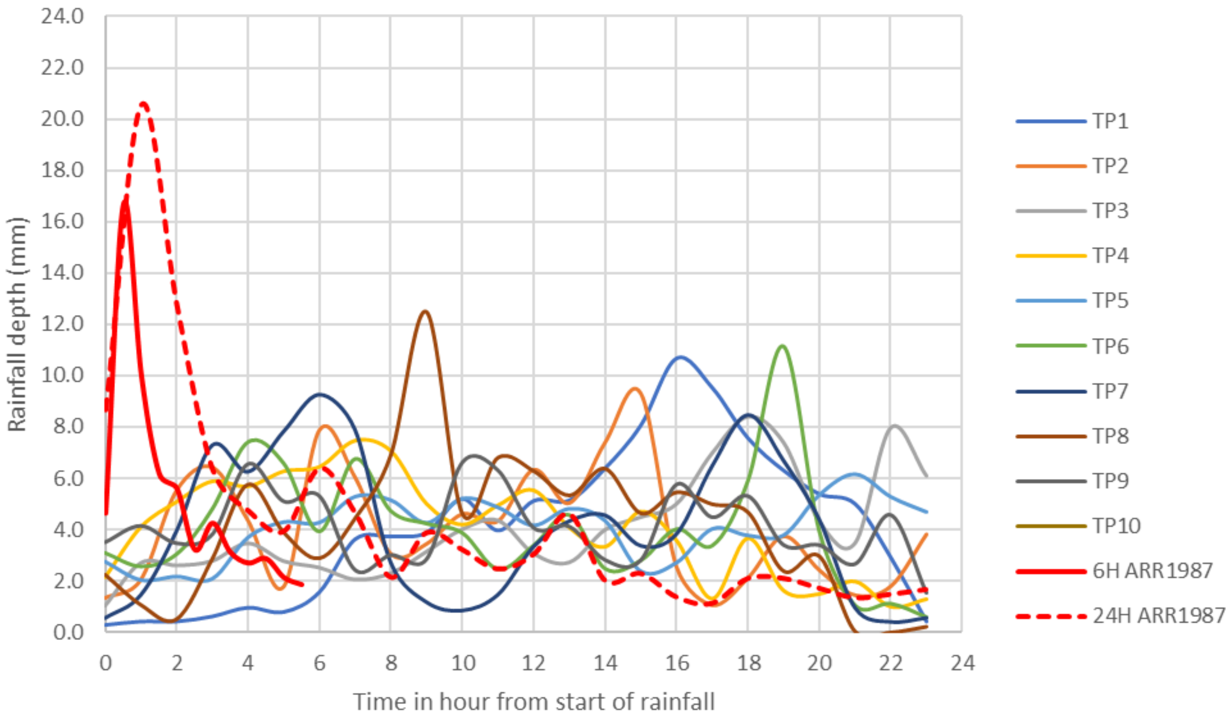

FIGURE 2-13 COMPARISON OF TEMPORAL PATTERN: ARR2016 & ARR 1987

The peak flows generated from the local catchment west of the township are plotted in Figure 2-14 and Figure 2-15 comparing the ARR 1987 and 2016 methodologies. The updated hydrology generated higher peak flows, showing short duration rainfall bursts to be critical.

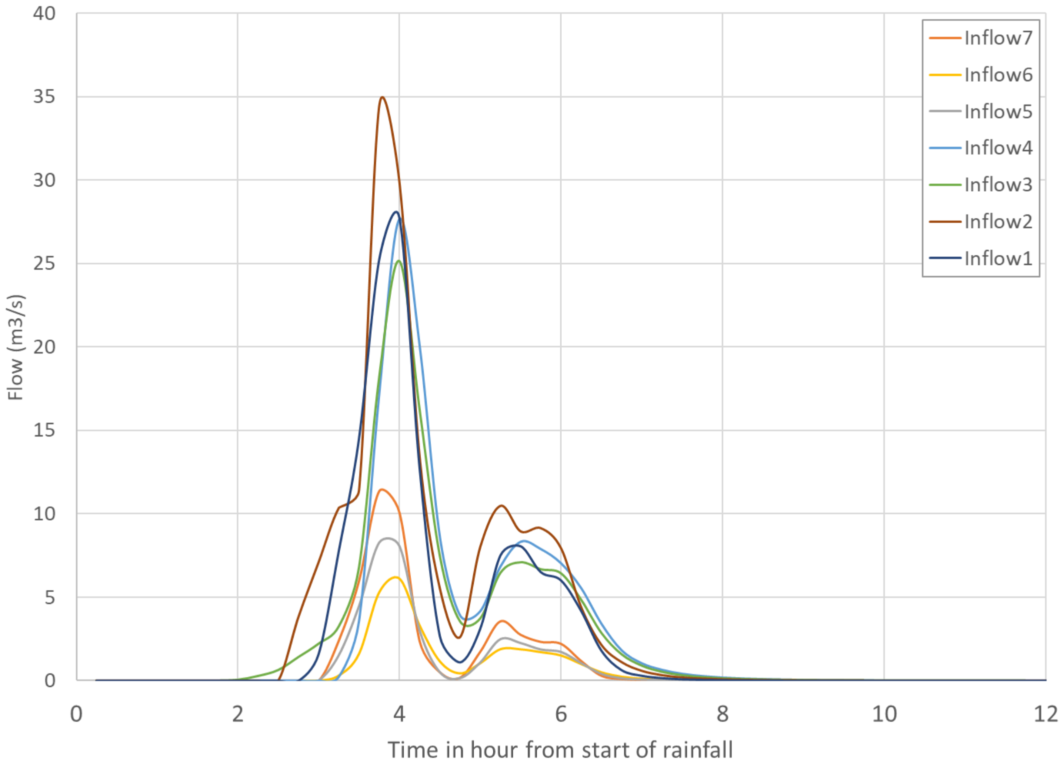

FIGURE 2-14 ARR 2016 1% AEP FLOW HYDROGRAPHS AT SELECTED LOCATIONS

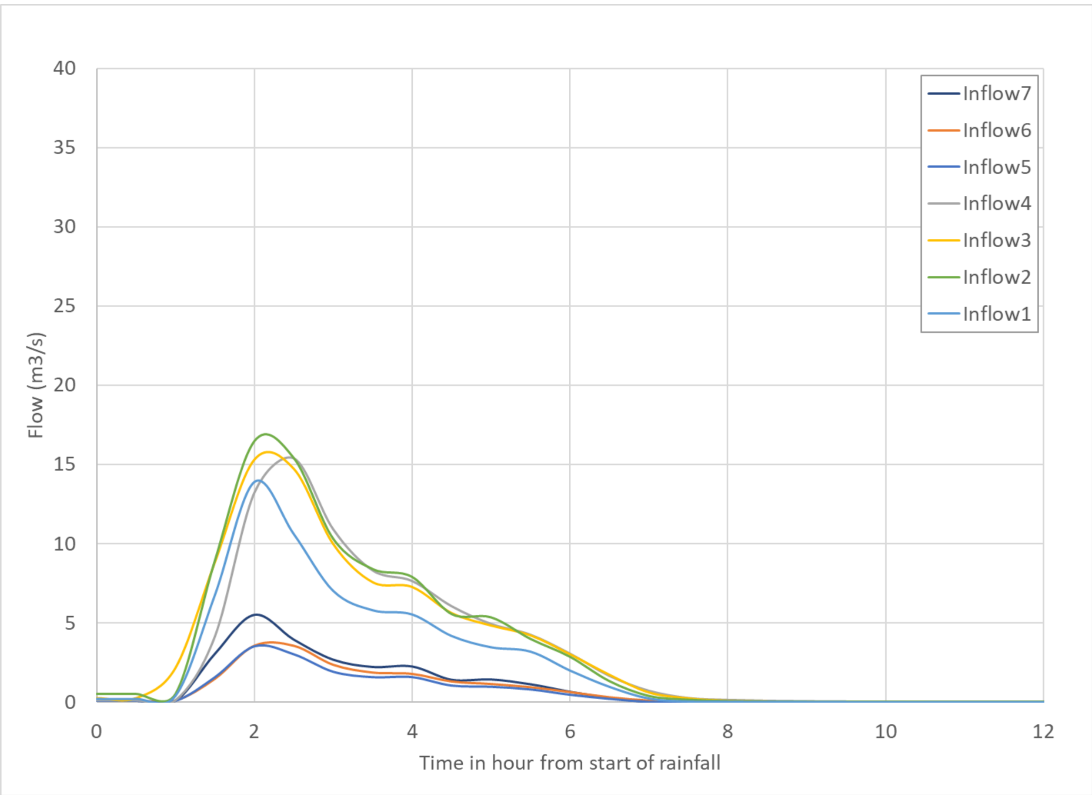

FIGURE 2-15 AR&R 1987 1% AEP FLOW HYDROGRAPHS AT SELECTED LOCATIONS

2.7 Model verification

The modelled design flow was verified against the flood quantiles produced by the ARR Regional Flood Frequency Estimation (RFEE) method (Rahman et al, 2012)[11]. The verification process is described in the following section.

The RFFE method is a replacement for the Probabilistic Rational Method described in the previous version of ARR. It is a software implementation of the ARR Revision Project 5 and can be accessed via http://rffe.arr.org.au/. A full description of the method is provided in ARR project reports (http://www.arr.org.au/revision-projects/project-list/project-5/).

The peak flow determined for each AEP using the RFFE at Tullaroop Reservoir outlet and MacCallum Creek gauge is presented in Table 2-9.

The Carisbrook RORB model (assuming natural catchment conditions and no urbanization or reservoir in place) was run in a Monte Carlo framework and different AEP flood quantiles were compared with results from the RFFE method. Natural catchment conditions were modelled during this step because the RFFE method is not applicable to catchments with significant impervious areas (urban).

TABLE 2-9 TULLAROOP RESERVOIR OUTFLOW AND MCCALLUM CREEK PEAK FLOWS FROM RFFE

AEP (%)	Discharge (m³/s)		Lower Confidence Limit (5%) (m³/s)		Upper Confidence Limit (95%) (m³/s)	
	Tullaroop Creek	McCallum Creek	Tullaroop Creek	McCallum Creek	Tullaroop Creek	McCallum Creek
50	96	67	32	24	290	193
20	179	124	63	46	513	334
10	250	170	87	63	723	467
5	331	223	113	80	979	626
2	456	302	149	104	1,410	891
1	565	378	178	124	1,820	1,130

The peak flow determined using RFFE and other verification methods, along with the current update and the previous study are compared in Figure 2-16 and Figure 2-17 at Tullaroop Creek and McCallum Creek. The previous study FFA was not updated due to the poor quality of gauge data and limited record. The results show that the RORB model (in natural conditions) estimates higher peak flows than the RFFE, but that the RORB estimates are well within the confidence limits of the RFFE.

[11] https://rffe.arr-software.org/

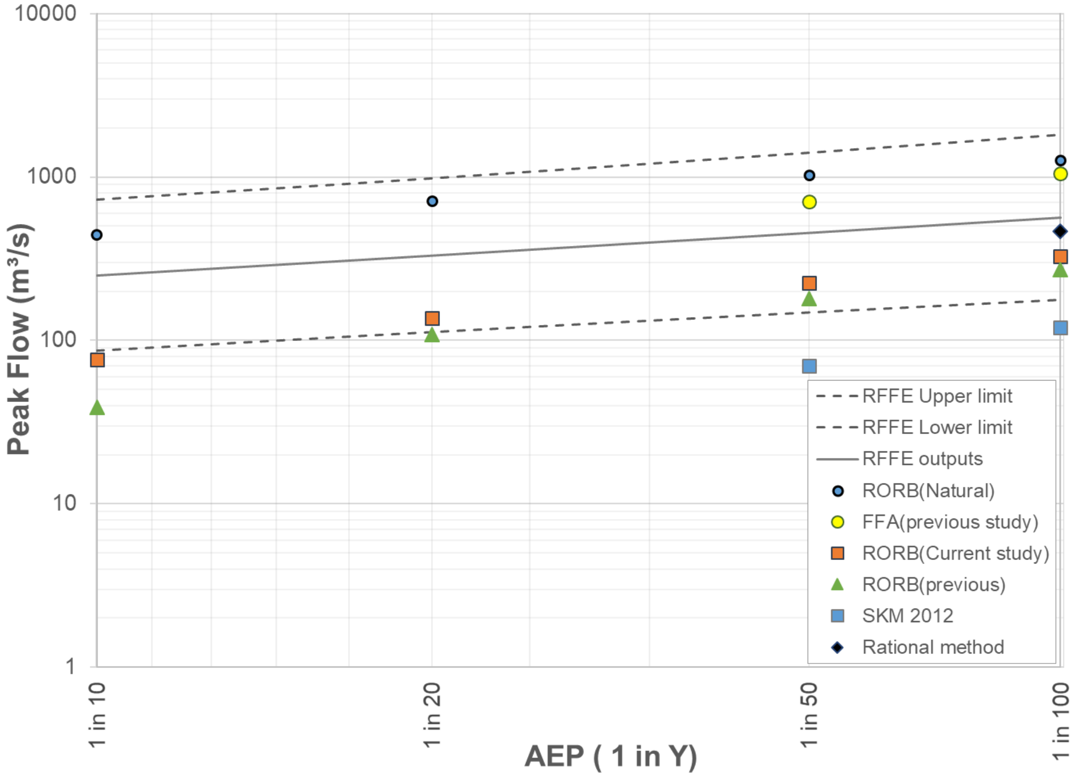

FIGURE 2-16 COMPARISON OF DIFFERENT METHOD PEAK FLOW AT TULLAROOP OUTLET

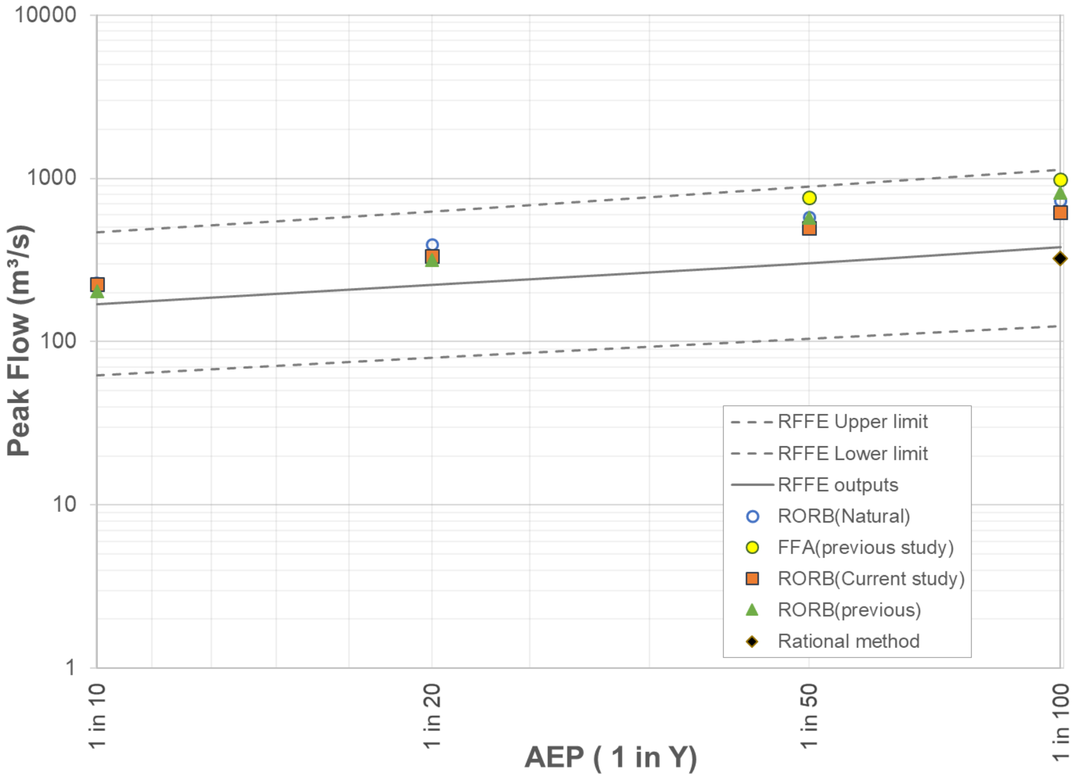

FIGURE 2-17 COMPARISON OF DIFFERENT METHOD PEAK FLOW AT TULLAROOP OUTLET

3 HYDRAULICS

3.1 Overview

The detailed combined 1D-2D hydraulic model developed during the previous study was used for the present update study. The hydraulic modelling was run with updated design inflows and updated existing as constructed mitigation topography. The hydraulic modelling approach consisted of the following components:

- One dimensional (1D) hydraulic model of key drains, drainage lines and hydraulic structures;
- Two dimensional (2D) hydraulic model of the broader floodplain; and
- Links between the 1D and 2D hydraulic models to accurately model the interaction between in bank flows (1D) and overland floodplain flows (2D).

The hydraulic modelling software MIKE FLOOD developed by the Danish Hydraulic Institute (DHI) was used for this study. MIKE FLOOD is a state-of-the-art tool for floodplain modelling that combines the dynamic coupling of the 1D MIKE 11 river model and 2D MIKE 21 model systems. Through coupling of these two systems it is possible to accurately represent river and floodplain processes.

The model was upgraded to the latest software version. The upgraded model was slightly adjusted to modify the head loss and roughness coefficients at the Pyrenees Highway Road bridge to replicate the (calibrated) model results obtained previously.

The Carisbrook Flood and Drainage Management Plan (Water Technology 2013) was successful in providing a much better understanding of flood behavior around Carisbrook. The numerical model was calibrated to two historical events and modelling results for the January 2011 and September 2010 floods replicated the observed flood behavior through the town quite accurately; this was confirmed by post flood level survey from debris marks, aerial images as well as community feedback during public consultation. The calibrated model was deemed appropriate for use for design event modelling and mitigation investigation.

Adjustments to the model geometry was undertaken to reflect current waterway condition and works carried out since the recent floods. The present modelling assumed the same existing condition, with the major update as listed below:

- levee constructed along Williams Road
- Levee constructed along Pleasant Street from railway line towards north
- Culvert under Pleasant Street was removed
- Low level floodway crossing constructed across Wills Street with a 1200mm wide by 450mm high culvert
- Open drain constructed along Wills Street up to the Racecourse north-east corner

3.2 MIKE model update

The updated levee and culvert location are shown in Figure 3-1. The drone survey covering Pleasant Street levee, Wills Street drain and Williams Road levee and drain was provided by Central Goldfields Shire Council and was incorporated in the model topography.

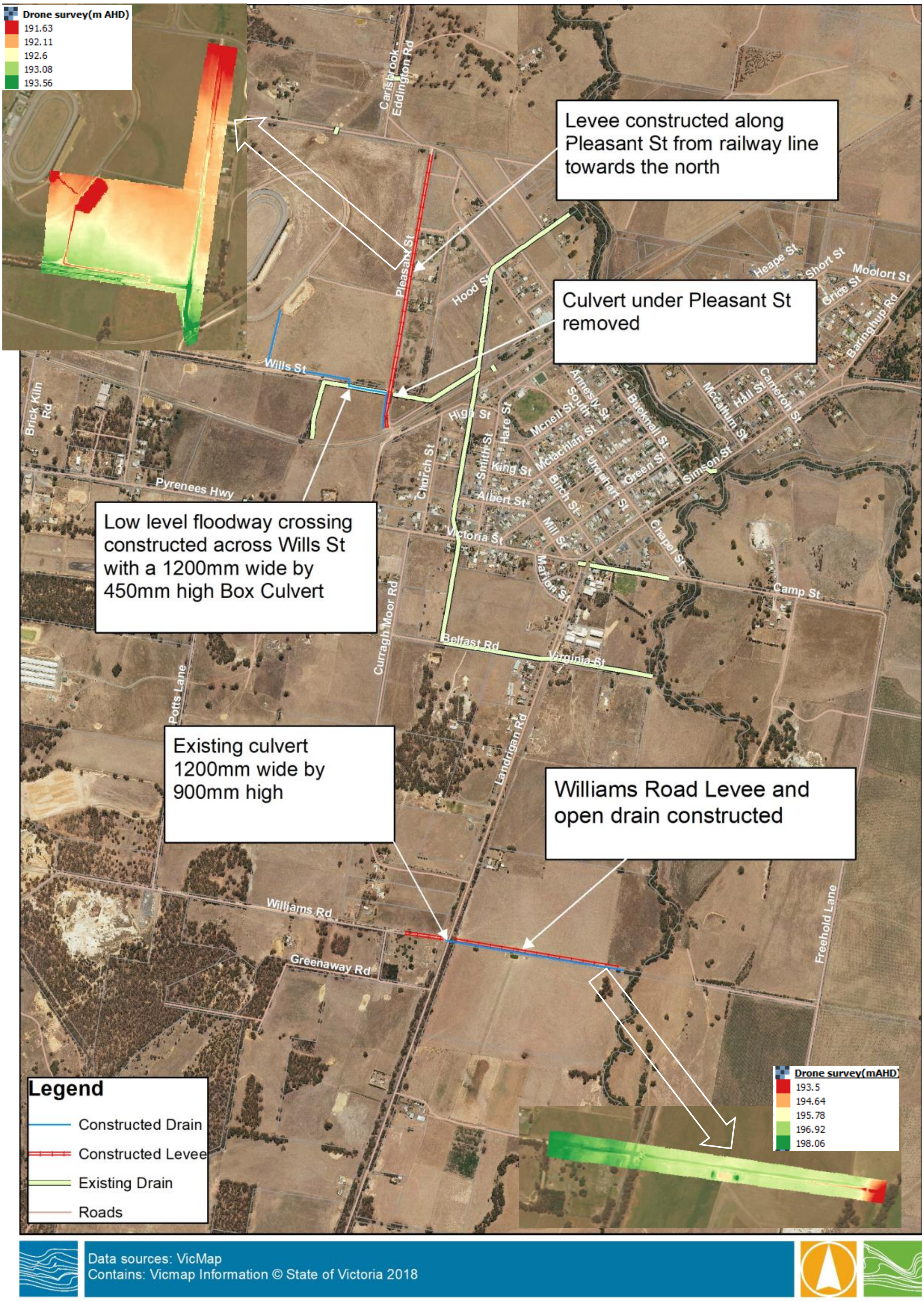

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FIGURE 3-1 LOCATION OF UPDATED CULVERT AND LEVEE (INSET: DRONE SURVEY DATA)

3.3 Design event modelling

Hydraulic modelling was undertaken for the 0.5%, 1%, 2%, 5%, 10% and 20% Annual Exceedance Probability (AEP) design storm events. The design hydraulic modelling adopted previous study design roughness in the creek (no post debris and veg removal work) and on the floodplain. Each design event was run for 2hr, 6hr, 12hr and 24hr duration rainfall and the results enveloped. A suite of flood maps was developed across the range of flood magnitudes (0.5%, 1%, 2%, 5%, 10% and 20% AEP events), as presented in Appendix A.

Figure 3-2 shows the 1% AEP design flood extent overlayed with the previous studies modelled extent. The dark green areas show locations where the latest modelling shows flood water where the previous model didn't. The gold coloured areas show locations where the new modelling is dry where the previous modelling was wet. The yellow/green areas are where both the new and old models overlap with both models showing as inundated.

Some observations regarding the comparison of the new and old modelling is made below:

- In general, the updated modelling with ARR2016 hydrology shows a smaller flood extent with lower depths (5 to 10 cm lower) of inundation through the central township.
- A large area north of the train line and east of Pleasant St is no longer inundated due to the Pleasant St levee and blocking of the drain that flowed west to east under Pleasant St along Wills St.
- The Williams Road levee and drain diverts water back to the creek, removing inundation along Landrigan Road to the north of Williams Road.
- The area of inundated between Victoria St and Mill St, is no longer inundated now.
- There is an increased area of inundation from the western catchments to the west of Pleasant St due to the changes in the hydrology of the local catchments with the update to ARR2016.
- The Pyrenees Hwy overtopped for larger 0.5% and 1% flood event and causing widespread inundation across the township.
- More frequent flood has lesser extent than the rare flood.
- Overall the 1% AEP flood extent has reduced.

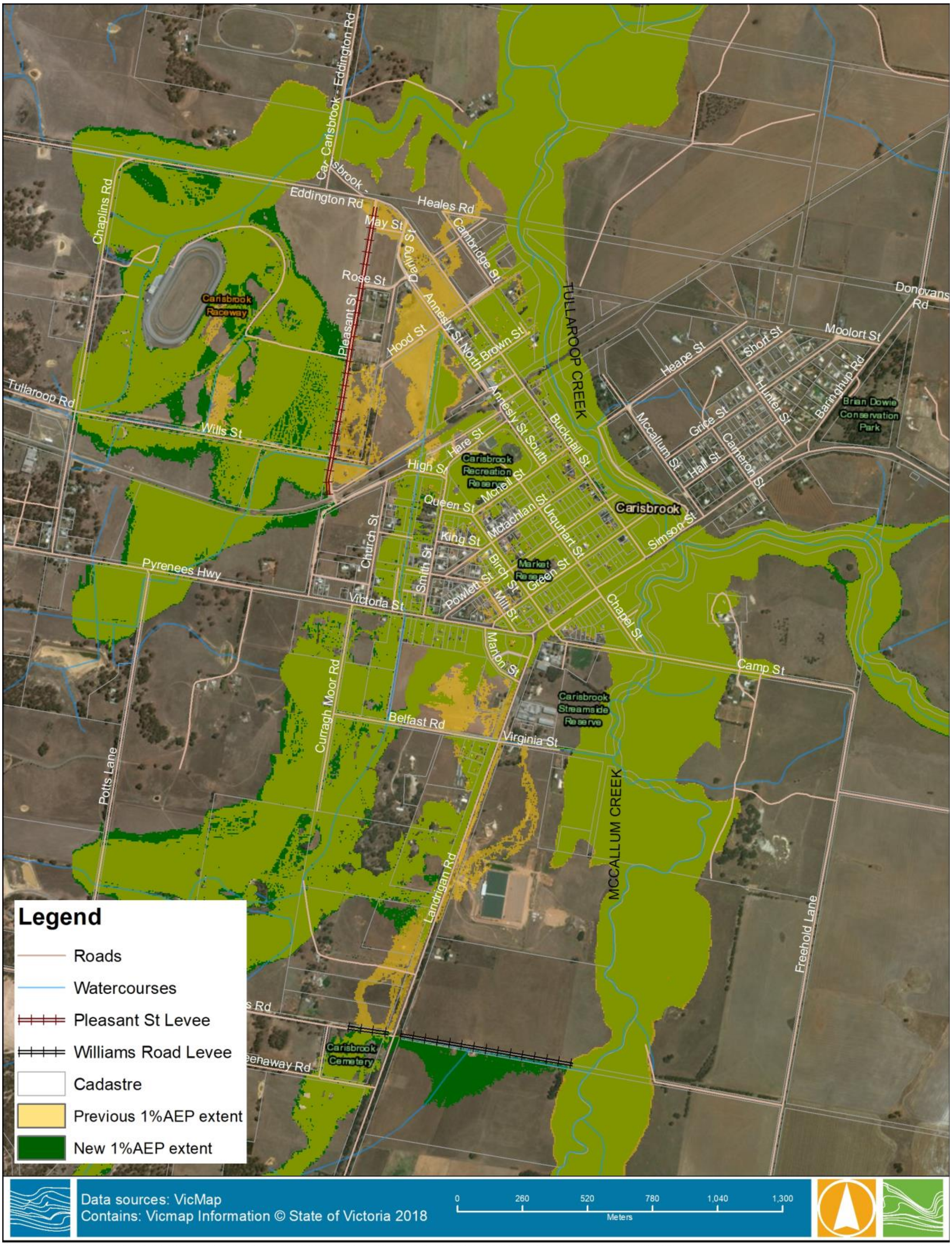

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FIGURE 3-2 COMPARISON OF 1% AEP FLOOD EXTENT: NEW AND PREVIOUS

4 DESIGN FLOOD BEHAVIOUR, EXISTING CONDITIONS

The existing conditions flood extents for all design floods modelled are shown in Figure 4-1, zoomed to the township area. It can be seen that flooding from McCallum and Tullaroop Creek in the 2%, 5%, 10% and 20% AEP events is generally well-confined within the creek floodways. These frequent to rare events have a fairly similar inundation extent along the creek with some minor incremental changes as the flood magnitude increases. The rare 1% and 0.5% AEP events show a significant breakout over the Pyrenees Highway, causing widespread inundation across the township.

The flooding from the local catchments to the west and southwest of the township in frequent flood events such as the 20%, 10% and 5% AEP generally cause some shallow inundation in the agricultural areas around the town, with more significant rural impacts around the trotting track. The Pleasant Street levee prevents water from overtopping from these western catchments for all the design flood events modelled. The local catchments to the south-west of the township are reasonably well confined south of Pyrenees Hwy and to the existing drainage channels, while events greater than 5% AEP event may overtop the highway and exceed the capacity of the existing drainage channels.

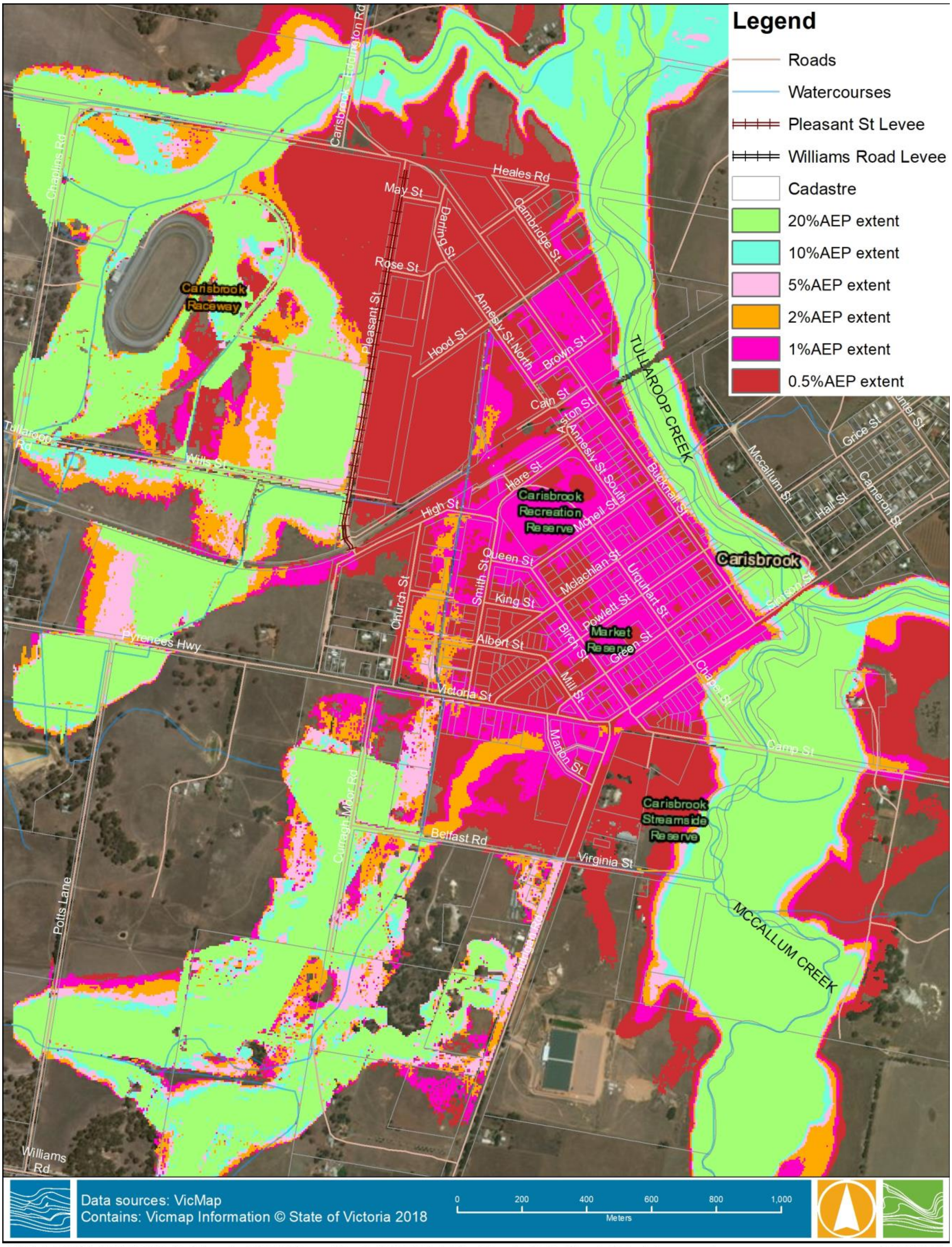

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FIGURE 4-1 DESIGN FLOOD EXTENTS

The following comments describe the key flood characteristics in Carisbrook for each design event. This description along with Figure 4-1 explains the areas inundated for each design event modelled.

4.1 20% AEP Flood Event

- Flood well-confined along McCallums and Tullaroop Creek floodways and the bluestone channels through the township.
- Some shallow inundation in agricultural areas to the west and south-west of the township including parts of the trotting track.

4.2 10% AEP Flood Event

- Flow well-confined along McCallums and Tullaroop Creek floodways and the bluestone channels through the township.
- Some shallow inundation in agricultural areas to the west and south-west of the township including parts of the trotting track.

4.3 5% AEP Flood Event

- Flow well-confined along McCallums and Tullaroop Creek floodways and the bluestone channels through the township.
- Some shallow inundation in agricultural areas to the west and south-west of the township including parts of the trotting track and areas immediately to the south of the railway line and Pyrenees Highway where water is banking up.
- Water starting to accumulate adjacent to Landrigan Road

4.4 2% AEP Flood Event

- Flood well-confined along McCallums and Tullaroop Creel floodways.
- A small breakout from McCallums Creek near Chapel Street impacting property at that location.
- Local flows from the south-west overtop the levee along Belfast Road causing some shallow inundation to properties along the south of Victoria Street
- Overtopping of the main north-south bluestone drain impacting several properties between Victoria and High Streets.
- Water surcharging up through the bluestone drain adjacent to the school causing some inundation of property at the corner of Victoria Street and Landrigan Road.

4.5 1% AEP Flood Event

In a 1% AEP design flood event (Figure 4-2) a significant breakout occurs over the Pyrenees Highway, causing widespread inundation across the township.

The flows from the western catchments cause overtopping of the main north-south bluestone drain and impact a number of properties between Church Street and Smith Street and properties along the southern side of Victoria Street. Inundation is observed over the Pyrenees Highway near Potts Lane intersection.

Further north, the drain upgrades and levee along Pleasant St prevent flood water from overtopping the road and flowing east, with flow redirected towards the racecourse drainage system. Water levels are slightly increased on the western side of Pleasant St.

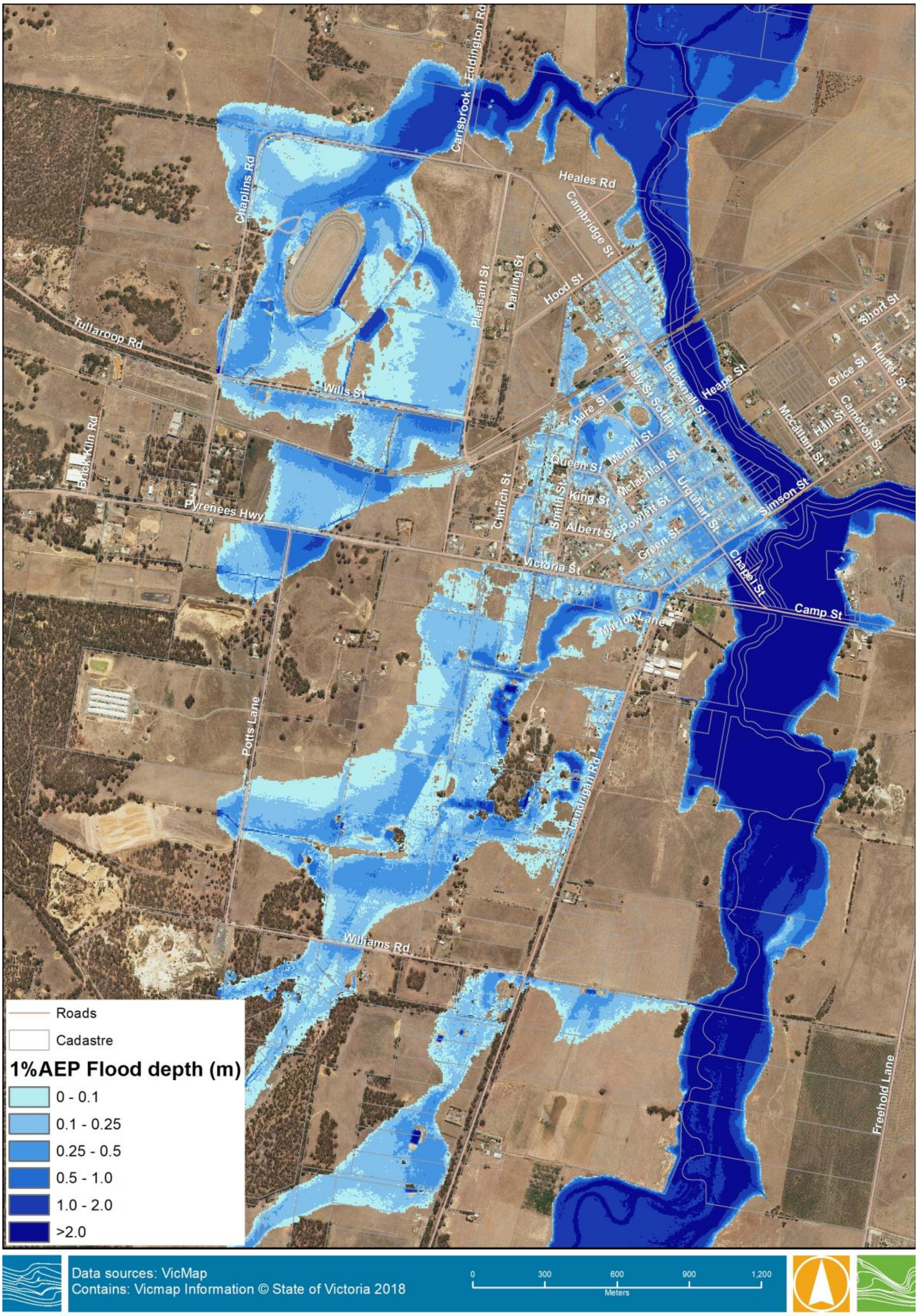

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FIGURE 4-2 EXISTING CONDITION 1% AEP FLOOD DEPTH

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The 1% AEP maximum water level along Pleasant Street is plotted along with the existing levee crest level as shown in Figure 4-3. It is confirmed that the existing design height of the Pleasant Street levee has adequate 300 mm freeboard.

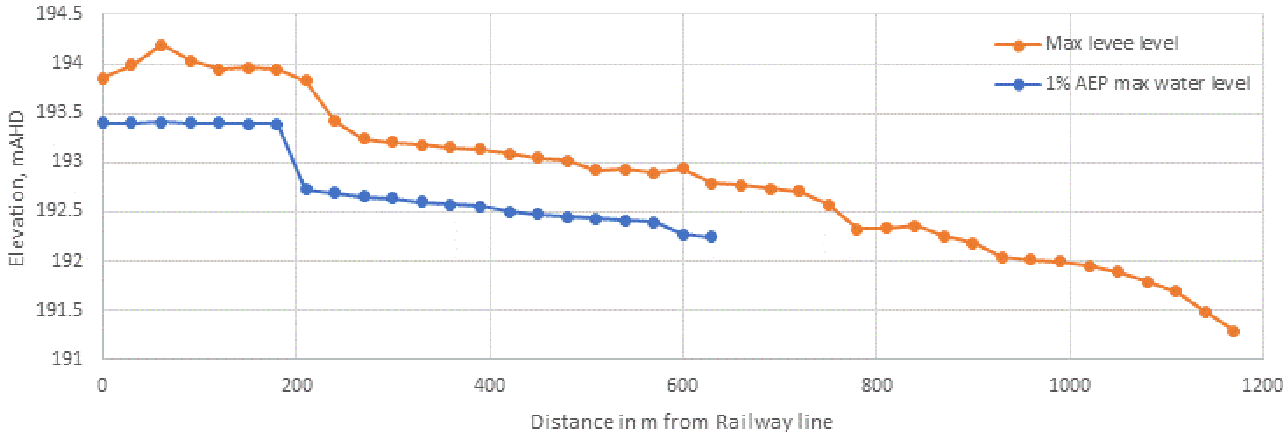

FIGURE 4-3 PLEASANT ST LEVEE CREST LEVEL AND 1% AEP FLOOD LEVEL

The flows from the catchment to the west of town causes significant inundation around the trotting track and across properties between Chaplins Road, Pyrenees Highway and Darling Street.

During flood events, the local tributaries around Carisbrook peak several hours before the Tullaroop Creek and McCallum Creek. It is likely that flooding will be experienced from these local catchments, inundating property and isolating homes. It is not until Tullaroop and McCallum Creeks overtop the Pyrenees Highway when widespread inundation above floor levels occurs through the township. There will be several homes inundated above floor prior to this occurring.

The existing Williams Road levee prevents flood water from overtopping the road and flowing further to the north. The levee and drain redirect flow back to the creek. Water levels are slightly increased on the southern side of Williams Road in rural land west of Landrigan Road. The constructed levee height has adequate 300 mm freeboard except at a low point on the western section near Carisbrook Cemetery where the freeboard is just 210 mm (Figure 4-4). Given that the consequences are low if this levee overtops, this lower level of freeboard may be considered acceptable.

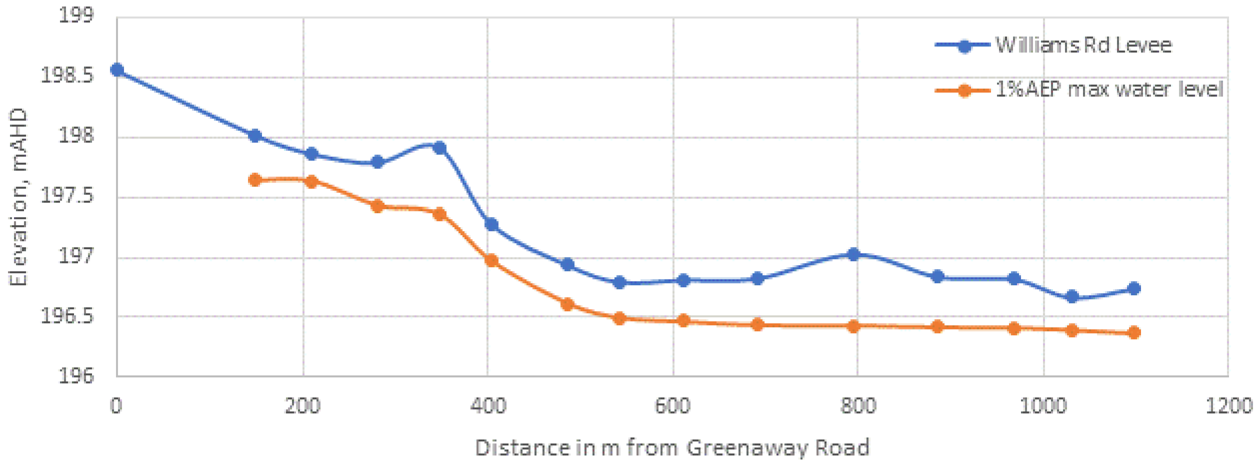

FIGURE 4-4 WILLIAMS ROAD LEVEE CREST LEVEL AND 1% AEP FLOOD LEVEL

4.6 0.5% AEP Flood Event

- Widespread inundation through the township as a large breakout from McCallums Creek overtops the Pyrenees Highway and flows through the township (Figure 4-1).
- The breakout is considerably deeper than in the 1% AEP event causing more inundation in the west and north of the central township.
- Properties in the west of the township adjacent to the main north-south drain and along the south side of Victoria Street are impacted first by local catchment flows overtopping the drain and then later from the main waterway breakout as it flows west across the township.

5 ULTIMATE FLOOD MITIGATION MODELLING

The ultimate mitigation plan was provided by Central Goldfields Shire Council. The plan consists primarily of structural measures such as levee and culvert upgrades in the township of Carisbrook. The aim is primarily to mitigate the flood impacts from the local tributaries.

The mitigation measures are marked below in Figure 5-1, key features include:

- A 2 km long levee extending from the southern end of the Curragh Moor Road Reserve, to the west of the developed properties on Curragh Moor Road, across the Pyrenees Highway, alongside Pleasant Street, up to the Railway Line.
- Excavation of trapezoidal channel adjacent to the levee primarily between Curragh Moor Road and the railway line as there is no natural fall in the topography along much of that section of the levee. The proposed levee and drain topography was provided by Central Goldfields Shire Council.
- Construction of culvert under railway line. Four 1,200 mm wide by 900 mm high culverts.
- Construction of culverts under Pyrenees Highway. Two 1200 mm wide by 1200 mm high culverts.
- Earthen levee to the south of the Pyrenees Hwy, the levee acts as a retarding basin and allows a small amount of water through a single 450 mm pipe culvert at CH.1017, with water discharging to the east of Curragh Moor Road and into the existing drain. The pipe also acts to drain water away from a low depression to ensure excessive water is not remaining in this area after a flood has passed through.
- Another outlet through a 225 mm pipe culvert at CH.450 to allow a minimal amount of water to drain under the levee to the area with a remnant patch of native vegetation.

The results of modelling incorporating the ultimate mitigation plan are presented in the figures below. Figure 5-2 presents the 1% AEP maximum water depth under mitigated conditions while Figure 5-3 presents a difference plot comparing 1% AEP water levels between existing and mitigated conditions.

The results demonstrate that the modelled western levee is very effective in reducing the flooding extent through the southern and western portion of the township, and adjacent to the existing bluestone drain. Flooding along Landrigan Road is reduced and several properties along Smith and Church St are no longer impacted by floods in the 1% AEP design event.

Significant depths occur behind the modelled western levee, with a depth of 1.2 m at the deepest point. If 300 mm of freeboard was assumed the levee would need to be 1.5 metres in height at its highest point.

The results show that water is draining to the east through the culvert at CH.450 and CH.1017 and discharging to the remnant patch of native vegetation and the bluestone drain. Flood water is noted to impact the paddock north of Belfast Road.

Flood water is also noted to impact the properties south of Victoria Street, west of Landrigan Road and to the east of the bluestone drain, however this is a result of flood water from McCallum Creek surcharging up through the drain adjacent to the primary school and through the culverts under Landrigan Road

Overall this scenario achieved its objective in terms of minimising the impact of inundation from the local catchments to the west, whilst ensuring no properties are adversely impacted within the township compared to existing conditions. The property inundation throughout the township due to the breakout of McCallum and Tullaroop Creeks over the Pyrenees Hwy in a 1% AEP event is still present and is not addressed by this mitigation option.

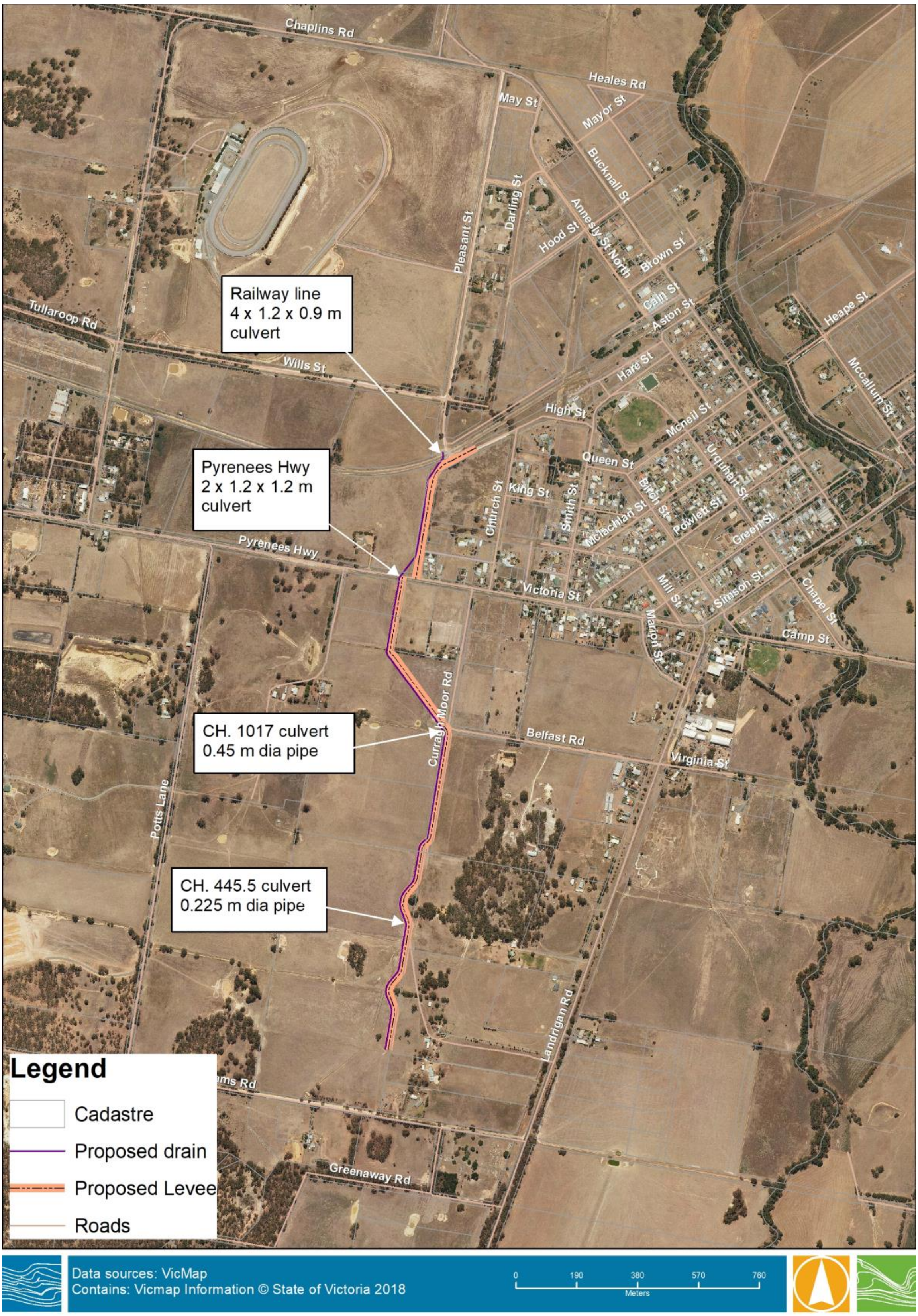

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FIGURE 5-1 ULTIMATE MITIGATION OPTION

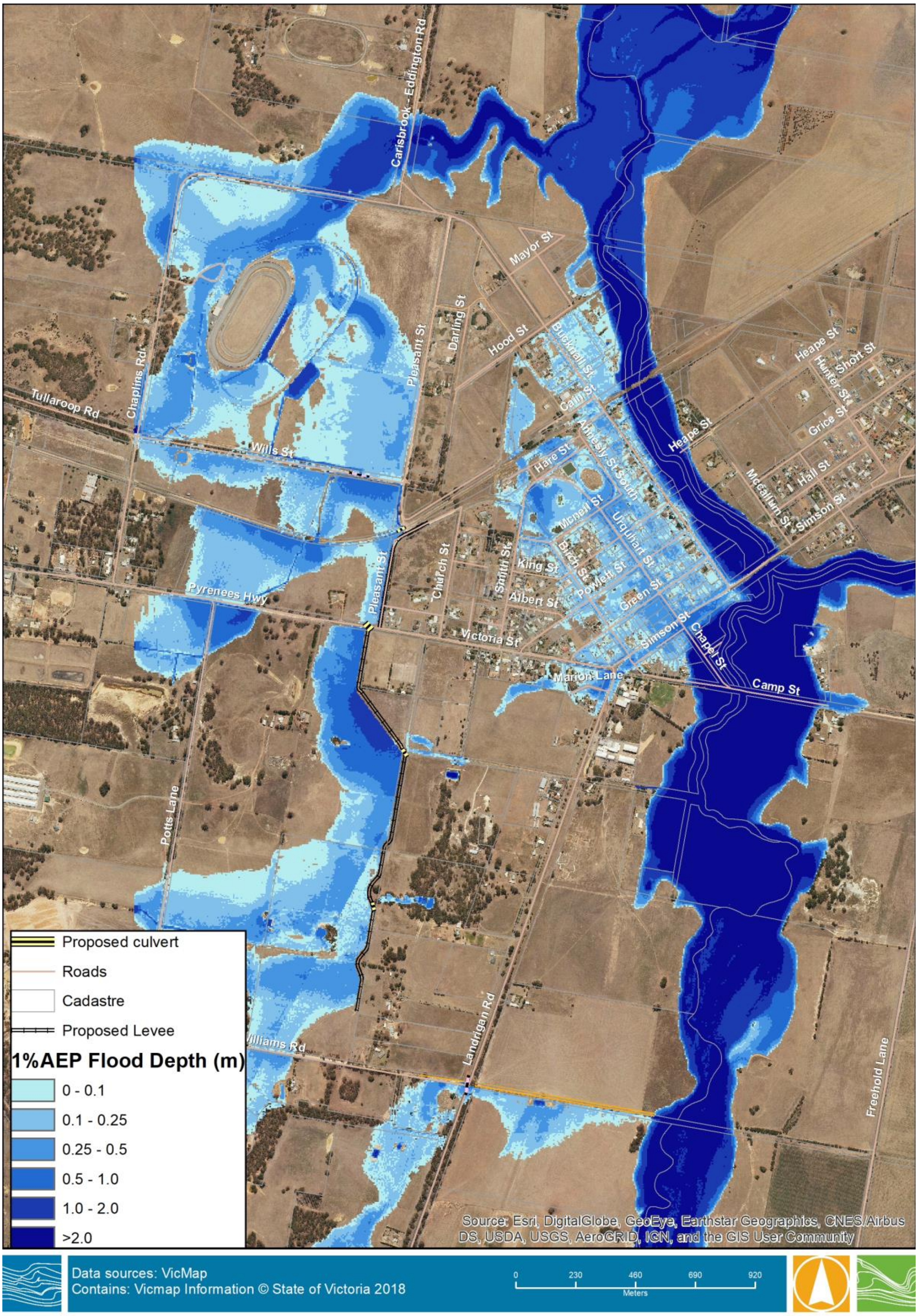

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FIGURE 5-2 ULTIMATE MITIGATION - 1% AEP FLOOD DEPTH

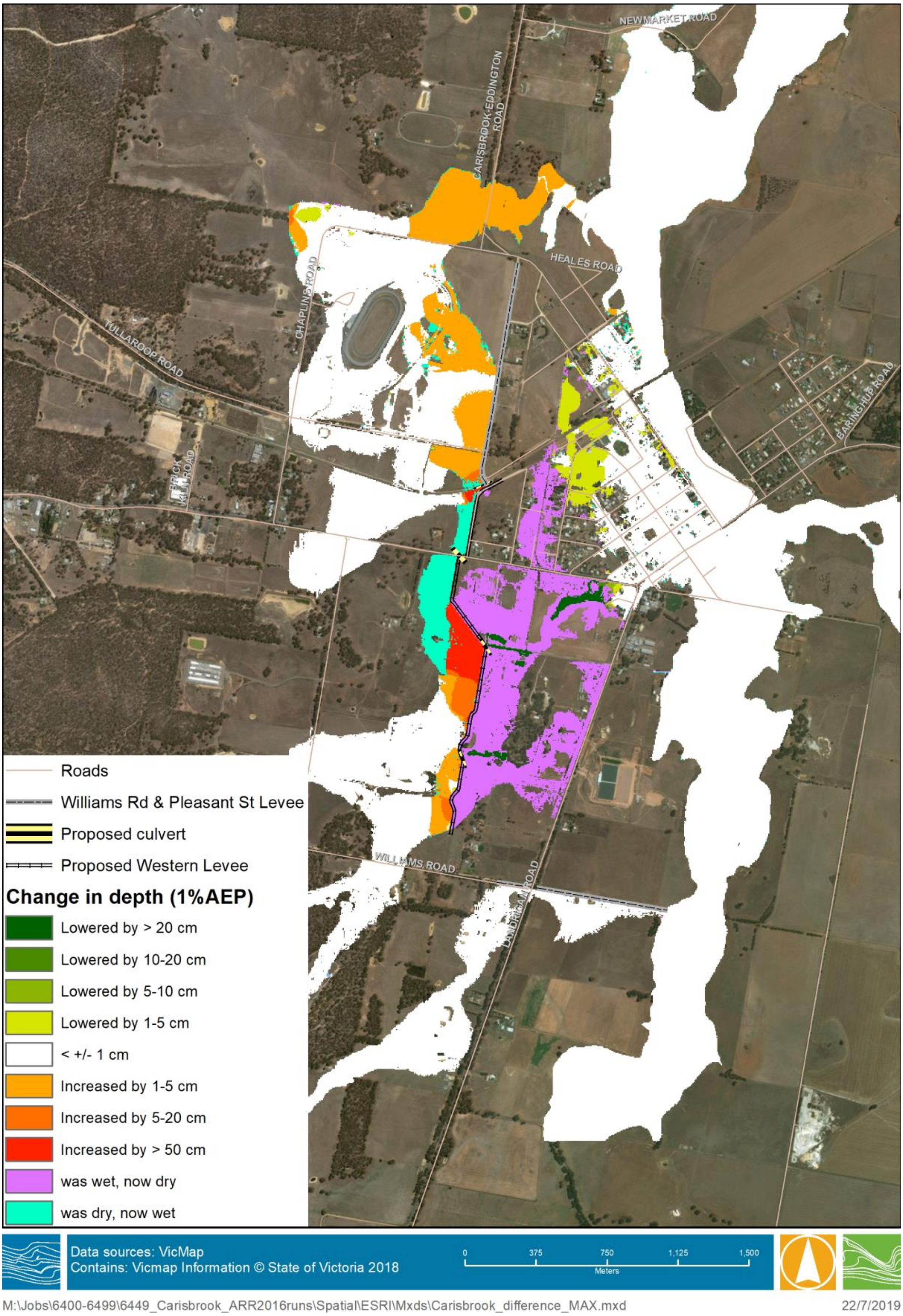


FIGURE 5-3 ULTIMATE MITIGATION - 1% AEP DIFFERENCE PLOT

6 SUMMARY

This report has described the updated hydrology modelling according to ARR 2016 recommendations, the update of the hydraulic model, and modelling of existing and ultimate mitigation conditions.

Overall the mitigation plan achieves its objective in terms of minimising the impact of inundation from the local tributaries to the west whilst ensuring no properties are adversely impacted within the township compared to existing conditions. The following are the key findings from this updated modelling:

- The new design rainfall depths are generally lower for all the AEP's. However, shorter duration rainfall has higher changes than longer duration rainfall events.
- The updated hydrology following the ARR2016 guidelines results in lower peak flows downstream of the McCallum/Tullaroop confluence, with longer critical storm durations. The revised hydrology produces higher peak flows from the local catchments.
- The updated modelling with ARR2016 hydrology shows smaller flood extents with lower depth (5 to 10 cm lower) of inundation through the central township.
- The revised hydrology does slightly change flood extents, with some areas no longer inundated, and some areas now inundated that weren't before.
- The Pleasant Street levee and Williams Road levee design height are adequate for 300 mm freeboard, except a low point on the Williams Road levee on the western section near the Carisbrook Cemetery. The freeboard at this location is 210 mm, which given the low level of consequence if the levee overtops is most likely acceptable.
- The mitigation results demonstrate that the western levee is very effective in reducing flooding through the southern and western portion of the township.
- Significant depths occur for 1% AEP flood behind the modelled western levee, with a depth of 1.2 m at the deepest point. With 300 mm freeboard, the levee would need to be 1.5 metres in height at its highest point.
- The largescale inundation through the central township from McCallum and Tullaroop Creeks overtopping the Pyrenees Hwy still occurs for rare 0.5% and 1% AEP flood events and is not address by this mitigation option.

7 RESPONSE TO JACOBS REVIEW

This section of the report responds directly to the relevant recommendations from the Jacobs review that were the focus of this scope of works.

Reviewing the assessment of probability assigned to peak flow events

See Section 5.9 and 5.10 of the Jacobs review.

Water Technology Response: The flood frequency analysis was not relied upon to determine design flows for Carisbrook because of two reasons. Firstly, the streamflow data for Tullaroop Creek at Clunes has recorded two very large events and no other major flood events, resulting in a high degree of uncertainty in the flood frequency analysis results. In addition, this gauge is located upstream of Tullaroop Reservoir, so does not account for the impact of the storage of the reservoir on peak flows at Carisbrook. Secondly, the McCallums Creek gauge at Carisbrook is only rated for low flows with a high degree of uncertainty in high flows. In addition, the data for September 2010 and January 2011 flood events is missing. The streamflow data for Tullaroop and McCallums Creeks is therefore unreliable for design flow estimates at Carisbrook.

So instead we placed more confidence in the rainfall-runoff RORB modelling. With the latest update using the revised Australian Rainfall and Runoff 2016 design rainfall and improved rainfall-runoff modelling approaches, the design hydrology for Carisbrook has been greatly improved.

Improvements to the rating curve at McCallums Creek could be made using the hydraulic modelling to construct a modelled rating curve for high flows. This work would have benefits for flood warning if the gauge is to be used as a forecast location, but it has no bearing on the structural flood mitigation plan.

Examining the short duration storms in the Western catchment

See Section 5.7 of the Jacobs review.

Water Technology Response: The modelling investigated the 10min, 15min, 20min, 25min, 30min, 45min, 1hr, 1.5hr, 2hr, 3hr, 4.5hr, 6hr, 9hr, 12hr, 18hr, 24hr, 30hr 36hr, 48hr and 72hr storm durations. The 2hr storm event produced the maximum flows off the western catchments. No further work is required.

Model the current flood mitigation configuration and the final detailed design

See Section 5.3 and 5.5 of the Jacobs review.

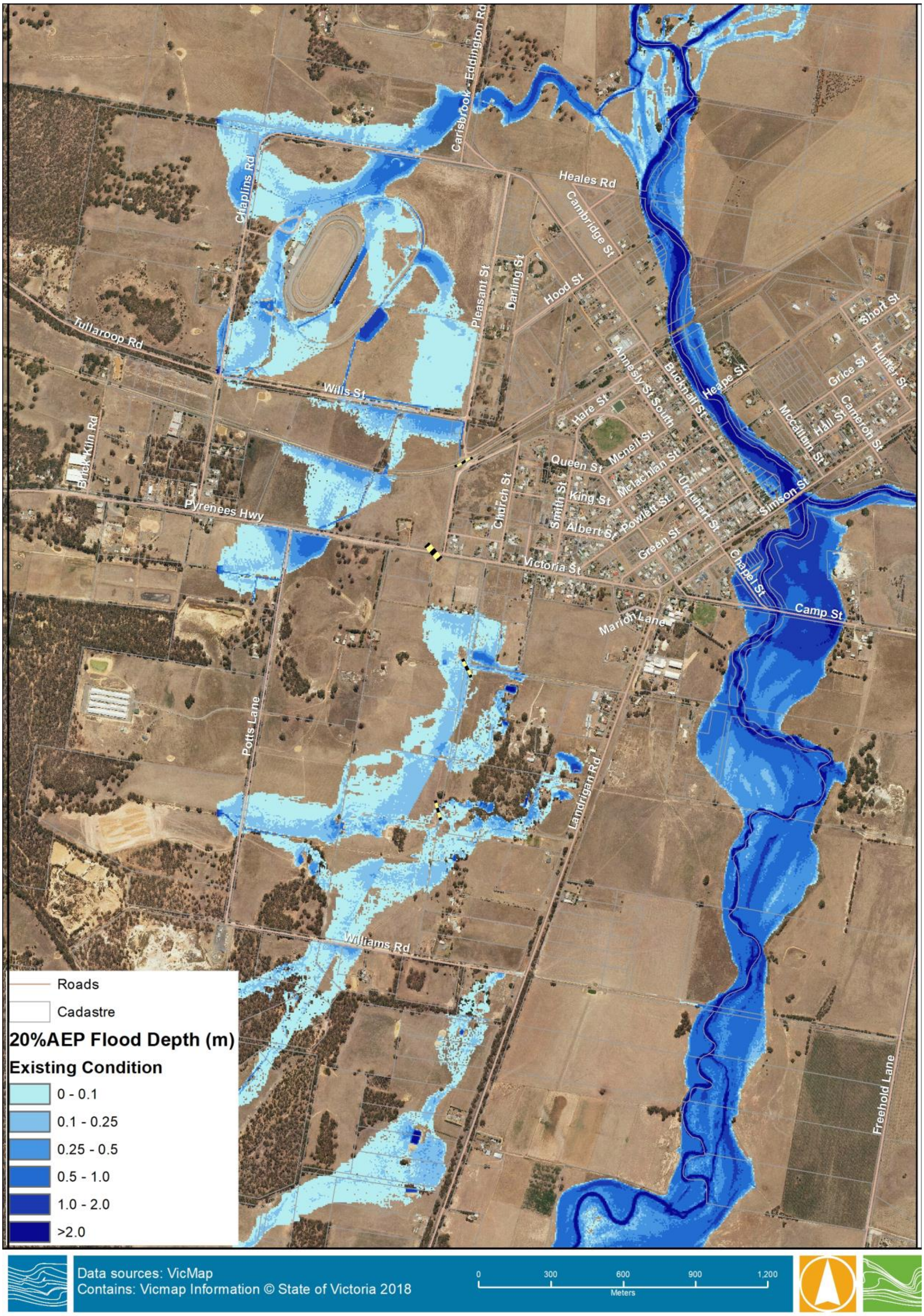
Water Technology Response: We have modelled the current flood mitigation configuration with the updated ARR2016 hydrology and have documented the changes in this report. We have also modelled the final detailed mitigation design and documented the benefits of the full mitigation scheme. As shown the detailed design is very effective at reducing flooding from the western catchments.

Update the Municipal Flood Emergency Plan

See Section 5.12 of the Jacobs review.

The MFEP was updated and was delivered to Council on completion of the flood study. The MFEP will be further updated to reflect the latest work documented in this report.

APPENDIX A
20%,10%,5%,2%,1% & 0.5% - FLOOD DEPTH, EXISTING CONDITION



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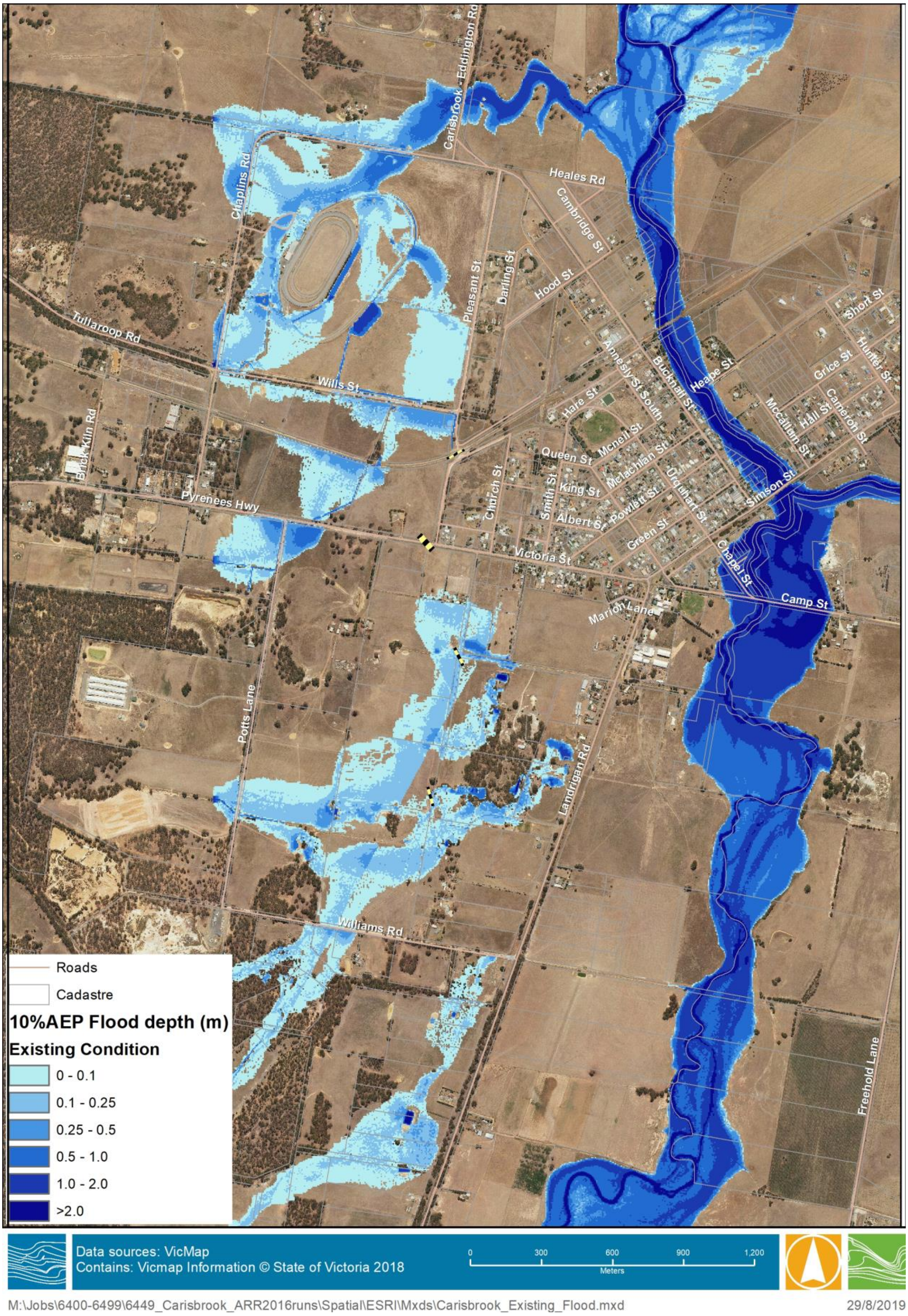
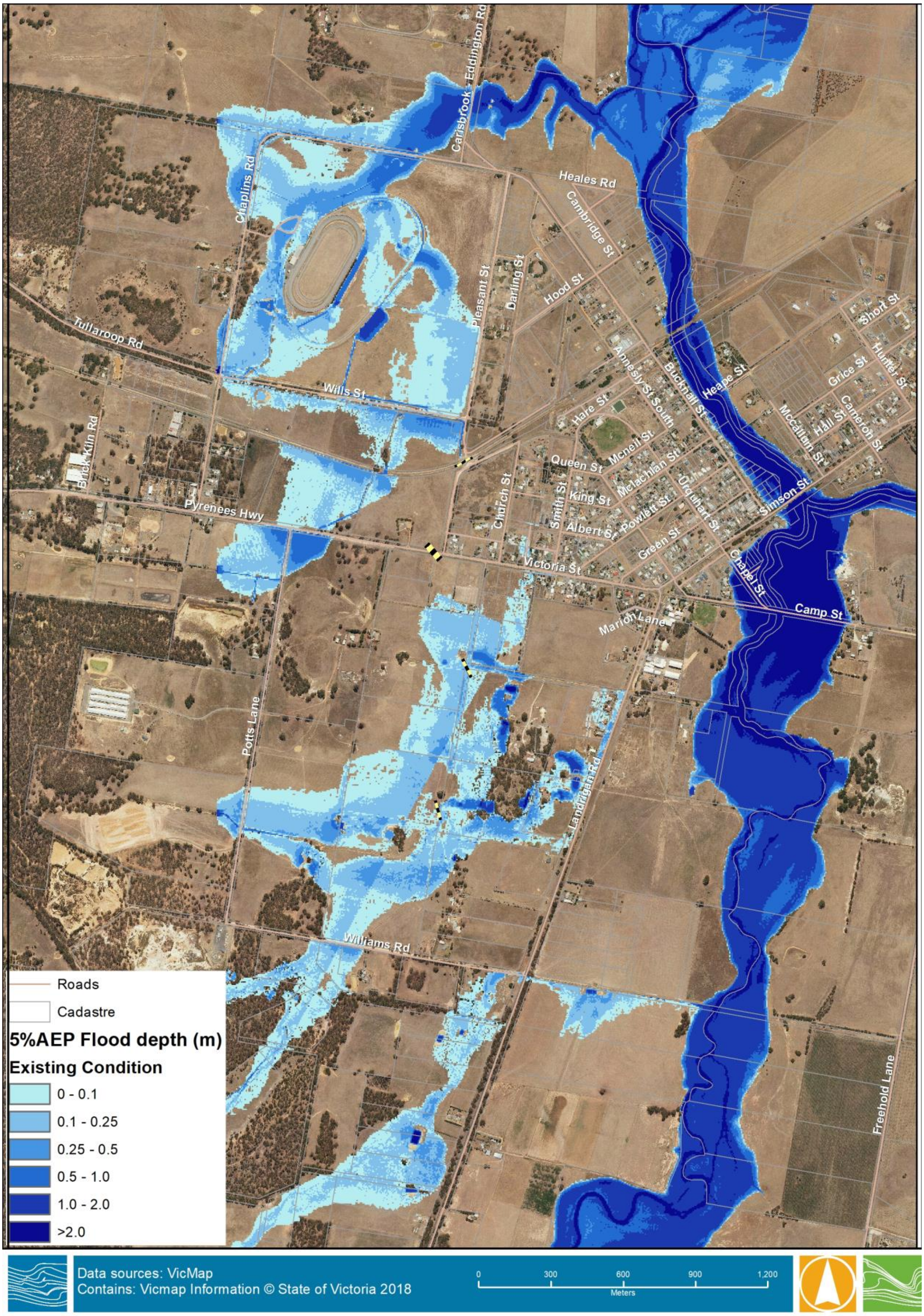

Carisbrook - Eddington Rd
Heales Rd
Cambridge St
Chaplins Rd
Pleasant St
Darling St
Hood St
Short St
Tullaroop Rd
Annesley St South
Bucknall St
Heape St
Grice St
Hunter St
Wills St
Hare St
Mccallum St
Hall St
Cameron St
Brick Kiln Rd
Queen St
Mcnell St
Mclachlan St
Church St
Smith St
King St
Urquhart St
Simson St
Pyrenees Hwy
Albert St
Powlett St
Green St
Victoria St
Chapel St
Camp St
Marion Lane
Potts Lane
Landrigan Rd
Williams Rd
Freehold Lane
Roads
Cadastre
10%AEP Flood depth (m)
Existing Condition
0 - 0.1
0.1 - 0.25
0.25 - 0.5
0.5 - 1.0
1.0 - 2.0
>2.0
Data sources: VicMap
Contains: Vicmap Information © State of Victoria 2018
0
300
600
900
1,200
Meters
M:\Jobs\6400-6499\6449_Carisbrook_ARR2016runs\Spatial\ESRI\Mxds\Carisbrook_Existing_Flood.mxd
29/8/2019



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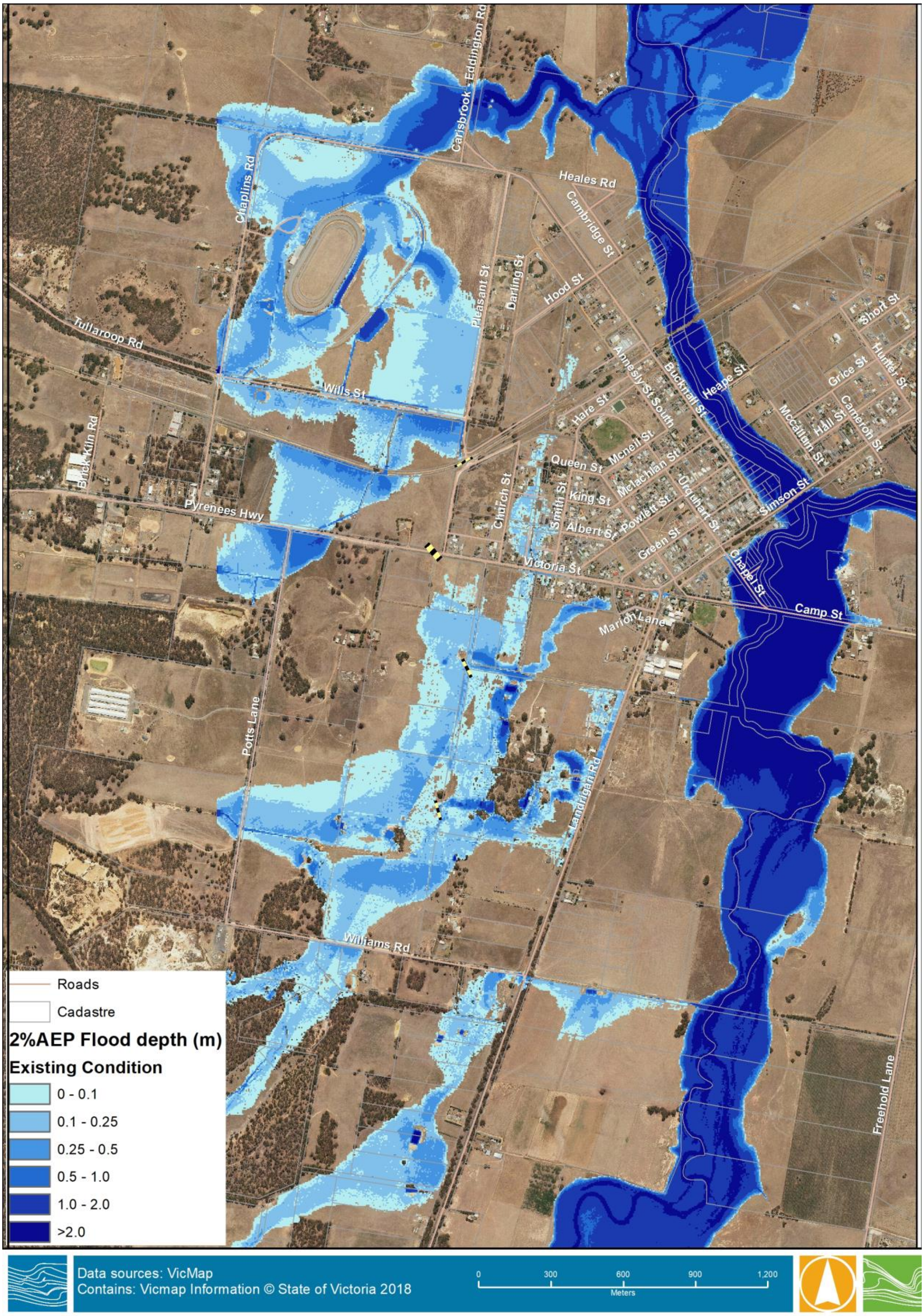

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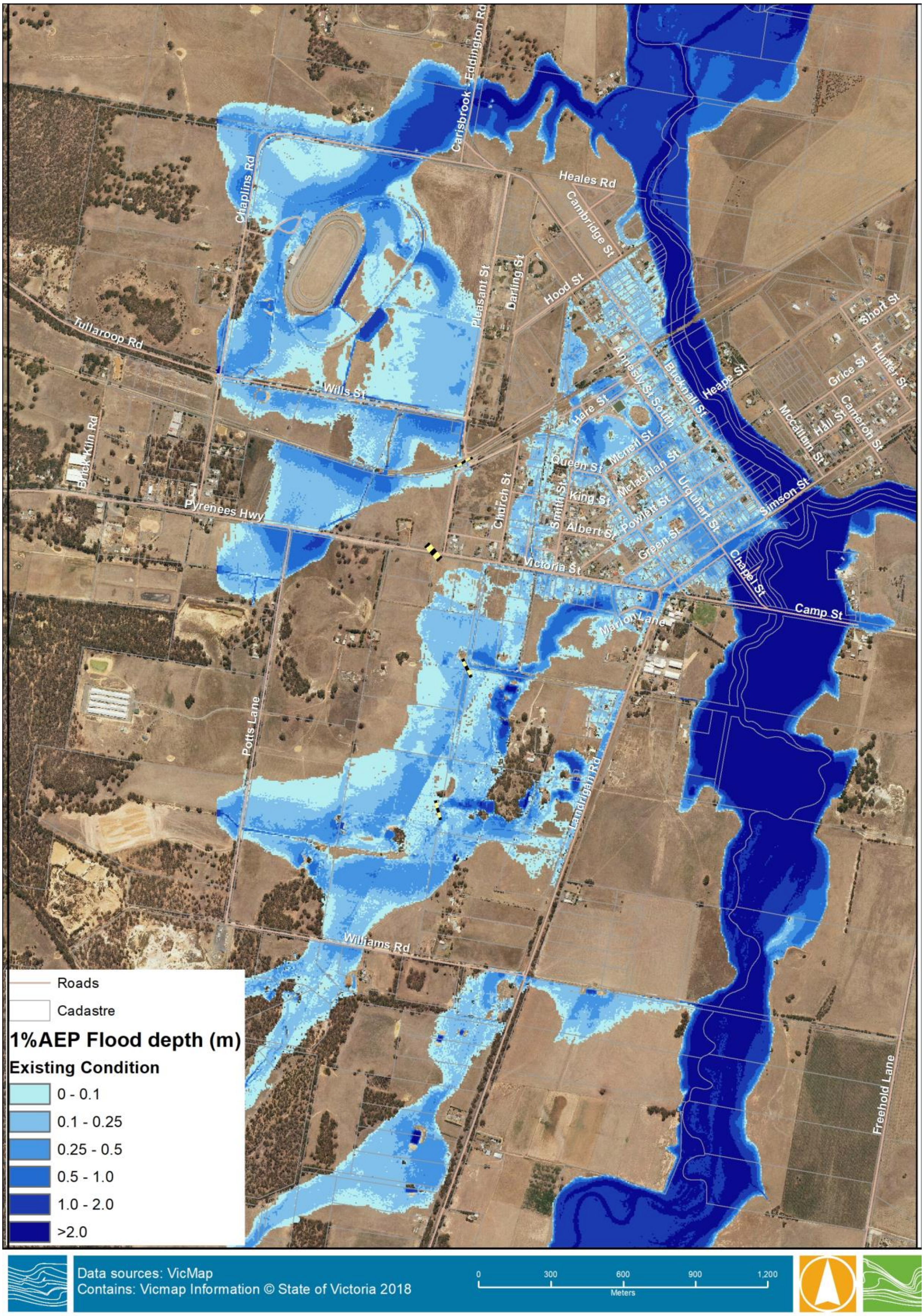

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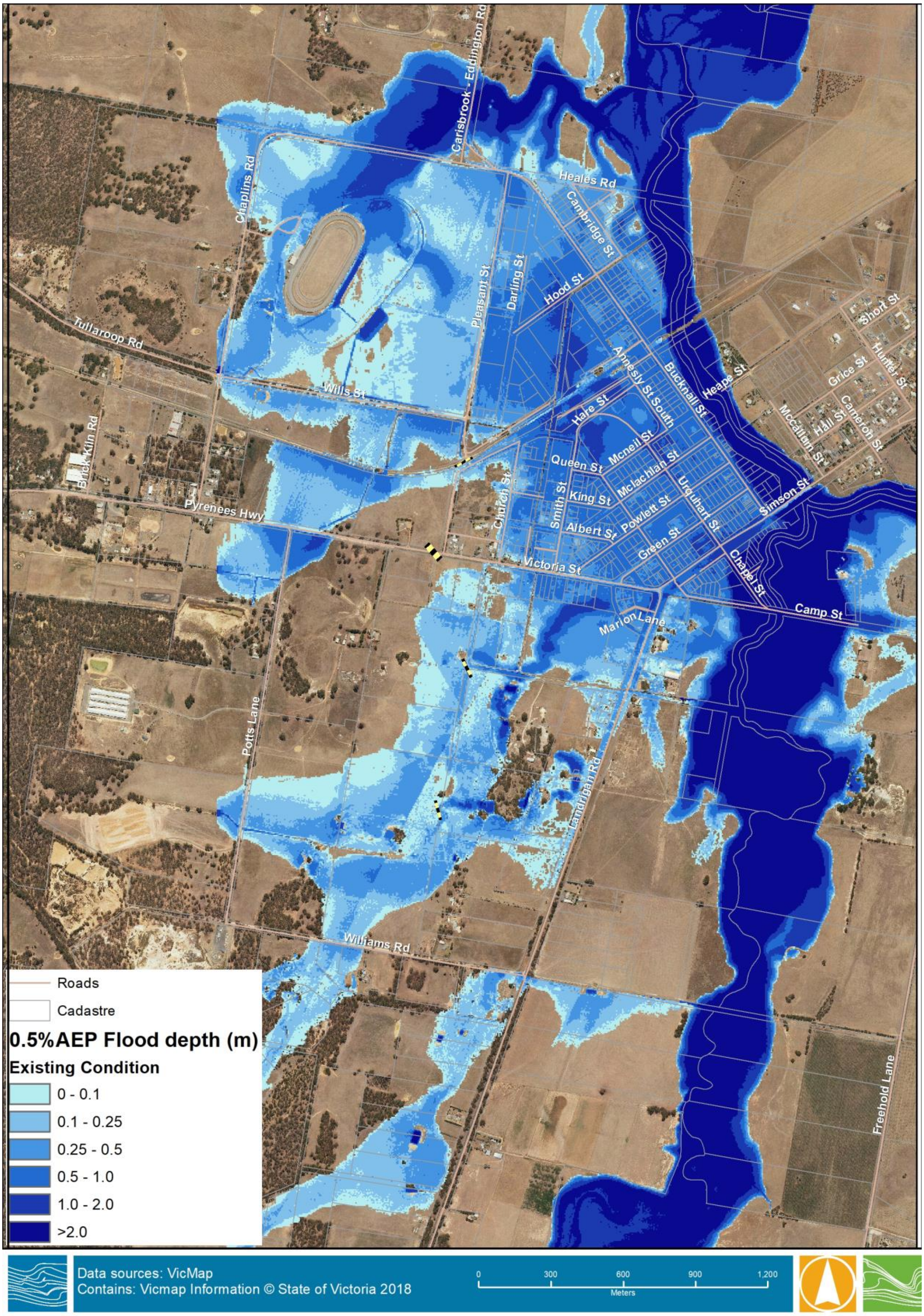

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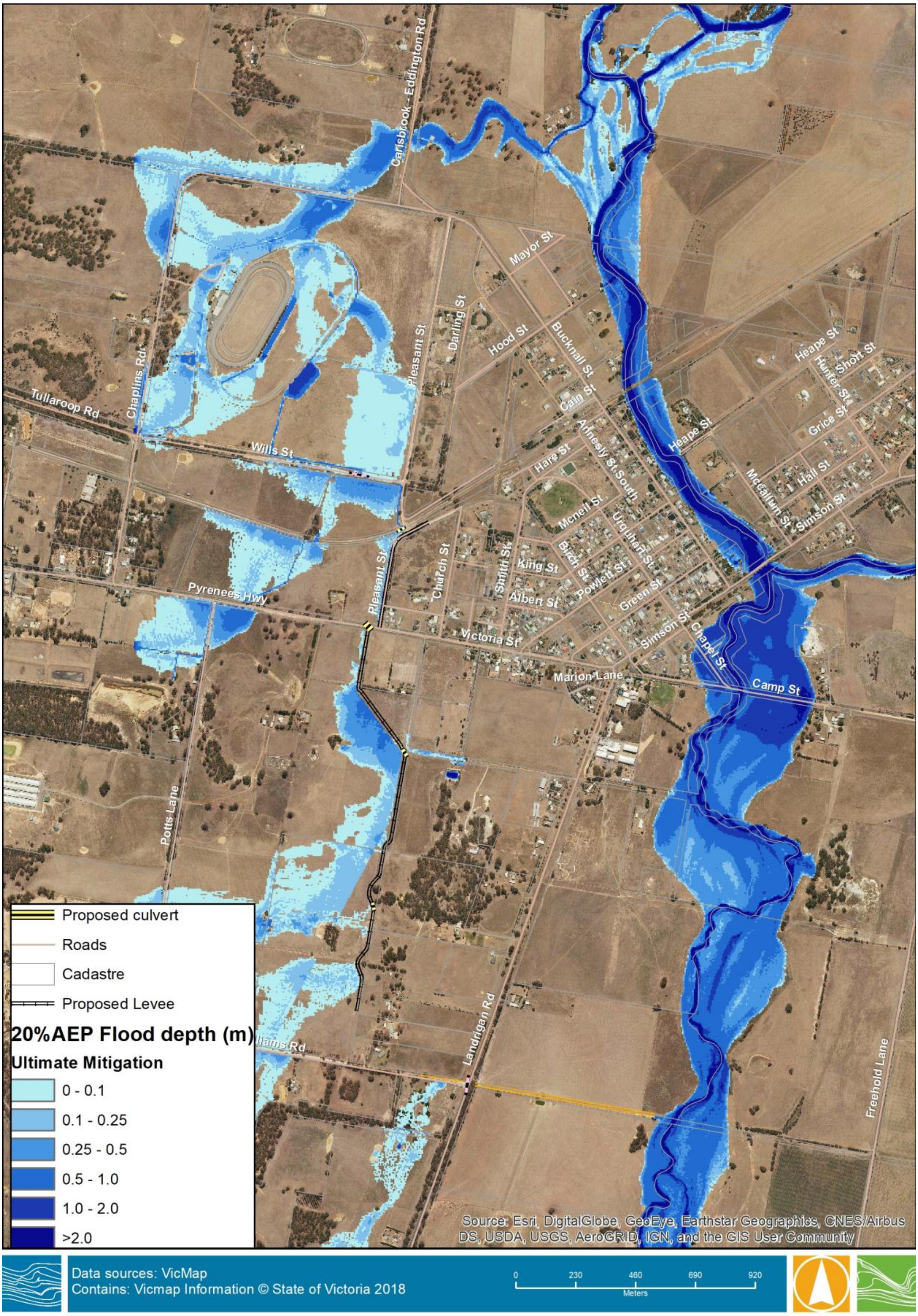
APPENDIX B
20%,10%,5%,2%,1% & 0.5% - FLOOD DEPTH, ULTIMATE MITIGATION



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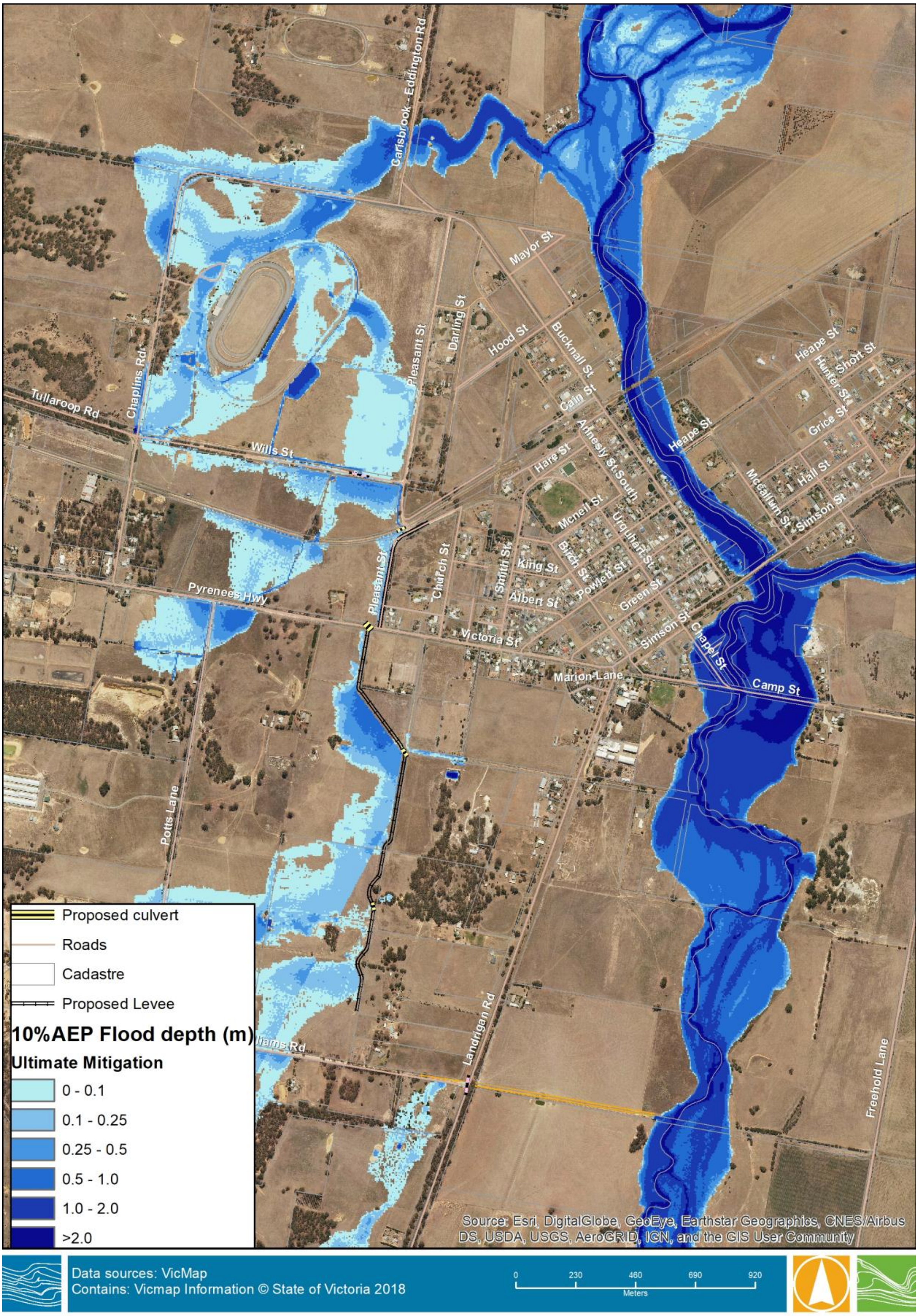

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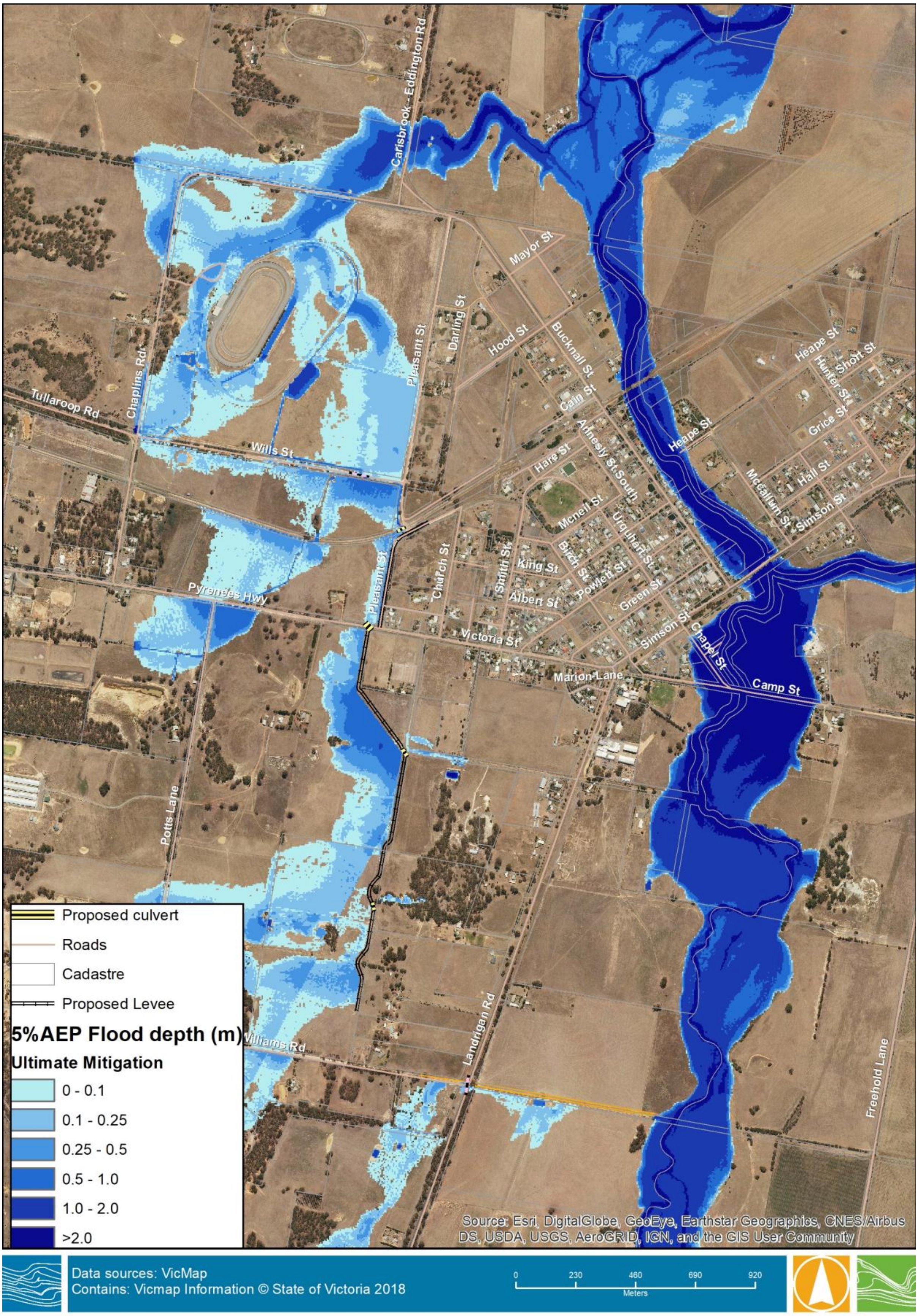
6449-01_R01v05_Hydrology_and_Hydraulics_ARR2016.docx



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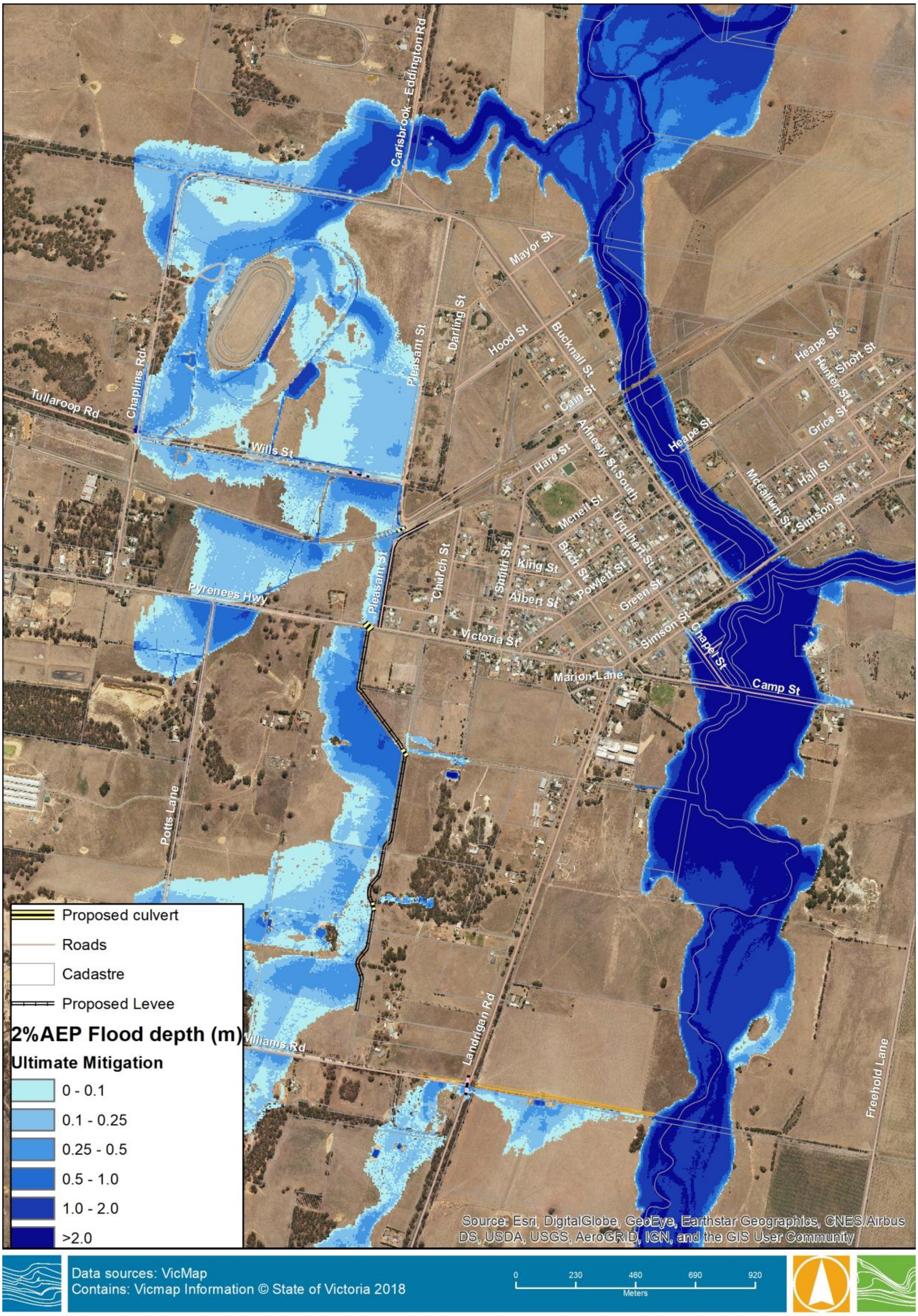

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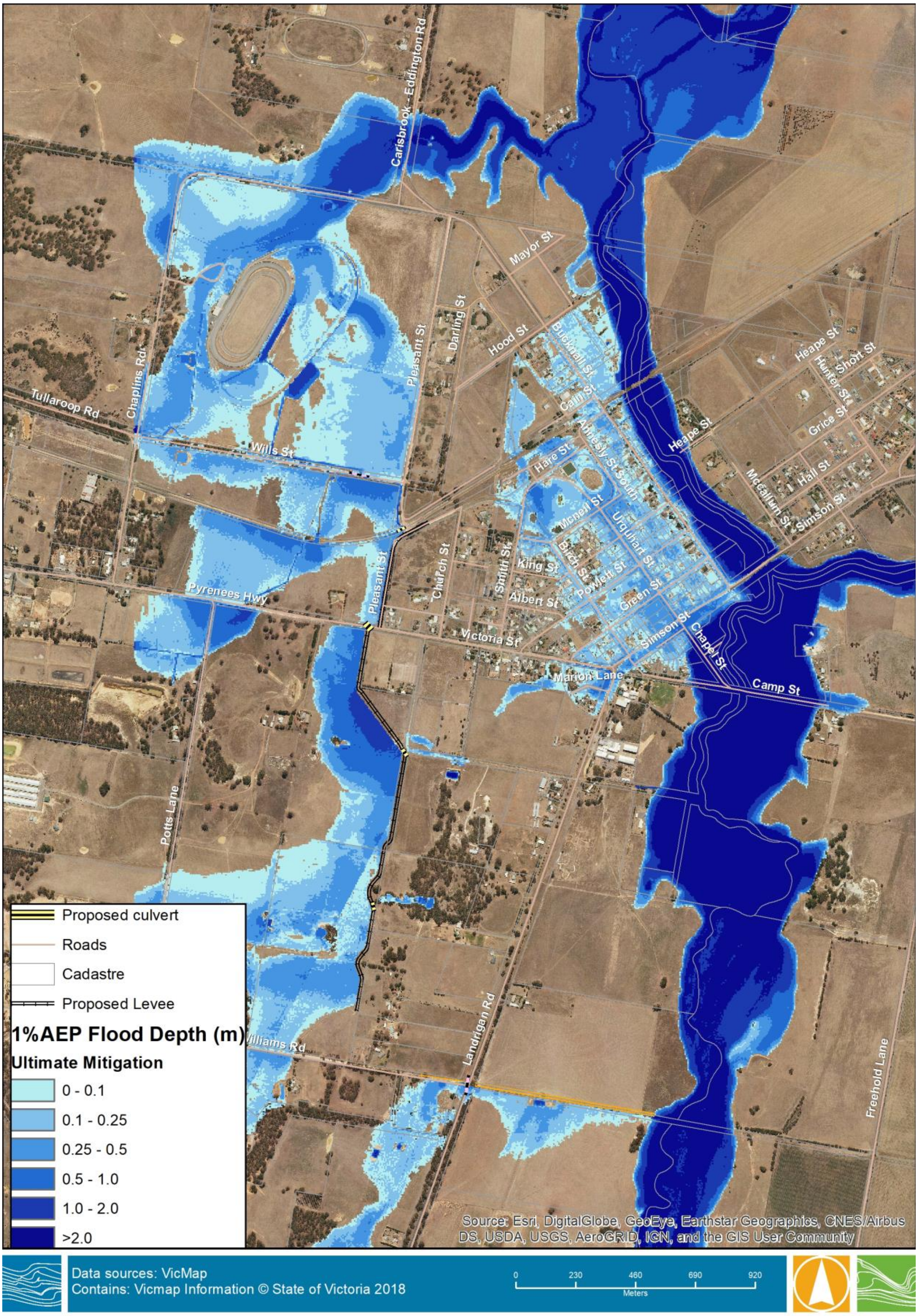

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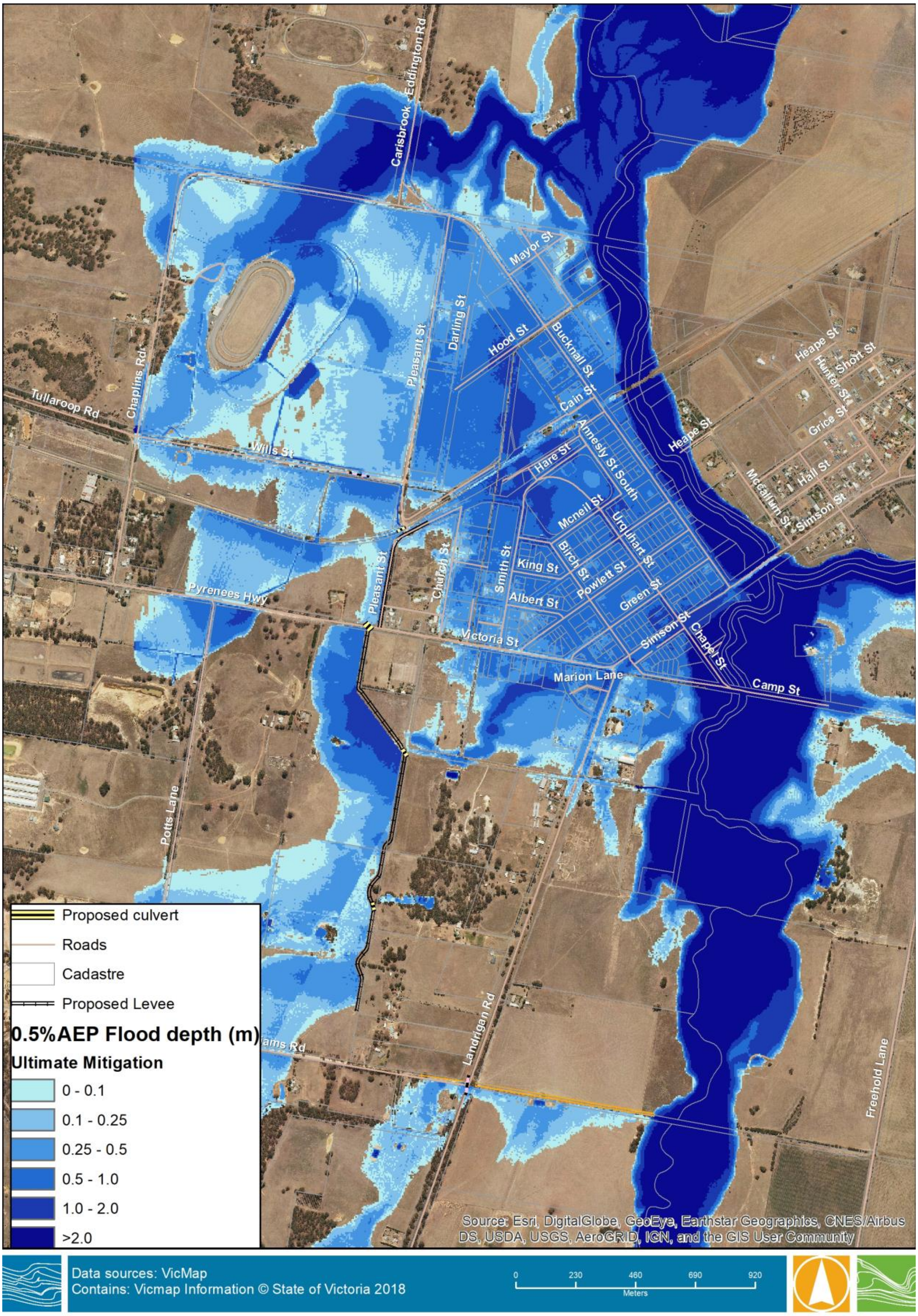

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WATER TECHNOLOGY
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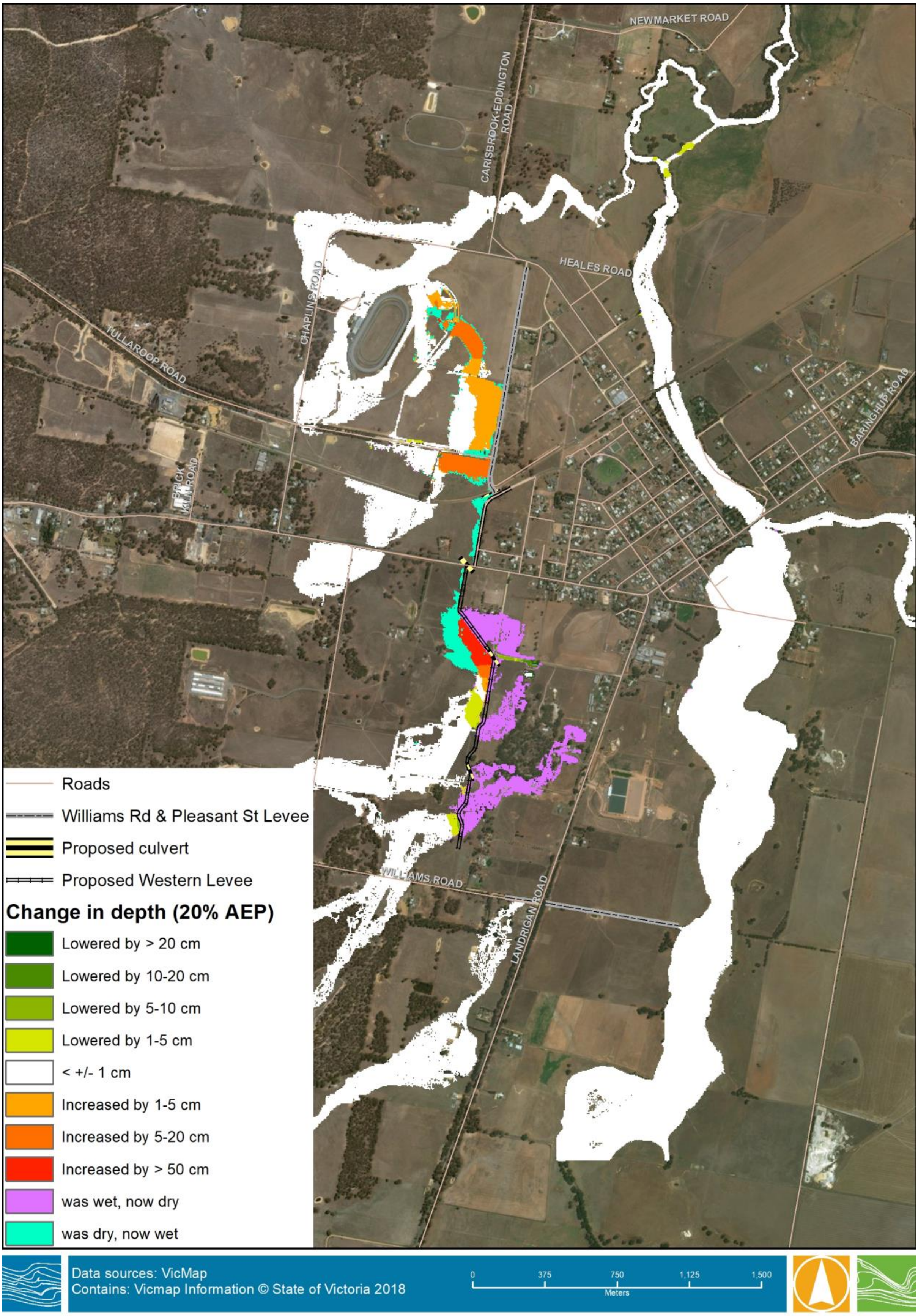
APPENDIX C
20%,10%,5%,2%,1% & 0.5% - FLOOD DEPTH, DIFFERENCE PLOTS



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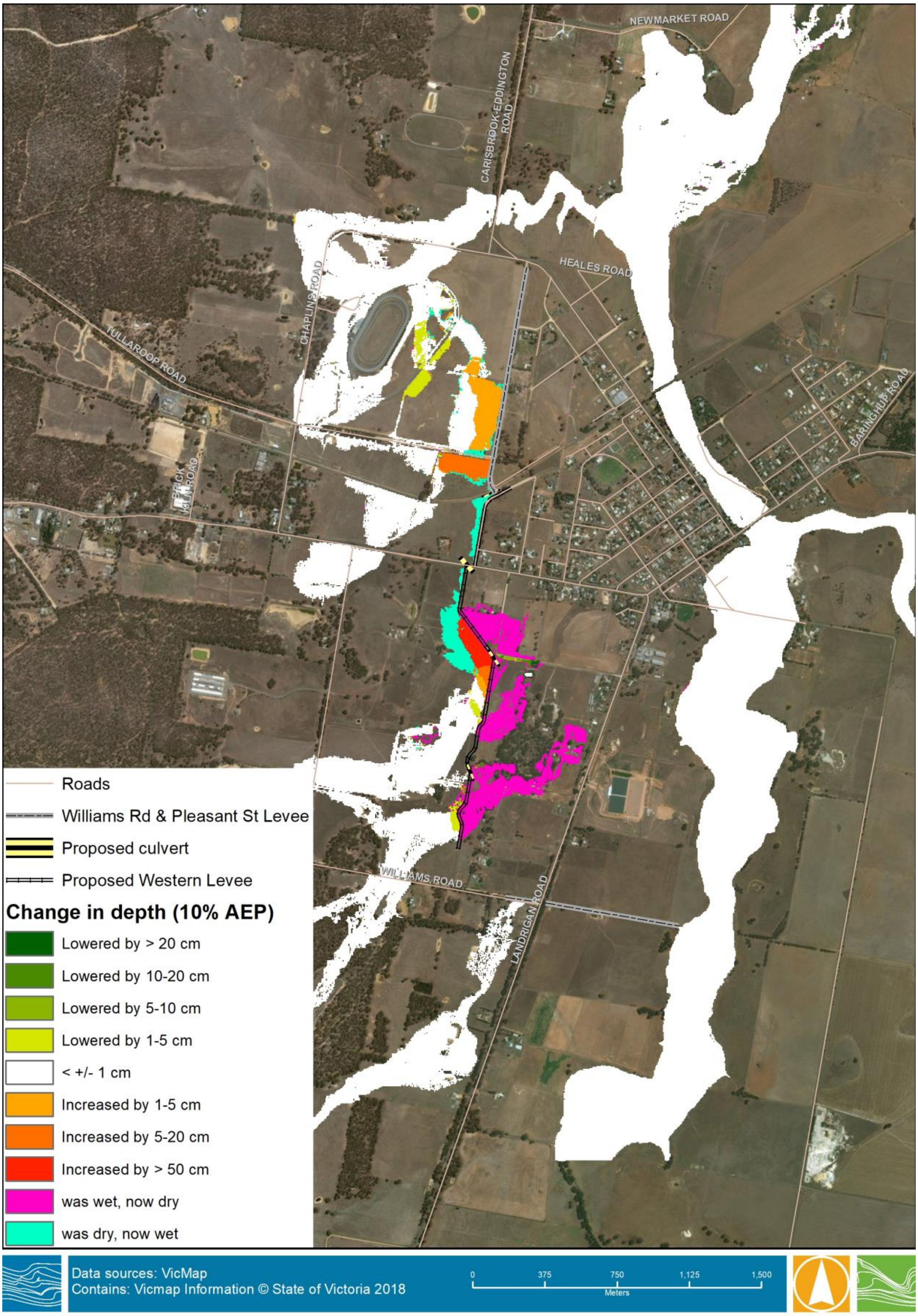

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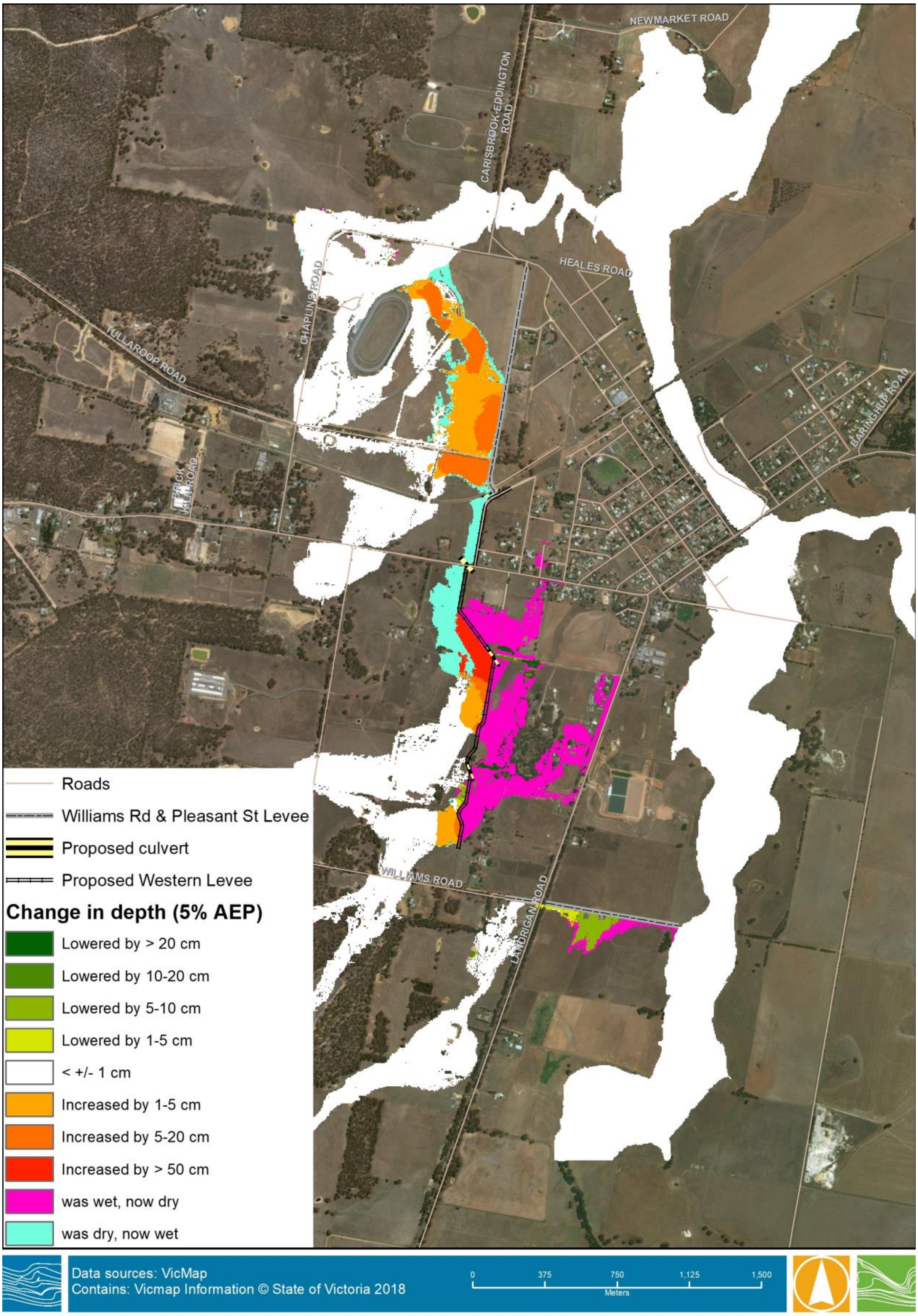

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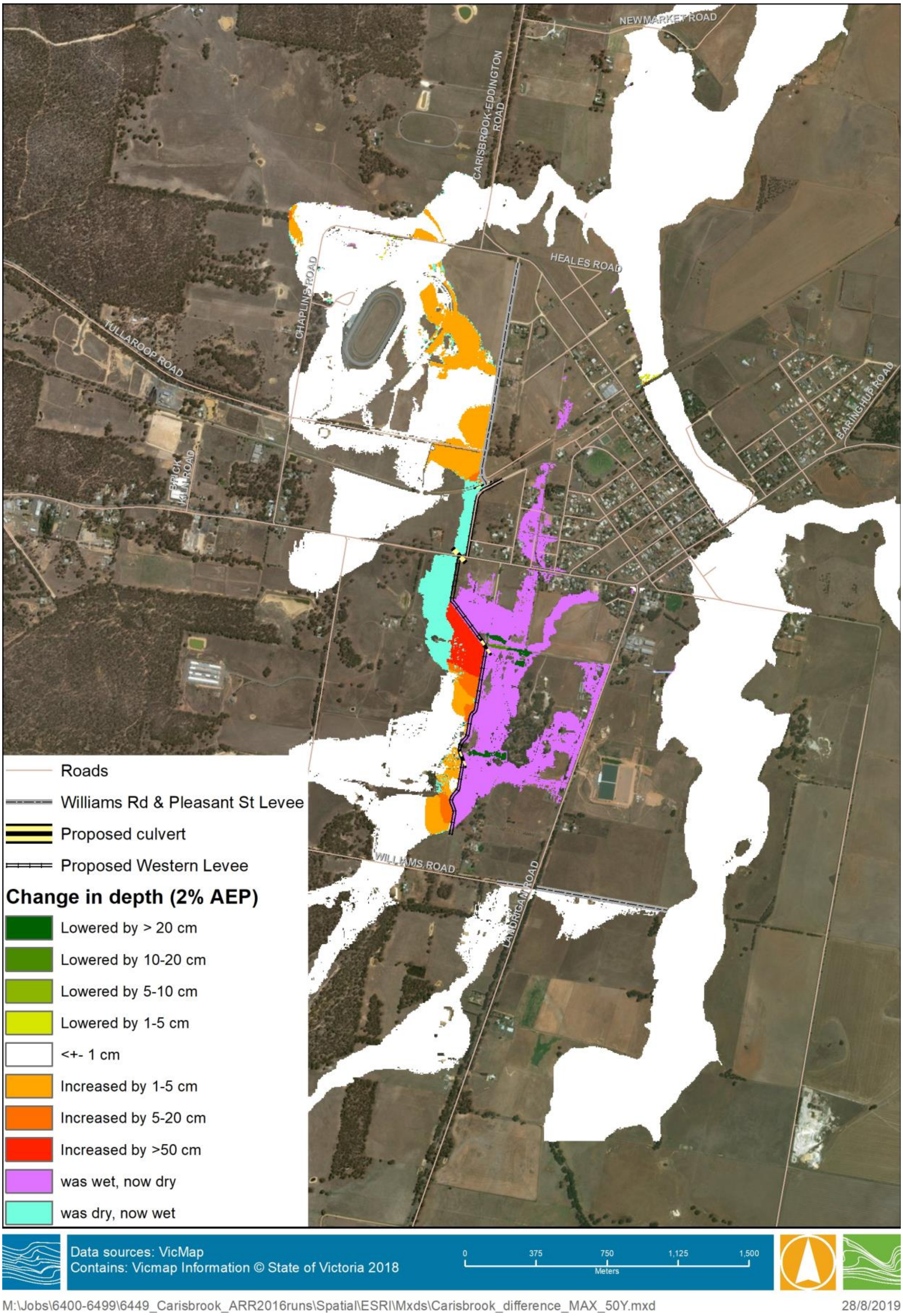
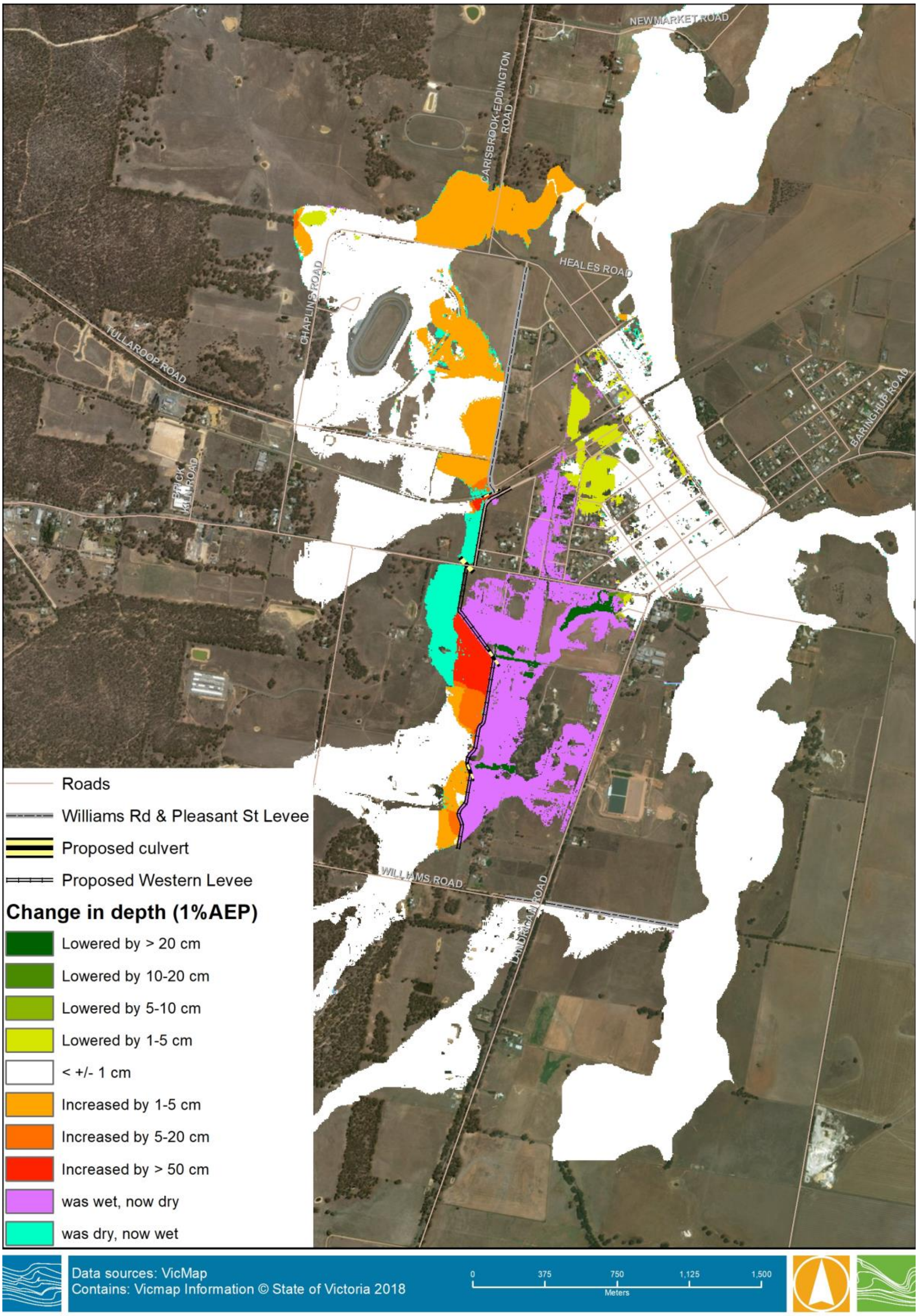

NEWMARKET ROAD
CARISBROOK-EDDINGTON ROAD
HEALES ROAD
CHAPLINS ROAD
TULLAROOP ROAD
BRICK KILN ROAD
BARINGHUP ROAD
WILLIAMS ROAD
LANDRIGAN ROAD
Roads
Williams Rd & Pleasant St Levee
Proposed culvert
Proposed Western Levee
Change in depth (2% AEP)
Lowered by > 20 cm
Lowered by 10-20 cm
Lowered by 5-10 cm
Lowered by 1-5 cm
<+- 1 cm
Increased by 1-5 cm
Increased by 5-20 cm
Increased by >50 cm
was wet, now dry
was dry, now wet
Data sources: VicMap
Contains: Vicmap Information © State of Victoria 2018
0
375
750
1,125
1,500
Meters
M:\Jobs\6400-6499\6449_Carisbrook_ARR2016runs\Spatial\ESRI\Mxds\Carisbrook_difference_MAX_50Y.mxd
28/8/2019



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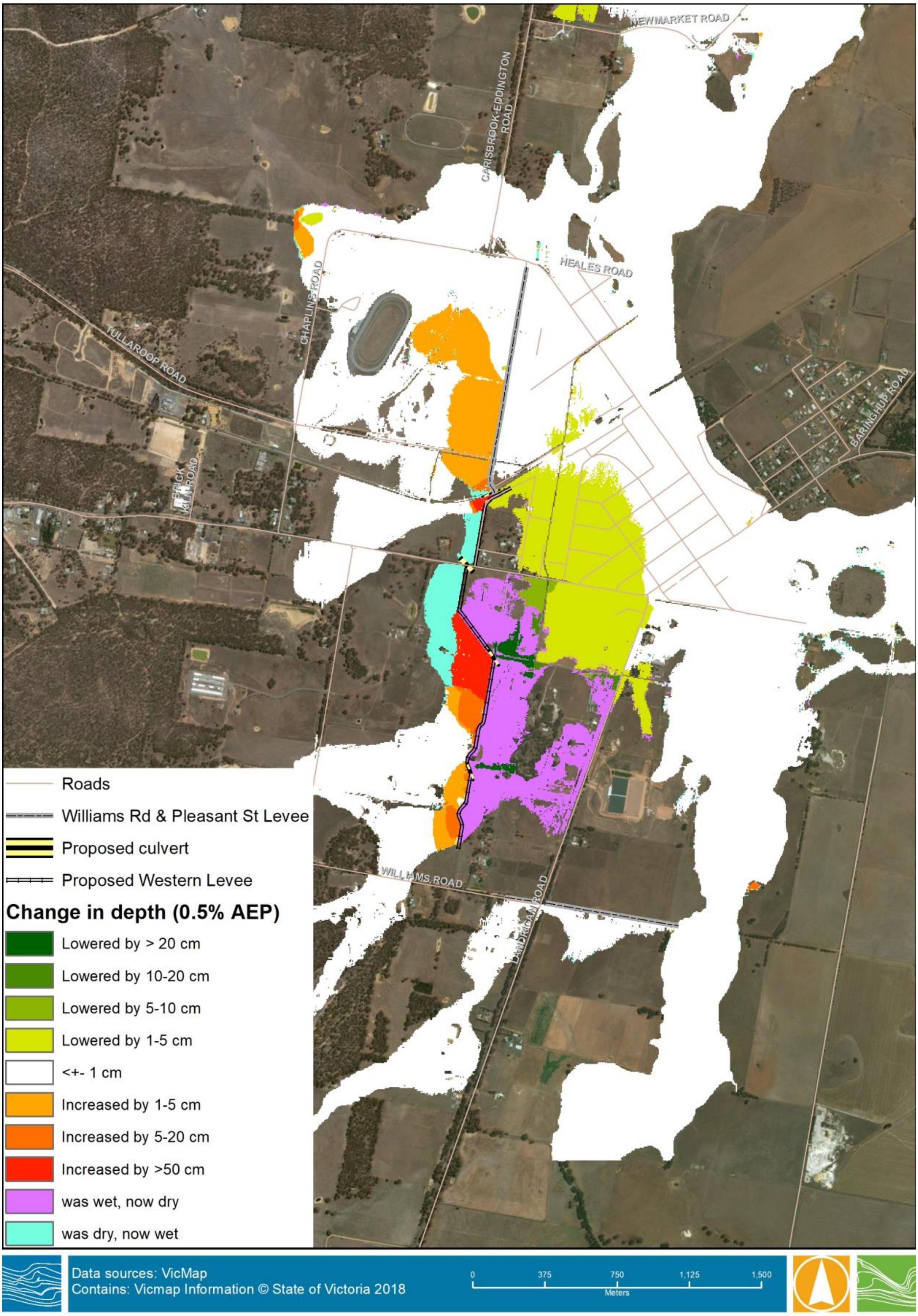

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6449-01_R01v05_Hydrology_and_Hydraulics_ARR2016.docx

WATER TECHNOLOGY
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