

Little Bendigo Creek & Hit or Miss Gully Flood Mapping Project

Hydrology and Hydraulics Report

City of Ballarat

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EXECUTIVE SUMMARY

Water Technology was engaged by the City of Ballarat (CoB) to review and update the existing hydrologic and hydraulic models for the Little Bendigo Creek and Hit or Miss Gully flood assessment. This report has been updated based on the changes made to the hydrologic and hydraulic models in response to recent development and newly available data within the catchment. A summary of the changes made to the hydrological and hydraulic models are listed below.

- **Hydrological Model (RORB) Changes**
 - Changed reach types to reflect development growth in sub-catchments south of the Western Freeway
 - Decreased fraction impervious of subareas where they were represented as residential but were undeveloped.
 - Revised subarea and reach arrangement to reflect the detention characteristics the Western Freeway imposes on the Little Bendigo Creek.
 - Added two storages nodes for the area immediately upstream of the Western Freeway and the median.
- **Hydraulic Model (TUFLOW) Changes**
 - Updated base terrain to LiDAR captured in October 2019 with 1 metre grid resolution
 - The TUFLOW model was updated to the latest build (2023-03-AB) and run as HPC. This ensured that the updated model was utilising the most recent modelling approaches within the TUFLOW software package and the use of HPC reduced model run times.
 - Revised inflow locations to match the changes made to the RORB subareas and reaches.



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1 INTRODUCTION

1.1 Background

Water Technology was commissioned by City of Ballarat (CoB) to update their flood mapping along Little Bendigo Creek. Current flood mapping has become outdated due to residential development, and council would like the flood mapping to reflect the updated modelling standards outlined in Australian Rainfall and Runoff (ARR) 2019¹.

The Little Bendigo Creek is located north of the Ballarat CBD and flows from its forested headwaters through rural residential and general residential zoned land before passing under the Western Freeway and through to the Yarrowee River. Downstream of the Western Freeway the creek passes through several wetlands and drainage basins. The Little Bendigo Creek headwaters drain the Nerrina Historic Area. The creek got its name from the Little Bendigo goldfield, where gravels were sluiced over large areas and along drainage lines. The upper catchment is highly disturbed from this historic goldmining activity, however, is now largely forested with some cleared agricultural areas.

A map of the Little Bendigo Creek catchment is shown in Figure 3-1.

This report outlines the hydrologic and hydraulic modelling component of the Little Bendigo Creek Flood Modelling, including modelling methodology, results and inputs to the hydraulic model.

1.2 Structure of the report

This report outlines the following:

- Hydrologic modelling of the Little Bendigo Creek & Hit or Miss Gully catchment including modelling methodology, inputs to the hydraulic model and results.
- Hydraulic modelling of Little Bendigo Creek & Hit or Miss Gully including modelling methodology, inputs to the hydraulic model and results.
- Flood mapping and discussion for the 1% AEP event, noting the remaining design events (20%, 10%, 5%, 2%, and the 0.5% AEP) flood events along with Climate Change are still to be modelled.

¹ Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors) Australian Rainfall and Runoff: A Guide to Flood Estimation, © Commonwealth of Australia (Geoscience Australia), 2016.



2 AVAILABLE INFORMATION

2.1 Overview

This section documents the data collated by Water Technology for the study. Data was sourced data from number of agencies and sources, including:

- City of Ballarat.
- Regional Roads Victoria (formerly VicRoads).
- Department of Energy, Environment and Climate Action (formerly DELWP).

2.2 Topographic Data

The topography data largely comprised of Light Distance and Ranging (LiDAR) data, which was used to generate a Digital Elevation Model (DEM). The DEM enabled delineation of the catchment for the hydrological model, completed in 2018, utilising LiDAR data captured in 2011. The hydraulic model utilised LiDAR data captured in 2019 (Ballarat2019Oct25_dem1m_v10cm).

2.3 Planning Scheme

The City of Ballarat Planning Scheme layers were used in conjunction with the available aerial photography to define the range of land uses within the catchment. The layers were used in the hydrologic and hydraulic models to define the Fraction Impervious (FI) and hydraulic roughness (Manning's 'n') respectively.

2.4 Drainage Information

City of Ballarat provided a GIS database containing information of Council drainage assets in the municipality, this included pit and pipe information. The provided layers were reasonably complete with pipe dimensions and pit depths. However, pit/pipe inverts were generally missing from the data sets. Where pit depths were available, inverts were assumed by subtracting these depths from the ground surface (based on LiDAR). Where the dataset was missing pit depths, invert levels were assumed by subtracting pipe diameter and standard pipe cover depth. The standard cover depth based on the pipe size outlined in Table 2-1.

Table 2-1 Standard cover levels for stormwater pipes

Pipe Size	Standard Cover Depth
≤ 900 mm	600 mm
≥ 900 mm	750 mm



3 HYDROLOGY

3.1 Overview

RORB was adopted as the hydrology modelling package. RORB was used to calculate inflow hydrographs from the available rainfall and catchment data. RORB is a non-linear rainfall runoff and streamflow routing model for calculation of flow hydrographs in drainage and stream networks. The model requires catchments to be divided into subareas, connected by a series of conceptual reaches and storage areas. Observed or design storm rainfall is input to the centroid of each subarea. Specific initial and continuing losses are then deducted, and the excess runoff is routed through the reach and storage network.

The adopted methodology was based on current guidelines described in the 2019 revision of Australian Rainfall and Runoff (ARR2019). The 20%, 10%, 5%, 2%, 1% and the 0.5% AEP flood events were modelled using Monte-Carlo and Ensemble approaches as recommended in ARR2019. There were no streamflow gauges within the catchment.

3.2 RORB Model Development

A RORB model was constructed to determine design flood flows through the study area. The RORB analysis aimed to represent the rainfall runoff processes occurring across the catchment and define a range of potential flows from Little Bendigo Creek, Surface Gully, Sawpit Gully, Schicer Gully, Kangaroo Gully and Hit or Miss Gully. A schematic of the RORB model is shown in Figure 3-1.

The RORB model included multiple detailed inputs to ensure accurate results, these included:

- Sub-catchments and reach delineation.
- Fraction impervious.
- Rainfall depths for various storms.
- Rainfall losses.
- Rainfall temporal patterns.
- Rainfall spatial patterns.
- Kc – key routing parameter.
- m – degree of catchment non-linearity

Each of these inputs are discussed in the following sections.

3.2.1 Catchment delineation

A catchment delineation was undertaken using the available Light Distance and Ranging (LiDAR) dataset resampled to a 1 m resolution Digital Elevation Model (DEM). The LiDAR was processed in the ESRI terrain modelling software *ArcHydro* and delineated into 56 sub-catchments and associated reaches. The delineated catchments and reaches are shown in Figure 3-1.

The RORB manual stipulates a minimum of three upstream subareas are needed to extract a flow from RORB that is reasonably attenuated. The model was developed to where possible ensure that at least three subareas were located in locations where flow hydrographs were extracted for input into the hydraulic model.

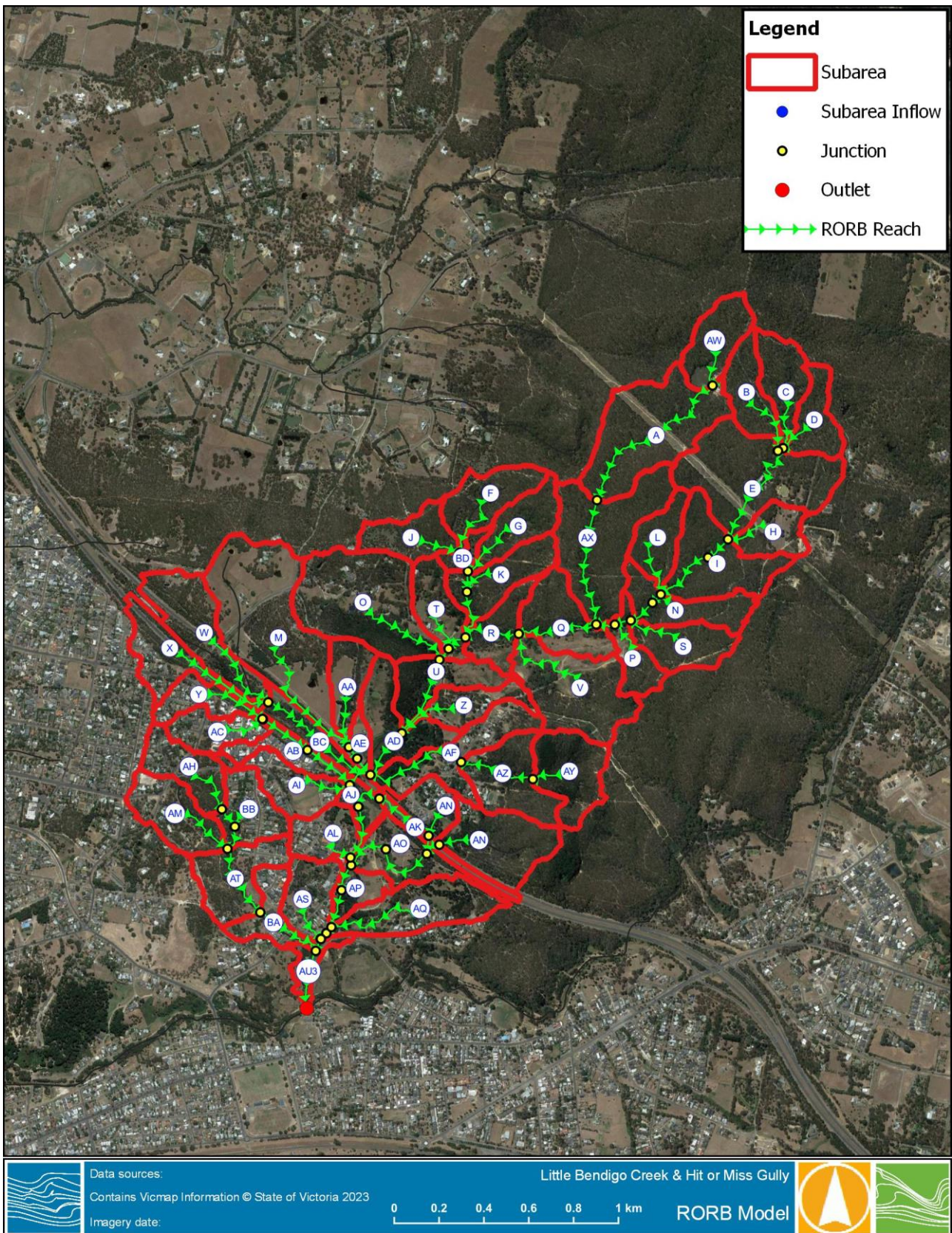


Figure 3-1 RORB Model Overview



3.2.2 Reaches and Nodes

The catchment and drainage line delineation were converted to RORB reaches and nodes using *ArcRORB*. Nodes were placed at sub-area centroids and junctions between any two reaches. These were connected via reaches, each with an ArcGIS calculated length and slope.

The majority of RORB model reaches were classified as “natural” as the upper catchment (north of the Western Freeway) are natural waterways. Reaches in urbanised sub catchments south of the western freeway were classified as “excavated but unlined” due to flows not been wholly contained within the stormwater network during major flood events.

3.2.3 Fraction Impervious (FI)

The estimated proportion of impervious surface within each sub-area was determined using land use planning (zoning) maps and modified based on aerial imagery and land cover mapping. Adopted FI values were based on relevant industry guidelines². Specific values were allocated to each zone and are shown in Table 3-1. An area weighted fraction impervious for each sub-area was calculated, as shown in Figure 3-2.

Table 3-1 Adopted Fraction Impervious Values

Land use	Adopted FI
FZ – Farming Zone	0.001
GRZ1 – General Residential Zone – Schedule 1	0.750
PCRZ – Public Conservation and Resource Zone	0.000
PPRZ – Public Park and Recreation Zone	0.100
PUZ1/2 – Public Use Zone (Service & Utility/Education)	0.500
RDZ1 – Road Zone – Category 1	0.700
RLZ – Rural Living Zone	0.200

² Melbourne Water – Table 1: Effective Impervious values for source nodes: MUSIC Guidelines (2016)

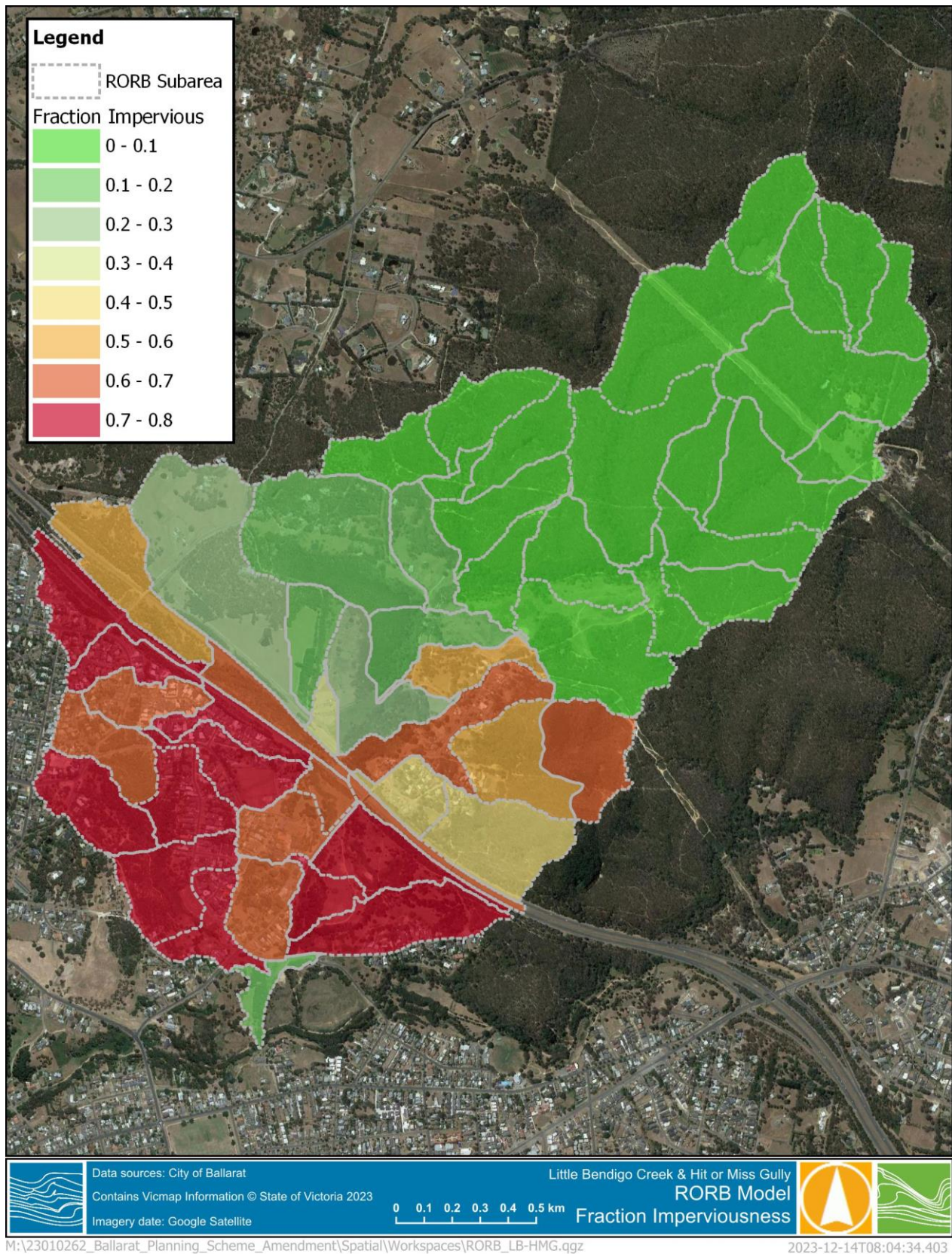


Figure 3-2 Fraction Impervious of Catchment Area



3.2.4 Routing Parameter (k_c)

As mentioned in Section 3.1, there were no streamflow gauges in the study area to calibrate the RORB model to. To verify the RORB model results, several regional equations for ungauged catchments were used to inform the selection of a 'reasonable' k_c parameter.

McMahon and Muller (1983) showed that k_c is directly proportional to the average flow distance (d_{av}). The relationship is expressed as:

$$k_c = C_{0.8} d_{av}$$

where $C_{0.8}$ is a characteristic of the catchment that is independent of catchment size, and c is the weighted average flow distance from the RORB model nodes to the catchment outlet.

Pearse et al (2002) analysed three large databases of k_c parameters collated by different sources and reported the average and range of $C_{0.8}$ values for each dataset:

- CRC for Catchment Hydrology – 72 catchments from all states of Australia and the ACT, as described in Dyer et al (1994)
- Yu (1989) – 119 catchments located in New South Wales, Queensland, Victoria and Western Australia
- Pearse et al. (2002) – 39 Victorian catchments from the Hansen et al (1986) study and other models calibrated by SMEC Victoria

Table 3-2 shows the range of $C_{0.8}$ and predicted k_c values from the three datasets.

Table 3-2 Expected Value and Range of $C_{0.8}$

Source	$C_{0.8}$	k_c
CRC for Catchment Hydrology	1.25 (range: 0.75 – 2.07)	2.79 (range: 1.67 – 4.62)
Yu (1989)	0.96 (range: 0.47 – 1.94)	2.14 (range: 1.05 – 4.33)
Pearse et al. (2002)	1.25 (range: 0.61 – 2.13)	2.79 (range: 1.36 – 4.75)

For the Little Bendigo Creek & Hit or Miss Gully catchment, the Pearse et. Al. (2002) estimation method of k_c was chosen to be adopted. The data the equation is based on is most relevant (Victorian based) and in Water Technology's experience with gauged catchments, the Pearse et. al. equation has shown to match gauge Flood Frequency Analysis data best. The $C_{0.8}$ was taken to have a value of 1.26, consistent with the expected value from Pearse et al (2002). Given that d_{av} equals 2.23 km for the RORB model, k_c value of 2.81 was adopted for the study.

An estimate of k_c was also against nearby catchments from the previous studies. There are several RORB models have been developed near the project area. These models include the Bonshaw Creek, Yarrowee River, Canadian Creek and Kensington Creek catchments. The Yarrowee River is the only gauged catchment of these. The ratio of k_c and d_{av} used in these models was used to confirm the adopted k_c value for this study site. A comparison of the estimated k_c values associated to each of the previous projects is provided in Table 3-3. The adopted k_c value was within the range of those previously adopted.



Table 3-3 Estimates of k_c Based on Nearby Existing RORB Models

Model	k_c	d_{av} (km)	k_c / d_{av} ratio	Estimated Warrenheip k_c
Yarrowee River	19	10.43	2.88	6.41
Canadian Creeks	8.46	3.56	2.38	5.30
Kensington Creek	5.6	4.52	1.24	2.76
Bonshaw Creek	5.37	4.58	1.17	2.61
Warrenheip Creek	3.39	2.71	1.25	2.79

To further verify the adopted k_c , the RORB Monte Carlo analysis was verified against the ARR Regional Flood Frequency Estimation Model (RFFE), this process is discussed in more detail in Section 3.2.7.

The RORB model m was set at 0.8. This is the recommended value for ungauged catchments³.

3.2.5 Design Rainfall

3.2.5.1 Rainfall Depth

Burst Depth

Design rainfalls were derived for burst durations between 0.5 and 6 hours, based on the expectation that the critical storm duration for the study area catchment would be relatively short, given the small catchment area. The rainfall burst depths for AEPs between 20% AEP and 0.5% AEP were extracted for the centroid of the catchment using the 2016 ARR IFD analysis available from the Bureau of Meteorology⁴.

Areal Reduction Factors

The point rainfall estimates were converted to catchment average values using the areal reduction factors developed for Victoria during the revision of ARR 2016⁵. Conceptually, this factor accounts for larger catchments which are less likely to experience high intensity rainfall over the whole of the catchment. Given the size of the Little Bendigo Creek and Hit or Miss Gully catchment, areal reduction was not applied.

The design rainfall totals for the catchment are shown in Table 3-4.

Table 3-4 Design Rainfall Depths in mm for Varying Event Durations and AEP's

Duration\AEP	20%	10%	5%	2%	1%	0.5%
30-min	18.4	22.8	27.6	34.4	40.1	45.714
1-hr	22.8	28.1	33.7	41.7	48.3	55.062
2-hr	27.9	34	40.3	49.3	56.6	64.524
3-hr	31.5	38.1	44.9	54.5	62.4	71.136
6-hr	39.8	47.4	55.2	66.4	75.6	86.184
12-hr	51.1	60.5	70.1	83.9	95	108.3

³ E.M. Laurenson, R.G. Mein, and R.J. Nathan (2010), RORB User Manual

⁴ <http://www.bom.gov.au/water/designRainfalls/ifd/>

⁵ 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



Duration\AEP	20%	10%	5%	2%	1%	0.5%
24-hr	18.4	22.8	27.6	34.4	40.1	45.714

3.2.5.2 Temporal Patterns

The 10 temporal patterns as downloaded from ARR 2019 Data Hub⁶ were used to simulate the distribution of burst rainfall depth during each storm duration modelled.

3.2.5.3 Spatial Patterns

The ARR2019 guidelines recommend non-uniform spatial patterns for catchment areas of more than 20 km². The catchment study area is 4.86km², therefore a uniform spatial pattern was applied in design modelling.

3.2.5.4 Design Losses

An initial/continuing loss model was applied for the RORB modelling. The initial losses were determined based the ARR online datahub⁶ suggested losses of 25 mm initial loss and 4.4 mm/hr continuing loss.

The Little Bendigo Creek & Hit or Miss Gully are tributaries of the Yarrowee River and converge with it upstream of the Ballarat CBD. Calibration of the Yarrowee River and Gnarr Creek hydrological model was completed 2019 and determined that the recommended losses from ARR were too high and a continual loss of 2.0 mm/hr was more appropriate for the broader Ballarat area. Considering the Little Bendigo Creek & Hit or Miss Gully are part of the Yarrowee River catchment, the calibrated continuing loss of 2.0 mm/hr was adopted for this catchment.

The adopted initial and continuing loss for the Little Bendigo Creek & Hit or Miss Gully catchment are shown in Table 3-5.

Table 3-5 Adopted Losses

Loss Type	Loss
Initial Loss	25.0 mm
Continuing Loss	2.0 mm/hr

3.2.6 Storages

The Western Freeway has been constructed in a manner that sees the roadway and embankment act as a de-facto storage along the waterway. Stage-storage information for the area upstream of the Western Freeway and in the median strip was determined by analysis of the LiDAR data. The data was used to calculate the volume relationships in both storages to incorporate into the RORB model. Storage increments were extracted for event 0.1 metre intervals of elevation. Summaries of the two storages, the Western Freeway and Western Freeway Median, are shown below in Table 3-6.

Table 3-6 Storages Summary Table

Storage	Design Element	Spillways
Western Freeway	Spillway – Western Freeway Eastbound	Crest Height = 461.09 m AHD Crest Width = 25 m Weir Coefficient (Kw) = 1.7

⁶ <http://data.arr-software.org/>



Storage	Design Element	Spillways
Western Freeway Median	Outlet Pipe Arrangement	1 x 750 mm RCP with inlet at 457.09 m AHD
	Estimated Volume at Spillway	84,189 m ³
	Spillway – Western Freeway Westbound	Crest Height = 459.12 m AHD Crest Width = 25 m Weir Coefficient (K _w) = 1.7
	Outlet Pipe Arrangement	1 x 1800 mm RCP with inlet at 454.12 m AHD
	Estimated Volume at Spillway	6,936 m ³

3.2.7 Model Verification

3.2.7.1 Approach

The adopted k_c and rainfall losses were assessed by comparing modelled peak flows with flood quantiles produced by the ARR Regional Flood Frequency Estimation (RFFE) method (Rahman et al, 2012)⁷. The sensitivity of the k_c parameter was also undertaken based on existing regional equations. Design losses were adopted based on the calibration of the Yarrowee River catchment and used in other studies in across Ballarat.

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/>).

3.2.7.2 Results

The RORB model of the Little Bendigo Creek & Hit or Miss Gully catchment (assuming natural catchment conditions and no urbanization in place) was run in a Monte Carlo framework and the 20% to 1% 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. The discharge for different AEP's from RFFE method is presented in Table 3-7.

Table 3-7 ARR Regional Flood Frequency Estimation Model Results

AEP (%)	Discharge (m ³ /s)	RORB Estimate (m ³ /s)	Lower Confidence Limit (5%) (m ³ /s)	Upper Confidence Limit (95%) (m ³ /s)
20	2.54	3.68	0.88	7.35
10	3.56	5.31	1.23	10.4
5	4.73	6.87	1.60	14.1
2	6.55	9.21	2.12	20.5
1	8.16	11.37	2.55	26.4

With a k_c of 2.81, a median initial loss of 25 mm and a continuing loss of 2.0 mm/hr, the RORB model results matched well with flood quantiles from the RFFE method. A comparison of the RORB model computed peak flows at the outlet with different k_c calculation methods presented in Table 3-8. This shows the k_c is not overly sensitive and the adopted parameters compute reasonable peak flows when compared with RFFE.

⁷ <https://rffe.arr-software.org/>



Table 3-8 Equation Based k_c Estimates

Description	Equation	k_c estimate
Victoria (Mean Annual Rainfall <800mm)*	$k_c = 0.49 * A^{0.65}$	1.37
Victorian based data (Pearse et al, 2002)	$k_c = 1.25 * D_{av}$	2.79
Australian based data (Dyer, 1994)	$k_c = 1.14 * D_{av}$	2.54
Australian based data (Yu, 1989)	$k_c = 0.96 * D_{av}$	2.14

* Ballarat has a mean annual rainfall of 689.9mm.

The adopted Pearse et. Al. (2002) k_c calculated 1% AEP peak discharge within the RFFE estimated confidence limits verifying its adoption for this study. The k_c and loss values adopted in the RORB model for design modelling for the study are presented in Table 3-9 below.

Table 3-9 Adopted RORB Model parameters for Design Flood Modelling

Parameter	Adopted value
m	0.8
k_c	3.39
Median initial loss (mm)	25
Continuing loss (mm/h)	2.0

3.3 Design Modelling

As recommended in ARR2019, Monte Carlo analysis was used to determine design peak flows at key locations within the Little Bendigo Creek catchment. RORB was then run using the Ensemble Modelling approach, and the most appropriate temporal patterns chosen for each event AEP to match the Monte Carlo produced peak flows. A flow chart showing the modelling process is shown in Figure 3-3.

This process resulted in a single temporal pattern chosen for each design run (based on the most common temporal pattern producing the peak flow closest to the Monte Carlo peak flow), leaving six durations and six AEPs to be modelled for a total of 36 model simulations.

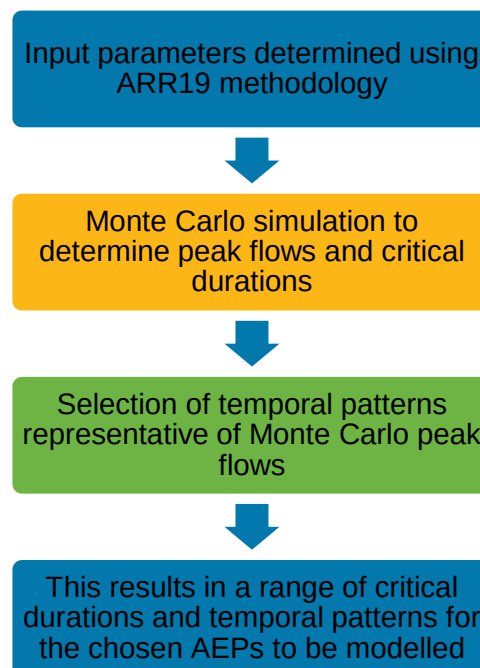


Figure 3-3 Design Modelling Process Diagram

3.3.1 Monte Carlo Analysis

The RORB Monte Carlo analysis was undertaken adopting the determined losses and k_c value discussed in Section 3.2.4. During a Monte Carlo analysis, the RORB model runs many times, sampling for an extensive range of temporal patterns and rainfall initial loss. 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. A schematic diagram of Monte Carlo approach is presented in Figure 3-4. The critical duration for several important locations throughout the model is shown in Table 3-10. These print locations are shown in Figure 3-5.

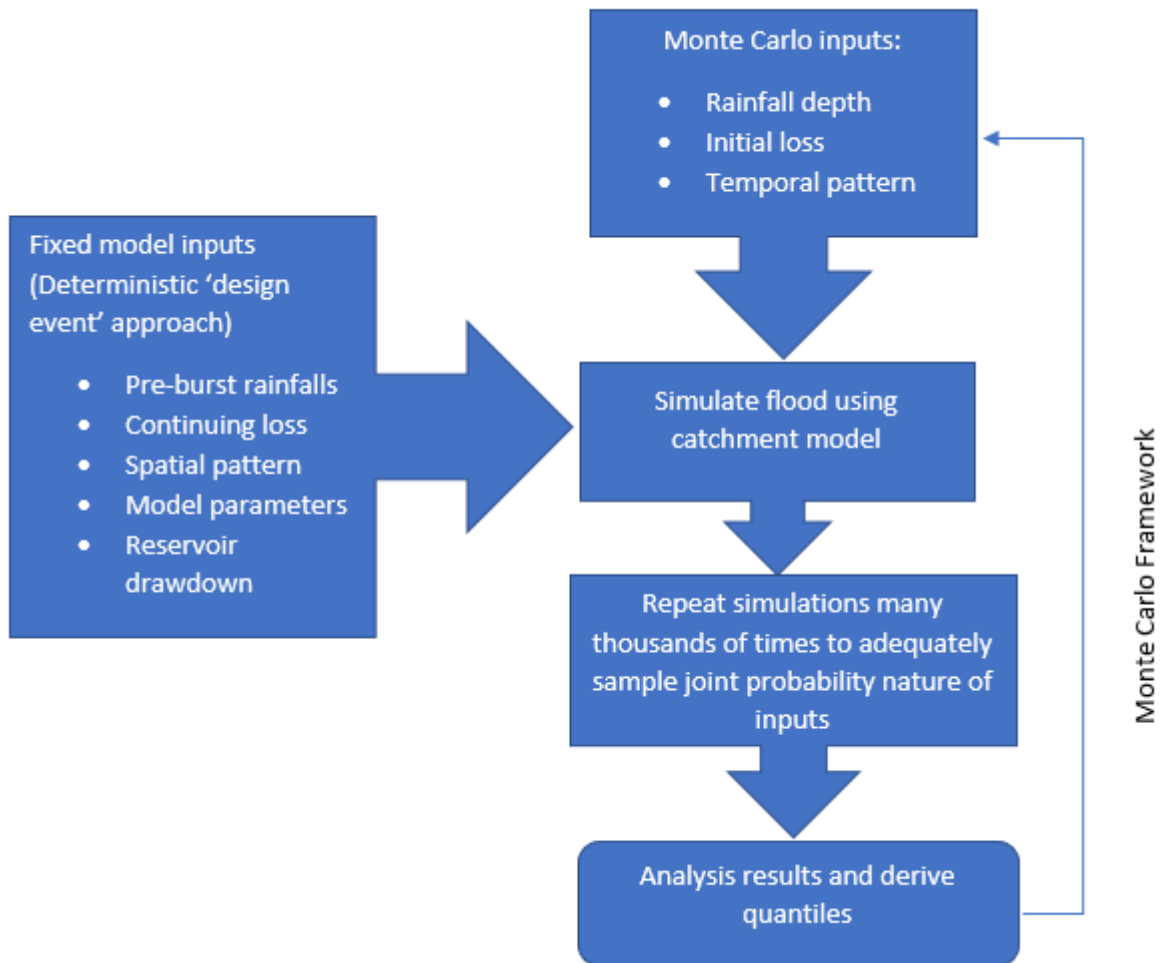
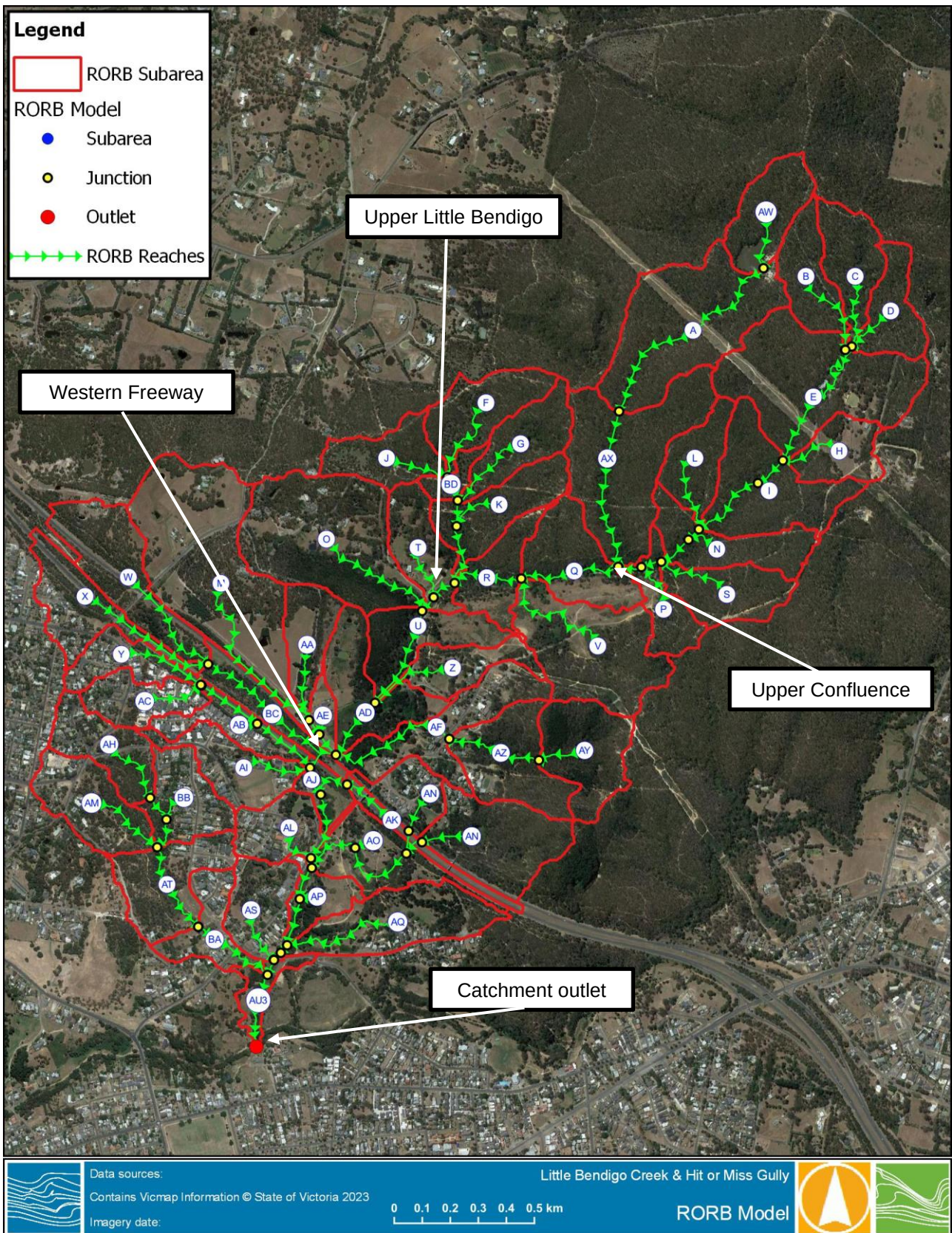


Figure 3-4 Overview of Monte Carlo Analysis

Table 3-10 RORB Critical Durations along Little Bendigo Creek

Location	Critical Duration					
	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP
Upper Confluence	12 hr	6 hr	2 hr			
Upper Little Bendigo	12 hr	6 hr	2 hr	3 hr	2 hr	
Western Freeway	12 hr	6 hr	3 hr			
Catchment outlet	2 hr					12 hr



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Figure 3-5 Little Bendigo Creek Hydrograph Print Locations



3.3.2 Ensemble Analysis

The RORB model was run as an Ensemble Analysis following the Monte Carlo analysis. Using the determined kc value of 2.81 and recommended ARR2019 and calibrated losses of 25.0 mm initial loss and 2.0 mm/hr continuing loss, the RORB Ensemble Analysis was run for all 10 ARR2019 recommended temporal patterns for each event duration. For this case, six design events were modelled, resulting in 60 design event temporal patterns for each of the six durations, 360 model simulations.

The peak flows determined in the Monte Carlo analysis were used to find a temporal pattern from the Ensemble Analysis producing a hydrograph with a similar peak flow. To reduce the potential number of hydraulic model runs, the temporal pattern that yielded peak flows similar to those produced in the Monte Carlo analysis at each of the key locations was selected as the representative design temporal pattern. For instance, temporal patterns 29 and 30 were shown to produce peak flows most like those produced in the Monte Carlo analysis for 2 of the 4 key locations for the 0.5% AEP event. These were therefore chosen as the temporal patterns to be used to produce inflows into the hydraulic model across the event durations.

Temporal patterns 29 and 30 were shown to produce peak flows most like those produced in the Monte Carlo analysis at three of the six locations along Little Bendigo Creek for the 0.5% AEP event and it was therefore chosen as the temporal pattern to be used to produce inflow to the hydraulic model across the event durations. The selected durations and temporal patterns for each design event are provided in Table 3-11 and the temporal pattern distributions displayed in Figure 3-6.

Table 3-11 Chosen Representative Temporal Patterns and Durations for each AEP

	20%	10%	5%	2%	1%	0.5%
Critical Duration & Temporal Pattern	2hr, TP07	2hr, TP11	2hr, TP15	2hr, TP27	2hr, TP28	2hr, TP29
	2hr, TP09	2hr, TP15	2hr, TP20	2hr, TP30	2hr, TP30	2hr, TP30
	12hr, TP07	6hr, TP11	3hr, TP15	3hr, TP27	3hr, TP28	3hr, TP29
	12hr, TP09	6hr, TP15	3hr, TP20	3hr, TP30	3hr, TP30	3hr, TP30
						12hr, TP29
						12hr, TP30

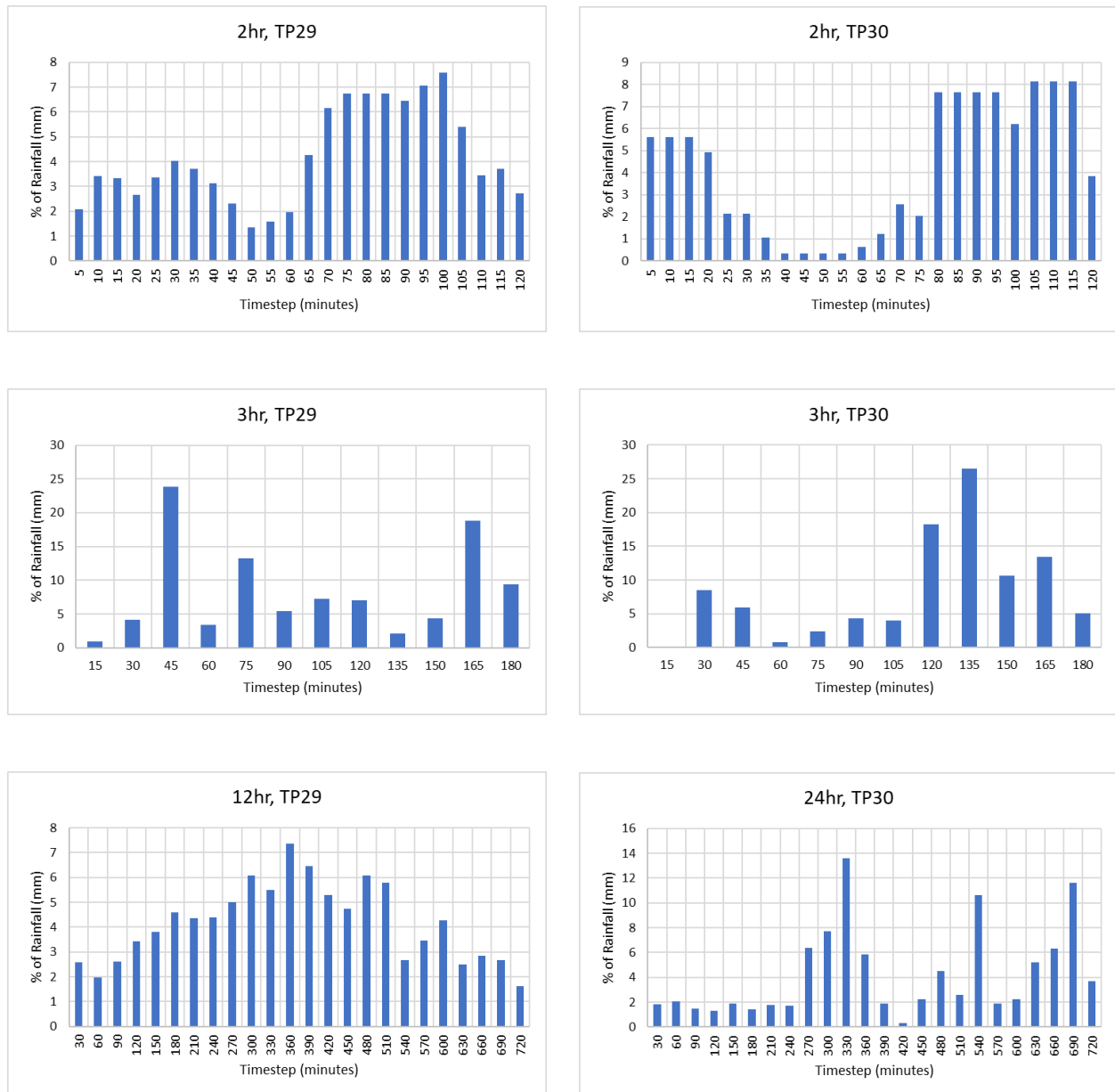


Figure 3-6 Adopted Temporal Patterns for 0.5% AEP Design Modelling

3.3.3 RORB modelling Outputs

The RORB model was used to produce inflows along Little Bendigo Creek, the inflow points will be discussed further in the hydraulic modelling report. The hydraulic model was run for six event durations (15mins, 30mins, 1 hr, 2hr, 3hr and 6hr) across the six AEPs, 36 total simulations. The RORB model outflows to the Yarrowee River, shown in Figure 3-7, represent a two-hour duration for each AEP as the critical duration for the catchment.

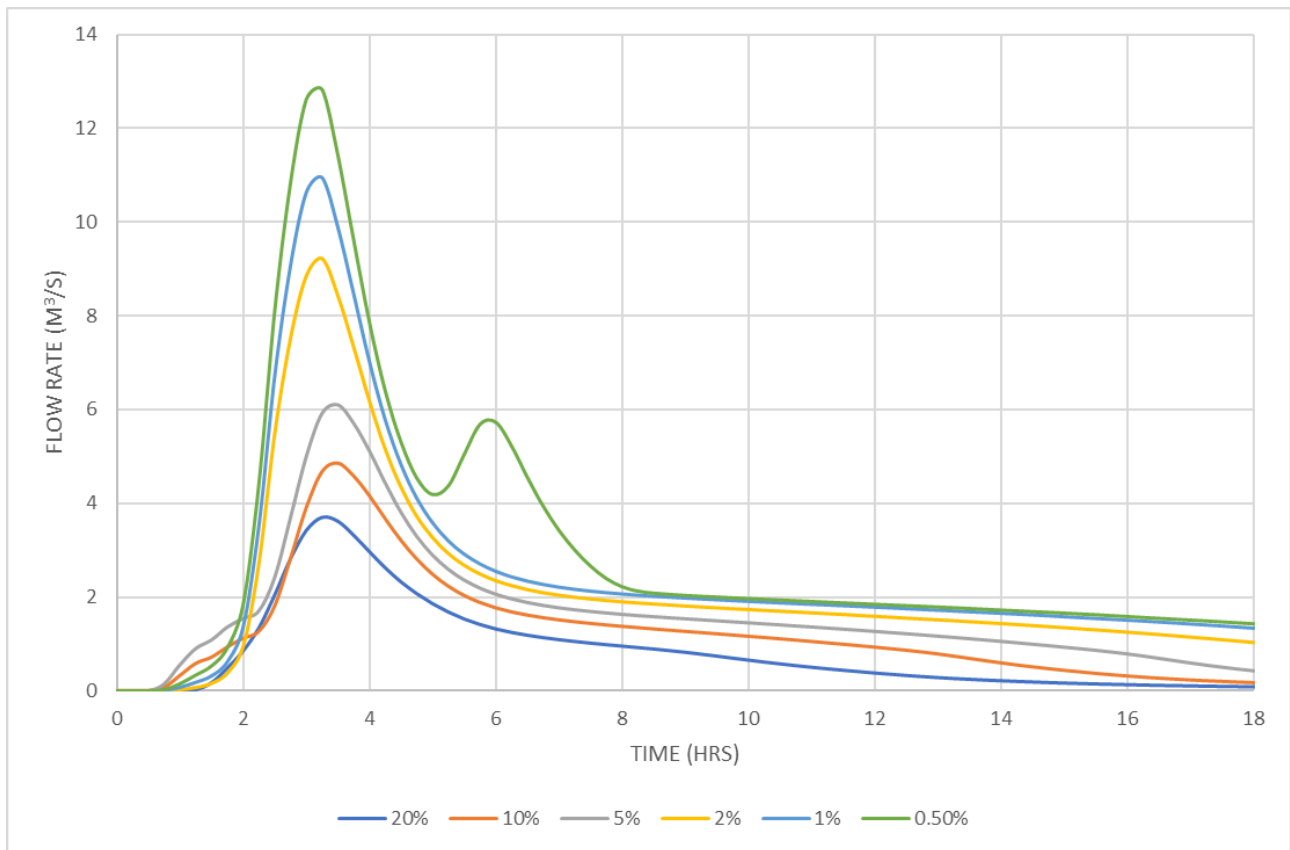


Figure 3-7 Design Hydrographs for 0.5% to 20% AEP EVENTS over a 12-hour Duration



4 HYDRUALICS

4.1 Overview

Hydraulic modelling covers Little Bendigo Creek from Wallaby Track in the Nerrina area in the north, to the Yarrowee River downstream of the Western Highway, as shown in Figure 4-1.

A detailed combined 1D-2D hydraulic modelling approach was adopted for this study, consisting of the following components:

- One dimensional (1D) hydraulic model of key hydraulic structures; and,
- Two dimensional (2D) hydraulic model of the broader floodplain.

The hydraulic modelling suite TUFLOW was used in this study. TUFLOW is a widely used hydraulic model that is suitable for the analysis of overland flows in urban areas. TUFLOW has four main inputs:

- Topography and drainage infrastructure data;
- Inflow data (based on catchment hydrology);
- Roughness; and,
- Boundary conditions.

This section of the report defines the scope of the hydraulic analysis, details the hydraulic model construction, and discusses the hydraulic model results. The design flood events modelled included the 20%, 10%, 5%, 2%, and 1% Annual Exceedance Probability (AEP) events.

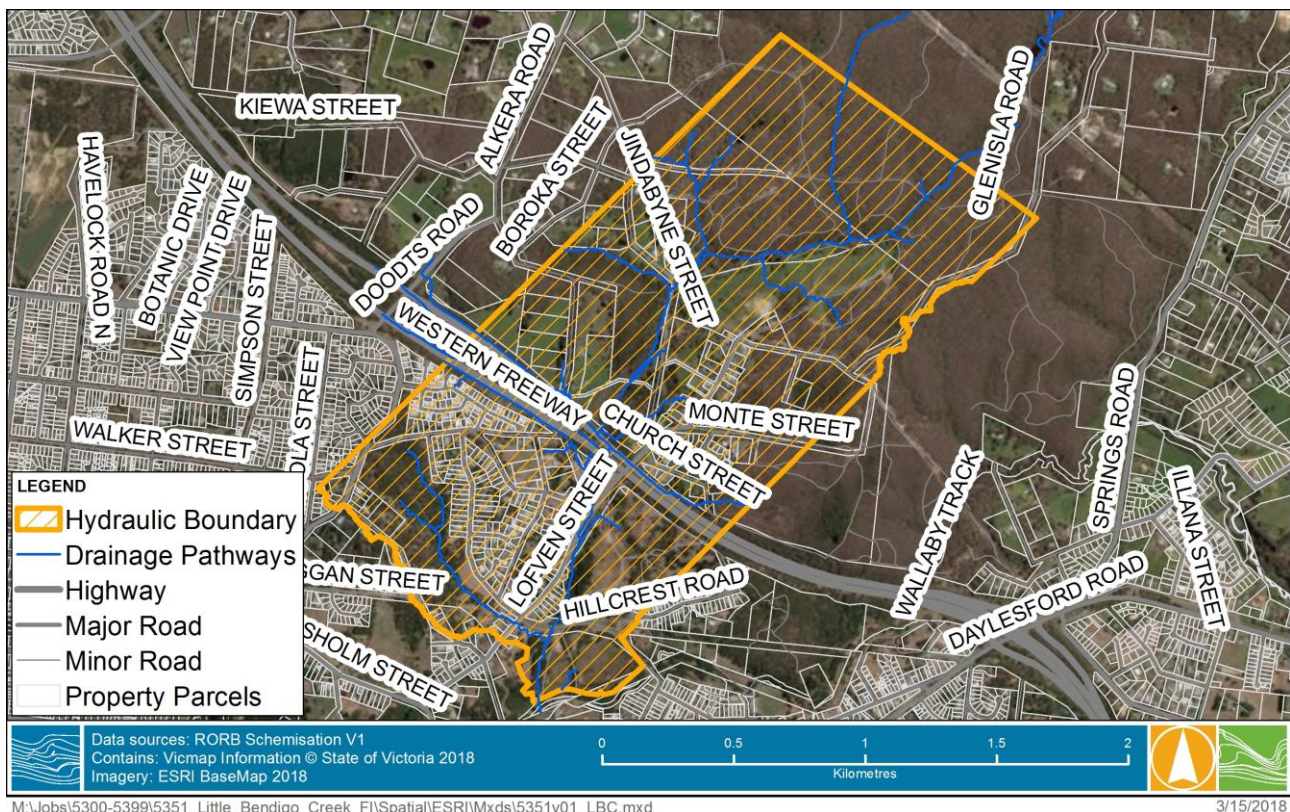


Figure 4-1 Hydraulic Model Domain



4.2 Boundary Conditions

4.2.1 Model Inflows

Inflow boundary conditions were extracted from the RORB hydrological model (as detailed in Section 0) at 19 locations draining into Little Bendigo Creek. These were modelled as source-area (SA) boundary types whereby the inflows are applied across a small polygon placed across the drainage line. The hydraulic model inflow locations are shown in Figure 4-2.

4.2.2 Model Outflows

The hydraulic model outflow adopted a downstream boundary near the outflow to the Yarrowee River. The outflow was modelled as a Water Level/Flow (HQ) boundary condition whereby the model determines a rating curve based on the model topography, slope and roughness.

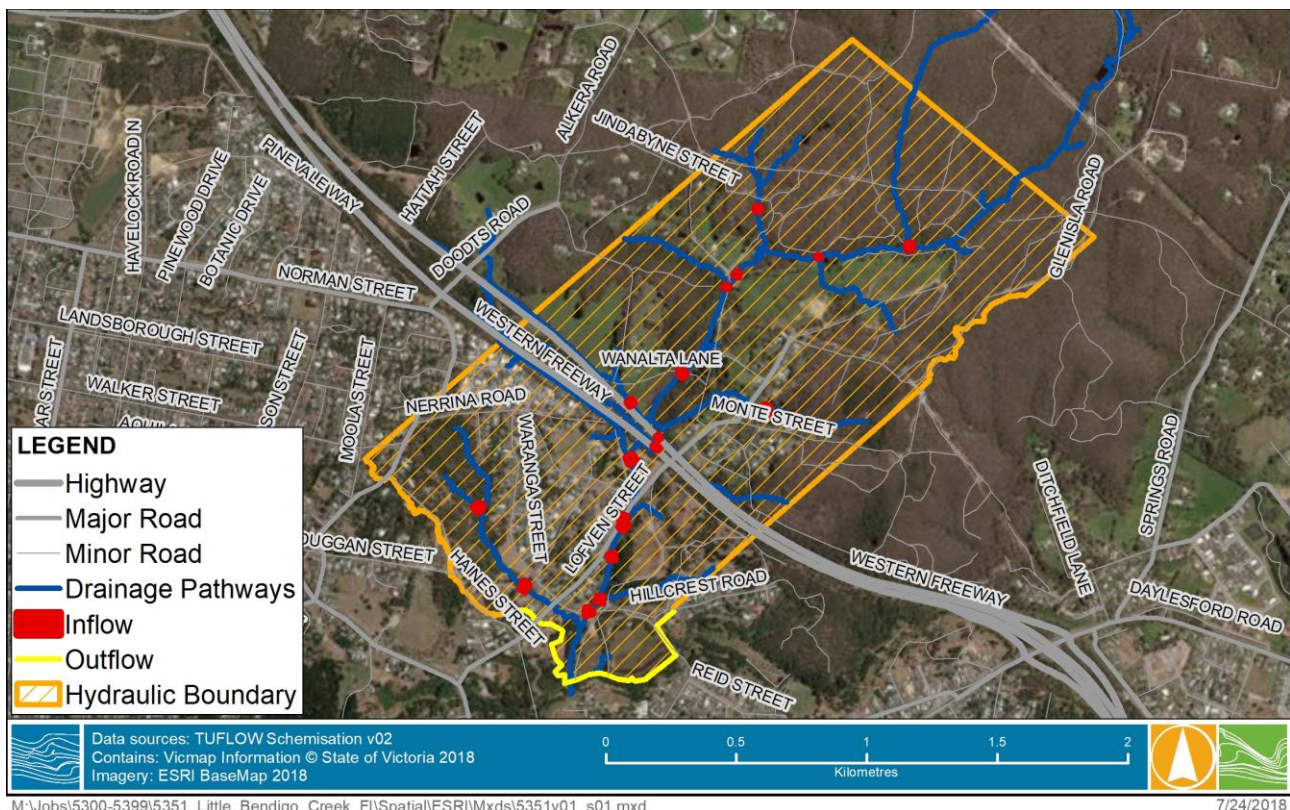
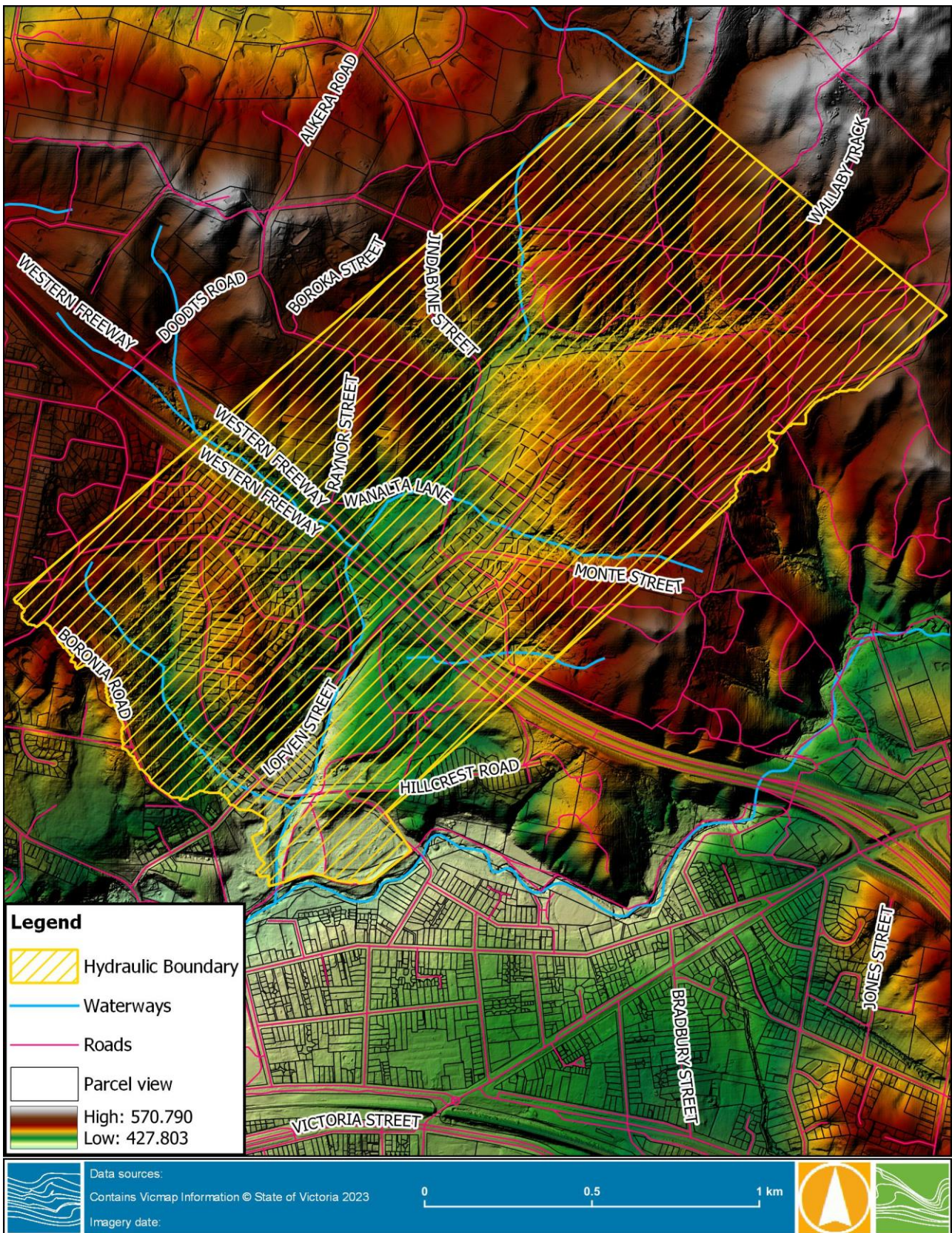


Figure 4-2 TUFLOW Model Boundaries

4.3 Grid Extent and Resolution

The model topography was based on 1 m resolution LiDAR data captured in October 2019 and held by DELWP. The LiDAR dataset is shown in Figure 4-3.

A key consideration in establishing an appropriate grid resolution for the 2D hydraulic model is to ensure waterways are well represented whilst ensuring reasonable model run times. A 2-metre grid resolution for Little Bendigo Creek catchment was adopted and considered sufficient to represent all the key drainage pathways and floodplain flood behaviour while ensuring reasonable run-times. This is considered a fine grid resolution for urban flood modelling.



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Figure 4-3 TUFLOW Model Extent and Topography



4.4 Hydraulic Roughness

Hydraulic roughness was determined using planning layers and land use data and then verified using aerial imagery. Table 4-1 shows the Manning's 'n' roughness values adopted for each land use, with the values adopted in the hydraulic model shown in Figure 4-4. The adopted roughness values are consistent with standard industry accepted values as outlined in ARR2019.

Table 4-1 Manning's Value "n" for the TUFLOW Model Area

Land Use	Manning's Value (n)
Residential – Urban	0.15
Residential – Rural	0.06
Open grassed or Pasture	0.04
Waterway – heavily vegetated	0.09
Sealed Road	0.0225
Unsealed Road	0.035
Dense Bushland	0.10

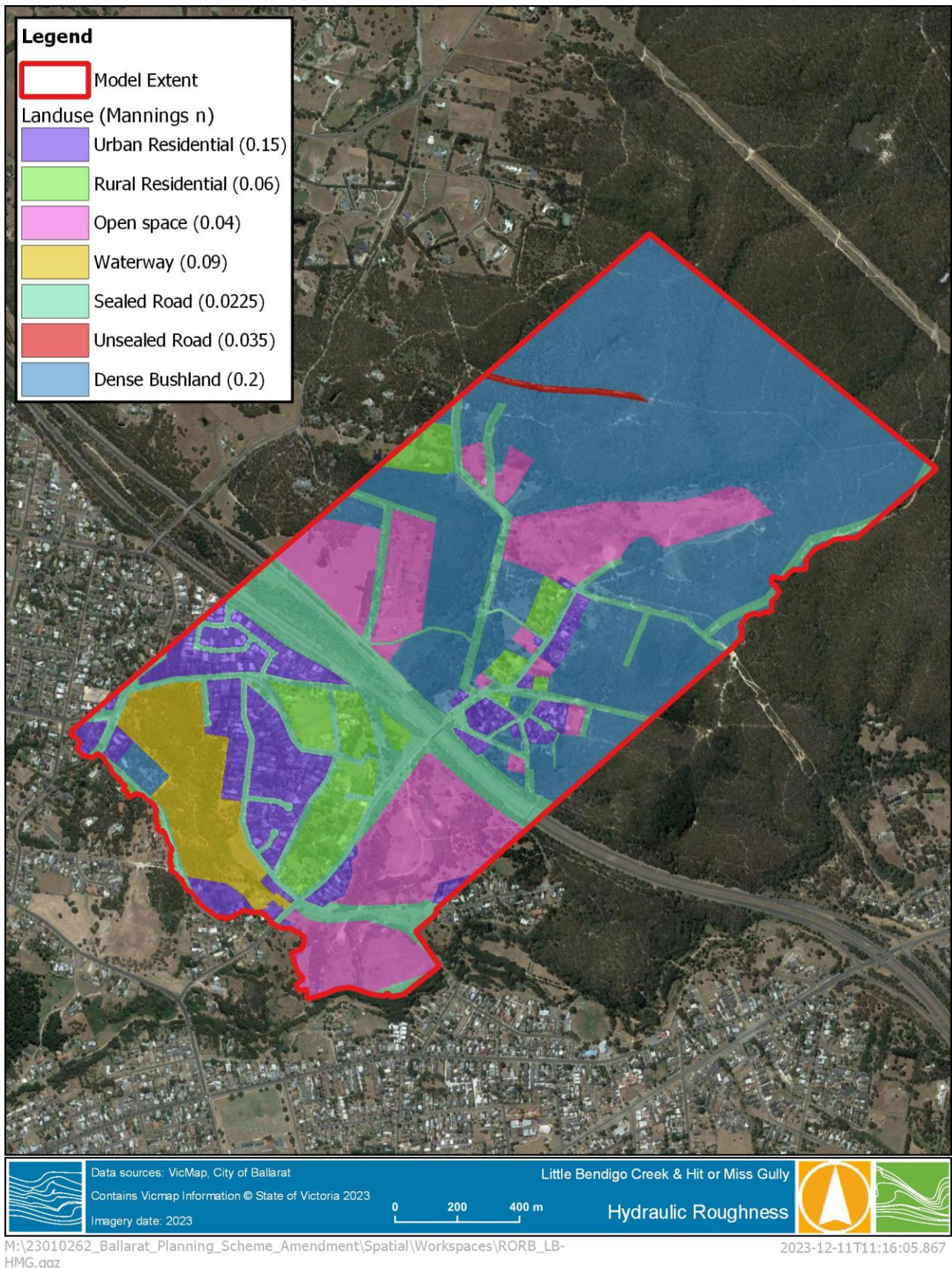


Figure 4-4 Mannings 'n' Roughness

4.5 Key Hydraulic Structures

There are a number of key hydraulic structures within the model area, varying in capacity and type i.e. culverts, pipes and pits. The primary structure is the culvert underpass of the Western Freeway at the centre of the hydraulic model. The culvert, pipe and pit details were available from previous modelling and were incorporated into the hydraulic model for this study. These structures were represented as 1D features to ensure capacity and hydraulic behaviour through the structures was accurately represented.

Figure 4-5 shown below highlights the location of key modelled structures, with photos for sites A to C shown below, taken in October 2017 during a site inspection. There were a number of smaller hydraulic structures incorporated into the model, spread across the catchment, many of these were observed during the site inspection. Figure 4-6 and Figure 4-7 shows examples of the culverts observed.

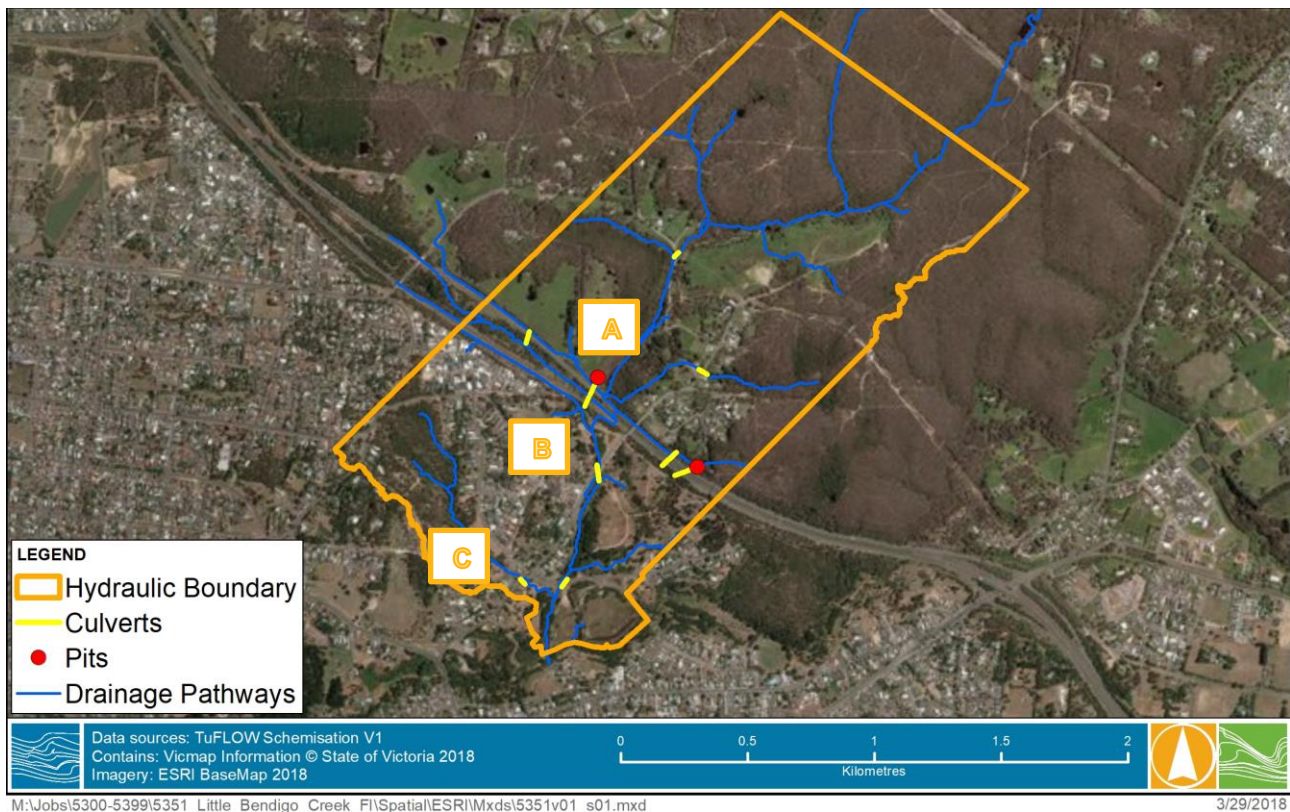


Figure 4-5 Hydraulic Structures Present in Little Bendigo Creek Catchment



Figure 4-6 Culvert Pit located at “A” (top); Large Culvert Located at “B” (bottom)



Figure 4-7 Small Culverts Located at “C”, Upstream (top), Downstream (bottom)



5 RESULTS

The design hydraulic modelling was completed for a suite of design events including the 20%, 10%, 5%, 2% and 1% AEP, each for the 2-hour duration, which was found to be critical across the model area in the RORB modelling.

The RORB and TUFLOW modelled hydrographs were compared at different locations within the model. It is common for hydrology and hydraulic models to perform differently if key structures attenuating the flows are not incorporated into the hydraulic model. Two storages were included in the RORB model to represent the detention properties the Western Freeway imposes on the Little Bendigo Creek. Figure 5-1 below shows the hydrograph comparison flows at the centroid (upstream of the Western Freeway) of the model and the outlet of the catchment.

There is a slight variation in the peak flows upstream of the Western Freeway between the RORB and TUFLOW models peaks of approximately 11.5 m³/s and 9 m³/s, respectively. This difference in peak flows can be attributed to the minor detention aspects of the tributary to the east, coming from Lofven Street, which has several ponds along the flow path.

At the model outlet, peak flows are closer at 9.5 m³/s and 8.7 m³/s, respectively. This small difference is considered acceptable and fit for purpose for use in this study. Given the RORB model has been developed to generate discrete inflow points into the hydraulic model which are then routed along the waterways.

Figure 5-1 below shows the hydrograph comparison flows at the centroid (upstream of the Western Freeway) of the model and outlet of the catchment.

The maximum flood extent for the 1% AEP for all the modelled durations is shown in Figure 5-2. The inundation extent along Little Bendigo Creek is significantly influenced by the capacity of culverts under the Western Freeway.

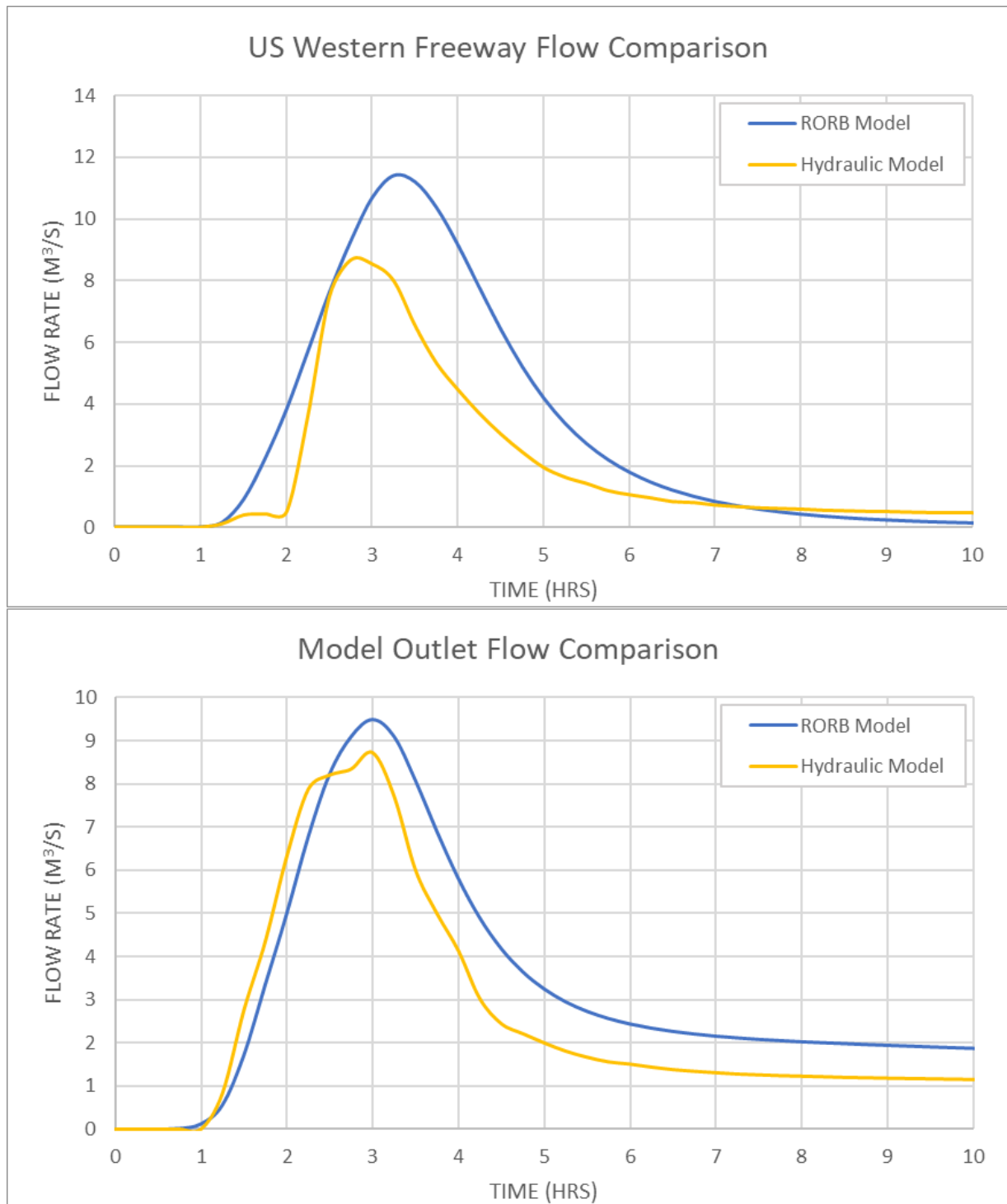


Figure 5-1 Flow Rate Comparison Between RORB and TUFLOW for Centroid (Upstream of the Western Freeway) and Outlet

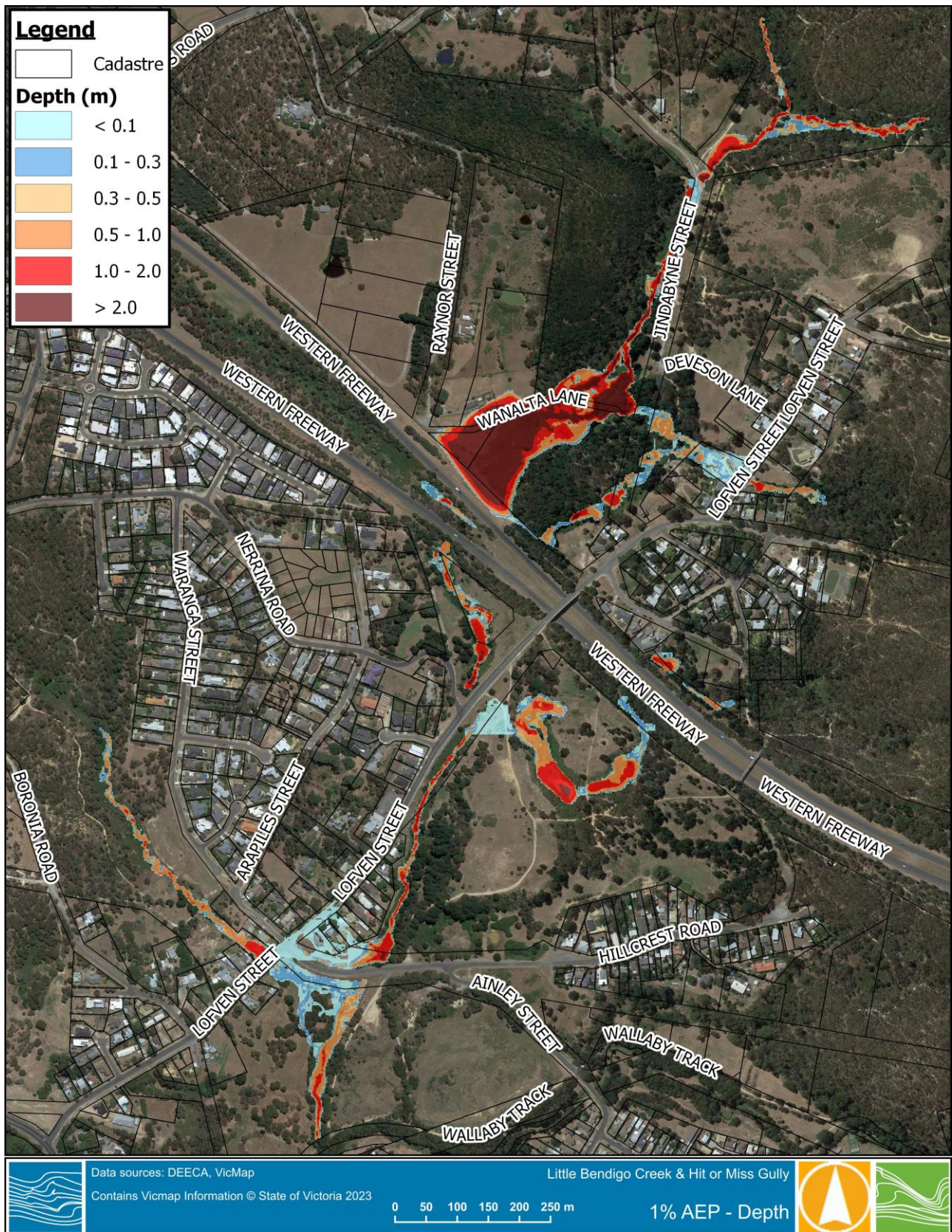


Figure 5-2 1% AEP Flood Depth (m) along Little Bendigo Creek

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