

Warrenheip Creek and Ryans Drain Hydrology and Hydraulics

Ballarat Flood Modelling Update

City of Ballarat

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Client	City of Ballarat
Client Project Manager	Susie Perera
Water Technology Project Manager	Jack Brook
Water Technology Project Director	Ben Hughes
Authors	Nasreen Mohal/Ben Hughes/Jack Brook
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15 Business Park Drive

Notting Hill VIC 3168

Telephone (03) 8526 0800

Fax (03) 9558 9365

ACN 093 377 283

ABN 60 093 377 283





EXECUTIVE SUMMARY

Water Technology was engaged by the City of Ballarat (CoB) to review and update the existing hydrologic and hydraulic models used to develop Land Subject to Inundation (LSIO), Floodway Overlay (FO), Special Building Overlay (SBO) layers covering several waterways within the CoB municipality. The following report details the current hydrologic and hydraulic modelling for Warrenheip Creek and Ryans Drain. A summary of the changes made to the hydrologic and hydraulic models since the original study in 2018 are listed below.

- Hydrologic model (RORB) updates:
 - Revision of k_c parameter to align with Pearse et al. to provide a consistent value across each of the studies within Ballarat.
 - Reduction to several sub-catchment FI values to reflect FI more accurately in lower density areas, primarily in the suburb of Warrenheip.
- Hydraulic model (TUFLOW) updates:
 - The base terrain for the model was updated to include topographic Light Distance and Ranging (LiDAR) data captured in October 2019 with a 1-metre grid cell size.
 - The TUFLOW model was updated to the latest build (2023-03-AB) and run as Highly Parallelized Computing (HPC). This ensured the update model utilised the most recent modelling approaches within the TUFLOW software package.
 - The Boundary Road culvert along Ryans Drain replaced a 900mm diameter steel pipe with a 1500mm diameter concrete pipe.
 - Inclusion of a 'pedestrian crossing' over Ryans Drain immediately upstream of Ryan Street, featuring a 750mm diameter concrete pipe.
 - Update to surface elevations at 340-348 Humffray Street North, where a childcare centre has been constructed.

The 1% AEP mapping was produced for review by Council and CMA. After approval, Water Technology will finalise the modelling by completing the remaining design events including climate change scenarios.



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1 INTRODUCTION

1.1 Background

Water Technology was commissioned by City of Ballarat (CoB) to carry out the Warrenheip Creek and Ryans Drain Flood Mapping Project in 2018. The original project was commissioned to improve the flood risk knowledge, address information gaps and provide valuable planning and flood intelligence within Warrenheip Creek and Ryans Drain catchments.

Warrenheip Creek and Ryans drain are located approximately 6km east of the Ballarat CBD. The two watercourses are in close proximity to each other (around 500m apart), so a combined study was determined as the most straight forward way to model their respective floodplains.

The modelling extent focuses on the catchment upstream of Old Melbourne Road to the Water Street. The two waterways run parallel to each other before flowing into the Yarrowee River at the same location, as shown in Figure 1-1. The catchments consist of several land use zones; including areas of Residential, Farming and some Industrial zoned land.

The flood modelling and mapping undertaken in this project was based on the updated guidelines outlined in Australian Rainfall and Runoff 2016¹. As identified above, this report has been updated based on changes made to the hydrologic and hydraulic models in response to recent development and newly available data within the catchment.

1.2 Structure of the report

This report outlines the following:

- A site visit along Warrenheip Creek and Ryans Drain undertaken by Water Technology and City of Ballarat staff in 2018.
- Hydrologic modelling of the Warrenheip Creek and Ryans Drain catchment including modelling methodology, inputs to the hydraulic model and results.
- Hydraulic modelling of Warrenheip Creek and Ryans Drain 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), 2016, Australian Rainfall and Runoff: A Guide to Flood Estimation, Commonwealth of Australia

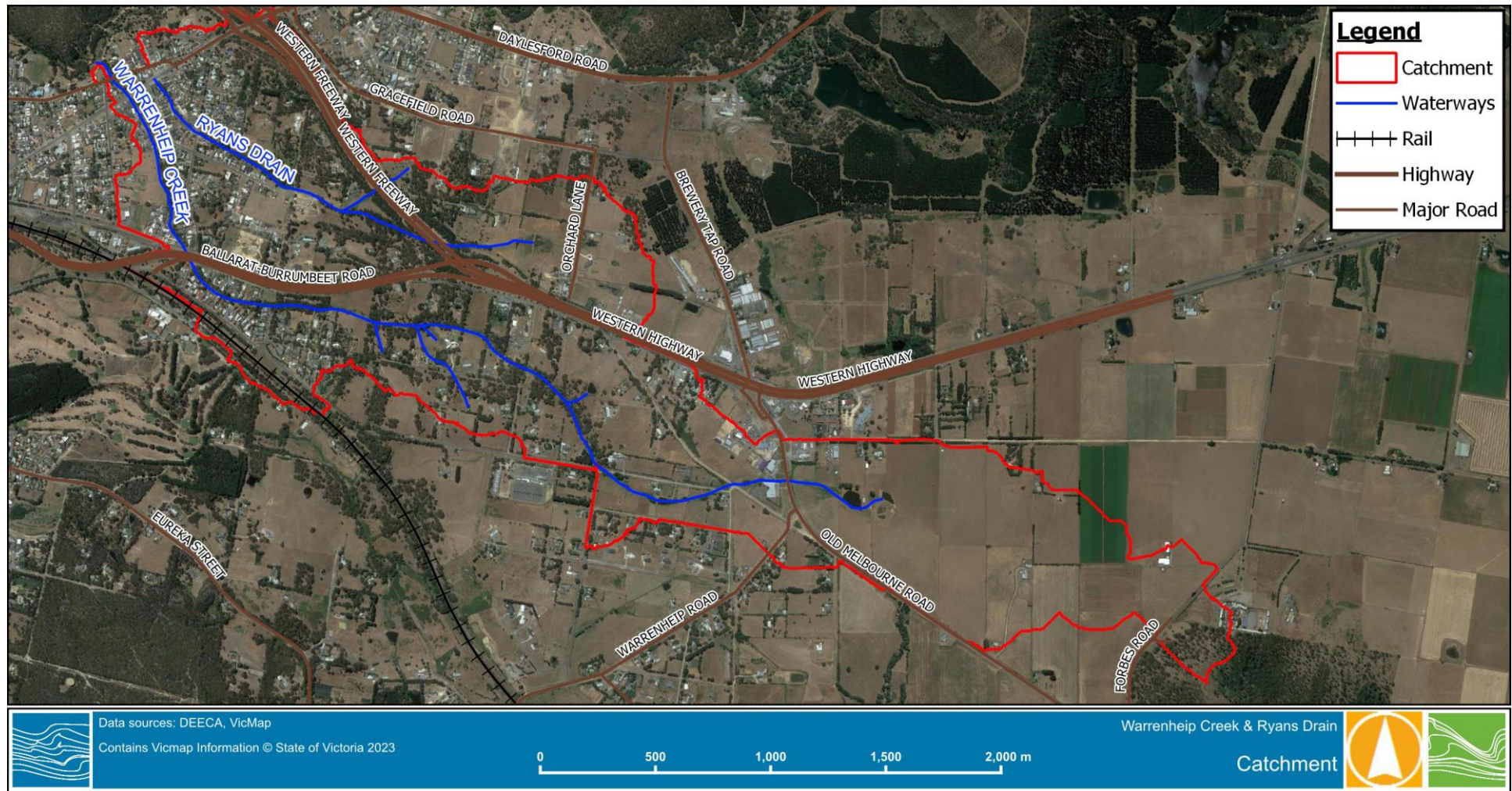


FIGURE 1-1 WARRENHEIP AND RYANS DRAIN CATCHMENT AND WATERWAYS

2 AVAILABLE INFORMATION & SITE VISIT

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:

- Several site visits.
- CoB.
- VicRoads.
- Department of Energy, Environment and Climate Action (formerly DELWP).

2.2 Site visit

A site visit was conducted on the 13th June 2018 by Water Technology and CoB staff. Key hydraulic structures / crossings and areas known to be impacted by flooding were visited. The objective of the site visit was to gain an understanding of the historic drainage conditions, recent and on-going flooding concerns from the perspective of the council, gather an understanding of the waterway and catchment terrain, vegetation and soil characteristics, while focussing on the critical inputs to the modelling e.g. Manning's 'n' roughness coefficients, pipe and culvert locations and characteristics and key topographical influences. A selection of photos captured during the site visit are shown in Figure 2-1, Figure 2-2 and Figure 2-3.



FIGURE 2-1 HUMFFRAY STREET NORTH CULVERT ON WARRENHEIP CREEK (UPSTREAM)



FIGURE 2-2 HUMFFRAY STREET NORTH CULVERT ON WARRENHEIP CREEK (DOWNSTREAM)



FIGURE 2-3 WATER STREET CULVERT ON WARRENHEIP CREEK (DOWNSTREAM)



2.3 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.

2.4 Planning Scheme

The CoB 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.

2.5 Drainage information

CoB provided the GIS layers of the drainage network, 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. In case of missing pit depth, pipe inverts 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

Any gaps in the infrastructure data were filled during the site visit.



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 is comprised of several key data inputs to produce accurate results, these include:

- Catchment delineation.
- Fraction impervious.
- Routing parameter (kc)
- Design inputs
 - Rainfall depth
 - Temporal patterns
 - Spatial pattern
 - Losses

Each of these inputs are discussed in the following sections.

3.2.1 Catchment delineation

The Warrenheip Creek and Ryans Drain catchment was delineated based on 1-metre LiDAR data capture in 2011. The catchment (4.27 km²) was delineated into 35 sub-areas, as shown in Figure 3-1. The available LiDAR data was used as a basis for the delineation, ensuring an even distribution of similar sized catchments with a minimum of three sub catchments upstream of each print point used as an inflow location to the Warrenheip Creek and Ryans Drain hydraulic model.

A series of nodes and reaches were defined in the RORB model to represent the model routing characteristics. Rainfall excess hydrographs were used as inflows in the hydraulic model. These definitions were derived from expected flow characteristics based on the aerial photography and the site visit.

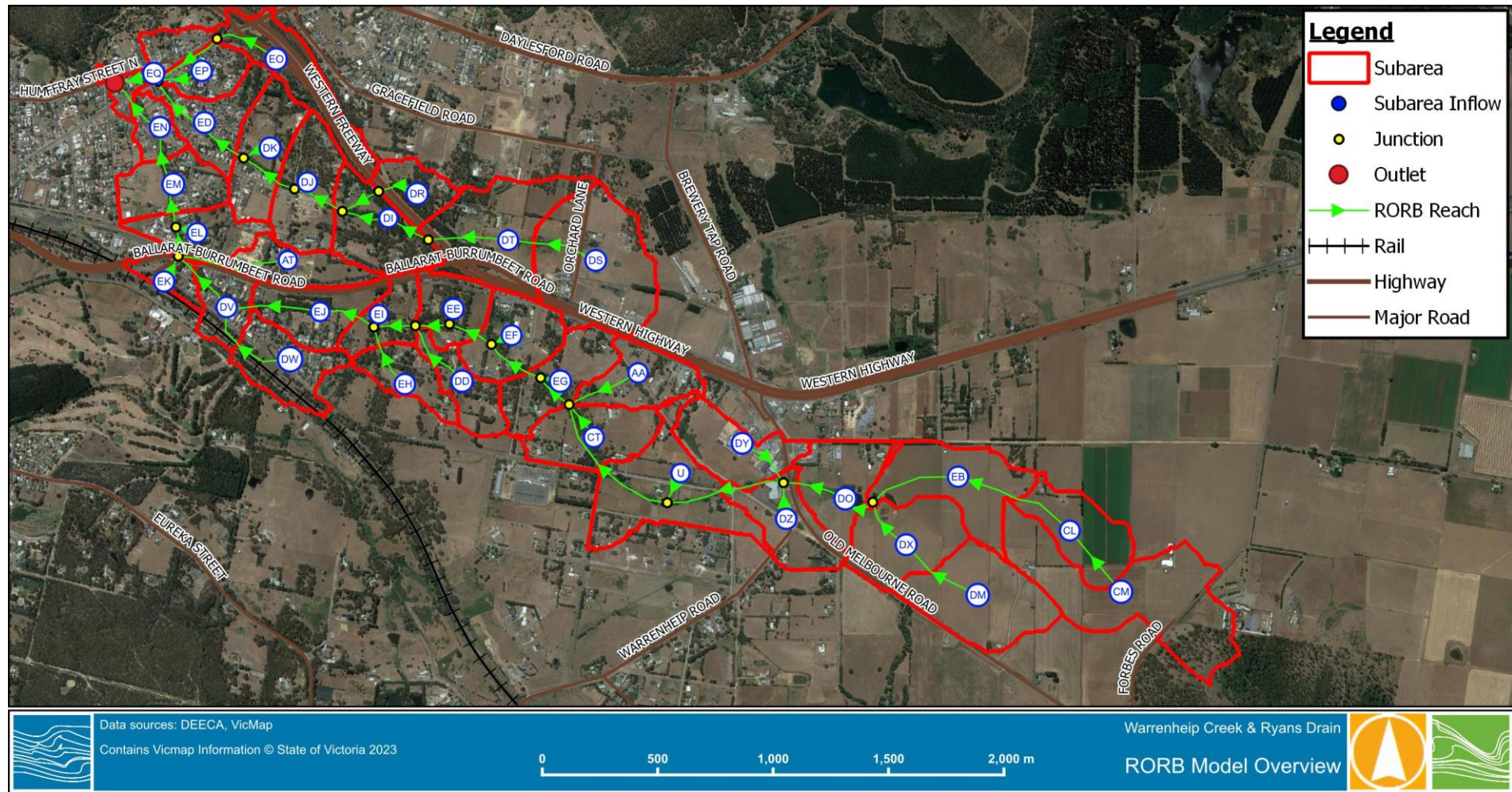


FIGURE 3-1 RORB MODEL STRUCTURE



3.2.2 Fraction Impervious

Impervious fractions values were determined for the different land use types across the catchment within each sub catchment, represented by a Fraction Impervious (FI). FI values were determined according to CoB planning zones as per Melbourne Water's Guidelines² and verified against aerial imagery. The catchment was largely separated into three main land uses; open space (including farming), residential and industrial. The adopted values for each are provided in Table 3-1, a map of the designated land uses is shown in Figure 3-2, with the adopted sub catchment FI values shown in Figure 3-3. A fraction impervious greater than zero was adopted for areas of open space due to the presence of constructed drains in both the parks and agricultural areas.

TABLE 3-1 ADOPTED FI VALUES USED IN RORB MODEL

Land use	Adopted FI
Open space including farming	0.1
Residential	0.45
Industrial	0.9

² Melbourne Water (2010), Melbourne Water's MUSIC Guidelines

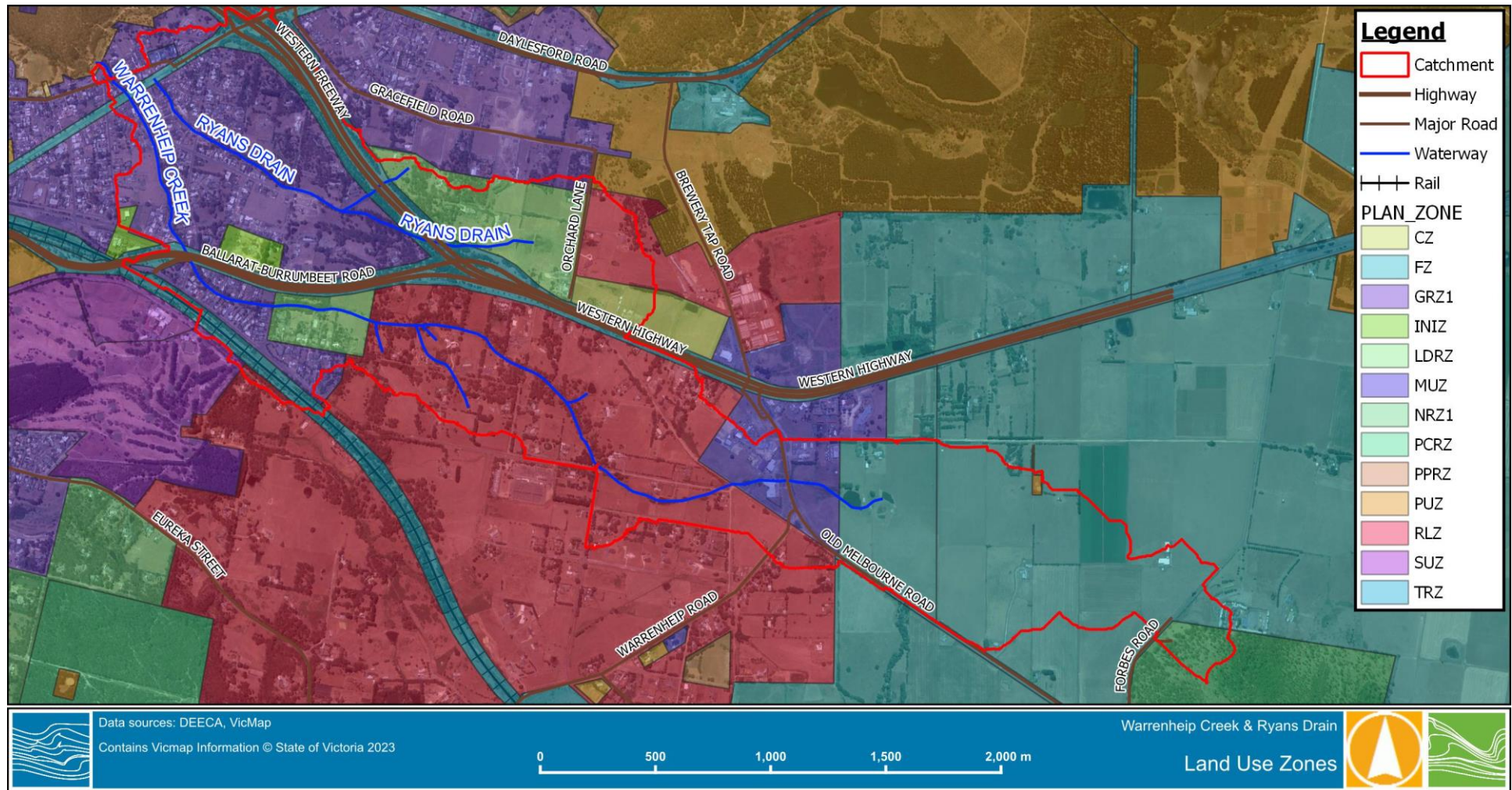


FIGURE 3-2 LAND USE AREAS BASED ON PLANNING ZONES

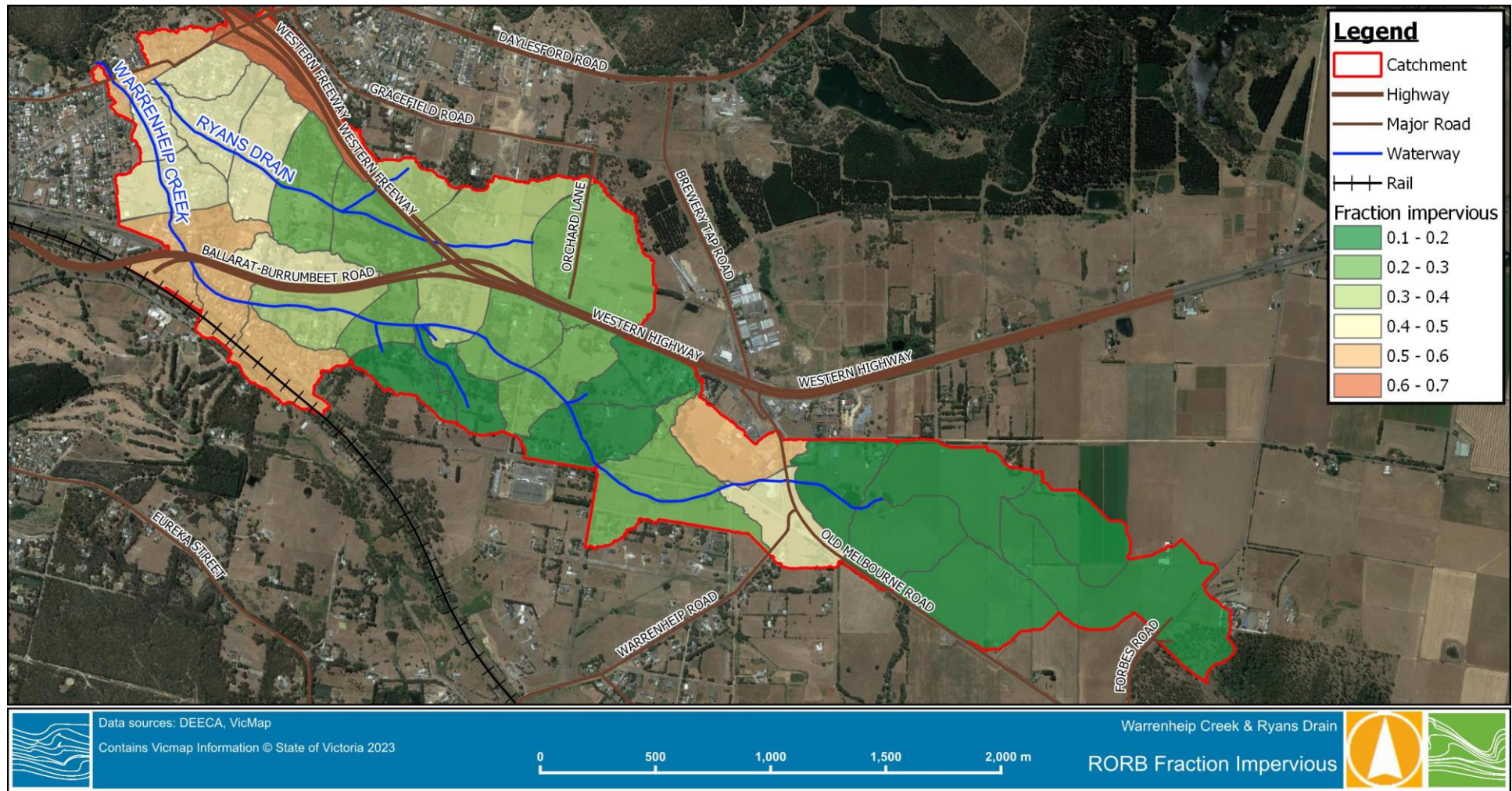


FIGURE 3-3 FRACTION IMPERVIOUS USED IN THE STUDY



3.2.3 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 3-3 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)	3.39 (range: 2.03 – 5.61)
Yu (1989)	0.96 (range: 0.47 – 1.94)	2.60 (range: 1.27 – 5.26)
Pearse et al. (2002)	1.25 (range: 0.61 – 2.13)	3.39 (range: 1.65 – 5.77)

For the Warrenheip Creek and Ryans Drain 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 1.14, consistent with the expected value from Pease et al (2002). Given that d_{av} equals 2.71 km for the RORB model, k_c value of 3.39 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	30	10.43	2.88	7.80
Canadian Creeks	8.46	3.56	2.38	6.44
Kensington Creek	5.6	4.52	1.24	3.39
Bonshaw Creek	5.37	4.58	1.17	3.18

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

3.2.4 Design rainfall

3.2.4.1 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 Warrenheip Creek & Ryans Drain catchment, areal reduction was not applied.

Summary

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

TABLE 3-4 DESIGN RAINFALL DEPTHS IN MM FOR VARYING EVENT DUAURATIONS AND AEP

Duration\AEP	20%	10%	5%	2%	1%	0.5%
30-min	18.3	22.7	27.4	34.2	39.9	45.49
1-hr	22.6	27.9	33.5	41.4	48.0	54.72
2-hr	27.6	33.7	40.0	48.8	56.1	63.95
3-hr	31.2	37.7	44.5	54.0	61.8	70.45
6-hr	39.3	46.9	54.7	65.8	74.9	85.39
12-hr	50.6	59.9	69.5	83.3	94.4	107.62

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	65.2	77.4	89.9	108	122	139.08

3.2.4.2 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.

3.2.4.3 Spatial patterns

The ARR2019 guidelines recommend non-uniform spatial patterns for catchment areas of more than 20 km². The catchment upstream of the study area is 4.27km², therefore a uniform spatial pattern was applied in design modelling.

3.2.4.4 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 Warrenheip Creek & Ryans Drain 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 proximity of the Warrenheip Creek & Ryans Drain to the Yarrowee River catchment, and the Ballarat region, the calibrated continuing loss of 2.0 mm/hr was adopted for this catchment.

The adopted modelling parameters for the Warrenheip Creek & Ryans Drain catchment are shown in Table 3-5.

TABLE 3-5 ADOPTED LOSSES

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

⁶ <http://data.arr-software.org/>



3.3 Design modelling

As recommended in ARR2019, Monte Carlo analysis was used to determine design peak flows at key locations within the Chase Waterway 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 2 3. This process resulted in target critical durations and temporals at each key location for the design event.

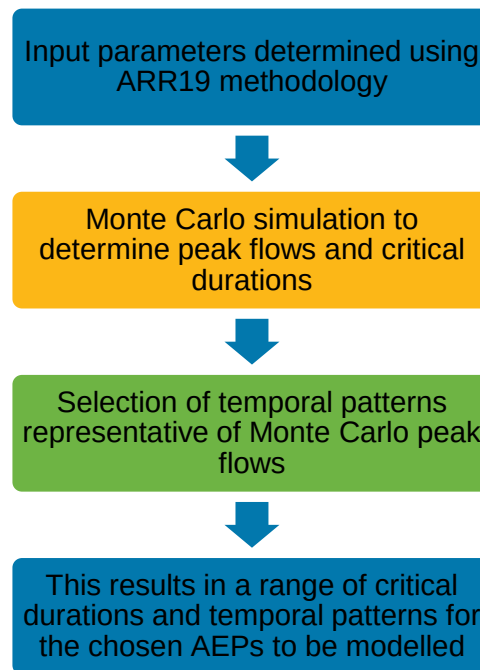


Figure 3-4 Design modelling flow chart

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. 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 3-5. The critical duration for several important locations throughout the model is shown in Table 3-6. These print locations are shown in Figure 3-6.

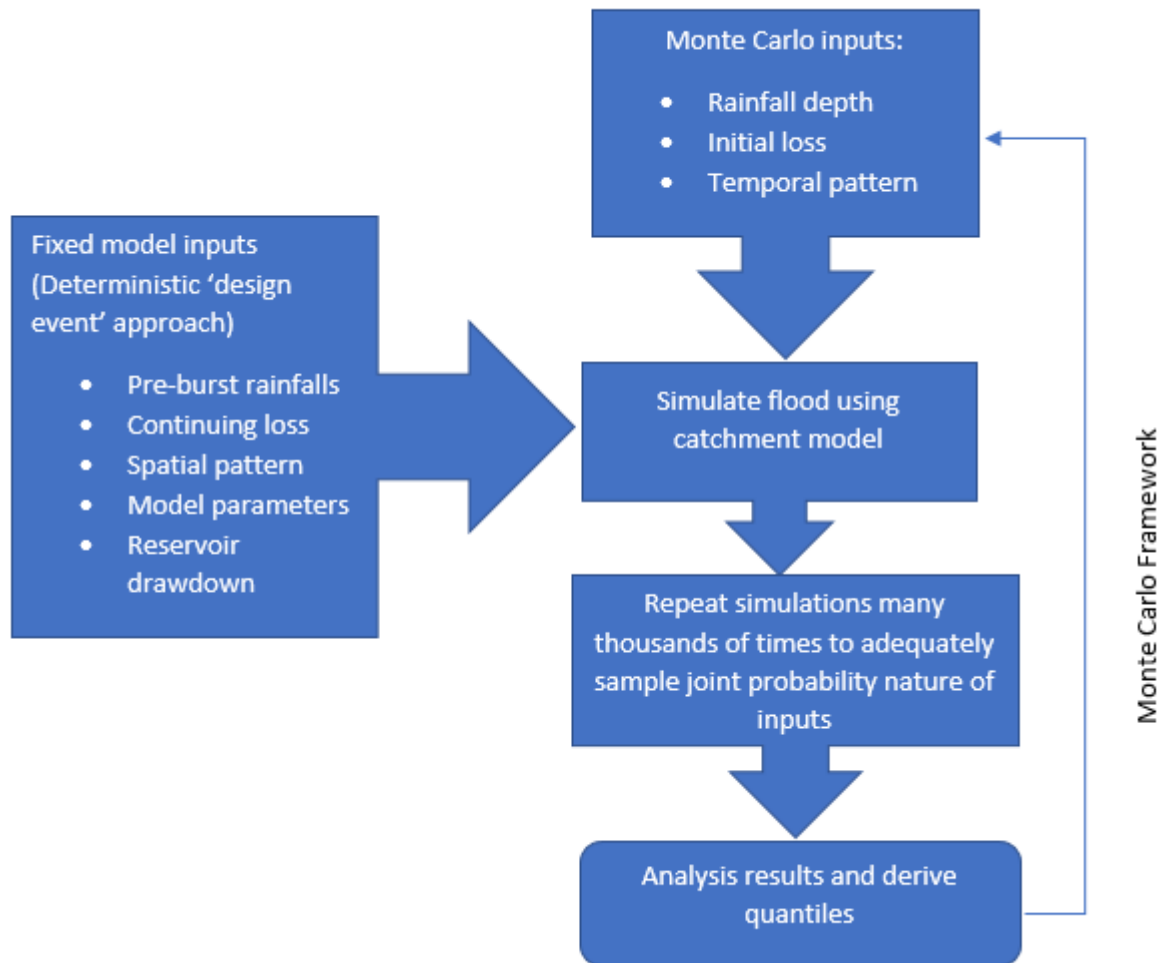


FIGURE 3-5 OVERVIEW OF MONTE CARLO ANALYSIS

TABLE 3-6 RORB CRITICAL DURATIONS ALONG WARRENHEIP CREEK & RYANS DRAIN

Location	Critical Duration					
	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP
Tributary 1	2 hr			1 hr		
Tributary 2	1 hr			30 min		
Boundary Rd	2 hr					
Peak 01	6 hr		2 hr		1 hr	
Victoria St	12 hr		6 hr		12 hr	
Model Outlet	12 hr		6 hr		3 hr	

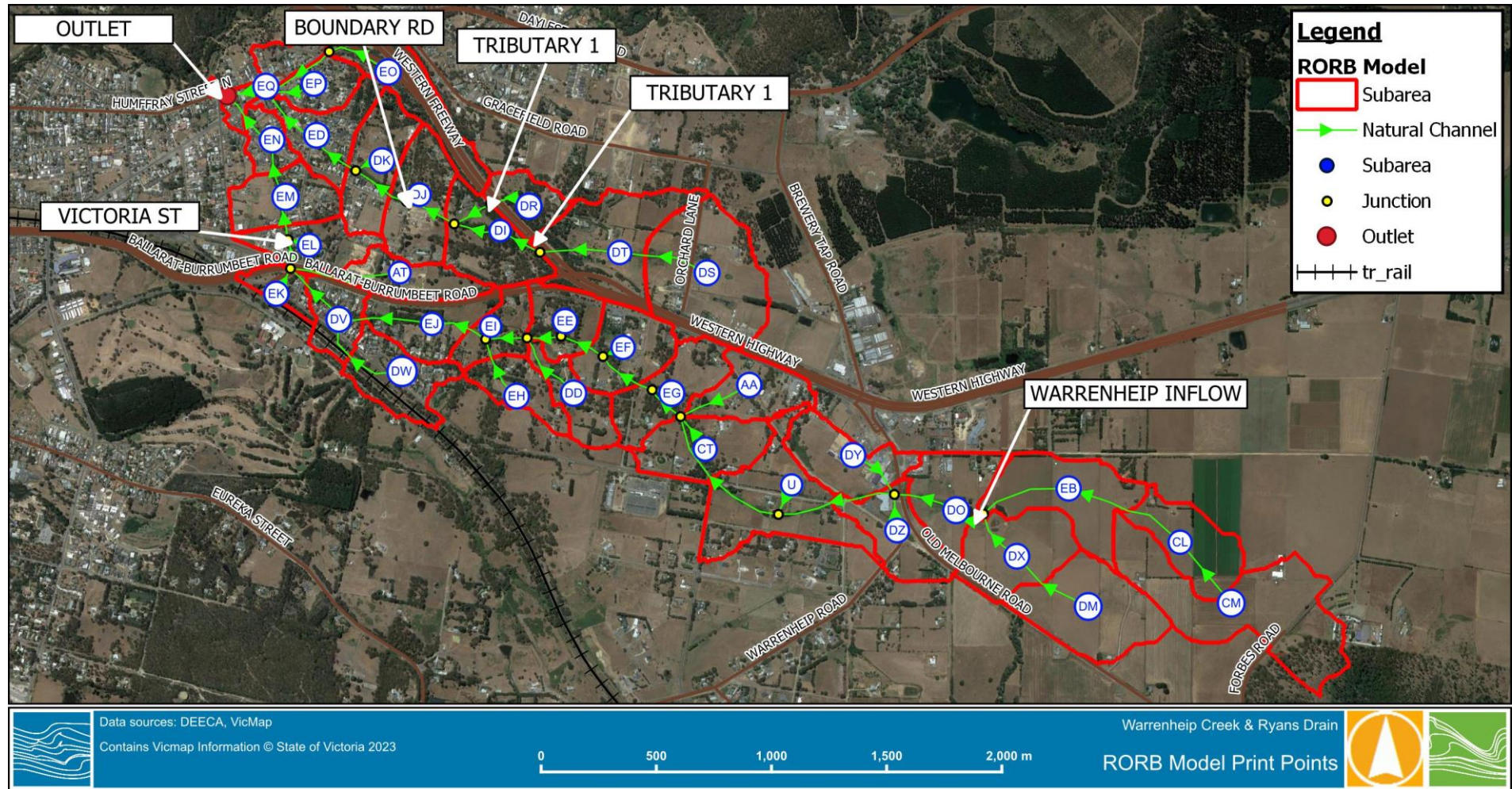


FIGURE 3-6 WARRENHEIP CREEK & RYANS DRAIN HYDROGRAPH PRINT POINTS

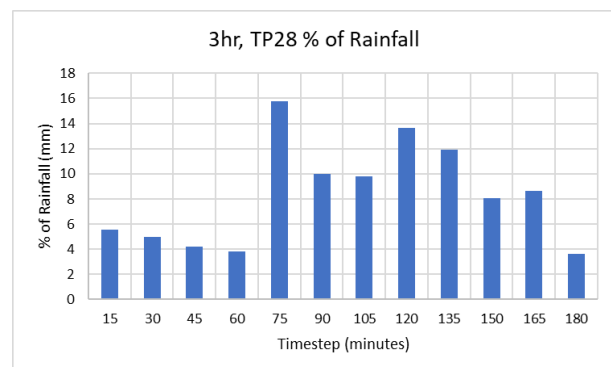
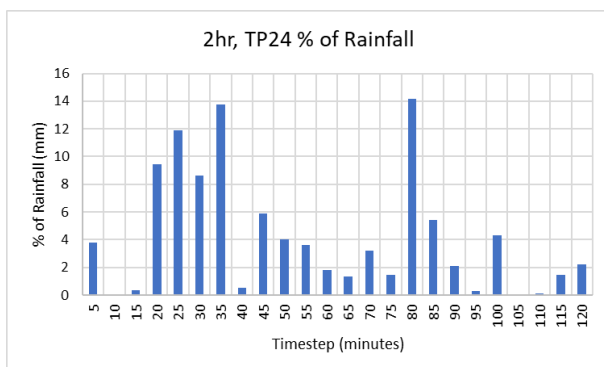
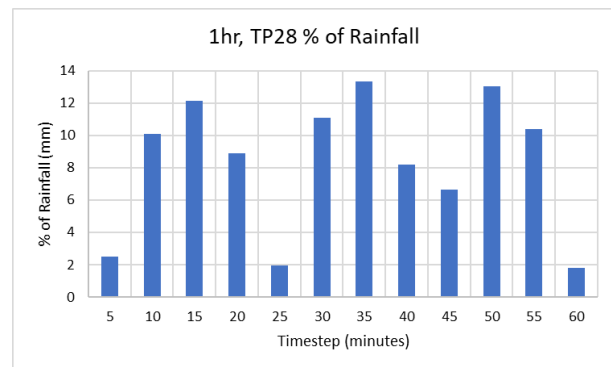
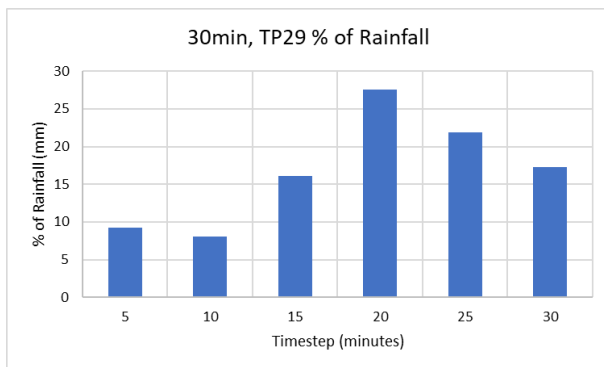


3.3.2 Ensemble Analysis

The RORB model was also run using the Ensemble Analysis, using the determined k_c value of 6.10 and adopted losses of 24 mm initial loss and 2.0 mm/hr continuing loss. The RORB Ensemble Analysis was run for all 10 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. To reduce the potential number of hydraulic model runs, temporal patterns that yielded peak flows similar to those produced in the Monte Carlo analysis at each of the key locations were simplified to produce a set of selected temporal patterns for each design event. These are summarised in Table 3-7 with the distribution of rainfall for the adopted temporal patterns during the 1% AEP event displayed in Figure 3-7.

TABLE 3-7 CHOSEN REPRESENTATIVE TEMPORAL PATTERNS AND DURATIONS FOR EACH AEP

	20%	10%	5%	2%	1%	0.5%
Critical Duration & Temporal Pattern	1hr, TP10	1hr, TP20	1hr, TP19	30min, TP30	30min, TP29	30min, TP30
	2hr, TP05	2hr, TP16	2hr, TP15	1hr, TP30	1hr, TP28	1hr, TP28
	3hr, TP10	3hr, TP16	2hr, TP11	2hr, TP30	2hr, TP24	2hr, TP25
	6hr, TP08	6hr, TP16	3hr, TP15	3hr, TP30	3hr, TP28	3hr, TP25
	12hr, TP10		6hr, TP16	6hr, TP30	6hr, TP28	6hr, TP25
				12hr, TP30	12hr, TP29	12hr, TP22



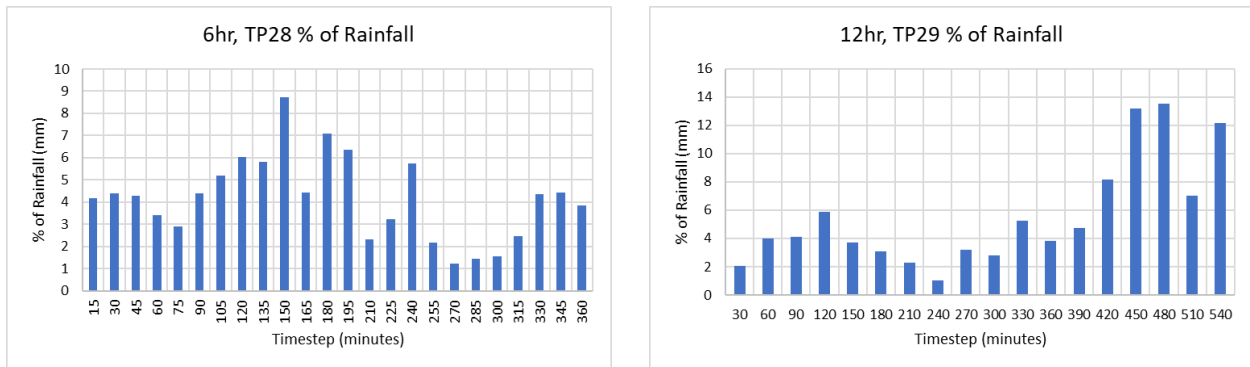


FIGURE 3-7 ADOPTED TEMPORAL PATTERNS FOR 1% AEP DESIGN MODELLING

3.3.3 Design Simulations

Hydraulic model inflow hydrographs were produced for the 20%, 10%, 5%, 2%, 1% and 0.5% AEP events. The resulting Warrenheip Creek and Ryans Drain 1% AEP outflows for each duration event are plotted in Figure 3-8.

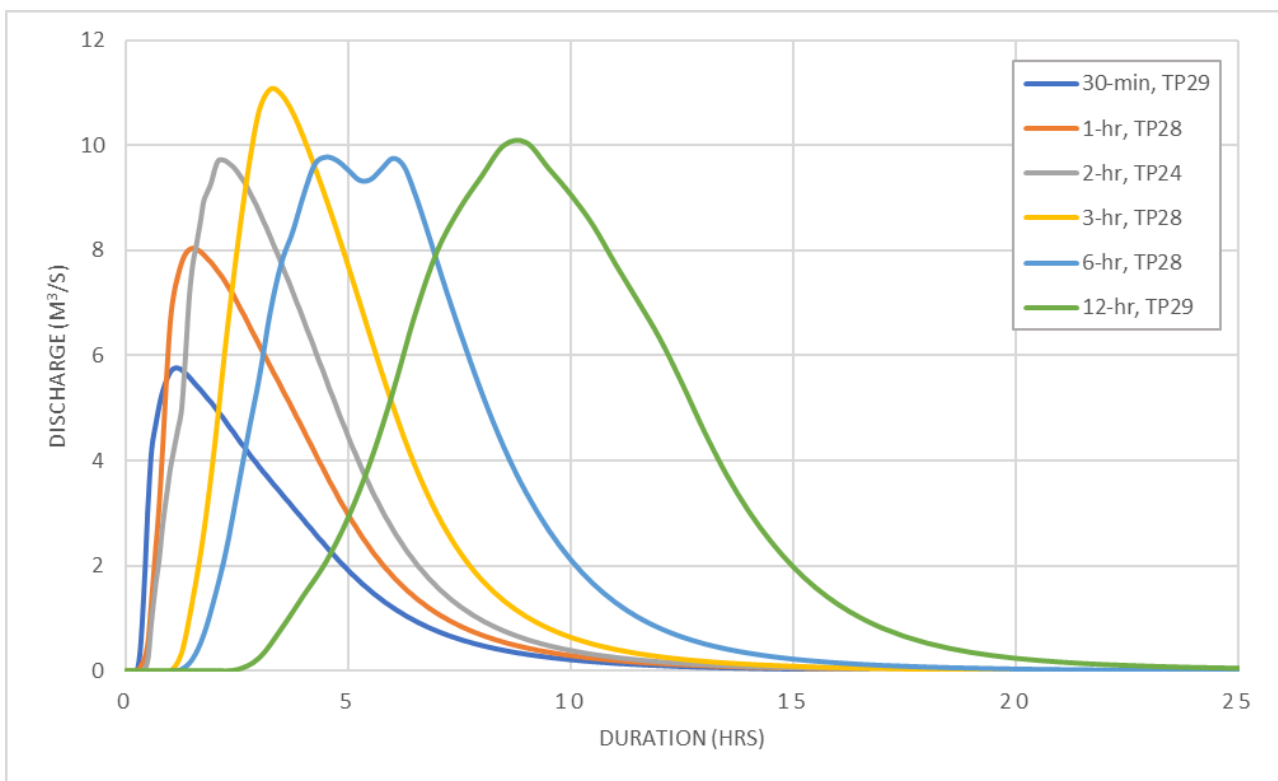


FIGURE 3-8 1% AEP FLOWS AT OUTLET INTO THE YARROWEE RIVER FOR REPRESENTATIVE MODEL SIMULATIONS



4 HYDRAULIC MODELLING

4.1 Overview

This section provides the description of the TUFLOW hydraulic model setup. Model runs were performed with a Highly Parallelized Computing (HPC) solution scheme using the 2023-03-AB build of TUFLOW. HPC technology enables 2D models to utilise the parallel processing ability of graphics cards, with many thousand processors operating in unison, significantly speeding up simulation run times.

Design flood modelling included the 20%, 10%, 5%, 2%, 1% and 0.5% AEP events along with the 1% AEP with the inclusion of climate change under 2100 RCP 4.5, RCP 6 and RCP 8.5. Currently only the 1% AEP events have been modelled.

4.2 2D Domain

4.2.1 Topography

Hydraulic modelling covered Warrenheip Creek from Old Melbourne Road and Ryans Drain from Western Freeway to the Yarrowee River, 300 m downstream (west) of Humffray Street. The 2D model extent is shown in Figure 4-1.

One of the key considerations in establishing a 2D hydraulic model relates to the selection of an appropriate grid size. Grid size affects the representation of the physical properties of the study area as well as the size of the model and its resulting run times. Selecting a very small grid size will result in both higher resolution and longer model run times. In adopting the grid size for the model, the above issues were considered in conjunction with the final objectives of the study. To ensure accurate representation of flooding within the catchment, a grid size of 2 metres was adopted.

Warrenheip Creek and Ryans Drain were represented in the 2D domain, typically 4-6 grid cells wide in the channel and 7-10 grid cells bank-to-bank. The raw LiDAR data was available at a 1 metre grid resolution, this was resampled to a 2 metre grid for inclusion in the hydraulic model. The model topography is shown in Figure 4-1.

Several roads and floodplain features were reinforced using break lines, the most prominent of these included Clarks Road (west of Old Melbourne Road) and its adjacent floodways and Boundary Road.

Earthworks upstream of Old Melbourne Road have increased the elevation of the paddocks between the dam and roadway since the LiDAR data was captured in October 2019. It is understood from the Corangamite CMA that these works were not undertaken with permit and the matter is yet to be resolved. The Corangamite CMA provided guidance on this site and the levels that were captured in the LiDAR dataset (pre earthworks) were maintained.

Manipulation of the LiDAR dataset using polygon and point layers (2d_ztin) in TUFLOW were incorporated to reflect changes in terrain. Such sites included:

- As-constructed conditions for a childcare centre at 340 Humffray Street North.
- Boundary Road culvert and road upgrade.

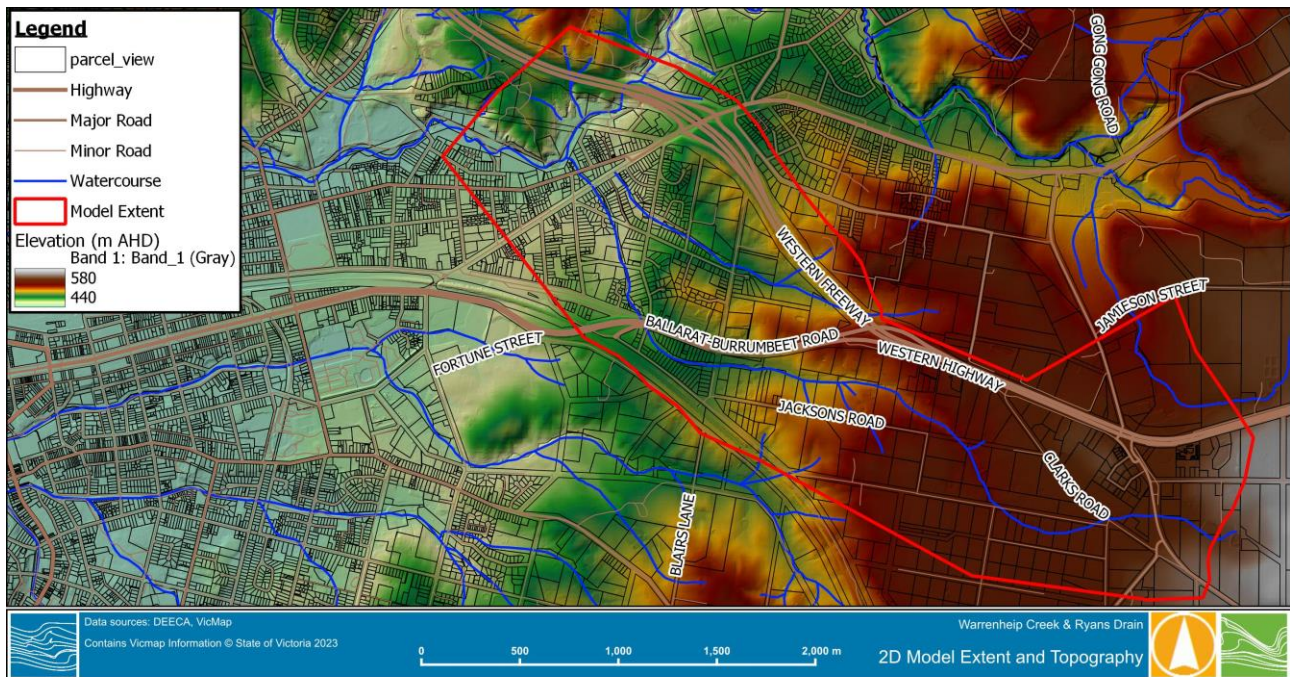


FIGURE 4-1 2D MODEL AREA AND TOPOGRAPHY

4.2.2 Surface roughness

Hydraulic roughness was determined using planning layers and verified using aerial imagery. The Manning's 'n' roughness values adopted for each land use in the hydraulic model is presented in Table 4-1. The adopted roughness's were based on values similar to those used in nearby studies in recent years.

TABLE 4-1 MANNING'S ROUGHNESS USED IN THE MODEL

Land Type	Manning's Value (n)
Residential – Rural (lower density) - when building footprints and remainder of parcel are modelled together (with one roughness value)	0.100
Residential Footprint – Urban (higher density) - when building footprints are modelled separately to remainder of parcel	0.400
Residential – Urban (higher density) - when building footprints are modelled separately to remainder of parcel	0.150
Industrial/Commercial or large buildings	0.300
Open Space or Waterway – minimal vegetation	0.040
Open Space or Waterway – moderate vegetation	0.060
Open Space or Waterway – heavy vegetation	0.090
Open water (with submerged vegetation)	0.020
Car park/pavement/wide driveways/roads	0.020
Railway line	0.125



4.3 1D Network

Underground drainage infrastructure (culverts, pipes and pits) was modelled as a 1D network. CoB provided a GIS database containing information of Council drainage assets in the municipality. All relevant GIS databases were reviewed and combined into two GIS databases; one for pipes and one for pits. Pipes with a diameter equal to and greater than 300 mm were included in the model.

During the review process, gaps in the provided drainage network datasets were found and in some instances it was possible to infer the missing information based on a site visit, engineering judgement, topographical information and cross-checks.

Pits were incorporated in the 1D network as 'weir pits' or 'rectangular pits' which was based on the pit being either a grated pit or side entry pit, respectively. Pits were connected to the surface with an SXL connection (an external connection that lowers the surrounding cells) which lowered them by 100 mm to encourage flow to enter the pits.

Based on the drainage network GIS database and the site visit, all pipes and culverts were modelled as reinforced concrete with a Manning's 'n' of 0.013 adopted. The culvert, pipes and pits modelled are shown in Figure 4-2.

4.4 Boundary conditions

The hydraulic model requires inflow and outlet boundaries to allow water into and out of the model. External inflow boundaries accounted for flow generated from outside of the model extent (external boundaries), whereas internal boundaries account for the runoff generated from within the model extent. Inflow boundaries were obtained from the RORB hydrological modelling described in Section 3.

The TUFLOW model had two external inflow boundaries; one at Warrenheip Creek near Old Melbourne Road and another at Ryans Drain near Western Freeway.

The downstream boundary was based on a water level condition consistent with observed water levels in the Yarrowee River Flood Study (2023). The boundary was located far enough downstream to ensure it did not impact on water levels in the mapped area.

A total of 27 internal inflow boundaries were applied. Internal inflow boundaries were "excess rainfall". These boundaries include runoff after the initial and continuous losses have been deducted. The internal inflow boundaries were applied as source over area boundaries (SA) allowing flow to be distributed along the creeks and drains. This was appropriate as the aim of the study was to map flood risk from the main watercourses. The location of these boundaries is shown in Figure 4-2.

4.5 Design event modelling

Hydraulic modelling was undertaken for the 0.5%, 1%, 2%, 5%, 10% and 20% Average Exceedance Probability (AEP) design storm events as well as the 2100 RCP 4.5, 6 and 8.5 scenarios. Results from the design events will be used to undertake existing conditions flood mapping to produce updated overlays and emergency management information.

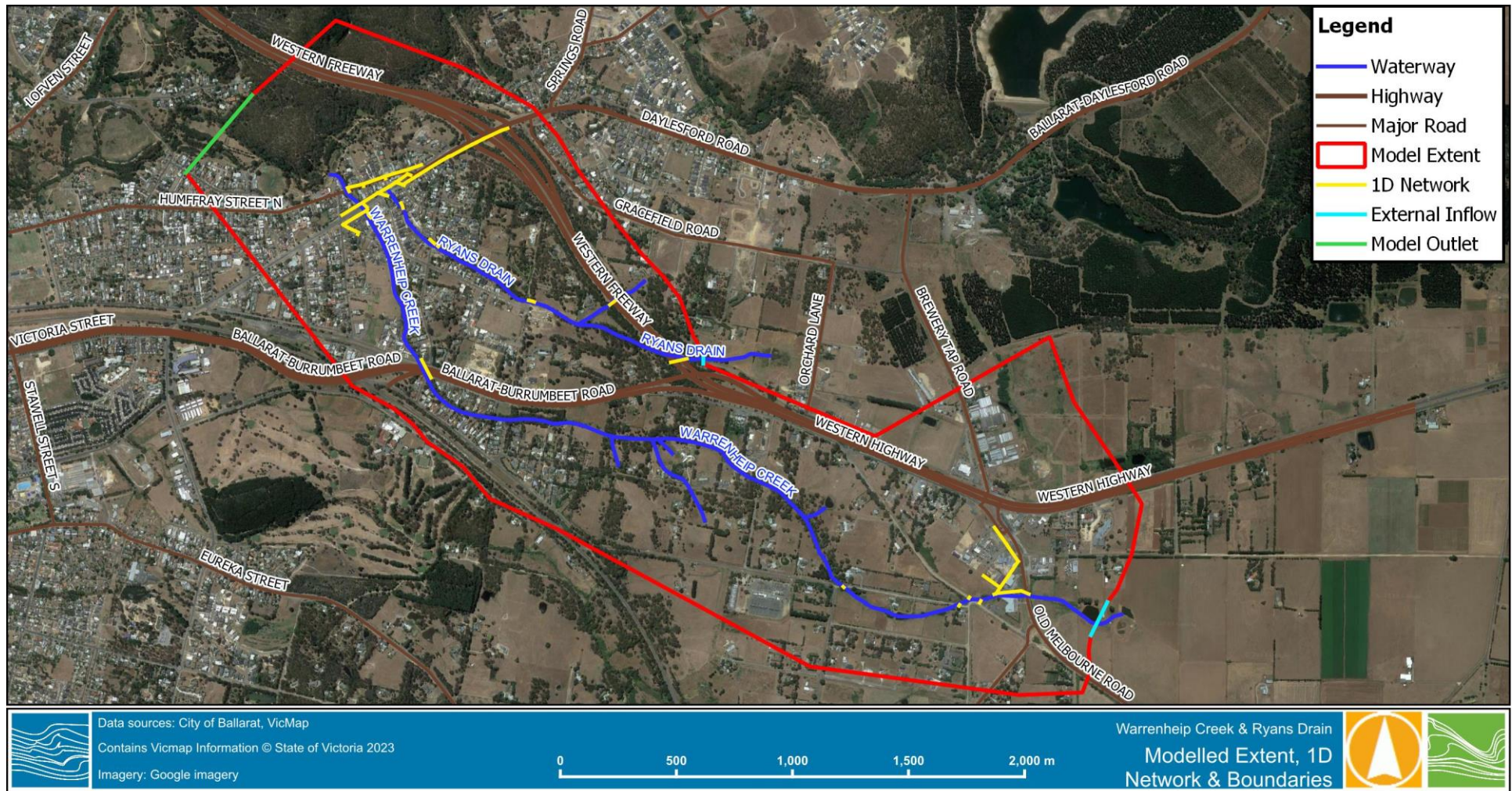


FIGURE 4-2 DRAINAGE INFRASTRUCTURE AND MODEL BOUNDARIES

5 HYDROLOGIC/HYDRAULIC MODEL COMPARISON

The hydraulic and hydrologic model flows were compared to gain an understanding of the differences in their results. A comparison of hydrographs on Ryans Drain at Jones Street is presented in Figure 5-1. The hydraulic model has a sharper peak, which occurs prior to that of the hydrology model. Comparison of total volume shows there is minimal loss in water volume, indicating that there is minimal storage within the catchment.

Peak flows in Warrenheip Creek differ more so than in Ryans Drain, due to the additional floodplain storage. Noticeable areas of storage include upstream of Old Melbourne Road and Victoria Street (Ballarat-Burrumbeet Road). These storages were not included in the RORB model, which routed all inflows to the outlet of Warrenheip Creek. Comparison between flows at Victoria Street (Ballarat-Burrumbeet Road) for the RORB and TUFLOW models are shown in Figure 5-2 below.

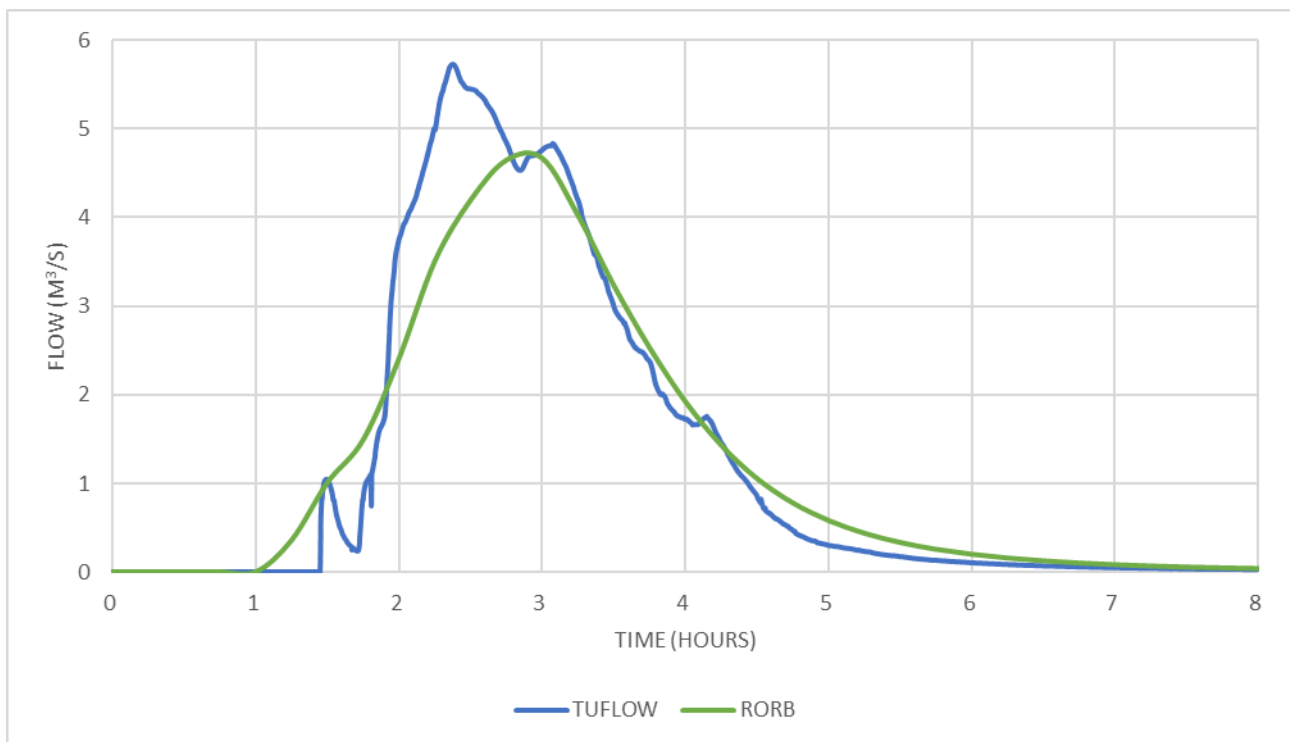


FIGURE 5-1 HYDROLOGIC AND HYDRAULIC MODEL FLOW HYDROGRAPH COMPARISON – RYANS DRAIN AT JONES STREET

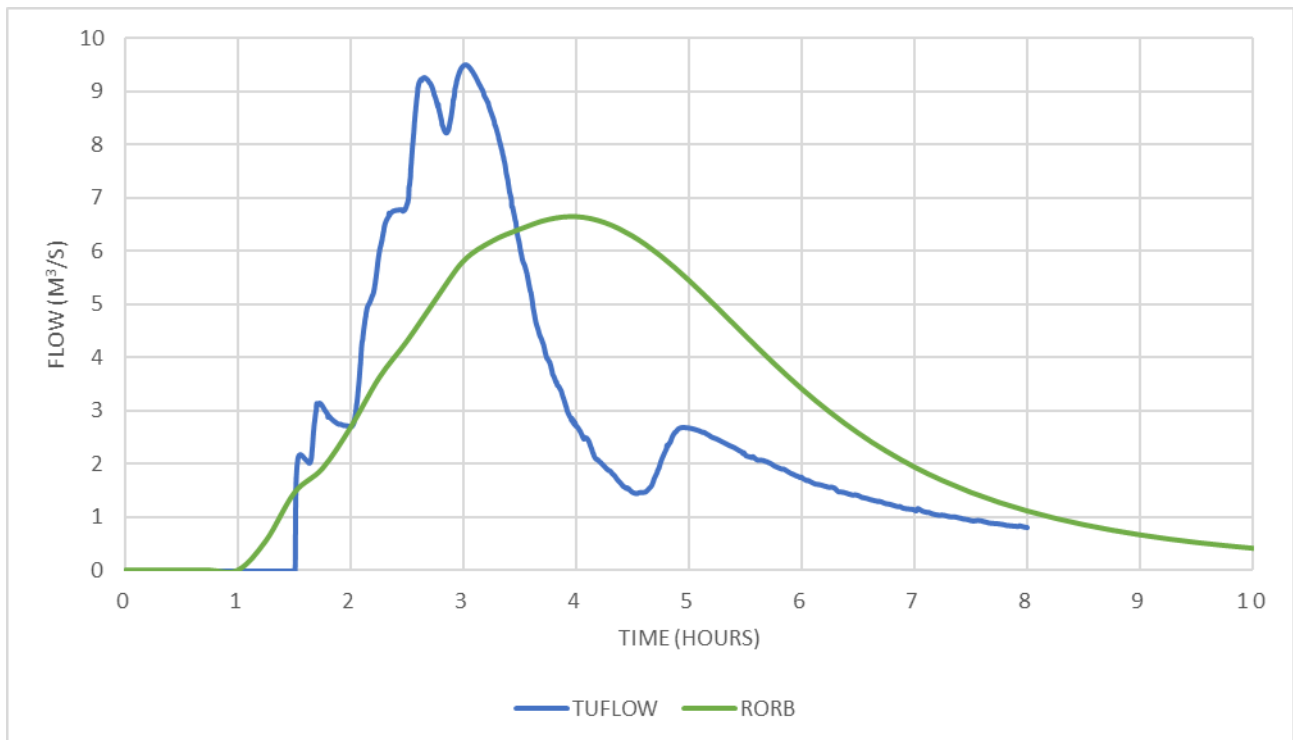


FIGURE 5-2 HYDROLOGIC AND HYDRAULIC MODEL FLOW HYDROGRAPH COMPARISON – WARRENHEIP CREEK AT VICTORIA STREET



6 FLOOD MAPPING AND RESULTS

This section provides an overview of the floodplain mapping process used in the study and presents a selection of the existing conditions mapping outputs. The model produced a series of gridded datasets defining peak water level, depth, velocity and flood hazard throughout the model.

1% AEP event flood depths are presented in Figure 6-1 to Figure 6-4 below.

Results show that flooding upstream of Warrenheip is generally very well contained within the banks of Warrenheip Creek and Ryans Drain.

Results also indicate the most flood-affected areas within the catchment are Water Street and a few properties at the corner of Raymond Court and Water Street. The water ponds in this area due to limited culvert and stormwater drainage capacity.

The results show a significant breakout of flow immediately upstream and downstream of Old Melbourne Road, overtopping the road. It should be noted the LiDAR is different to what is currently present upstream of Old Melbourne Road.

Figure 6-1 also illustrates shallow flooding on Clarks Road. Flow runs along the road reserve, private properties and inundates the road before it flows into farm dams located south of the road.



FIGURE 6-1 MAXIMUM FLOOD DEPTH – 1% AEP (VIEW 1)



FIGURE 6-2 MAXIMUM FLOOD DEPTH – 1% AEP (VIEW 2)



FIGURE 6-3 MAXIMUM FLOOD DEPTH – 1% AEP (VIEW 3)



FIGURE 6-4 MAXIMUM FLOOD DEPTH – 1% AEP (VIEW 4)



Melbourne

15 Business Park Drive
Notting Hill VIC 3168
Telephone (03) 8526 0800
Fax (03) 9558 9365

Brisbane

Level 3, 43 Peel Street
South Brisbane QLD 4101
Telephone (07) 3105 1400
Fax (07) 3846 5144

Adelaide

1/198 Greenhill Road
Eastwood SA 5063
Telephone (08) 8378 8000
Fax (08) 8357 8988

Perth

Ground Floor
430 Roberts Road
Subiaco WA 6008
Telephone 0438 347 968

Geelong

PO Box 436
Geelong VIC 3220
Telephone 0458 015 664

Gippsland

154 Macleod Street
Bairnsdale VIC 3875
Telephone (03) 5152 5833

Wangaratta

First Floor, 40 Rowan Street
Wangaratta VIC 3677
Telephone (03) 5721 2650

Wimmera

PO Box 584
Stawell VIC 3380
Telephone 0438 510 240

www.watertech.com.au

info@watertech.com.au

