

Redan Creek 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 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 City of Ballarat municipality. These updates focussed on recent development (i.e., greenfield) and infrastructure upgrades. The following report details the updated hydrologic and hydraulic modelling for Redan Creek based on the changes made 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.

■ RORB

- Increased FI of subarea K from 0.239 to 0.573.
- Increased FI of subarea F from 0.0 to 0.70
- Increased FI of subarea G from 0.1 to 0.638.
- Increased FI of subarea H from 0.0 to 0.70.
- Increased FI of subarea AO from 0.0 to 0.70.
- Increased FI of subarea AL from 0.139 to 0.70.
- Boundaries of subarea AK and AL were altered to define the extent of residential and parkland land use zones.
- Subareas AG, AI, AH and AE were removed from the RORB model.
 - These subareas are technically located in the Bonshaw Creek catchment as large stormwater pipes convey flows into the Bonshaw Creek; however, previous modelling has indicated that overland flows can enter the Redan Creek catchment during extreme events. To replicate this, the subareas were removed from the Redan Creek RORB model, so they did not influence the critical duration assessment. Their inflow hydrographs (from the Bonshaw Creek RORB model) were then included in the hydraulic model to account for any overland flows exiting the Bonshaw Creek catchment during the modelled storm events.
- Reach types were altered so that constructed channels were represented as type 3 (lined), general stormwater infrastructure and overland flows in urban areas were represented as type 2 (excavated unlined) and overland flows in open spaces were represented as type 1 (natural).

■ TUFLOW

- Based terrain was updated to feature the 2019 LiDAR dataset that has a resolution of 1-metre.
- 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.
- 1D open channels previously used to model the constructed channels in the Redan Creek catchment were removed. These channels are now modelled in the 2D domain using Sub-Grid-Sampling (SGS).
- Inflows upstream of Subarea H were previously modelled as one inflow region in the open channel located between Queen Victoria Street and Salisbury Avenue. Inflows for each of the subarea upstream of H are now modelled individually as pit inflow regions. The following subareas have now been included as individual pit inflow regions:
 - Subarea J, K, F & H

- Updated stormwater drainage network in the following road reserves to accommodate for new inflow regions:
 - Exchange Street
 - Murray Street
 - Inkerman Street
 - Smith Street
 - Collard Street
 - Stewart Street
- Increase the size of the pit inflow region for subarea AF and H to distribute inflow across more pits.
- Inflow regions for subareas AA, AB and AC were increased in size to include more pits and only select pits with that are connected to pipes with diameters equal to or greater than 300mm.
- Pit inflow region for subarea Z was split into two regions and placed over pits that connect to pipes with diameters equal to or greater than 300mm.
- Inflow regions for subareas O and V were increased in size to include more pits along Rubicon Street.

Initial simulations for the updated model used the original 1D open channels. However due to the changes in the topography, this approach encountered instabilities. To improve the stability of the model, the open channels were modelled in the 2D domain using Sub-Grid-Sampling (SGS). Using SGS has allowed for the 2D domain to still be modelled at a 2m grid cell size while utilising the underlying (1-metre) LiDAR, allow for more accurate representation of conveyance in the open channels.

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1 INTRODUCTION

1.1 Background

Water Technology was commissioned by the City of Ballarat in 2018 to carry out the Redan Creek Flood Modelling Update Project. The original project was commissioned to improve the flood risk knowledge, address information gaps and provide valuable planning and flood intelligence within the Redan Creek catchments.

The Redan Creek catchment drains predominately well-established residential areas from Ballarat Central and Lake Wendouree surrounds in a southerly direction almost parallel to the Yarrowee River before outfalling into the Yarrowee River at the Redan-Yarrowee Wetland Reserve. A map of the Redan Creek and its catchment is shown in Figure 1-1.

The flood modelling and mapping undertaken in this project was based on the updated guidelines outlined in Australian Rainfall and Runoff (ARR) 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:

- Hydrologic modelling of the Redan Creek catchment including modelling methodology, results and inputs to the hydraulic model.
- Hydraulic modelling of Redan Creek including modelling methodology and results.
- Flood depth 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 Redan Creek Catchment and Waterway

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.

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 Redan Creek catchment was delineated based on 1-metre LiDAR data captured in 2011. The catchment (5.77 km²) was delineated into 39 sub-areas, as shown in Figure 3-1. The LiDAR data was used as a basis for the delineation, ensuring an even distribution of similar sized sub-catchments with a minimum of three sub catchments upstream of each print point used as an inflow location to the Redan Creek hydraulic model.

A series of nodes and reaches were defined in the RORB model to represent the model routing characteristics. Flow hydrographs were extracted from the RORB model and input as inflows into the hydraulic model. The model reaches were defined as 'natural', 'lined channel' or 'pipe' based on the typical flow regime along each section of the catchment. These definitions were derived from expected flow characteristics based on the aerial photography and the site visit.

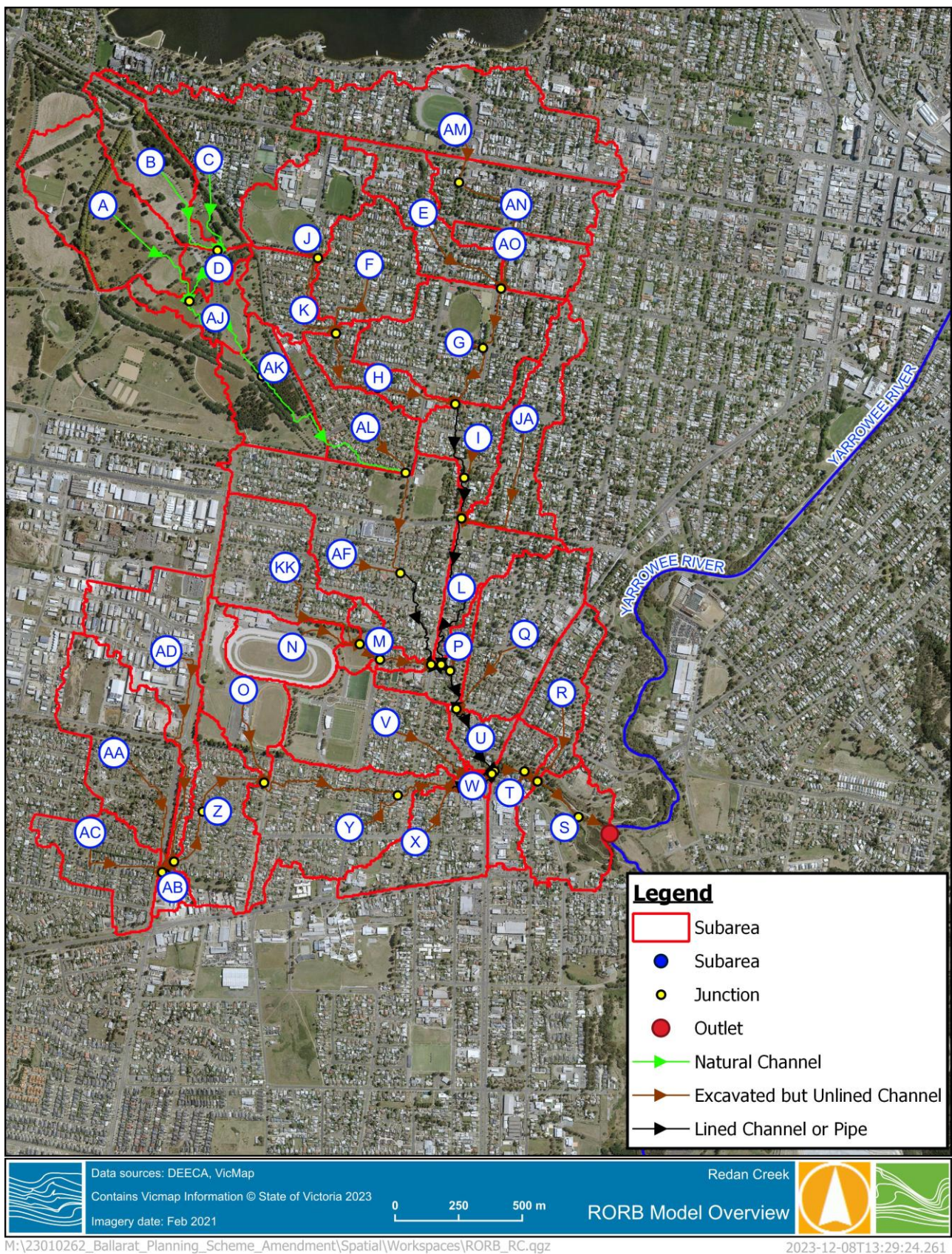


Figure 3-1 RORB Model Structure

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 City of Ballarat 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 of 0.1 was adopted for areas of open space due to the presence of constructed drains in both the parks areas located in the upper part of the catchment.

Table 3-1 Adopted FI values used in RORB Model

Land use	Adopted FI
Open space including farming	0.1
Residential	0.75
Industrial	0.9

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

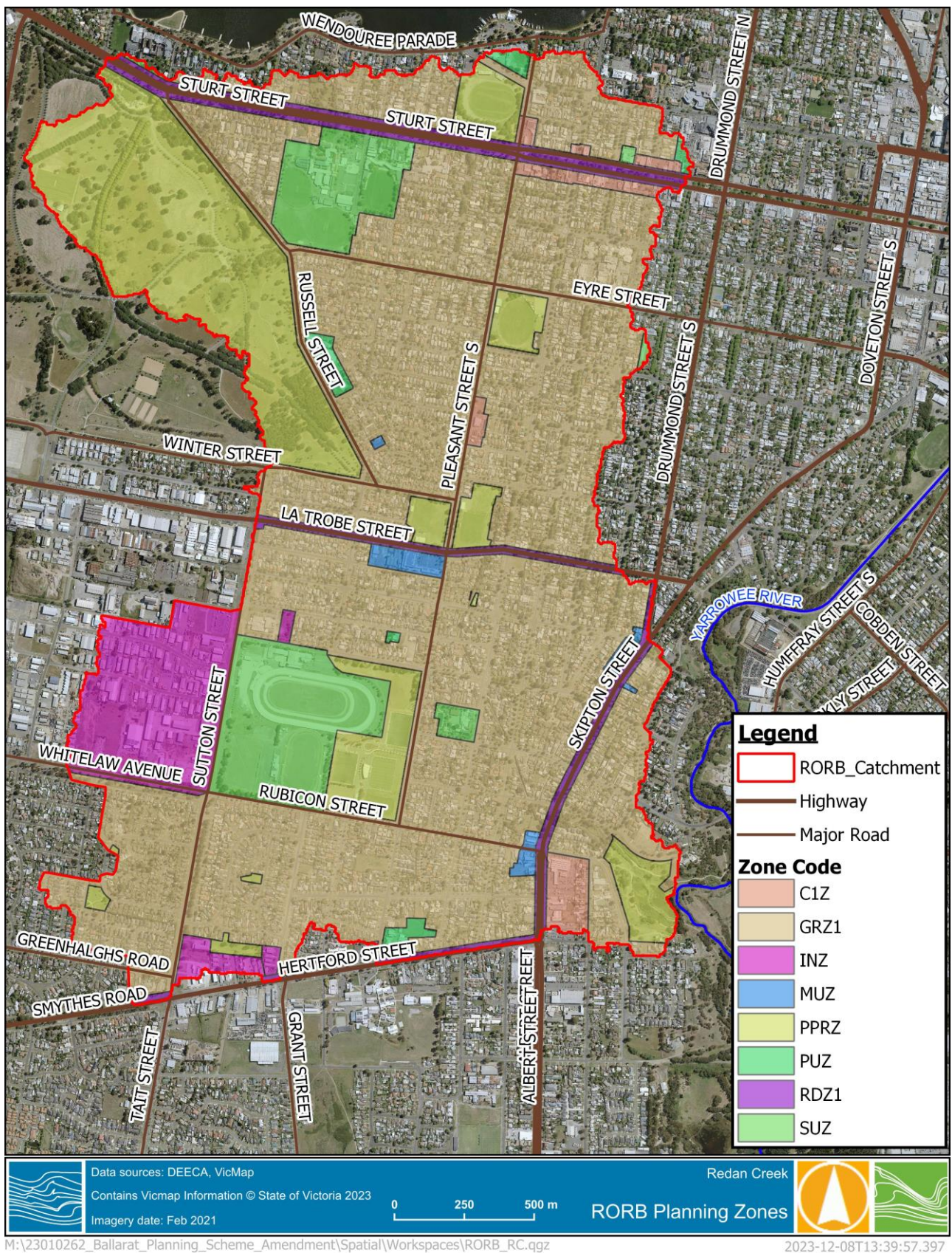


Figure 3-2 Land Use Areas Based on Planning Zones

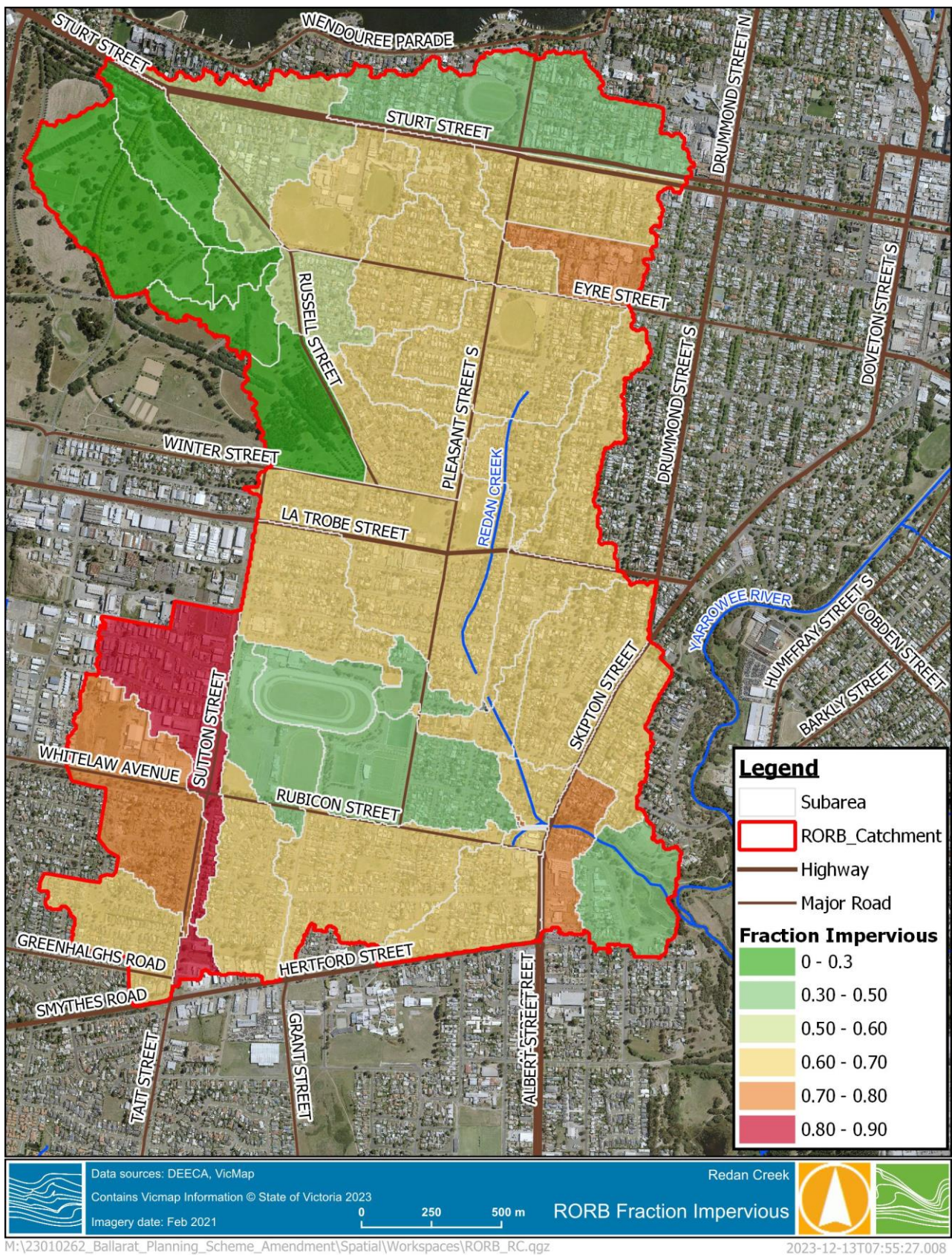


Figure 3-3 Fraction Impervious used in the Study

3.2.3 Routing Parameter (k_c)

As mentioned in Section 2.1, there were no streamflow gauges in the study area to calibrate the RORB model. 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 four datasets.

Table 3-2 Equation Based k_c Estimates

Source	Equation	k_c Estimate
Victoria (Mean Annual Rainfall <800mm)*	$kc = 0.49 * A^{0.65}$	1.53
Victorian based data (Pearse et al, 2002)	$kc = 1.25 * D_{av}$	3.47
Australian based data (Dyer, 1994)	$kc = 1.14 * D_{av}$	3.00
Australian based data (Yu, 1989)	$kc = 0.96 * D_{av}$	2.52

For the Redan Creek catchment, the Pearse et. al. (2002) estimation method of k_c was chosen. The data the equation is based on is most relevant (Victorian based) and in Water Technology's experience with gauged catchments, has shown to match gauge Flood Frequency Analysis data best. The $C_{0.8}$ was taken to have a value of 1.32, consistent with the expected value from Pease et al (2002). Given that d_{av} equals 2.63 km for the RORB model, a k_c value of 3.47 was adopted for the study.

An estimate of k_c was also compared 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 kc 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 (Gnarr Creek)	2.96	2.34	1.26	3.33
Canadian Creeks	8.46	3.56	2.38	6.25
Kensington Creek	5.6	4.52	1.24	3.26
Bonshaw Creek	5.37	4.58	1.17	3.08

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 2016. 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 Redan Creek 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 Durations and AEP

Duration\AEP	20%	10%	5%	2%	1%	0.5%
30-min	17.6	21.9	26.4	32.9	38.3	43.66
1-hr	21.9	27	32.4	40	46.4	52.9
2-hr	26.9	32.8	38.9	47.5	54.6	62.24
3-hr	30.5	36.8	43.4	52.7	60.3	68.74
6-hr	38.5	45.9	53.5	64.4	73.2	83.45

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

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

3.2.4.2 Temporal Patterns

The 10 temporal patterns as downloaded from ARR 2019 Data Hub⁵ were used to simulate the distribution of burst rainfall depths 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 of the study area is 5.77 km², 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 datahub⁵ suggested losses of 25 mm initial loss and 4.4 mm/hr continuing loss.

Redan Creek is a tributary of the Yarrowee River and converges with it downstream of the Ballarat CBD. Calibration of the Yarrowee River and Gnarr Creek hydrological model was completed in 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 Redan Creek 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 initial and continuing loss for the Redan Creek catchment are shown in **Error! Reference source not found..**

Table 3-5 Adopted RORB Model Parameters for Design Modelling

Parameter	Adopted Value
M	0.8
Kc	5.6
Initial Loss (mm)	25.0
Continuing Loss (mm/hr)	2.0

3.3 Design Modelling

A RORB Monte Carlo analysis was used to determine the design peak flows at several key locations within project catchment. A Monte Carlo simulation was run in RORB to determine the maximum peak flow for each design event and their correlating critical duration. RORB Version 6.45 has the option to select the representative hydrograph from the 10 available temporal patterns and the critical duration at the selected output location for the specified AEP. The temporal pattern chosen resulted in the peak flow immediately higher than the median flow peak flow from Monte Carlo simulation. RORB focuses on selecting an individual run that matches the peak flow from Monte Carlo runs for the determined critical duration, and then focuses on matching the burst depth for the correct AEP. The closest rainfall depth matches within 5% tolerance. If more than one hydrograph is found, the tolerance is lowered.

RORB was simulated with the selected temporal pattern for each AEP event and critical duration. The flow chart outlined in Figure 3-4 demonstrates the modelling process.

⁵ <http://data.arr-software.org/>

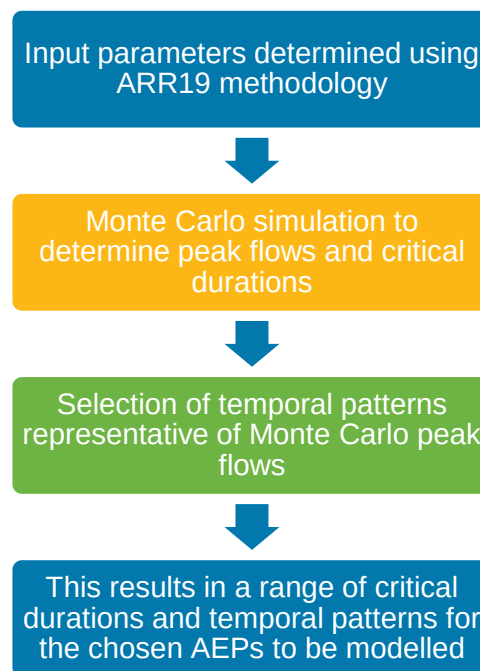


Figure 3-4 Design modelling flow chart

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 simulations, 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 the Monte Carlo approach is presented in Figure 3-5. The critical duration for several print locations where the comparison of critical duration is undertaken throughout the model is shown in Table 3-6. These print locations are shown in Figure 3-6.

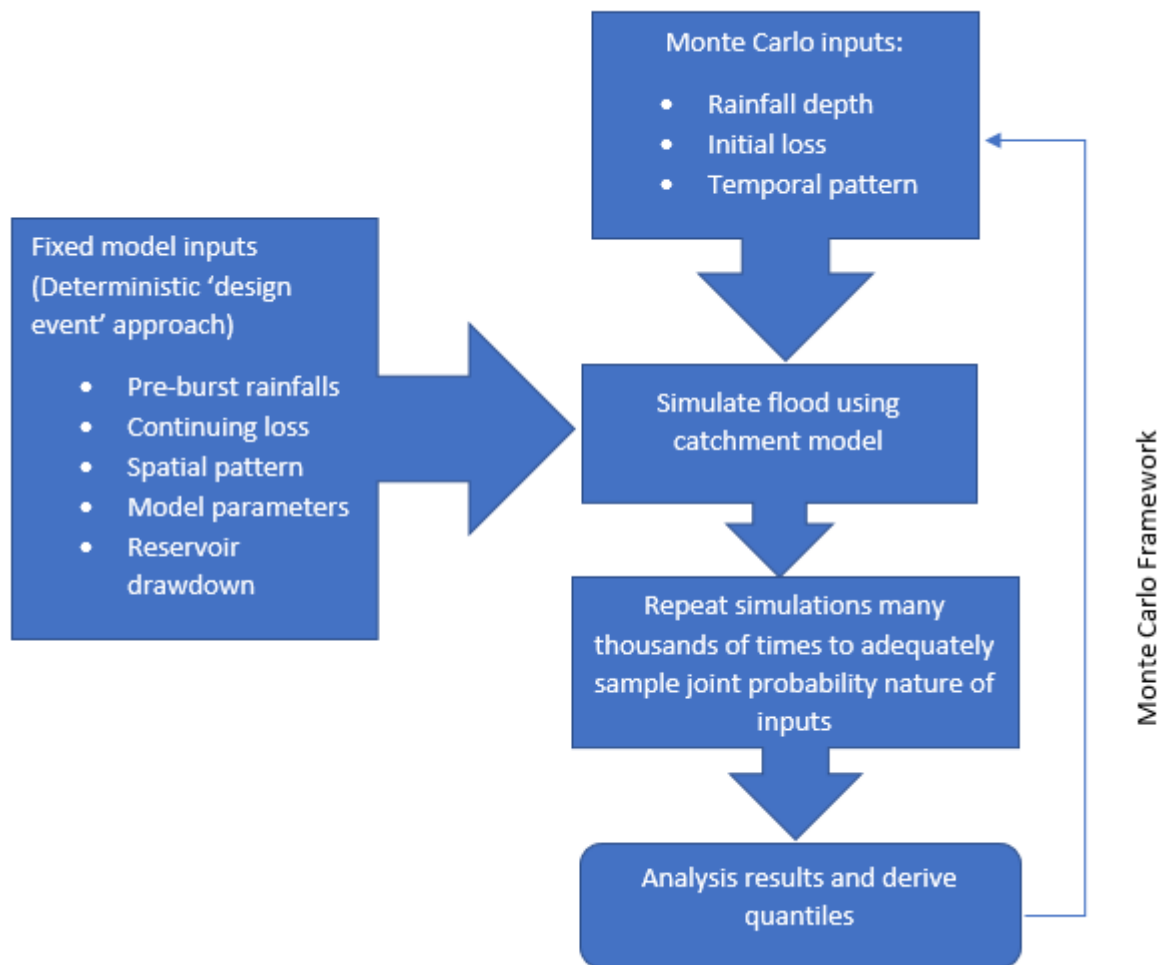


Figure 3-5 Overview of Monte Carlo Analysis

Table 3-6 RORB Critical Durations along Redan Creek

Location	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP
Upper Catchment B	6-hr	3-hr	2-hr			
Mid Catchment B+C	1-hr		30-min			
Upper Catchment C	1-hr		30-min			
Mid Catchment A	1-hr					
Lower Catchment	1-hr		30-min			
End of Catchment	1-hr		30-min			

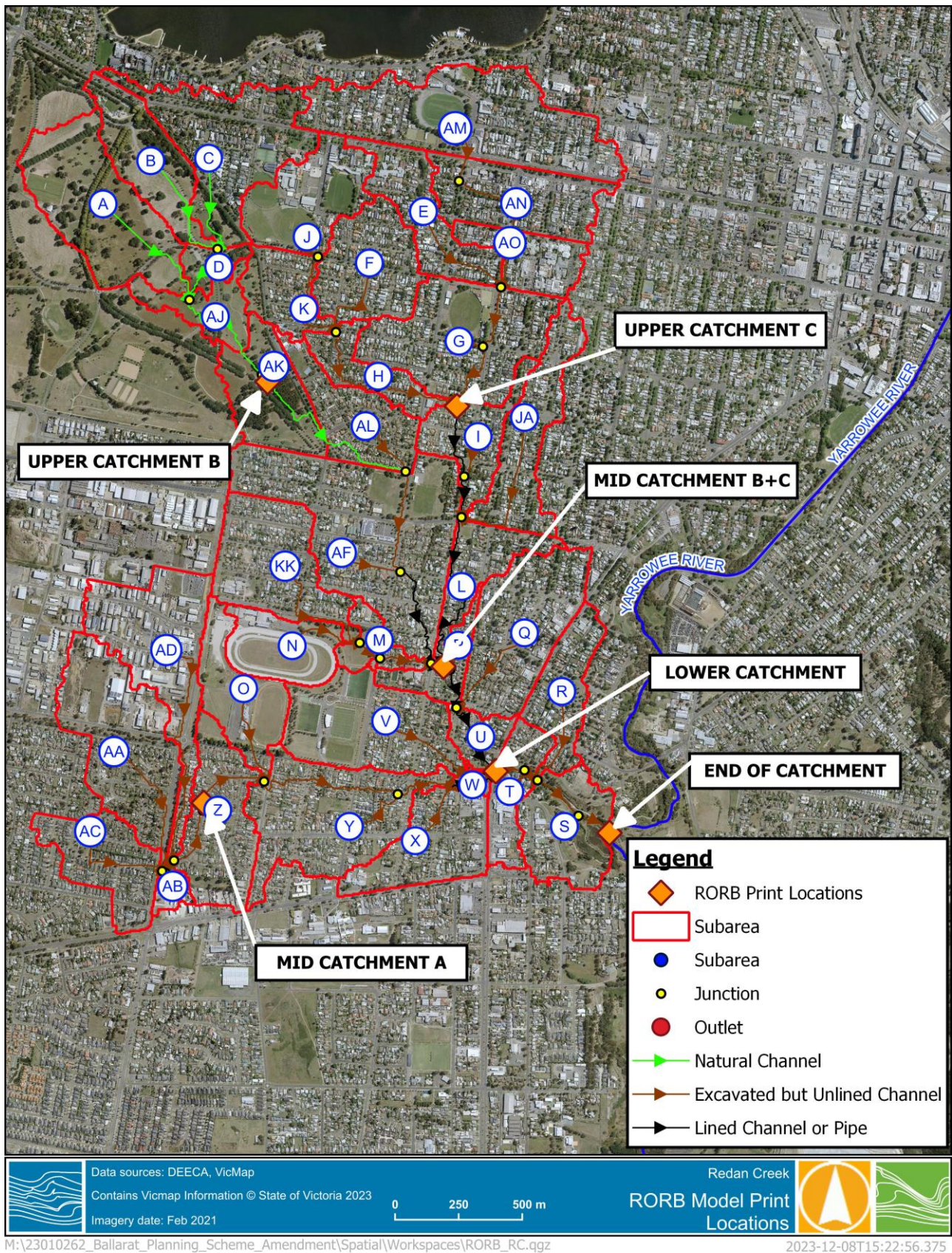


Figure 3-6 Redan Creek Hydrograph Print Locations

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 3.47 and calibrated losses of 24 mm initial loss and 2.0 mm/hr continuing loss, the RORB Ensemble Analysis was run for all 10 ARR2016 recommended temporal patterns for each event duration and AEP. 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 temporal pattern resulting in an Ensemble Analysis peak flow closest to the Monte Carlo analysis peak flow was selected for each output location. 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 design storms in the 1% AEP event displayed in Figure 3-7

Table 3-7 Chosen Representative Temporal Patterns and Durations for each AEP

Critical Duration & Temporal Pattern	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP
	1-hr, TP06	1-hr, TP12	30-min, TP20	30-min, TP26	30-min, TP25	30-min, TP25
	1-hr, TP10	1-hr, TP19	1-hr, TP15	30-min, TP29	30-min, TP26	30-min, TP30
	6-hr, TP06	3-hr, TP20	2-hr, TP20	30-min, TP30	1-hr, TP23	1-hr, TP23
				1-hr, TP23	2-hr, TP30	2-hr, TP25
				2-hr, TP30		

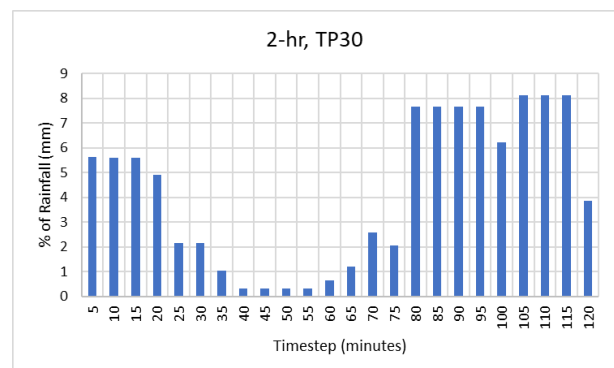
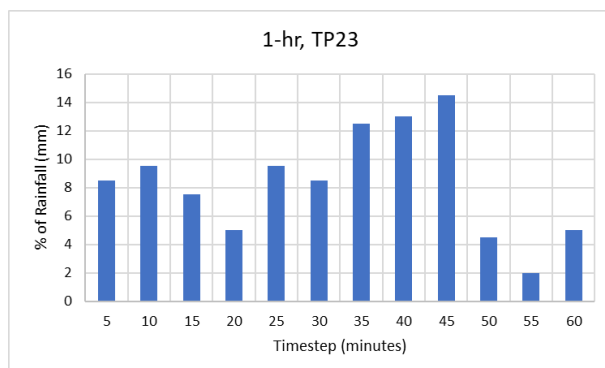
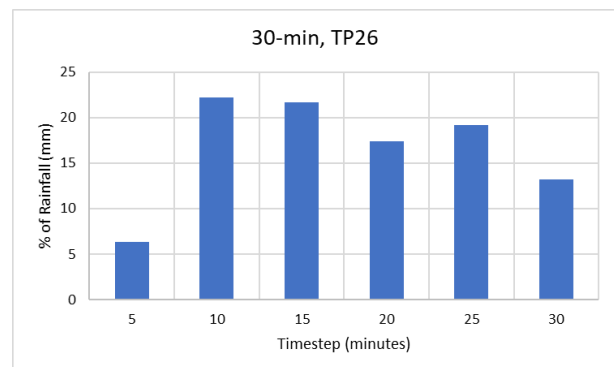
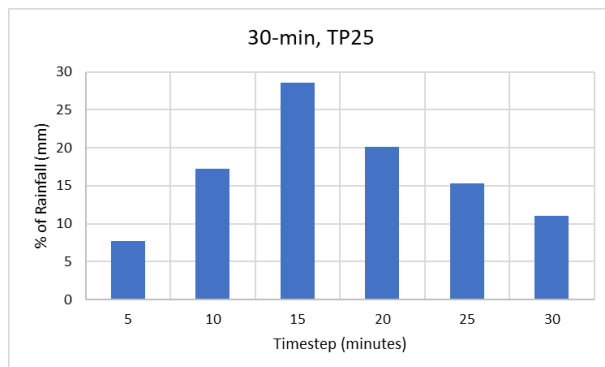


Figure 3-7 Adopted Temporal Patterns for 1% AEP Design Modelling

3.3.3 Design Simulations

The RORB model was used to produce inflow hydrographs that were placed the along the Redan Creek to represent flows for the 20%, 10%, 5%, 2%, 1% and 0.5% AEP evets. The resulting Redan Creek 1% AEP outflows from the RORB model for each duration event are plotted in Figure 3-8.

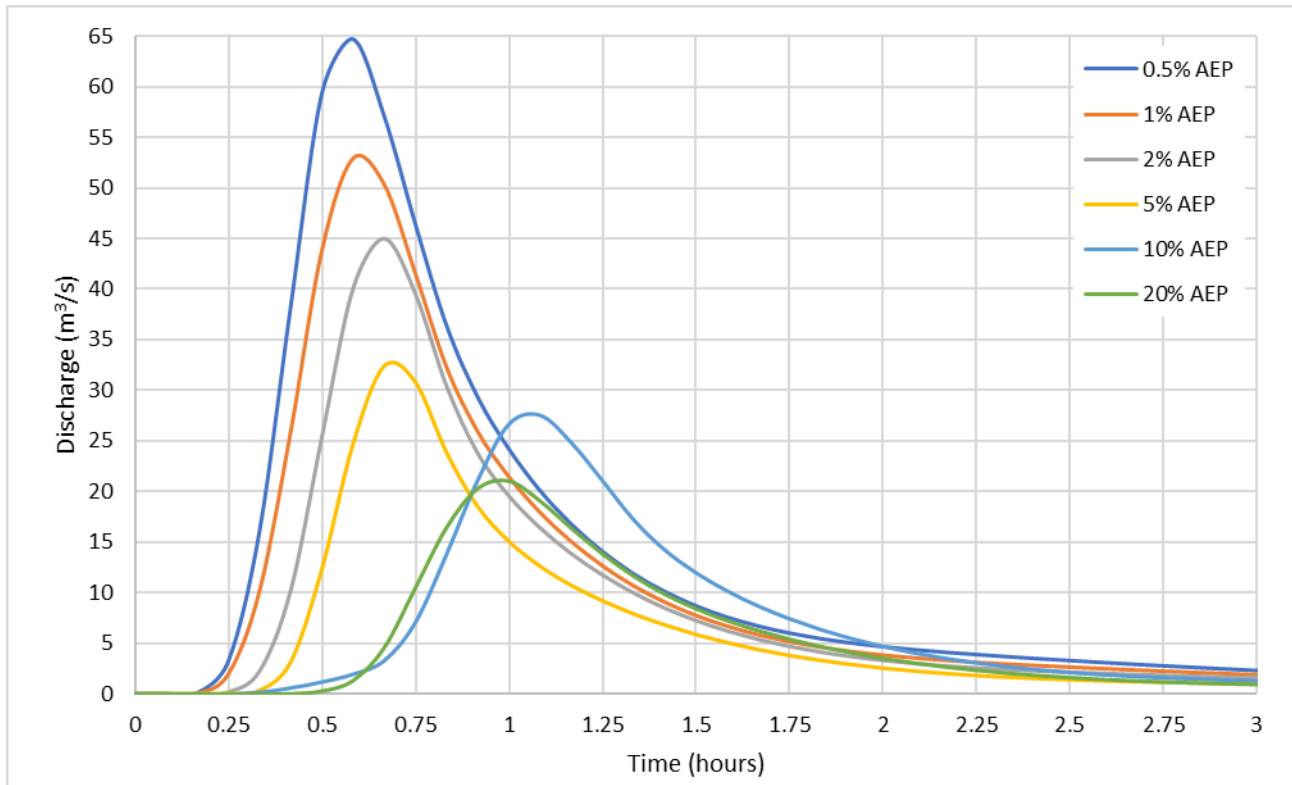


Figure 3-8 Flows at model outlet (Downstream of Skipton Street) for all Critical Design Events

4 HYDRAULICS

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 and Sub-Grid-Sampling (SGS). 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. Using SGS allows for the hydraulic model to adopt a coarser grid cell size for the entire model, but storage and conveyance in the open channels are being appropriately represented with the 1-metre LiDAR dataset.

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.

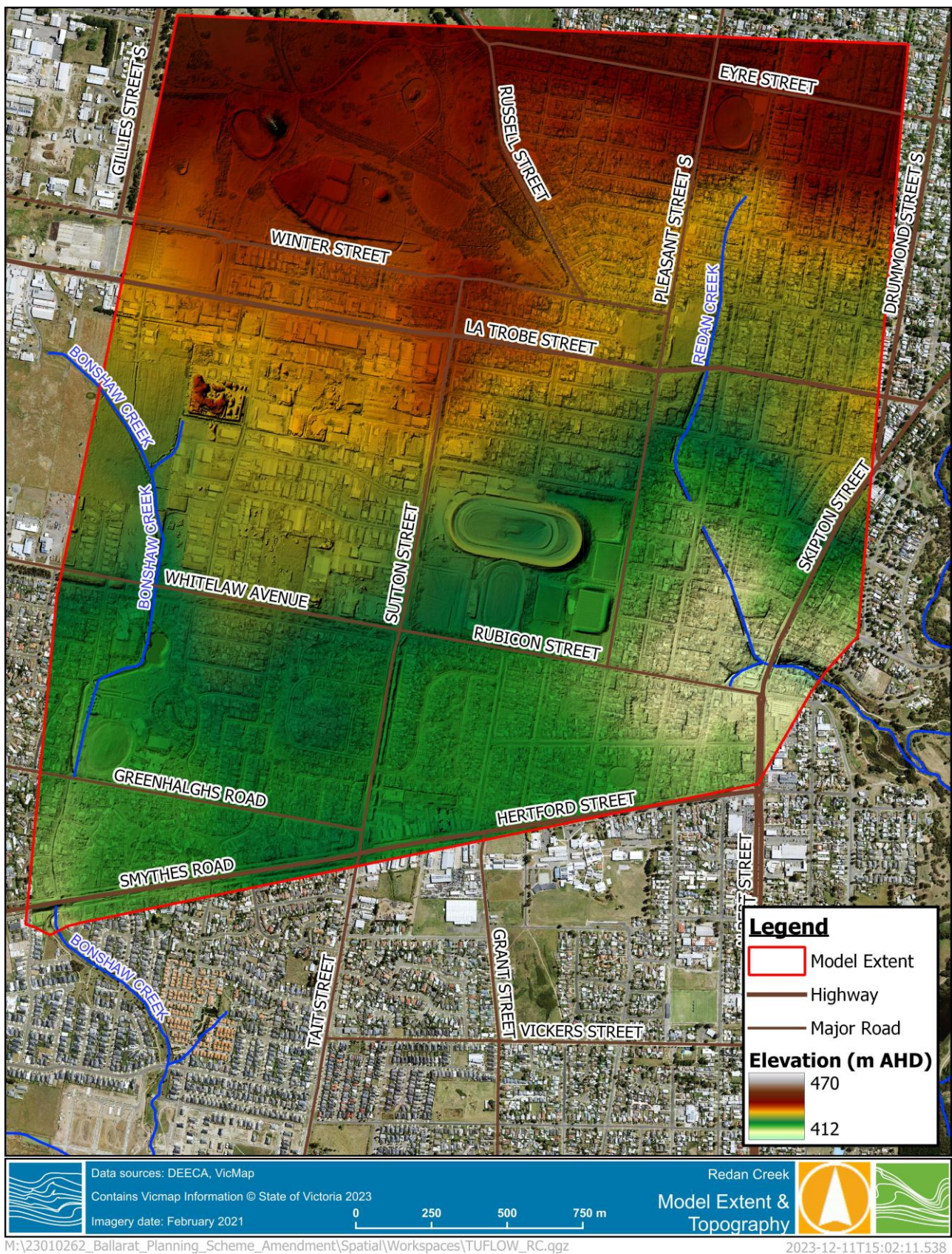
4.2 2D Domain

4.2.1 Topography

The hydraulic model topography was based on 1-metre resolution LiDAR data captured in 2019. The LiDAR data was resampled within TUFLOW to a 2-metre grid resolution output of the hydraulic model, as shown in Figure 4-1 below.

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 above grid size for the model and utilising 1 metre SGS, the above issues were considered in conjunction with the objectives of the study.

The Redan Creek is largely concrete/brick lined channels that are typically narrow (4-8-metres wide) and flows between properties. The model extent was represented in the 2D domain using SGS which allowed for the channel capacity to be captured while a larger grid size (2m) was adopted.



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Figure 4-1 Hydraulic Model Extent 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 Manning's Roughness Used in the Hydraulic Model. The adopted roughness's were based on values similar to those used in nearby studies in recent years. An overview of the Manning's 'n' values used in the hydraulic model is shown in Figure 4-2 below.

Table 4-1 Manning's Roughness Used in the Hydraulic Model

Land Type	Manning's Value (n)
Residential – Urban (Higher density)	0.35
Industrial/Commercial or large buildings on site	0.15
Parks/Recreation	0.05
Open Space or Waterway – minimal vegetation	0.04
Open Space or Waterway – heavy vegetation	0.09
Car park/pavement/wide driveways/roads	0.02
Concrete Lined Channels	0.025

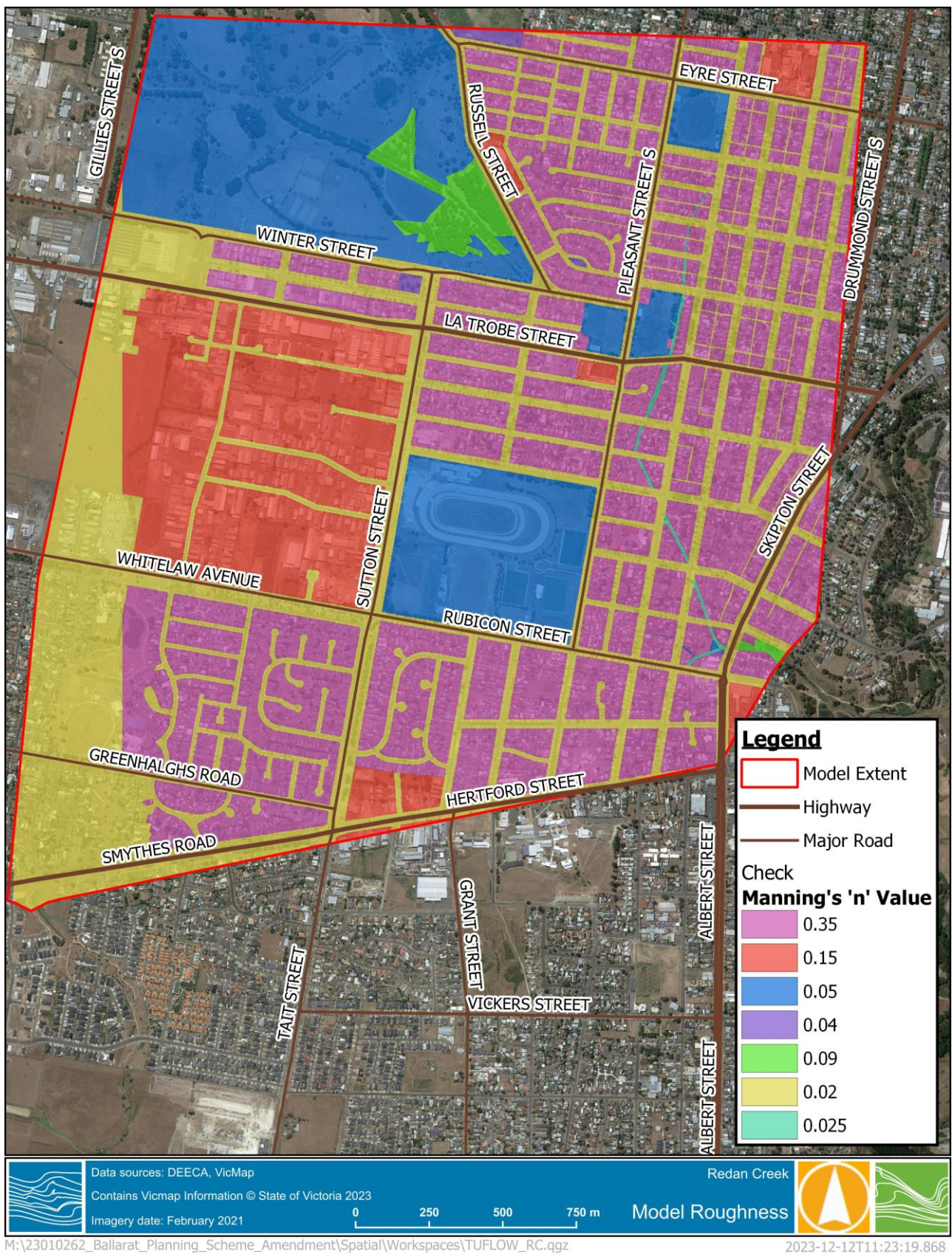


Figure 4-2 Detailed Hydraulic Roughness Map

4.3 1D Domain

Underground drainage infrastructure (culverts, pipes and pits) was modelled as a 1D network. City of Ballarat 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 4-3.

4.4 Boundary Conditions

4.4.1 Model Inflows

Inflow boundary conditions were extracted from RORB at 27 locations throughout the Redan Creek catchment. Additionally, inflow boundary conditions from the Bonshaw Creek catchment were extracted from the Bonshaw RORB model and inserted into the Redan Creek model. This was done to capture any potential of cross-catchment runoff between the Redan Creek and Bonshaw Creek. All of these inflow conditions were modelled as source-area (SA) boundary types. Two types of source-area inflow boundary types were adopted, direct inflow and pit inflow regions. Direct inflow applied the runoff hydrograph directly to the 2D domain, while the pit inflow equally divided the flows amongst the selected pits. The hydraulic model inflow locations are shown in Figure 4-3.

4.4.2 Model outflows

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

4.5 Design Event Modelling

Hydraulic modelling is to be 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. Currently only the 1% AEP events have been modelled.

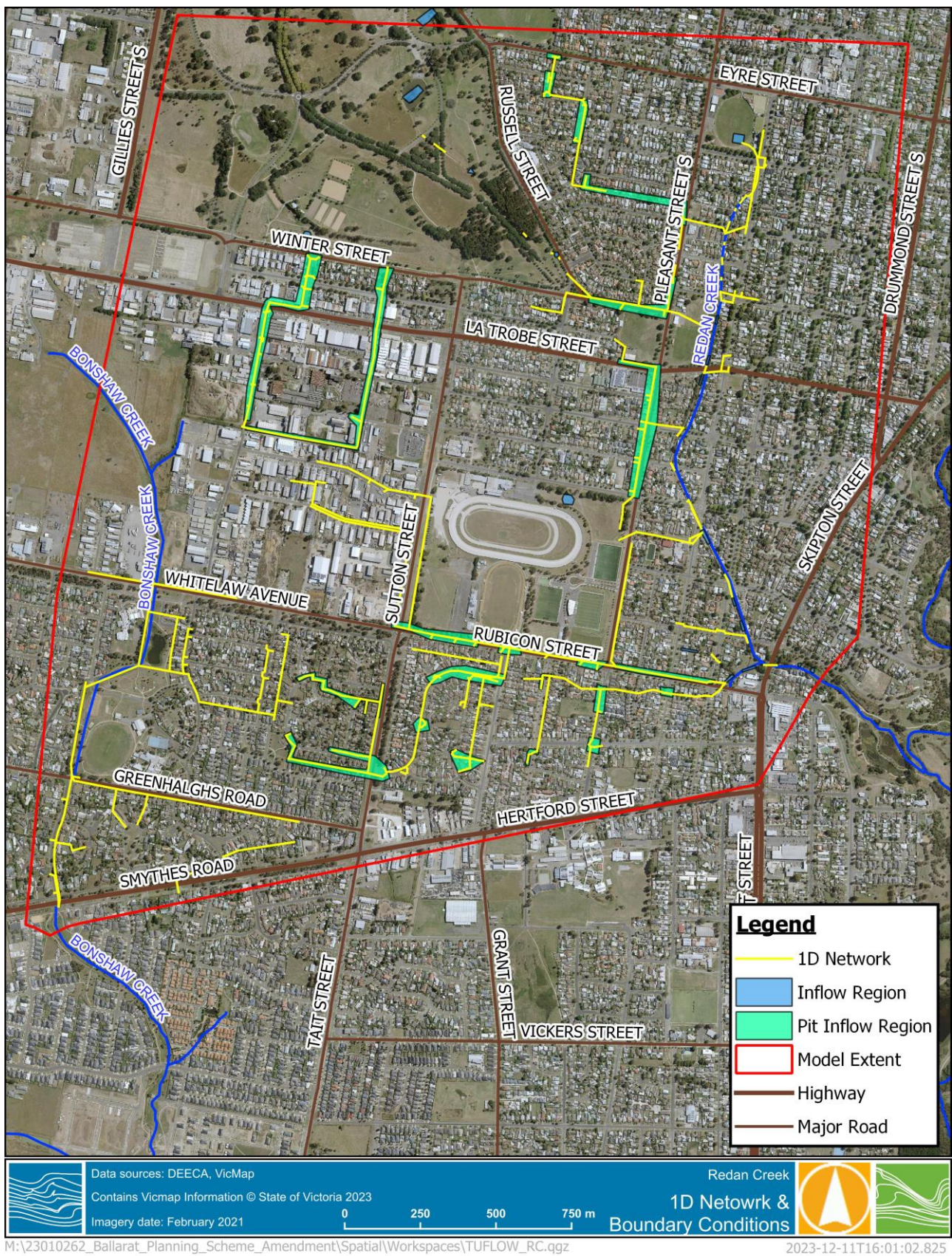


Figure 4-3 1D Network and Model Boundaries

5 RESULTS

5.1 Hydraulic Model Validation

The hydraulic and hydrologic model flows were compared to gain an understanding of the differences in the results. A comparison of hydrographs at the outlet of both models, downstream of Skipton Street, is shown in Figure 5-1 below.

The hydraulic (TUFLOW) model indicates a peak flow of approximately 23 m³/s while the hydrologic model displays a flow of approximately 53 m³/s. The key difference between the two peak flows being the Skipton Street hydraulic control which is not included in the hydrology (RORB) model.

The overall shape of the hydrographs and timing of the peak flows is relatively consistent between the RORB model and TUFLOW model. The RORB model (which has no storages included in its modelled catchment) does not account for constrictions and localised storages within the catchment which are captured in the hydraulic model. The shape of the hydraulic hydrograph declines at a much slower rate than the hydrologic model, which is consistent with a catchment featuring hydraulic controls whereby flows are retarded.

While there is a difference in the peak flows between the two hydrographs, the total volume leaving the models was measured at 105 and 133 megalitres for the hydraulic and hydrologic models, respectively. The difference of approximately 20 megalitres can be attributed to flows captured in basins and upstream of roadways with hydraulic controls, such as Skipton Street, Pleasant Street South and Victoria Park.

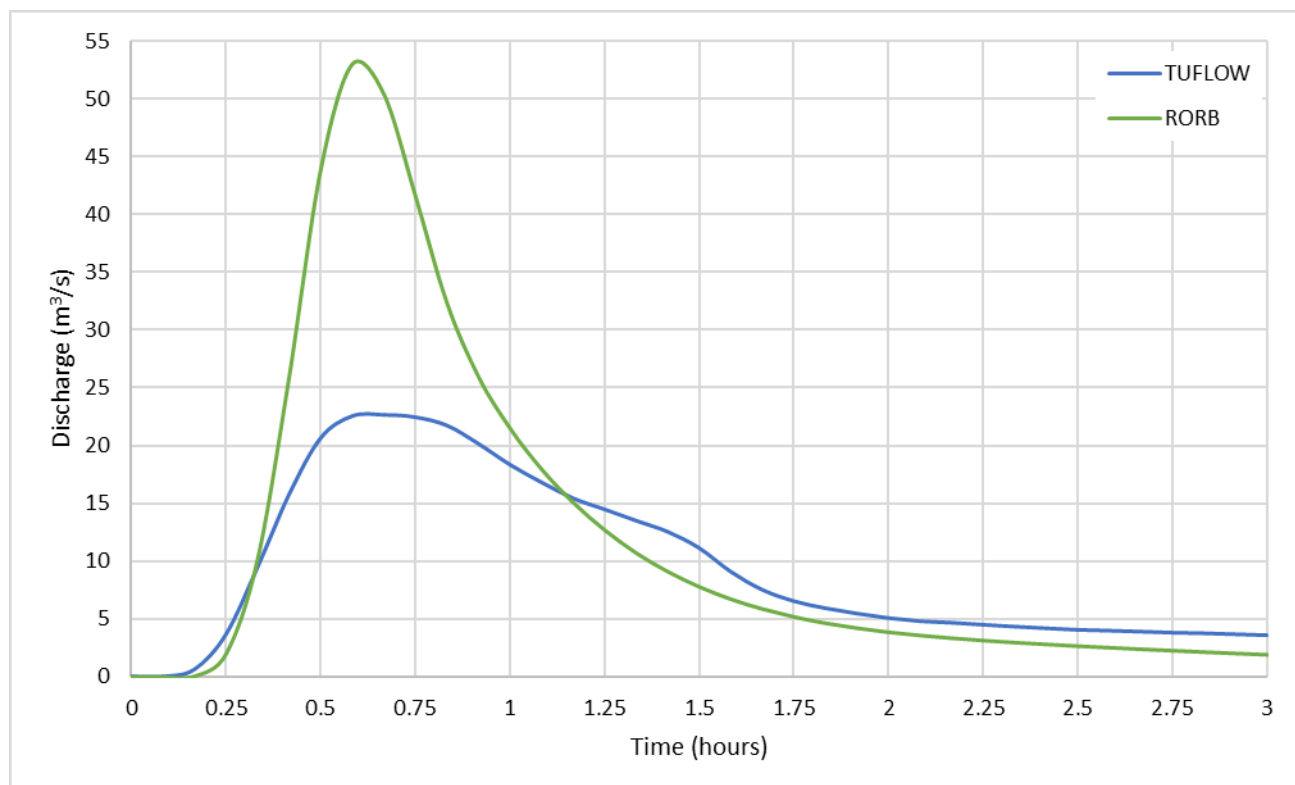


Figure 5-1 Hydrologic and Hydraulic Model Flow Hydrograph Comparison

5.2 Flood Mapping Results

Mapping of the Redan Creek flood outputs underwent post-processing whereby all modelled durations and temporal patterns for each design event (i.e., 1% AEP) were compared and the result grids were spliced together to generate maximum result grids outputs. Outputs from this study include depth, velocity, water surface elevation, and flood hazard. Mapping of the 1% AEP peak depths is presented in Figure 5-2 to Figure 5-3 below, with the remaining outputs to be delivered to the City of Ballarat as separate appendices.

During the 1% AEP flood event, flows escape from the Redan Creek constructed open channels in numerous locations. Some of the critical locations where large clusters of properties are inundated include areas west of Queen Victoria Street, north of Winter Street and Pleasant Street South between Darling Street and Kent Street. Flood depths in these areas are primarily less than 0.3 metres.

Along the main waterway, many properties are impacted by inundation due to waters escaping the constructed channels. Flood depths during the 1% AEP range from 0.3 to 1.0 metres with deeper areas located closer to the constructed channel.

The southern catchments of the Redan Creek show a large amount of flooding in the road reserves, which encroaches onto several properties. Flooding that is impacting these properties is generally less than 0.3 metres.

There are two noticeable storages located within the Redan Creek catchment, the basin east of Bray Raceway and the confluence upstream of Skipton Street. Water levels in the basin east of Bray Raceway engage the spillway onto Pleasant Street south and also spill into the northern soccer pitch. Upstream of Skipton Street, at the confluence of the Redan Creek and its tributary, water levels during the 1% AEP event do not exceed those of the roadway.

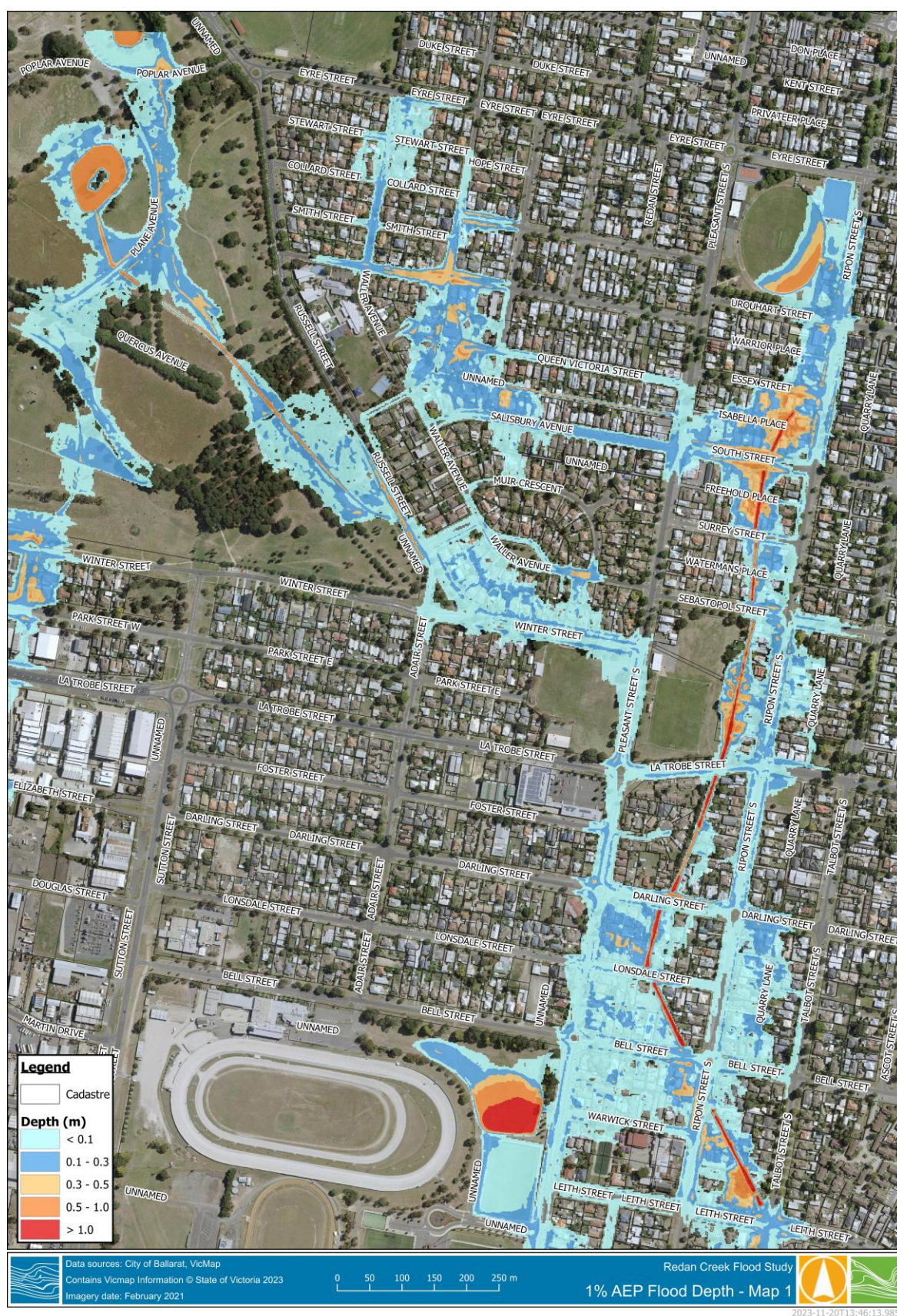


Figure 5-2 Maximum Flood Depth – 1% AEP (Map 1)

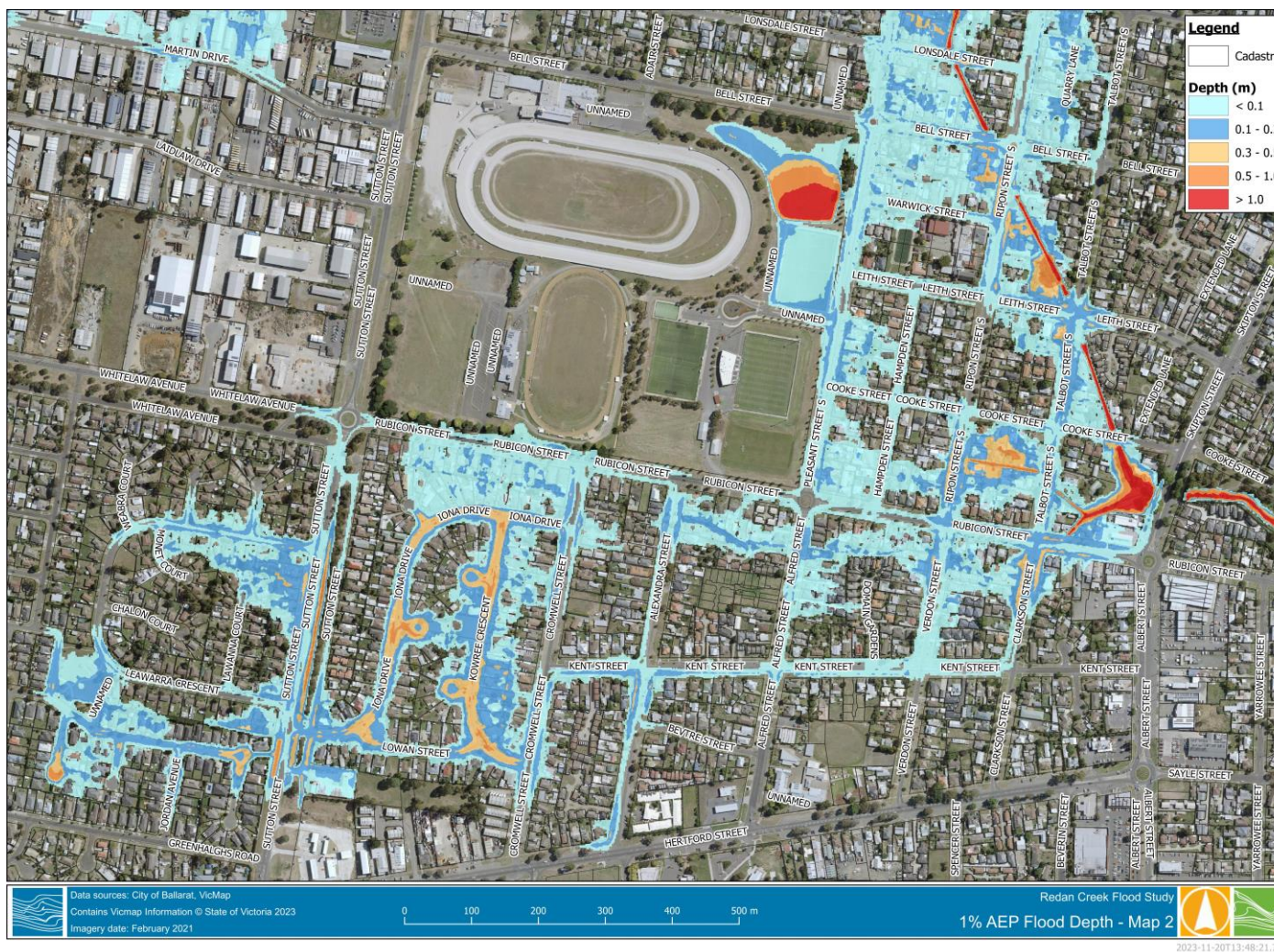


Figure 5-3 Maximum Flood Depth – 1% AEP (Map 2)

Melbourne

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Notting Hill VIC 3168
Telephone (03) 8526 0800

Sydney

Suite 3, Level 1, 20 Wentworth Street
Parramatta NSW 2150
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Brisbane

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South Brisbane QLD 4101
Telephone (07) 3105 1460

Adelaide

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Eastwood SA 5063
Telephone (08) 8378 8000

Perth

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Subiaco WA 6008
Telephone (08) 6555 0105

New Zealand

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Cambridge New Zealand 3434
Telephone +64 27 777 0989

Wangaratta

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

Geelong

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Geelong VIC 3220
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Wimmera

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