

# Canadian Creek and Tributaries Hydrology and Hydraulics

## Ballarat Flood Modelling Update

City of Ballarat

22 December 2023





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## Project Details

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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. The following report details the current hydrologic and hydraulic modelling for Canadian Creek and its tributaries. A summary of the changes made to the hydrologic and hydraulic models since the original reference study in 2018 are listed below.

- Hydrologic model (RORB) updates:
  - Increased fraction impervious of subarea 'K' to 0.75 from 0.5 due to the development of the Ryans IGA shopping complex and residential properties at 200 Victoria Street, Ballarat East.
  - The lower reaches of the Pennyweight Gully were changed to type 2 (excavated but unlined) from type 1 (natural) and type 3 (lined) in subareas BH, BA, AO and AP.
    - Flows in the lower reaches of the Pennyweight Gully are not confined to the channel/waterway, as shown in the original flood mapping results from 2018.
  - Changed reach type from type 1 (natural) to type 2 (excavated but unlined) in subareas AX and BB where flows enter the Boyd Court development.
  - Changed reach type from type 1 (natural) to type 2 (excavated but unlined) in Subarea BG.
  - Changed reach type from type 3 (lined) to type 2 (excavated but unlined) in Subareas AD, AN, BA and K.
- Hydraulic model (TUFLOW) updates:
  - The hydraulic model was run on the build 2023-03-AA, as opposed to build AD, due to rendering issues with water level lines in the open channel network.
  - Changed the layer used to represent bridge structures from 2d\_lfcsh to 2d\_bg shapes.
    - The 2d\_bg shape is similar to the 2d\_lfcsh shape, but it is simplified and leaves less room for misrepresenting the bridge structure.
  - Updating the base terrain with the 2019 LiDAR dataset required re-extracting all 1d cross-sections in the open channel segments and adjusting the boundaries of the open channel domain.
  - Updated invert levels of the Charlesworth Street culvert to match the 2019 flood assessment inputs.
  - Updated the surface elevations at 200 Victoria Street (corner of Stawell Street South and Victoria Street) due to the development of residential properties and wetland system.
  - Updated the surface elevations at 217 Joseph Street with the design surface provided by Axiom. The development included topographical changes between Joseph Street and Rodier Street along the Pennyweight Gully, as well as expansion works to the basin and channel in the Spencer Street Reserve.
    - Post-processing of the design surface from Axiom was required to 'smooth' the digital elevation model (DEM). This was done within TUFLOW by manipulating the design surface with 2d\_ztin layers.
  - The basin for the Boyds Court development was included in the model by manipulating the terrain within TUFLOW using 2d\_zsh layers. The road reserve and residential lots were shown appropriately in the LiDAR.
  - Updated the surface elevations at 846 Eureka Street (The Meadows Estate) using the TUFLOW terrain output (DEM\_Z) for the development by Jens Consulting.



- The DEM\_Z required some post-processing to remove the elevation set for the residential properties during the flood impact assessment.
- Changing the levels of the lots was done within TUFLOW by manipulating the design surface with 2d\_ztin layers.
- Updated the drainage network to include pit and pipe data for the developments at:
  - 200 Victoria Street, Ballarat East
  - 846 Eureka Street, Ballarat East (The Meadows Estate)
  - 217 Joseph Street, Canadian
  - Boyd Court

The 1% AEP mapping has been produced for review by Council and CMA. Following approval, Water Technology will finalise the modelling by completing the remaining design event (including climate change scenarios) modelling.



# CONTENTS

|                                                 |           |
|-------------------------------------------------|-----------|
| EXECUTIVE SUMMARY                               | 2         |
| <b>1 INTRODUCTION</b>                           | <b>6</b>  |
| 1.1 Background                                  | 6         |
| 1.2 Structure of the report                     | 6         |
| <b>2 AVAILABLE INFORMATION &amp; SITE VISIT</b> | <b>8</b>  |
| 2.1 Overview                                    | 8         |
| 2.2 Topographic data                            | 8         |
| 2.3 Planning Scheme                             | 8         |
| 2.4 Drainage information                        | 8         |
| <b>3 HYDROLOGY</b>                              | <b>9</b>  |
| 3.1 Overview                                    | 9         |
| 3.2 RORB model development                      | 9         |
| 3.2.1 Catchment delineation                     | 10        |
| 3.2.2 Fraction Impervious                       | 13        |
| 3.2.3 Routing parameter (kc)                    | 17        |
| 3.2.4 Design rainfall                           | 18        |
| 3.3 Design modelling                            | 19        |
| 3.3.1 Monte Carlo Analysis                      | 20        |
| 3.3.2 Ensemble Analysis                         | 24        |
| <b>4 HYDRAULIC MODELLING</b>                    | <b>26</b> |
| 4.1 Overview                                    | 26        |
| 4.2 2D Domain                                   | 26        |
| 4.2.1 Topography                                | 26        |
| 4.2.2 Surface roughness                         | 28        |
| 4.3 1D Network                                  | 30        |
| 4.4 Boundary conditions                         | 35        |
| <b>5 HYDROLOGIC/HYDRAULIC MODEL COMPARISON</b>  | <b>37</b> |
| <b>6 FLOOD MAPPING AND RESULTS</b>              | <b>38</b> |

## LIST OF FIGURES

|            |                                                         |    |
|------------|---------------------------------------------------------|----|
| Figure 1-1 | Canadian Creek and Tributaries catchments and waterwayS | 7  |
| Figure 3-1 | RORB Model Structure (Canadian Creek)                   | 11 |
| Figure 3-2 | RORB Model structure (Tributaries)                      | 12 |
| Figure 3-3 | Land use areas based on planning zones                  | 14 |



|                   |                                                                                               |    |
|-------------------|-----------------------------------------------------------------------------------------------|----|
| Figure 3-4        | Fraction impervious used in the study (Canadian Creek)                                        | 15 |
| Figure 3-5        | Fraction impervious used in the study (Tributaries)                                           | 16 |
| <b>FIGURE 3-6</b> | <b>DESIGN MODELLING FLOW CHART</b>                                                            | 20 |
| Figure 3-7        | Overview of monte carlo analysis                                                              | 21 |
| Figure 3-8        | Canadian Creek Model Hydrograph Print Points                                                  | 22 |
| Figure 3-9        | Tributaries Model Hydrograph Print Points                                                     | 23 |
| Figure 3-10       | Adopted temporal patterns for 1% AEP design modelling                                         | 25 |
| Figure 4-1        | 2d model area and topography                                                                  | 27 |
| Figure 4-2        | Detailed Hydraulic Roughness Map                                                              | 29 |
| Figure 4-3        | Drainage Infrastructure (North)                                                               | 31 |
| Figure 4-4        | Drainage Infrastructure (East)                                                                | 32 |
| Figure 4-5        | Drainage Infrastructure (South)                                                               | 33 |
| Figure 4-6        | Hydraulic Model Lined Channel Extents                                                         | 34 |
| Figure 4-7        | Model Boundaries                                                                              | 36 |
| Figure 5-1        | Hydrologic and hydraulic model flow hydrograph comparison – Canadian Creek at Elsworth Street | 37 |
| Figure 6-1        | Maximum flood depth – 1% AEP (Map 1)                                                          | 39 |
| Figure 6-2        | Maximum flood depth – 1% AEP (Map 2)                                                          | 40 |
| Figure 6-3        | Maximum flood depth – 1% AEP (Map 3)                                                          | 41 |
| Figure 6-4        | Maximum flood depth – 1% AEP (Map 4)                                                          | 42 |
| Figure 6-5        | Maximum flood depth – 1% AEP (Map 5)                                                          | 43 |

## LIST OF TABLES

|           |                                                                             |    |
|-----------|-----------------------------------------------------------------------------|----|
| Table 2-1 | Standard cover levels for stormwater pipes                                  | 8  |
| Table 3-1 | Adopted FI values used in RORB Model                                        | 13 |
| Table 3-2 | K <sub>c</sub> Estimates                                                    | 17 |
| Table 3-3 | Estimates of k <sub>c</sub> based on nearby existing RORB models            | 18 |
| Table 3-4 | Design rainfall depths in mm for varying event durations and AEP            | 18 |
| Table 3-5 | Adopted losses                                                              | 19 |
| Table 3-6 | RORB critical durations along Canadian Creek Model                          | 21 |
| Table 3-7 | RORB critical durations along Tributaries Model                             | 21 |
| Table 3-8 | Chosen Representative Temporal Patterns and Critical Durations for Each AEP | 24 |
| Table 4-1 | Manning's roughness values used in the model                                | 28 |



# 1 INTRODUCTION

## 1.1 Background

The Canadian Creek catchment has been previously modelled under several flood studies, including the 2014<sup>1</sup> by Water Technology. In 2018, Water Technology undertook a study<sup>2</sup> to update the previous flood modelling to Australian Rainfall and Runoff 2016<sup>3</sup> (ARR 2016) standards and extend the flood modelling towards the south of the catchment was completed.

Canadian Creek is located in the south-eastern region of Ballarat, and drains from upstream of Gear Avenue, Mount Helen in the south and into the Yarrowee River near central Ballarat. The key tributaries of Specimen Vale Creek, Lal Lal Drain and Warrenheip Gully drain the areas to the east of Canadian Creek and arise from the localities of Ballarat East, Warrenheip and Canadian, as show in Figure 1-1. Canadian Creek and its tributaries pass through a range of residential, conservation, recreational and commercial planning zones. Much of Canadian Creek consists of residential housing in the lower catchment, and forested areas in the upper catchment.

The flood modelling and mapping undertaken in this project was based on the updated guidelines outlined in ARR 2019. 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 Canadian Creek and tributaries catchments including modelling methodology, inputs to the hydraulic model and results.
- Hydraulic modelling of Canadian Creek and its tributaries 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.

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<sup>1</sup> Water Technology (2014), Canadian Creek Tributaries Flood Investigation, prepared for Corangamite CMA and City of Ballarat

<sup>2</sup> Water Technology (2018), 11 Waterways Flood Mapping Project, prepared for City of Ballarat

<sup>3</sup> 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

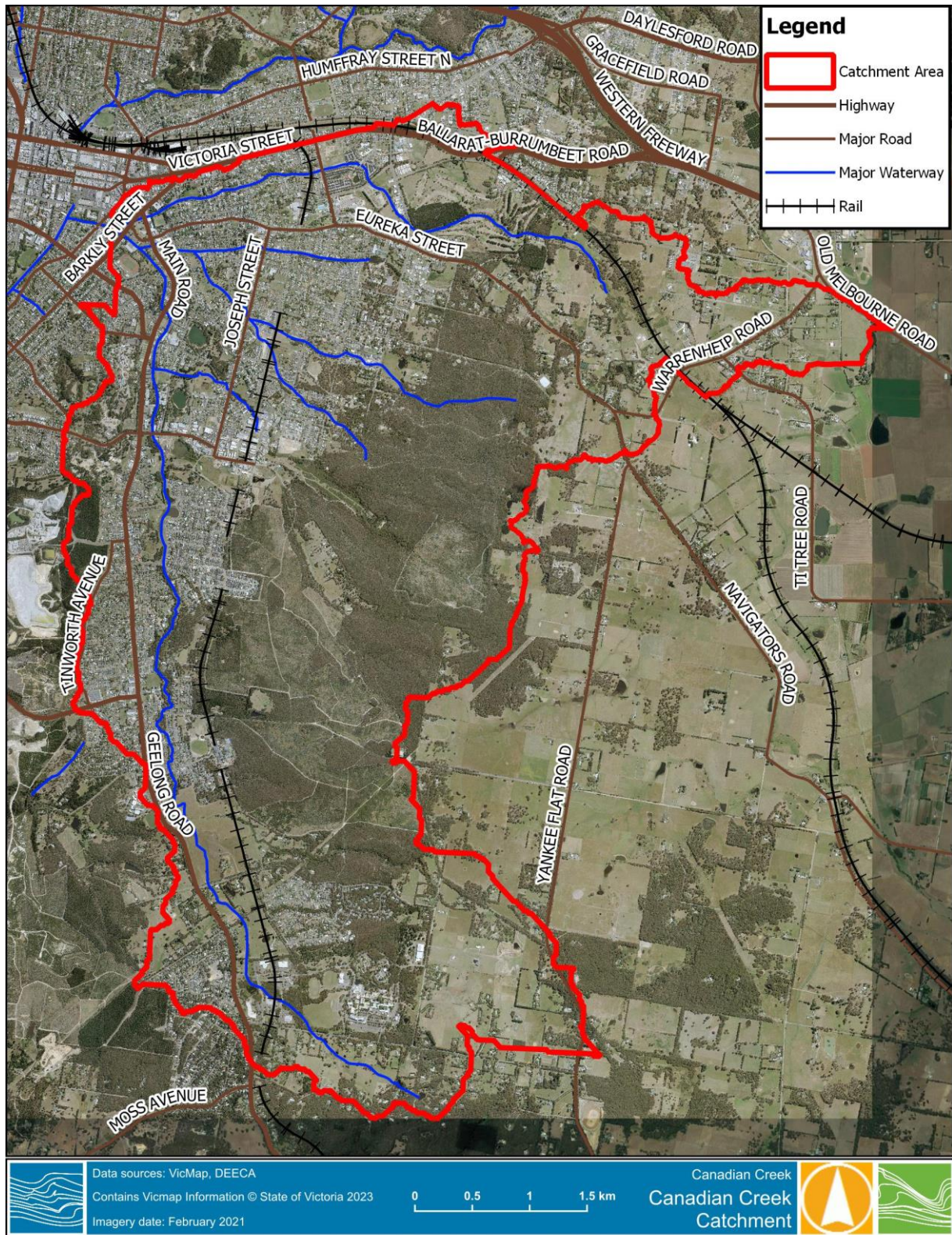


FIGURE 1-1 CANADIAN CREEK AND TRIBUTARIES CATCHMENTS AND WATERWAYS



## 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.
- City of Ballarat.
- Regional Roads Victoria.
- Department of Energy, Environment and Climate Action (DEECA).
- Bureau of Meteorology (BoM).

### 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 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               |



## 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 (ARR 2019). The 20%, 10%, 5%, 2%, 1% and the 0.5% AEP flood events were modelled using Monte-Carlo and Ensemble approaches as recommended in ARR 2019. There were no streamflow gauges within the catchment.

Two RORB models were used for the hydrological analysis: a model of the Canadian Creek tributaries (incorporating Lal Lal Drain, Pennyweight and Warrenheip Gullies and Specimen Vale Creek) was used for the simulation of those areas, and a second RORB model was developed for the remainder of the catchment south of the noted tributaries.

### 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 ( $k_c$ )
- 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 Canadian Creek tributaries catchment (14.79 km<sup>2</sup>) was delineated into 81 sub-areas based on a combination of 2-metre LiDAR data captured in 2012 and 5-metre LiDAR data captured in 2008, while the Canadian Creek catchment upstream of Lal Lal Drain (16.89 km<sup>2</sup>) was delineated into 63 sub-areas based on the 20-metre VicMap DTM. The delineated catchments are shown in Figure 3-1 and Figure 3-2.

The available DTM and 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 Canadian Creek and Tributaries 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.

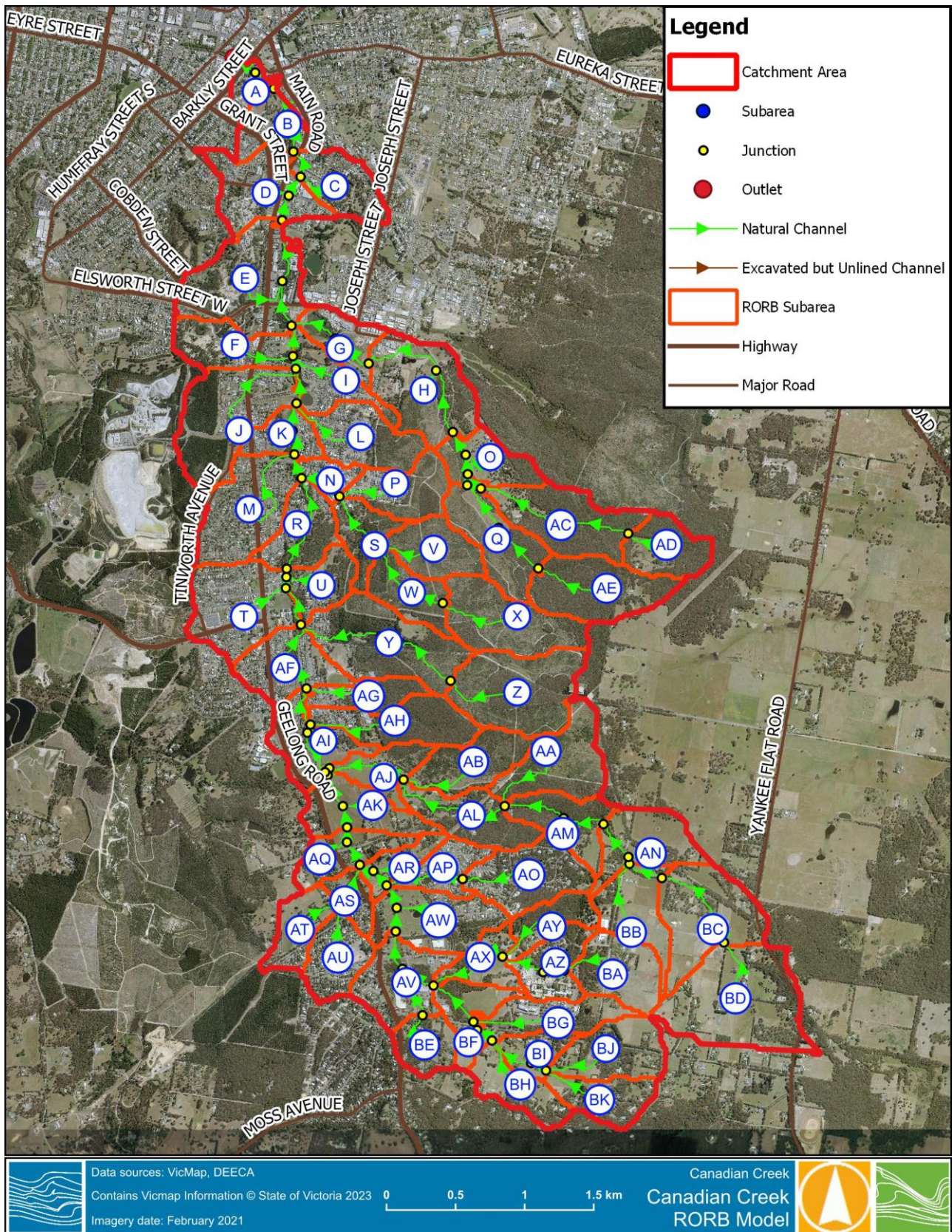


FIGURE 3-1 RORB MODEL STRUCTURE (CANADIAN CREEK)

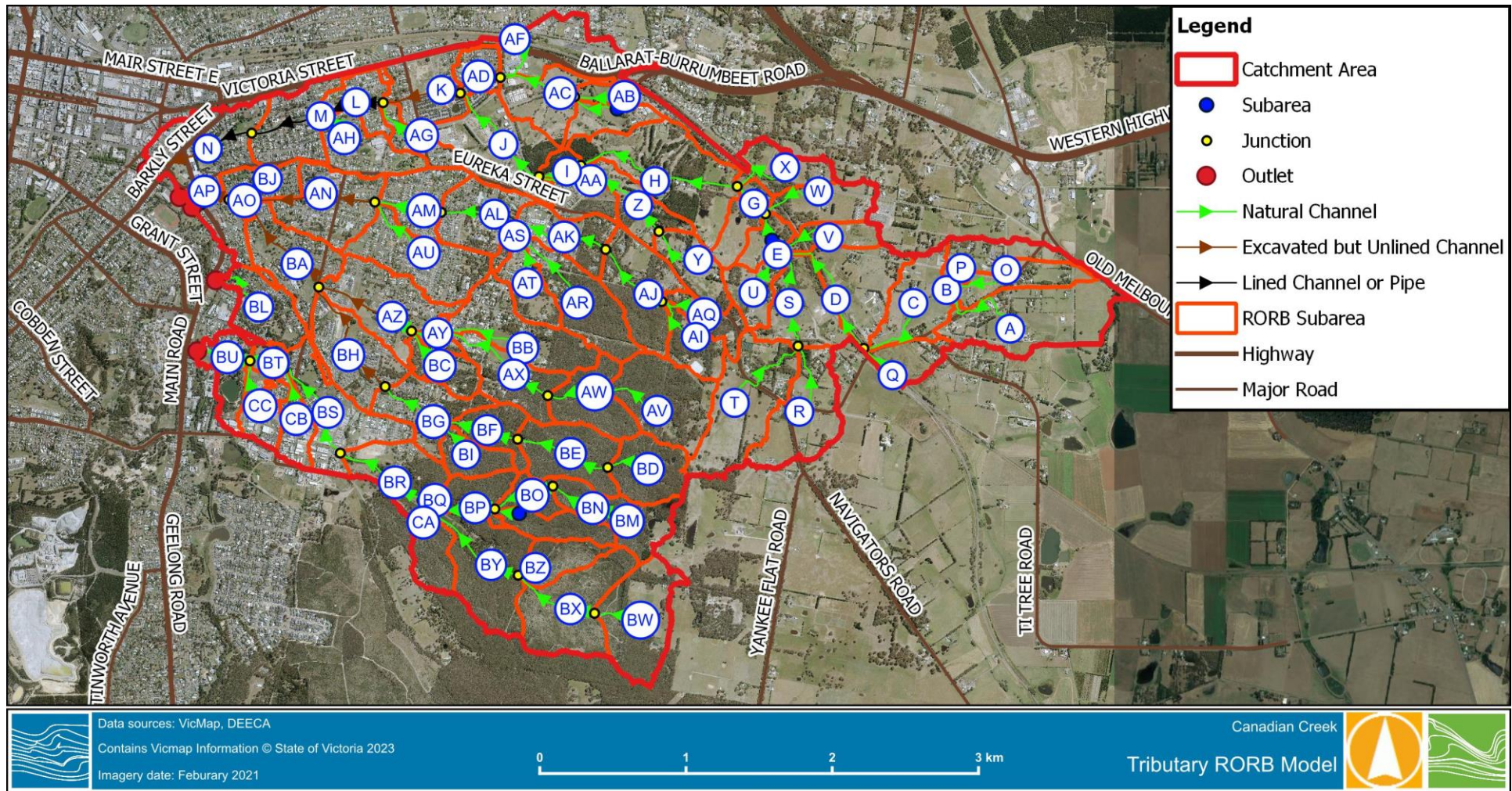


FIGURE 3-2 RORB MODEL STRUCTURE (CANADIAN CREEK TRIBUTARIES)



### 3.2.2 Fraction Impervious

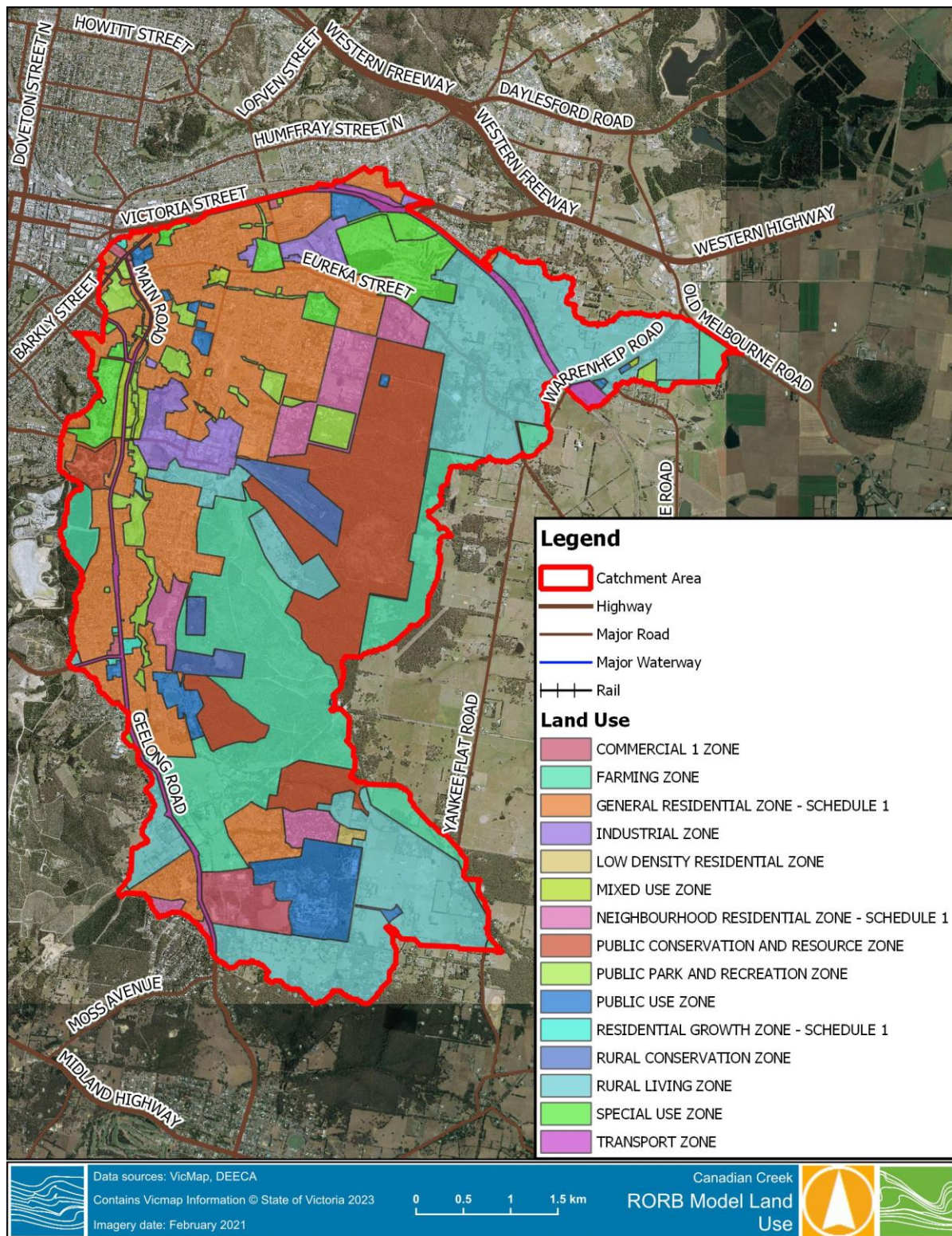
Impervious fractions values were determined for the different land use types across the catchment within each sub-area, represented by a fraction impervious (FI). FI values were determined according to City of Ballarat planning zones as per Melbourne Water's MUSIC Guidelines<sup>4</sup> and verified 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, and maps of the designated land uses are shown in Figure 3-3, with the adopted sub-area FI values shown in Figure 3-4 and Figure 3-5. 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 |
|---------------------------------------|------------|
| Commercial Zone                       | 0.9        |
| Farming Zone                          | 0.01       |
| Industrial Zone                       | 0.9        |
| Residential Zone                      | 0.75       |
| Transport Zone                        | 0.8        |
| Rural Living Zone                     | 0.2        |
| Mixed Use Zone                        | 0.9        |
| Low Density Residential Zone          | 0.6        |
| Public Park and Recreation Zone       | 0.2        |
| Public Conservation and Resource Zone | 0.01       |

---

<sup>4</sup> Melbourne Water (2010), Melbourne Water MUSIC Guidelines



\\fs01\M-Drive\23010262\_Ballarat\_Planning\_Scheme\_Amendment\Spatial\Workspaces\RORB\_CC\_condensed.qgz

2023-11-28T16:40:43.886

**FIGURE 3-3 LAND USE AREAS BASED ON PLANNING ZONES**

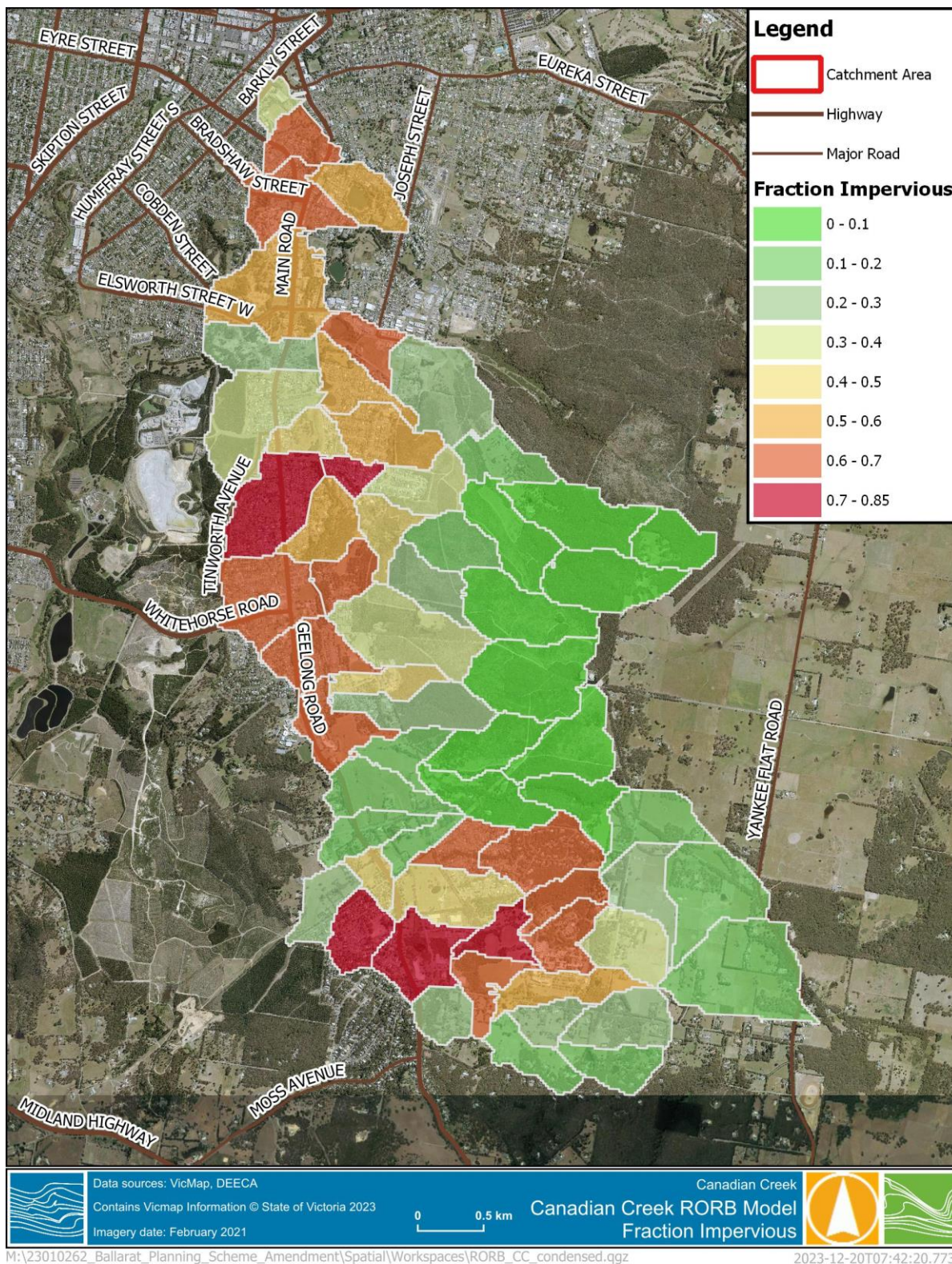


**FIGURE 3-4 FRACTION IMPERVIOUS USED IN THE STUDY (CANADIAN CREEK)**

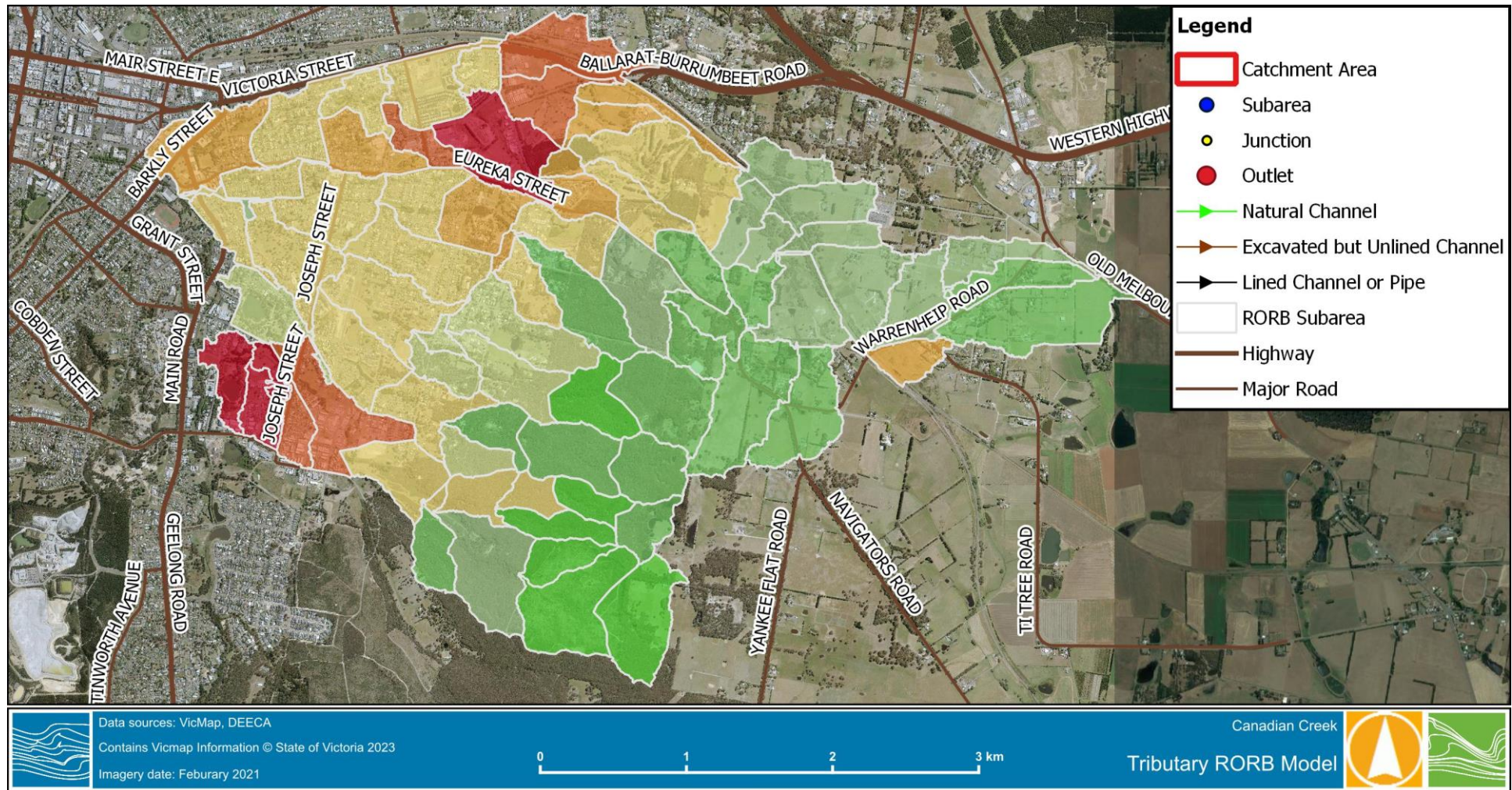


FIGURE 3-5 FRACTION IMPERVIOUS USED IN THE STUDY (TRIBUTARIES)



### 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 'reasonable'  $k_c$  parameters.

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  $d_{av}$  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  $C_{0.8}$  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  $K_C$  ESTIMATES**

| 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 Canadian Creek and Tributaries catchments, 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, the Pearse et. al. equation has shown to match gauge flood frequency analysis data best. The  $C_{0.8}$  was taken to having a value of 2.38, which is close to the range of expected values from Pearse et al. (2002). Given that  $d_{av}$  equals 6.21 km for the Canadian Creek RORB model and 3.56 km for the Tributaries RORB model,  $k_c$  values of 14.76 and 8.46 were adopted for the study, respectively.

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, Warrenheip 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 with each of the previous projects is provided in Table 3-3. The adopted  $k_c$  value was within the range of those adopted for nearby studies.



**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 Canadian Creek $K_c$ | Estimated Tributaries $K_c$ |
|-------------------------|-------|---------------|----------------------|--------------------------------|-----------------------------|
| Yarrowee River – DS CBD | 6.74  | 5.61          | 1.20                 | 7.46                           | 4.28                        |
| Warrenheip Creek        | 3.39  | 2.71          | 1.25                 | 7.76                           | 4.45                        |
| Kensington Creek        | 5.6   | 4.52          | 1.24                 | 7.7                            | 4.41                        |
| Bonshaw Creek           | 5.37  | 4.58          | 1.17                 | 7.27                           | 4.17                        |

The RORB model  $m$  was set at 0.8. This is the recommended value for ungauged catchments<sup>5</sup>.

### 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 Canadian Creek catchment using the 2016 ARR IFD tables available from the Bureau of Meteorology<sup>6</sup>.

##### **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<sup>1</sup>. Conceptually, this factor accounts for larger catchments which are less likely to experience high intensity rainfall over the whole of the catchment. The areal reduction factor was updated in both models to reflect the total combined catchment area across the two models.

##### **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 DUAARATIONS AND AEP**

| Duration | 20%  | 10%  | 5%   | 2%   | 1%   | 0.5% |
|----------|------|------|------|------|------|------|
| 30-min   | 18.2 | 22.6 | 27.3 | 34   | 39.6 | 45.1 |
| 1-hr     | 22.6 | 27.9 | 33.4 | 41.2 | 47.7 | 54.1 |
| 2-hr     | 27.7 | 33.7 | 40   | 48.7 | 56   | 63.5 |
| 3-hr     | 31.4 | 37.9 | 44.6 | 54.1 | 61.9 | 70.4 |
| 6-hr     | 39.8 | 47.4 | 55.2 | 66.5 | 75.6 | 86.5 |

<sup>5</sup> E.M. Laurenson, R.G. Mein, and R.J. Nathan (2010), RORB User Manual

<sup>6</sup> <http://www.bom.gov.au/water/designRainfalls/ifd/>



#### 3.2.4.2 Temporal patterns

The 10 temporal patterns as downloaded from ARR 2019 Data Hub<sup>7</sup> were used to simulate the distribution of burst rainfall depth during each storm duration modelled.

#### 3.2.4.3 Spatial patterns

The ARR 2019 guidelines recommend non-uniform spatial patterns for catchment areas of more than 20 km<sup>2</sup>. With the catchment of the Canadian Creek and Tributaries model being 16.6 and 14.8 km<sup>2</sup>, respectively, a uniform spatial pattern was applied in design modelling.

#### 3.2.4.4 Design losses

An initial loss / continuing loss model was applied for the RORB modelling. The losses were determined based on the ARR Online Data Hub<sup>7</sup> suggested losses of 25 mm initial loss and 4.4 mm/hr continuing loss.

Canadian Creek is a tributary of the Yarrowee River and converges with it upstream of the Ballarat CBD. Calibration of the Yarrowee River and Gnarr Creek hydrological model was completed in 2019 and it was determined that the recommended losses from ARR were too high, and a continual loss of 2 mm/hr was more appropriate for the broader Ballarat area. Considering the proximity of Canadian Creek and its tributaries to the Yarrowee River catchment and the Ballarat region, the calibrated continuing loss of 2 mm/hr was adopted for these respective catchments.

The adopted modelling parameters for the Canadian Creek and Tributaries catchments are shown in Table 3-5.

TABLE 3-5 ADOPTED PARAMETERS

| Parameter               | Adopted Value        |                   |
|-------------------------|----------------------|-------------------|
|                         | Canadian Creek Model | Tributaries Model |
| m                       | 0.8                  | 0.8               |
| $k_c$                   | 14.76                | 8.46              |
| Initial Loss (mm)       | 25.0                 | 25.0              |
| Continuing Loss (mm/hr) | 2.0                  | 2.0               |

### 3.3 Design modelling

A RORB Monte Carlo analysis was used to determine the design peak flows at several key locations within the 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 ten 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 peak flow from the 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 focus of 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.

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<sup>7</sup> <http://data.arr-software.org/>



RORB was run with the selected temporal patterns for each AEP event and critical duration. The flow chart outlined in Figure 3-6 demonstrates the modelling process.

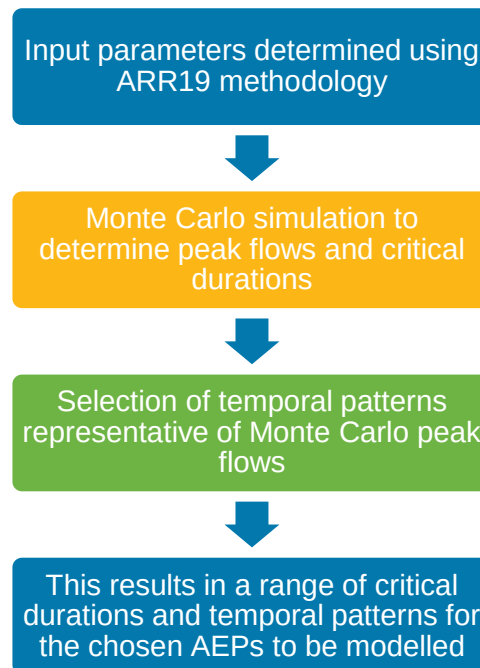


**FIGURE 3-6      DESIGN MODELLING FLOW CHART**

### 3.3.1      Monte Carlo Analysis

The RORB Monte Carlo analysis was undertaken adopting the determined continuing losses and  $k_c$  values 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 the Monte Carlo approach is presented in Figure 3-7. The critical duration for several important locations throughout the models is shown in Table 3-6 and Table 3-7. These print locations are shown in Figure 3-7.

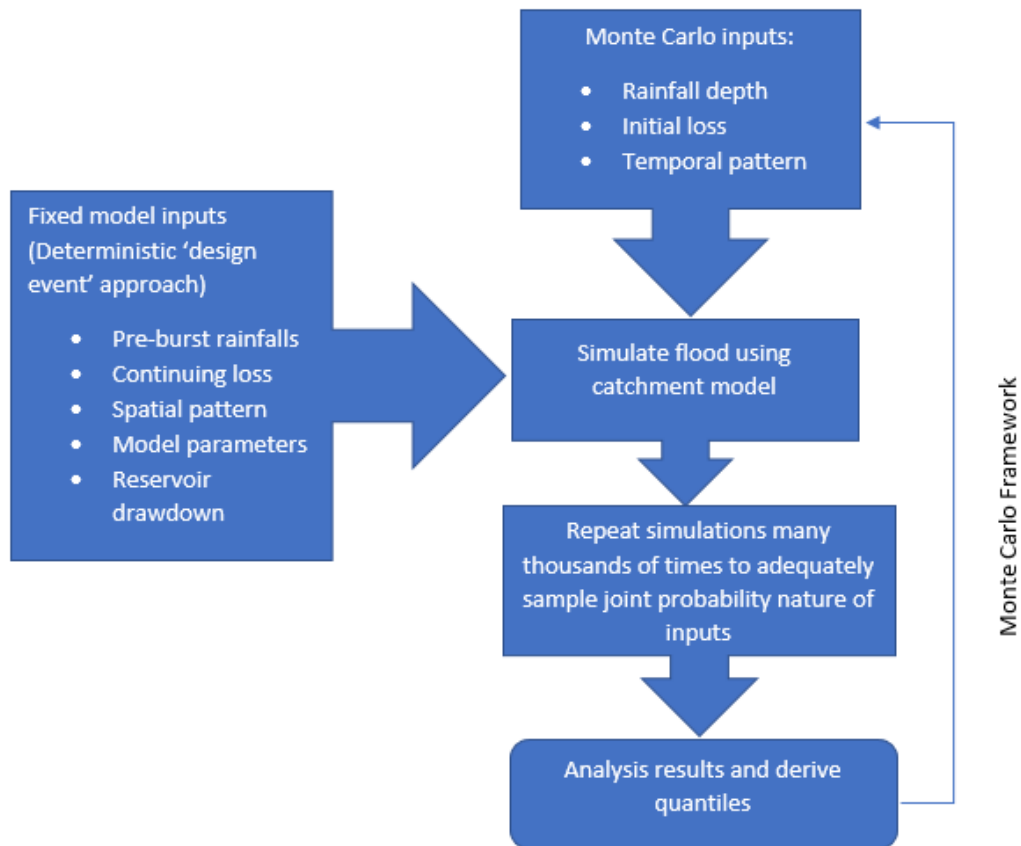


FIGURE 3-7 OVERVIEW OF MONTE CARLO ANALYSIS

TABLE 3-6 RORB CRITICAL DURATIONS ALONG CANADIAN CREEK MODEL

| Location           | Critical Duration |         |        |        |        |          |
|--------------------|-------------------|---------|--------|--------|--------|----------|
|                    | 20% AEP           | 10% AEP | 5% AEP | 2% AEP | 1% AEP | 0.5% AEP |
| US Gear Avenue     | 1-hr              |         | 2-hr   |        |        | 3-hr     |
| DS Gear Avenue     | 1-hr              | 30-min  |        | 6-hr   |        |          |
| Recreation Road    | 12-hr             |         | 6-hr   |        | 12-hr  |          |
| US Elsworth Street | 2-hr              | 12-hr   |        |        |        |          |
| DS Elsworth Street | 6-hr              | 12 hr   |        |        |        |          |

TABLE 3-7 RORB CRITICAL DURATIONS ALONG TRIBUTARIES MODEL

| Location                   | Critical Duration |         |        |        |        |          |
|----------------------------|-------------------|---------|--------|--------|--------|----------|
|                            | 20% AEP           | 10% AEP | 5% AEP | 2% AEP | 1% AEP | 0.5% AEP |
| Warrenheip Gully Outlet    | 1-hr              |         | 2-hr   |        | 6-hr   | 12-hr    |
| Specimen Vale Creek Outlet | 2-hr              |         |        |        |        | 12-hr    |
| Rodier Street              | 1-hr              | 2-hr    |        |        | 1-hr   | 12-hr    |
| Lal Lal Drain Outlet       | 3-hr              | 6-hr    |        | 12-hr  |        |          |

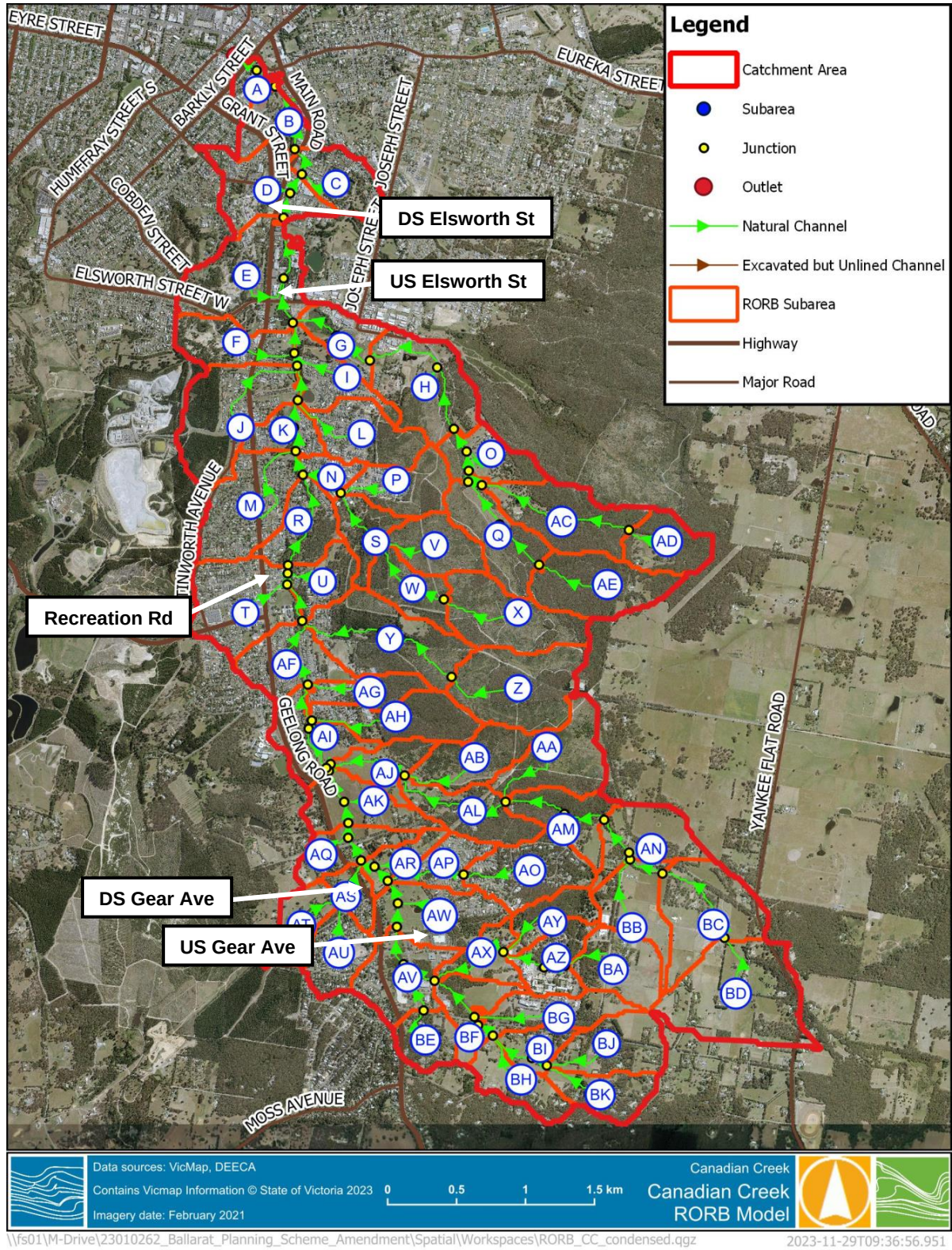


FIGURE 3-8 CANADIAN CREEK MODEL HYDROGRAPH PRINT POINTS

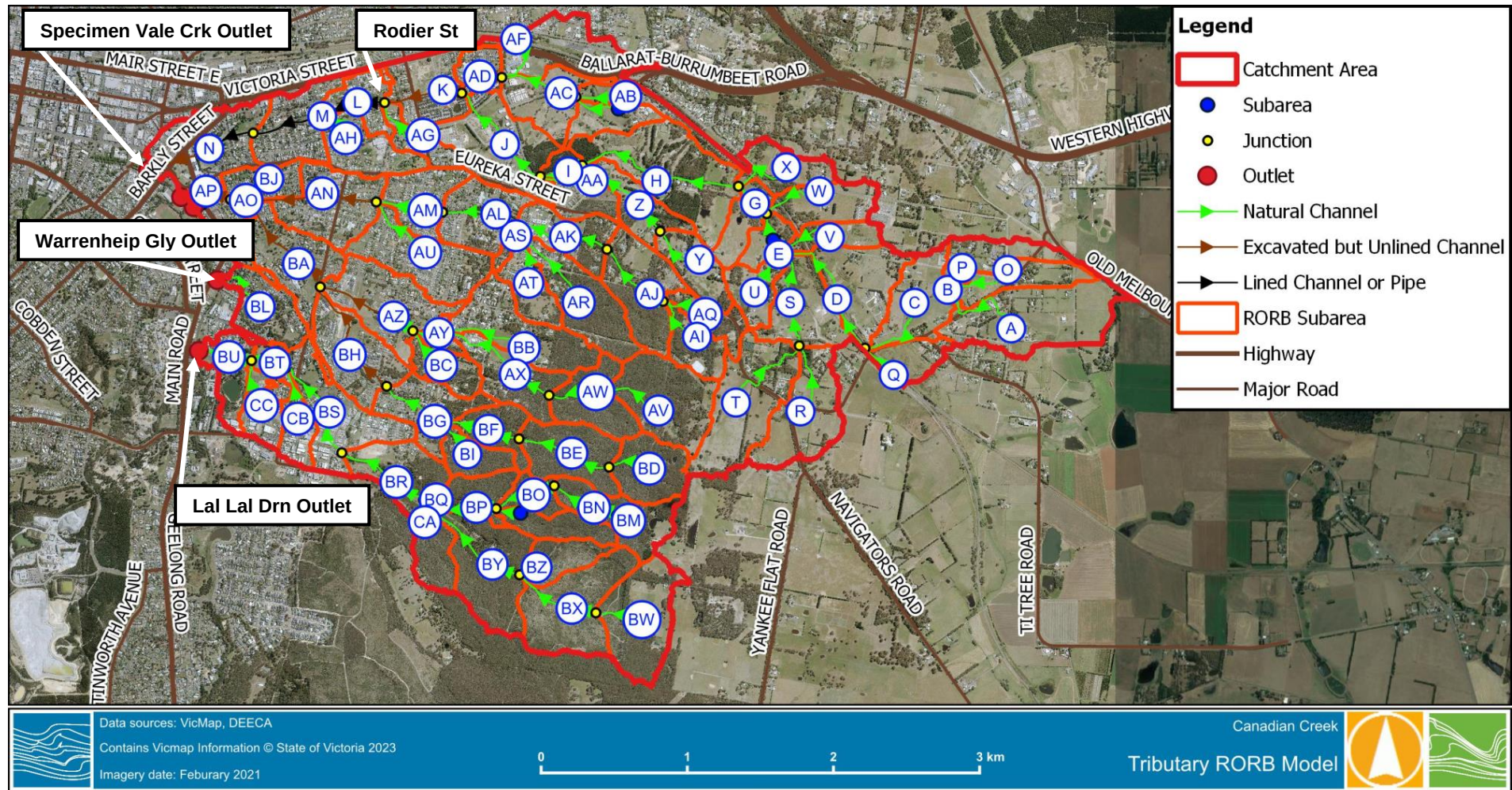


FIGURE 3-9 TRIBUTARIES MODEL HYDROGRAPH PRINT POINTS



### 3.3.2 Ensemble Analysis

The RORB model was run using the ensemble method following the Monte Carlo analysis. Using the determined  $k_c$  values for the two catchments and the recommended ARR 2019 and calibrated losses of 25 mm initial loss and 2 mm/hr continuing loss, the RORB ensemble analysis was run for all ten 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 in total).

To reduce the number of hydraulic model simulations, temporal patterns that yielded peak flows similar to those produced in the Monte Carlo analysis at each key location were simplified to produce a representative temporal pattern for each modelled duration. These are summarised in Table 3-8, with the distribution of rainfall for the adopted temporal patterns in the 1% AEP event displayed in Figure 3-10.

**TABLE 3-8 CHOSEN REPRESENTATIVE TEMPORAL PATTERNS AND CRITICAL DURATIONS FOR EACH AEP**

| Critical Duration & Temporal Pattern |              |              |              |              |              |
|--------------------------------------|--------------|--------------|--------------|--------------|--------------|
| 20% AEP                              | 10% AEP      | 5% AEP       | 2% AEP       | 1% AEP       | 0.5% AEP     |
| 30-min, TP07                         | 30-min, TP20 | 30-min, TP20 | 30-min, TP29 | 30-min, TP26 | 30-min, TP29 |
| 1-hr, TP07                           | 1-hr, TP20   | 1-hr, TP20   | 1-hr, TP29   | 1-hr, TP26   | 1-hr, TP29   |
| 2-hr, TP07                           | 2-hr, TP20   | 2-hr, TP20   | 2-hr, TP29   | 2-hr, TP26   | 2-hr, TP29   |
| 3-hr, TP07                           | 3-hr, TP20   | 3-hr, TP20   | 3-hr, TP29   | 3-hr, TP26   | 3-hr, TP29   |
| 6-hr, TP07                           | 6-hr, TP20   | 6-hr, TP20   | 6-hr, TP29   | 6-hr, TP26   | 6-hr, TP29   |
| 12-hr, TP07                          | 12-hr, TP20  | 12-hr, TP20  | 12-hr, TP29  | 12-hr, TP26  | 12-hr, TP29  |



**FIGURE 3-10 ADOPTED TEMPORAL PATTERNS FOR 1% AEP DESIGN MODELLING**



## 4 HYDRAULIC MODELLING

### 4.1 Overview

This section provides the description of the TUFLOW hydraulic model setup. Model runs were performed with a Highly Parallelised Computing (HPC) solution scheme using the 2023-03-AA 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 Representative Concentration Pathway (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 the Canadian Creek catchment flowing from south to north to the model boundary at Peel St South. 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 resolution of 3 metres was adopted.

Canadian Creek and its tributaries were represented in the 2D domain, typically this provided 2-3 grid cells wide in the main lined channels and 4-5 grid cells bank-to-bank. The raw LiDAR data was available for the majority of the model extent at a 1 metre grid resolution; this was resampled to a 3-metre grid for inclusion in the hydraulic model. The model topography is shown in Figure 4-1.

The surface elevations of several development sites located within the model extent were updated using design surfaces or digital elevation models (DEMs) generated in separate TUFLOW simulations. These sites included:

- 200 Victoria Street, Ballarat East
- 217 Joseph Street, Canadian
- 846 Eureka Street, Ballarat East

Manipulation of the LiDAR dataset using terrain modification layers (2d\_zsh and 2d\_ztin) in TUFLOW were incorporated to reflect changes in terrain. Such locations included:

- The basin constructed as part of the Boyds Court development
- The finished floor levels of the 846 Eureka Street development

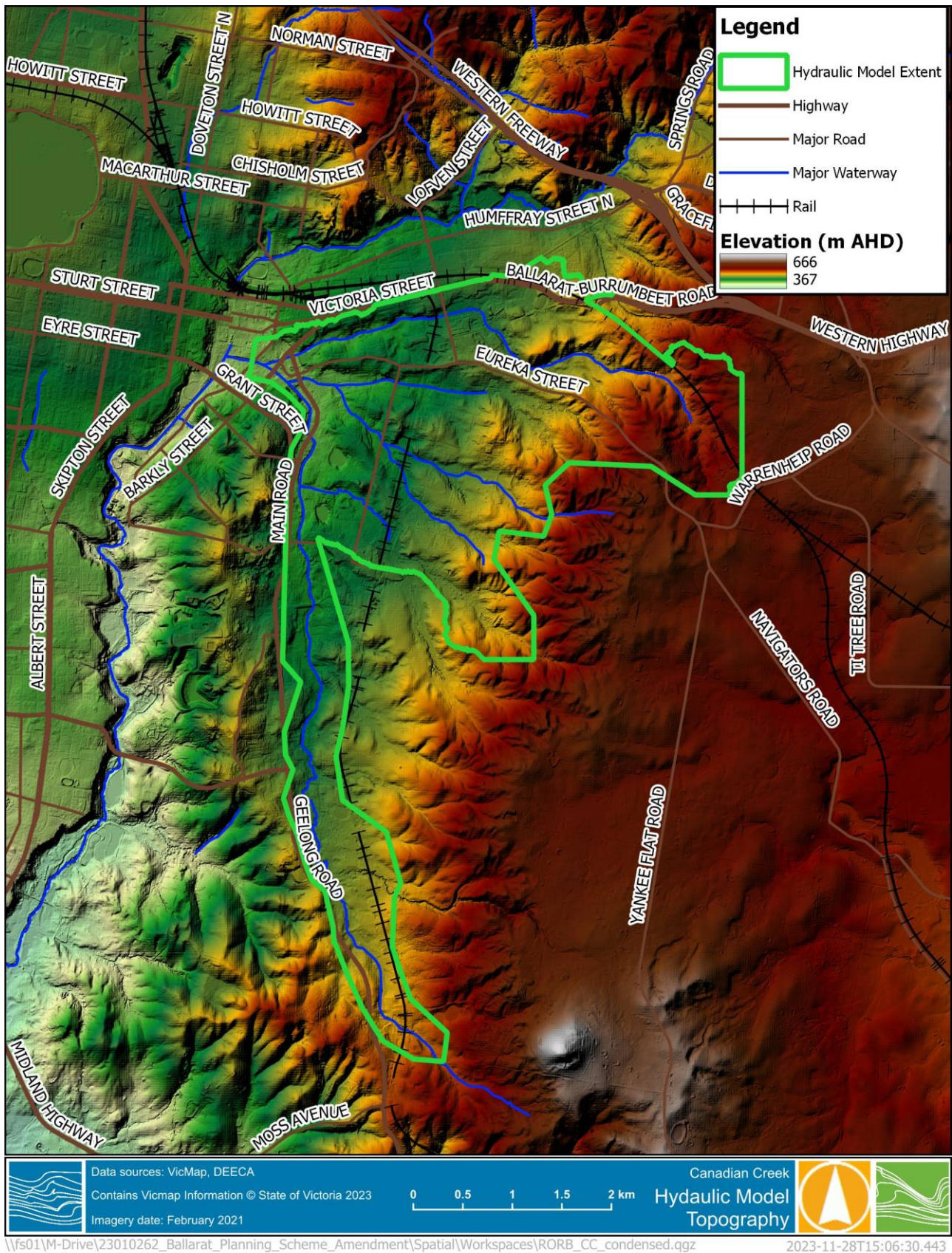


FIGURE 4-1 2D MODEL AREA AND TOPOGRAPHY



## 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' were based on values similar to those used in nearby studies in recent studies. An overview of the Manning's  $n$  values using in the hydraulic model is shown in Figure 4-2 below.

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

| Land Type                         | Manning's Value ( $n$ ) |
|-----------------------------------|-------------------------|
| Pasture & Small Trees             | 0.04                    |
| Residential                       | 0.2                     |
| Industrial                        | 0.3                     |
| Car Park                          | 0.025                   |
| Cemetery                          | 0.15                    |
| Grass                             | 0.035                   |
| Paved Road                        | 0.02                    |
| Unpaved Road                      | 0.03                    |
| Ponds & Other Waterbodies         | 0.03                    |
| Railway                           | 0.04                    |
| Rural Residential                 | 0.1                     |
| Dense Bushland                    | 0.08                    |
| Densely Vegetated Watercourses    | 0.08                    |
| Moderately Vegetated Watercourses | 0.055                   |

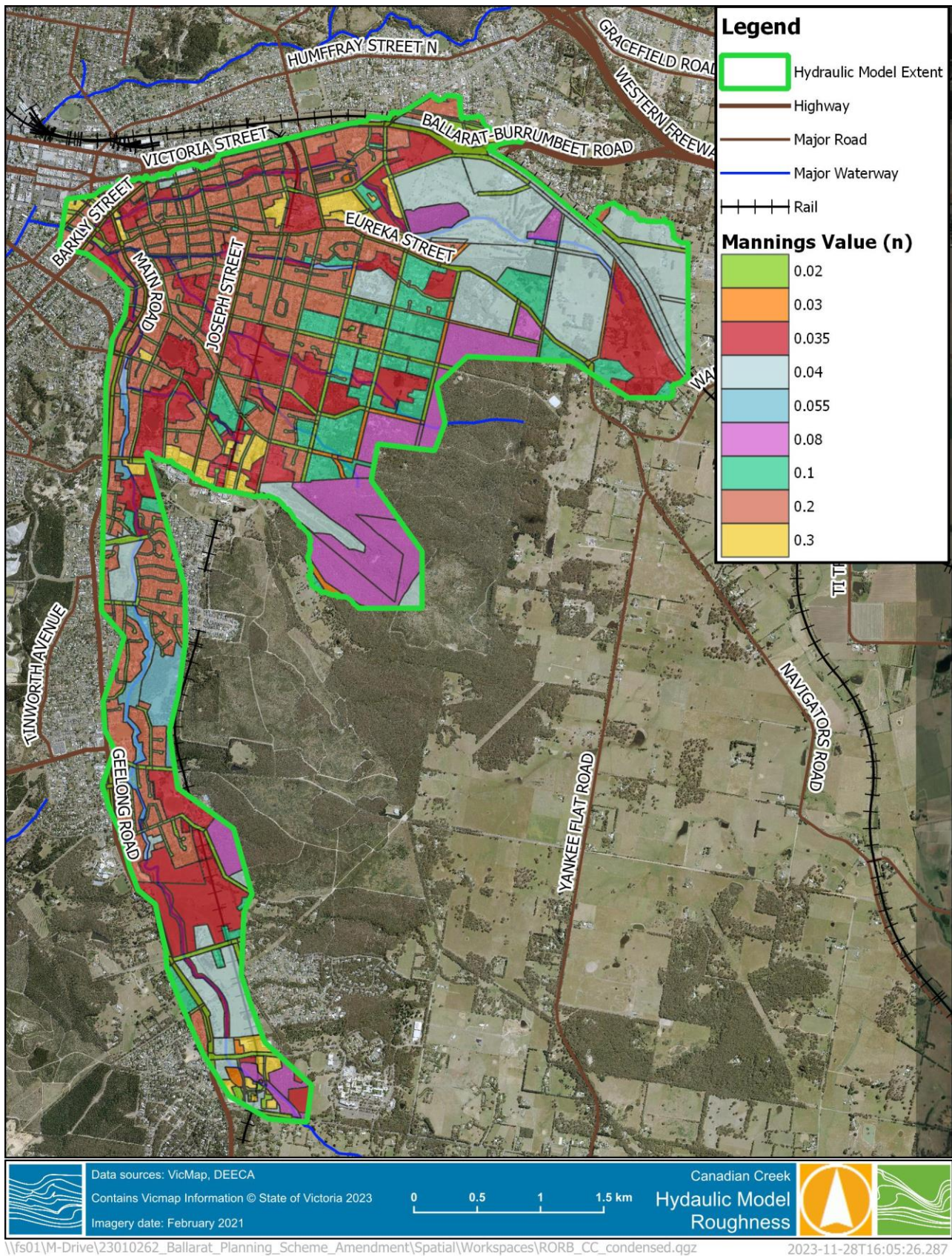


**FIGURE 4-2 DETAILED HYDRAULIC ROUGHNESS MAP**



## 4.3 1D Network

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.

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 ground 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 visits, all pipes and culverts were modelled as reinforced concrete, with a Manning's  $n$  of 0.013 adopted. The culverts, pipes and pits modelled are shown in Figure 4-3, Figure 4-4 and Figure 4-5.

The Canadian Creek and Tributaries catchment included multiple reaches of lined channels constructed out of bluestone or brick. These channels were modelled in the 1D domain as open channels (1d\_nwk type S) with their geometry based on LiDAR data, construction plans provided by the City of Ballarat, and previous site visits/surveys (completed in 2017 and 2018). Extents of the lined channels included in the hydraulic models 1D domain are shown in Figure 4-6 below.

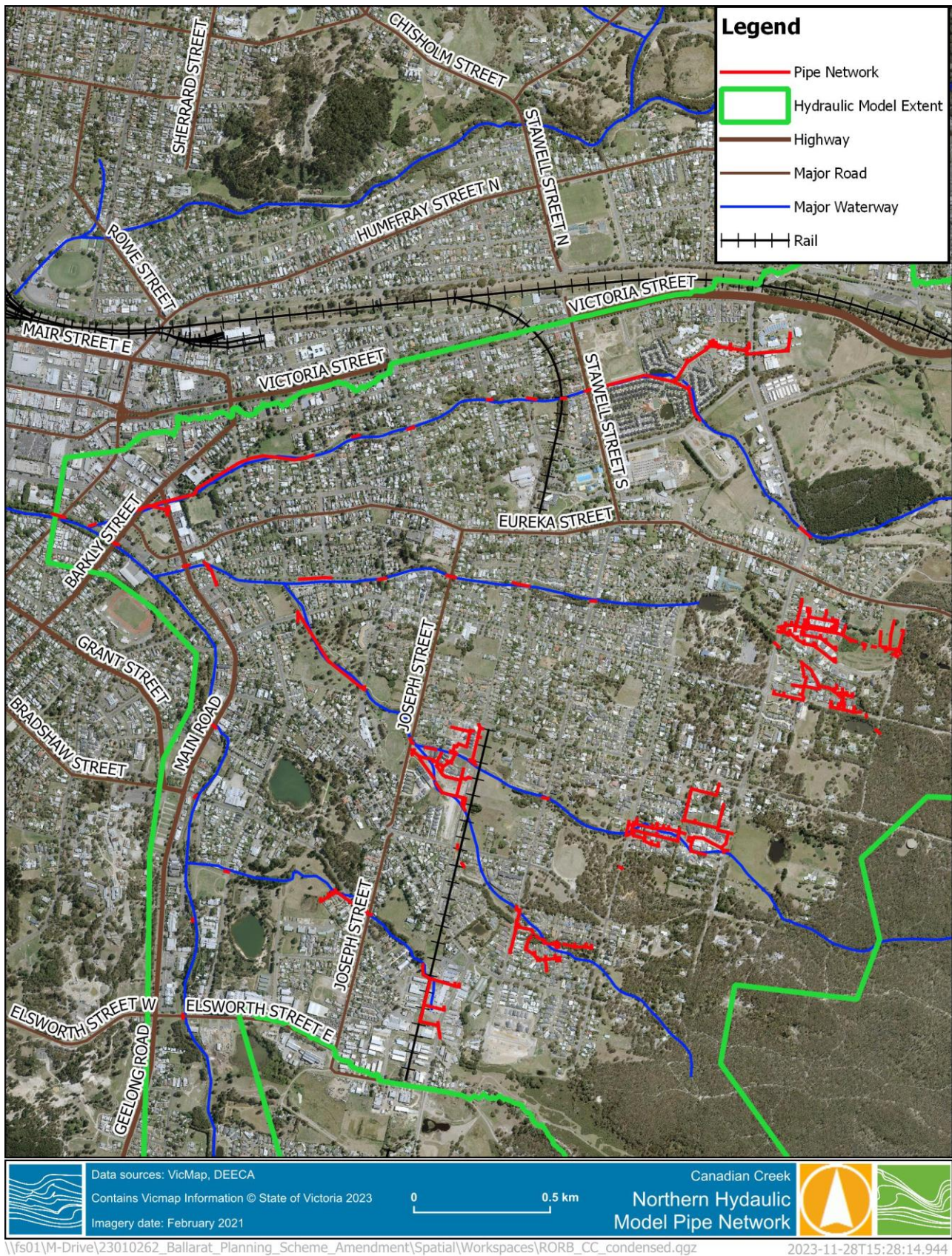


**FIGURE 4-3 DRAINAGE INFRASTRUCTURE (NORTH)**

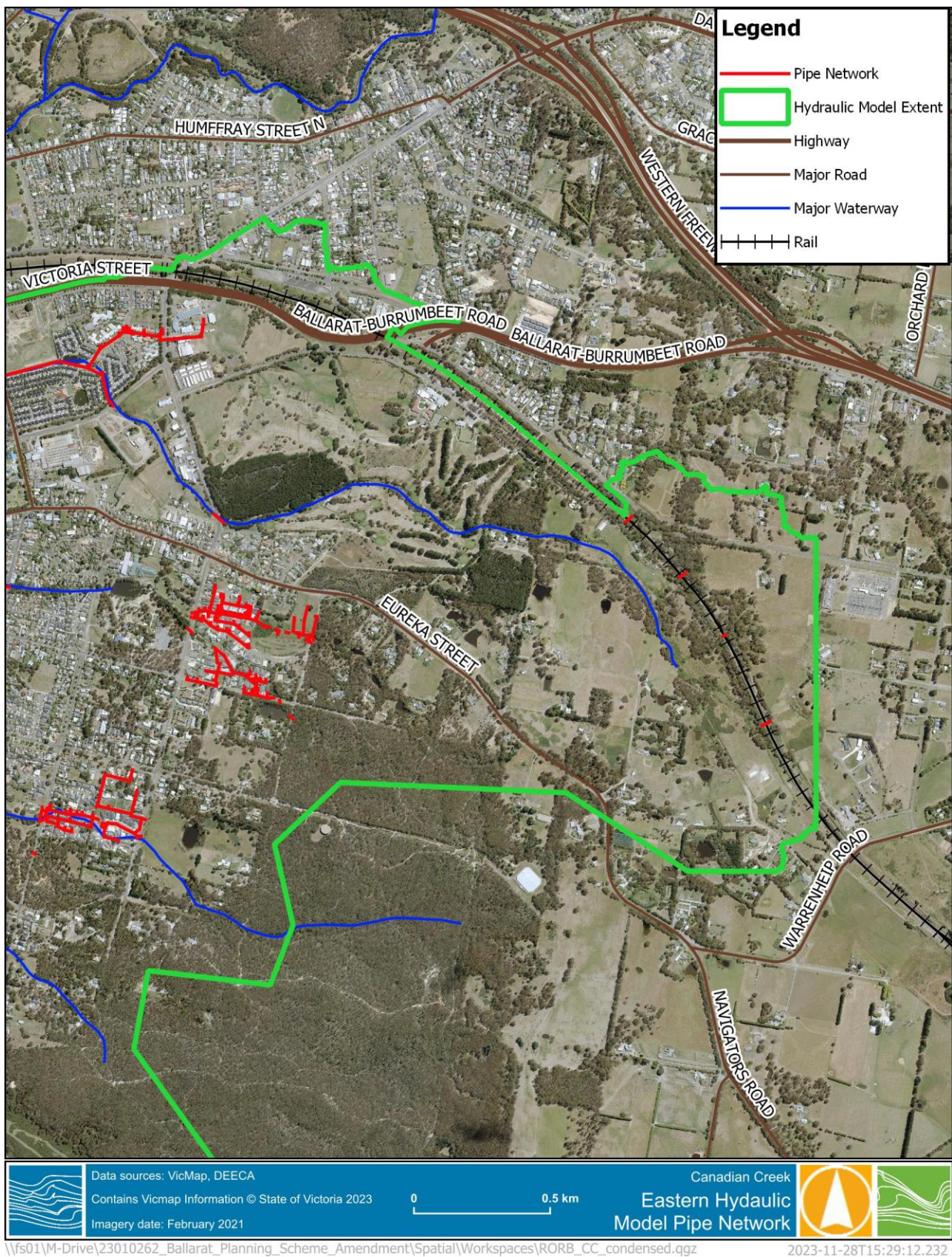


FIGURE 4-4 DRAINAGE INFRASTRUCTURE (EAST)

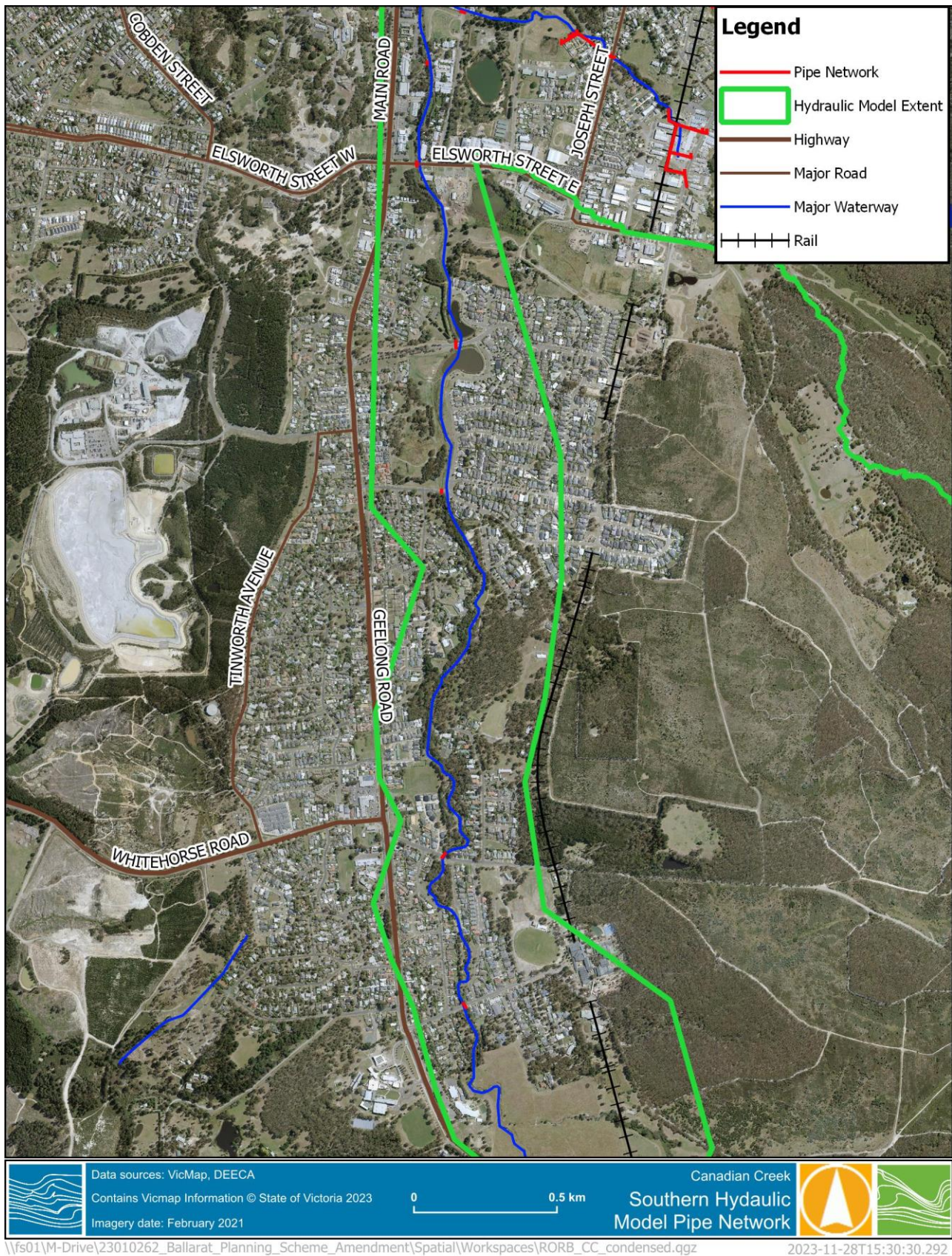


**FIGURE 4-5 DRAINAGE INFRASTRUCTURE (SOUTH)**

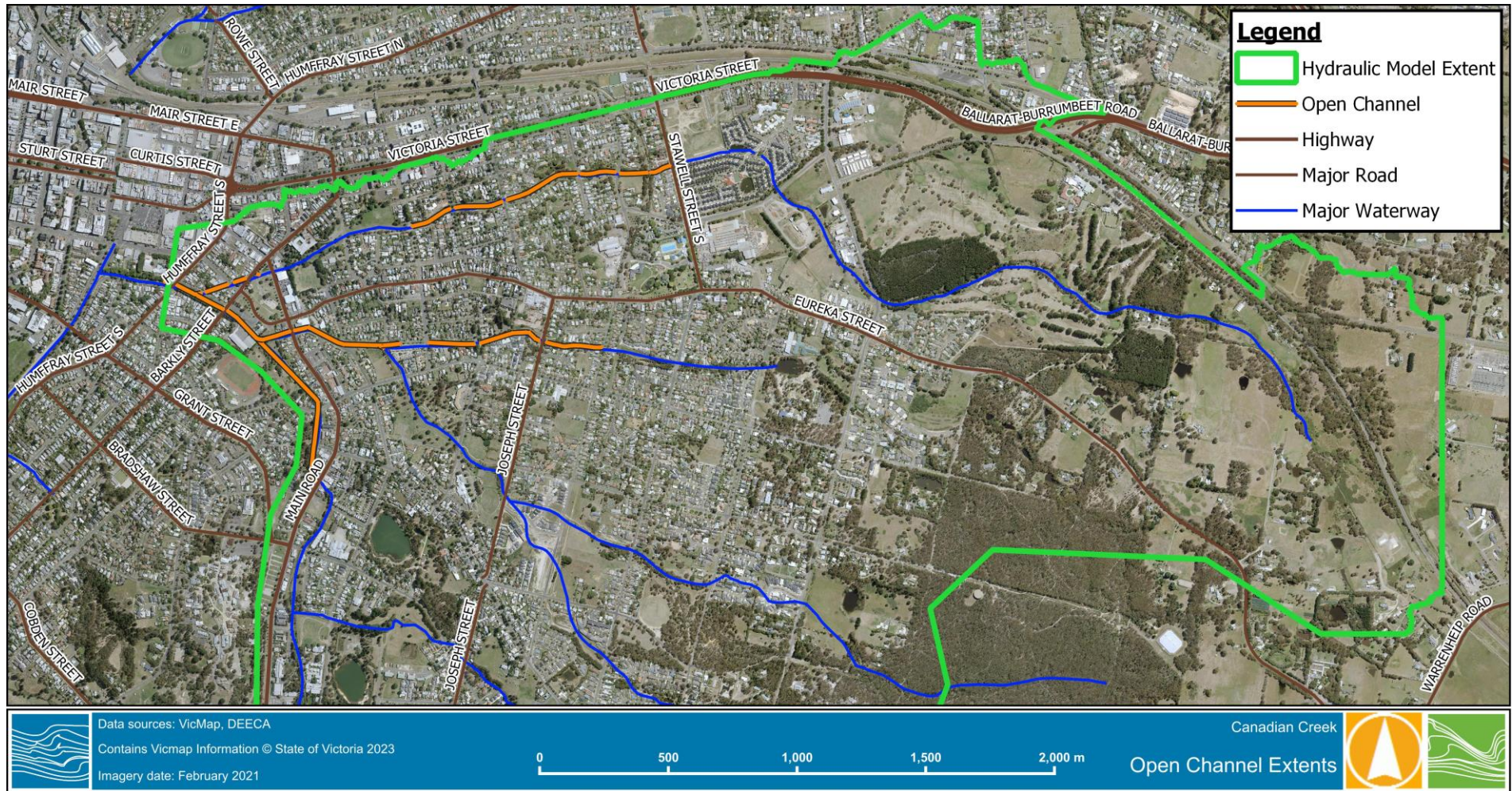


FIGURE 4-6 HYDRAULIC MODEL LINED CHANNEL EXTENTS



## 4.4 Boundary conditions

The hydraulic model requires inflow and outlet boundaries to allow water into and out of the model. External inflow boundaries account 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.

Canadian Creek has one hydraulic outflow at Peel St South. This outflow has been modelled as discharge/water level boundary (HQ). This boundary allows water to exit the model based on a stage discharge curve generated by TUFLOW.

A total 96 internal inflow boundaries were applied. 80 of the inflow boundaries were applied as source area boundaries (SA) where inflow hydrographs were applied to a region in the 2D domain, while 16 of the inflow boundaries were applied to the drainage network via pits in the 1D domain. The location of these boundaries are shown in Figure 4-7.

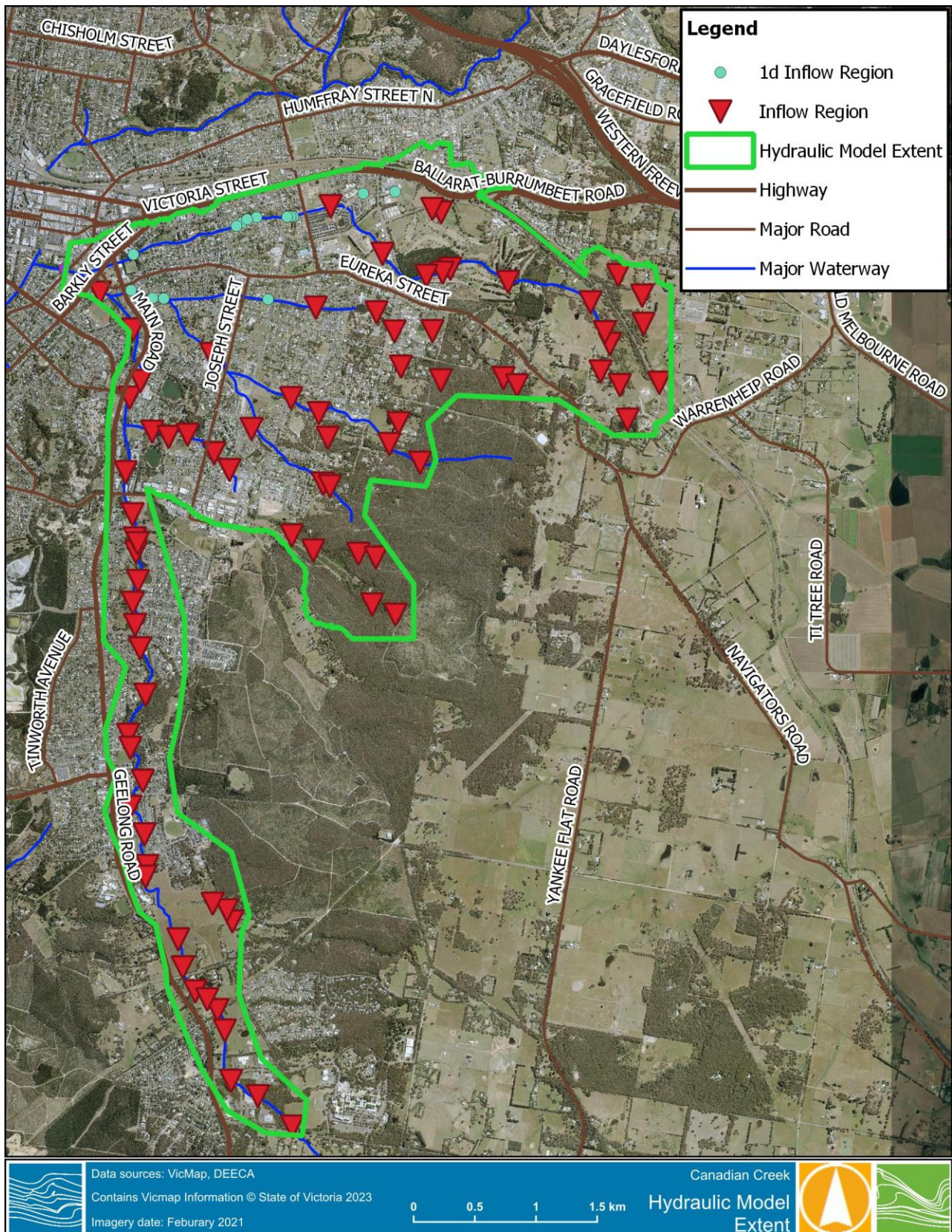


FIGURE 4-7 MODEL BOUNDARIES



## 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 for the Canadian Creek immediately upstream of Elsworth Street is presented in Figure 5-1. The hydrograph is from the 1% AEP, 12-hour TP 26 event.

The comparison shows a similarity in the peak flows of 27 m<sup>3</sup>/s and 25 m<sup>3</sup>/s for the TUFLOW and RORB models, respectively. The TUFLOW model demonstrates a slightly faster response time. The TUFLOW model routes flows quicker through the catchment in comparison the RORB model, given the different methods of routing flows, the comparison is considered suitable.

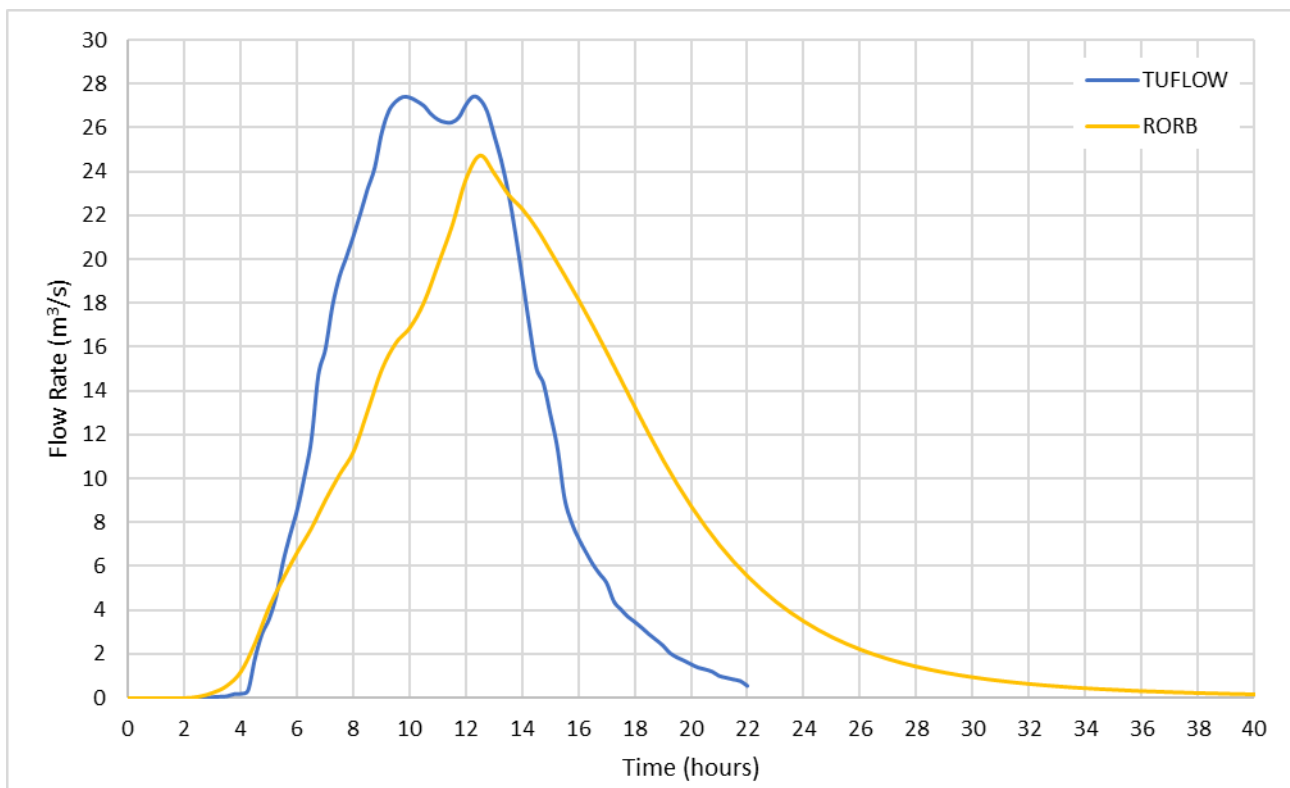


**FIGURE 5-1 HYDROLOGIC AND HYDRAULIC MODEL FLOW HYDROGRAPH COMPARISON – CANADIAN CREEK AT ELSWORTH STREET**



## 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 6-5 below.

Results show that the flooding upstream of the Ballarat CBD widely breaks out Canadian Creek and its tributaries, only being contained within Specimen Vale Creek from Blairs Lane to Fussell Street, and Canadian Creek from Clayton Street to Humffray Street.

Results also indicate that there are numerous areas affected by flooding, including: Charlesworth Street; the development along Navy Jack Road; Pennyweight Gully from between Richard Street and Wilson Street, Lal Lal Drain from between Butt Street and Otway Street; and residential lots along the eastern side of Main Road from between Elsworth Street and Wainwright Street.



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

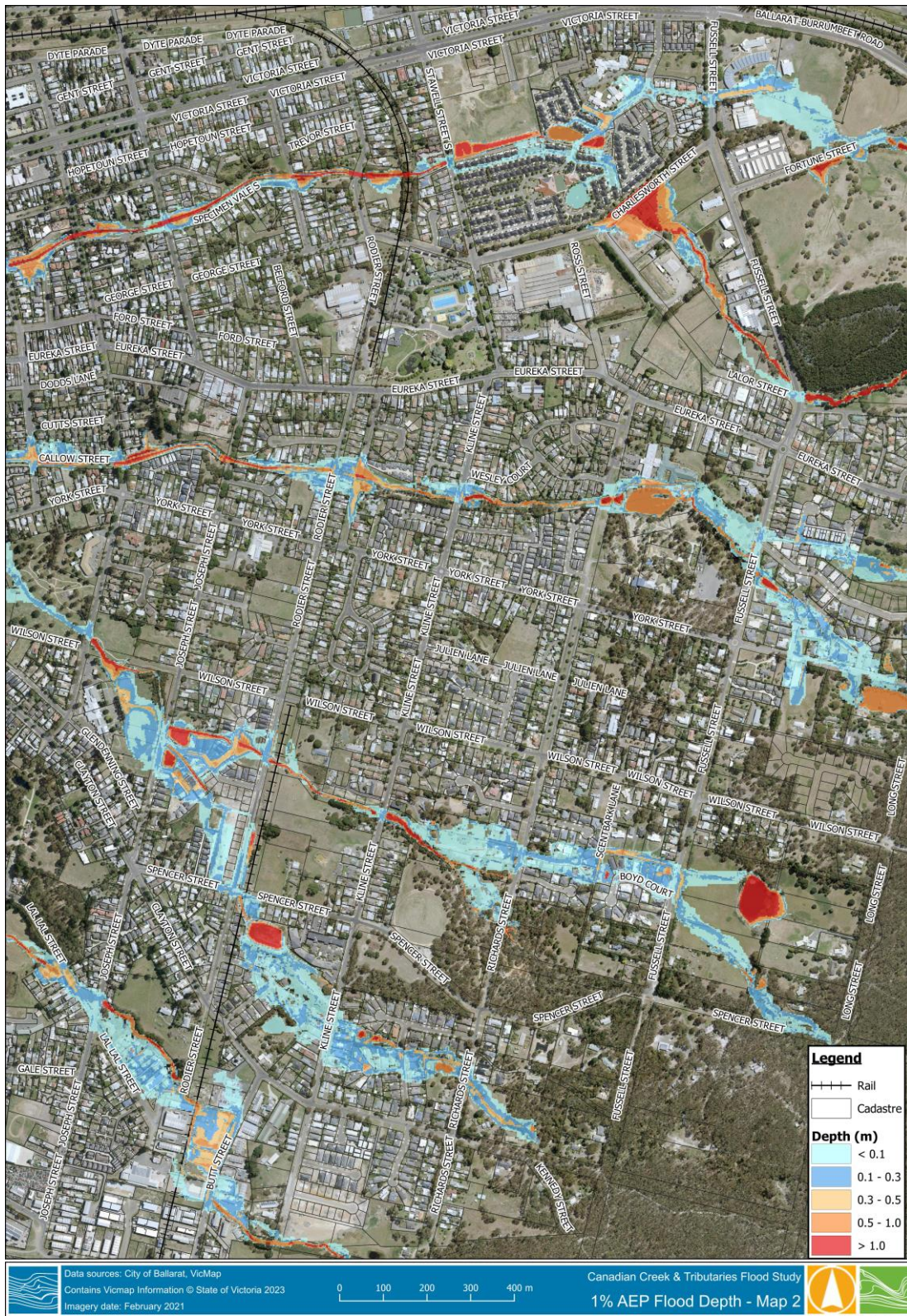


**FIGURE 6-2 MAXIMUM FLOOD DEPTH – 1% AEP (MAP 2)**

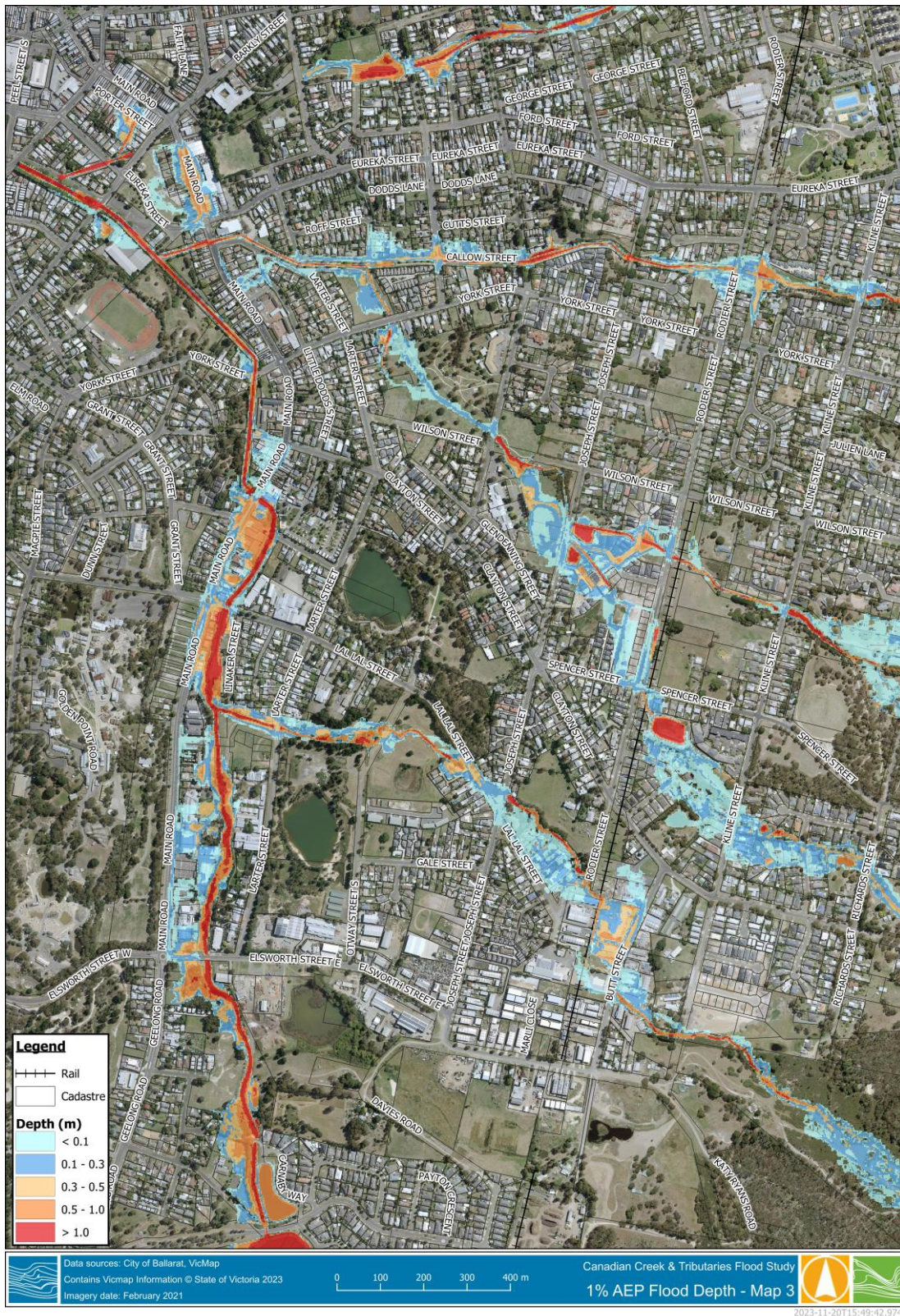


**FIGURE 6-3 MAXIMUM FLOOD DEPTH – 1% AEP (MAP 3)**

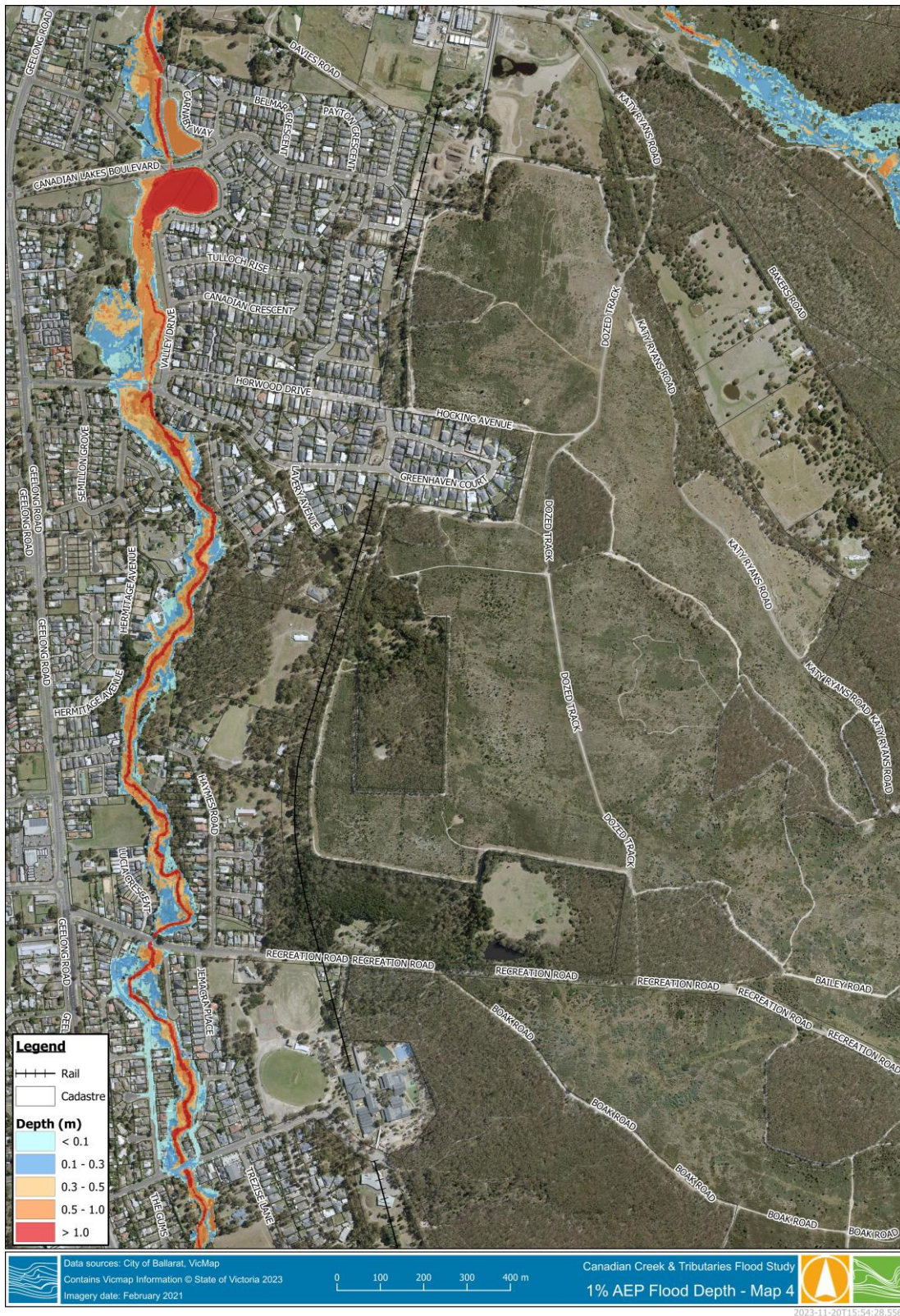


**FIGURE 6-4 MAXIMUM FLOOD DEPTH – 1% AEP (MAP 4)**

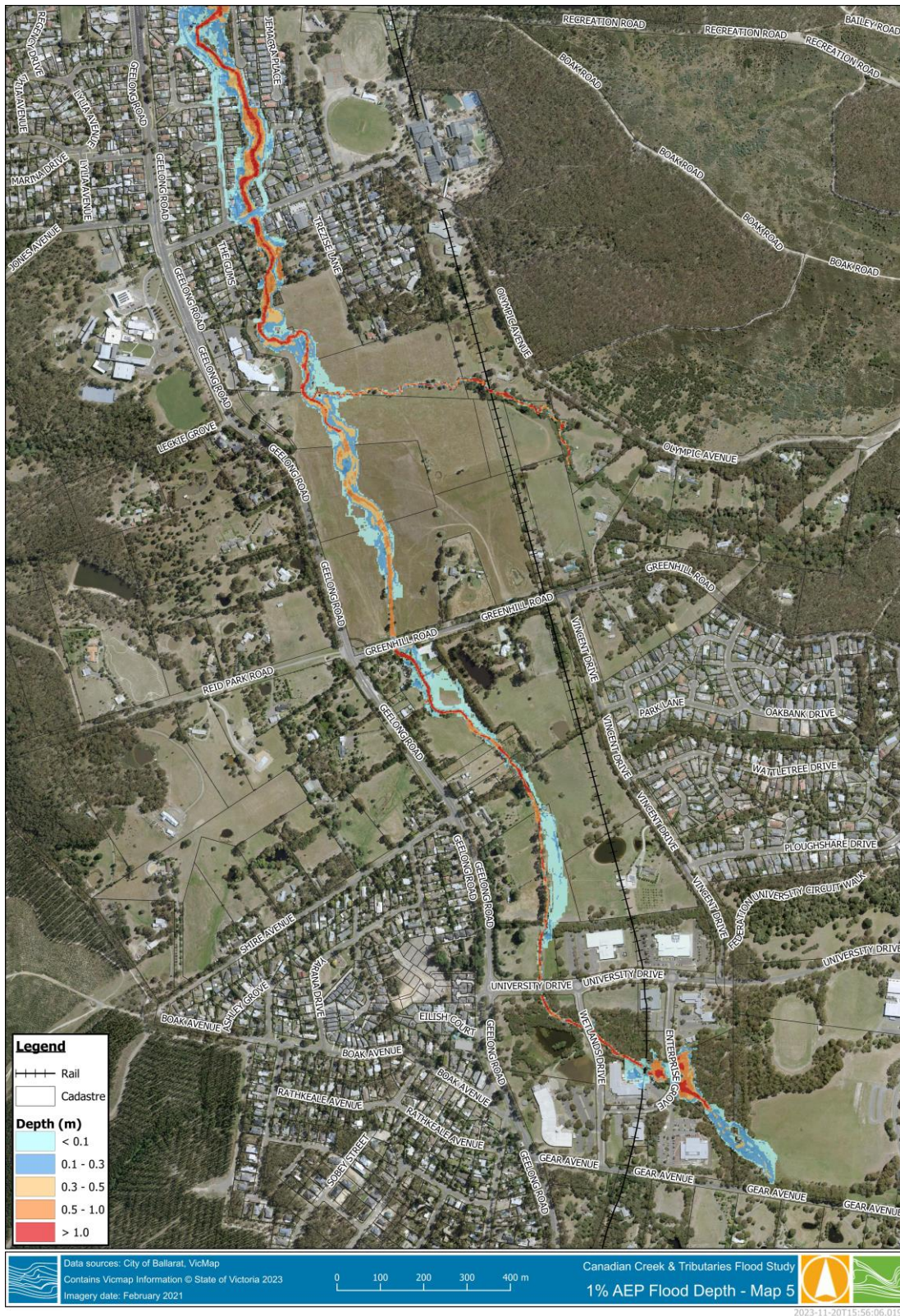


FIGURE 6-5 MAXIMUM FLOOD DEPTH – 1% AEP (MAP 5)



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