KYABRAM FLOOD STUDY AND MANAGEMENT PLAN – FINAL STUDY REPORT

NOVEMBER 2021

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EXECUTIVE SUMMARY

Campaspe Shire Council (CSC) and Goulburn Broken CMA engaged Water Modelling Solutions to undertake a detailed flood study and management plan of Kyabram and its immediate surrounds including the influence of the Mosquito Depression to the south. The project involves hydrologic and hydraulic modelling of the study area in order to produce flood mapping and a comprehensive set of intelligence outputs for a wide range of design storm events.

This report presents the key components of the Kyabram Flood Study. The points below detail the study key findings and recommendations:

- The study has involved the development of hydrologic (RORB) and hydraulic (TUFLOW) models of Kyabram Township and broader Mosquito Creek catchment.
- Hydrologic models for both the Kyabram Township and Mosquito Depression catchments were built in the software RORB. Appropriate parameters were determined in line with the latest ARR2019 guidelines and the models used to model two historic validation events – the March 2012 and October 1993 events. The outputs from this modelling were then be input into a TUFLOW hydraulic model as part a joint hydrologic/hydraulic model validation approach
- An extensive range of design events and have been modelled, with critical storm durations from 30 minutes up to 168 hours included. The modelled design events include the 20% AEP up to the 0.01% AEP, as well as the PMF event.
- A range of sensitivity scenarios were modelled including sensitivity to roughness change, blockage and pump failure. The pump failure scenarios highlighted the importance of the pumps operating at capacity during storm events. This also highlights the importance of regular pump maintained, ongoing Council staff training regarding pump operations during storm events as well as compliance with the operations manual during such events.
- A number of mitigation options have been assessed, first at a preliminary level, to assess their effectiveness in reducing flood risk, and then at a detailed level to assess the feasibility of the options which were shown to provide benefit. Three packages of options have been assessed in detailed which included modelling the full range of design events, costings, damages assessment and benefit cost analysis. All three options had lower benefit-cost ratios of well below one. Option P4 had the highest benefit cost ratio, with a BCR of 0.27. While the BCR for these options is low it is recommended that aspects of these works including pipe and culvert upgrades are considered within Council's future capital works program as the network is upgraded over time.
- In addition to the mitigation assessment described above, a voluntary house purchase scheme was assessed at a preliminary level. The scheme was found to have a higher benefit-cost ratio than the other mitigation options with a BCR of 0.51 determined for purchase of all dwellings flooded above floor in the 10% AEP event, and a BCR of 0.42 for purchase of all dwellings flooded above floor in the 5% AEP event. Given these schemes have a higher BCR than the structural mitigation options it is recommended that a VHP scheme be investigated in more detail as part of a feasibility assessment.
- A range of flood intelligence outputs have been produced from this project and it is recommended that these be adopted by Council and VICSES to support flood response during times of flood.
- Draft planning layers have been produced and it is recommended that these be implemented through a planning scheme amendment, to ensure flood-related planning overlays for the township represent the current level of flood risk.

Council approved formal exhibition of the report seeking community comment on the 16th June 2021. No written submissions and four verbal submissions relating to specific properties were received generally confirming the accuracy of modelling. The key issues consistent raised was reliability of the large diesel pump at the Lake Road Sump; several examples of its failure to operate were cited. Results of this consultation indicates a high level of community support for the study and its recommendations.

Following formal exhibition and consultation with the broader Kyabram community this study was adopted by Campaspe Shire Council in a Council Meeting on 20th October 2021.

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LIST OF ABBREVIATIONS

AEP	Annual Exceedance Probability
CSC	Campaspe Shire Council
DTM	Digital Terrain Model
FFA	Flood Frequency Analysis
FI	Fraction Impervious
CMA	Catchment Management Authority
IFD	Intensity-Frequency Duration

1 INTRODUCTION

1.1 BACKGROUND

Campaspe Shire Council (CSC) and Goulburn Broken CMA engaged Water Modelling Solutions to undertake a detailed flood study and management plan of Kyabram and its immediate surrounds including the influence of the Mosquito Depression to the south. The project involves hydrologic and hydraulic modelling of the study area in order to produce flood mapping and a comprehensive set of intelligence outputs for the full range of design events.

1.2 SCOPE OF PROJECT

The key tasks of the hydrologic and hydraulic analysis includes:

- Review all available hydrological data including rainfall and streamflow/water level data;
- Undertake community consultation to gather flood data and seek feedback on the outputs of the study.
- Develop two new hydrological RORB models – of the Kyabram township local catchments and of the Mosquito Depression catchment upstream of Kyabram;
- Develop a new hydraulic TUFLOW model of the study area which includes the Kyabram township local catchments and Mosquito Depression floodplain to the south;
- Calibrate both the RORB and TUFLOW models by modelling 2-3 historical events for which data is available. Given the lack of gauging in and around the study area a joint hydrologic/hydraulic model calibration will be adopted whereby the resulting flows are tested in the TUFLOW model prior to adoption;
- Determine 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2%, 0.1%, 0.05% AEP and PMP design rainfall excess hyetographs using an ensemble approach in RORB;
- Model the 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2%, 0.1%, 0.05% AEP and PMP events in TUFLOW;
- Undertake a sensitivity analysis of relevant model parameters and assumptions;
- Ensure both the hydrological and hydraulic modelling is in line with best practice and consistent with ARR2019;
- Undertake a flood damages assessment under existing conditions;
- Undertake a structural mitigation assessment which includes modelling, damages assessment and benefit-cost analysis;
- Undertake a flood warning assessment for Kyabram;
- Develop draft planning layers for the study area; and
- Prepare a study report which describes the methodology and findings of the above tasks.

1.3 CATCHMENT DESCRIPTION

Kyabram is located within the Campaspe Shire municipality approximately 35km west-north-west of Shepparton and roughly midway between Echuca and Shepparton. The town is effectively "land-locked", in that it is surrounded by irrigation supply and drainage channels. This infrastructure has a significant impact on flood behaviour around the township and means there is a significant reliance on pumping during and following large rainfall events. The Mosquito Depression, located to the south and west of Kyabram, may also impact inundation of the town and has a catchment area of approximately 340km^2 upstream of the study area extending as far east as Mooroopna.

The Kyabram Township RORB Model boundary is illustrated in Figure 1-1.

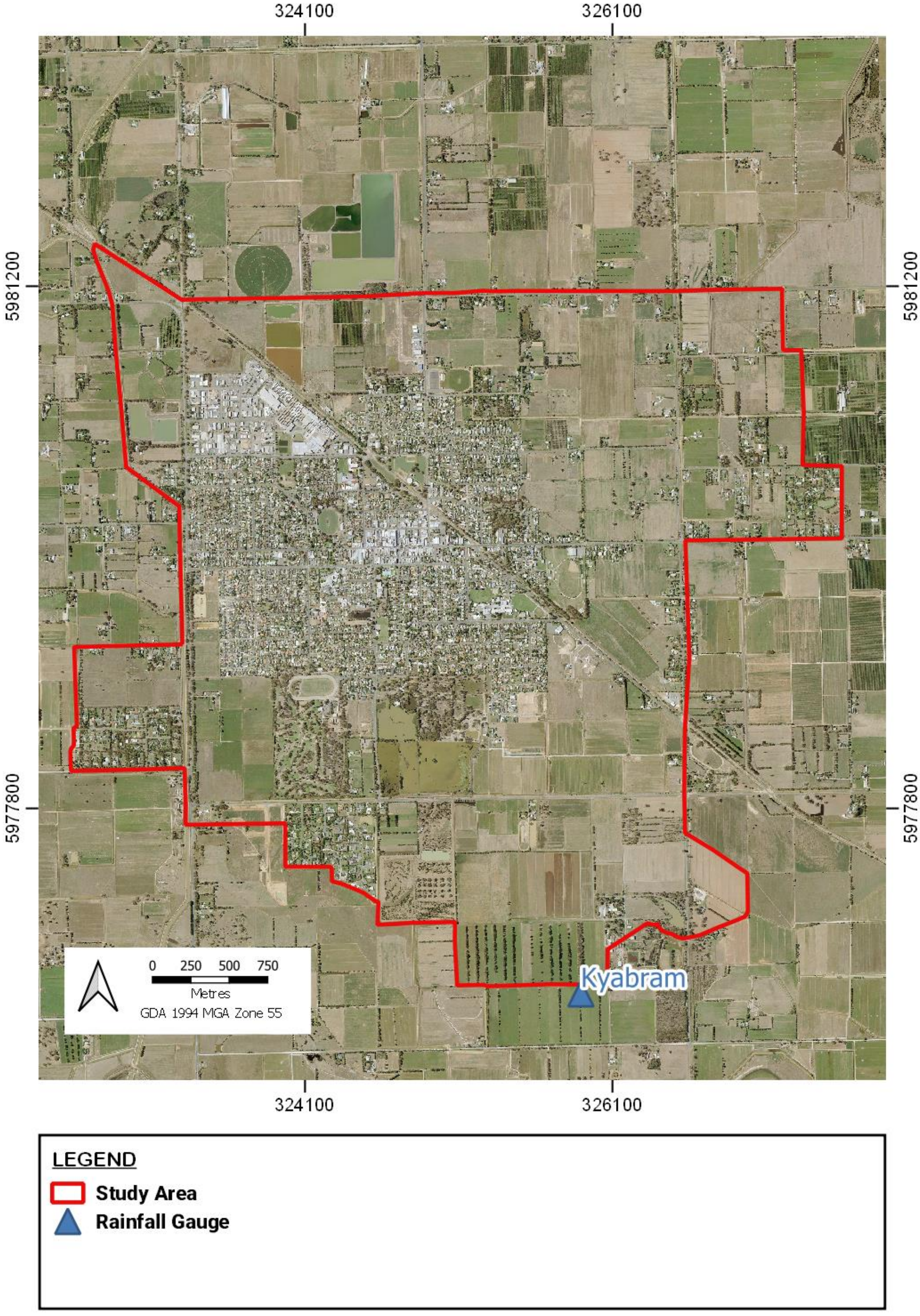

Figure 1-1 Boundary of Kyabram Township Hydrological Catchments

2 COMMUNITY CONSULTATION AND STAKEHOLDER ENGAGEMENT

A community reference panel meeting and community drop-in session was held at the Kyabram Community Hub on the 22nd of October 2019. The meeting was attended by some 25-30 people and useful feedback and suggestions was obtained. The information below has been presented previously in the data review report, but has been presented again as much of the information is relevant to the hydraulic calibration process described in this report.

The community identified several different locations where flooding is of concern. Of particular note is the potential change to the flow regime due to the change from open channel to pipe along Lake Road, blockage of syphons in the vicinity of Gray Road and Tisdall Road. The 1993 and 2012 flood events were also highlighted as events where flooding and drainage problems were most evident.

A summary of all community and stakeholder feedback has been provided in Table 2-1 and the map highlighting the locations of concern is given in Figure 2-1.

Table 2-1 Community and stakeholder consultation feedback

ID/Map Location	Feedback
1	Tisdall Road, Northern Oval area - serious issues
1	Tisdall Road - several floods, worse since Northern Oval done. Greg McKenzie knows detail
7	2012 / 1993 - Dawes / McEwen Road. 93 Dawes Road (and) Service Road - McCormick Road sheet of water including D'Alburb showroom floor. 2012 - 48 McEwen Road house - surrounded for 26 hours till clear and didn't get in. 2012 - North corner McEwen and Daniel - flooded inside house, next door in Daniel - flooded inside house. 2012 - Banyule - McCormick Road along service Road locked in for 26 hours per above (too deep for cars) When lot of rain runs back to east along Dawes Road
11	Haslem Street - Richard Street - Park Street. See GBCMA Flood Map in Project Brief. 2012 was minor c.f. 1993. Pettifer/Chaston Street - Home flooded above floor 1993.
12	On a high rainfall event the drainage pipes in Koala Court are nowhere near sufficient to cope with the amount of water. We rely on the overflow from Court to run through my property and into the Fauna Park. If alterations in the Fauna Park restrict or block the natural flow of the water, houses in Koala Court will definitely be inundated.
19	All storm water in Kyabram (pumped to Fauna Park from centre of town plus the local runoff) must eventually run west and pass under the G-MW No. 9 channel, which is immediately west of McEwen Road. The current pipes under the channel are incapable of passing large flood events causing exacerbated flooding east of the channel. In other locations channels are piped under depressions because the channel has a known capacity and pipes can be sized accordingly. Mother Nature does not have such limitations, so give flood flows an open go to pass over the channel.
20	Ern Miles Reserve (Kyabram Drainage Basin). Flooded Dec 2011, Jan 2012, Feb 2012. Trees planted by KyLandcare were flooded for 3 weeks, surface water off for 1 week. This was then followed by Jan flooding again 3 weeks on, 1 week off

ID/Map Location	Feedback
	and repeated again in February. 40% of all plantings lost. Drainage Basin does not function as it was designed to. It all would have drained quicker if the outfall drains had been cleaned. Photos and video available.
21	Corner McEwen and McCormick East to Barton Road Barton Road to factories. South to Allan Street. East of Barton Road to Allan Street.
22	Corner Saunders and Fenaughty
23	Lake Road to South Boundary Road (1993)
24	Fischer Street to Green Avenue and Park Street - 1993
25	Albion Street between Edith Street and Graham Road - 1993-2012
26	Tisdall Road East - 1993 and 2012.
27	Union Street South of Fenaughty Street. 1993 - Storm of 2012
28	Corner of Fenaughty and Goegan Drive - 1993-2012
29	Chaston between Lake and Mitchell Road Anytime it rains (1993)
31	Homes Corner Lake road and South Boundary Road. 1993 - 2012
32	Concerns that the channel at South Boundary Road has been filled
33	2012 Flood. NW corner Union Street and Fenaughty St (M&S) Banksia building. Up to front door. 1 foot water in intersection
34	2012 Flood extent
35	In 2012 this land received overflow water from Fauna Park Lakes. NB: 33 Union Street is the lowest point.
54	Goegan Drive, Waratah Street, Cowan Court - flood issues
55	Syphon under channel blocked
56	In 1974/75 we pumped (for Council) water from town along Lake Road into channel going down South Boundary Road, now that channel is pipe line - where will the water go?
57	Syphon was blocked off years ago that took water from north of Gray road to South of Gray Road and westwards
	Photos - suggest contacting Free Press Newspaper

ID/Map Location	Feedback
	Koala Court - always floods in a localised event
	Union Street between Fischer and Fenaughty
	Contacts for local knowledge = Dan Anderson, 1973 Richards, Thot, & Hospital flooded?, Historical Society - Eileen Sullivan
	Roger Road drainage to the north to Tisdall Road.
	Maintenance required to improve drainage capacity for the east.
	Check comparative storage volumes - Fauna Park Lakes, overflow storage south of South Boundary Road.
	Regular maintenance to outfall from Fauna Park Lakes to west of town.
	Review outfall drain to west of GMW channel which provides for this outflow
	Review capacity of under-channel "subways".
	Fauna Park Lake. Management, possible redirection in flood storage? Lake takes some 80% of town drainage.
	LGA Briefed Community post 2012.

A period of formal community consultation involving exhibition of the draft final flood study report and flood warning sub-report was conducted between the 23 June and 23 July 2021. It involved invitations to comment and attend six community presentation sessions via advertisements and press releases in the Kyabram Free Press, letters to 80 randomly selected property owners and the Campaspe Shire website. In summary:

- Copies of the reports were available at the Kyabram Customer Service Centre and online via the Campaspe Shire Council project page for review and comment.
- A mapping portal was established which allowed users to inspect the mapping results in more detail in a "Google Maps"-style environment.
- The study findings were presented at six community drop-in sessions over a two day period, on the 8th and 12th July 2021, at the Kyabram Community Hub with both Council staff and consultants present where a total of four people attended.
- Some positive verbal feedback was received regarding the mapping and findings of the project. Some specific inquiries were received regarding flood levels and surveyed floor levels at individual properties. One attendee had concerns that the project would result in runoff being directed to the south into the Mosquito Depression – it was clarified that while this had been tested in some mitigation scenarios, it is not a recommendation of the study.
- No written submissions were received

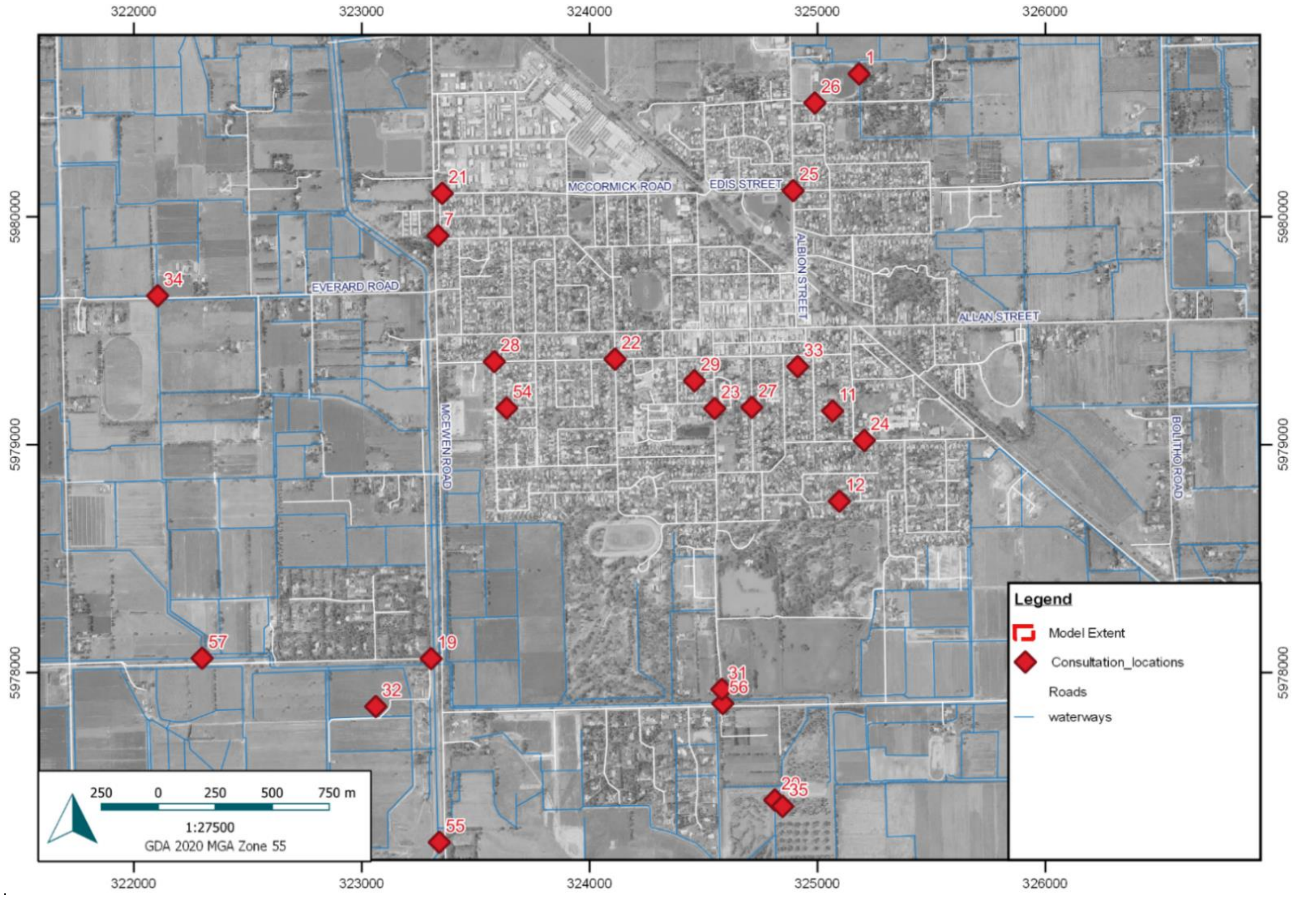

Figure 2-1 Community and stakeholder consultation feedback, location of observed flood/drainage problems

3 HYDROLOGICAL ANALYSIS

3.1 HYDROLOGICAL ANALYSIS OVERVIEW

The study area is characterised by numerous irrigation channels, farm dams and a number of depressions that traverse the surrounding areas as well as the upstream Mosquito Depression catchment. The hydrological process focussed on the natural flow pathways throughout, however, the catchment is so modified that there are few natural reaches of watercourse remaining.

The hydrology for the study area is complex and impacted by the local, township catchments in Kyabram as well as the broader Mosquito Depression catchment. These two components have been modelled separately. The first is the Kyabram Township model and the second is the Mosquito Depression model.

The Kyabram Township model is further complicated by very flat terrain, which includes a series of sumps and pumps that have been built throughout the township in an attempt to move the water from the town out into the irrigation channels – primarily though one main culvert to the west of the town. The Mosquito Depression includes numerous dams, irrigation channels through the landscape which impact the natural flow of floodwater significantly and create additional storage through the catchment.

The complexities of the two catchments need to be taken into consideration when designing the modelling approach and the following points outline the methodology that has been undertaken;

- Gather and assess relevant hydrological data including but not limited to streamflow, rainfall, LiDAR etc.;
- Catchment delineation using GIS packages;
- Build two RORB hydrological models for the town catchments, and the broader Mosquito Depression catchment;
- Calibration of the RORB models to two historical events – the October 1993 and March 2012 events as part of a joint hydrological / hydraulic calibration;
- Run the RORB models for design flows using ARR2019 rainfall data and temporal and spatial patterns, using an Ensemble approach

Due to limited availability of gauged streamflow data, as discussed later in Section 3.2, the final calibration to determine routing and loss parameters will utilise a combined hydrological / hydraulic method, that will be undertaken once the hydraulic model build is complete at a later stage in the project timeline.

3.2 HYDROLOGICAL DATA COLLECTION AND REVIEW

To undertake the hydrological modelling, a range of data has been collected and reviewed. The data collected is outlined in Table 3-1.

Table 3-1 Data collected for hydrological analysis

Data	Source	Notes
Gauged Streamflow, Rainfall and Water Level Data Mosquito Depression @ Curr Road Gauge Number 406756	Water Data Online (State Government of Victoria, 2019)	• Stream Discharge – 17/9/1992 – 18/12/2019 @ 0.25hour increments • Rainfall (mm) 30/7/1992 – 23/5/2013 @ 0.25hour increments • Stream Water Level (m) – 17/9/1992 – 18/12/2019 • The rating curve is limited; therefore, the gauge data is not suitable for undertaking flood frequency analysis. The rating only accurately captures along flow within ta perched channel where the gauge is located up to 0.9m deep, and does not account for the flow across the broader floodplain.
Design Rainfall	ARR Data Hub	Provides the design rainfall for all AEPs, the areal reduction factors, the temporal

Data	Source	Notes
		pattern shape intersection and the preburst depths, and climate change factors.
IFD Charts	Bureau of Meteorology (Commonwealth of Australia, 2020)	Relevant Intensity-Frequency-Duration Data for the Kyabram Township Catchment and Mosquito Depression Catchment.
6-minute pluviograph data This data will be used for the calibration of the combined hydrologic/hydraulic models.	Bureau of Meteorology (Commonwealth of Australia, 2020)	• Tatura (Thiess Services) 8/1/1975 – 1/8/1999 • Tatura Inst. Sustainable Ag 28/5/1996 – 13/1/2020 • Echuca Aerodrome 20/8/2008 – 13/1/2020 • Wanalta Daen Station 23/7/1996 – 13/1/2020 • Wanalta Recorder Three 1/2/1974 – 5/2/2002 • Wanalta recorder Two 1/2/1974 – 5/2/2002 Note, not all of the above gauges have data spanning the required periods.
Daily Rainfall Gauges 26 Daily and Sub Daily Gauges were considered for the study and 14 local, daily gauges were used to generate the spatial pattern of rainfall.	Bureau of Meteorology (Commonwealth of Australia, 2020)	These gauges are detailed in the Data Review Report (WMS, 2019).
Pump Capacity Data	See details in Appendix F.	
Sump Stage Storage Tables	These were obtained by utilising functionality available in the Hec Ras 5.6 software to calculate stage-storage tables based on the input of a DEM. These tables have been included in Appendix F	

In most cases, the data collected has been accepted without requiring any adjustment. It has been assumed that the owners of the data, in each case, have provided the best available data.

It is of note that while streamflow data is available in the vicinity of the study area (Mosquito Depression @ Curr Road Gauge 406756) the quality of the data is considered poor for the purpose of design flood estimation, as a result of a limited rating curve. For this reason, the data was deemed unsuitable for flood frequency analysis.

3.2.1 LiDAR Data

Accurate topographic data provides a basis for the hydrologic and hydraulic model build and allows for a better representation of hydrologic pathways within the catchment. LiDAR was used in the hydrological analysis to assist in sub area and reach delineation and was used in the hydraulic model as the basis of the model terrain.

3.2.1.1 Kyabram Township

For the Kyabram Township model, LiDAR was captured in July 2019 and entitled the West Yarrawonga and Kyabram LiDAR Acquisition, shown in Figure 3-1. The data was captured on behalf of the Department of Environment, Land, Water and Planning by Photomapping Services using Airborne Laser Scanning. The metadata of the LiDAR is as follows:

- GDA2020 MGA Zone 55

- Datum – m AHD
- Gridded 1m DEM as ASCII
- Horizontal Accuracy is +/- 0.3m
- Vertical Accuracy is +/- 0.1m
- 1st through 4th return provided (where this includes all data, ground LiDAR, low vegetation and medium vegetation)
- Water was identified primarily based on laser intensity
- Bridges identified and removed from the ground surface

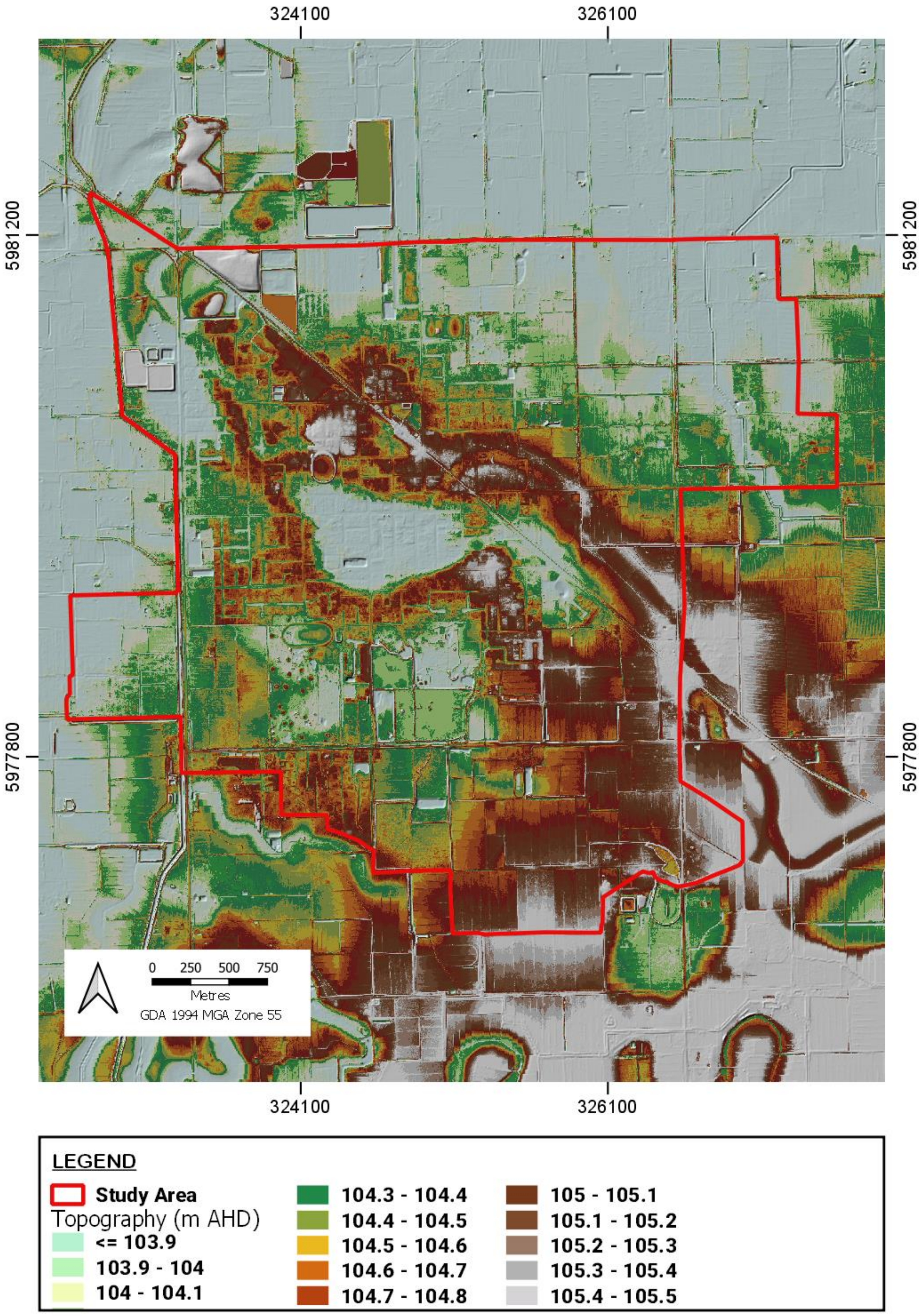

Figure 3-1 Kyabram 1m LiDAR captured in 2019.

3.2.1.2 Mosquito Depression

The LiDAR captured in 2019 for the Kyabram Township model extending from the streamflow gauge at Merrigum Bridge to the outlet near Tongala was used in the Mosquito Depression model. The LiDAR data was converted to 1m grid resolution, which was determined a suitable size to represent the various key hydraulic features. The model DEM is shown in Figure 3-2.

The upstream model which extended to Murchison was not located within the Victoria 10 metre DEM datasets. Instead, the data was sourced from the ELVIS – Elevation and Depth – Foundation Spatial Data. The Shuttle Radar Topography Mission or SRTM-derived 1 second data captured in February 2000 provided an adequate dataset to assess the hydrology of the catchment.

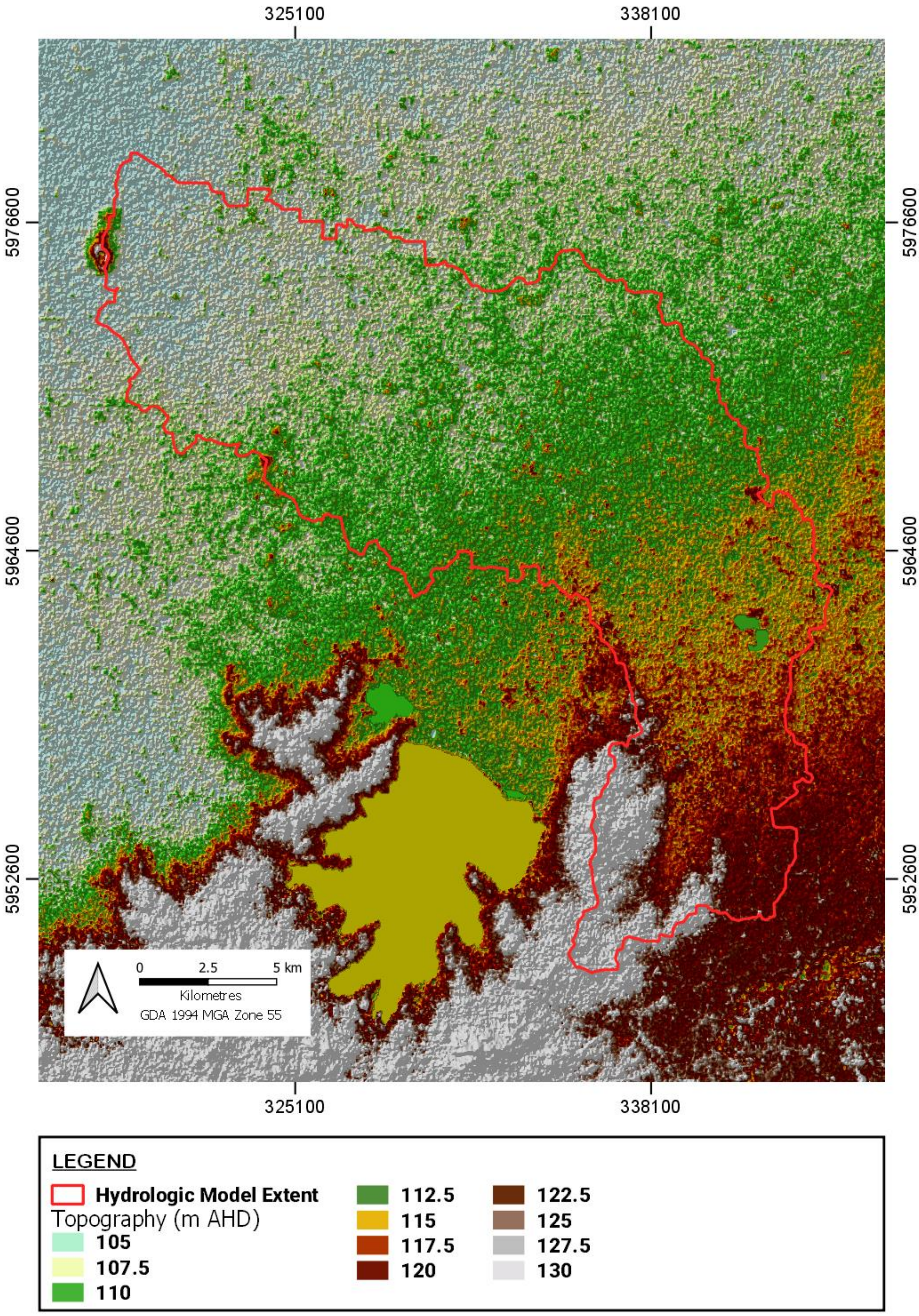

Figure 3-2 SRTM derived – 1 second DEM for the Mosquito Depression Catchment

3.3 HYDROLOGICAL MODELLING

3.3.1 Overview

Two RORB models were constructed to determine historic and design flood flows through the Kyabram Township and the Mosquito Depression. The RORB analysis aimed to represent the rainfall-runoff processes occurring across the study catchment.

Key RORB inputs included:

- Sub-catchment, reach and node delineation;
- Fraction impervious values determined from town planning land use types;
- Rainfall depth data;
- Rainfall losses;
- Rainfall temporal patterns;
- Rainfall spatial patterns;
- K_c – key routing parameter;
- m – degree of catchment non-linearity;

Each of these inputs are discussed in the following sections. A summary of the RORB modelling process is shown in Figure 3-3.

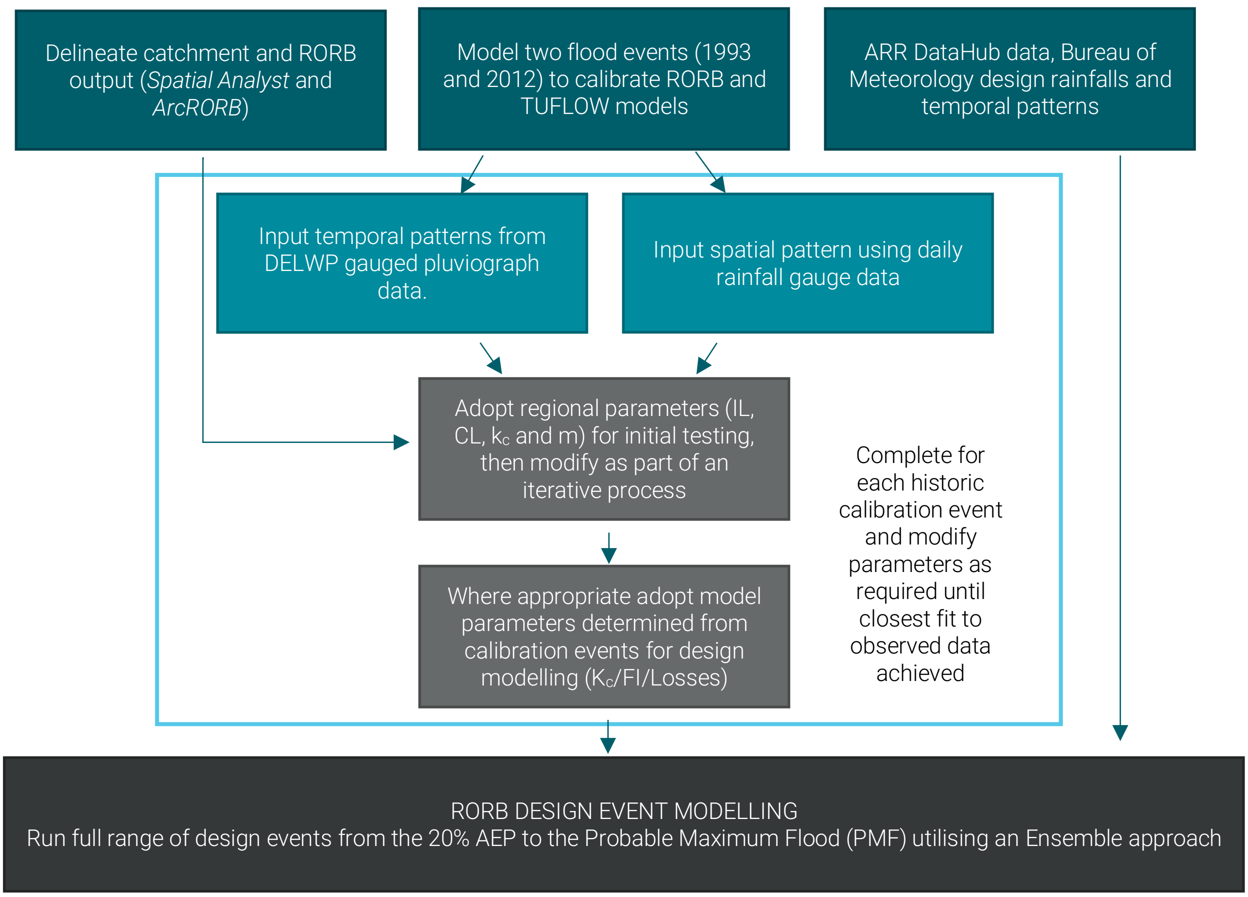

Figure 3-3 RORB Modelling approach

3.3.2 Hydrological Model Build – Kyabram Township Model

The key aspects of the hydrological build for the Township model is as follows (and is also applicable to the Mosquito Depression model):

- Delineate sub areas, reaches, nodes and the full catchment boundary;
- Determine sub area areas, fraction impervious values, reach types, reach lengths and slopes;
- Determine the details for the sumps and pumps for the Kyabram Township model;
- Convert the above data into a RORB catchment vector file.

3.3.2.1 Catchment delineation

Catchment sub area, reach and node delineation was undertaken using a combination of the free spatial software QGIS, in combination with the specialised GIS software plugin ArcRORB. ArcRORB is a purpose-built software to assist with delineation of RORB models, extraction of all details such as sub catchment areas, reach lengths, slopes and fraction impervious values and then conversion of this data into a RORB catchment vector.

The Kyabram Township catchment is a total area of 15.91 km^2, and has been divided into 64 sub-catchments. The catchment was delineated such that there is a minimum of 5 sub-areas upstream of any hydrograph print location expected to be utilised in the hydraulic model. In the first instance, the sub catchment delineation was undertaken following the sub areas marked by GHD in Figure 1 of the original report entitled Drainage System Report on Surface Drainage Strategy (GHD, 1994) and illustrated in Figure 3-4 below. The sub areas were subsequently refined based on the latest 1m LiDAR DEM, which was flown in 2019 as discussed in Section 3, in combination with the local knowledge of the Campaspe Shire Council Project Manager. These sub areas were further refined to ensure approximately evenly sized catchments (within less than 10% between the smallest and largest sub areas). Ensuring the sub areas are of approximately equal sizes maintains a consistent average travel distance within the sub areas.

3.3.2.2 Sub areas

The model delineation of sub areas, reaches and nodes is illustrated in Figure 3-5 below. Note that a dummy outlet has been provided in the north-west corner of the model as RORB models require a single outlet for all sub-catchments within the model. A table of the sub catchment areas and fraction impervious values has been provided in the appendices.

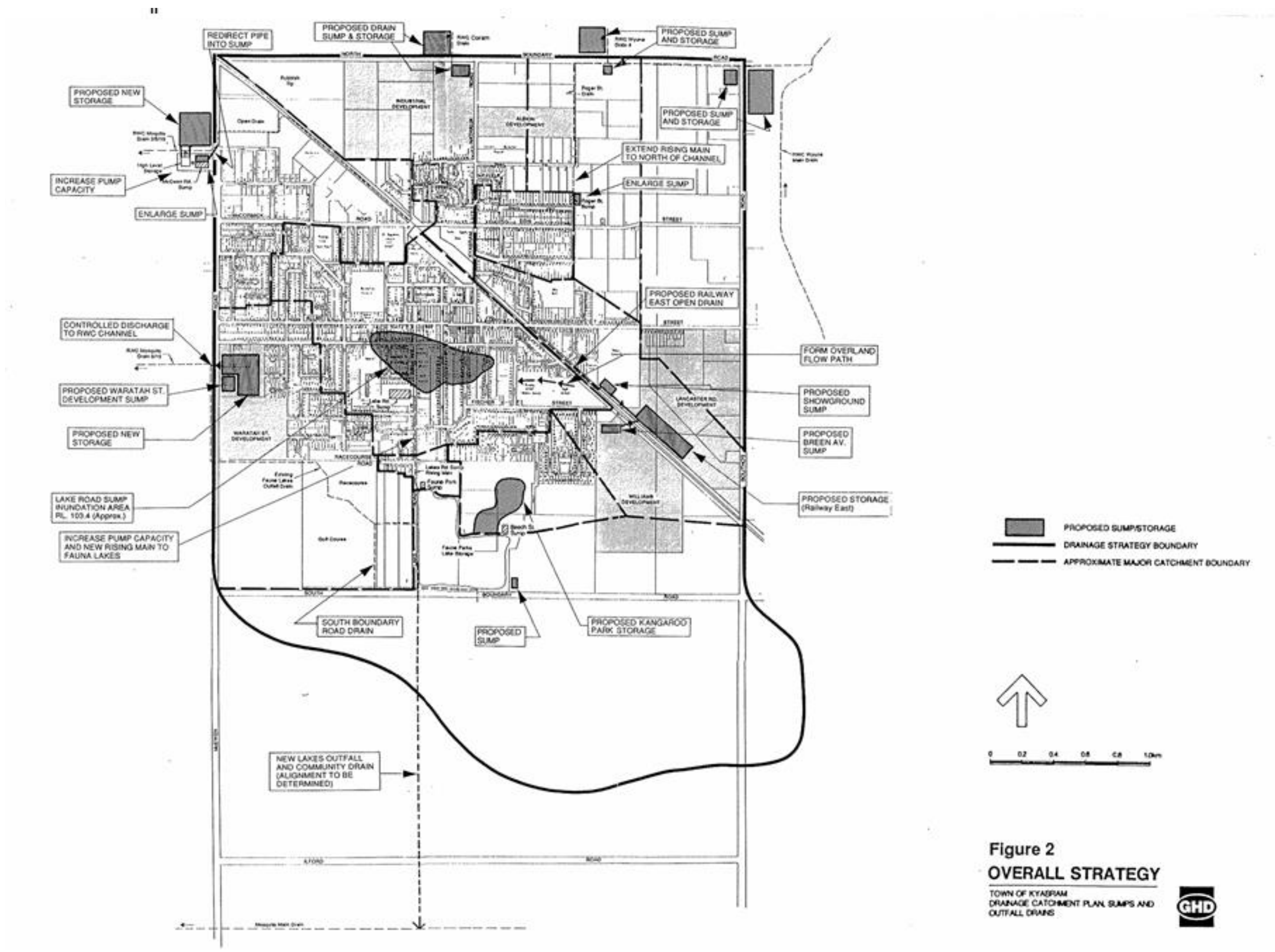

Figure 3-4 Original GHD catchment delineation (GHD, 1994)

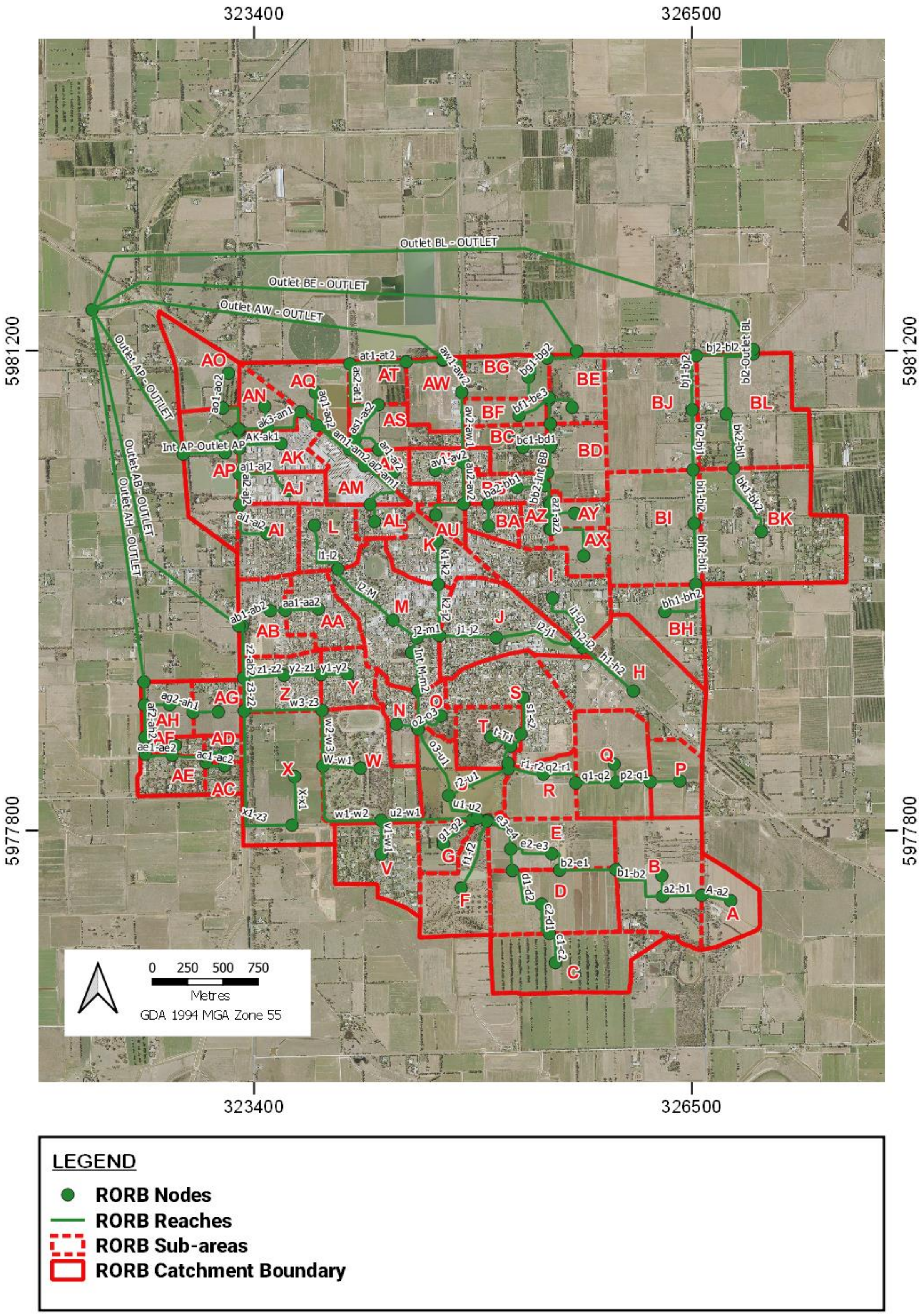

Figure 3-5 *Kyabram Township RORB Model Delineation*

Figure 3-6 illustrates the RORB graphical editor catchment vector, in which the sumps and pumps are also included in the model. The data for all sumps and pumps as utilised in the RORB model is outlined in Appendix F. Both the Kyabram Township RORB model sub area delineation and the catchment vectors are included in a larger format in Appendix A and Appendix B respectively. The model generally reflects the alignment of overland flow paths and drains, as well as some key culvert structures and trunk mains. The full pit and pipe network have been included as part of the hydraulic modelling discussed in the next section.

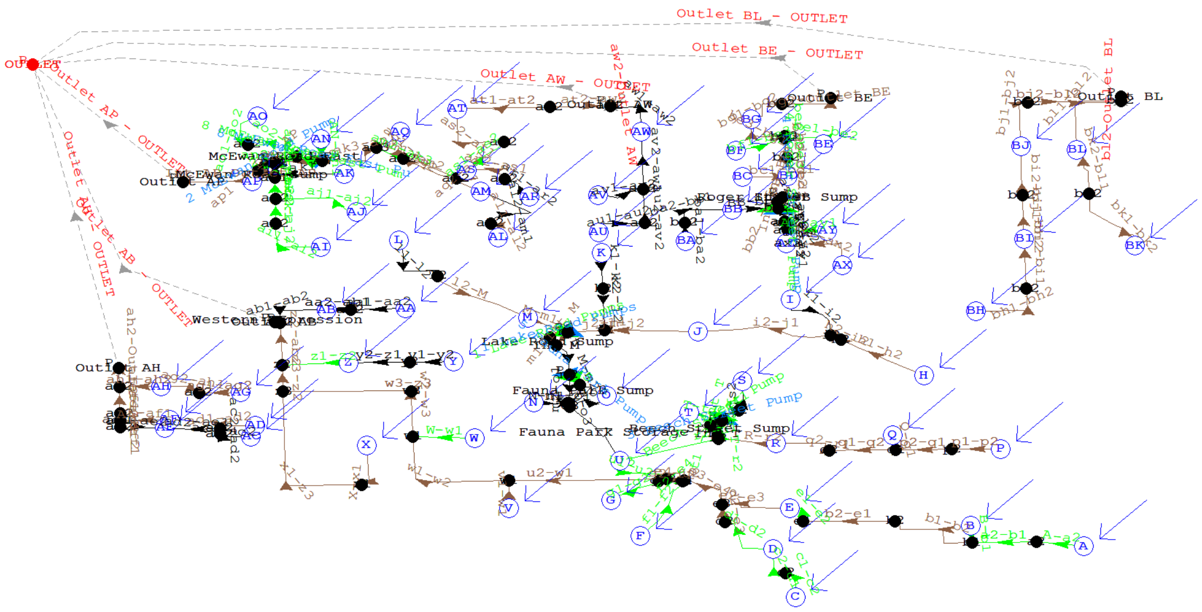

Figure 3-6 RORB graphical editor catchment vector

3.3.2.3 Reaches

RORB offers five reach type classifications for the purposes of modelling reach storage. These are as follows:

- Type 1 - natural,
- Type 2 - Excavated and unlined,
- Type 3 - Lined channel or pipe,
- Type 4 - Drowned reach, and
- Type 5 - Dummy reach.

Within the Kyabram Township model, the majority of the reaches are modelled as Type 2 – Excavated and unlined reaches. This has been selected due to the majority of the reaches flowing along drainage and irrigation channels, which are generally modified or constructed channels. Similarly, there are cases where water is flowing through backyards through Kyabram Township and blocked by fences and other obstructions. There is not expected to be significant storage within these reaches.

There are also quite a number of reaches, particularly within the township, where water flows overland along roadways – these have been modelled as Type 3 – Lined channel or pipe.

The remaining reaches are modelled as Type 1 – Natural reach, these reaches are typically where water flows across farm paddocks and there is expected to be significant storage within the reach.

It should be noted that the RORB software does not handle negative reach slopes. The Kyabram Township has uncovered a number of negative reach slopes due to extremely flat terrain throughout and drainage channels, in particular, can change direction along their course to tie in with irrigation channels. As such, a very flat 1:5000 slope has been adopted for these negative reach slopes to ensure the model will run.

3.3.2.4 Nodes

Sub area nodes have generally been placed close to the sub area centroids, and in some cases to align with reaches traversing the subarea.

3.3.2.5 Sumps and Storages

As discussed in the introduction, Kyabram Township includes a number of designed and excavated sumps for the purpose of capturing and pumping flows within the township. These sumps have been built into the hydrological model to model the drainage behaviour of the town as accurately as possible. The details for the sumps have been obtained from LiDAR data using a stage-storage function that is built into the software Hec Ras in combination with manually interpolated spillway details.

3.3.2.6 Pumps

As discussed in the introduction, Kyabram Township includes a number of pumps that are connected to the sumps discussed in Section 3.3.2.5 above. These pumps have been built into the hydrological model to model the township drainage scheme as accurately as possible. The details for the pumps have been obtained from historical reports and discussions with Council staff. The pump data is summarised in Appendix F.

3.3.2.7 Fraction Impervious

The estimated impervious surface within each sub-area was determined using Council land use planning maps and then modified based on aerial imagery and land cover mapping. Adopted FI values were based on the relevant industry standard guidelines. Specific values were allocated for each zone and are shown in Table 3-2. An areally-weighted fraction impervious for each sub-area was calculated and is mapped below in the sections related to Kyabram Township and Mosquito Depression.

Table 3-2 Adopted Fraction Impervious Values (Melbourne Water, 2018)

Land Use	Adopted FI
Activity Centre Zone (ACZ1)	0.55
Commercial Zone (C1Z and C2Z)	0.90
Farming Zone (FZ1 and FZ2)	0.01
General Residential (GZ and GZ1)	0.75
Industrial Zone (IN1Z and IN3Z)	0.90
Low Density Residential (LDRZ)	0.20
Mixed Use Zone (MUZ)	0.75
Neighbourhood Residential (NRZ1)	0.75
Public Conservation and Resource (PCRZ)	0.00
Public Park and Recreation (PPRZ)	0.10
Public Use – Cemetery/Crematorium (PUZ5) – Other (PUZ7)	0.60
Public Use – Education (PUZ2) – Health and Community (PUZ3) – Local Government (PUZ6) – Transport (PUZ4)	0.70

Land Use	Adopted FI
Public Use – Service and Utility (PUZ1)	0.05
Residential Growth (RGZ1)	0.75
Road (RDZ1)	0.70
Road (RDZ2)	0.60
Rural Living (RLZ and RLZ1)	0.20
Special Use (SUZ1, 2, 3, 4, 6, 7, 8, 9, 10 and 11)	0.60
Township (TZ)	0.55
Urban Floodway (UFZ)	0.00
Urban Growth (UGZ and UGZ1)	0.75

As discussed above, the fraction impervious values for Kyabram Township were created by combining land use planning maps, aerial imagery and accepted industry standard values. The mapped FI values are illustrated in the schematic in Figure 3-7.

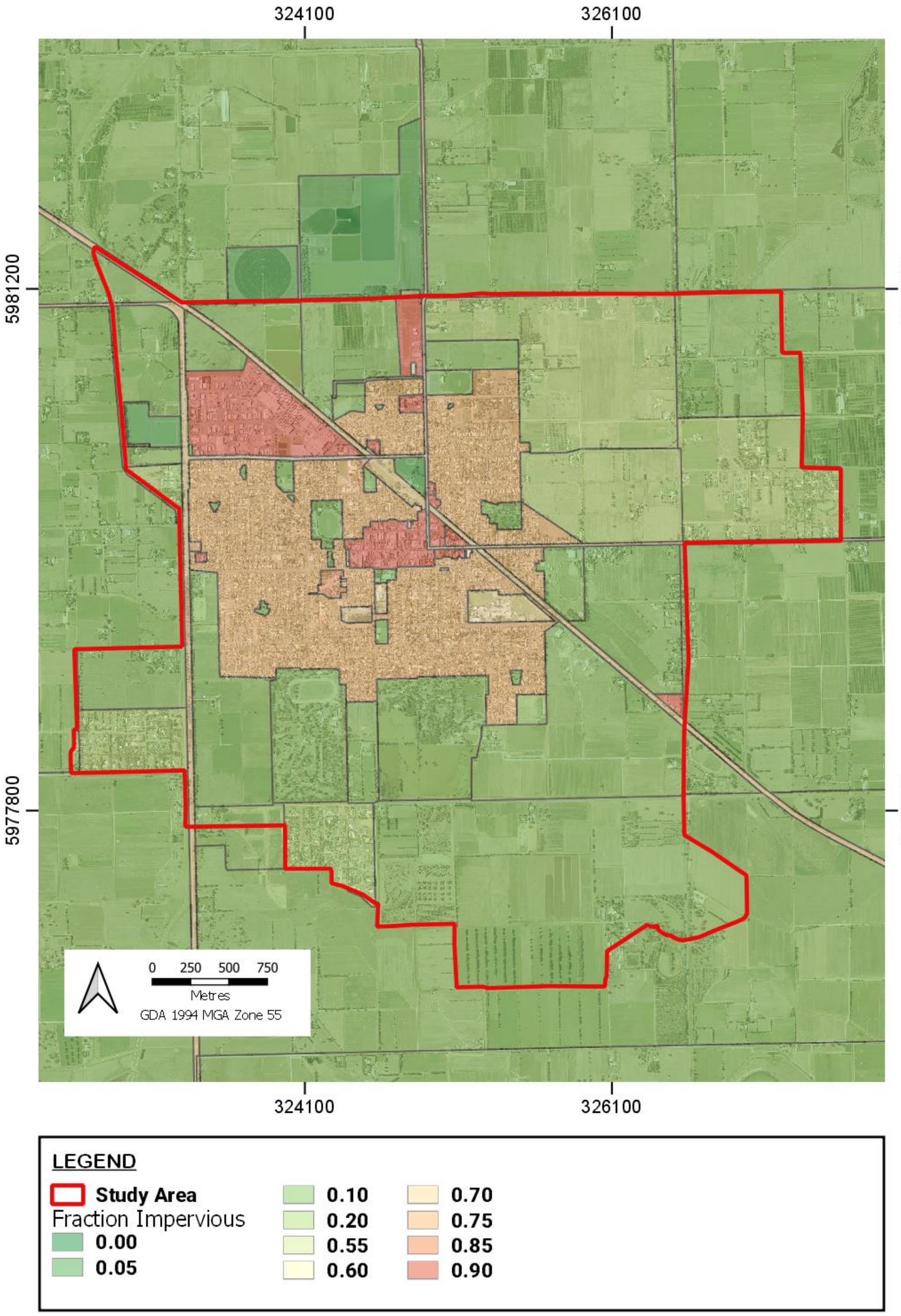

Figure 3-7 Fraction impervious values for the Kyabram Township model

3.3.2.8 Hydrological Model Software

To undertake the hydrological modelling of the Kyabram Township and Mosquito Depression, RORB was used. RORB is an industry-standard runoff and streamflow routing program that calculates catchment losses and streamflow hydrographs resulting from rainfall events and/or other forms of inflow to channel networks. It can be used for flood estimation, spillway and retarding basin design and flood routing (Laurenson, E.M., R.G. Mein & R.J. Nathan, 2007).

Discussion of how the software has been applied to each of the Kyabram Township model and the Mosquito Depression model is included in the relevant sections below.

3.3.2.9 Hydrologic Modelling Parameters

Routing Parameters

Routing in the software RORB is primarily built on the formula $S = 3600kQ^m$, where S is storage in m^3, Q is discharge in m^3/s, m is a dimensionless exponent and k is a dimensional empirical coefficient (Laurenson, E.M., R.G. Mein & R.J. Nathan, 2007). Given this equation, there are four main parameters that need to be selected in order to run a RORB model. These are k_c, which is an empirical coefficient applicable to the catchment and stream network. The value k_c is dependent upon the size of the catchment and in product with k_r, the relative delay time, makes up the value k in the above equation. The second parameter that needs to be determined is m, which is a dimensionless exponent in the formula above. The value of m is typically selected to be 0.8.

Loss Parameters

For catchment studies, in which area and rainfall are modelled, RORB models the losses as deducted from the rainfall to produce rainfall-excess, which is routed through the catchment storage model (Laurenson, et.al., 2007). There are two types of losses to be modelled, initial loss and continuing loss. Laurenson et. al. (2007) have described initial loss as a threshold process whereby a depth of loss must be satisfied by the storm rainfall before any rainfall-excess occurs. Whereas, the continuing loss rate is a capacity rate of loss that occurs only if rainfall is equal to or greater than that rate (Laurenson et. al., 2007). The initial loss and continuing loss are calculated using equations that are based on the fraction impervious values as input by the model user.

The specific parameter values used in each of the Kyabram Township model and the Mosquito Depression model are outlined in the relevant sections below.

3.3.3 Hydrological Model Calibration – Kyabram Township

3.3.3.1 Observed Rainfall Temporal Patterns

Rainfall data was obtained from data.water.vic.gov.au (State Government of Victoria, 2020) for the Mosquito Depression @ Curr Road gauge no. 406756.

Two events were chosen for calibration:

The 1993 3rd – 4th October event with a total rainfall of

- 69.4mm over a 24hour period (2.9 mm/hr); and

The February / March 2012 event, which contained 3 rainfall bursts with the following rainfall:

- 55mm on 27th – 28th February over 24 hours (2.3 mm/hr);
- 84.2mm on 29th February – 1st March over 24 hours (3.5 mm/hr); and
- 13.4mm on 3rd – 4th March over 24 hours (0.56 mm/hr).
- The rainfall temporal patterns for 1993 and 2012 are shown in Figure 3-8 and Figure 3-9 below.

Both of these historical rainfall patterns were used within the RORB model for the purposes of obtaining calibration hydrographs at various locations around the catchment.

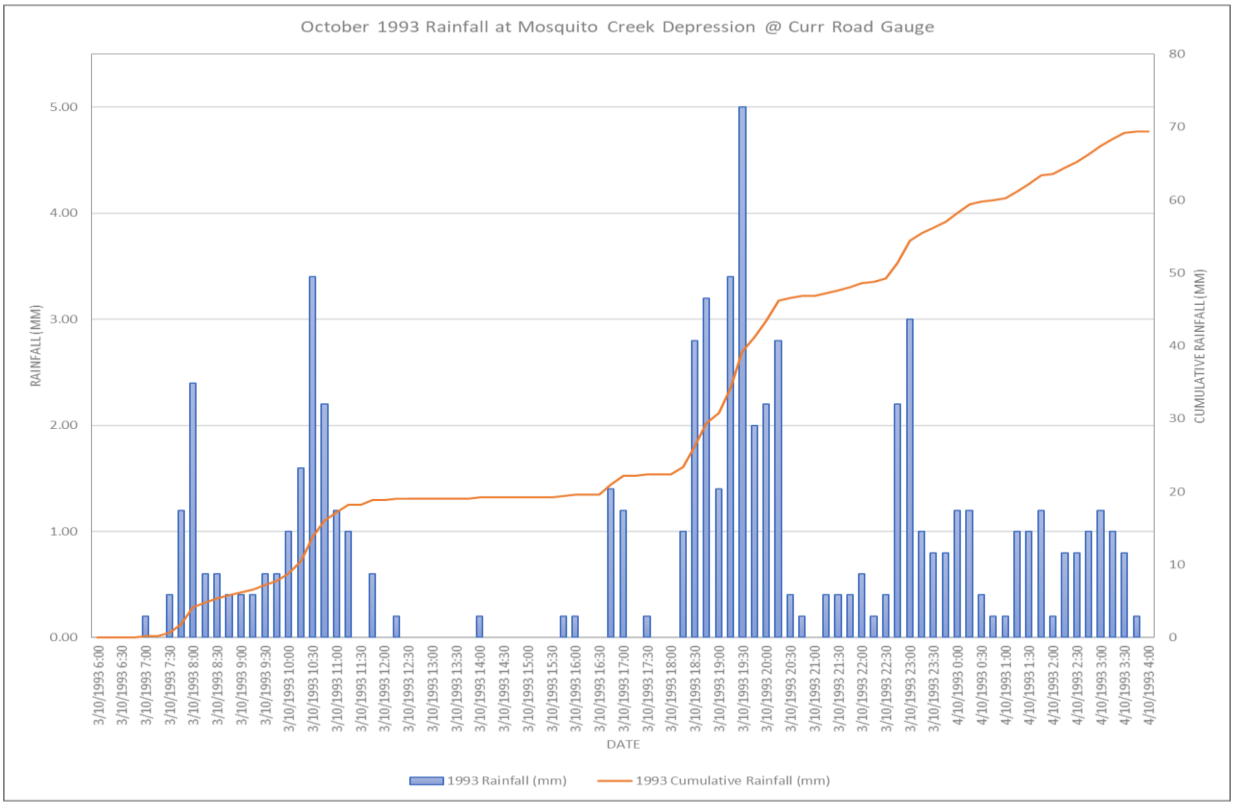

Figure 3-8 1993 Historical Rainfall at Mosquito Depression @ Curr Road gauge

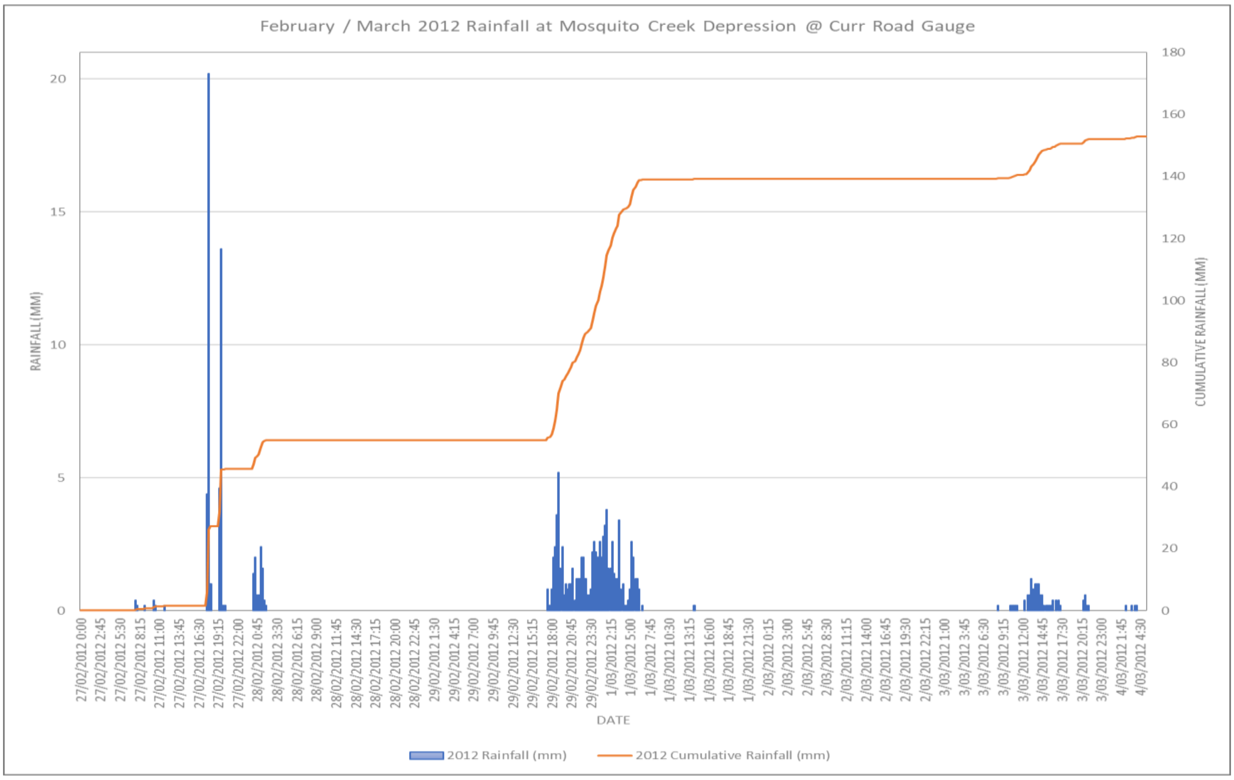

Figure 3-9 2012 Historical Rainfall at Mosquito Depression @ Curr Road gauge

3.3.3.2 Spatial Variation

Rainfall spatial grids were built from data acquired from the Bureau of Meteorology: daily rainfall database. The total rainfalls in millimetres were extracted from 14 local rainfall gauges for the 1993 event, and the 1-day and 3-day 2012 events and were interpolated as shown in Figure 3-10, Figure 3-11 and Figure 3-12. The spatial variation was completed using ESRI's *Spatial Analyst* in *ArcGIS*. A point feature was created for each of the 14 rainfall gauges around the study area with attributes representing the storm rainfall totals. These totals were then separated into point features for each storm event. The points were interpolated as a raster surface, creating a weather graph of the storm, using the inverse distance weighted (IDW) technique. The IDW technique is widely used throughout Victoria in determining spatial variation in Storm Events. The tool interpolation predicts values for each cell in a raster from the sample data points (daily total rainfalls). Spatially distributed objects are spatially correlated; in other words, things that are close together tend to have similar characteristics[2]. The maximum rainfalls that occur over each sub-area are then calculated via Zonal Statistics by identifying the maximum average rainfall totals.

For the purposes of a combined hydrologic / hydraulic calibration, the 2012 rainfall varied across the catchment by only 3mm (or 2%). It was thus considered that a uniform spatial pattern could be adopted. However, this did not occur in the 1993 rainfall. There was a variation across the catchment of up to 25%. As such, it was decided to adopt a non-uniform spatial pattern for the 1993 combined hydrologic / hydraulic calibration model. The mean of the rainfall for each sub area was adopted for the sub area rainfall patterns for the 1993 event. Figure 3-10, Figure 3-11 and Figure 3-12 illustrate the spatial pattern of rainfall grids for the township model for Kyabram.

[2] Understanding interpolation analysis, *esri: ArcGIS Pro*, https://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/understanding-interpolation-analysis.htm

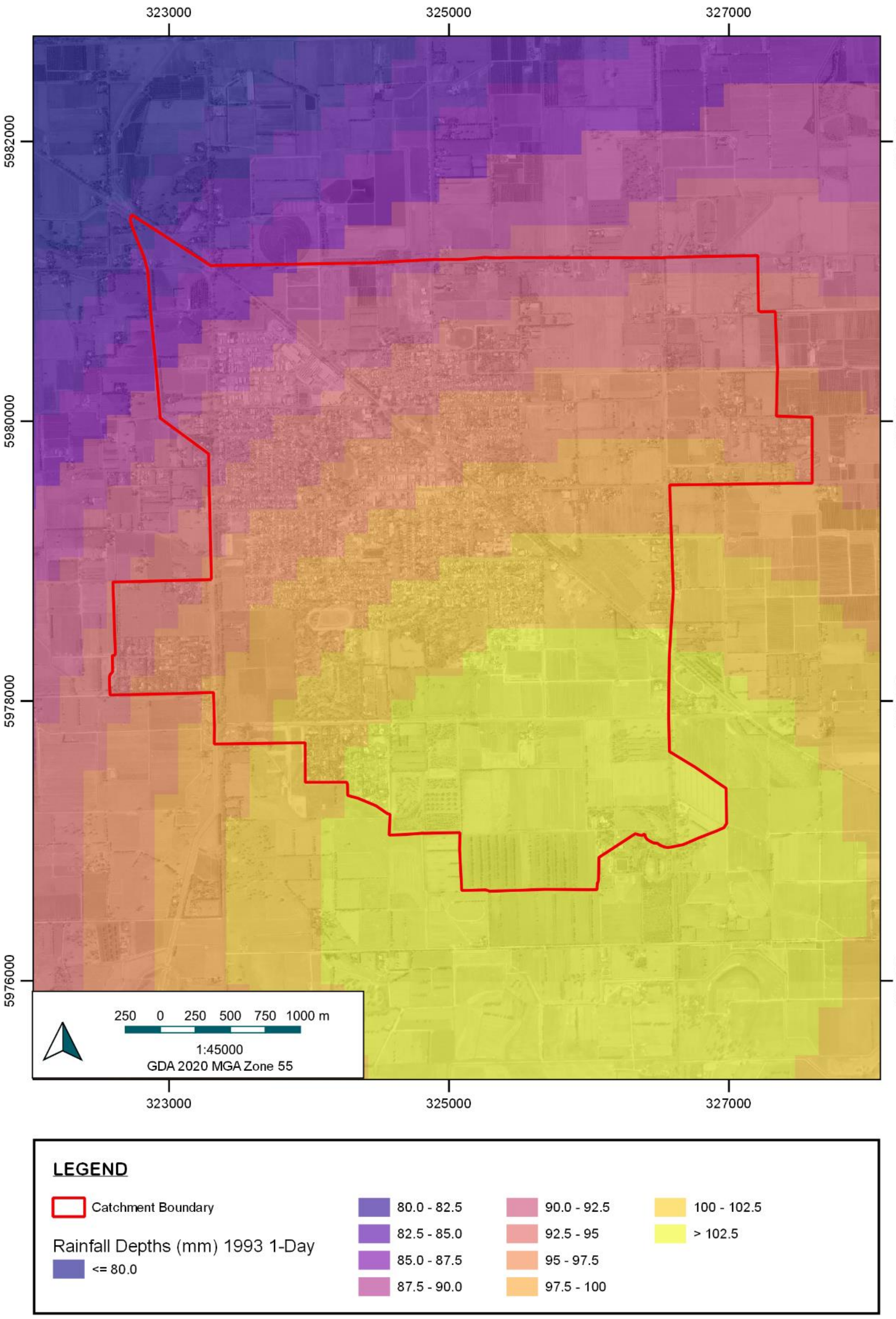

Figure 3-10 October 1993 Spatial pattern of rainfall (1-day)

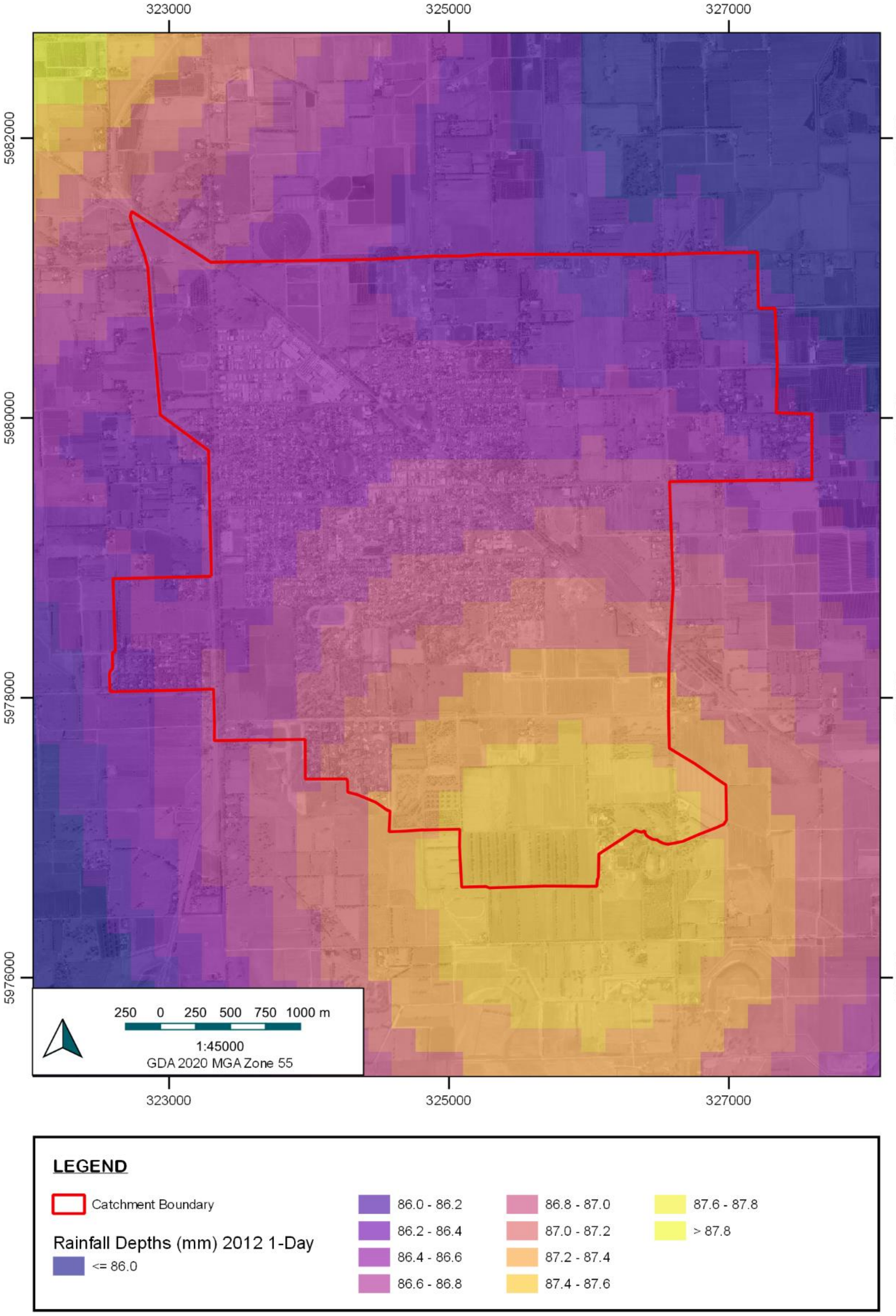

Figure 3-11 March 2012 Spatial pattern of rainfall (1-day)

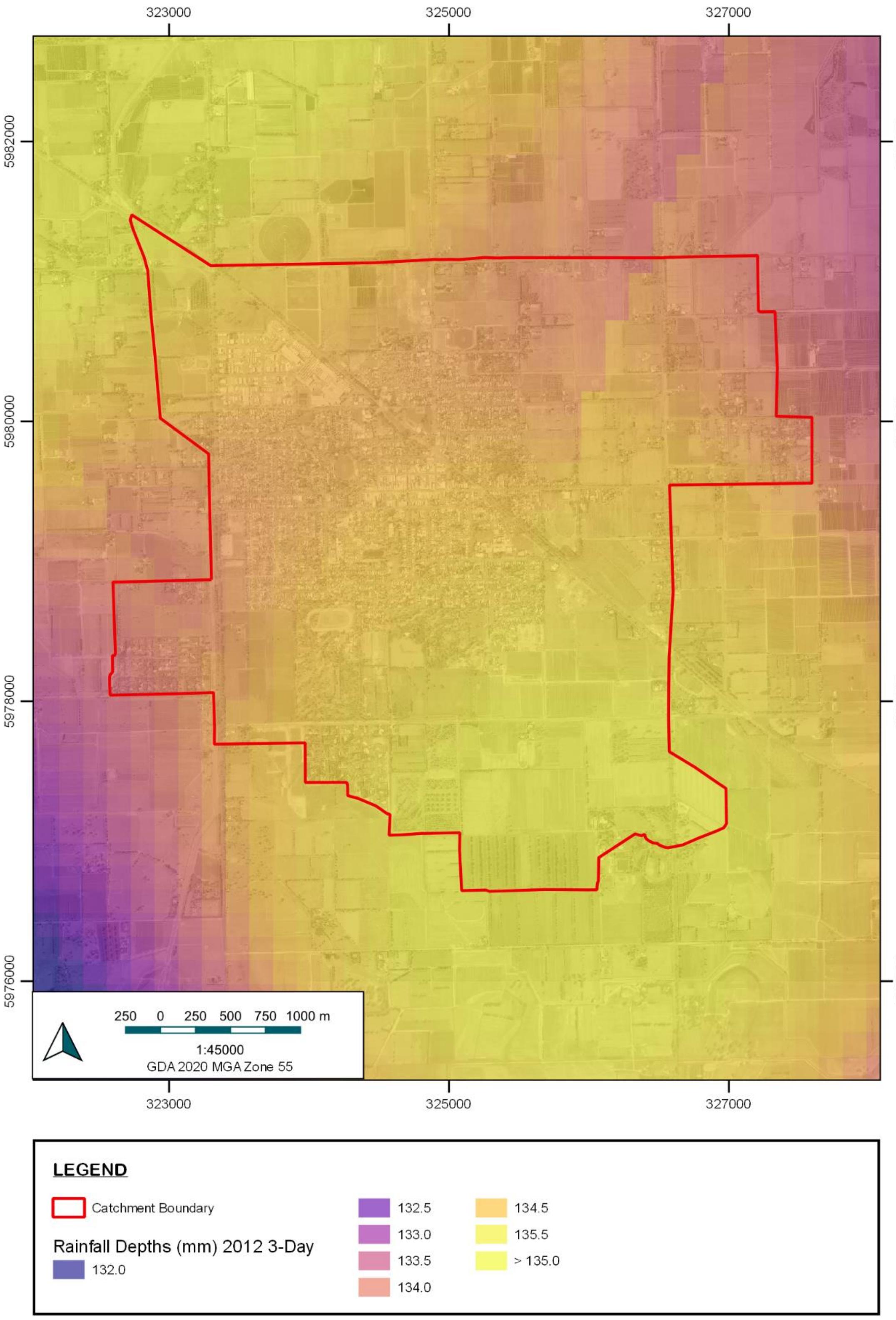

Figure 3-12 March 2012 Spatial Pattern of Rainfalls (3-day)

3.3.3.3 Calibration parameters

As discussed in Section 3.3.2.9, RORB parameters ideally should be determined through a process of calibration to historical events, with these parameters then applied to design modelling. In the case of the Kyabram township model there is no streamflow gauge data to calibrate to and so the value of k_c was determined using the regional formula developed by Pearse et. al. (2002), where k_c = 1.25 * D_{av} and D_{av} is the average flow distance in the channel network. This formula resulted in a K_c value of 4.78 for the Kyabram township model. A regional equation was used to derive K_c, due to the lack of streamflow gauge data for the town catchments to calibrate the model to.

The initial and continuing losses were obtained from the ARR2016 data hub (Commonwealth of Australia, 2016) and these were applied to the calibration model for initial calibration modelling. Following testing of the hydrology in the hydraulic model the losses were reduced by 50% from the original datahub losses for the October 1993 event, as this found to provide a better fit to the observed data which included estimated extents and levels by GBCMA and anecdotal evidence. All parameters used in the calibration models are summarised in Table 3-3. It is of note that the current ARR2019 design losses for Victoria are under review and the findings from that work are expected to be available in late 2020.

Table 3-3 Adopted calibration parameters for the Kyabram Township model.

RORB Parameter	Value
K_c	4.78
M	0.8
Initial Loss (IL) – October 1993 event	11.5mm
Initial Loss (IL) – March 2012 event	23.0 mm
Continuing Loss (CL) - October 1993 event	2.35 mm/hour
Continuing Loss (CL) – March 2012 event	4.70 mm/hour

3.3.3.4 Calibration Results

The peak flows produced at various locations across the Kyabram Township catchment for the two calibration events are illustrated in Table 3-4 and Table 3-5.

Table 3-4 Flow results from 1993 calibration model

Location	Flow (m^3/s)	Time of Peak (3rd October 1993)
Upstream Lake Road Sump	10.51	8:15pm
Lake Road Sump Inflow / Outflow	8.12 Inflow, 8.00 Outflow	8:15pm
Downstream Lake Road Sump Combined	10.39	8:15pm
Upstream Fauna Park Sump	10.02	8:15pm
Fauna Park Sump Inflow / Outflow	9.97 Inflow, .9.83 Outflow	8:15pm Inflow and 8:30pm Outflow
Downstream of Fauna Park Sump	10.5	8:15pm
Upstream of Beech Street Sump System	3.25	8:15pm
Beech Street Sump Inflow / Outflow	2.85 Inflow, 2.57 Outflow	8:15pm
Downstream Beech Street Sump Combined	2.97	8:15pm
Upstream of Roger Street Sump System	2.45	8:15pm
Roger Street Sump Inflow / Outflow	2.38 Inflow, 2.38 Outflow	8:15pm
Roger Street Sump Downstream	2.45	8:15pm

Location	Flow (m³/s)	Time of Peak (3rd October 1993)
Upstream of Mc Ewan Road Sump	3.75	8:30pm
Mc Ewan Road Sump Inflow / Outflow	3.6 Inflow, 3.57 Outflow	8:30pm Inflow and 8:45pm Outflow
Downstream of Mc Ewan Road Sump No. 9 Channel – West of industrial precinct	3.73	8:45pm
Upstream of Mc Ewan Road East Sump	1.15	8:30pm
Mc Ewan Road East Sump Inflow / Outflow	1.08 Inflow, 1.03 Outflow	8:30pm Inflow / 8:45pm Outflow
Downstream of Mc Ewan Road East Sump	3.1	8:45pm
Outlet at main culvert to west of township	12.76	10:45pm
Outlet at new residential precinct at Brose Road	2.34	8:15pm
Outlet at Graham Road West	3.31	8:15pm
Outlet at Graham Road North	5.2	8:30pm
Outlet at Graham Road East	9.62	8:15pm

Table 3-5 Flow results from 2012 calibration model

Location	Flow (m³/s)	Time of Peak (29th February 2012)
Upstream Lake Road Sump	12.14	6:45pm
Lake Road Sump Inflow / Outflow	9.74 Inflow, 8.9 Outflow	6:45pm
Downstream Lake Road Sump Combined	11.61	6:45pm
Upstream Fauna Park Sump	10.0	8:30pm
Fauna Park Sump Inflow / Outflow	9.95 Inflow, 9.62 Outflow	8:30pm
Downstream of Fauna Park Sump	10.4	8:30pm
Upstream of Beech Street Sump System	4.38	8:30pm
Beech Street Sump Inflow / Outflow	3.98 Inflow, 3.0 Outflow	8:30pm
Downstream Beech Street Sump Combined	3.4	8:30pm
Upstream of Roger Street Sump System	3.26	6:45pm
Roger Street Sump Inflow / Outflow	3.2 Inflow, .13 Outflow	6:45pm Inflow, 8:30pm Outflow
Roger Street Sump Downstream	3.2	8:30pm
Upstream of Mc Ewan Road Sump	4.05	8:30pm
Mc Ewan Road Sump Inflow / Outflow	3.89 Inflow, 3.55 Outflow	8:30pm Inflow, 8:45pm Outflow
Downstream of Mc Ewan Road Sump No. 9 Channel – West of industrial precinct	3.71	8:45pm
Upstream of Mc Ewan Road East Sump	1.37	7:00pm
Mc Ewan Road East Sump Inflow / Outflow	1.7 Inflow, 1.08 Outflow	7:00pm Inflow, 7:15pm Outflow
Downstream of Mc Ewan Road East Sump	3.15	8:30pm
Outlet at main culvert to west of township	10.03	1/3/2012 @ 4:15 am
Outlet at new residential precinct at Brose Road	2.93	8:30pm

Location	Flow (m^3/s)	Time of Peak (29th February 2012)
Outlet at Graham Road West	3.6	8:30pm
Outlet at Graham Road North	5.16	8:45pm
Outlet at Graham Road East	10.13	8:30pm

The results in Table 3-4 and Table 3-5 indicate that peak flooding typically occurs approximately 12-14 hours after the beginning of the rainfall event in central Kyabram. It is noted the main outfall west of Kyabram Township is significantly retarded due to a constrained outfall and water banking up behind the No 9 Channel. The modelling results indicated that the peak at the outfall under the Number 9 Channel did not occur for some 16 hours in the 1993 event and 2.5 days in the 2012 event. Note that the RORB model representation of the drainage scheme through Kyabram is somewhat simplified, and the hydraulic model will likely give a more accurate understanding of the time to peak at key locations. There is little recorded information regarding the timing of inundation during the two events but the results generally correlate with anecdotal reports.

3.3.4 Hydrological Design Modelling – Township model

For design RORB modelling in the township model, an ensemble analysis was undertaken. The technique recognises that any design flood characteristics (such as peak flow) could result from a variety of combinations of flood producing factors, rather than from a single combination.

The design rainfall parameters were obtained from the ARR2016 Data Hub (Commonwealth of Australia, 2016). Using the ARR DataHub involves submitting a shape file of the catchment boundary, upon which the DataHub outputs the design rainfall temporal and spatial patterns for all frequent and infrequent AEPs as well as all chosen durations. In addition, information about areal reduction factors and climate change is included in the output text file. Finally, the IFD charts are obtained from the Bureau of Meteorology and in conjunction with the above rainfall data from the ARR2016 DataHub, RORB has sufficient input data to calculate hydrographs based on design rainfall events.

3.3.4.1 Design Temporal Patterns

The temporal patterns are downloaded from the ARR2016 DataHub (Commonwealth of Australia, 2016) and for catchments under 75 km^2 it is advised that point temporal patterns be used (Babister, M., M. Retallick, et. al., 2019).

3.3.4.2 Design Spatial Variation

For catchments less than 20 km^2, the advice provided by ARR2019 is that a uniform spatial pattern is acceptable and as such a uniform spatial pattern has been adopted for the design modelling for Kyabram Township.

3.3.4.3 Filtering of embedded burst patterns

In Book 2, Chapter 5 of ARR2019 (Babister, M., M. Retallick, et. al, 2019), Retallick discusses the issues with filtering embedded bursts from the design temporal patterns in that filtering can often produce unrealistically long critical durations. However, later in 5.9.8 it is pointed out that the regional point temporal patterns have been sourced from various locations throughout the region and due to IFD gradients within the regions embedded burst may occur. As such, depending upon the severity of the embedded burst, filtering of rarer bursts is recommended. Given a Monte Carlo approach has been selected for the design hydrology and there is possibility of rarer bursts occurring, a decision has been made to filter the embedded bursts from the temporal patterns.

3.3.4.4 Areal Reduction Factors

Areal reduction factors were applied, and recognise that storms across larger geographical areas have a comparatively lower intensity. ARR2019 provides a methodology which is dependent upon the area of the catchment and the applicable storm duration being modelled. For Kyabram township, the applicable ARF values are those that fall between the 10 and 1000 km^2 catchment area and then calculated using the equations provided in ARR2019 in Book 2 Section 4.3 for the applicable durations (<12 hours, > 12 hours and 12-24 hours). The latest version of the RORB software has in-built capacity to calculate these equations provided the text file is extracted from the ARR Data Hub (Commonwealth of Australia, 2016). Kyabram falls into the Southern Semi-Arid zone (Commonwealth of Australia, 2016).

3.3.4.5 Design Losses

The model calibration was not deemed sufficiently robust to adopt those losses for design purposes and so losses were based on regional losses from the ARR datahub. As a conservative approach the method currently being used in NSW, which is to factor the regional CL by 40%, was adopted. This is a conservative approach which recognises that the current regional design losses for Victoria are generally considered too high. It is understood that these are currently being reviewed, similar to the process already undertaken in NSW, but the results of the investigation are not yet available.

Additional sensitivity will be undertaken on design losses and presented in the design modelling report.

Table 3-6 Adopted Design Losses

Loss Parameter	Value
Initial Loss (IL)	23.0mm
Continuing Loss (CL)	1.88 mm/hour

3.3.4.6 RORB Ensemble Simulation Design Results

The results from the RORB ensemble analysis at key locations around the township are outlined in Table 3-7.

Table 3-7 Flow results from the RORB Ensemble simulation for a 1% AEP design event

Location	Ensemble Median Flow (m³/s)	Critical Storm Duration (hours)
Upstream Lake Road Sump	20.8	45 min
Lake Road Sump Inflow / Outflow	18.41 / 17.9	45 min/ 1 Hour
Downstream Lake Road Sump Combined	20.11	45 min
Upstream Fauna Park Sump	19.21	1 Hour
Fauna Park Sump Inflow / Outflow	19.13 / 18.98	1 Hour
Downstream of Fauna Park Sump	19.93	1 Hour
Upstream of Beech Street Sump System	9.13	25 min
Beech Street Sump Inflow / Outflow	8.72 / 5.85	25 min / 45 min
Downstream Beech Street Sump Combined	6.23	45 min
Upstream of Roger Street Sump System	6.41	25 min
Roger Street Sump Inflow / Outflow	6.31 / 6.0	25 min / 45 min
Roger Street Sump Downstream	6.0	45 min
Upstream of Mc Ewan Road Sump	7.64	1 Hour
Mc Ewan Road Sump Inflow / Outflow	7.5 / 7.2	1 Hour
Downstream of Mc Ewan Road Sump No. 9 Channel – West of industrial precinct	7.36	1 Hour
Upstream of Mc Ewan Road East Sump	2.37	1 Hour
Mc Ewan Road East Sump Inflow / Outflow	2.31 / 2.1	1 Hour
Downstream of Mc Ewan Road East Sump	6.17	1Hour
Outlet at main culvert to west of township	14.4	6 Hour
Outlet at new residential precinct at Brose Road	4.91	1 Hour
Outlet at Graham Road West	6.11	1 Hour
Outlet at Graham Road North	10.14	1 Hour
Outlet at Graham Road East	17.22	1 Hour
Mosquito Depression @ Merrigum Gauge	42.77	48 Hour
Mosquito Depression @ Model Outlet	52.48	96 Hour

It can be seen from Table 3-7 that the design flows are higher than those produced in both the 1993 and 2012 storm events. In addition, it can be seen that these high flows are typically produced by very short duration storm events. It should also be noted that while the RORB gives an indication of peak flows and critical durations, the TUFLOW model will give a better indication as it can better represent the flat terrain and complex drainage behaviour. The findings from the design TUFLOW modelling is described further below.

Additionally, it is noted in the modelling that all of the sumps and naturally occurring depressions are overtopping their embankments where the terrain is low lying. This may be real or it may be a modelling artefact due to lack of survey data for the sumps. This was further tested in the hydraulic modelling.

3.3.5 Mosquito Depression Hydrological Model

3.3.5.1 Overview of Modelling Approach

The Mosquito Depression model was constructed using RORB modelling software as described in Section 3.3.2. The model required the larger catchment divided into sub-areas, connected by nodes and reaches. The Mosquito Depression model was a difficult model build due to the complexities in the catchment, namely the number of irrigation channels and dams. The parameters were compared with the previous Merrigum Flood Study as an initial calibration of results. Observed rainfalls from historic events 1993 and 2012 were inputted into the centroid of each catchment during the further calibration. The specific losses, adopted originally from the previous Merrigum Study, are then deducted, and the excess is routed through the network. The results for these calibrations were limited and not used.

The process described in Section 3.3.2 was adopted, which involved the following:

- The *Spatial Analyst* toolbox in *ArcGIS* was used to create an initial delineation for the larger Mosquito Depression catchment model;
- The *ArcRORB* toolbox in *ArcGIS* was used to construct the RORB model, determining node and reach locations and types, slopes, and sub-area fraction imperious values;
- The key routing parameter K_c was determined by modelling the 100-year 36-hour peak event, which was modelled in the Merrigum Flood Study. Identical rainfall was applied. K_c was adjusted until it matched the same peak flow from that study, therefore ensuring the model has similar routing behaviour to the Merrigum model;
- The historic, validation events which occurred in 1993 and 2012 events were modelled and hydrographs extracted for input into TUFLOW;
- The events were tested in the TUFLOW model prior to adoption of the RORB parameters;
- Key parameters for design RORB modelling have been determined and are presented below.

3.3.6 Hydrological Model Build – Mosquito Depression Model

3.3.6.1 Catchment Delineation

Catchment delineation was undertaken using the available topographic datasets, as described in Section 1.4. The 1 metre resolution Digital Elevation Model (DEM) was used to determine the downstream catchment from streamflow gauge at Merrigum Bridge. The larger Mosquito Depression model used the ELVIS SRTM-derived 1 second data to determine the catchment areas. ESRI's *Spatial Analyst* for *ArcGIS* was used to determine sub-catchment areas which were then manually checked to ensure consistent shapes and sizes relative to the previous study in the region.

Due to the size of the catchment, the presence of previous studies, and the intricate waterway and channel systems downstream of the gauge 29 sub-areas were created. The catchment was also separated into two interstation areas, located at the Merrigum gauge and the catchment outlet. The downstream portion of the catchment has smaller sub-areas, due to the 1 metre resolution DEM, therefore a different k_c was adopted for that area.

The catchment delineation is shown in Figure 3-14, highlighting the study area and the interstation areas.

The catchment delineation was converted to RORB reaches and nodes using *ArcRORB*.

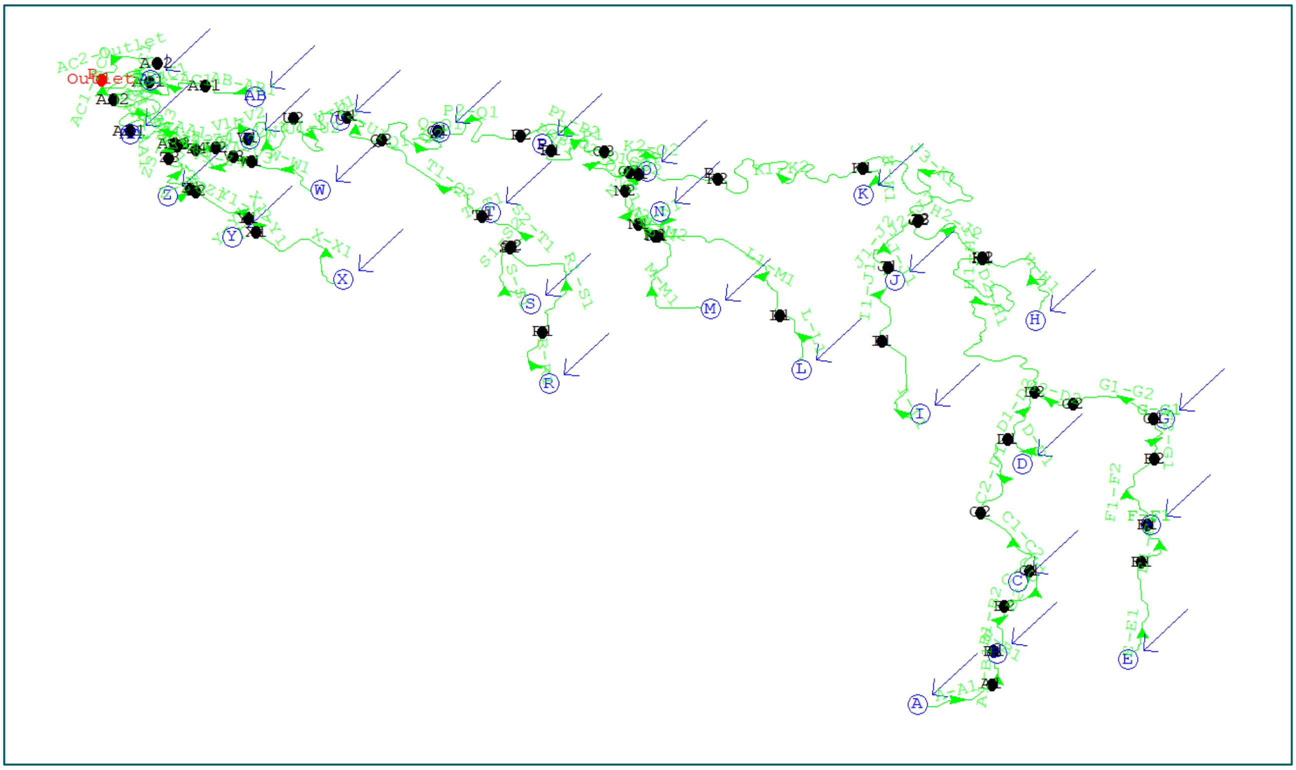

Figure 3-13 Mosquito Depression RORB model schematic

3.3.6.2 Sub areas

The model delineation of sub areas, reaches and nodes is illustrated in Figure 3-14 below. A table of the sub area values and fraction impervious values have been provided in the appendices.

3.3.6.3 Reaches

Each RORB model reach was classified into one of five different reach types (1 = natural, 2 = excavated and unlined, 3 = lined channel or pipe, 4 = drowned reach, 5 = dummy reach). All reaches within the Mosquito Depression catchment were classified as “Natural”, noting that drainage lines were based on natural drainage lines which are engaged in large flood events as opposed to modified sections of drain which have limited capacity.

The schematic of the RORB model sub-areas, reaches and nodes is shown in Figure 3-13.

3.3.6.4 Nodes

Nodes were placed at sub-area centroids and junctions between any two reaches.

3.3.6.5 Fraction Impervious (FI)

The estimated proportion of impervious surface for each sub-area was determined as per the procedure discussed in Section 3.3.2.7. An areally-weighted fraction impervious for each sub-area was calculated and this is shown in Figure 3-15.

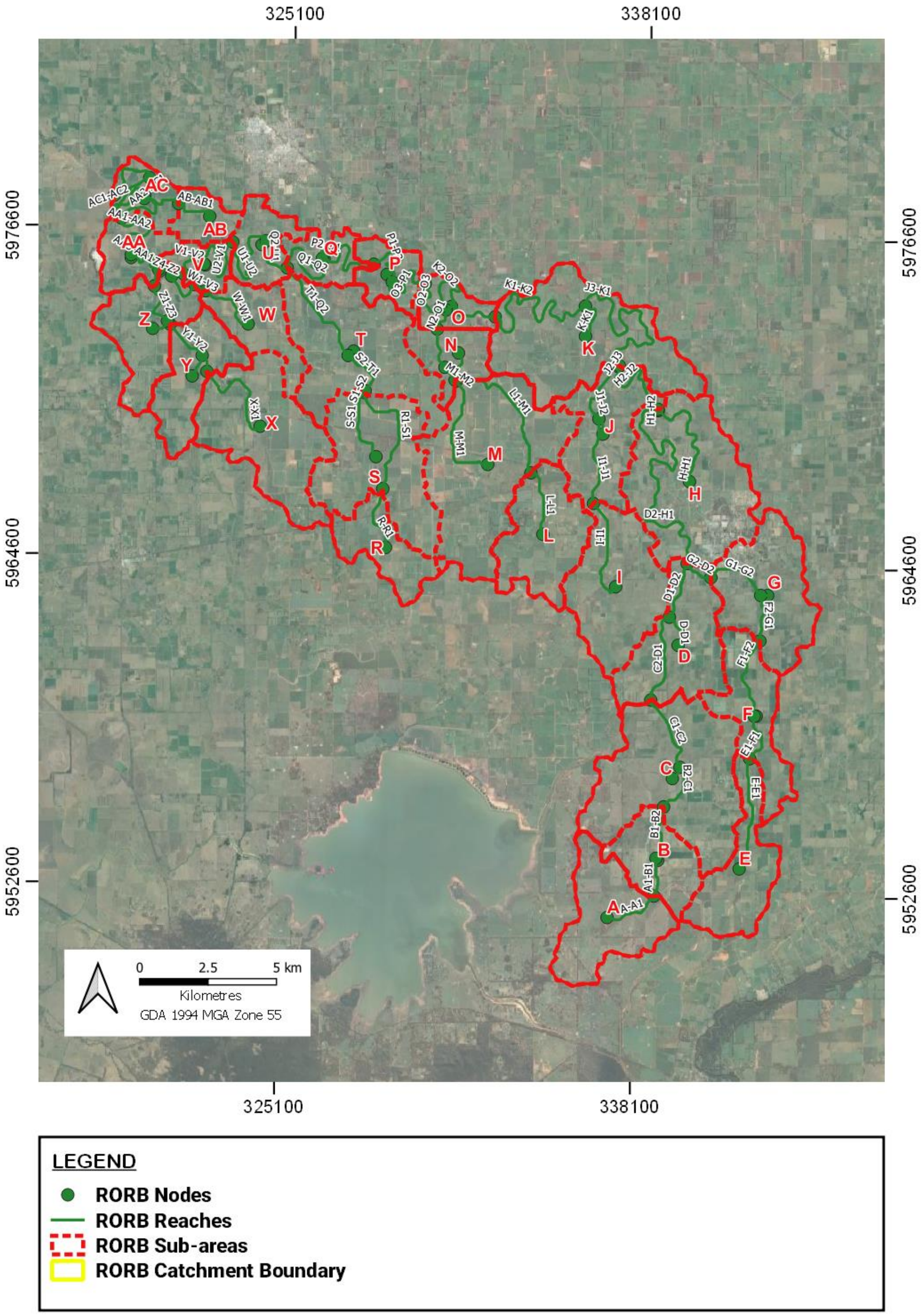

Figure 3-14 Mosquito Depression Catchment Delineation

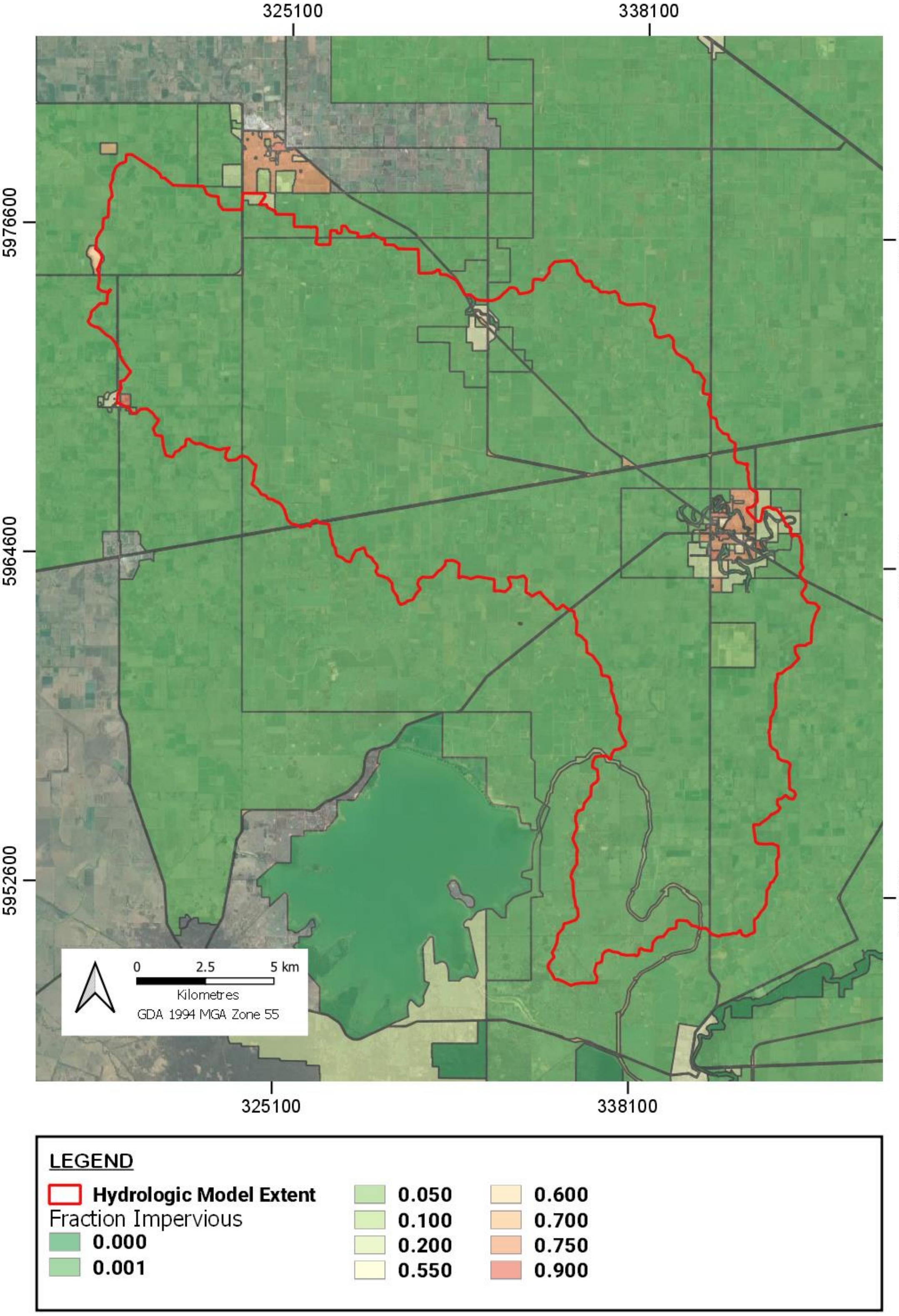

Figure 3-15 Mosquito Depression Catchment Fraction Impervious Map

3.3.7 Hydrological Model Calibration – Mosquito Depression

3.3.7.1 RORB K_c and m

The k_c, as discussed in Section 5.2.3, is the key routing parameter used to calibrate RORB models in gauged catchments. The k_c for the Mosquito Depression was determined by modelling the 1% AEP event from the original Merrigum Flood Study, and ensuring the RORB model produced the same peak flow at Merrigum, given the same rainfall inputs. That approach ensured that the RORB model produced comparable routing behaviour to the XP-RAFTS model developed for the Merrigum study.

The XP-RAFTS modelling determined a 1% AEP flow of 38 m^3/s at the Merrigum gauge. The same initial and continuing loss values and ARR1987 design rainfall from the Merrigum modelling was input in RORB, and the K_c was adjusted to accurately match the peak flow ensuring a similar routing behaviour throughout the model.

The k_c for the upstream catchment was found to be 80, to produce a matching 1% AEP flow of 38 m^3/s. The K_c for the lower section of the model was scaled based on the K_c and D_{av} upstream of Merrigum. The resulting K_c values are shown in Table 3-8.

Table 3-8 Adopted Routing Parameters for Validation the new RORB model to XP-RAFTS model

RORB Parameter	Merrigum Gauge K_c	Outlet K_c (scaled from Merrigum Gauge K_c)
K_c	80.00	83.6
m	0.8	0.8

The RORB 'm', as discussed in Section 5.2.3, is typically set at 0.8. There was no reason to vary the m parameter from this value.

3.3.7.2 Validation Parameters

A summary of the parameters adopted for validation of the Mosquito Depression model are provided in Figure 3-3. The loss values remained constant throughout the catchment as the entire catchment is characterised by flat grassed floodplain and a number of irrigation channels. The Merrigum Flood Study outlined two loss scenarios of non-irrigated and irrigated areas. As the entire catchment is irrigated and significantly modified it was determined that the higher initial loss would best represent the catchment, and subsequently for each interstation area.

Table 3-9 Summary of RORB parameters used for the Mosquito Depression Validation

RORB Parameter	Merrigum Gauge – Interstation	Outlet
K_c	80.00	83.6
M	0.8	0.8
Initial Loss (IL)	41.0	41.0
Continuing Loss (CL)	1.20	1.20

3.3.7.3 Gauged Rainfall Data

Rainfall depths for the historic calibration events were based on recorded daily rainfalls for all active gauges during the event throughout the catchment and in nearby localities. Daily totals were sourced from the Bureau of Meteorology (BoM) and used in generating a spatial pattern across the catchment for the 1993 and 2012 events, as discussed in Section 3.3.3.2. There were a few gauges with fair to good quality data record utilised in the analysis, while the gauges with poor or missing data were omitted.

3.3.7.4 Loss Model

The loss model chosen for the hydrology was an initial and continuing loss model, described in detail in Section 3.3.2.9. This is consistent with ARR2019 recommendations and also consistent with the Merrigum study. The adopted losses were identical to those used in the Kyabram Town RORB model.

Table 3-10 Calibration Loss Values

Loss Parameters	Values
Initial Loss (IL) – October 1993 event	11.5 mm
Initial Loss (IL) – March 2012 event	23.0 mm
Continuing Loss (CL) - October 1993 event	2.35 mm/hour
Continuing Loss (CL) – March 2012 event	4.70 mm/hour

3.3.7.5 Spatial Variation

The methodology for developing historic gridded rainfall spatial rainfall data is described in Section 3.3.3.2 above. The resultant grids across the Mosquito Depression RORB model extent are illustrated below in Figure 3-16, Figure 3-17 and Figure 3-18.

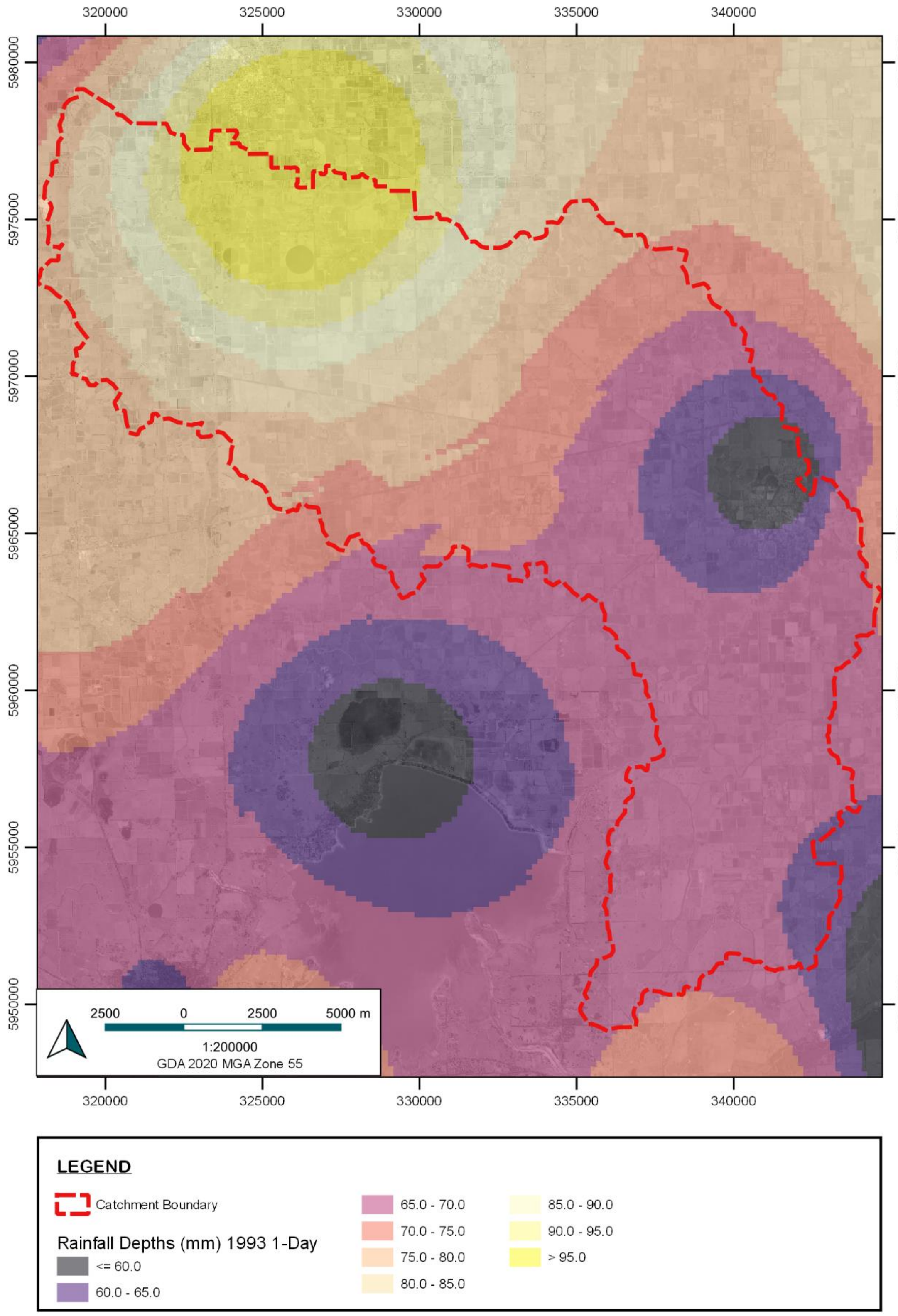

Figure 3-16 October 1993 Spatial Pattern of Rainfalls (1-day)

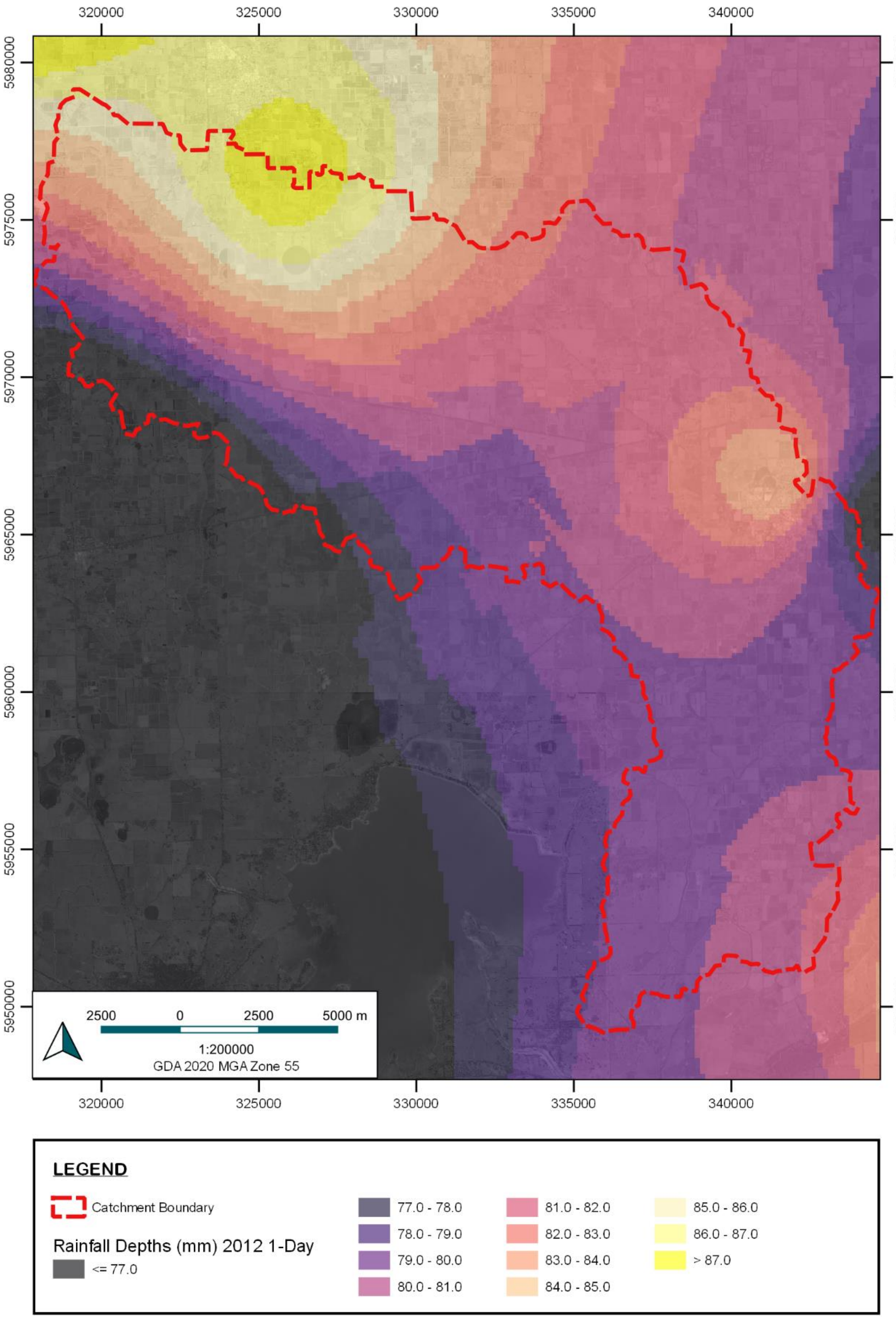

Figure 3-17 March 2012 Spatial Pattern of Rainfalls (1-day)

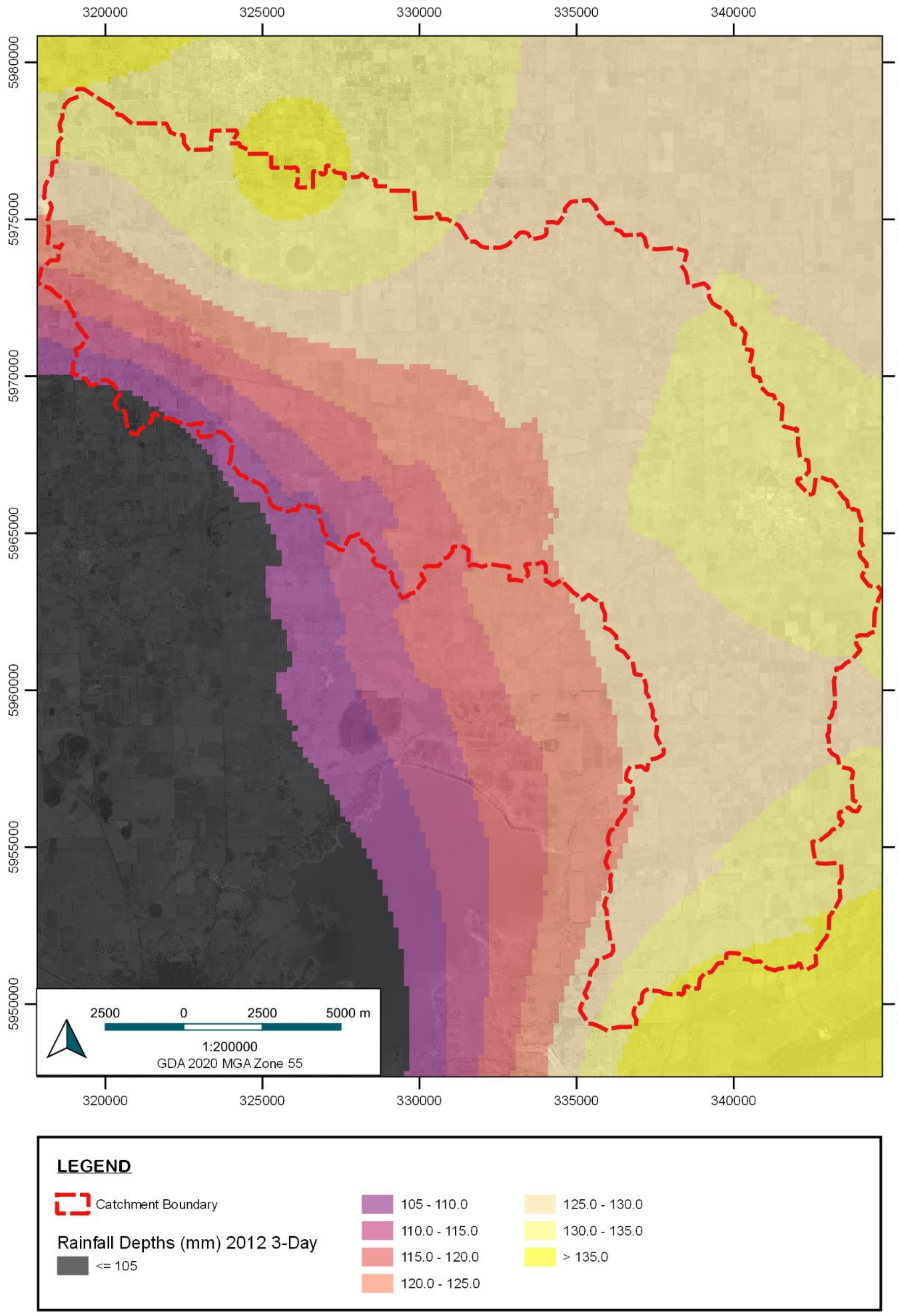

Figure 3-18 March 2012 Spatial Pattern of Rainfalls (3 - day)

3.3.8

3.3.8 Hydrological Design Modelling – Mosquito Depression

Similar to the town model an ensemble design approach was used as it recognises that any design flood characteristics (such as peak flow) could result from a variety of combinations of flood producing factors, rather than from a single combination.

Rainfall depths for the Mosquito Depression catchment were determined with the ARR2019 guideline recommendations. Areal reduction factors and temporal patterns were sourced from the ARR datahub, while the intensity frequency duration (IFD) rainfall depths were sourced from the Bureau of Meteorology (BoM) online IFD tool.

3.3.8.1 Design Temporal Patterns

Design temporal patterns were extracted from the ARR2016 DataHub (Commonwealth of Australia, 2016) for catchments over 75 km^2 and up to 30 000 km^2.

3.3.8.2 Filtering of embedded burst patterns

As discussed in Section 5.5.3, filtering of embedded bursts from design temporal patterns is necessary as patterns have been sourced from various locations. As stated in ARR2019, depending on the severity of the embedded burst, filtering of the rarer bursts will occur.

3.3.8.3 Areal Reduction Factors

The applicable ARF values for the Mosquito Depression catchment are the same as the Kyabram Township, those that fall between the 10 and 1000 km^2 catchment area and then calculated using the equations provided in ARR(2019) in Book 2 Section 4.3 for the applicable durations (<12 hours, > 12 hours and 12-24 hours).

3.3.8.4 Design Losses

As with the town model the model calibration was not deemed sufficiently robust to adopt those losses for design purposes and so losses were based on regional losses from the ARR datahub. As a conservative approach the method currently being used in NSW, which is to factor the regional CL by 40%, was adopted. This is a conservative approach which recognises that the current regional design losses for Victoria are generally considered too high. It is understood that these are currently being reviewed, similar to the process already undertaken in NSW, but the results of the investigation are not yet available.

Additional sensitivity will be undertaken on design losses and presented in the design modelling report.

Table 3-11 Adopted Design Losses

Loss Parameter	Value
Initial Loss (IL)	23.0mm
Continuing Loss (CL)	1.88 mm/hour

3.3.8.5 RORB Ensemble Simulation Design Results

The results from the RORB ensemble analysis at the model inflow point at Merrigum are outlined in Table 3-7.

Table 3-12 Flow results from the RORB Ensemble simulation for a 1% AEP design event

Event	Ensemble Median Flow (m^3/s)	Critical Duration
1% AEP	20.8	72 hours

3.4 HYDROLOGY SUMMARY

The first major component of the project was to undertake hydrologic modelling of the study area which included modelling two historical events and developing excess rainfall hyetographs for input into the hydraulic model. In addition, the hydrologic modelling will determine a set of key critical storm durations for consideration in the TUFLOW hydraulic model.

The hydrological analysis has reviewed all existing hydrological data including rainfall pluviograph data, streamflow and level data, rainfall spatial patterns and terrain and surface data such as LiDAR, culvert structures, storages and pumps. Two new RORB models of Kyabram Township and Mosquito Depression catchment have been developed and used to model two historical storm events as part of a joint hydrology-hydraulic calibration. The storm events selected for calibration were the October 1993 and March 2012 events. These events were considered to be the most appropriate as they are the largest in recent memory and pluviograph rainfall data was available for them as well as anecdotal evidence, photography and observations from Council staff and community members.

Given the lack of streamflow gauging in and around the study area for calibration of the hydrologic model, a joint hydrologic / hydraulic calibration was undertaken. This involved modelling the historic events on the hydraulic model to ensure it produce realistic flood behaviour, prior to adoption of the hydrological and hydraulic model parameters. The hydraulic model development and subsequent calibration and design modelling is described in the section below.

4 HYDRAULIC MODELLING

4.1 APPROACH

The hydraulic model was undertaken as a 1-dimensional, 2-dimensional combined hydraulic model in the industry standard software TUFLOW. TUFLOW is a numerical model used to simulate the hydrodynamic behaviour in rivers, floodplains and urban drainage environments (BMT Group Ltd, 2007 – 2018). The software is ideal for large scale catchment studies such as Kyabram and surrounds as it is equally capable of modelling riverine and floodplain environments such as Mosquito Depression as well as the urban drainage environment with the complexity of Kyabram, which includes culvert, pipes, pits and sumps and pumps.

Further, the TUFLOW HPC (Heavily Parallelised Compute) model was used, which delivers a 10-100 times simulation speed increase compared to the standard CPU version (BMT Group Ltd, 2007 – 2018).

The modelling approach used for the hydraulic model was a rainfall excess methodology. A rainfall excess approach has some similarities to rain-on-grid, however, the hydrological modelling is initially undertaken in RORB, where there is better control over the losses, through the application of the fraction impervious map as well as initial and continuing losses. The resultant excess rainfall hyetographs are applied to the hydraulic model extents via source-area polygons and the routing is then undertaken in two dimensions within the hydraulic model.

Two historical events have been modelled for the purposes of calibration and the design events to be modelled are the 0.05%, 0.1%, 0.2%, 0.5%, 1%, 2%, 5%, 10% and 20% AEP event and the PMF event. Historical calibration has been undertaken and the 1% design event critical durations modelled include the 30minute, 45minute, 1hour, 1.5hour, 12hour, 24hour and 72hour. For each critical duration the median temporal pattern has been chosen at the locations where they were found to be critical.

Discussion on the model development is provided below and the TUFLOW model parameters are outlined in Appendix G.

4.2 MODEL DEVELOPMENT

4.2.1 Broader Floodplain Model

Given the complexity of Kyabram Township and the number of structures involved, the hydraulic model was built using a staged approach over several months.

4.2.1.1 Topography

In the first instance, the model DEM was developed using the 1m LiDAR supplied by Campaspe Shire Council as discussed in Section 3.2. The DEM was supplied by Campaspe Shire Council as a mosaic dataset, ..tiff file. As such, all that was required for DEM development was to convert the .tiff into an .flt for use in TUFLOW. The digital elevation model is illustrated in Figure 4-1.

4.2.1.2 Model Extent and Boundary Conditions

The extent of the modelling required was provided in the project brief and captures an area of 95 km^2. This boundary was adopted as the full model extent for the Kyabram project. The reasoning for this extent is to capture the overflows from Mosquito Depression, the impacts on the township and the impacts on surrounding rural land. However, due to the size of the model extent and relatively fine grid resolution, it was found that run times modelling could be in the order of 4-5 days.

The flows developed in the two hydrological RORB models (Mosquito Depression and the Kyabram Township model) as discussed in Section 3.3 were applied to the model as source-area polygons. The source area polygons apply the rainfall excess across the whole terrain and the routing is then undertaken in two dimensions as discussed in Section 4.1 above. In addition, there is one inflow boundary at Mosquito Depression where the Mosquito Depression outflow hydrograph from RORB is directly applied to the TUFLOW hydraulic model. The rainfall excess polygons and the inflow hydrograph location are illustrated in Figure 4-2.

The outflow boundary was applied around the majority of the model extent. A HQ boundary type was used as the outflow boundary condition whereby TUFLOW generates an automatic Head vs Time table within the software based on a specified terrain slope. The terrain is extremely flat in Kyabram and as such the slope across the outflow boundary is approximately uniform for the majority of the model extent with one exception at the eastern boundary. The terrain slope is typically 1 in 1500 – 1 in 2000 and the eastern boundary slope is 1 in 100. Figure 4-2 illustrates the inflow and outflow boundaries applied to the Kyabram hydraulic model.

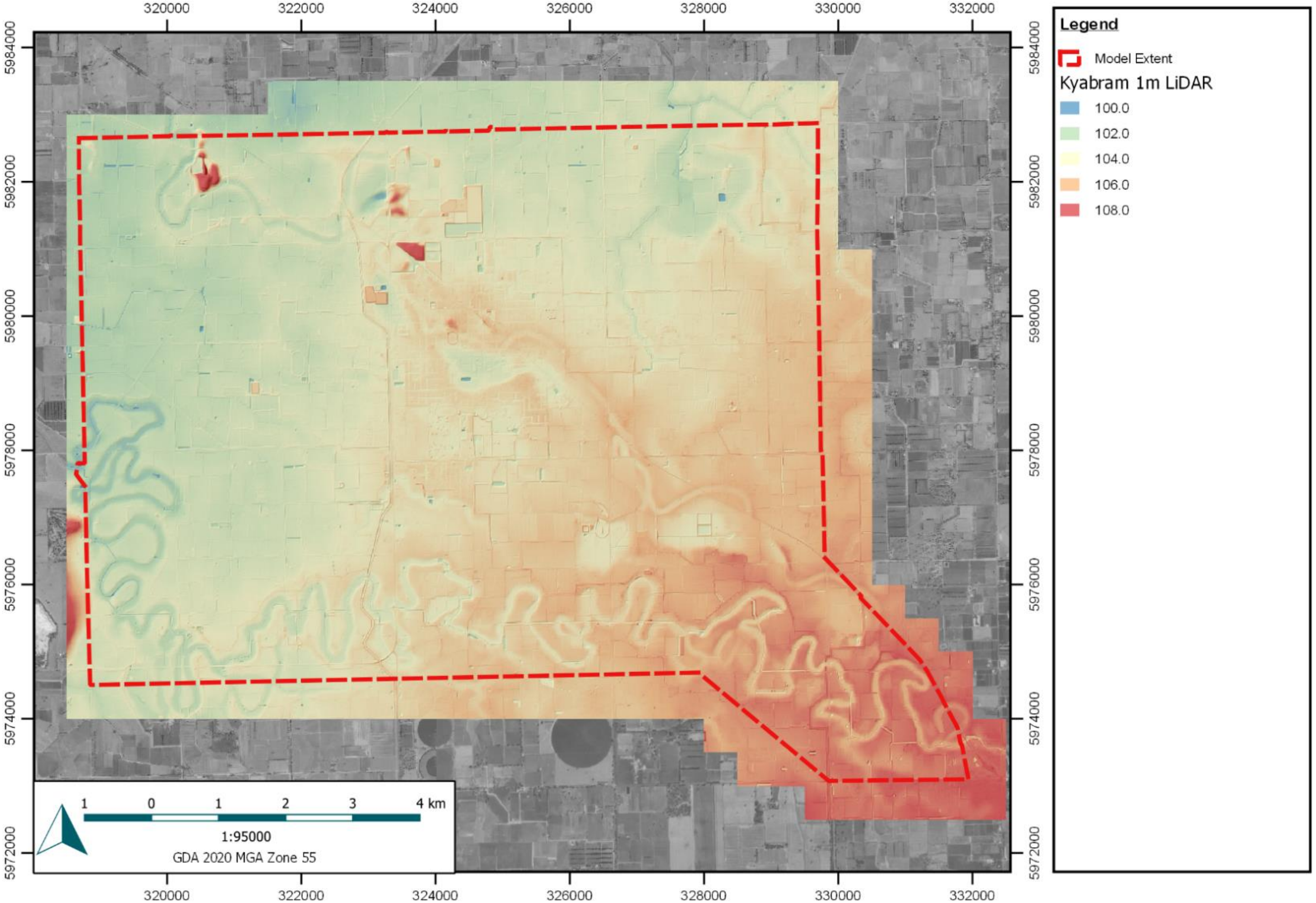

Figure 4-1 Model Schematic of the Digital Terrain Elevation Mode

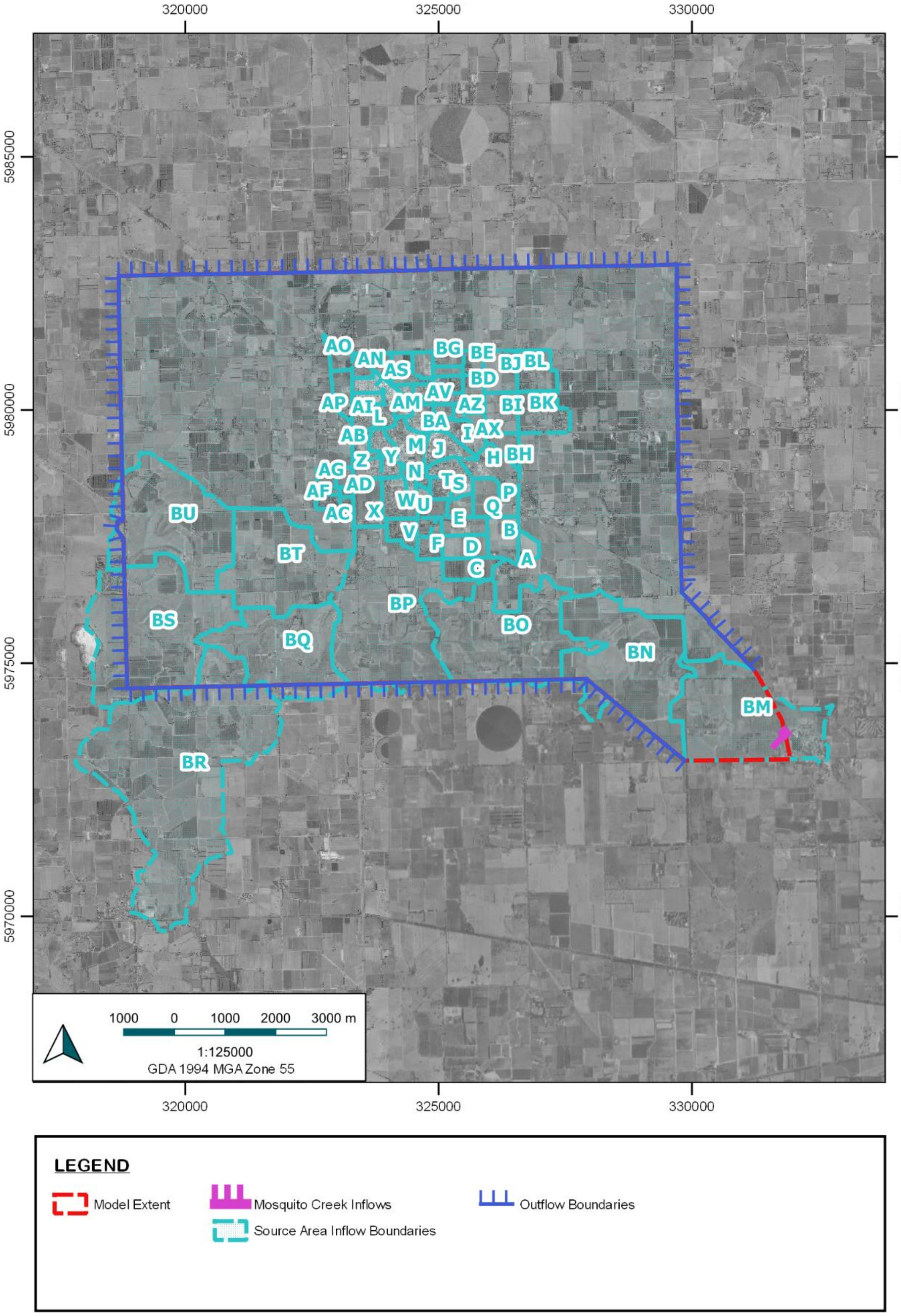

Figure 4-2 Model Schematic of Inflow and Outflow Boundaries

4.2.1.3 Manning's Roughness

Following development of the terrain and boundary conditions, the Manning's roughness map was built. The roughness map applies bed friction to the model based on land use type. The Manning's values that have been used throughout the model were developed to comply with the ARR2019 Guidelines as per Table 6.2.1 – Values of Roughness Coefficient n for different channel conditions (Sellin 1961) and Table 6.2.2 Valid Manning 'n' Ranges for Different Land Use Types as cited in (Lambert, M. B. Cathers & R Keller, 2019). The planning scheme zones were used to obtain the land use types and these were adjusted as required based on aerial imagery.

The roughness values used within the hydraulic model are outlined in Table 4-1 and the full map is illustrated in Figure 4-3.

Table 4-1 Manning's roughness values applied to the model

Land Use Type	Manning's value	Land Use Type	Mannings Value
Pasture and some tall trees	0.04	Low density residential	0.2
Industrial, Commercial	0.3	Carpark	0.02
Cemetery	0.15	Grassed waterways with minimal vegetation	0.035
Paved roads and fully lined waterways	0.02	Unpaved roads	0.03
Ponds and water bodies	0.03	Railway reserve	0.06
Rural residential	0.1	Dense bush	0.1
Creeks with dense vegetation	0.08	High density residential	0.35
Waterways with minimal vegetation	0.045	Waterways with moderate vegetation	0.06
Unlined irrigation channels	0.03	Pasture with some dense brush	0.06
Unmaintained channels	0.05	Mixed use zones	0.3

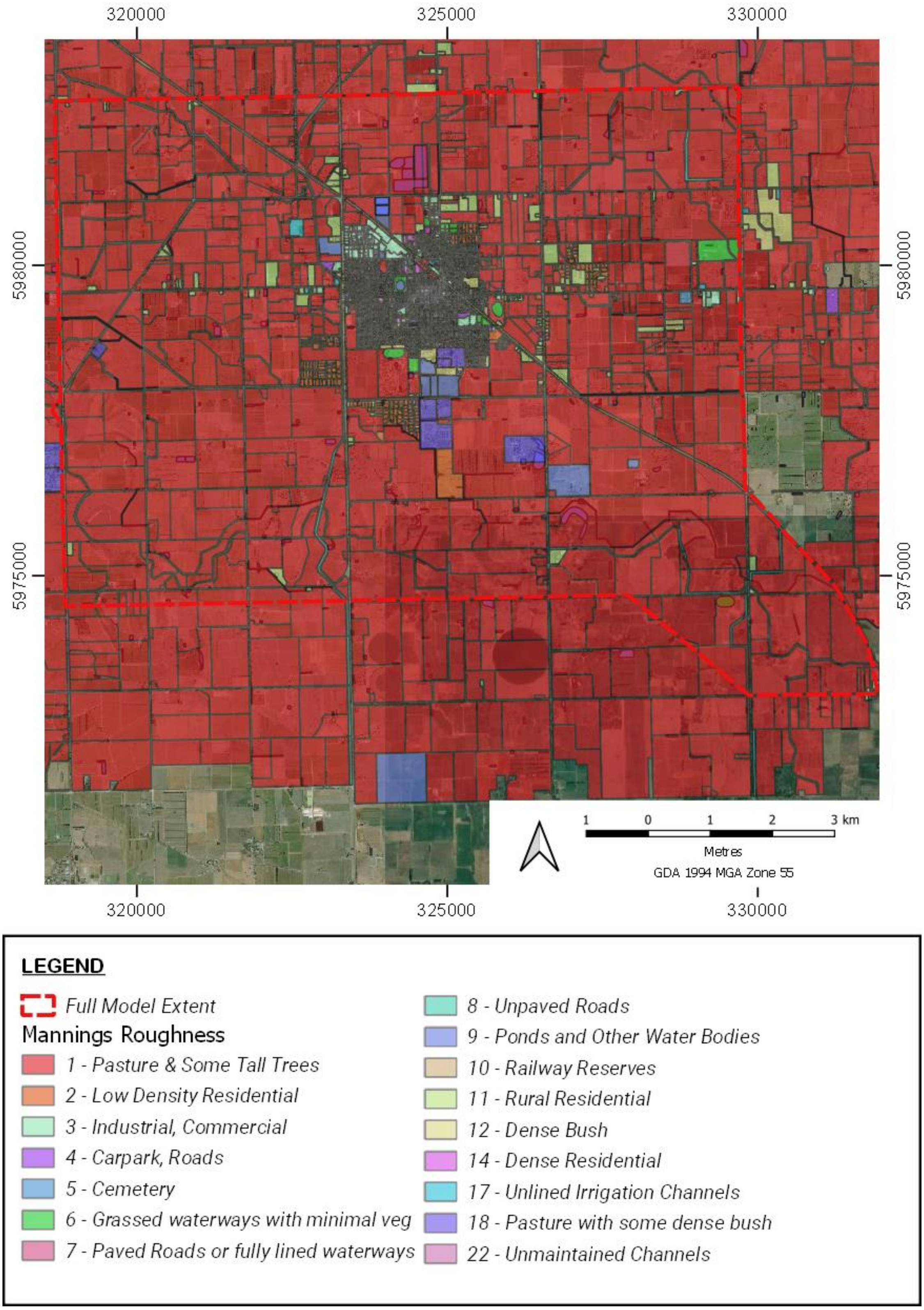

Figure 4-3 Model Schematic of Mannings Roughness Layers

4.2.1.4 Structures

The 1-dimensional network was itself a staged build. This was undertaken to ensure model integrity and optimal model health. The Goulburn Murray Water (GMW) assets were provided to WMS as an excel asset database with information regarding type, size and length of each asset. However, no invert data was provided. The structures were manually digitised and the invert elevations were assumed from the LiDAR data. The GMW assets were built as separate layers for irrigation and drainage so that the model could be sensitivity tested with and without these structures if required at a later date. In total, there are 165 irrigation culverts and 76 drainage culverts that have been included in the model. Very small drainage culverts, less than approximately 300 – 450mm in diameter have not been included as the outlying rural areas are not the focus of the study and it was impractical to explicitly model them all.

The GMW asset layout is illustrated in Figure 4-4 below.

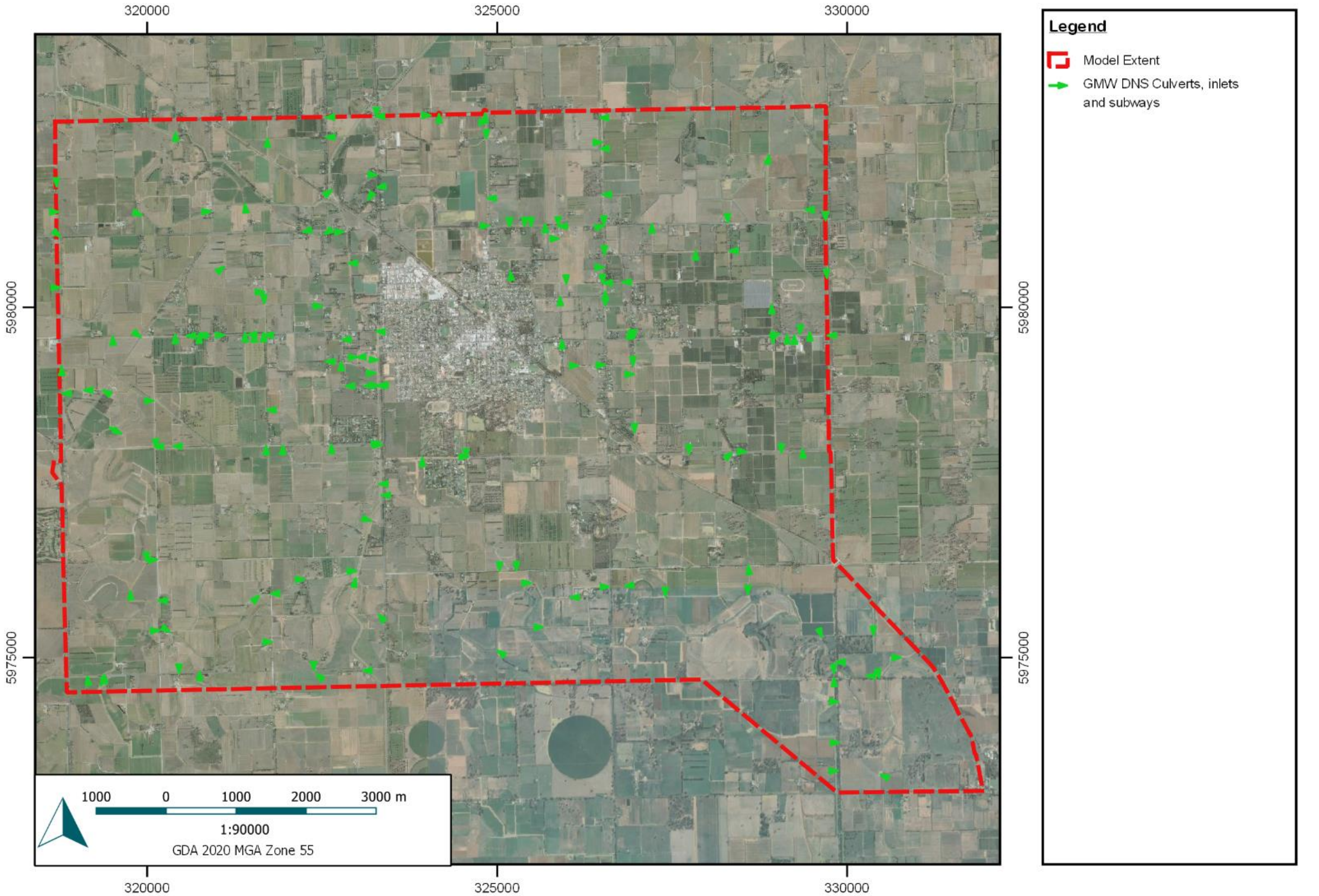

Figure 4-4 Model Schematic of GMW Drainage Assets (DNS)

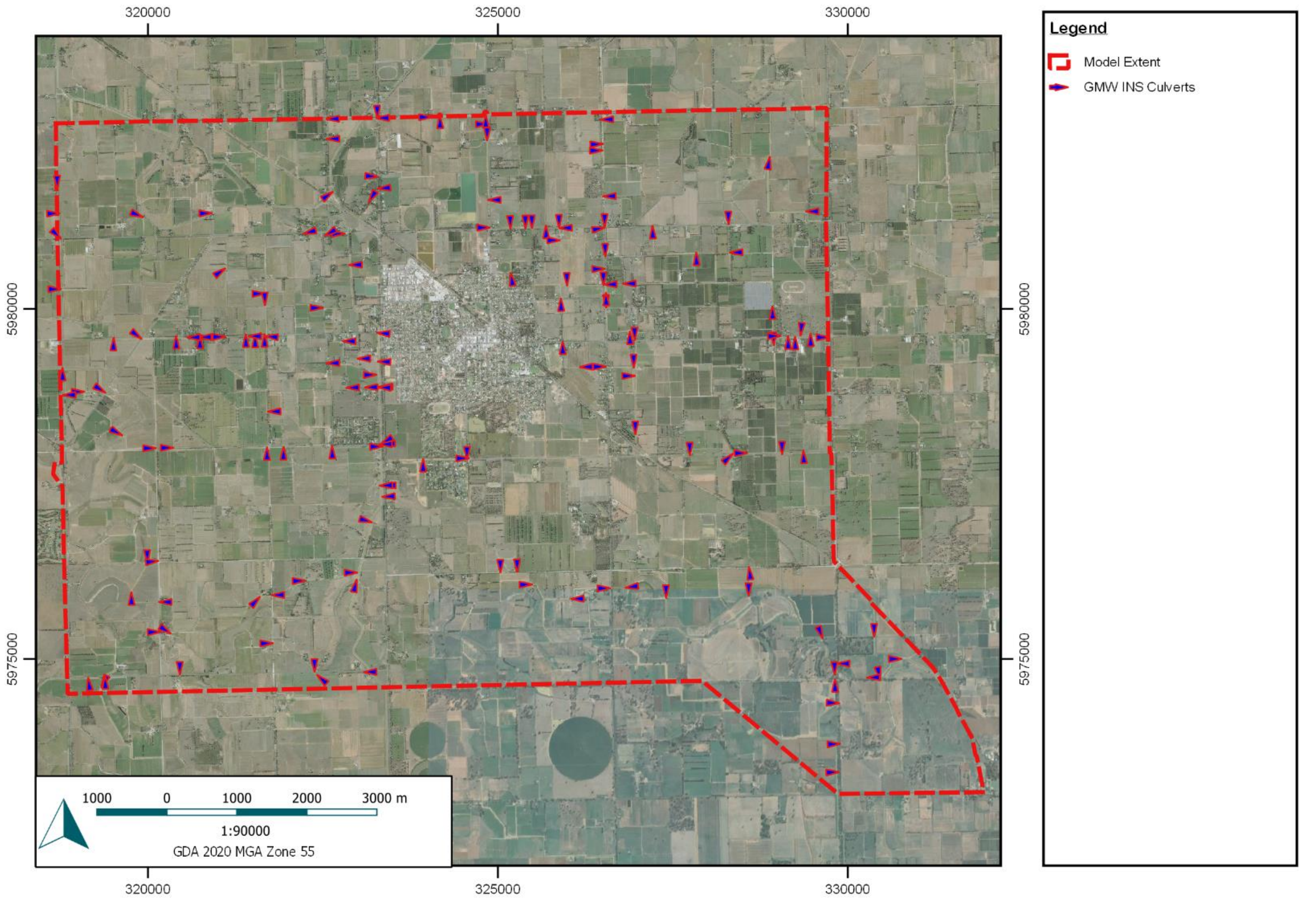

Figure 4-5 Model Schematic of GMS Irrigation Assets (INS)

The township pit and pipe network was provided as a combination of shape files and digital plans. This information contained type, shape and invert levels in the majority of cases. However, there was some missing data. All pipes were assumed to be circular unless otherwise stated. Where diameter data was missing – the diameter was assumed from upstream and downstream pipes. Where invert data was missing the depth of cover values in Table 4-2 were assumed to calculate pipe invert levels, where IL = terrain surface – cover – diameter.

Table 4-2 Assumed Pipe Cover to determine pipe invert levels

Pipe Diameter (mm)	Assumed Depth of Cover (mm)
Less than or equal to 900 mm	600
Greater than 900 mm	750

Culvert and open channel data around the vicinity of South Boundary Road and Fauna Park Lakes was provided as digital plans. This data was manually digitised into the TUFLOW model in a similar manner to that described for the GMW assets.

The township pit and pipe network, the South Boundary Road assets and the Fauna Park Lake assets are illustrated in Figure 4-6.

In total, there are 22 town culverts, with 12 associated pits, 731 town pipes with 732 associated town pits and seven additional culverts around the South Boundary Road / Fauna Park Lakes vicinity.

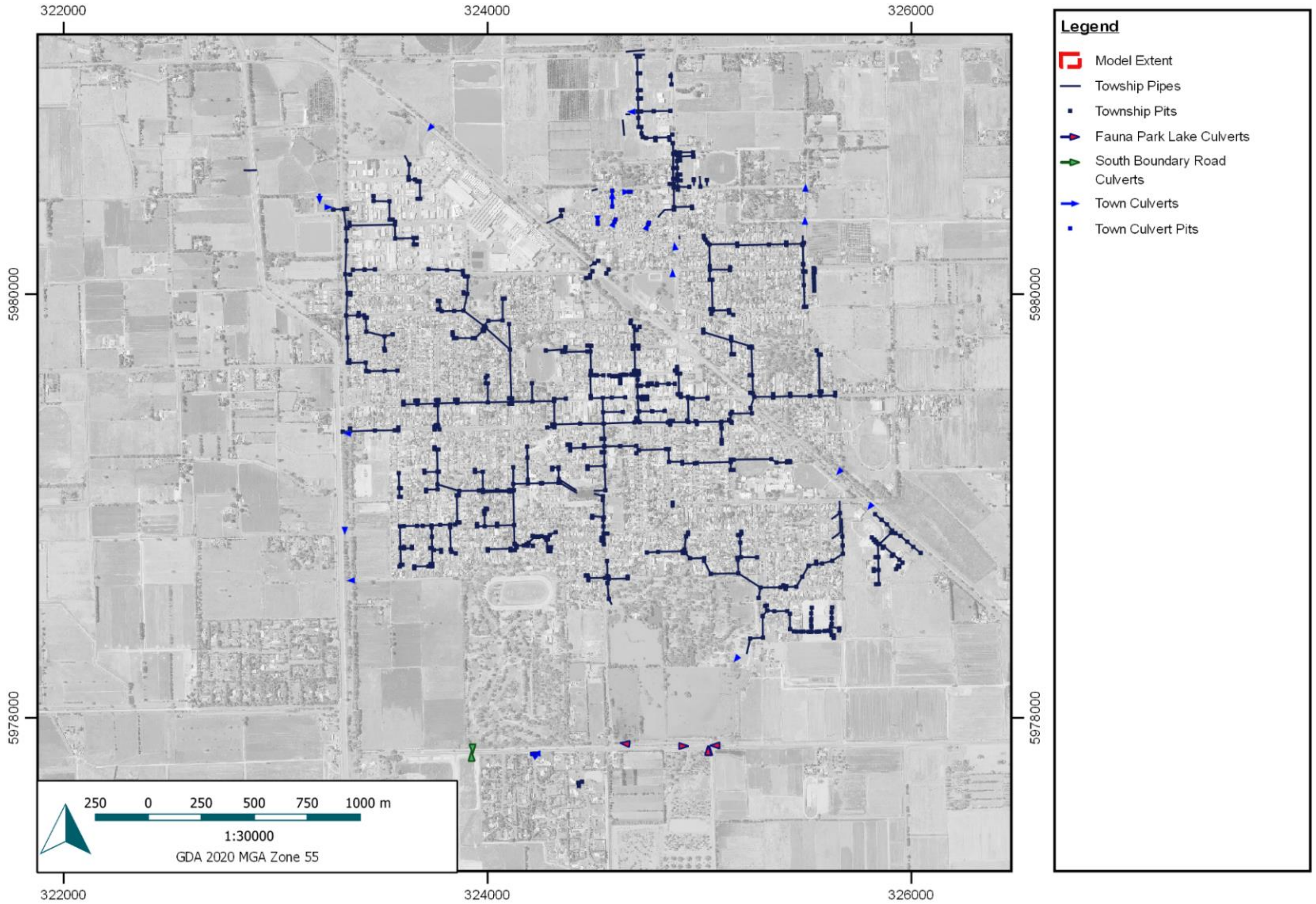

Figure 4-6 Model Schematic of Township Pits and Pipes, and Fauna Park Lake and South Boundary Road structures

The final stage of the 1D build was for the pump network to be incorporated into the model. Pump data was primarily sourced from the Pumps_Asset Condition_Collection Form, maintained by Campaspe Shire Council, but previous studies were also a source of information regarding the placement and capacity of the pumps. In the majority of cases the pumps run at a constant capacity, however, in the case of the Lake Road pumps and the new McEwen Road pump, the pump operation is via water trigger levels in the sump. These trigger levels have been included where that data is available.

The operation of the pumps has slightly changed over time. These changes have been captured via the creation of a 'historical' pump operating control file and a 'design' pump operating control file.

The pump data included in the model is outlined in Table 4-3 and illustrated in Figure 4-7.

Table 4-3 Kyabram Pump Details

Pump	Historical	Design
Beech Street	2 Pumps – constant capacity 1 x 0.2 m^3/s 1 x 0.4 m^3/s	2 Pumps – constant capacity 2 x 0.045 m^3/s
Lake Road	4 Pumps – with varying trigger levels 3 x 0.174 m^{3}s (electric) 1 x 1.2 m^3/s (diesel)	4 Pumps – with varying trigger levels 3 x 0.4 m^{3}s (electric) 1 x 1.2 m^3/s (diesel)
McEwen Road	1 Pump – constant capacity 1 x 0.16 m^{3}s	1 Pump – constant capacity 1 x 0.16 m^{3}s
New McEwen Road	1 pump triggered at 99.1m AHD Capacity = 0.07 m^3/s	1 pump triggered at 99.1m AHD Capacity = 0.07 m^3/s
McEwen Road East	2 Pumps Constant Capacity 2 x 0.0636 m^3/s	2 Pumps Constant Capacity 2 x 0.0636 m^3/s
Roger Street	2 Pumps – constant capacity 1 x 0.0694 m^3/s 1 x 0.1157 m^3/s	2 Pumps – constant capacity 1 x 0.0694 m^3/s 1 x 0.1157 m^3/s
Fauna Park Lake Pump	1 Pump 1 x 0.006 m^3/s	1 Pump 1 x 0.006 m^3/s
Breen Avenue Pumps	2 Pumps 1 x 0.085 m^3/s 1 x 0.2 m^3/s	2 Pumps 1 x 0.085 m^3/s 1 x 0.2 m^3/s
Jenmar Drive Pumps	1 Pump – constant capacity 1 x 0.092 m^{3}s	1 Pump – constant capacity 1 x 0.092 m^{3}s
Shelley Lake Road Pumps	1 Pump – constant capacity 1 x 0.19 m^{3}s	1 Pump – constant capacity 1 x 0.19 m^{3}s

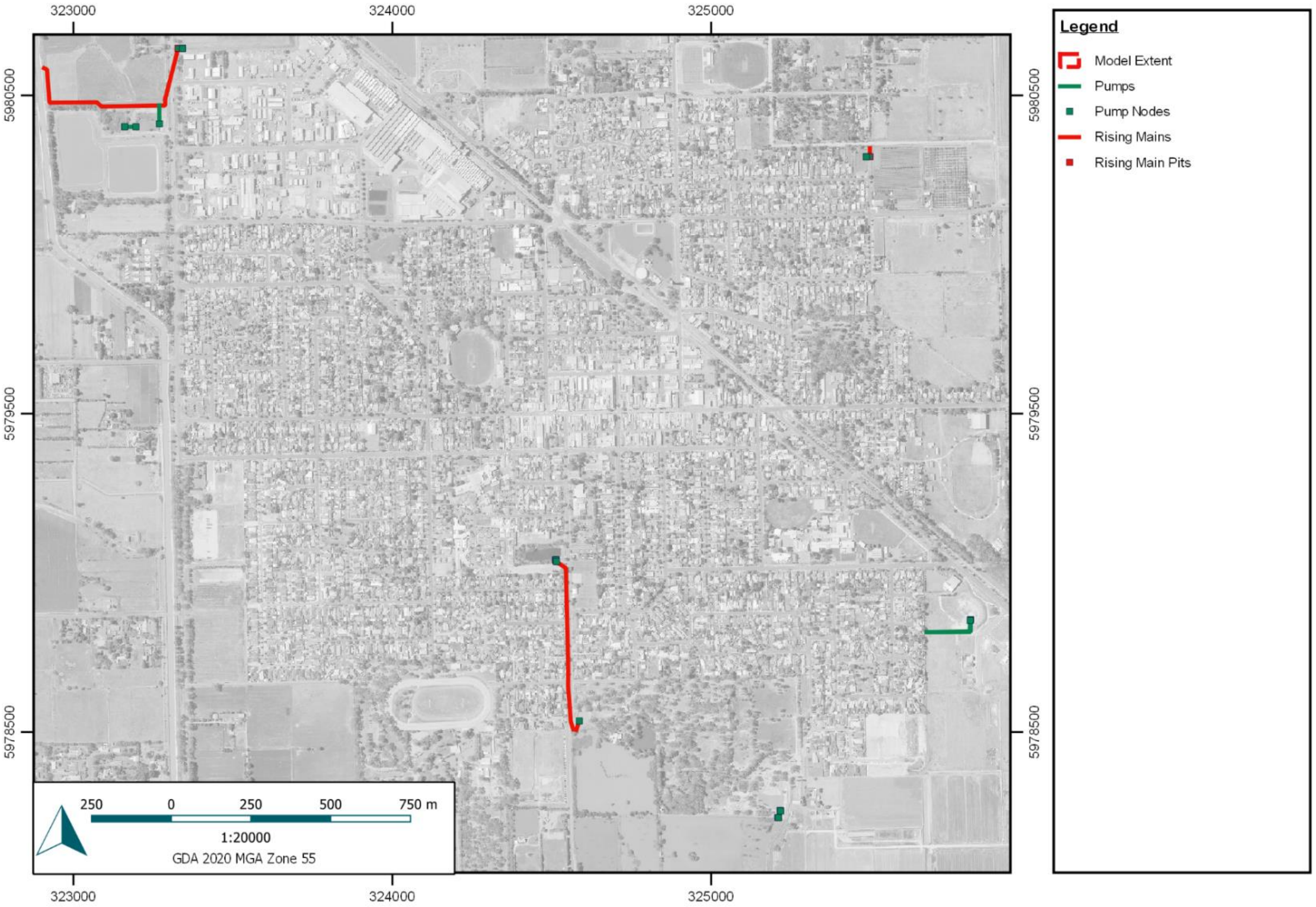

Figure 4-7 Model Schematic of Township Pump and Rising Main System

4.2.1.5 Terrain Modification

A number of terrain modifiers have been used within the model. The majority of modifiers have been used, where necessary, to reinforce terrain features such as waterways, channels and levee or road crests where the LiDAR was not sufficiently representing these features.

In addition, a terrain modifier was used to distinguish between the historical 1993 model and the 2012 and design models at South Boundary Road. Prior to 2011 South Boundary Road was a raised road that acted as a weir between Fauna Park and the reserve, south of South Boundary Road – preventing flow from entering this reserve. In later years, South Boundary Road was lowered it to form a spillway in large storm events so that flow could enter the reserve for the purposes of flood mitigation within the township.

In addition to the above, key open channels including the channel from the South Boundary Road area to the outfall under the No. 8 Channel were modelled as 1D open channels to ensure their capacity was accurately represented. An open, shallow channel in the Tisdall Road area, which receives flow from the Roger Street sump and pumps was also modelled in 1D.

The terrain modifiers used within the model are illustrated in Figure 4-8.

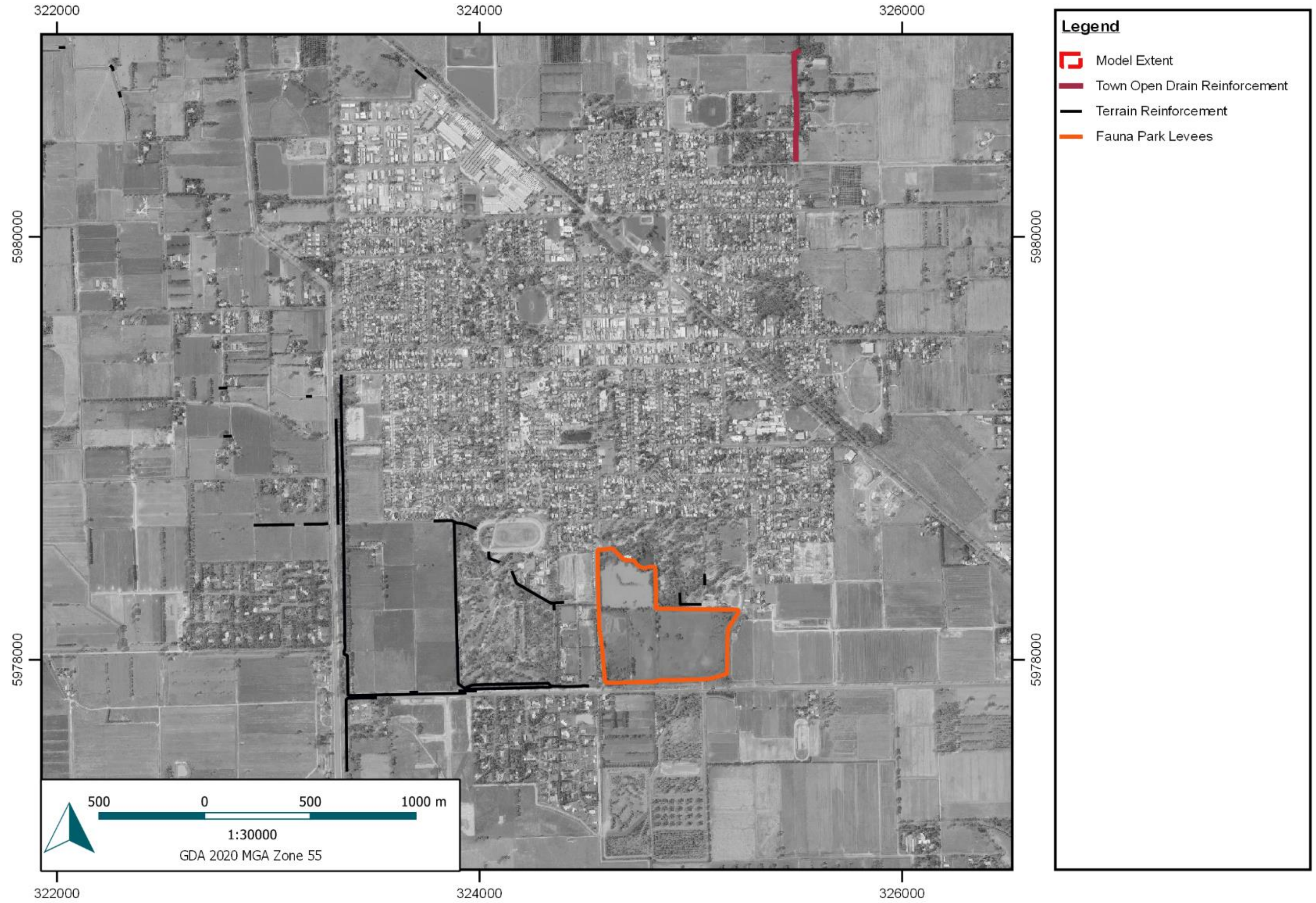

Figure 4-8 Model Schematic of Terrain Modification

4.2.1.6 Town-Mosquito Depression Interaction

Initial hydraulic model runs resulted in model simulation times of 3-5 days which was deemed impractical, and risked project timelines being delayed considerably. To reduce model run-times a smaller model was developed which focused on the town catchments only and did not include the Mosquito Depression floodplain. In order to justify this decision, the impact of the Mosquito Depression flows on the town catchments was assessed to ensure there would be no impact on modelling results within the town, if the Mosquito Depression floodplain was excluded. To test this the 1993 and 1% AEP event was modelled with and without any upstream flow at the inflow boundary at Merrigum. A difference plot is shown in Figure 4-9 below and it can be seen that the removal of the Merrigum Flow primarily impacts levels within the Creek channel. The impact across the floodplain was limited, and there was certainly no impact to the town catchments.

Based on these findings it can be reasonably assumed that flow in the Mosquito Depression catchment up to the 1993 discharge does not impact flood levels in the Kyabram town catchments, and that it is acceptable to model the town catchments in isolation without consideration for levels in Mosquito Depression.

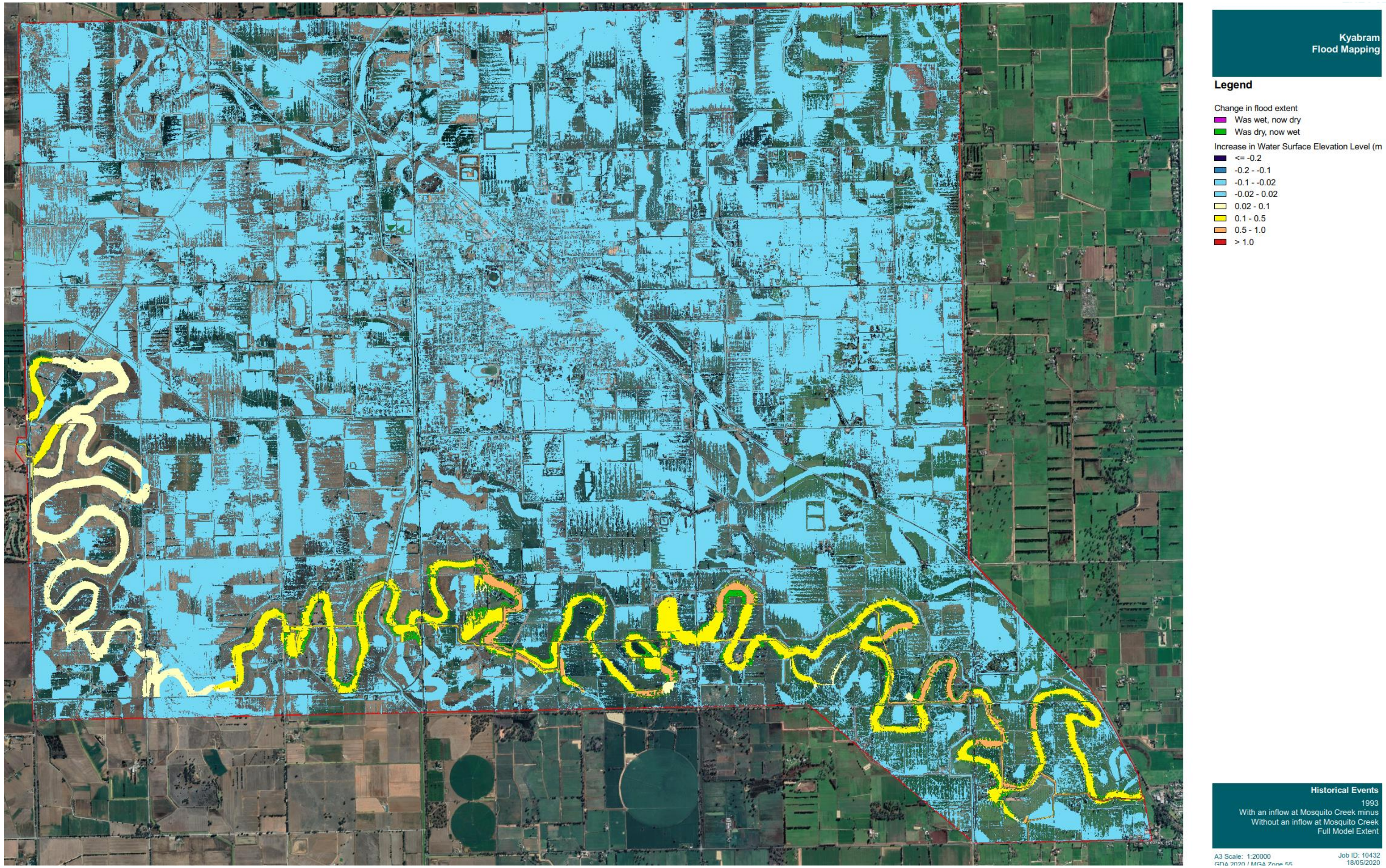

Figure 4-9 Afflux map comparing flood levels with and without inflows from Mosquito Depression for the 1993 event.

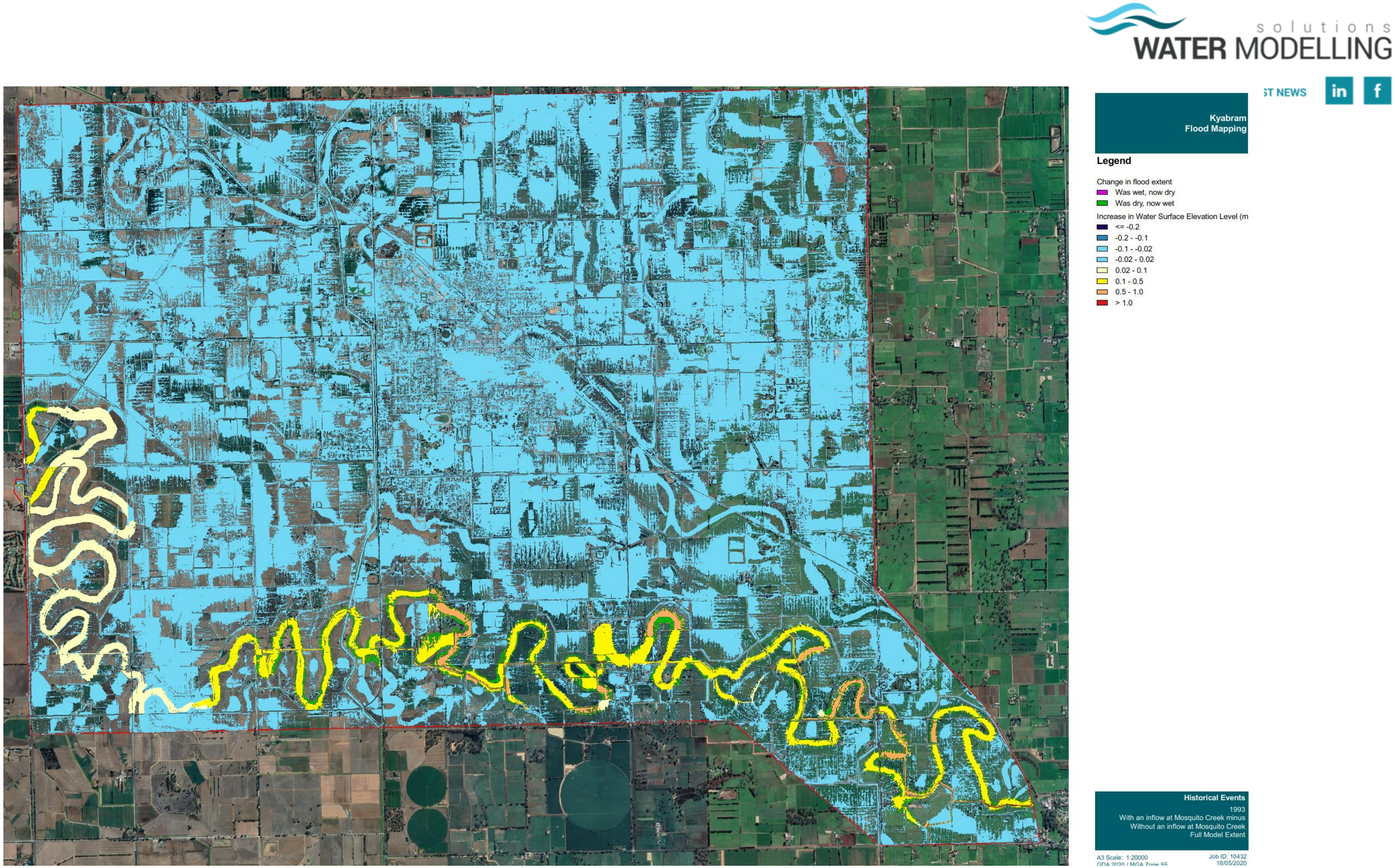

Figure 4-10 Afflux map comparing flood levels with and without inflows from Mosquito Depression for the 1% AEP event.

4.2.2 Town Flood Model Development

Aside from the model extent, the schematisation for the localised town model was identical to the larger model described in the sections above. All pits, pumps, sumps, 1D channels and terrain modifiers from the broader model were retained in the town model. The grid resolution remained at 4 metres. The revised model extent is shown below in Figure 4-11.

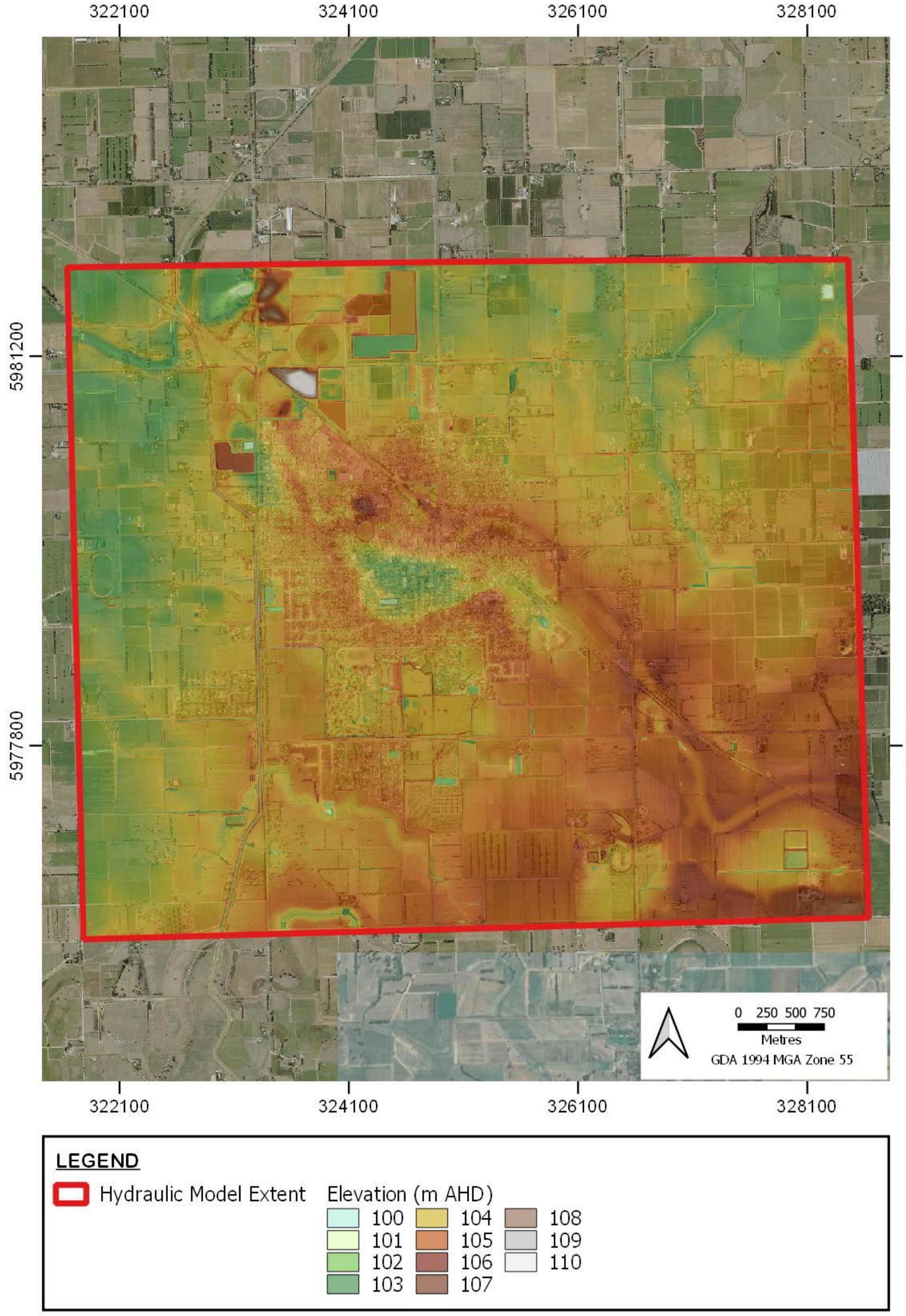

Figure 4-11 Revised Town Hydraulic Model Extent

4.2.3 Model Health and Stability

TUFLOW HPC is both volume and momentum conserving with adaptive time stepping. It is unconditionally stable which means the standard TUFLOW Classic checks, such as mass error, are not applicable to HPC. Alternatively, there are additional checks recommended to ensure model health. The minimum timestep (dt) across the model remains above 0.75 seconds for the duration of the simulation. Given the cell size is 4m, and the recommended values for timestep is between 1/5 and ½ of the 2d cell size this is an acceptable result. It is not uncommon for HPC to run on a slightly lower timestep than recommended. There are isolated areas in which the dt drops below the recommended 1/5 associated with isolated depressions in the DEM. The lowest dt value recorded in the model was 0.62 in one of these depressions for the 1993 calibration event. The dt map for the 1993 calibration event is shown in Figure 4-12 while the dt graphs for the 1% AEP 60 minute design storm is shown in Figure 4-13. Both the dt mapping and charts of dt show the model remains healthy throughout the simulation.

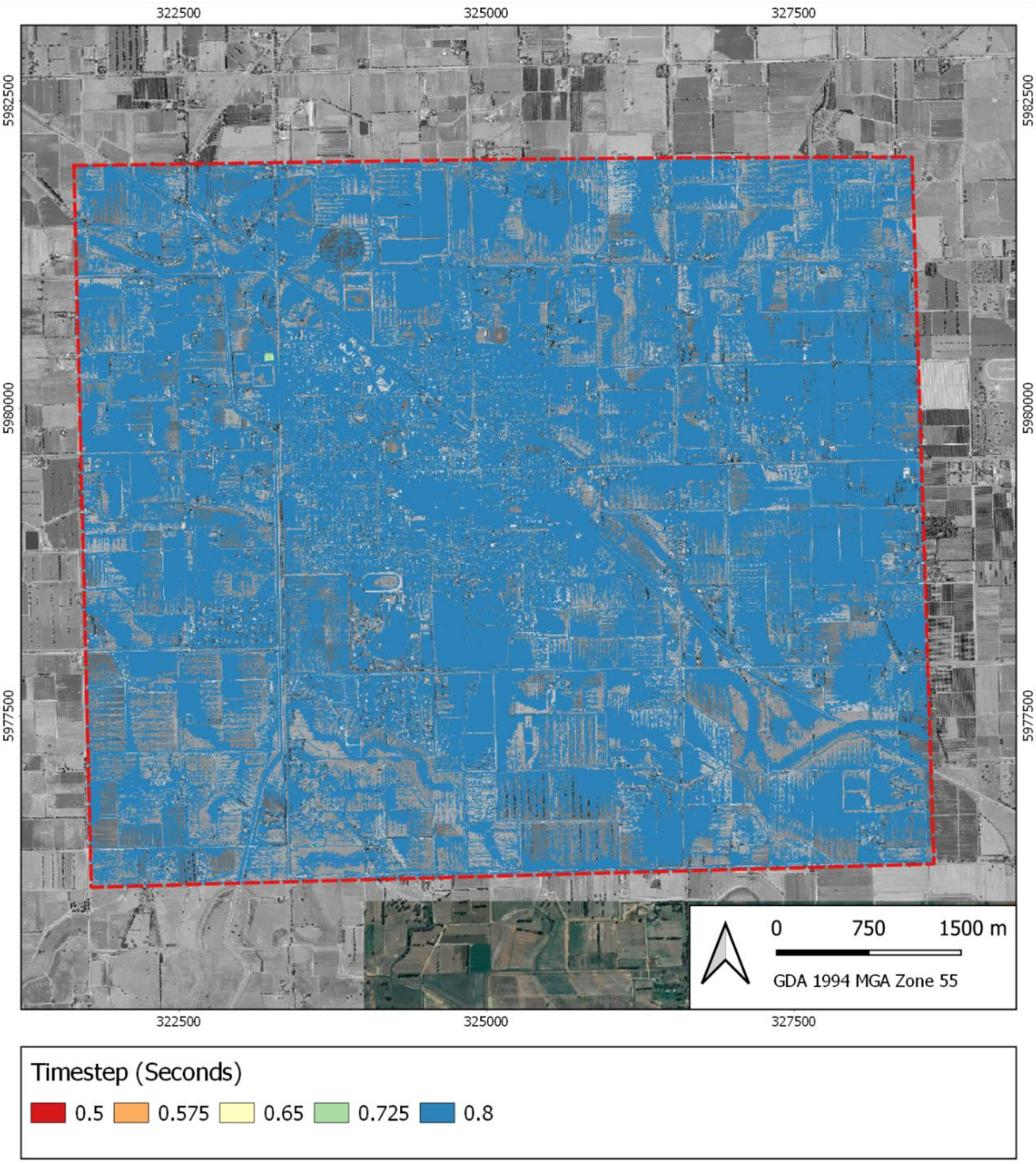

Figure 4-12 Minimum Timestep (dt) for the 1993 Calibration Run

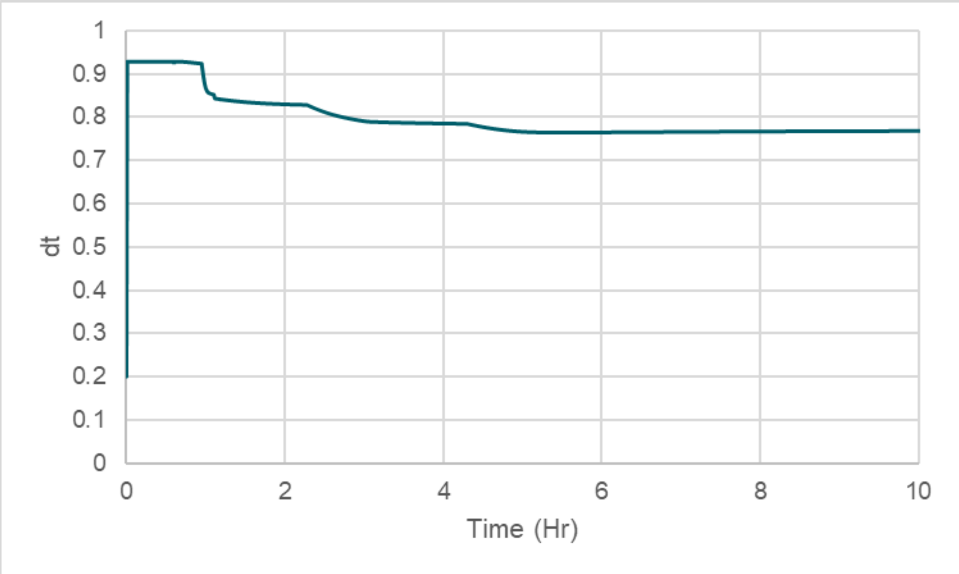

Figure 4-13 Minimum Timestep (dt) for the 1% AEP 60 minute event

4.3 HYDRAULIC MODEL CALIBRATION/VALIDATION

4.3.1 October 1993 Event Calibration

The October 1993 hydraulic model results were compared to available information for that event. Both full and halved regional losses were modelled and it was found that the half losses resulted in flood extents and levels that more closely matched observed behaviour.

The key aspects of the model calibration/validation process are described below:

- Flood levels were compared to recorded levels in central Kyabram. A reported peak flood level of 103.65 mAHD is reported in the GHD (1993) report at the Municipal Offices, which compares to a modelled level of 103.63 mAHD. This is a very close match and indicates good performance of the model in this area, and realistic rainfall and runoff.
- Comparisons were made between the model results and historic flood extents and levels developed by GBCMA. These were available in GIS Shape format and are compared to the model results in the mapping below. They generally show a good correlation in terms of both flood extents and levels. Note that the GBCMA mapping is understood to not be event specific but the 1993 and 2012 results are generally fairly similar, with the 1993 generally having higher levels particularly in central Kyabram. Comparisons are provided below in Figure 4-14 to Figure 4-17.
- A number of photos from the event including photos in central Kyabram and in the vicinity of South Boundary Road. Comparisons to the model results show similar depths of flooding at those locations. It should be noted that historic imagery is likely not to have captured the peak of the flood and so must be treated with some caution. An example of some available flood photos is provided below in Figure 4-18 and Figure 4-19.
- Comments from a resident on Lake Road (opposite the Lake Road sump), who noted that the 1993 flood extent came up to his neighbour's house. This closely matches the model results which shows the extent of the large body of water in central Kyabram extending to a similar location on Lake Road.

In addition to the above feedback was received from a number of community members, Council and GBCMA, most of which concluded that the results matched their recollection and knowledge of the October 1993 flood event. The results were compared against data gather during the community consultation session (see details in Section 2 of this report) and several observations correlate with the model results, namely:

- Item 1 - Flooding in Tisdall Road area in both 1993 and 2012. WMS also met with residents in this area and their observations of the 1993 and 2012 generally matched the modelling results.

* Item 7 - Flooding around the intersection of Dawes and McEwen Road. The model results show depths of 50-200mm through this area in both the 1993 and 2012 events.
* Item 11 - Significant flooding through central Kyabram around Haslem/Richard/Park Streets in the 1993 event, correlates with modelling with depths of up 400-600mm through those area. Flood levels observed to be lower in 2012, which concurs with model results with levels around 30-50mm lower in the modelled March 2012 event (there was also greater pumping capacity in March 2012 from the Lake Road sump).
* Item 12 – Flooding in Koala court, including an overland flowpath through private property towards the Fauna Park. The modelling results show this flowpath in both the 1993 and 2012 events.

There were some comments that the modelled events seemed to underestimate flooding in the vicinity of McEwen Road, where flood water drains through the key subway under the Number 9 channel. In the past it has been observed that water backs up in this location due the limited 450mm capacity subway pipe culvert. The differences between modelled and observed in this area is likely related to the performance of the subway culvert. The modelling has assumed the culvert has no blockage and indicates that under head it has a peak discharge of approximately 20 ML/day in the 1993 event. This compares to an assumed maximum flow rate of 6 ML/d by Campaspe Shire Council. The performance in reality could vary considerably, and any blockage or siltation of the culvert would adversely impact the culvert performance significantly. This highlights the importance of sensitivity testing of blockage in key culverts as part of the next phase of the project.

In addition to the calibration process described above, some further photos and newspaper articles regarding the 1993 event were provided by community members in August 2020. Additional comparisons were made between the modelling results and this material which is presented in Appendix I. They showed a strong correlation between the modelling results and the historic behaviours, further increasing confidence in the modelling.

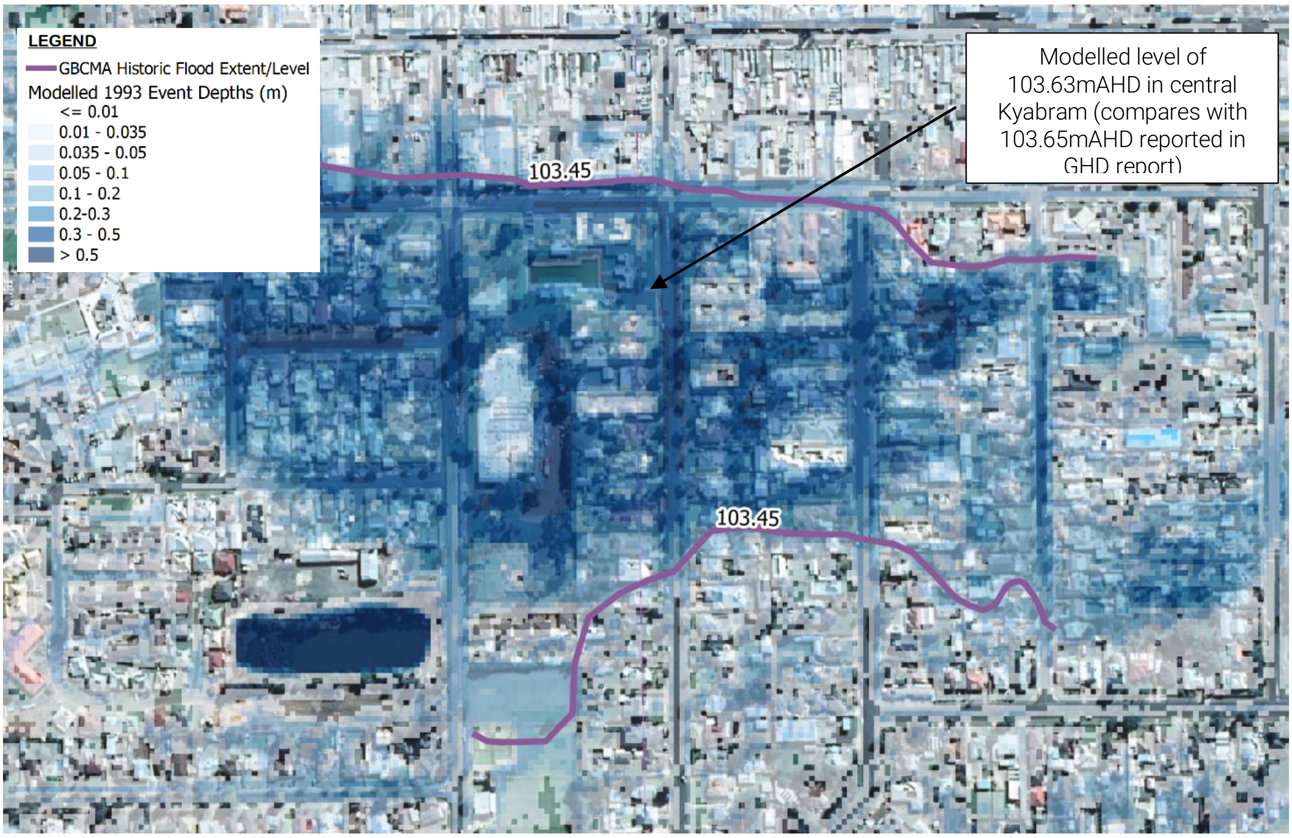

Figure 4-14 Comparison of October 1993 results in central Kyabram to historic flood extent and levels (in purple)

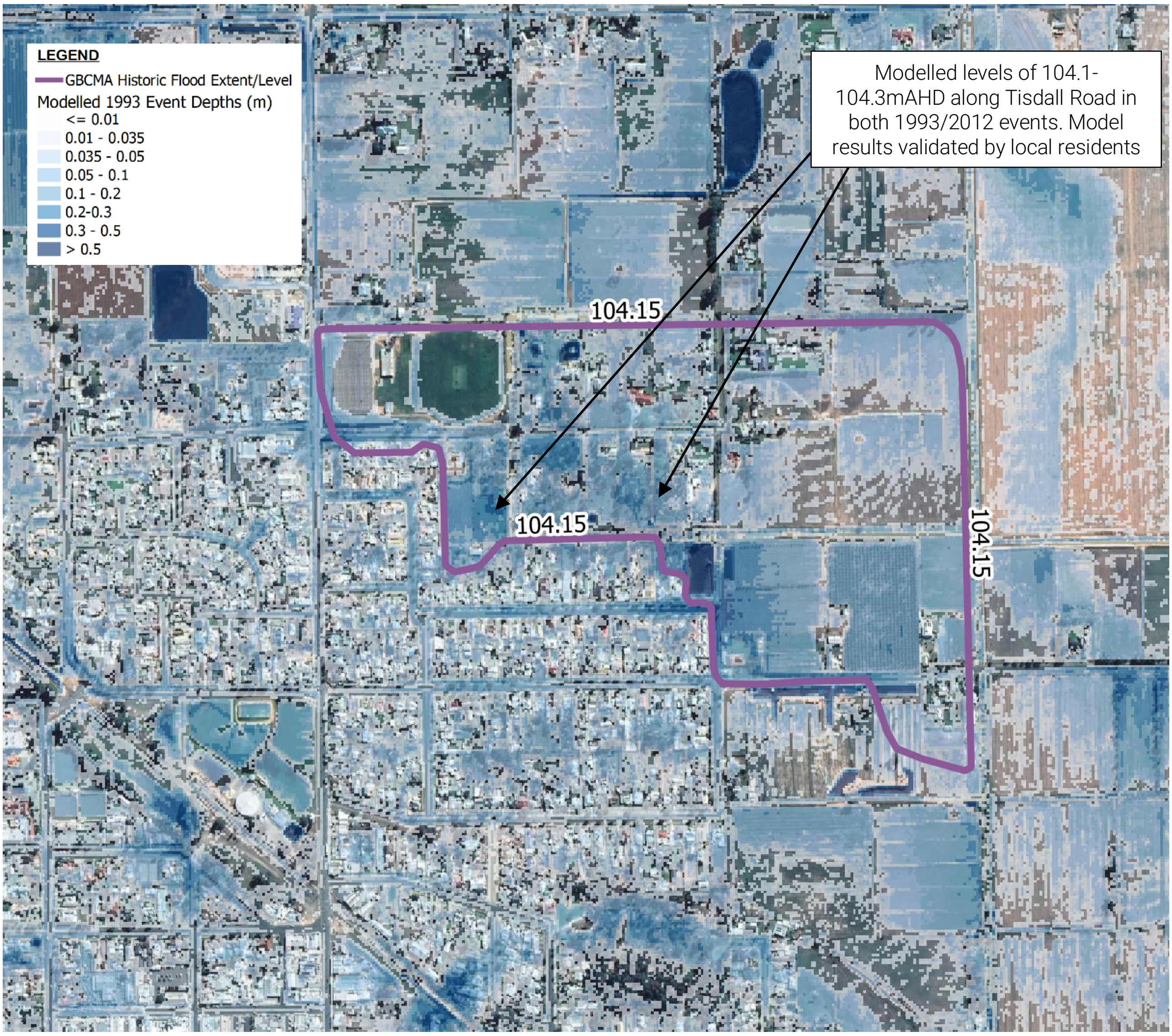

Figure 4-15 Comparison of October 1993 results in north-east Kyabram to GBCMA historic flood extent and levels (in purple)

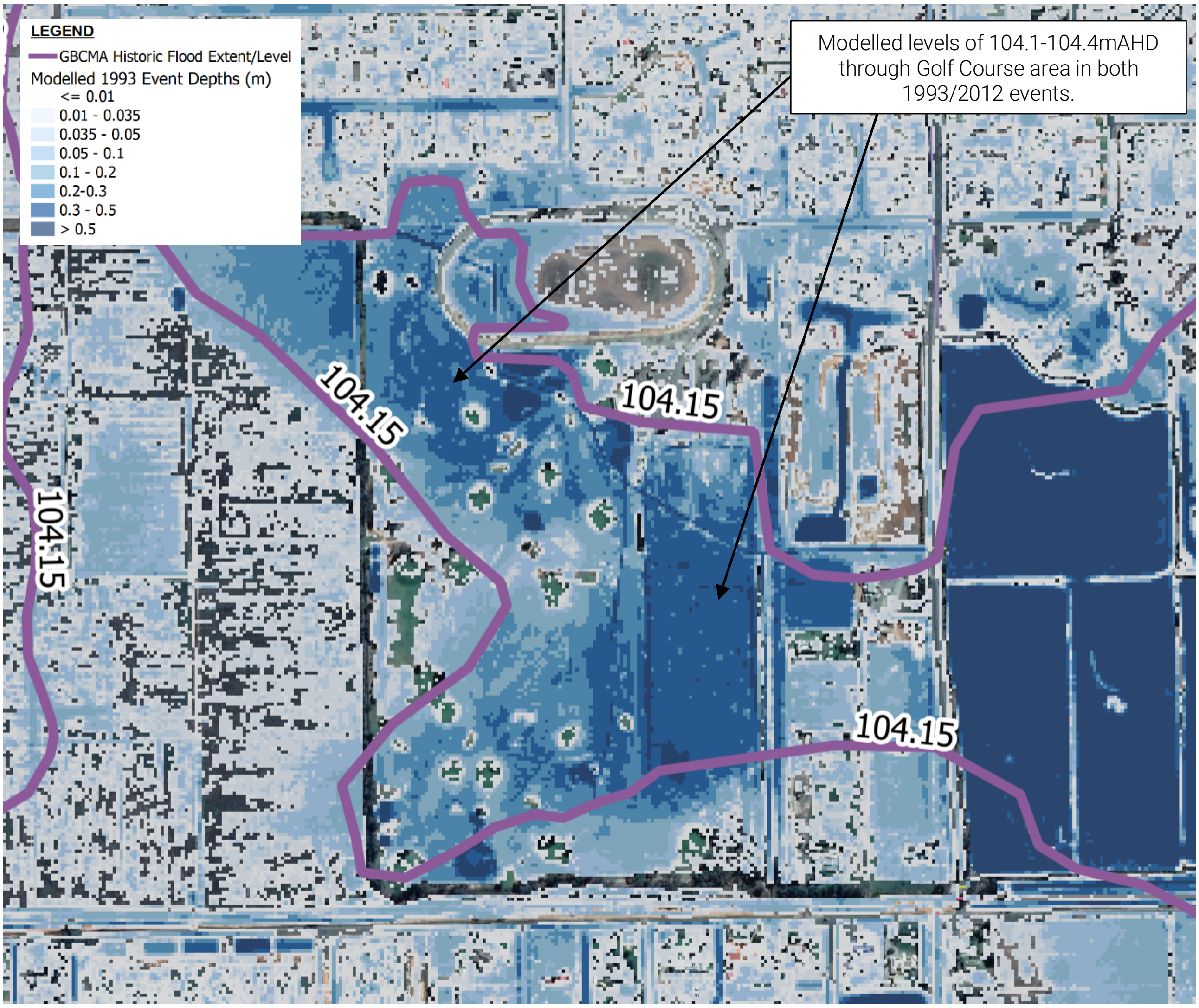

Figure 4-16 Comparison of October 1993 results in southern Kyabram in the vicinity of the Golf Course to GBCMA historic flood extent and levels (in purple)

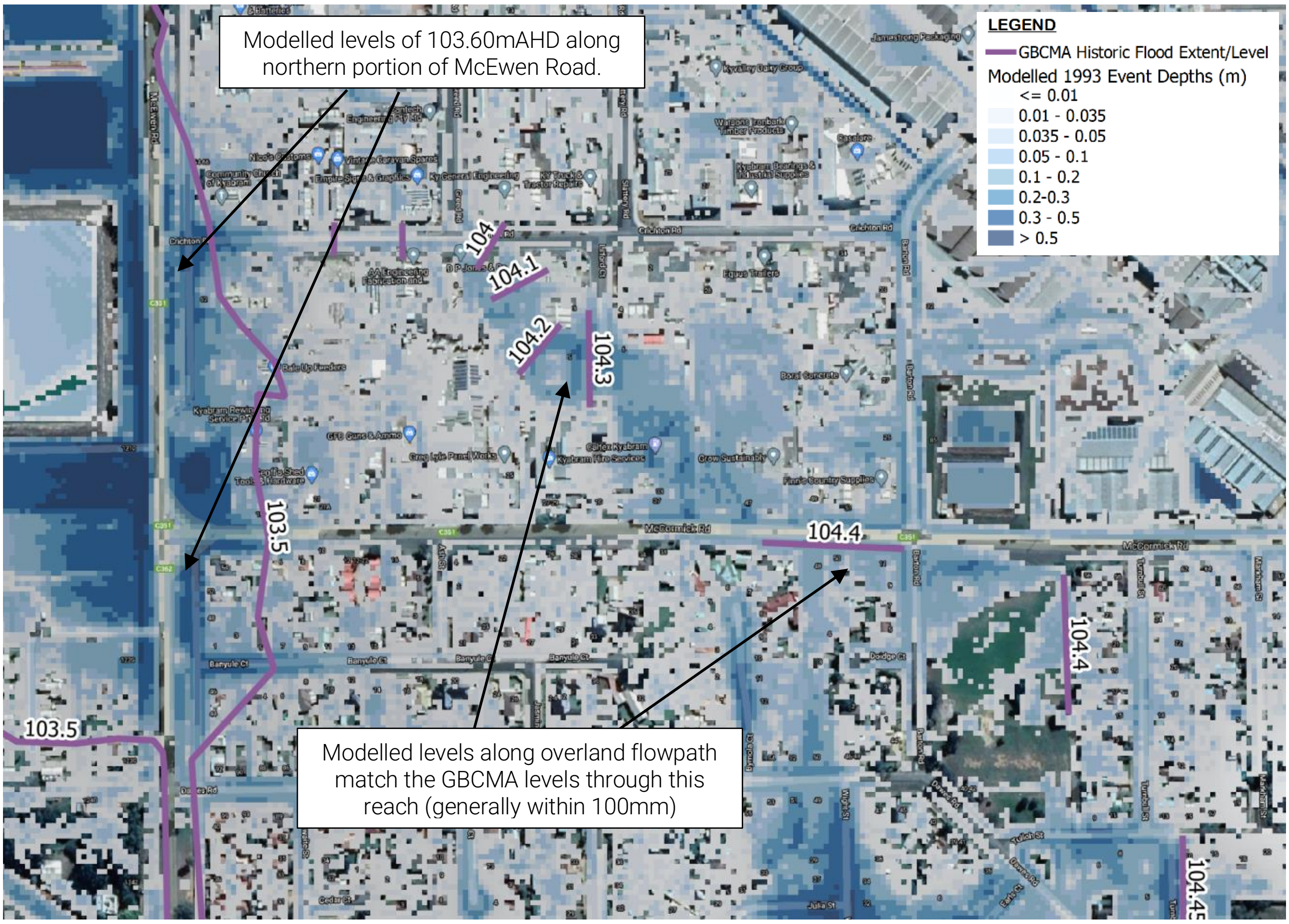

Figure 4-17 Comparison of October 1993 results in southern Kyabram in the north-west Kyabram to GBCMA historic flood extent and levels (in purple)

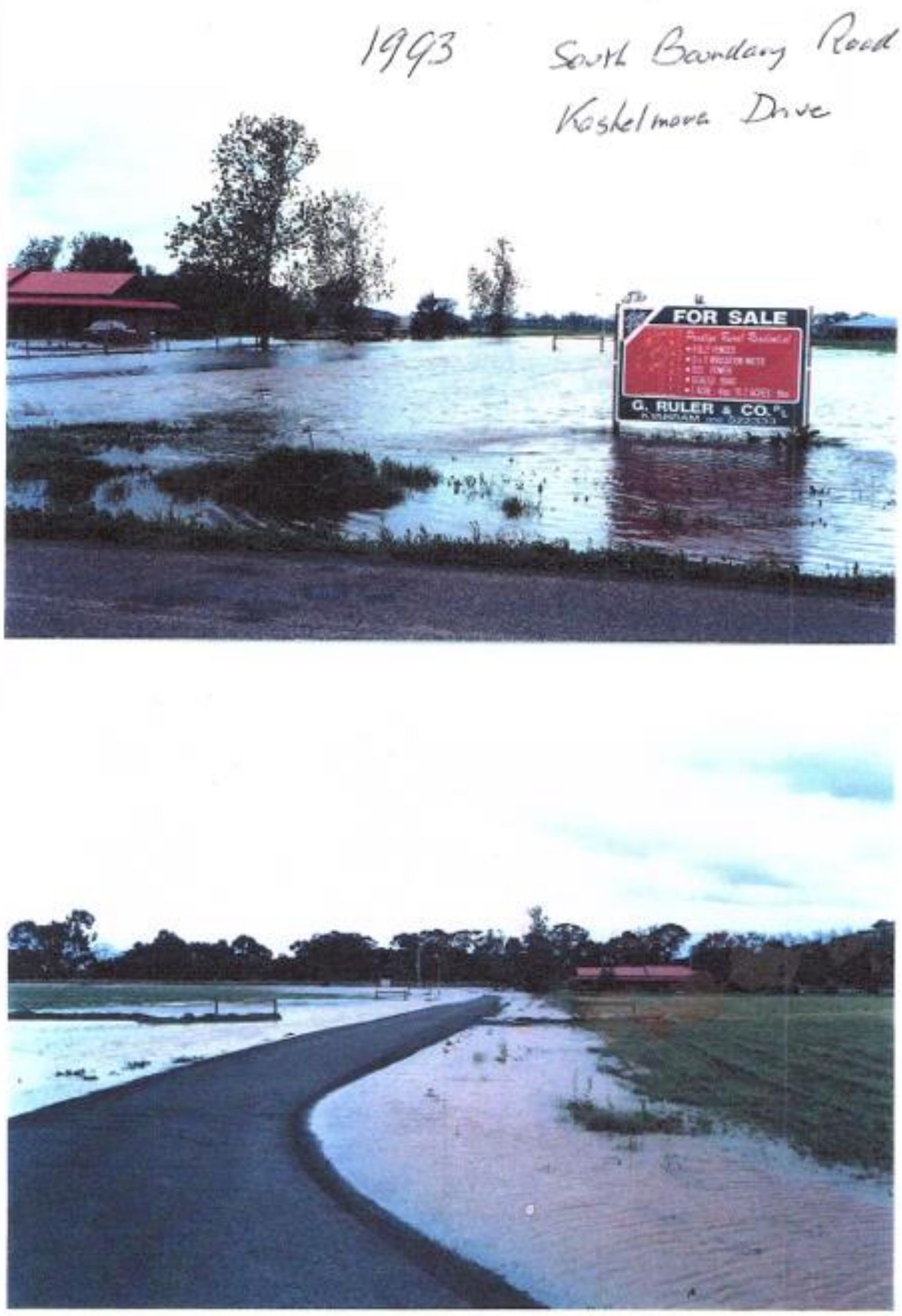

Figure 4-18 Photos from the October 1993 flood event from South Boundary Road

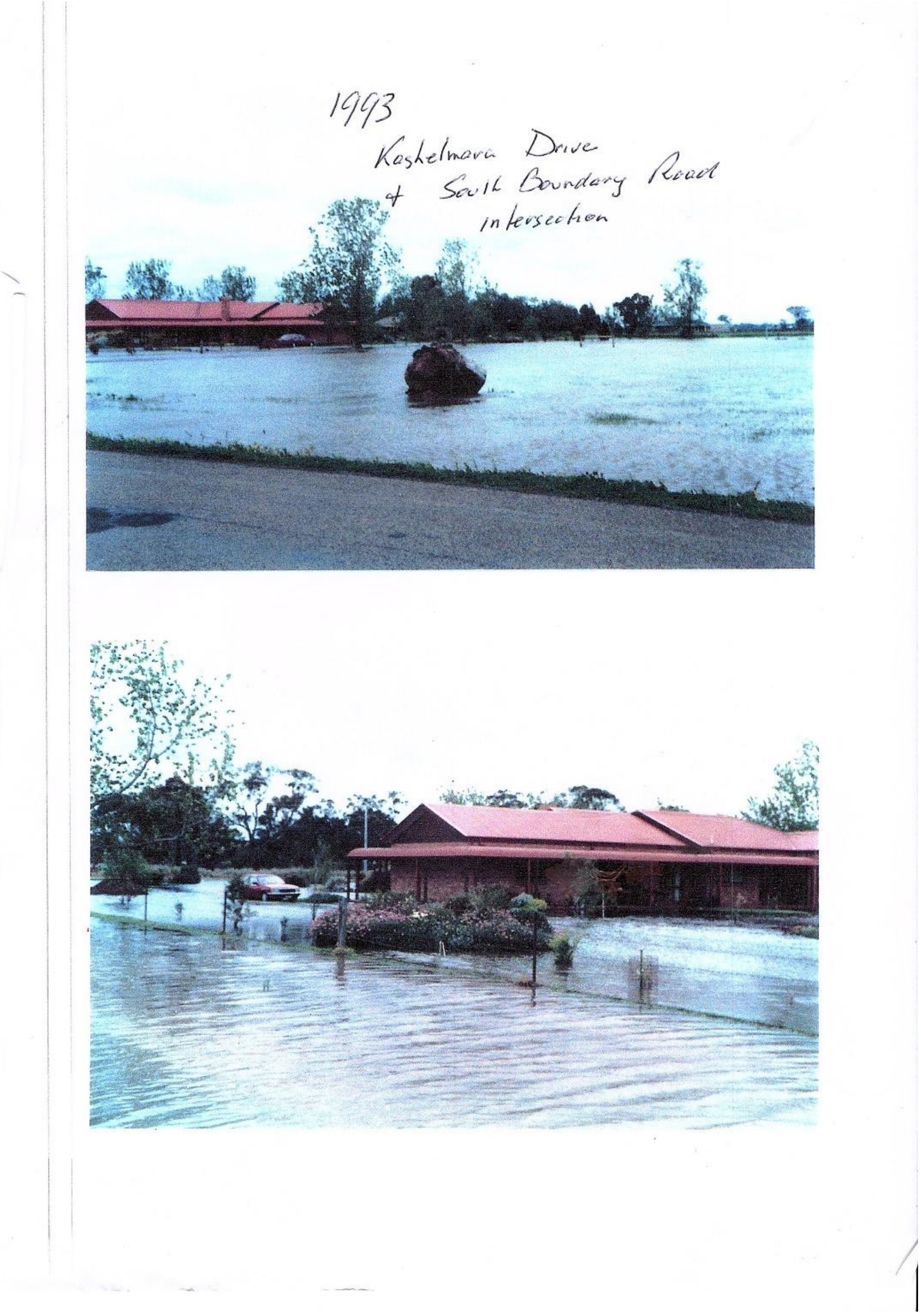

Figure 4-19 Photos from the October 1993 flood event from South Boundary Road

4.3.2 March 2012 Event Calibration

The March 2012 hydraulic model results were compared to available information for that event. Both full and halved regional losses were modelled and it was found that the full regional losses resulted in flood extents and levels that more closely matched observed behaviour. Additional iterations could be undertaken with further revision of losses but it was deemed that the results showed sufficient correlation to observed behaviour, and given much of the data is anecdotal or approximate, there was little benefit in running further iterations.

The key aspects of the model calibration/validation process are described below:

- Comparisons were again made between the model results and historic flood extents and levels developed by GBCMA. These generally show a good correlation in terms of both flood extents and levels. As stated above GBCMA dataset is understood to not be event specific but the 1993 and 2012 results are generally fairly similar, with the 1993 generally having higher levels particularly in central Kyabram. Additional comparisons for the March 2012 event are provided below in Figures Figure 4-20 to Figure 4-23.
- A number of photos from the event including photos in central Kyabram and in the vicinity of South Boundary Road. Comparisons to the model results similar depths of flooding at those locations. It should be noted that historic imagery is likely not to have captured the peak of the flood and so must be treated with some caution. An example of some available flood photos is provided below in Figure 4-24 and Figure 4-25 .
- As previously stated, a resident on Lake Road (opposite the Lake Road sump) noted that the 2012 flood extent came to a neighbouring property which matches the model results which shows the extent of the large body of water in central Kyabram extending to a similar location on Lake Road.

In addition to the above feedback was received from a number of community members, Council and GBCMA, most of which concluded that the results matched their recollection and knowledge of the October 1993 flood event. The results were compared against data gather during the community consultation session (see details in Section 2 of this report) and several observations correlate with the model results. A number of the items presented in the October 1993 section were also relevant to this event and have not been reported. Other items which are pertinent to the March 2012 event include:

- Item 1 - Flooding in Tisdall Road area in both 1993 and 2012. WMS also met with residents in this area and their observations of the 1993 and 2012 generally matched the modelling results.
- Item 20 - Flooding in Ern Miles Reserve during the March 2012 event (forms part of the Fauna Park Storage in large flood events). The model results confirm inundation in this area, which is expected and how the Fauna Park Lake Storage is designed to operate, with the Ern Miles Reserve area doubling the available flood storage.
- Item – Albion Street inundated between Edis and Street and Graham Road, consistent with modelling results which shows extensive sections inundated, particularly around Tisdall Road.
- Item 31 – Home impacted at corner of Lake Road and South Boundary Road in 1993 and 2012, consistent with modelled depths in both events.
- Item 35 - Overflow from Fauna Lake storage, consistent with model results.

There were some comments that the modelled also seemed to underestimate modelling in the vicinity of McEwen Road in the March 2012 event. Again, this is attributed to the performance of the 450mm diameter subway pipe culvert, which is assumed to be at full capacity in the modelling but may well have had a level of blockage due to siltation or flood debris.

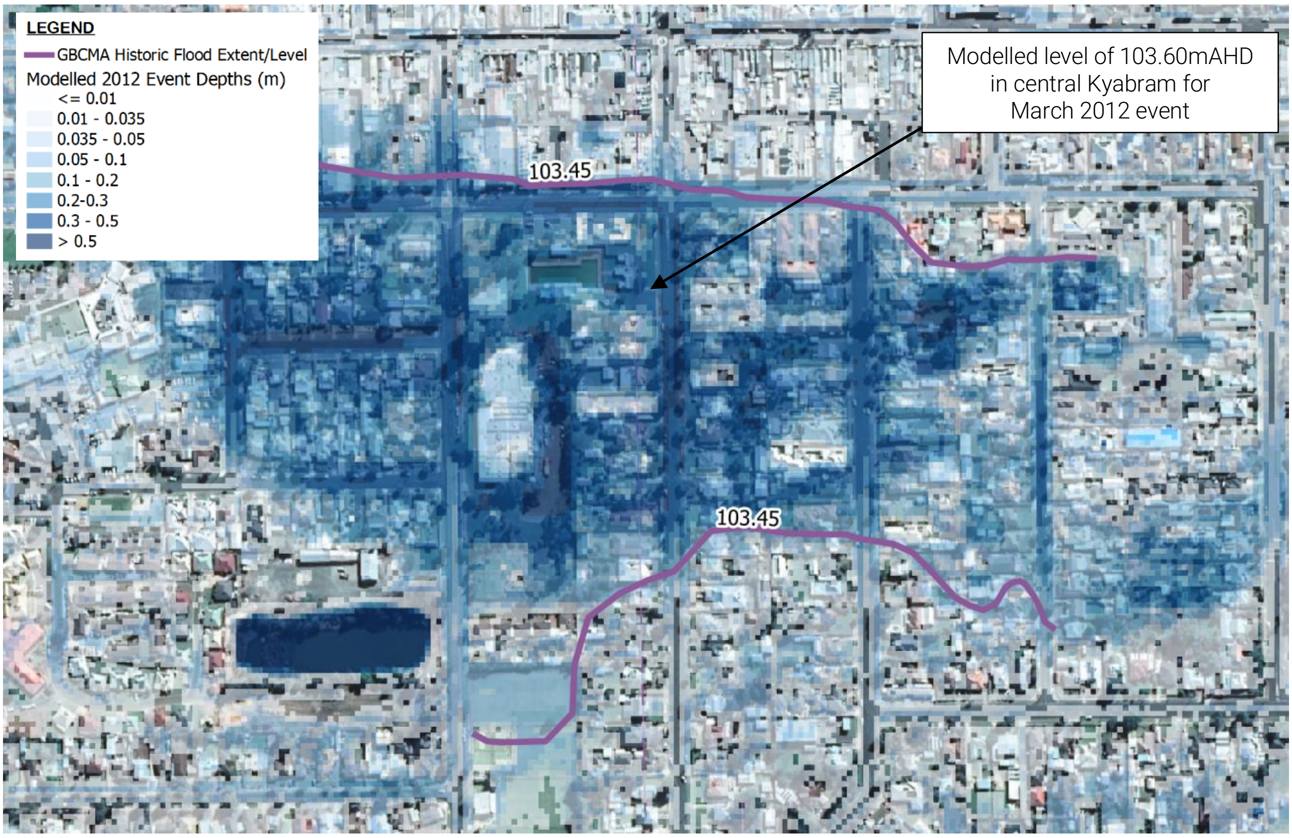

Figure 4-20 Comparison of 2012 results in central Kyabram to historic flood extent and levels (in purple)

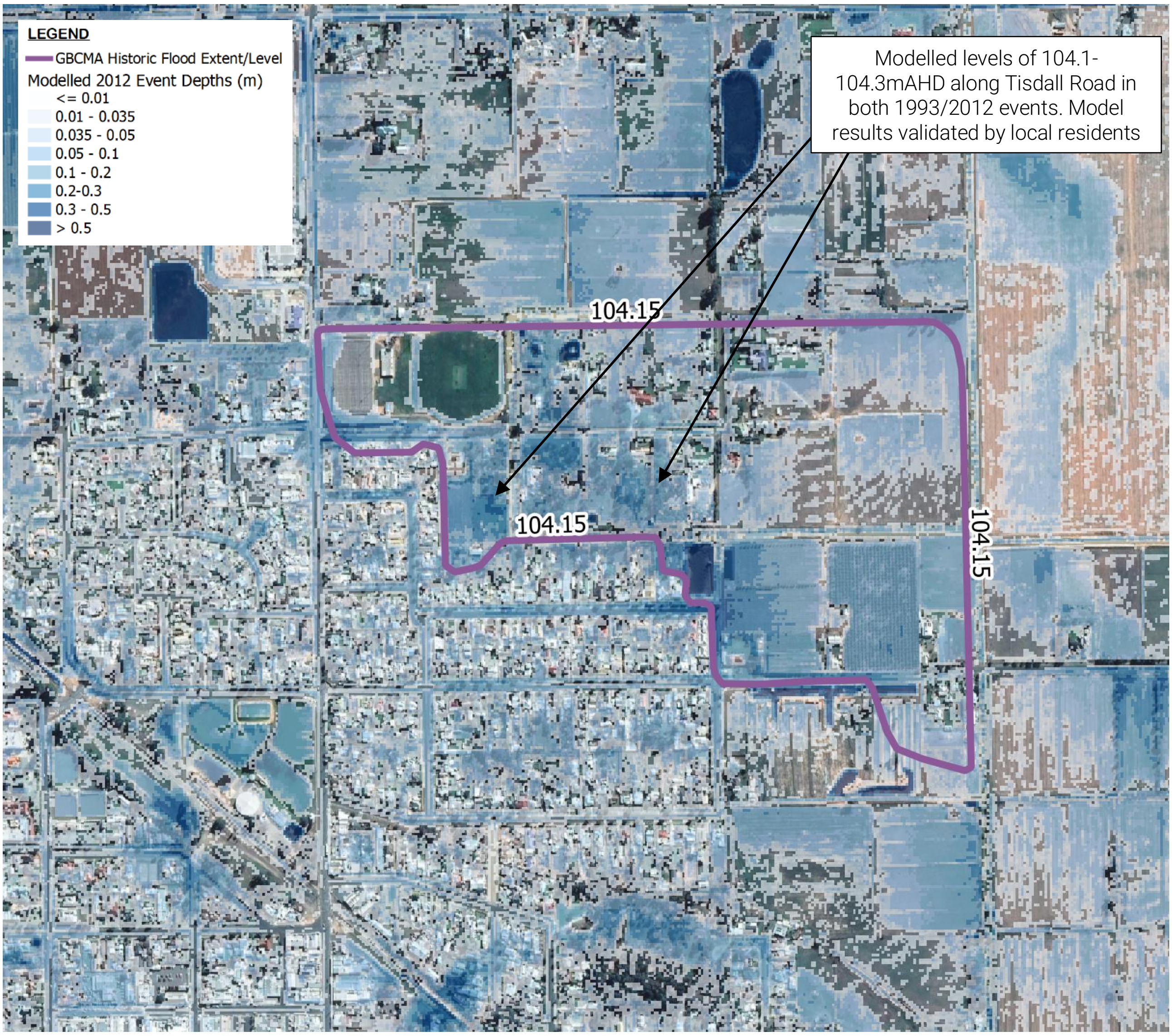

Figure 4-21 Comparison of March 2012 results in north-east Kyabram to GBCMA historic flood extent and levels (in purple)

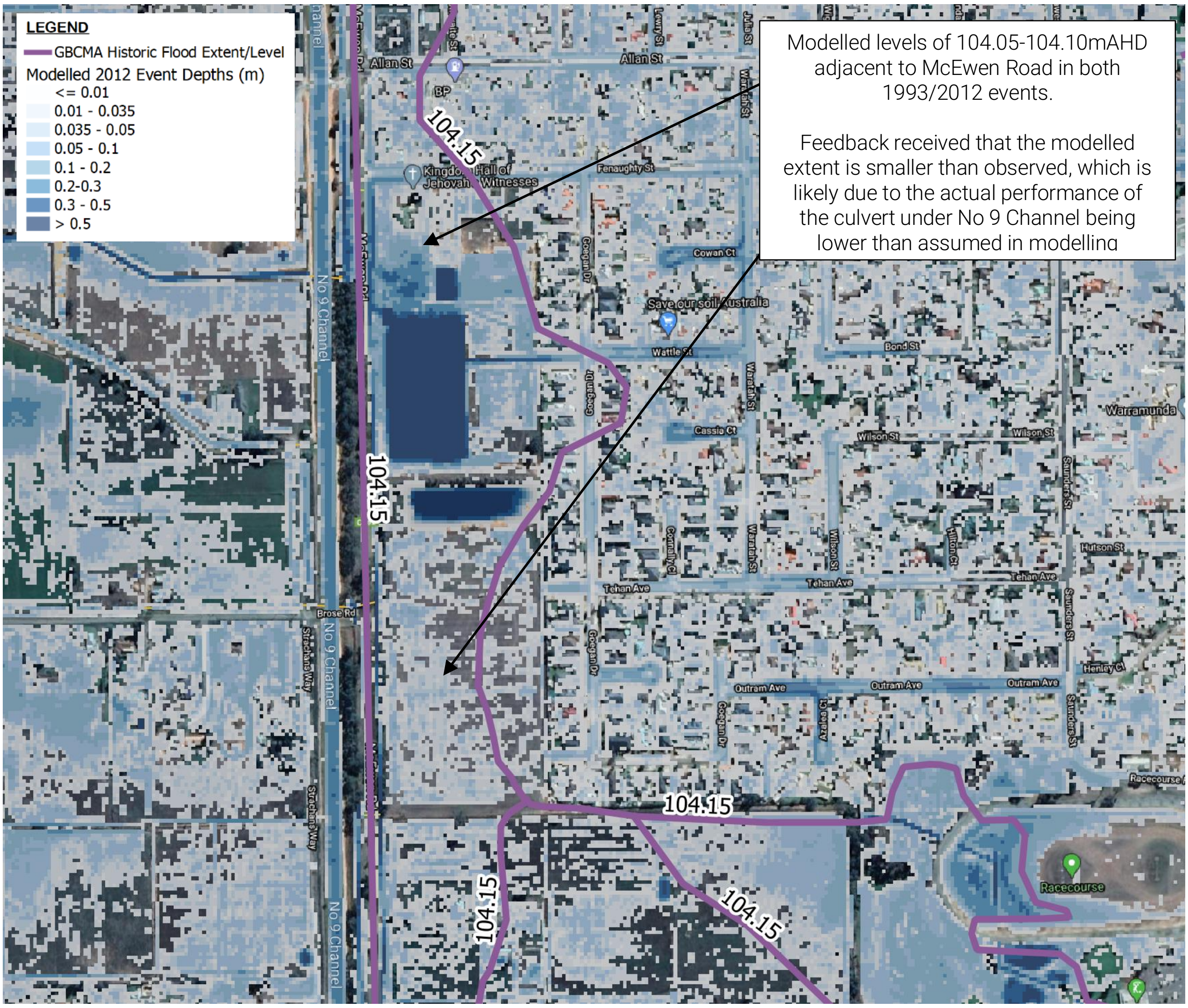

Figure 4-22 Comparison of March 2012 results in western Kyabram adjacent to McEwen Road to GBCMA historic flood extent and levels (in purple)

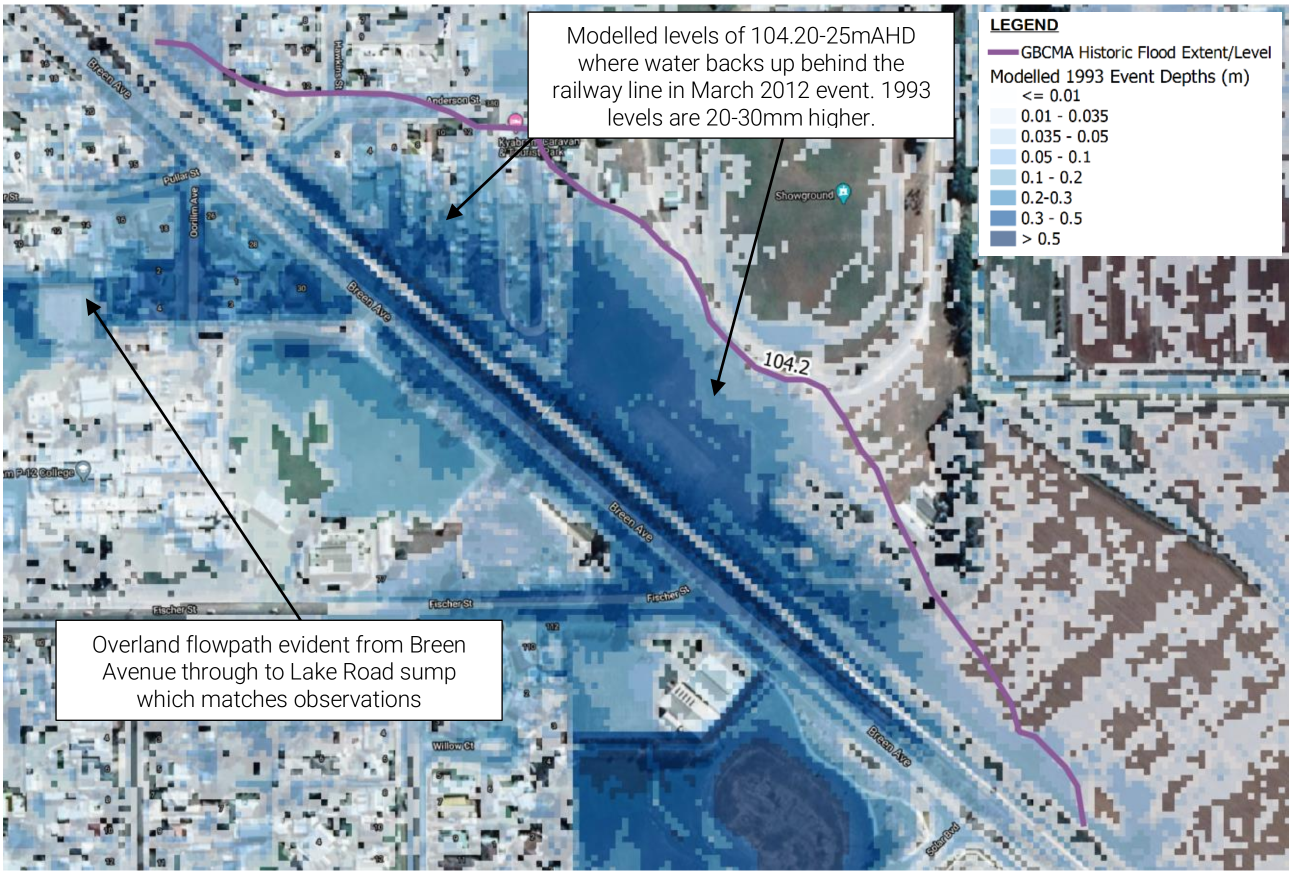

Figure 4-23 Comparison of March 2012 results in eastern Kyabram around Breen Avenue and the railway line to GBCMA historic flood extent and levels (in purple)

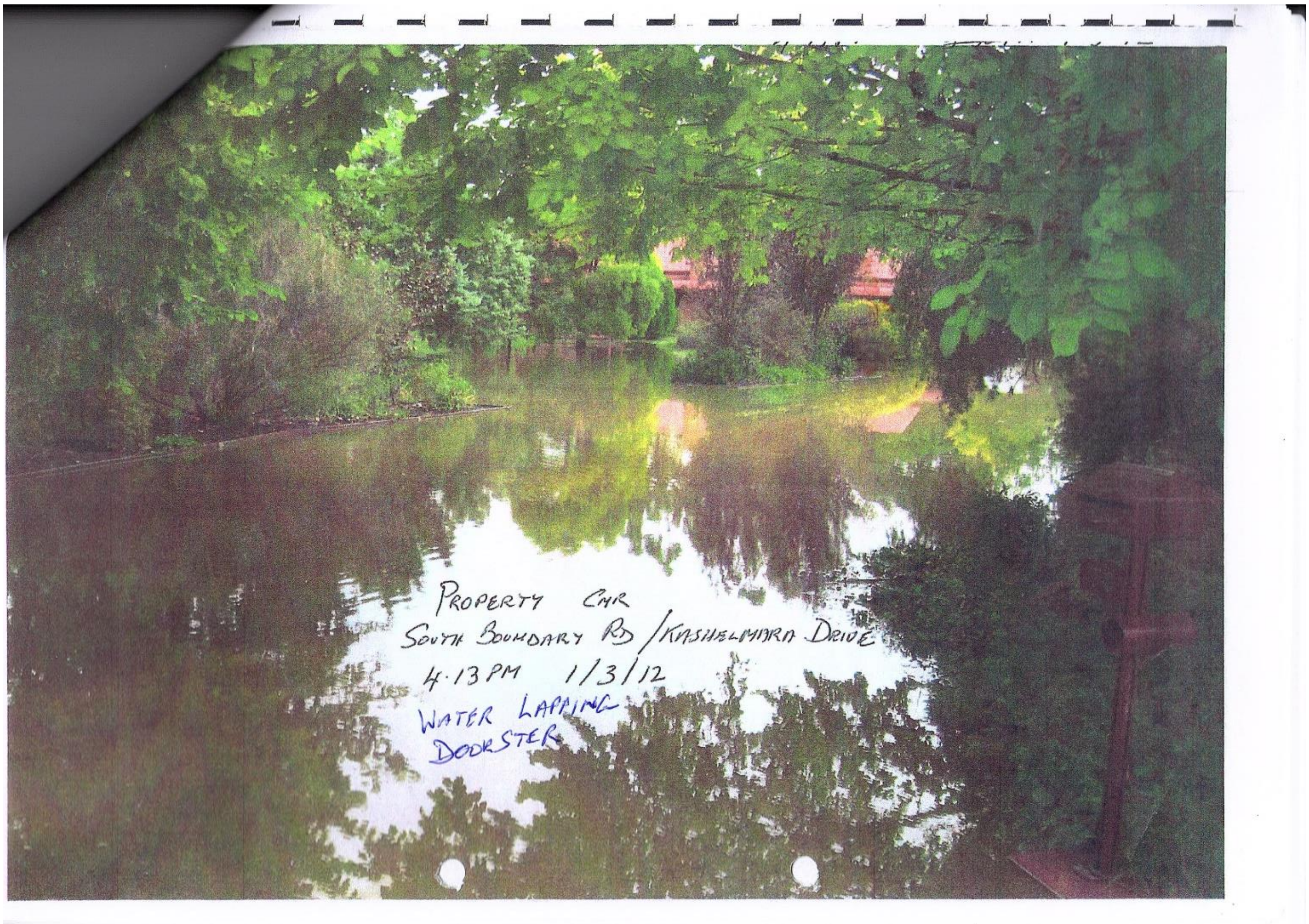

Figure 4-24 Photo from the March 2012 flood event at corner of South Boundary Road and Kashelrmara Drive (Note: model results show depths of 100-200mm in this location which appears consistent with image)

Figure 4-25 Photos from the March 2012 flood event in the South Boundary Road area

4.3.3 Calibration Summary

Based on the calibration process described above the modelling is considered to have produced a realistic representation of the two historic flood events, with similar flood behaviour observed at numerous locations around the township. Based on these findings the model is deemed suitable for use in design modelling.

5 SUMMARY OF FLOOD BEHAVIOUR

5.1 OVERVIEW

This section describes the key inundation characteristics across the study area for the 1% AEP event. It should be noted that the above floor flooding impacts described below do not take into account individual flood protection measures such as local flood walls or levees which protect individual homes. The condition of such works are generally unknown and they often require additional preparation such as sandbagging to be effective. For this reason, such measures cannot be assumed to be in place and operating effectively under design conditions.

5.2 DESIGN MODELLING RESULTS

5.2.1 Modelled Events

Kyabram is a small township surrounded by agricultural land, characterised by flat, low-lying topography. The impervious catchments and overland drainage paths throughout the township result in a short time of concentration, typically between 30 and 90 minutes for the developed areas. The undeveloped areas and farmland surrounding Kyabram have a longer time of concentration, between 12 hours and 72 hours, as to be expected from the flat rural landscape and presence of natural and artificial depressions and storages. As discussed in the hydrology section the critical durations have been selected from an ensemble simulation and confirmed in the TUFLOW model. The modelled event durations modelled are presented in the table below:

- 20% AEP Event - 10 minutes, 30 minutes, 60 minutes, 90 minutes, 24 hours, 48 hours, 72 hours, 168 hours
- 10% AEP Event – 10 minutes, 20 minutes, 30 minutes, 60 minutes, 90 minutes, 12 hours, 48 hours, 72 hours, 168 hours
- 5% AEP Event - 30 minutes, 60 minutes, 90 minutes, 12 hours, 48 hours, 72 hours, 168 hours
- 2% AEP Event - 30 minutes, 60 minutes, 90 minutes, 24 hours, 48 hours, 72 hours, 168 hours
- 1% AEP Event - 30 minutes, 45 minutes, 60 minutes, 90 minutes, 12 hours, 24 hours, 72 hours, 168 hours
- 0.5% AEP Event - 30 minutes, 45 minutes, 60 minutes, 90 minutes, 12 hours, 48 hours, 72 hours, 168 hours

A single temporal pattern for each of the above events was run, with the selection of the temporal pattern generally based on the median value determined in the RORB modelling at key locations. For the longer duration events (24- and 72-hour events), which were found to be critical for some areas of Kyabram in the TUFLOW modelling (but not the RORB modelling), centrally-weighted temporal patterns were adopted.

The critical durations for the 1% AEP event are mapped in Figure 5-1. It can be seen that a wide range of durations are critical across the township, which is a somewhat different result to the RORB analysis which found that predominantly the shorter duration events were critical. This highlights the unique drainage behaviour in Kyabram with inundation in many areas dependant on storm and runoff volumes due to the numerous hydraulic controls, constrained outfalls and low relief topography creating numerous informal storages around the township.

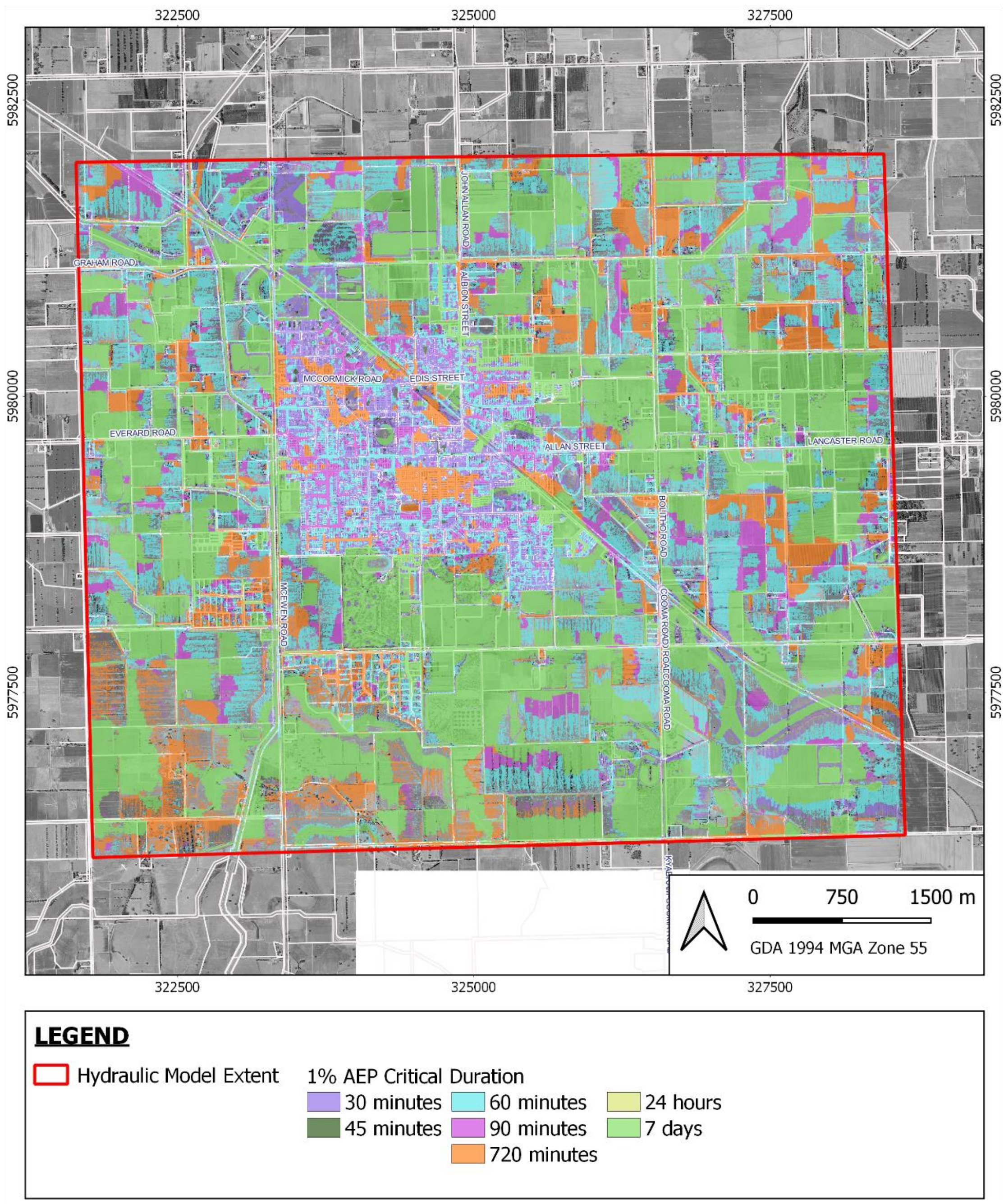

Figure 5-1 1% AEP Critical Duration

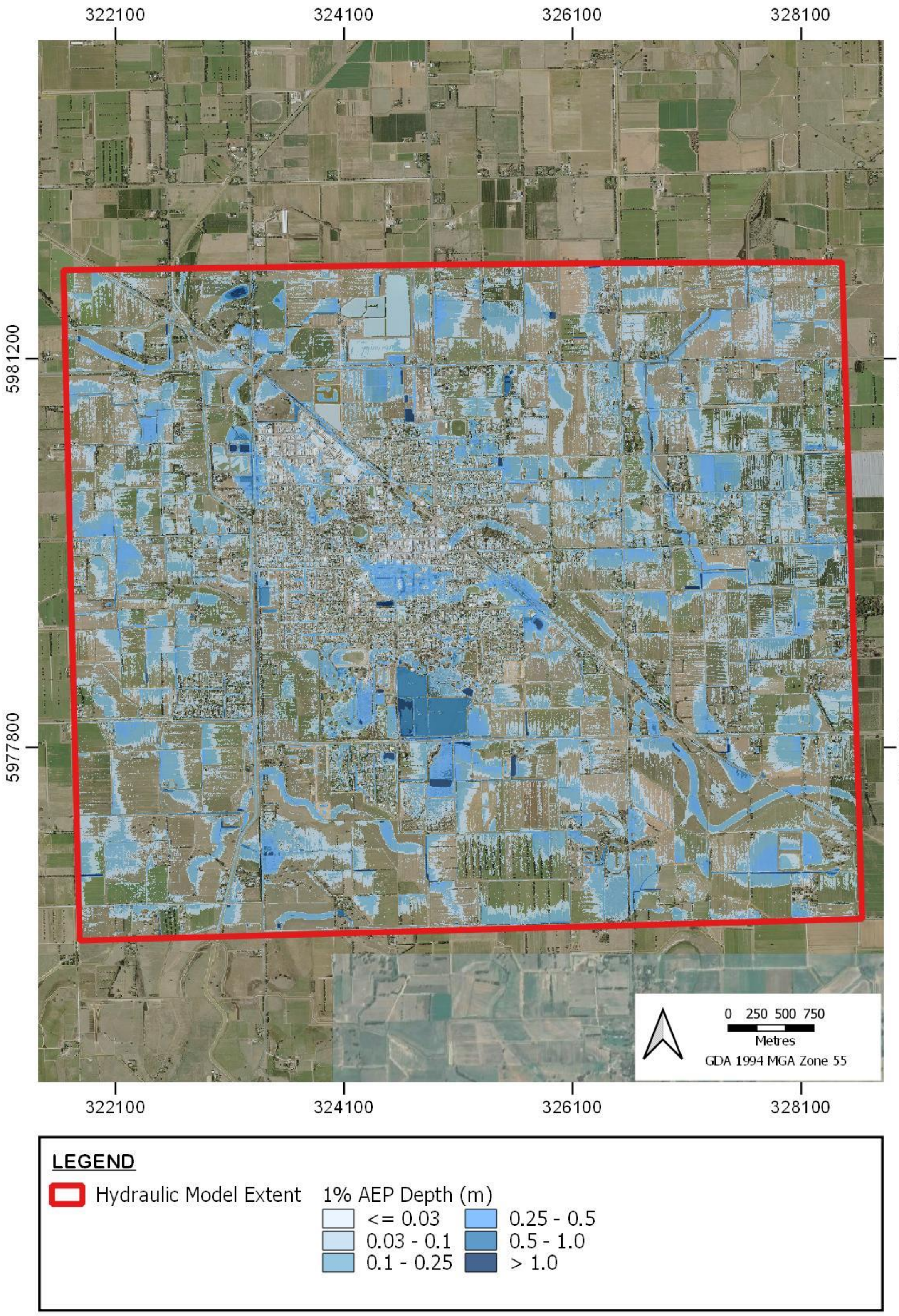

Figure 5-2 1% AEP Flood Depths

5.2.2 Summary of Flood Behaviour

The township's low relief and numerous depressions and informal storages make for challenging flood conditions and drainage design. Flood waters travel as concentrated overland flow through the streets before pooling in natural and artificial depressions throughout the town. The depressions are generally in the vicinity of known flooding hotspots with council operating a complex pump and sump system, which has been explicitly represented in the modelling. The largest of these depressions, as confirmed in the modelling, is in the centre of Kyabram around Kyabram Library and Community Hub. This area sees 1% AEP flood depths in excess of 500mm which extend from Mitchell St to Richards St and Fenaughty St to Pettifer St. An additional major depression occurs along Breen Avenue which sees inundation above 500mm in the 1% AEP event. Breen Avenue is a major road running through the centre of town, parallel to the railway. There is also significant backing up of flood water behind the railway line.

The flood behaviour outside of Kyabram is predominantly overland sheet flow and pooling of water in depressions. Overland sheet flow is to be expected due to the flat landscape and rural nature of the catchment. There are isolated depressions throughout the area that act as waterways during hydraulic events. The overland flow pools within pastured areas due to roads and irrigation channels acting as hydraulic controls. These pools are frequently below 500mm in depth but with minimal velocity generally resulting in low hydraulic hazard.

There is a range of critical duration events. Some low-lying areas such as the golf course and key storages such as the Fauna Park Lake have longer critical storm durations of 7 days and more. The central township which

5.2.2.1 20% AEP Flood Behaviour

From the flood modelling undertaken, the following observations are made regarding the 20% AEP event:

- 3 residential dwellings flooded above floor level.
- 9 commercial buildings flooded above floor level.
- Generally shallow inundation across roadways and through private property (depths predominantly less than 50mm).
- Some above floor impacts to dwellings and commercial buildings which are low-lying or have floor level set at or close to natural surface level.
- Some ponding in drains adjacent to Breen Avenue and Railway Line and in low-lying areas of the Kyabram Caravan Park, with depths of 300-600mm in those areas.
- Small pockets of ponding on roadways and in low-lying areas around Chaston Street, Union Street and Park Street.
- Minimal flooding on roads in excess of 300mm.
- 20% AEP rainfall (although catchment conditions at the start of the event will strong influence impact):
    - XX mm in 12 hours
    - XX mm in 24 hours
    - XX mm in 168 hours

5.2.2.2 10% AEP Flood Behaviour

From the flood modelling undertaken, the following observations are made regarding the 10% AEP event:

- 5 residential dwellings flooded above floor level.
- 10 commercial buildings flooded above floor level.
- Peak flood levels are generally less than 10mm higher than the 20% AEP event, aside from in sumps/storages and low-lying areas where significant ponding occurs.
- Generally shallow inundation across roadways and through private property (depths predominantly less than 50-70mm).
- Some above floor impacts to dwellings and commercial buildings which are low-lying or have floor level set at or close to natural surface level.

- Additional ponding in drains adjacent to Breen Avenue and Railway Line and in low-lying areas of the Kyabram Caravan Park, with depths of 300-600mm in those areas.
- Pockets of ponding on roadways and in low-lying areas around Chaston Street, Union Street and Park Street slightly larger than in the 20% AEP event.
- Minimal flooding on roads in excess of 300mm.
- 10% AEP rainfall (although catchment conditions at the start of the event will strong influence impact):
  - XX mm in 12 hours
  - XX mm in 24 hours
  - XX mm in 168 hours

5.2.2.3 5% AEP Flood Behaviour

From the flood modelling undertaken, the following observations are made regarding the 5% AEP event:

- 11 residential dwellings flooded above floor level.
- 10 commercial buildings flooded above floor level.
- Inundation across roadways and through private property increasing with depths of 300-390 mm in some areas.
- Some low-lying or floor level set at or close to natural surface level residential dwellings and commercial buildings are also impacted.
- The Kyabram Library carpark, Kyabram Community Church, Kyabram Community and Learning centre are all inundated.
- Some parts of the Kyabram Caravan park are flooded with depths ranging from 300 mm to 680 mm.
- Some parts of Koala Court junction of Julia Street and Wight street are flooded with depths of 330 mm and have potential impact to the adjacent residential dwellings.
- Pockets of ponding on roadways and in low-lying areas around Chaston Street, Union Street and Park Street are found, with depths greater than the 10% AEP event.
- Residential Dwellings adjacent to the junction of Eden Grove and The Link impacted by inundation.
- Fenaughty street, Corella Crescent, Azalea Court, Wight street, Okeefe street, Crichton Road are experiencing small ponding with depths of 300 mm- 350 mm.
- 5% AEP rainfall (although catchment conditions at the start of the event will strong influence impact):
  - XX mm in 12 hours
  - XX mm in 24 hours
  - XX mm in 168 hours

5.2.2.4 2% AEP Flood Behaviour

From the flood modelling undertaken, the following observations are made regarding the 2% AEP event:

- 16 residential dwellings flooded above floor level.
- 11 commercial buildings flooded above floor level.
- Fell street (300 mm), McEwen road (340 mm to 650mm) are inundated. Some parts of Cowan Court, Wattle street, Cassia Court, Cashelmara Drive (350 mm), Fenaughty street, Curtis Court, Aldersyde Drive are flooded with depths more than 300 mm.
- Some ponding in drains adjacent to McEwen Road, Lancaster Road and in low-lying areas of the Kyabram Caravan Park, have flood depths more than 500 mm.

- Heavy ponding in drains adjacent to Breen Avenue (depths 300 mm to 600 mm), small ponding in Fischer Street (<300 mm) with 2% AEP flood event.
- The Kyabram Library and its carpark, Kyabram community Church, Kyabram Community and Learning centre, Caravan park parking lot all are inundated with depth of more than 350 mm in a 2% AEP event
- 2% AEP rainfall (although catchment conditions at the start of the event will strong influence impact):
  - XX mm in 12 hours
  - XX mm in 24 hours
  - XX mm in 168 hours

5.2.2.5 1% AEP Flood Behaviour

- From the flood modelling undertaken, the following observations are made regarding the 1% AEP event:
- 31 residential dwellings flooded above floor level
- 15 commercial buildings flooded above floor level.
- The roads act as concentrated overland flow paths once the stormwater network is overwhelmed. The velocities are generally well below 0.5m/s and as such the flood risk is generally low.
- The Kyabram Library, Kyabram Baptist Church, Kyabram Community and Learning centre are all inundated to depth greater than 500mm in a 1% AEP event.
- Kyabram's Business Centre along Allan Street is generally unaffected by flooding in a 1% AEP event, or depths are shallow.
- The worst flooding occurs in isolated depressions throughout the town which are known flooding hotspots and are generally located where council operated pumps and sumps are located.
- Some roads inundated to a depth greater than 300mm in a 1% AEP event include
  - Breen Avenue – 400mm
  - Fenaughty Street – 420mm
  - Lake Road – 410mm
  - Tisdall Road – 300mm, and,
  - Wight Street – 530mm
- Although some residential areas are inundated, the grid like road network and varying elevation means evacuation routes and refuge points are generally plentiful.
- Rural areas experience flooding predominantly from shallow overland flow with low velocities.
- 1% AEP rainfall (although catchment conditions at the start of the event will strong influence impact):
  - XX mm in 12 hours
  - XX mm in 24 hours
  - XX mm in 168 hours

5.2.2.6 0.5% AEP Flood Behaviour

- From the flood modelling undertaken, the following observations are made regarding the 0.5% AEP event: The overall flooding condition becomes quite worse with 0.5% AEP flooding condition.
- 38 residential dwellings flooded above floor level.
- 16 commercial buildings flooded above floor level.
- Heavy ponding in drains adjacent to Cashelmara drive and Cooma Road with depths more than 500 mm and South Boundary road (depths > 800 mm) are found.

- Flooding depths are high in Chaston street, Union Street, Park Street, Corella Crescent, Koala street in which the depths could reach up to 600 mm.
- Large areas adjacent to McEwen Road are flooded with depths up to 600 mm. Significant areas close to John Allan road are experiencing inundation of depths up to 780 mm.
- The nearby road of Community church (Junction of McEwen Road and Fenaughty Street) and some parts of it are heavily inundated.
- Similar to 1% AEP event, Kyabram's Business Centre along Allan Street is slightly affected by flooding in a 0.5% AEP event with shallow depths.
- Worsening Inundation around the depressions adjacent to Council's pumping locations for 0.5% AEP.
- 0.5% AEP rainfall (although catchment conditions at the start of the event will strong influence impact):
    - XX mm in 12 hours
    - XX mm in 24 hours
    - XX mm in 168 hours
-

6 FLOOD DAMAGES ASSESSMENT

6.1 OVERVIEW

A flood damages assessment was undertaken for the study area under existing conditions. The flood damage assessment determined flood damages across the range of design floods (20%, 10%, 5%, 2%, 1% and 0.5% AEP flood events). Floor level survey was obtained for 299 properties in the study area and was a key input into the assessment along with the modelling results.

The damages assessment was undertaken based on industry best practice methodology which combined aspects of the Rapid Appraisal Method, ANUFLOOD and DPIE (NSW) methodologies. The assessment included an assessment of above floor flooding to residential and commercial buildings, as well as external flood damages. The damages curves are provided in Appendix Q.

6.2 EXISTING CONDITIONS

The 1% AEP flood damage estimate for existing conditions was calculated to be just over $4.5 million. A total of 46 properties are predicted to be flooded above floor in the 1% AEP flood event. The Average Annual Damages (AAD) was determined as part of the flood damage assessment and is estimated to be $561,234. The AAD is effectively a measure of the amount of money that must be put aside each year to compensate for the physical impacts of flooding over time.

The commercial damages make up the largest proportion of the total damage costs which is a result of the significant number of commercial properties impacted, and the higher assessed value of such properties.

Table 6-1 Flood damage assessment for Existing Conditions

		Annual Exceedance Probability					
		20%	10%	5%	2%	1%	0.5%
Properties Flooded Above Floor Level	Residential Properties	3	5	7	14	31	35
	Commercial Properties	9	10	10	11	15	17
	Total Properties Flooded	12	15	17	25	46	52
Total Damage Cost		$2,595,384	$2,832,550	$3,079,227	$3,511,085	$4,548,809	$5,738,813

7 SENSITIVITY AND CLIMATE CHANGE MODELLING

7.1 OVERVIEW

In addition to base case modelling, a range of sensitivity and climate scenarios were modelled for the study area. These are described below and mapping provided in Appendix K and L respectively.

7.2 SENSITIVITY MODELLING

7.2.1 Roughness Sensitivity

Roughness sensitivity testing was undertaken on the model with +/- 20% roughness scenarios tested in the model for the 1% AEP event. The results have been provided in Appendix K and indicate the modelling is fairly insensitive to roughness changes. This is not surprising given the low gradients and velocities, and ponding of runoff through the study area.

7.2.2 Blockage Sensitivity

Blockage Sensitivity testing was undertaken for all modelled culverts and pipes within the model. Given there is effecrtiverlyt no upstream catchments within the study area, and the catchments are largely urban the potential for natural flood debris is considered relatively low. All culverts and the pipe network were therefore tested with a uniform 20% blockage factor. The results show that there are some small pockets which are sensitive to blockage, however the increase in flood levels is generally fairly low (less than 100mm).

Blockage sensitivity maps are provided in Appendix K.

7.2.3 No. 9 Channel RCP Blockage Sensitivity

An additional blockage scenario was undertaken with 100% blockage applied to a key 450mm RCP culvert to the west of Kyabram that passes under the No. 9 GMW irrigation channel. This is a critical outfall for much of the western and southern areas of the township, and the ultimate outfall for the Fauna Park Lakes storage. The results showed that when blocked there are increases of flood level of 50-100 immediately to the east of the culvert, and interestingly increases of 100-200mm to the north of the culvert across McEwen Road and in the vicinity of the McEwan West basin. This indicates that once that area ponds, it eventually starts flowing to the north to the McEwan Road basin area.

The No. 9 culvert blockage sensitivity maps are provided in Appendix K.

7.2.4 Pump Failure Sensitivity

The township is heavily reliant on pumps during large rainfall events to pump runoff out of the sumps located throughout the township. A scenario was modelled with all pumps switched off (i.e., failure). The results showed that there are several areas of the town which are vulnerable if the pumps were to fail during a significant storm event. The central township area in particular was found to have increased floor levels of 300-400mm under these conditions and highlights the important of regularly maintained pumps and effective operation during storm events, as well as ongoing training of staff in operations during such events.

The pump failure sensitivity maps are provided in Appendix K.

7.3 CLIMATE CHANGE MODELLING

Climate change modelling has been undertaken for both mid-range RCP4.5 and high-range RCP8.5 emissions scenarios for both the 1^% and 10% AEP events. The climate change modelling mapping is presented in Appendix L. An analysis for the increase in rainfall intensity has been conducted on both the mid-range RCP 4.5 and high-range RCP 8.5 emissions scenarios with the resultant intensities being correlated to current intensities and annual exceedance probabilities. All events shown below are for the 24-hour duration which is a critical event for a number of locations in the township. The equivalent AEP to current intensities has been calculated through linear interpolation.

Table 7-1 2050 Climate Change IFD Comparison – 24 Hour Duration

AEP	Current Depth (mm)	2050 RCP 4.5 Depth (mm)	Equivalent to present AEP	2050 RCP 8.5 Depth (mm)	Equivalent to present AEP
10%	69.1	73.5	≈8%	75.2	≈7%
1%	108	114.8	≈0.8%	117.5	≈0.7%

Table 7-2 2090 Climate Change IFD Comparison – 24Hour Duration

AEP	Current Depth (mm)	2090 RCP 4.5 Depth (mm)	Equivalent to present AEP	2090 RCP 8.5 Depth (mm)	Equivalent to present AEP
10%	69.1	75.5	≈7%	83.1	≈4%
1%	108	118.0	≈0.7%	129.8	≈0.35%

As displayed above, climate change is likely to have a significant impact on the magnitude of flooding around Kyabram across the full range of design events. Under the worst-case scenario by 2090 (RCP8.5) a 1% AEP event is likely to be similar in magnitude to a 0.35% AEP event, an event three times rarer than currently predicted.

Increases of approximately 50-100mm in water level are observed in pockets around the township for an RCP 4.5 Projected 2050 scenario and 100-200mm in an RCP 8.5 projected scenario for the 1% AEP event. The increases are larger in the outlying rural areas where water ponds in low-lying areas, with resulting higher flood levels due to the larger runoff volume.

The change in water level predicted to occur from climate change is provided in Appendix L for the 1% and 10% AEP events for both the RCP 4.5 and 8.5 scenarios respectively.

8 FLOOD MITIGATION ASSESSMENT

This section provides an overview of the mitigation options available to reduce the flood risk and flood damages in Kyabram. The options are divided into structural and non-structural mitigation options.

8.1 STRUCTURAL MITIGATION

8.1.1 Overview

A number of mitigation options were collated from suggestions from the community, project reference group and project control group. The options were first tested at a preliminary level to determine their benefit in terms of reducing flood risk. Options which were found to improve flood risk then progress to detailed assessment which included

It is of note that the nature of the topography and inundation in Kyabram makes effective flood mitigation challenging. The township is located in a low-lying area with very flat grades so determining options which can effectively redirect runoff away from residential areas is difficult,

8.2 PRELIMINARY MITIGATION MODELLING

A large number of individual options and combination of options were tested prior to the final packages of mitigation works being selected. Further detail regarding the various options tested and modelling results can be found in Appendix N, where the preliminary options are fully documented. The range of options modelled at a preliminary level and findings are presented in the table below. These options were run for the 1% AEP event initially.

Table 8-1 Summary of Preliminary Mitigation Options

Option ID	Option Description	FIndings
P1	South Boundary Road Drainage Upgrade – new open channel to drain runoff from this area to depression to the south-west	Limited benefit, some reduced flood level through drains but no benefit to houses.
P2	Increased pipe capacity through central township and upgrade of Lake Road sump (increase capacity by 50%)	Reduction of 150-200mm in flood levels through central township. Progressed to detailed modelling.
P3	Increased pipe capacity through central township and new sump in location of existing swimming pool	Modest benefit, not as effective as other options in central township.
P4	Drainage upgrades in north-west area of town, and balance pipe between new basins (McEwan Road East and West basins)	Effective in reducing flood levels in 1% AEP event across both residential and industrial area. Progressed to detailed modelling.
P5	Doubling the capacity of the key culvert under the No. 9 channel which is the ultimate outfall for much of the central and western areas of the township.	Limited, localised benefit.
P6	Combination of options around Breen Avenue, including new culverts under railway, and levee to reduce runoff flowing towards central township.	Limited benefit, also significant cost and challenges in constructability associated with this option.
P7	Tisdall Road drainage upgrades and doubling of Roger Street pump flowrate	Very minor benefit.
P8	Koala/Corella Court Drainage upgrades – doubling the capacity of the pipe network in this area to reduce overland flow through properties.	Very minor benefit.
P9	Development of an overland flowpath through the central township area to better drain runoff into the Lake Road sump	Reduction of 200-250mm in flood levels through central township. Progressed to detailed modelling.

Based on the results of preliminary mitigation modelling and consultation with the community based project reference group, three recommend packages of mitigation works were determined and assessed in details. The detailed assessment is described below.

8.3 DETAILED OPTION MODELLING

8.3.1 Option P2

8.3.1.1 P2 Overview

This option will consist of upgrading the capacity of the Lake Road sump by approximately 50%, by extending the sump to the south and north and relocating the existing pumps.

In additional, the capacity of the pipes along Lake Road would be doubled from 1 x 1200 RCP to 2 x 1200 RCP in order to understand the benefit that could achieved by maximising pipe capacity. The pipe capacity along Chaston and Fenaughty Streets will also be doubled.

This package of works has been costed and the total capital cost is estimated to be $18,948,000 (ex. GST) (inclusive of land acquisition, contingencies, admin and engineering). The cost excludes any local mitigation measures that might be required as a result of increased water levels upstream and downstream.

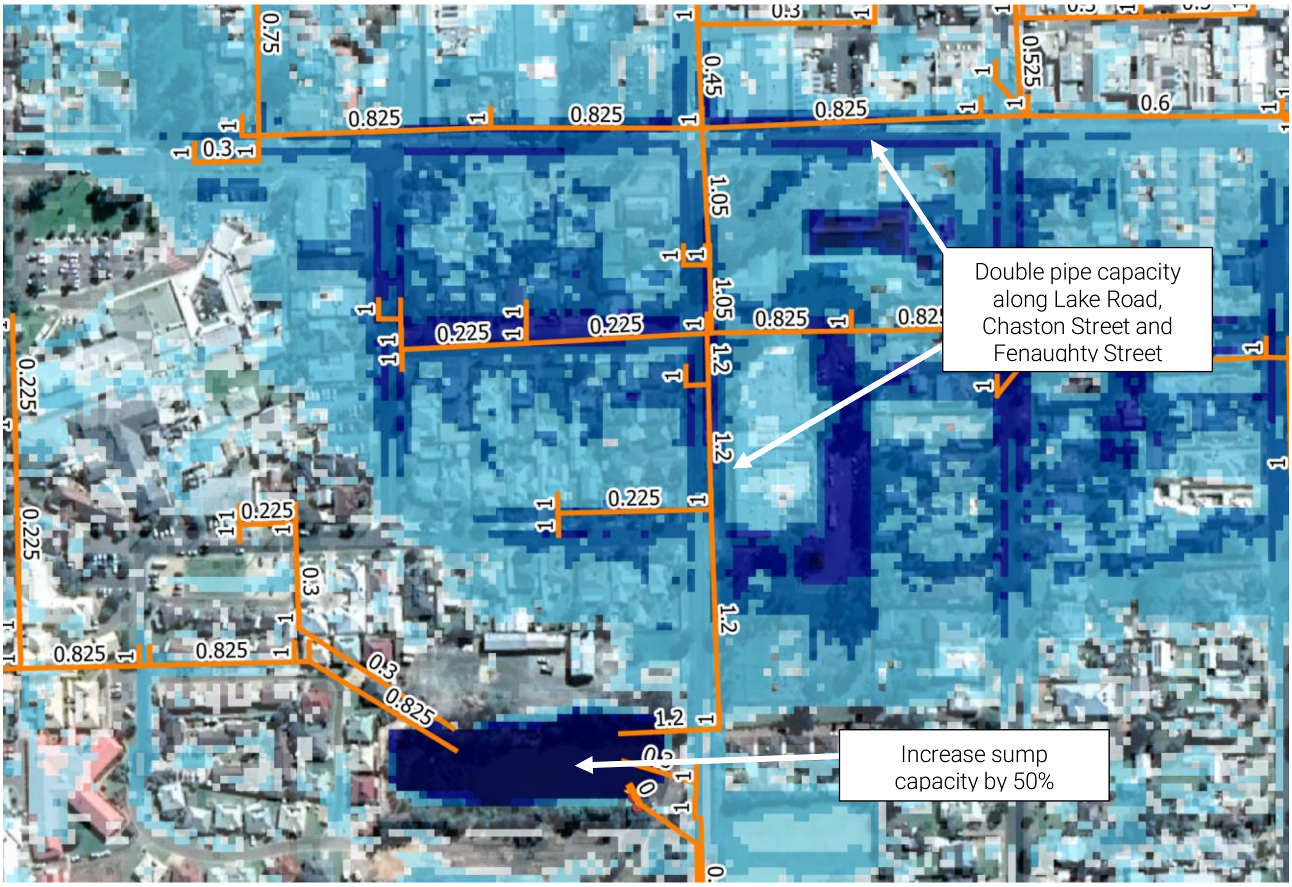

Figure 8-1 Key Features of Mitigation Option P2

8.3.1.2 P2 Results

The results of Option P2 modelling show that:

- Flood levels are reduced by generally 50 to 150 mm through the central township. A large number of properties benefit from reduced flood levels however only 1 dwelling moves from above floor flooding to below floor flooding.
- The option results in some increased flood levels within the Lake Road sump which is expected given the central township can better drain due to the increased pipe capacity, There are no adverse impacts to private property in terms of increased flood levels.

- In the 10% AEP event the benefits are minimal in terms of reduced flood levels. This indicates the service level of the pipes is reasonable up to that event, and surface flooding is insensitive to larger pipe capacity.

A difference plot for this option is presented in Figure 8-2 below.

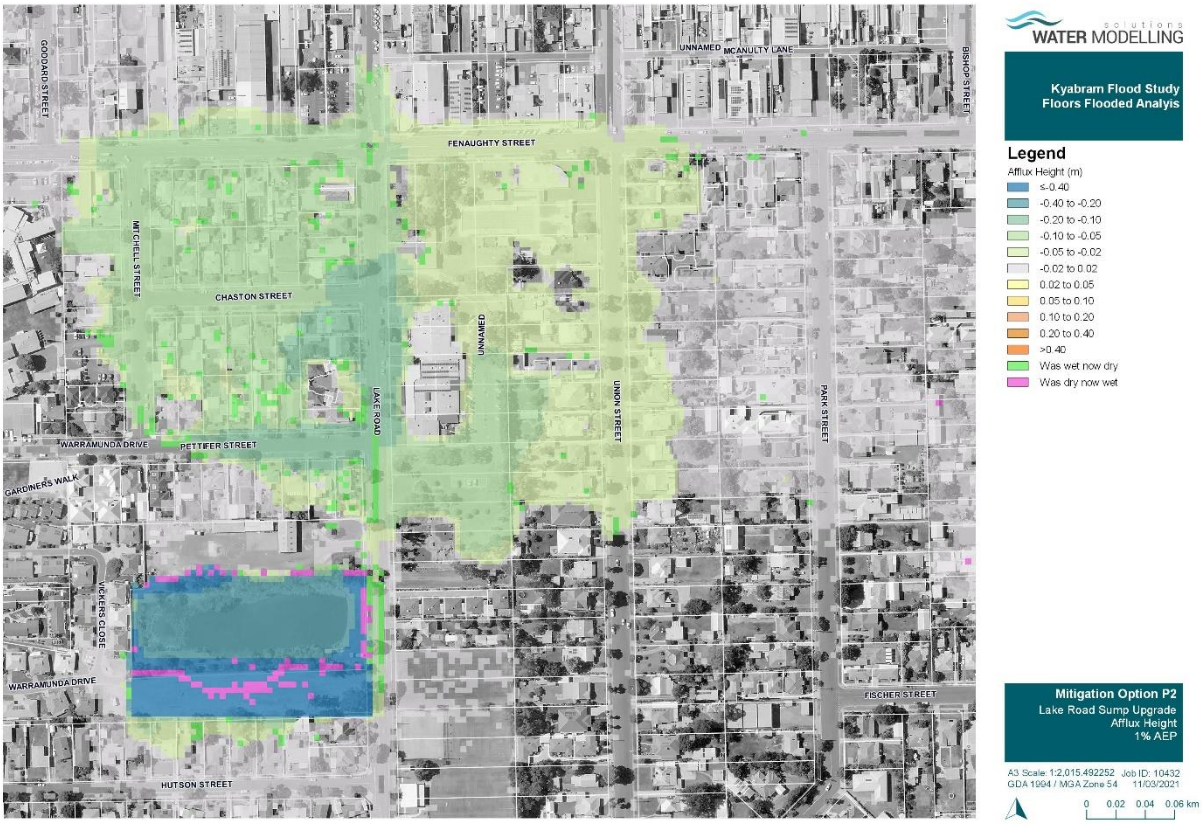

Figure 8-2 Afflux Map - Mitigation Option P2

8.3.2 Option P4

8.3.2.1 P4 Overview

This option will consist of upgrading the capacity of the Lake Road sump by approximately 50%, by extending the sump to the south and north and relocating the existing pumps.

In additional, the capacity of the pipes along Lake Road would be doubled from 1 x 1200 RCP to 2 x 1200 RCP in order to understand the benefit that could achieved by maximising pipe capacity. The pipe capacity along Chaston and Fenaughty Streets was also doubled.

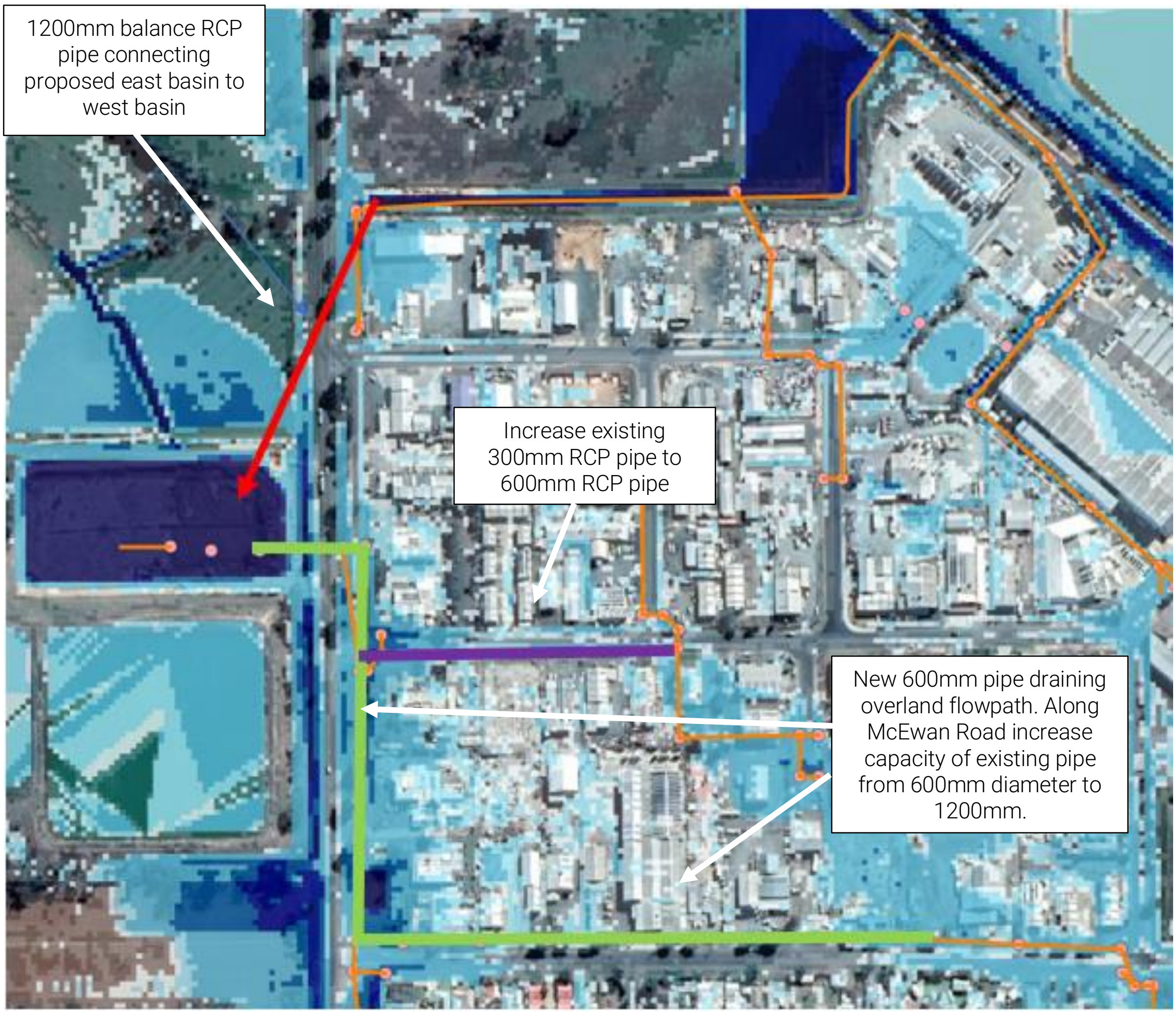

Figure 8-3 Key Features of Mitigation Option P4

8.3.2.2 P4 Results

The results of Option P4 modelling show that:

- Flood levels are reduced by 100 to 150 mm in some pockets in the north-western area of Kyabram. A number of properties benefit from reduced flood levels and 3 commercial buildings move from above floor flooding to below floor flooding.
- The option results in some increased flood levels within the McEwen East basin which is expected, with the balance pipe ensuring more storage in the eastern basin is utilised during the events. There are no adverse impacts to private property in terms of increased flood levels.
- In the 10% AEP event the benefits are minimal in terms of reduced flood levels. This indicates the service level of the pipes is reasonable up to that event, and surface flooding is insensitive to larger pipe capacity.

A difference plot for this option is presented in Figure 8-4 below.

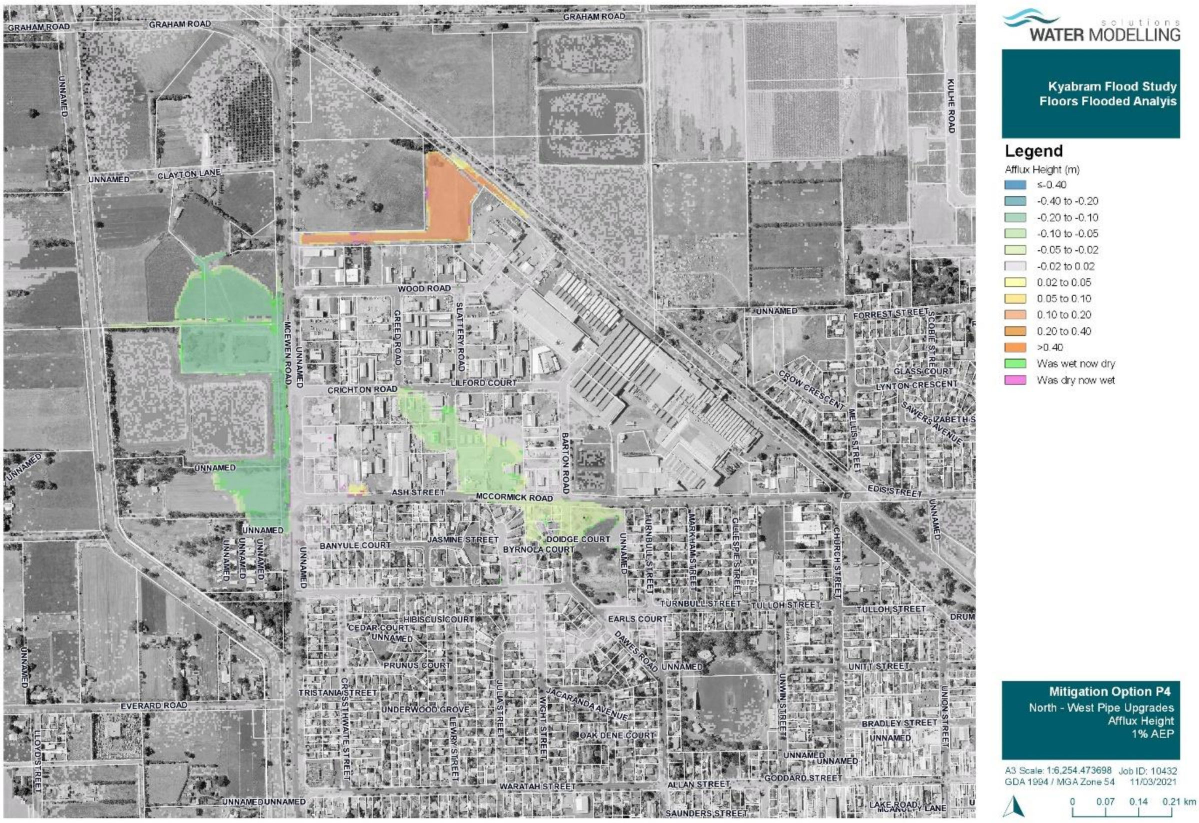

Figure 8-4 Afflux Map - Mitigation Option P4

8.3.3 Option P9

8.3.3.1 P9 Overview

This option would consist of constructing an overland flowpath from the central township area to the Lake Road sump in order to better drain the central township. The modelled overland flowpath extended from Park Street to the east, for 500 metres to the Lake Road sump. This includes crossing private property, Council land and Union St, Lake Road and Pettifer Street.

The modelled option assumed the purchase of four private properties, lowering roadways and utilising a portion of Council land to the south of the library and community centre. The modelled flowpath assumed a lowering of existing surface levels by 200-300mm on average which would likely have an impact on services including communications and the sewer network. These impacts and constraints have been factored into the costing of this option.

The option wo

Figure 8-5 Key Features of Mitigation Option P9

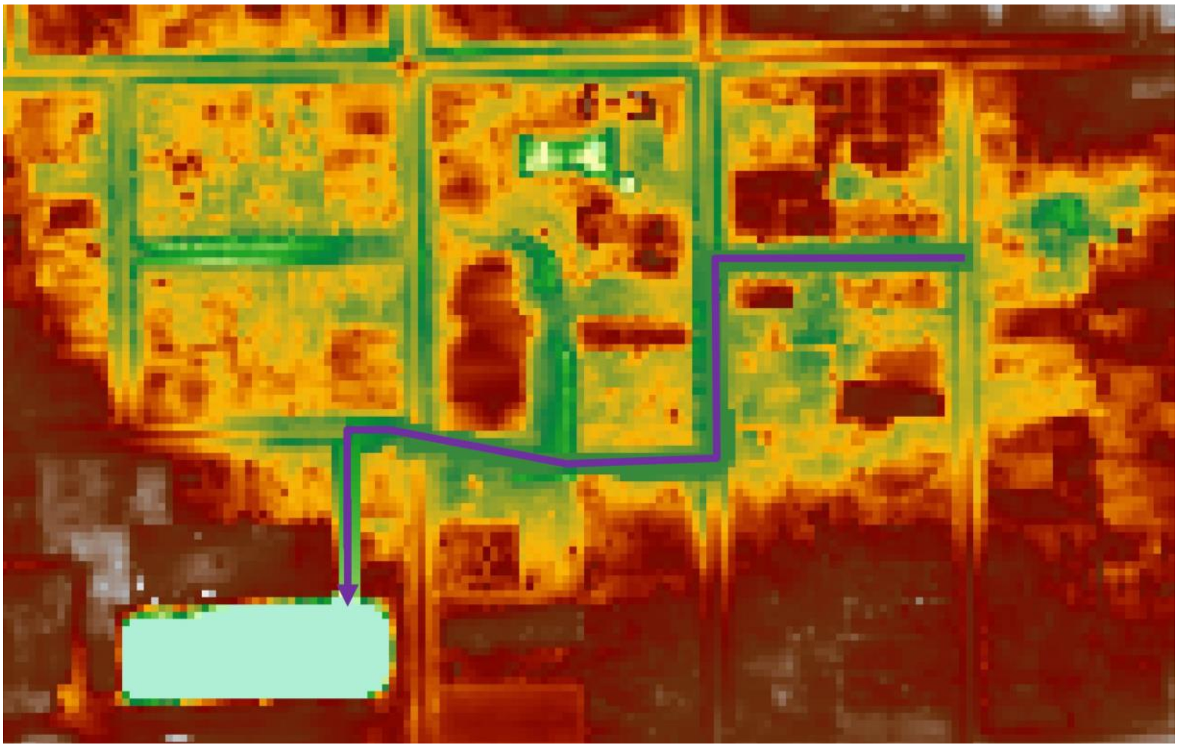

Figure 8-6 P9 Model topography showing route of overland flowpath

8.3.3.2 P9 Results

The results of Option P9 modelling show that:

- Flood levels are reduced by 100 to 200 mm through the central township. A large number of properties benefit from reduced flood levels however only 4 dwellings move from above floor flooding to below floor flooding. The reduction on flood levels is slightly more than Option P2 and there are more properties which benefit.
- The option results in some increased flood levels within the Lake Road sump which is expected given the central township can better drain due to the new overland flowpath. There are no adverse impacts to private property in terms of increased flood levels.
- The option has minimal benefit in the 10% AEP event with no improvement in above floor flooring for residential or commercial buildings..

A difference plot for this option is presented in Figure 8-7 below.

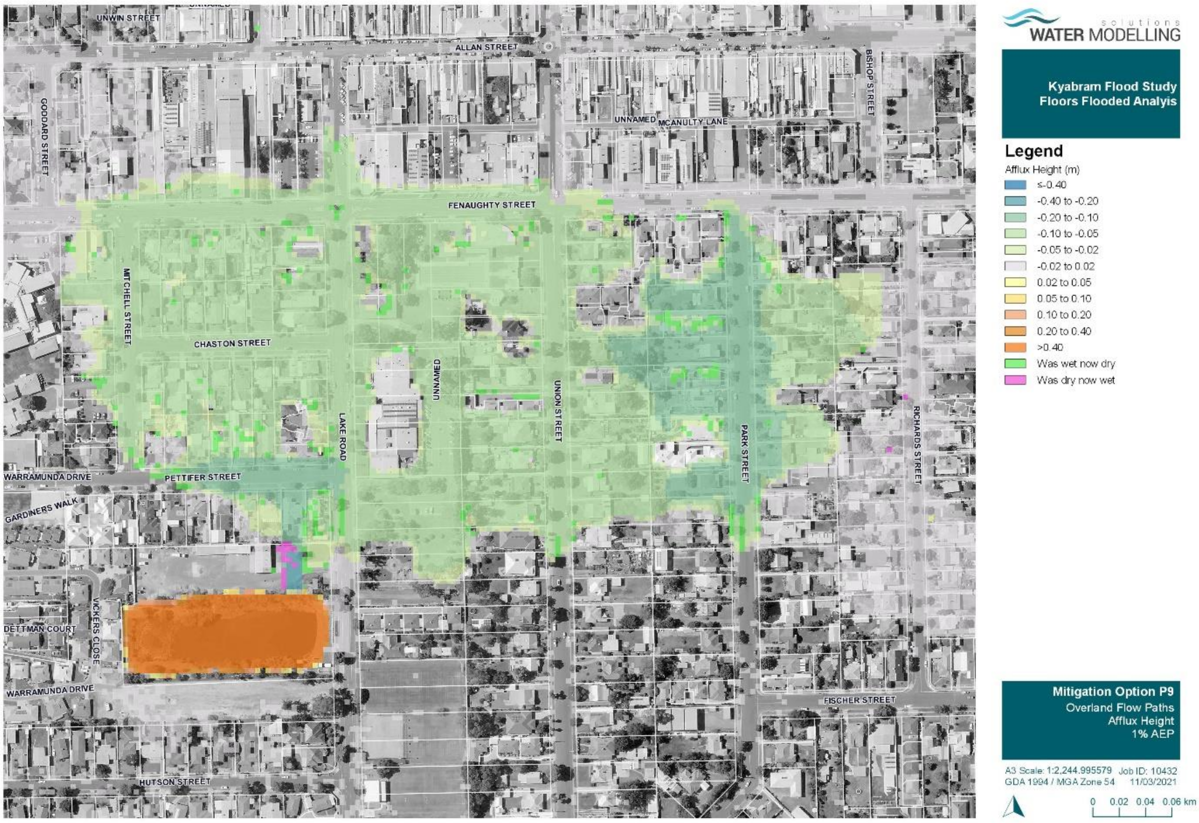

Figure 8-7 Afflux Map – Mitigation Option P9

8.4 VOLUNTARY HOUSE PURCHASE – PRELIMINARY ANALYSIS

8.4.1 Overview

A preliminary voluntary purchase analysis was undertaken examining the feasibly of purchasing the more flood-prone dwellings in Kyabram. For the purpose of the assessment the value of the properties was assumed to be $250,000 which was based on a review of recent sales in Kyabram for 3-bedroom houses.

Two scenarios were considered:

- Purchase of the 5 residential properties flooded above floor in the 10% AEP event

- Purchase of the 7 residential properties flooded above floor in the 5% AEP event.

The existing conditions damages assessment was updated by removing those property above floor damages from the analysis. The reduction in Average Annual Damages was then determined and a benefit cost ratio determined based on the AAD benefit and the cost of the voluntary purchase of the properties.

Based on the above analysis the following findings were made:

- For the 10% AEP impacted dwellings, the purchase of the 5 residential properties was assumed to cost $1,250,000, and found to reduce the AAD by $445,839 resulting in in a benefit-cost ratio of 0.51.
- For the 5% AEP impacted dwellings, the purchase of the 7 residential properties, was assumed to cost $1,750,000, and found to reduce the AAD by $52,789, and resulted in a benefit-cost ratio of 0.42.

The two scenarios had relatively low benefit-cost ratios but notably they had significantly higher BCR than the mitigation scenarios presented in the previous section. Based on this it is recommended that a voluntary house purchases scheme be assessed in more detail.

8.5 LAND USE PLANNING

8.5.1 Overview

The Victoria Planning Provisions (VPPs) contain a number of controls that can be employed to provide guidance for the use and development of land that is affected by inundation from floodwaters. These controls include the Floodway Overlay (FO), the Land Subject to Inundation Overlay (LSIO), the Special Building Overlay (SBO), the Urban Floodway Zone (UFZ) and the Environmental Significance Overlay (ESO).

An existing LSIO exists for Kyabram. It is recommended that the planning scheme for Kyabram is amended to reflect the flood risk identified by this project. Appendix M shows proposed LSIO for consideration in such an amendment.

8.5.2 Draft Overlays

Land Subject to Inundation overlays have been prepared for and are based on the following:

- Use of the climate change 8.5RCP to 2090 results as the basis for the layers.
- Depths of less than 50mm removed (a larger depth than typical which reflects the “rainfall excess” methodology),
- Extent smooth to remove “blocky” appearance from raw model outputs
- Isolated puddles of less than 100m^2 removed from the extent, and islands/gaps less than 4000m^2 within the extent also removed.

The resulting draft LSIO is shown in Appendix M and will be provided with the study deliverables in GIS format (Shapefile)

8.6 FLOOD WARNING SYSTEM

A flood warning assessment is currently being undertaken by Risk Frontiers. This has been included as an Appendix to this report.

8.7 MITIGATION FLOOD DAMAGES ASSESSMENT

8.7.1 Overview

Flood damages assessments were undertaken for the three mitigation scenarios and compared to the existing conditions assessment results. conditions. As with existing conditions the damages assessment was undertaken based on industry best practice methodology which combined aspects of the Rapid Appraisal Method, ANUFLOOD and DPIE (NSW) methodologies. The adopted damages curves are presented in Appendix Q.

8.7.2 Existing conditions

As previously presented the 1% AEP flood damage estimate for existing conditions was calculated to be just over $4.5 million. A total of 46 properties are predicted to be flooded above floor in the 1% AEP flood event. The Average Annual Damages (AAD) was determined as part of the flood damage assessment and is estimated to be $561,234.

Table 8-2 Flood damage assessment for Existing Conditions

		Annual Exceedance Probability					
		20%	10%	5%	2%	1%	0.5%
Properties Flooded Above Floor Level	Residential Properties	3	5	7	14	31	35
	Commercial Properties	9	10	10	11	15	17
	Total Properties Flooded	12	15	17	25	46	52
Total Damage Cost		$2,595,384	$2,832,550	$3,079,227	$3,511,085	$4,548,809	$5,738,813

8.7.3 Mitigation Option P2

The AAD for Mitigation Option P2, as described in Section 7.3.1, was calculated to be approximately $559,126. During a 1% AEP event, the package reduces the total number of properties inundated above floor from 46 to 45. Over a long period of time with a range of flood events, the AAD may be reduced by approximately $2,108 per year by implementing this package of works.

Table 8-3 Flood damage assessment for Mitigation Option P2

		Annual Exceedance Probability					
		20%	10%	5%	2%	1%	0.5%
Properties Flooded Above Floor Level	Residential Properties	3	5	7	14	30	34
	Commercial Properties	9	10	10	11	15	17
	Total Properties Flooded	12	15	17	25	45	51
Total Damage Cost		$2,591,914	$2,829,359	$3,071,714	$3,502,374	$4,516,807	$5,605,052

8.7.4 Mitigation Option P4

The AAD for Option P4, as described in Section 7.3.2, was calculated to be approximately $523,380. During a 1% AEP event, the package reduces the total number of properties inundated above floor from 46 to 43. Over a long period of time with a range of flood events, the AAD may be reduced by approximately $37,854 per year by implementing this package of works.

Table 8-4 Flood damage assessment for Mitigation Option P4

		Annual Exceedance Probability					
		20%	10%	5%	2%	1%	0.5%
Propertie s Flooded Above i	Residential Properties	3	5	7	14	31	35
	Commercial Properties	8	9	9	11	12	14

		Annual Exceedance Probability					
		20%	10%	5%	2%	1%	0.5%
	Total Properties Flooded	11	14	16	25	43	49
Total Damage Cost		$2,440,818	$2,643,095	$2,874,056	$3,351,148	$4,523,793	$4,732,030

8.7.5 Mitigation Option P9

The AAD for Option P9, as described in Section 7.3.3. was calculated to be approximately $558,580. During a 1% AEP event, the package reduces the total number of properties inundated above floor from 46 to 43. Over a long period of time with a range of flood events, the AAD may be reduced by approximately $2,654 per year by implementing this package of works.

Table 8-5 Flood damage assessment for Mitigation Option P9

		Annual Exceedance Probability					
		20%	10%	5%	2%	1%	0.5%
Properties Flooded Above Floor Level	Residential Properties	3	5	7	14	28	34
	Commercial Properties	9	10	11	11	15	17
	Total Properties Flooded	12	15	18	25	43	51
Total Damage Cost		$2,593,387	$2,831,483	$3,073,411	$3,502,153	$4,415,008	$5,599,162

8.8 AVERAGE ANNUAL DAMAGE SUMMARY

The damage assessments presented above shows that all three mitigation options have fairly modest benefits, with little benefit in terms of above floor flooding seen until significant flood events. As a result, the reduction in AAD is low across all three scenarios, particularly with Options P2 and P9. A summary table of the AAD for existing conditions and each mitigation options is shown below in Table 8-6.

Table 8-6 Average Annual Damage Summary

Scenario	Average Annual Damage	*Reduction in AAD*
Existing Conditions	$561,234	
Option P2	$559,126	*$2,108*
Option P4	$523,380	*$37,854*
Option P9	$558,580	$2,654

8.9 BENEFIT COST ANALYSIS

8.9.1 Overview

A flood damages assessment was undertaken for the study area under existing conditions. The flood damage assessment determined flood damages across the range of design floods (20%, 10%, 5%, 2%, 1% and 0.5% AEP flood events). Floor level survey was obtained for 299 residential and commercial buildings.

8.9.2 Mitigation Options Costs

The mitigation works were costed based on a number of key references:

- Rawlinson's Australian Construction Handbook Rates;
- Comparison to cost estimates for similar mitigation works for other flood studies; and
- Council estimates of works costs.

A summary of the cost estimates for the final mitigation options are shown in Table 8-7 below. A detailed breakdown of the costing for each mitigation option is included in Appendix O.

A 40% contingency cost has been added along with engineering and administration costs. Annual maintenance costs have been estimated and included in the benefit cost analysis described below.

Table 8-7 Mitigation Option Cost Summary

Option	Estimated Capital Cost	Annual Maintenance Cost
Mitigation Option P2	$3,138,327	$7,473
Mitigation Option P4	$2,490,880	$7,034
Mitigation Option P9	$2,937,692	$2,327

8.9.3 Benefit Cost Analysis

A benefit-cost analysis has been undertaken based on the damages assessment and costings described tin the previous sections. The results are summarised in Table 8-8 below. It can be seen that the Benefit Cost Ratio is low across all options, and well below a BCR of 1 which is generally the minimum required for a scheme to be considered feasible i.e., for every dollar spent on the scheme, at least a dollar is saved in terms of reduced flood damage.

The reason for the low benefit-cost ratio is predominately a result of there being limited benefits across all options and that the benefit is not seen until fairly infrequent events, hence the options generally provide minimal benefit in the smaller, more frequent flood events.

Table 8-8 Cost Benefit Ratio for Mitigation Options P2, P4 and P9

Mitigation Option	Capital Cost Estimate	Annual Maintenance	Reduction in AAD	Benefit			Benefit Cost Ratio		
				4% NPV	7% NPV	11% NPV	4% NPV	7% NPV	11% NPV
Option P2	$3,138,327	$7,473	$2,108	$58,451	$37,367	$24,356	<0.01	<0.01	<0.01
Option P4	$2,490,880	$7,034	$37,854	$670,429	$428,598	$279,358	0.17	0.27	0.11
Option P9	$2,937,692	$2,327	$2,654	$7,111	$4,546	$2,963	<0.01	<0.01	<0.01

9 SUMMARY AND RECOMMENDATIONS

This report has presented the key components of the Kyabram Flood Study. The points below detail the study key findings and recommendations:

- The study has involved the development of hydrologic (RORB) and hydraulic (TUFLOW) models of Kyabram Township and broader Mosquito Creek catchment.
- Hydrologic models for both the Kyabram Township and Mosquito Depression catchments were built in the software RORB. Appropriate parameters were determined in line with the latest ARR2019 guidelines and the models used to model two historic validation events – the March 2012 and October 1993 events. The outputs from this modelling were then be input into a TUFLOW hydraulic model as part a joint hydrologic/hydraulic model validation approach.
- An extensive range of design events and have been modelled, with critical storm durations from 30 minutes up to 168 hours included. The modelled design events include the 20% AEP up to the 0.01% AEP, as well as the PMF event.
- A range of sensitivity scenarios were modelled including sensitivity to roughness change, blockage and pump failure. The pump failure scenarios highlighted the importance of the pumps operating at capacity during storm events. This also highlights the importance of regular pump maintained, ongoing Council staff training regarding pump operations during storm events as well as compliance with the operations manual during such events.
- A number of mitigation options have been assessed, first at a preliminary level, to assess their effectiveness in reducing flood risk, and then at a detailed level to assess the feasibility of the options which were shown to provide benefit. Three packages of options have been assessed in detailed which included modelling the full range of design events, costings, damages assessment and benefit cost analysis. All three options had lower benefit-cost ration of well below one. Option P4 had the highest benefit cost ratio, with a BCR of 0.27. While the BCR for these options is low it is recommended that aspects of these works including pipe and culvert upgrades are considered within Council's future capital works program as the network is upgraded over time.
- In addition to the mitigation assessment describe above, a voluntary house purchase scheme was assessed at a preliminary level. The scheme was found to have a higher benefit-cost ratio than the other mitigation options with a BCR of 0.51 determined for purchase of all dwellings flooded above floor in the 10% AEP event, and a BCR of 0.42 purchase of all dwellings flooded above floor in the 5% AEP event. Given these schemes have a higher BCR than the structural mitigation options it is recommended that a VHP scheme be investigated in more detail as part of a feasibility assessment.
- A range of flood intelligence outputs have been produced from this project and it is recommended that these be adopted by Council and VICSES to support flood response during times of flood.
- Draft planning layers have been produced and it is recommended that these be implemented through a planning scheme amendment, to ensure flood-related planning overlays for the township represent the current level of flood risk.

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