3 Hydrologic Modelling

The aim of the hydrological modelling is to calculate runoff at locations throughout the study area to apply the TUFLOW hydraulic model. When determining the hydrological response of the study area, there are a number of factors that need to be considered. These include catchment characteristics, design rainfalls and model parameters determined through model calibration.

The level of development, hence the proportion of impervious ground within a catchment, is an important factor in the generation of runoff. The current levels of development in a catchment can be determined from existing information such as aerial photography and Council GIS layers. Future development, or the ultimate development, can be determined from planning schemes. The method for determining these values is set out in Section 3.1.

Catchment and sub-catchment areas together with other physical catchment characteristics are determined from topographic information. The method for determining these values is set out in Section3.3.1.1.

The hydrological model requires design rainfall events to produce design flood events. These design rainfall events are determined using standard methodologies published in Australian Rainfall and Runoff (ARR) (Institute of Engineers, 1999).

It is expected that future rainfall intensities for rare events will increase, with research suggesting that rainfall will increase by 32% in and around Melbourne by 2030. The MW Technical Specification requires flood studies to increase rainfall intensity by 32% to account for the expected increase in future rainfall intensities, and this has been adopted for this study. This is further outlined in Section 3.3.1.6.

Once the physical characteristics of a catchment have been determined and design rainfall calculated it is necessary to determine the hydrological model parameters. These parameters can be determined through standard relationships or, more commonly, through calibration. The approach to calibration is dependent on the available data. If there is sufficient data available, the hydrological model should be calibrated to this data. As a minimum this would require streamflow data at one location. However, there was no streamflow data available within the study area. For this reason the hydrological model was calibrated to the Rational Method in accordance with the MW Technical Specification.

The Rational Method is a well-established method for determining runoff in ungauged catchments and standard methods to achieve this are published in ARR. The rational method calculation is set out in Section 3.2.

The hydrologic model underwent a joint verification in conjunction with the TUFLOW hydraulic model to the February 2013 flood event.

In total four scenarios were modelled in the hydrologic model, these were; Existing Conditions (base case), Developed Conditions, Climate Change, and Climate Change under Developed Conditions.

The output from the RORB model provided inputs into the TUFLOW hydraulic model.

The following sections detail the development of the hydrologic model used to produce the flood maps. This chapter is presented in the following format:

- Determination of fraction impervious
- Catchment delineation
- Rational method calculations
- RORB model development and verification

3.1 Fraction Impervious

As part of the development of the RORB hydrologic model, BMT WBM determined Fraction Impervious (FI) values across the Shepparton East Overland catchment. The FI was determined using the existing planning scheme zones provided by GBCMA and Greater Shepparton City Council. Typical impervious fractions based on planning zones were used as recommended in the RDS Planning Assessment Report Appendix A (GHD 2004). This is the method outlined in the MW Technical Specification. The adopted FI value for Residential Zone Type 1 was 0.4. This was taken from Table A-2 *Determination of Residential Impervious Fractions for Outer Area* of the RDS Planning Assessment Report Appendix A for all residential properties within the study area based on an average property size of 800 m^2 – 1000 m^2.

The FI values were then reviewed against aerial photography provided by GBCMA and Google Earth imagery to ensure accurate representation of the catchment. For the majority of the catchment, the review of the RDS Planning Assessment values indicated that the values were reasonable and were subsequently adopted. The only exception was some of the industrial zoned land to the west of Doyles Road that is currently undeveloped. The FI for these undeveloped parcels was adjusted to reflect current conditions. Table 3-1 outlines the FI for each planning scheme zone across the catchment.

The Ultimate FI represents the full extent of future development allowed under the current zoning and uses values recommended within Appendix A of the RDS Planning and Assessment Report. The areas for future development and the proposed land use are set out in the following documents:

- Greater Shepparton Housing Strategy (David Lock Associates, 2011)
- Industrial Land Review (Habitat Planning, 2011)
- North East Corridor Plan (Reeds Consulting, 2011)
- Shepparton South East growth Corridor Framework Plan. Draft (Hansen Partnership, 2009)

The ultimate developed scenario has included regions identified for re-zoning in the above documents. Specifically, this included the increase in industrial zoning to the east of Doyles Road between New Dookie Road and the Midland Highway, the increase of residential zoning south of Ford Road and West of Grahamvale Road, and the increase in residential zoning between the Midland Highway and Channel Road to the West of Doyles Road.

Table 3-1 Planning Scheme Zone Fraction Impervious

Planning Scheme Zone	Zone Code	Existing Planning Zone FI	Ultimate Planning Zone FI
Business 1 Zone	B1Z	0.9	0.95
Business 4 Zone	B4Z	0.9	0.95
Business 5 Zone	B5Z	0.8	0.95
Farming Zone	FZ	0.05	0.2
Industrial 1 Zone	IN1Z	0.9	0.95
Industrial 3 Zone	IN3Z	0.9	0.95
Low Density Residential Zone	LDRZ	0.2	0.3
Mixed Use Zone	MUZ	0.6	0.7
Public Conservation and Resource Zone	PCRZ	0	0.05
Public Park and Recreation Zone	PPRZ	0.1	0.2
Public Use Zone – Service and Utility	PUZ1	0.05	0.1
Public Use Zone – Education	PUZ2	0.7	0.8
Public Use Zone - Health	PUZ3	0.7	0.8
Public Use Zone – Transport	PUZ4	0.7	0.8
Public Use Zone – Cemeteries and Crematoriums	PUZ5	0.6	0.7
Public Use Zone – Local Government	PUZ6	0.7	0.9
Residential 1 Zone	R1Z	0.4	0.7
Road Zone Category 1	RDZ1	0.7	0.9
Road Zone Category 2	RDZ2	0.6	0.8
Rural Living Zone	RLZ	0.2	0.3
Special Use Zone	SUZ	0.5	0.8
Special Use Zone	SUZ4	0.5	0.8
Special Use Zone	SUZ6	0.5	0.8
Special Use Zone	SUZ7	0.5	0.8
Special Use Zone	SUZ8	0.5	0.8
Township Zone	TZ	0.55	0.7
Urban Floodway Zone	UFZ	0	0.05

3.2 Rational Method

3.2.1 Description

The Rational Method, as outlined by Book VIII of Australian Rainfall and Runoff (ARR) (1999), has been utilised to calculate the peak flow from the catchment. The Rational Method is an established method for determining the peak flow from urban and rural catchments. Open drains from within agricultural properties connect throughout the catchment to Main Drain 2 and Main Drain 3. Whilst the majority of the catchment is agricultural, the runoff rates and connectivity of drains will create a drainage environment, which is similar to that of an urban catchment. For this reason run-off times can be calculated in a similar manner to that of a fully urbanised catchment. Due to the extensive network of open unlined drains throughout the catchment, the urban approach to implementing the Rational Method has been used for the catchment.

The urban catchments that drain directly to the Goulburn and Broken Rivers will be modelled in the hydraulic model using rainfall 'excess'. A rainfall excess hydrograph is the resulting hydrograph when only losses are subtracted from design rainfalls; hence there is no hydrological routing of flow before application. All routing will occur in the hydraulic model. This is considered appropriate as only the upper portions of the urban catchments are modelled. Given this, there is no requirement to calibrate the RORB model output for the urban catchments to the rational method and no Rational Method calculation for these catchments has been undertaken.

The Rational Method equation is:

$$Q_Y = C_Y I_{t_c,Y} A$$

where Q_Y is the peak flow with an Annual Exceedance Probability (AEP) of Y, C_Y is the runoff coefficient for a flood with an AEP of Y, I is the AEP of Y rainfall intensity for a duration of t_c, and A is the catchment area.

A description of each of these parameters and variables is provided below.

3.2.2 Time of Concentration

The time of concentration (t_c) used for the Rational Method calculations were based upon flow travel times for the longest flow path through the catchment. This is to ensure that the entire catchment is contributing to runoff at the outlet.

The t_c values where calculated using velocities determined from a preliminary 1D/2D hydraulic model, as recommended by the MW Technical Specification. These velocities were available for the majority of Main Drain 2 and Main Drain 3. The preliminary hydraulic model was run using flow boundaries from a preliminary existing conditions RORB model with default parameters and a 1% AEP 2 hour duration storm event. Where detailed information about the drainage network and topography was not available, in the upper reaches of the catchment, an average velocity from the downstream drainage network was applied. This was based on the assumption that there would be no significant change in grade or dimensions of the man-made drains. The calculated *tc* values are shown in Table 3-2 and are documented in more detail in Appendix B.

Table 3-2 Calculated *tc* Values

Location	t_c (mins)
Main Drain 2	
Beckham Road	65
Central Avenue	128
Doyles Road	218
Outlet	288
Main Drain 3	
314 Old Dookie Road	123
Railway	239
Outlet	296

3.2.3 Runoff Coefficient

The 10% AEP runoff coefficient (C_{10}) was derived from the relationship between $C_{10\%}$ and fraction impervious presented in Book VIII of AR&R (1999). $C_{1\%}$ was derived from the $C_{10\%}$ using the frequency factors in Table 1.6 in AR&R Book VIII. The resulting values for each of the main drains are shown in Table 3-3.

Table 3-3 Shepparton East Runoff Coefficient Values

Drain	$C_{10\%}$	$C_{1\%}$
Main Drain 2	0.25	0.30
Main Drain 3	0.27	0.33

3.2.4 Rainfall

Design rainfall was determined using the methodology outlined in ARR. This method requires the determination of Intensity Frequency Duration (IFD) parameters from standard maps published for all of Australia. These parameters are then used to determine the IFD relationship.

A summary of the Intensity Frequency Duration IFD parameters used for the Rational Method calculation are summarised in Section 3.3.1.6 and the full IFD table is provided in Appendix C. The IFD parameters were obtained from the online Bureau of Meteorology Rainfall IFD Data System (Bureau of Meteorology 2012), using the co-ordinates of the centroid of the study area (36.383°S, 145.400°E). These parameters where then used as inputs to the software package Aus – IFD Version 2.0, which created average rainfall intensities for storm durations from 5 minutes to 72 hours and from the 20% to 1% AEP.

3.2.5 Results

The 1% Rational Method parameters and results at key locations within the catchment are shown in Table 3-4.

Table 3-4 Rational Method Parameters and Results for the 1% AEP event

Location	Area (ha)	t_c (mins)	Fraction Impervious	Intensity (mm/h)	Runoff Coefficient	Q (m^3/s)
Main Drain 2						
Beckham Road	320	65	9%	44.49	0.27	10.7
Central Avenue	634	128	9%	27.28	0.27	12.8
Doyles Road	1150	218	12%	18.45	0.30	17.6
Outlet	1575	588	13%	15.06	0.30	20.1
Main Drain 3						
314 Old Dookie Road	886	123	9%	28.08	0.27	19.0
Railway	1730	239	13%	17.17	0.31	25.3
Outlet	1939	297	15%	14.73	0.33	26.0

3.3 RORB Modelling

Hydrological modelling of the Shepparton East Overland Urban catchment was undertaken using RORB. A RORB model was established for the purpose of extracting total and sub-area hydrographs to be used as boundary conditions (inflows) to the TUFLOW hydraulic model. As the majority of flow routing would be calculated in the hydraulic model, flow routing results from an 'undiverted' RORB model were considered appropriate for the purpose of this study.

The three distinct catchments (Main Drain 2, Main Drain 3 and the urban catchments) were connected within the one RORB model. This was achieved using 'dummy' reaches. The different parameters required to calibrate each catchment area were applied using RORB's interstation area feature. The catchments were incorporated into a single model to aid data handling.

A description of the RORB modelling process for the Shepparton East Overland Urban catchment and results are discussed in the following sections. The RORB CATG file and all other associated files have been provided digitally as an accompaniment to this report. Results for each of the scenarios outlined in Table 1-1 are presented in Section3.3.2.

3.3.1 Model Schematisation

RORB simulates the linkages between sub-catchments as reach storages with the storage discharge relationship defined by the following equation:

$$S = 3600kQ^m$$

where S represents the storage (m^3), Q is the discharge (m^3/s), m is a dimensionless exponent and k is non-dimensional empirical coefficient. k is defined by the product of the catchment value k_c and the individual reach k_i. Both m and k_c are defined as calibration parameters. As per the recommended RORB modelling practices from the RORB Manual, in the absence of calibration events or ungauged catchments, an *m* value of 0.8 was adopted.

3.3.1.1 Catchment Delineation

Discussions with GBCMA and GSCC highlighted the importance of irrigation channels in the delineation of the catchment. These irrigation channels are generally raised above the surrounding land and form a barrier to flow, heavily influencing the catchment boundary. The initial catchment delineation was based on these irrigation channels. The catchment delineation was then confirmed using the 0.5m gridded Digital Elevation Model (DEM) developed from the LiDAR data provided by GBCMA, the CatchmentSIM computer program and field inspections.

Once the initial catchment boundary was identified it was reviewed against the catchment boundary computed by the CatchmentSIM computer program. In locations where the study area extended beyond the LiDAR data, the catchment boundary was established along irrigation channels that were provided as a GIS layer by GBCMA. The catchment boundary in these areas was also confirmed during site inspections.

This boundary was then refined using contours and taking into account other influences including:

- major roads and flow paths;
- irrigation structures, including drains and channels; and
- relevant council drainage networks.

The final Shepparton East Overland Urban catchment area was determined to be 49 km^2 in size. The area includes the catchments for Main Drain 2 and Main Drain 3 along with the urban sub-catchments which drain directly into the Broken River or Goulburn River without forming part of the catchments for either of the Main Drains (as shown in Figure 3-1). The urban sub-catchments have been included for completeness of the hydrological model as only the uppermost urban sub-catchments are located with the study area as shown in Figure 3-4. Those that are outside of the study area will not be included within the hydraulic modelling.

The three distinct study catchments (i.e. Main Drain 2, Main Drain 3 and the Urban Ares) were all included.

3.3.1.2 Sub-Catchment Definition

Similarly to the development of the catchment boundary, the sub-catchments, illustrated in Figure 3-2 to Figure 3-4, were developed using a variety of methods. In this case the sub-catchments were initially defined using the CatchmentSIM computer program and the DEM. The sub-catchments were refined using topographic data including information on irrigation channels, roads, flow paths, contours and drainage networks. It was assumed that the flow was predominately overland and via farm drains in the agricultural areas. In these areas, property boundaries are also assumed to influence drainage as run-off would be directed via farm drainage to the network of drains. In the urban areas, flow was assumed to be through overland flowpaths, via the open drains and by the Council pipes where appropriate.

The sub-catchments were also defined in a manner which would allow for the flow boundaries to be correctly applied to the hydraulic model. The sub-catchment definition also allowed for flows to be extracted from the hydrological model at key flow locations including at the drain confluences, retarding basins and other hydraulic structures and major roads.

Where possible, a minimum of three to four sub-catchments were defined upstream of any of inflows to the hydraulic model. Additionally, uniformity in sub-catchment area and shape was sought after. The catchment was divided into 71 sub-catchments and 171 reaches.

3.3.1.3 Reach Types

The following reach types were used in the RORB model setup:

- Reach Type 2 for excavated but unlined channels, farm drainage and undefined flow paths (e.g. through residential property/fences).
- Reach Type 3 for flow in lined channels, roads and pipes.

Where the flow was in unlined channels or where the majority of the flow was through farm drainage or residential/commercial properties Reach Type 2 has been used. Where flow would be largely contained within piped assets or within the road reserve Reach Type 3 was used. Reach alignments and types for the Main Drain 2 sub-catchments, Main Drain 3 sub-catchments and the urban sub-catchments are shown in Figure 3-2 to Figure 3-4 respectively.

Automatically calculated reach slopes were found to have small or adverse gradients which are due to the flat nature of the catchment and the influence of channel embankments on automated slope calculation processes. Manual calculation of slope from the LiDAR data in fields adjacent to reaches confirmed the flat nature of the catchment, with the overwhelming majority of reaches tested having gradients less than 0.05% (0.0005 m/m), the default minimum gradient in RORB. Given the minimum gradient that RORB accepts is 0.05% a reach slope of 0.05% was assumed for all reaches and the assumption was sensitivity tested.

From visual inspection there are a few reaches that have a slope slightly higher that 0.05% gradient, but typically less than 0.1%. A sensitivity analysis was run where all reach slopes were increased to 0.1%. This resulted in a 15% increase in flows both the outlet of Main Drain 2 and Main Drain 3, an increase of approximately 4 m^3/s. As the majority of the inflow boundaries will be applied to the hydraulic model as rainfall excess hydrographs, the small change in discharge resulting from minimal change in reach slope across the catchment will not affect the outcome from the hydraulic model. Therefore the reach slope of 0.05% has been adopted.

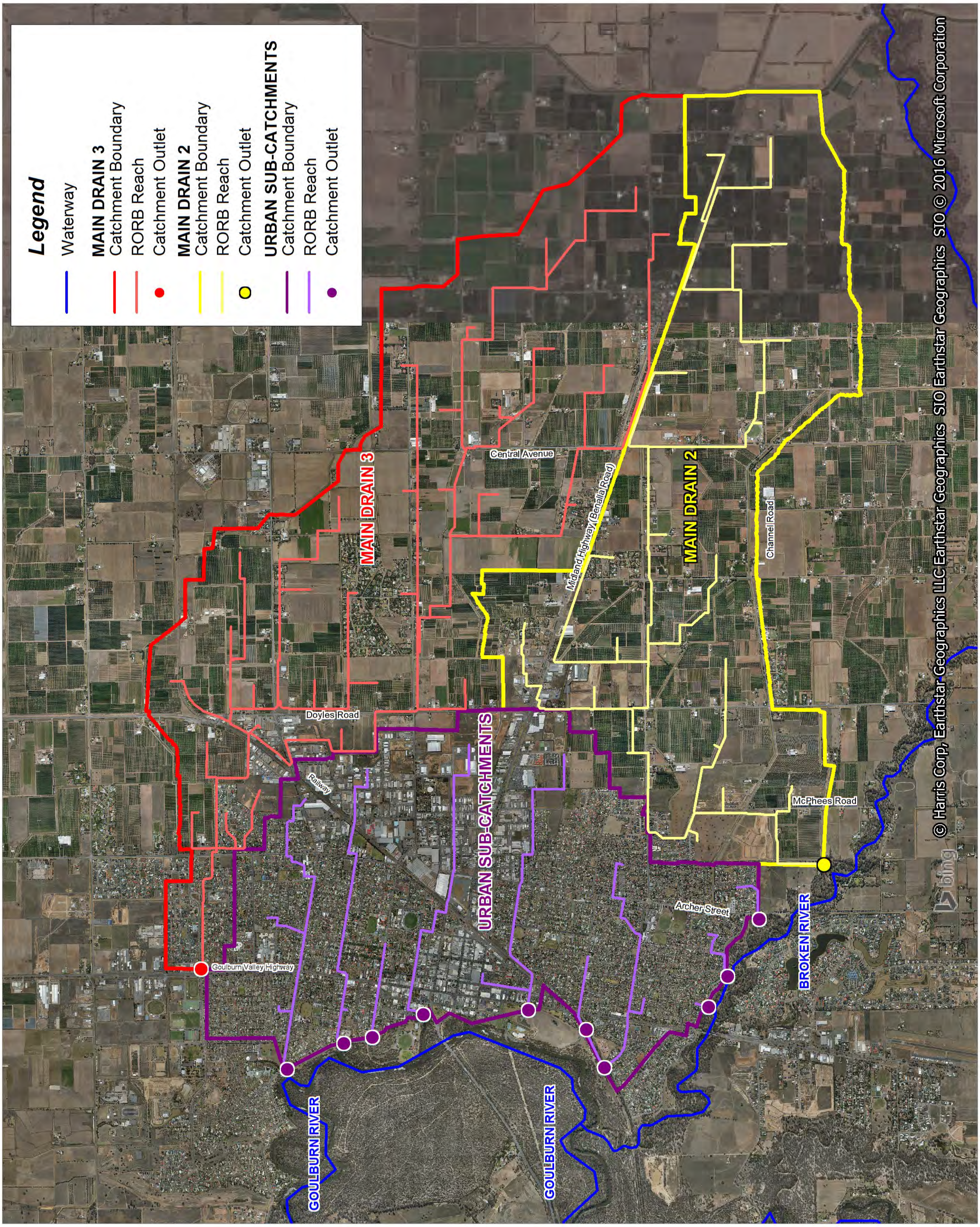
3.3.1.4 Retarding Basins and Storages

The Shepparton East Overland Urban catchment includes 23 retarding basins as listed in Table 3-5. These retarding basins have not been included in the RORB model as all storage and routing effects that result from the retarding basins will be accounted for in the hydraulic model. The effects of flood storage behind roads and other flow obstructions will also be taken into account by the hydraulic model.

Table 3-5 Retarding Basins Located with Study Area

Site Name	Location
Redgum Court Drainage Reserve	Behind Elm Terrace
King Richard Drive	King Richard Drive
Telford Drive Drainage Reserve	End McHarry Place
Ross Alan Drive Drainage Reserve	17 Ross Alan Drive
Sofra Drive	21 Sofra Drive Shepparton
Pine Road (Nth)	Beside 29-35 Pine Road
Florence Street	Behind 64-70 Florence
Perrivale Drive Drainage Reserve	No. 17
Orchard Circuit	63-67 Orchard Circuit
Zurcas Lane Drainage Reserve	No. 35
Channel Road	between Channel Rd and Cezanne
Shepparton East	Central Park Rec Reserve - Channel Road
Unknown*	Doyles Road / Benalla Road
Unknown*	Shepparton Marketplace
Unknown*	Smythe Street
Unknown*	Ducat Reserve
Unknown*	Walnut Court
Unknown*	Florence Street / Williams Road
Unknown*	Wheeler Street
Unknown*	116-136 New Dookie Road
Unknown*	19-33 Graham Street
Unknown*	Fitzgerald Street
Unknown*	Pine Road

*Retarding Basin not included in Basin MapInfo Table provided by GBCMA/GSCC.



Title:

Shepparton East

RORB Model Schematisation - Interstational Catchments

Figure: **3-1**

Rev: **A**

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

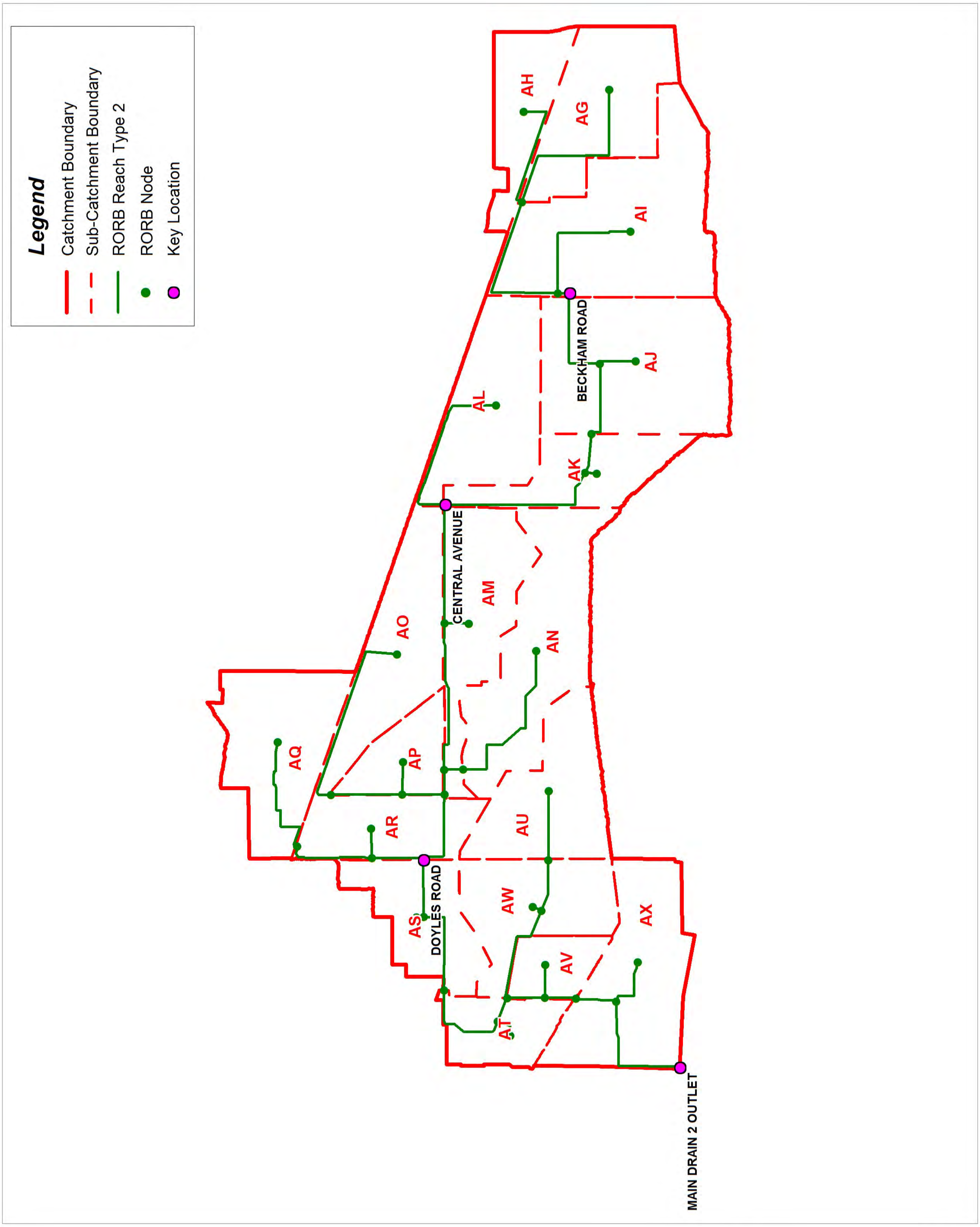
0 1.25 2.5km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : T:\M8415.JL.SheppartonEast_Urban_FS\MapInfo\Drawings\R.M8415.003.00.Final\Fig3-1_RORB_Interstational_RevA.wor



Title:

Shepparton East
RORB Model Schematisation - Main Drain 2

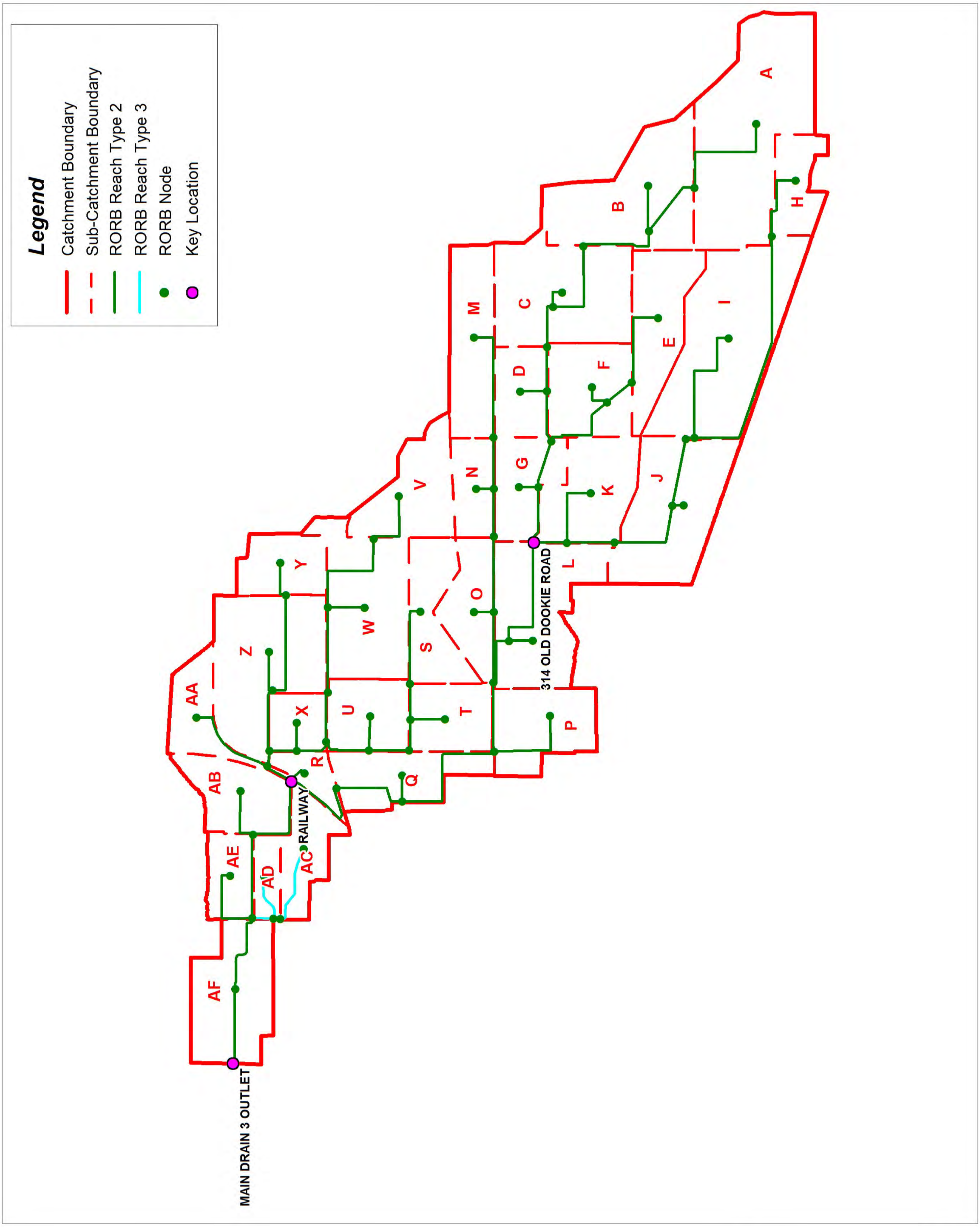
Figure: **3-2**

Rev: **A**

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

BMT WBM
www.bmtwbm.com.au

Filepath : T:\M8415.JL.SheppartonEast_Urban_FS\MapInfo\Drawings\R.M8415.003.00.Final\Fig3-2_RORB_Model_MD2_RevA.wor



Title:

Shepparton East
RORB Model Schematisation - Main Drain 3

Figure: **3-3**

Rev: **A**

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

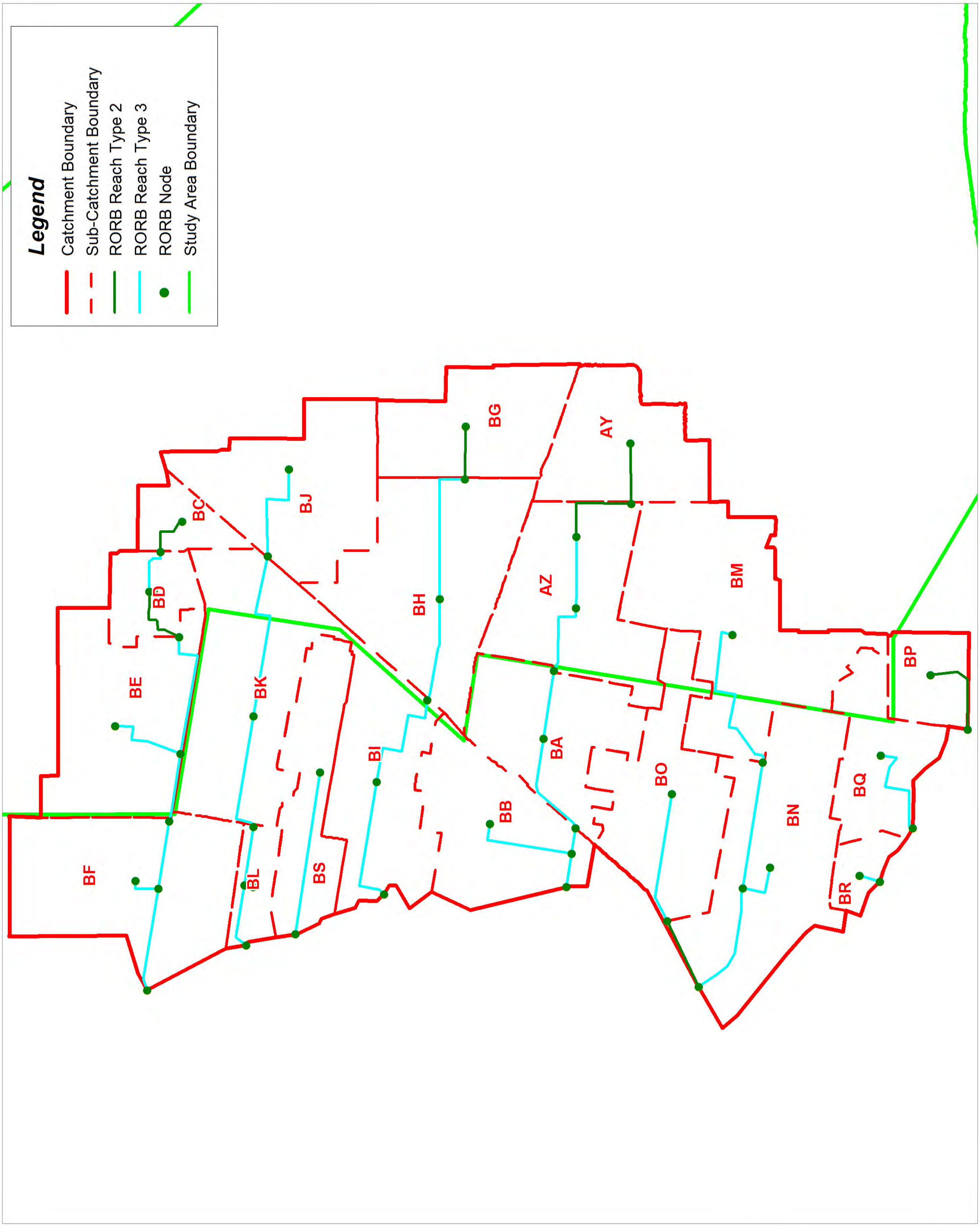
0 1 2km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : T:\M8415.JL.SheppartonEast_Urban_FS\MapInfo\Drawings\R.M8415.003.00.Final\Fig3-3_RORB_Model_MD3_RevA.wor



Title:

Shepparton East
RORB Model Schematisation - Urban Sub-Catchments

Figure: **3-4**

Rev: **A**

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 0.75 1.5km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : T:\M8415.JL.SheppartonEast_Urban_FS\MapInfo\Drawings\R.M8415.003.00.Final\Fig3-4_RORB_Model_URBAN_RevA.wor

3.3.1.5 Diversions

The Shepparton East Overland Urban RORB model does not include any piped diversions. The TUFLOW hydraulic model covers the majority of the catchment and includes all significant GSCC assets within the catchment. Therefore, any diversions will be accounted for dynamically within the 2D-1D hydraulic model.

3.3.1.6 Intensity Frequency Duration (IFD) Parameters

Storm data was generated using IFD parameters sourced from the Bureau of Meteorology IFD program (Bureau of Meteorology, 2012) and the software package Aus – IFD Version 2.0, as discussed in Section 3.2.4. The adopted IFD parameters for the catchment are presented in Table 3-6. The full IFD Table is provided in Appendix C. The Climate Change scenario is based on the existing IFD rainfall intensity parameters factored by 32% as required by the MW Technical Specification. In addition, the F2 and F50 geographic factors were also adjusted using the methodology applied by Melbourne Water.

Table 3-6 IFD Parameters

IFD Parameter		Base Case	Climate Change
Rainfall Intensity (mm/hr)	50% AEP, 1 Hour Duration	19.7	25.8
	50% AEP, 12 Hour Duration	3.5	4.7
	50% AEP, 72 Hour Duration	0.9	1.2
	2% AEP, 1 Hour Duration	39.9	51.8
	2% AEP, 12 Hour Duration	6.7	8.8
	2% AEP, 72 Hour Duration	1.8	2.4
Skew Coefficient		0.16	0.16
Geographical Factor F2		4.33	4.45
Geographical Factor F50		15.09	16.86
Zone		2	2

3.3.1.7 Loss Model

RORB generates rainfall excess (runoff) by subtracting losses at each time-step from the rainfall occurring in that time period. The “initial loss followed by a continuing loss” loss model was adopted. The adopted initial loss and continuing loss for pervious areas were 15 mm and 2 mm/hr respectively in the agricultural catchments of Main Drain 2 and Main Drain 3. An initial loss of 10 mm and continuing loss of and 2 mm/hr was adopted for the urban sub-catchments. For impervious areas, RORB has a “hardwired” initial loss of 0 mm and runoff coefficient of 0.9. The losses in the RORB model were varied across the 3 distinct catchment areas using RORB’s interstation area feature.

3.3.1.8 Model Calibration

There are no stream gauges within the catchment, so the RORB model was calibrated to the Rational Method. RORB can be calibrated by varying the pervious area, initial loss, continuing loss, reach type, k_c and m. An initial loss of 15 mm, continuing loss of 2.0mm/hr and m of 0.8 were adopted as per similar studies within the region. An initial loss of 10 mm was adopted for the urban sub-catchments. The RORB reach types used were consistent with the properties of the channels used for the calculation of t_c (e.g. reach type 2 for excavated unlined channels).

The RORB model was calibrated to the Rational Method by varying the k_c parameter. The k_c value was the only parameter adjusted during the calibration process and was varied to ensure that the peak discharge from the RORB model matched that of the Rational Method at the catchment outlets for the 1% AEP flood event. A k_c of 18.67 and 17.68 was adopted for Main Drain 3 catchment and Main Drain 2 catchment respectively.

As noted in Section 3.3.1.1 there are a number of catchments which drain directly to the Broken River and Goulburn River as shown in Figure 3-1. Figure 3-4 shows that the majority of these sub-catchments will not be modelled in the hydraulic model as they are located outside of the study area. Therefore it was not considered practical to determine individual k_c values for each of these sub-catchments. The k_c value was determined by assuming there was a consistent k_c/d_{av} relationship between these individual catchments and Main Drain 2 and Main Drain 3.

A k_c/d_{av} value of 2.6 and 2.5 was calculated for sub-catchment outlets for Main Drain 2 and Main Drain 3 respectively. Table 3-7 shows the calculated k_c value for each additional outlet using a k_c/d_{av} value of 2.55.

For the Ultimate Developed scenario, the increase in residential zoning between Grahamvale Road and Ford Road has redirected flows into the Main Drain 3 catchment that are currently flowing away from the catchment area as shown in Appendix C of the North East Corridor Plan (Reeds Consulting 2011). This has resulted in the addition of two sub-catchments to the Ultimate Developed scenario and therefore a changed d_{av} value. To ensure consistency, the k_c/d_{av} ratio has been maintained as shown in Table 3-7.

Table 3-7 k_c and d_{av} Parameters for Shepparton East outlets

Location/Sub-Catchment Outlet	D_{av}	k_c
Main Drain 3	7.50	18.45
Main Drain 2	6.70	17.60
Main Drain 3*	7.29	17.90
BB	1.68	4.27
BF	1.61	4.09
BI	2.03	5.16
BL	2.1	5.34
BN	1.62	4.12
BF	0.53	1.35
BQ	0.66	1.68
BR	0.13	0.33
BS	0.97	2.47

*Ultimate Developed Case

Table 3-8 compares the calibrated RORB model results to the Rational Method flows at various locations within the catchment. The percentage difference at each calibration point is less than ten precent with the exception at the top of the drainage system. The magnitude of discharge is small at the top of drainage systems; therefore the percentage difference is insignificant when considering the impact on flood extents within the hydraulic model.

Table 3-8 Rational Method and RORB comparisons for Shepparton East

Location	1% AEP Peak Discharge (m^3/s)		Difference (%)
	RORB	Rational Method	
Main Drain 2			
Beckham Road	9.3	10.7	-13.1
Central Avenue	12.3	12.8	-3.9
Doyles Road	18.1	17.6	2.8
Outlet	20.1	20.1	0.0
Main Drain 3			
314 Old Dookie Road	20.7	19.0	8.2
Railway	26.4	25.3	4.4
Outlet	26.0	26.0	0.0

3.3.1.9 RORB Parameter Summary

RORB model parameters used in the modelling of the Shepparton East Overland Urban catchment are summarised in Table 3-9.

Table 3-9 RORB Parameters

Parameter	Shepparton East Overland Urban Flood Study
Storm Data	Varies (refer Section 3.3.1.6)
Catchment Area (km^2)	49
Initial Loss (mm)	15 (Rural) 10 (Urban)
Continuing Loss (mm/hr)	2.0 (Rural) 2.0 (Urban)
m	0.8
k_c	Varies from 0.33 to 18.45 (refer Section 3.3.1.8)
Fraction Impervious	Varies (refer Section 3.1)
Reach Type	2 and 3

3.3.1.10 Probable Maximum Precipitation

The RORB model was used to generate probable maximum flood (PMF) flow hydrographs, which required the development of the probable maximum precipitation (PMP). The PMP was developed using the methodologies described in the *"Guidebook to the Estimation of Probable Maximum Precipitation: Generalised Southeast Australia Method"* and *"The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method"*. The resulting PMP storm events were run using the RORB model using the parameters outlined above.

The Generalised Short-Duration Method (GSDM) is limited to the 3 hour duration storm event for inland catchments which includes the Shepparton East catchment, whilst the Generalised Southeast Australia Method (GSAM) is only relevant for rainfall event durations 24 hours and longer. The intervening durations were determined in accordance with the GSAM guidebook and the resulting estimated PMP depth was applied to both the 3 hour temporal pattern and the 24 hour temporal pattern within the RORB model. The higher value of the two results has been included within this report where appropriate. The PMF Summary worksheets are provided in Appendix D and the peak hydrographs for key locations within the catchment are shown in Figure 3-12. Peak flows in key locations are included in Table 3-10 and Table 3-11.

3.3.2 RORB Results Summary

3.3.2.1 Base Case Scenario

A summary of the peak discharge output from the RORB hydrologic model for the Base Case Scenario is shown in Table 3-10. The critical storm duration hydrographs at each location are shown in Figure 3-5 through Figure 3-11 respectively. It should be noted that due to catchment response, longer durations are critical for the 20% AEP Base Case event at the Main Drain 2 Outlet, Railway and Main Drain 3 Outlet reporting locations.

Table 3-10 Base Case Predicted Peak Discharges

AEP	Critical Flow Path Peak Discharge (m^3/s)						
	Beckham Road	Central Avenue	Doyles Road	Main Drain 2 Outlet	314 Old Dookie Road	Railway	Main Drain 3 Outlet
20%	3.1	4.0	6.3	6.9	7.1	8.5	8.6
10%	4.2	5.4	8.3	8.6	9.4	11.2	11.1
5%	5.7	7.3	10.8	11.8	12.6	15.5	15.3
2%	7.6	10.0	14.9	16.4	17.1	21.6	21.1
1%	9.3	12.3	18.1	20.1	20.7	26.4	26.0
0.5%	11.1	14.6	21.5	24.0	24.5	31.6	31.1
0.2%	13.6	17.9	26.4	29.6	30.1	38.8	38.4
PMF	88.6	136.5	204.5	217.6	216.5	282.8	276.2

3.3.2.2 Developed Case Scenario

A summary of the peak discharges output from the RORB hydrologic model for the ultimate developed case is shown in Table 3-11. The critical storm duration hydrographs at each location are shown in Figure 3-5 through Figure 3-11 respectively.

Table 3-11 Ultimate Developed Case Predicted Peak Discharges

AEP	Critical Flow Path Peak Discharge (m^3/s)						
	Beckham Road	Central Avenue	Doyles Road	Main Drain 2 Outlet	314 Old Dookie Road	Railway	Main Drain 3 Outlet
20%	3.8	4.9	7.4	8.5	8.5	10.9	11.8
10%	4.8	6.3	9.4	10.8	10.9	14.0	14.9
5%	6.2	8.3	12.2	14.1	14.2	18.4	19.4
2%	8.3	11.0	16.4	18.7	18.6	24.5	25.9
1%	10.0	13.2	19.6	22.5	22.3	29.4	31.0
0.5%	11.8	15.6	23.1	26.4	26.2	34.6	36.5
0.2%	14.4	18.9	28.0	32.1	31.9	41.8	44.2
PMF	89.1	137.7	206.7	220.4	218.8	287.1	292.3

3.3.2.3 Climate Change Scenarios

A summary of the peak discharges for Climate Change Scenario A and B are shown in Table 3-12 and Table 3-13 respectively. As above, the critical storm duration hydrographs at each location are shown in Figure 3-13 through Figure 3-19 respectively.

Other than the different IFD parameters all other files and parameters, i.e. catchment definition, k_c and *m*, were the same as used for the Base Case Scenario or Developed Case Scenario as appropriate.

Table 3-12 Climate Change A – Increased Rainfall Intensity Predicted Peak Discharge

AEP	Critical Flow Path Peak Discharge (m^3/s)						
	Beckham Road	Central Avenue	Doyles Road	Main Drain 2 Outlet	314 Old Dookie Road	Railway	Main Drain 3 Outlet
20%	5.6	7.3	10.8	11.9	12.5	15.6	15.4
10%	7.0	9.3	13.7	15.2	15.9	20.0	19.5
5%	9.0	12.1	17.6	19.8	20.4	25.9	25.6
2%	11.9	15.9	23.4	26.3	26.5	34.5	34.0
1%	14.2	18.9	27.9	31.5	31.7	41.1	40.9
0.5%	16.7	22.1	32.8	36.9	37.2	48.0	48.0
0.2%	20.3	26.7	39.7	44.8	45.0	58.0	58.0

Table 3-13 Climate Change B – Increased Rainfall Intensity Predicted Peak Discharge

AEP	Critical Flow Path Peak Discharge (m^3/s)						
	Beckham Road	Central Avenue	Doyles Road	Main Drain 2 Outlet	314 Old Dookie Road	Railway	Main Drain 3 Outlet
20%	6.2	8.2	12.3	14.2	14.1	18.5	19.5
10%	7.7	10.3	15.2	17.5	17.5	22.8	24.1
5%	9.7	13.0	19.1	22.1	22.1	28.9	30.5
2%	12.6	16.9	24.9	28.7	28.2	37.5	39.6
1%	15.0	19.9	29.5	33.9	33.5	44.1	46.7
0.5%	17.5	23.1	34.4	39.4	39.0	51.1	54.3
0.2%	21.3	27.8	41.3	47.4	47.0	61.2	64.9

3.3.3 Existing Condition Scenarios: Base Case and Developed Case Peak Hydrographs

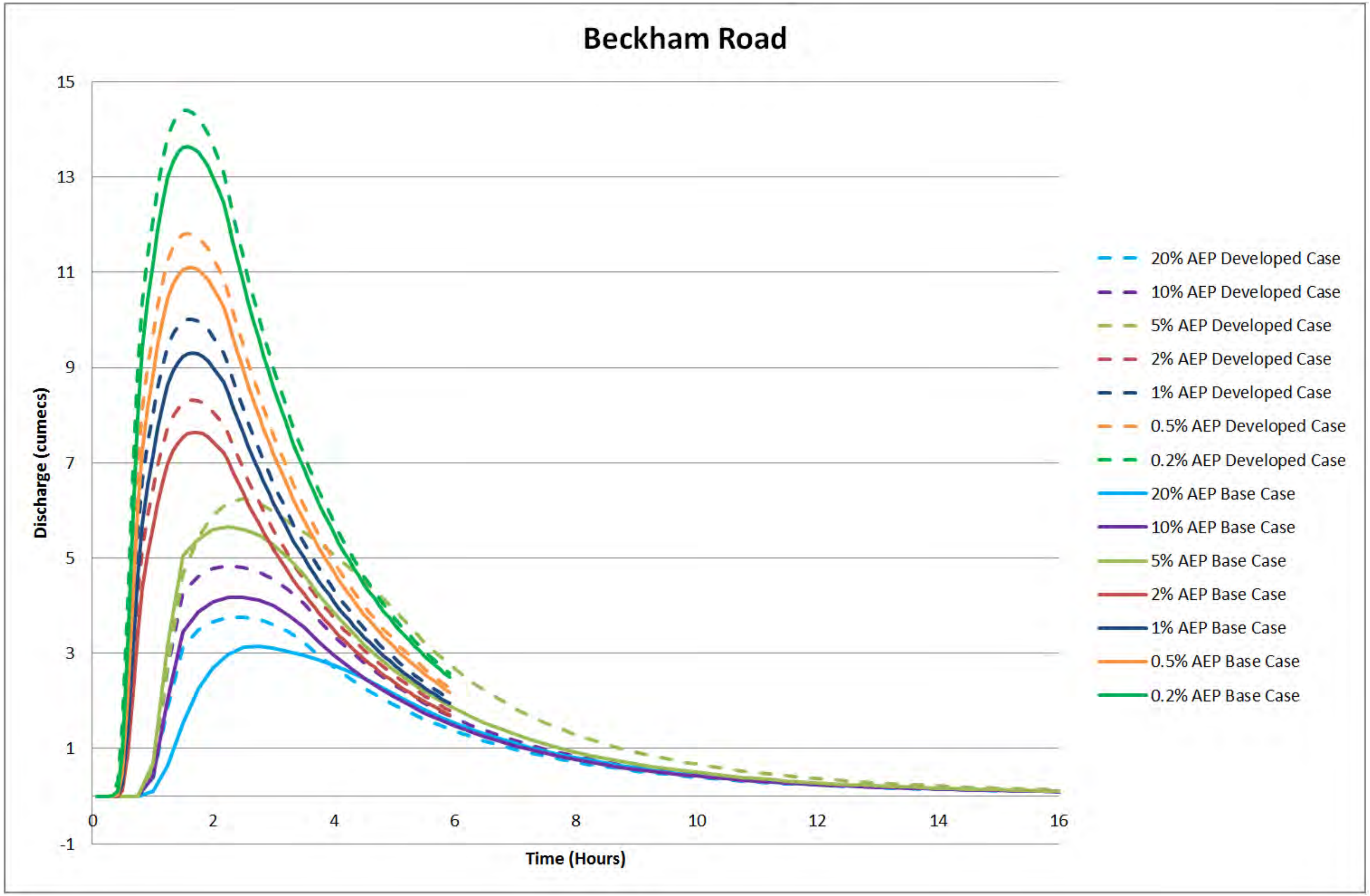


Figure 3-5 RORB Critical Hydrographs at Beckham Road

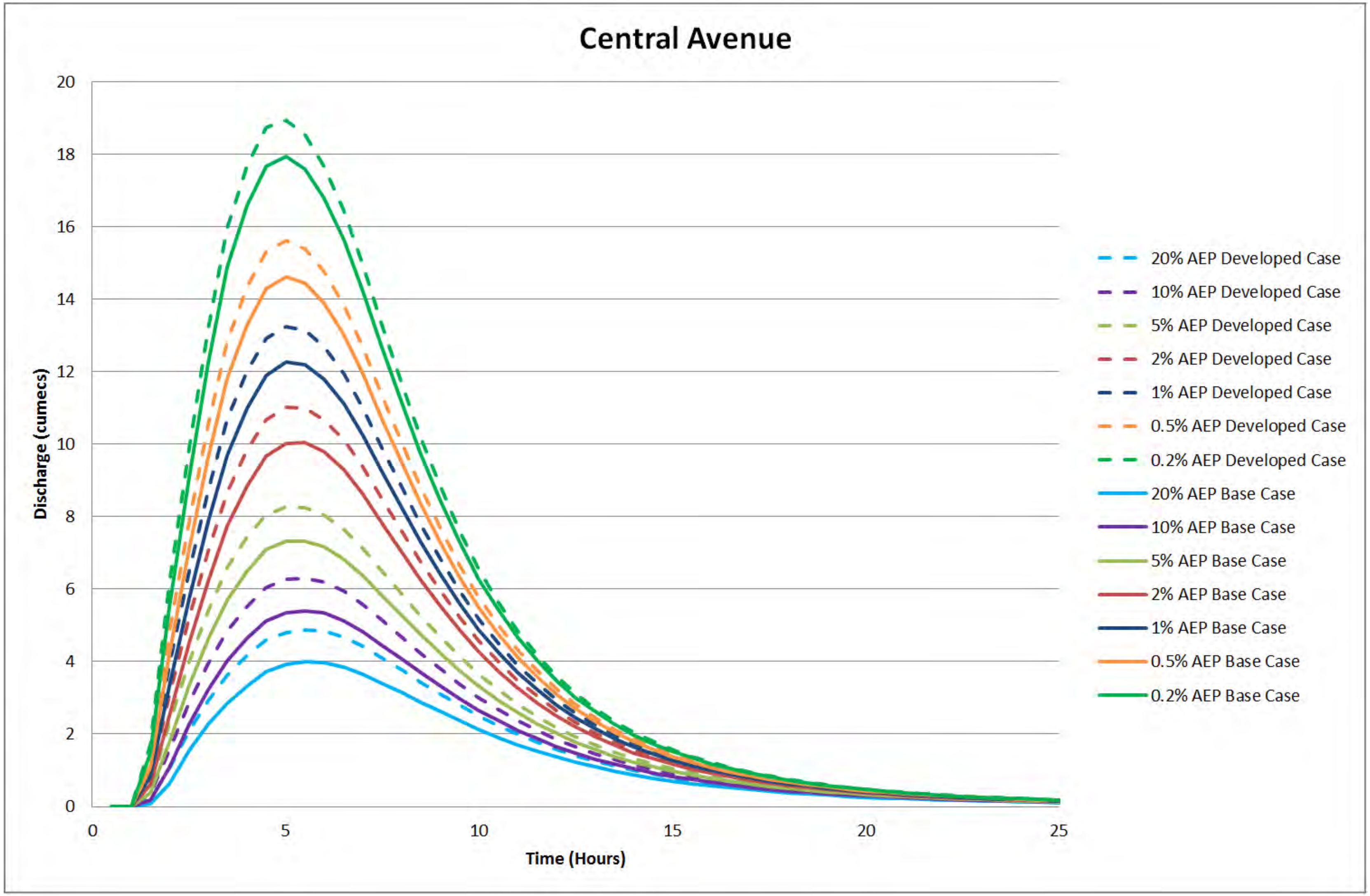


Figure 3-6 RORB Critical Hydrographs at Central Avenue

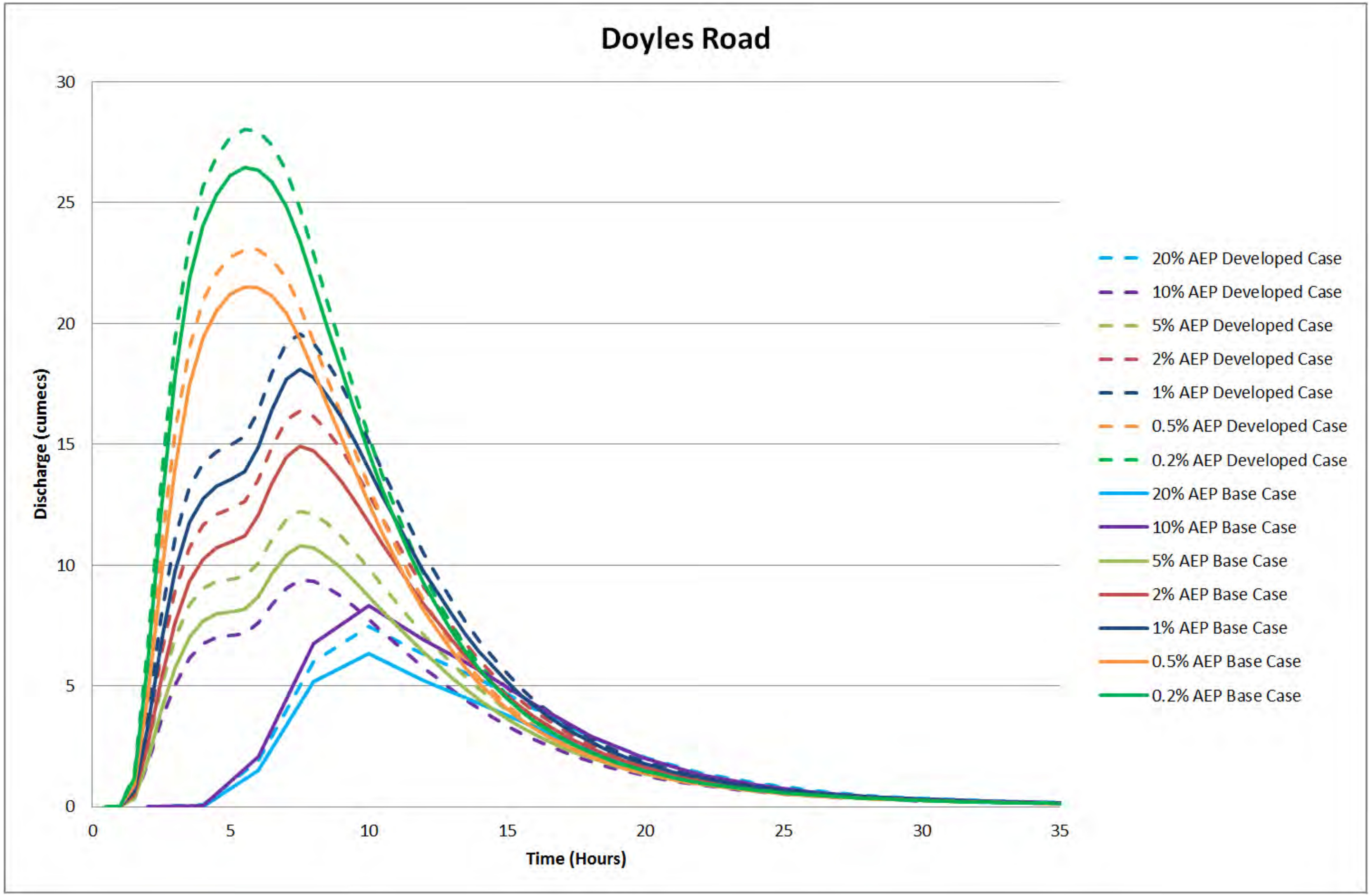


Figure 3-7 RORB Critical Hydrographs at Doyles Road

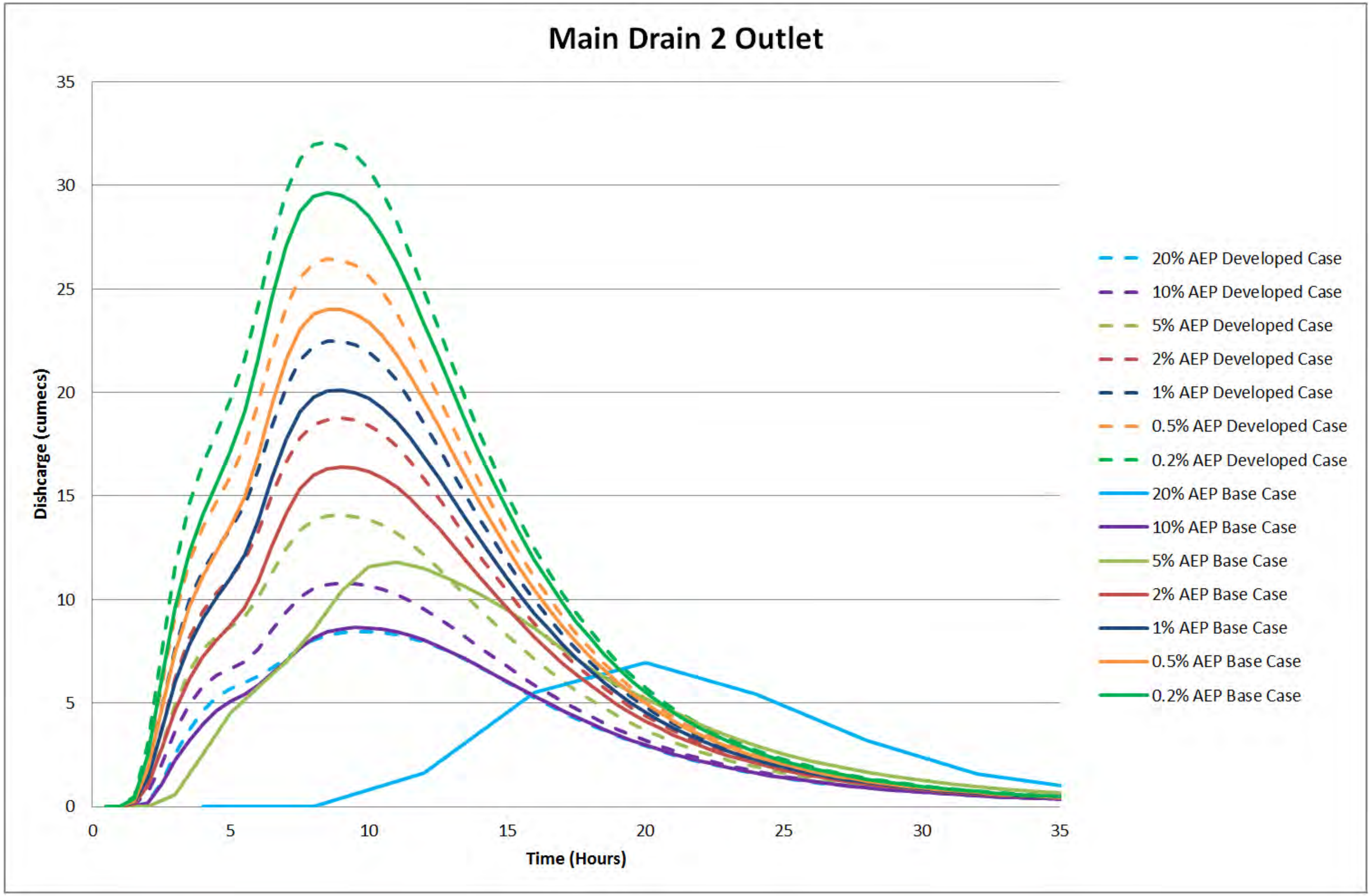


Figure 3-8 RORB Critical Hydrographs at Main Drain 2 Outlet

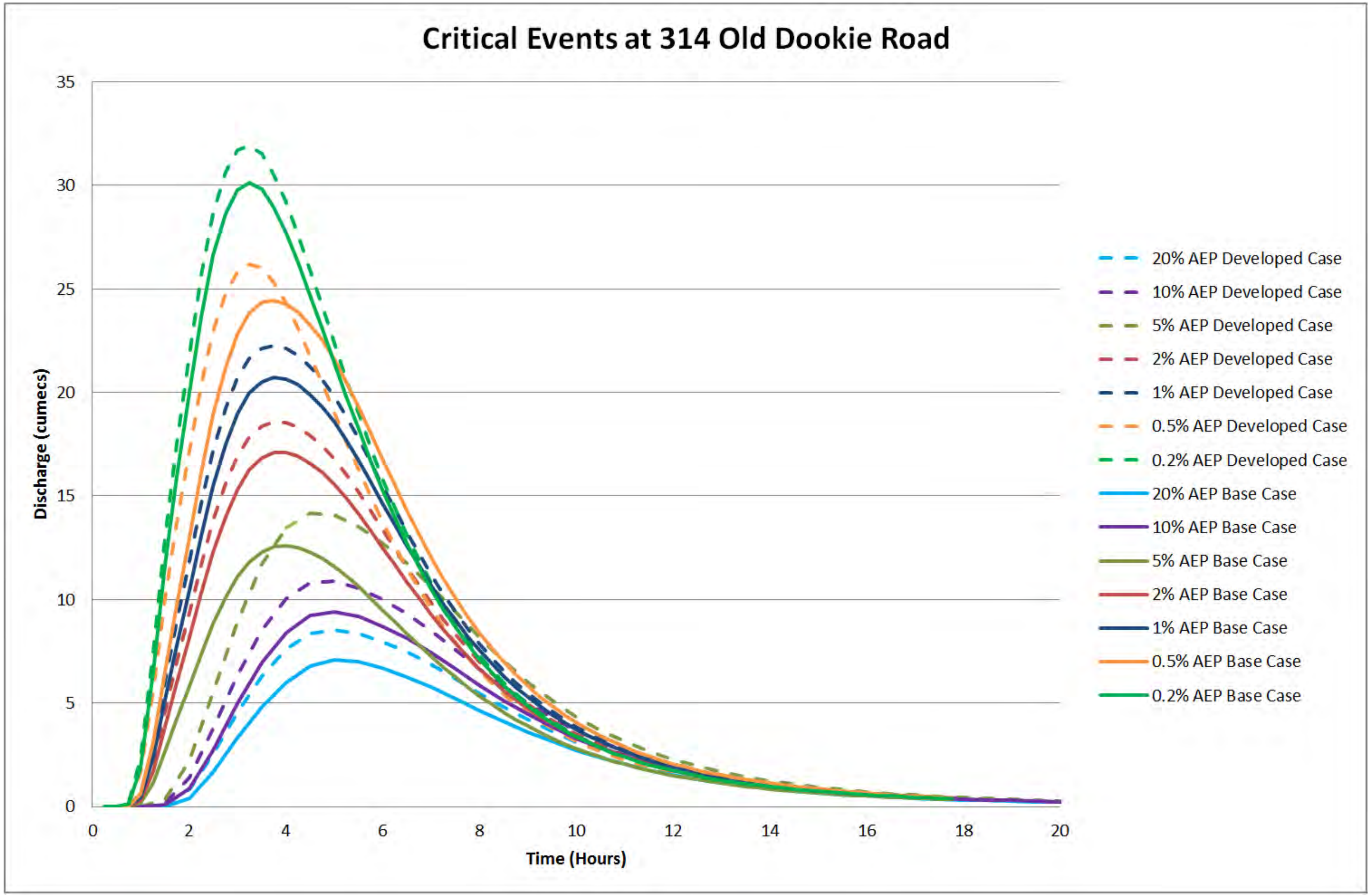


Figure 3-9 RORB Critical Hydrographs at 314 Old Dookie Road

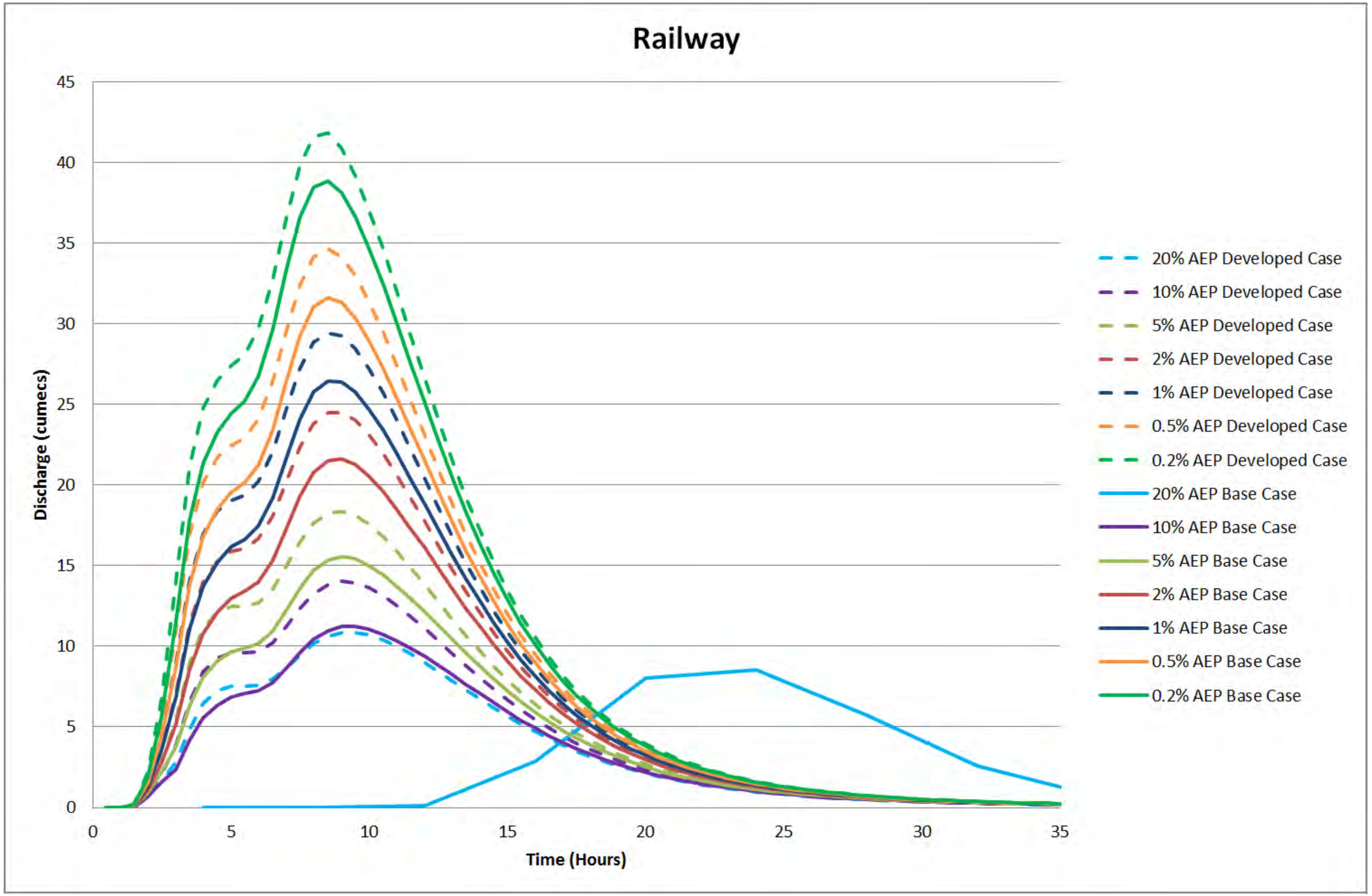


Figure 3-10 RORB Critical Hydrographs at Railway

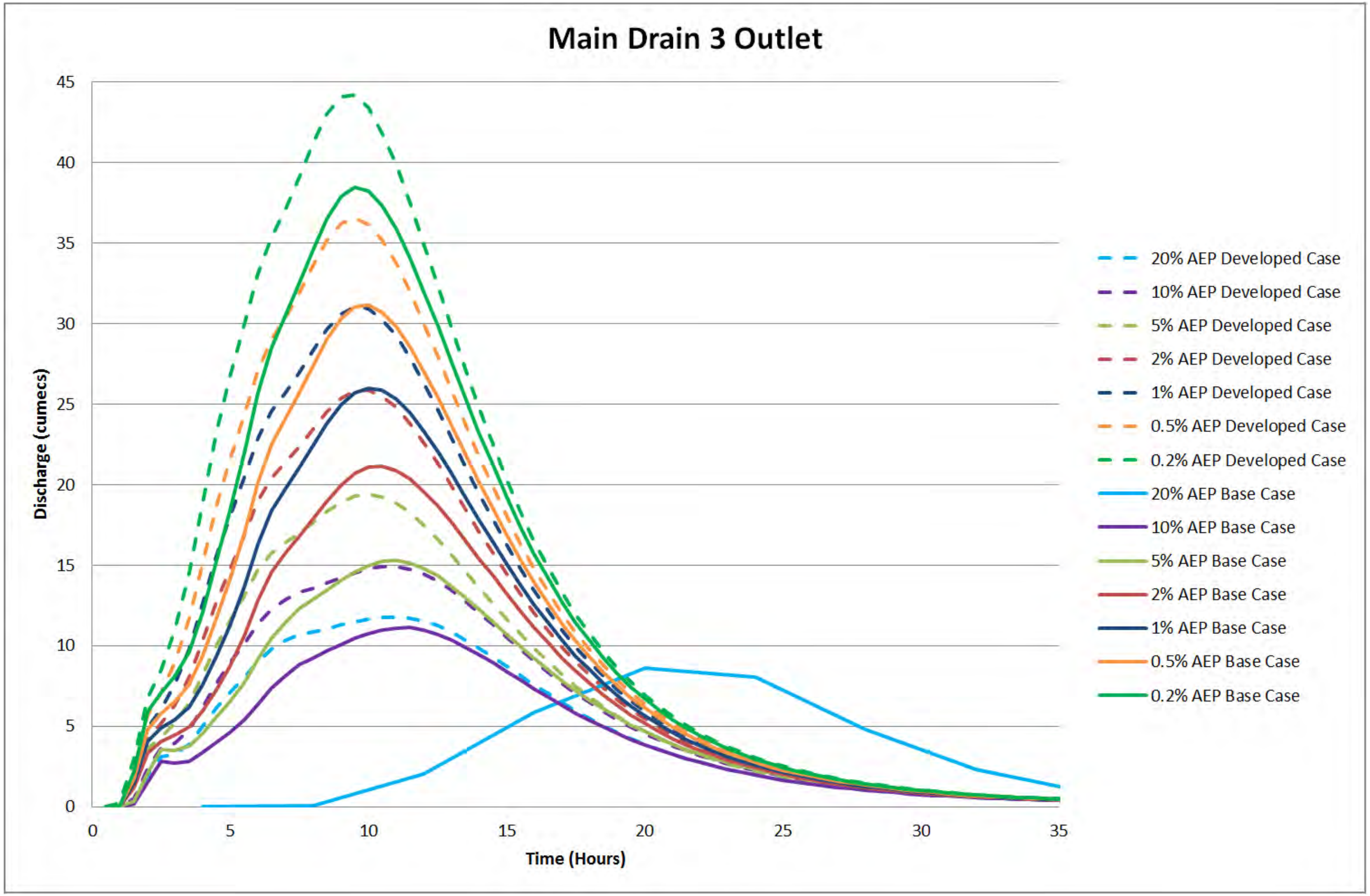


Figure 3-11 RORB Critical Hydrographs at Main Drain 3 Outlet

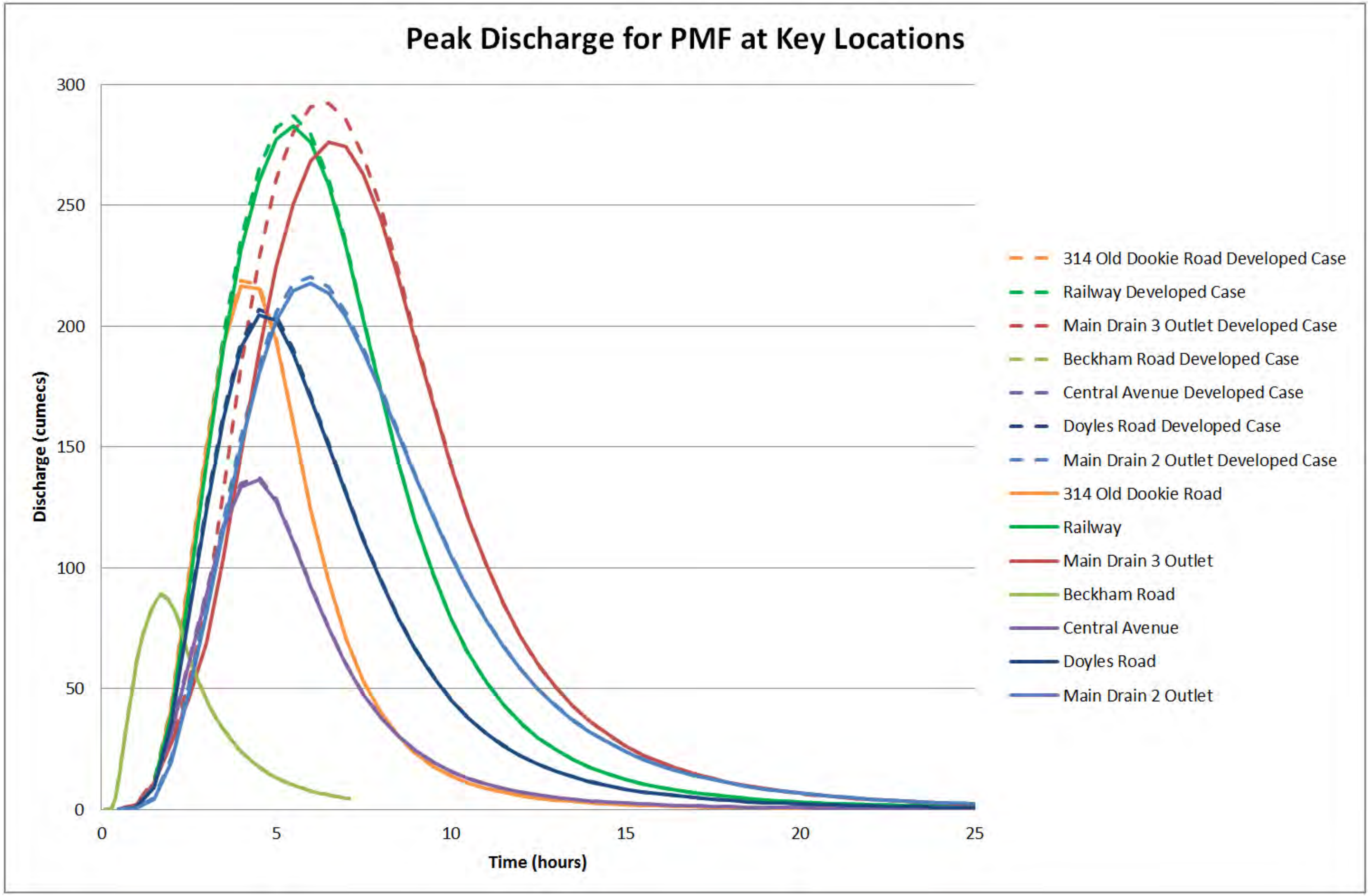


Figure 3-12 Peak Discharge Hydrographs for PMF at Key Locations

3.3.4 Climate Change Scenarios: Base Case and Developed Case Peak Hydrographs

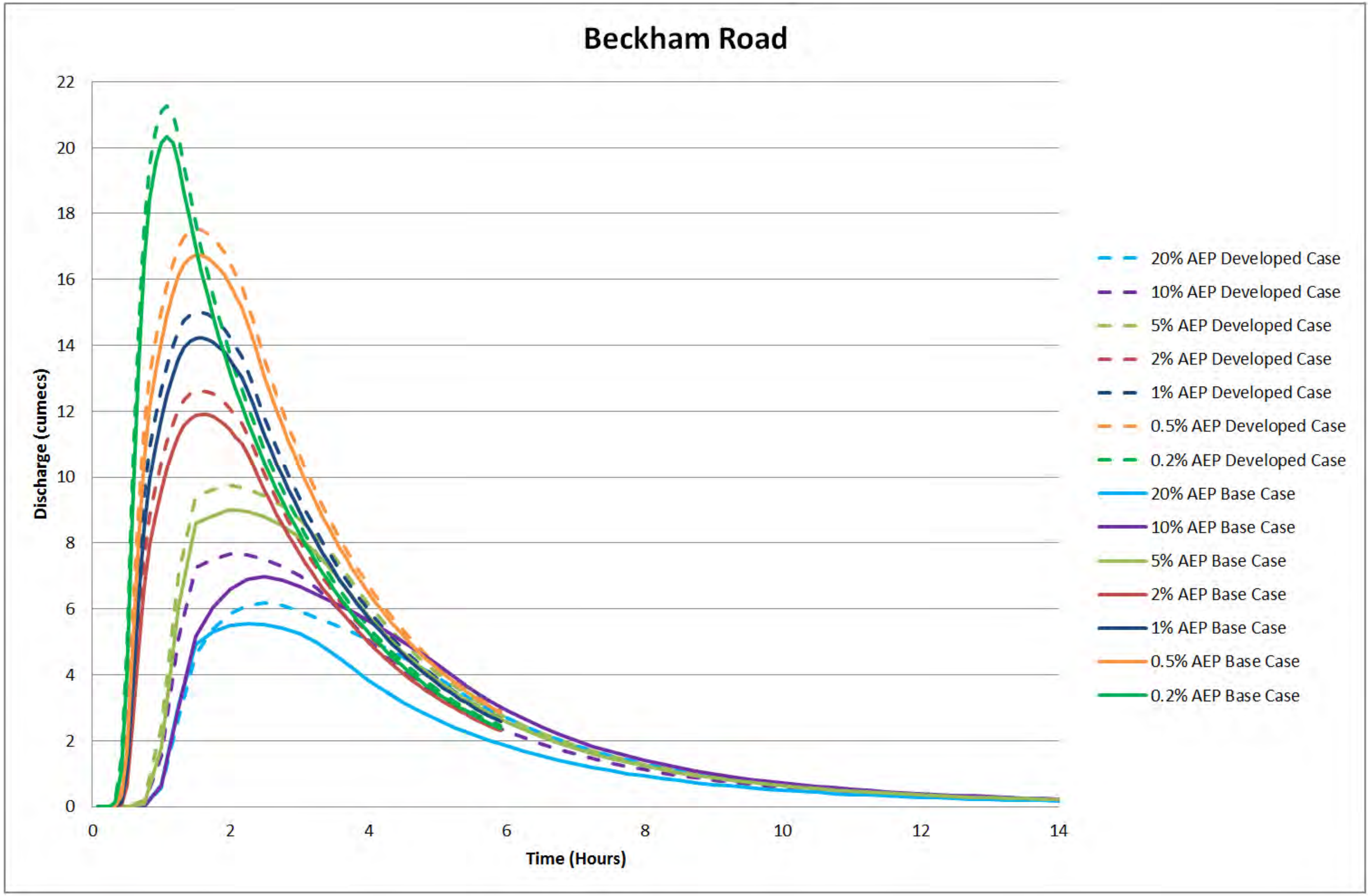


Figure 3-13 RORB Critical Climate Change Hydrographs at Beckham Road

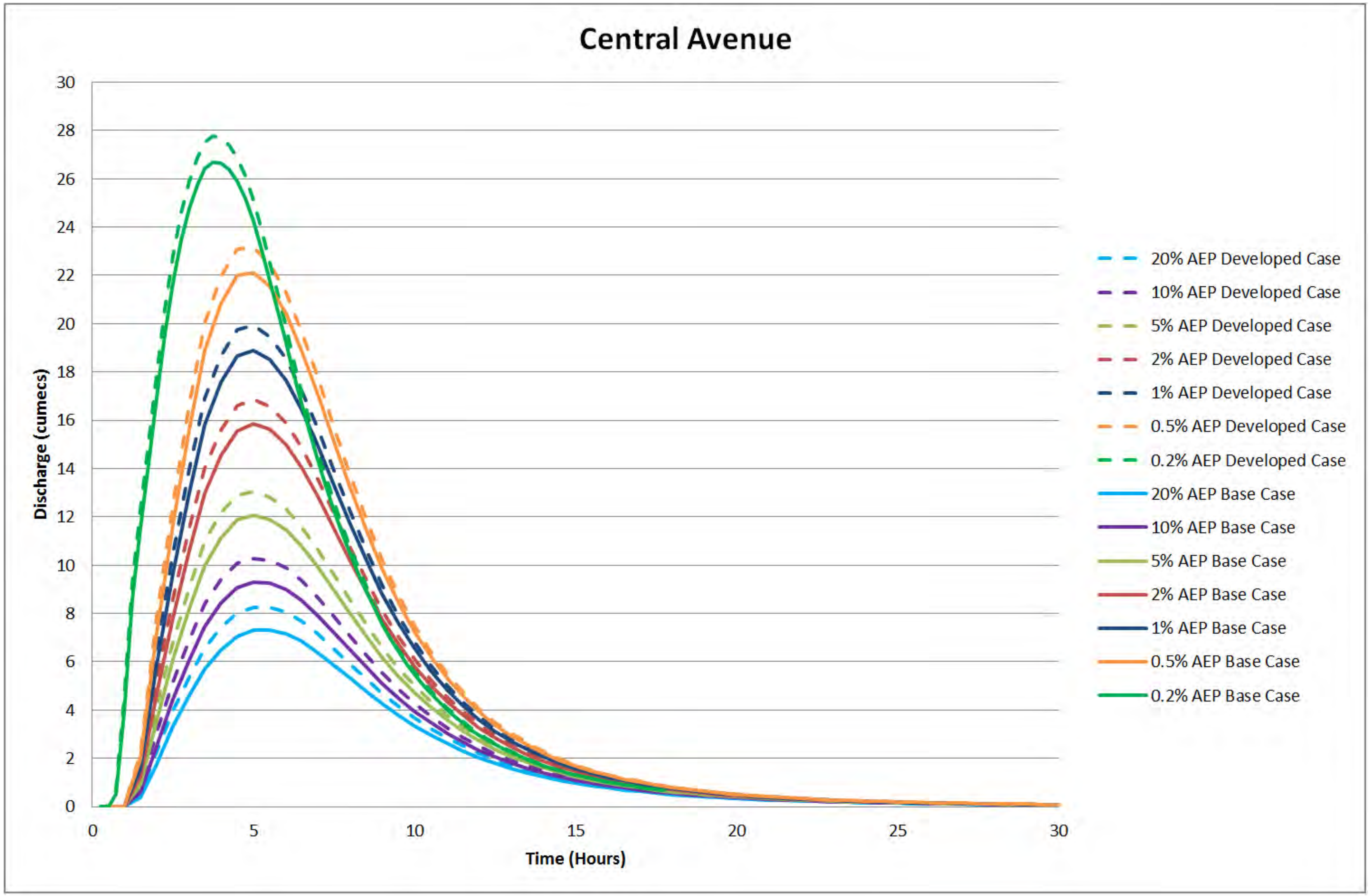


Figure 3-14 RORB Critical Climate Change Hydrographs at Central Avenue

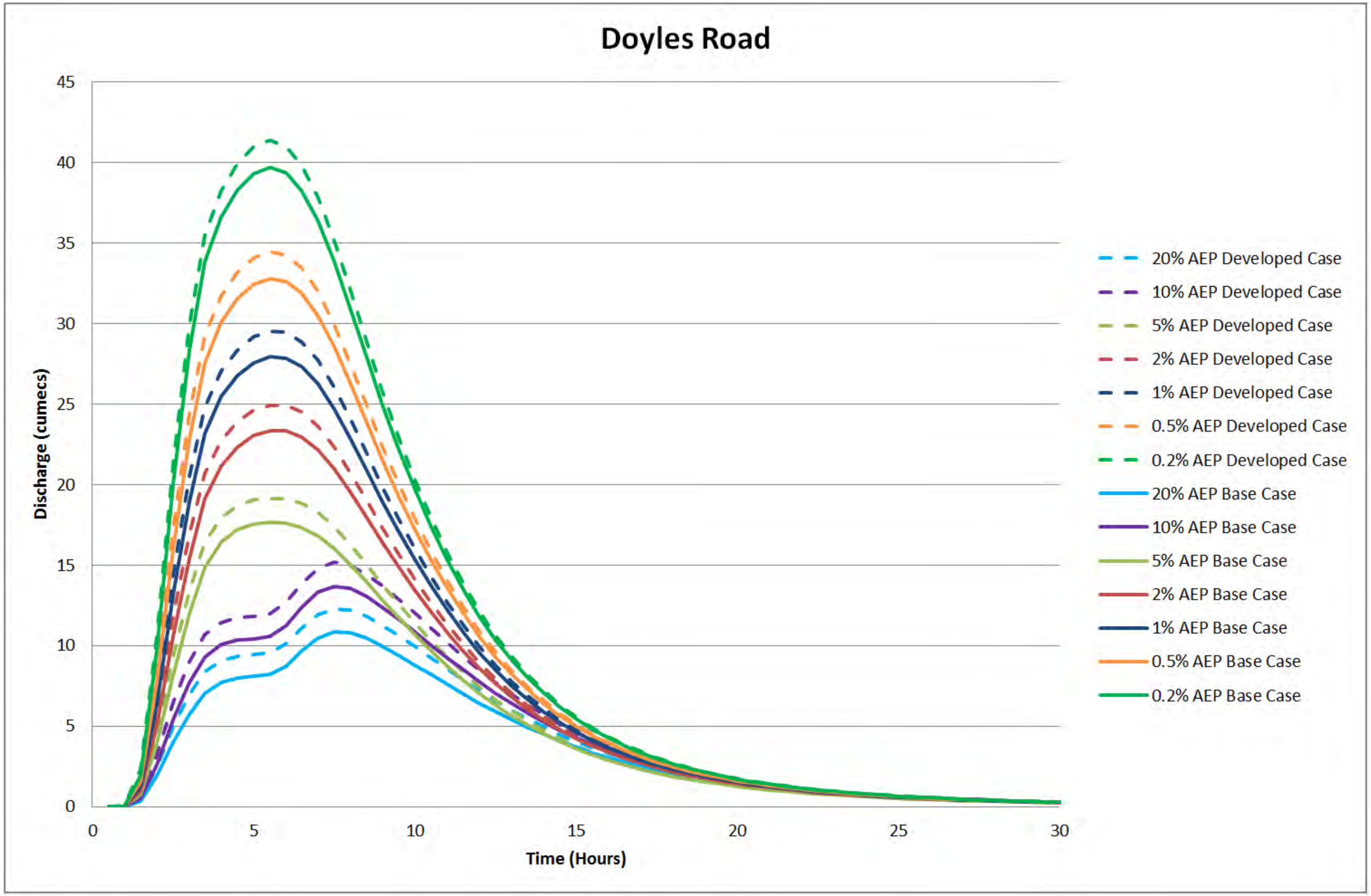


Figure 3-15 RORB Critical Climate Change Hydrographs at Doyles Road

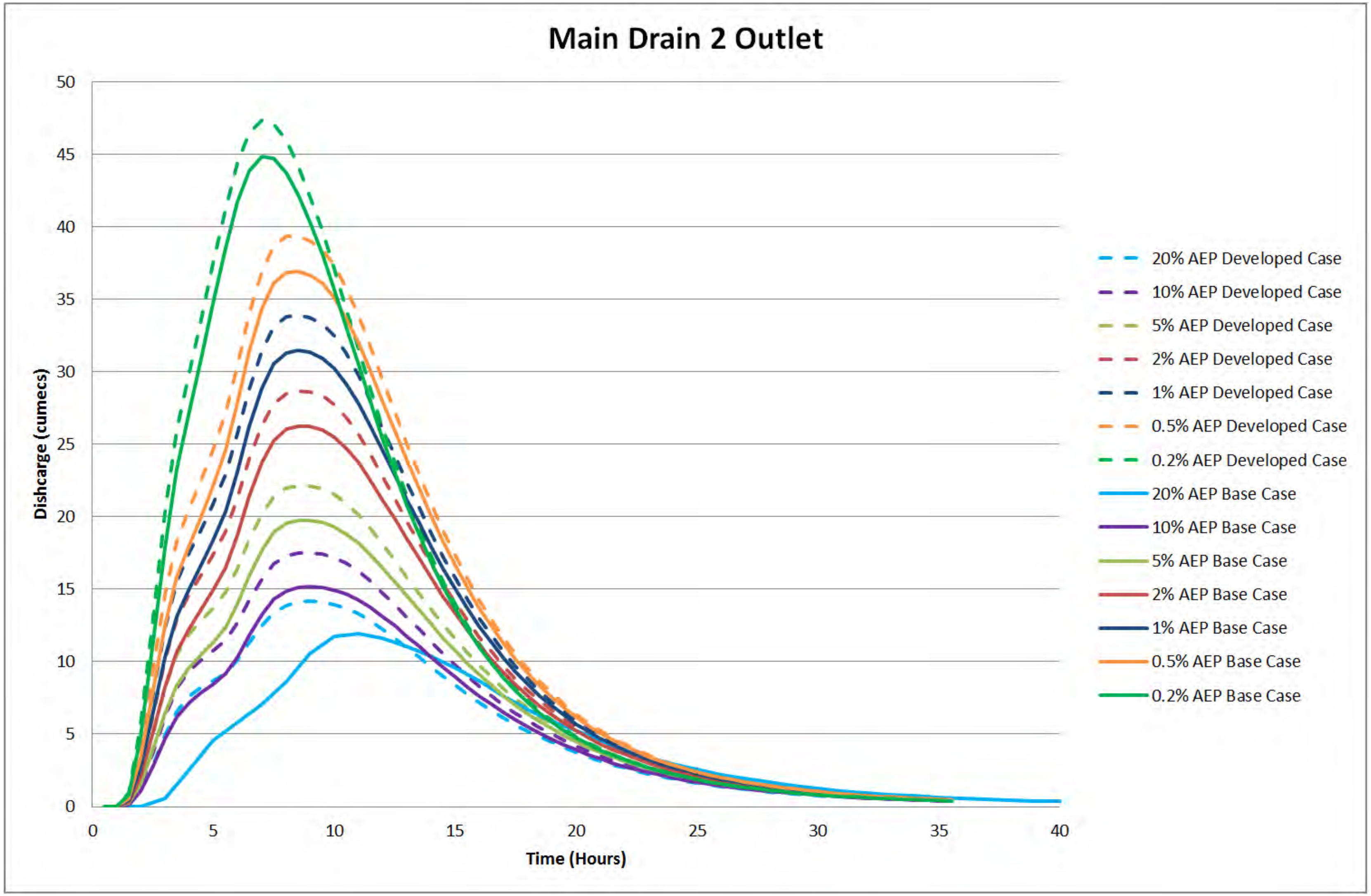


Figure 3-16 RORB Critical Climate Change Hydrographs at Main Drain 2 Outlet

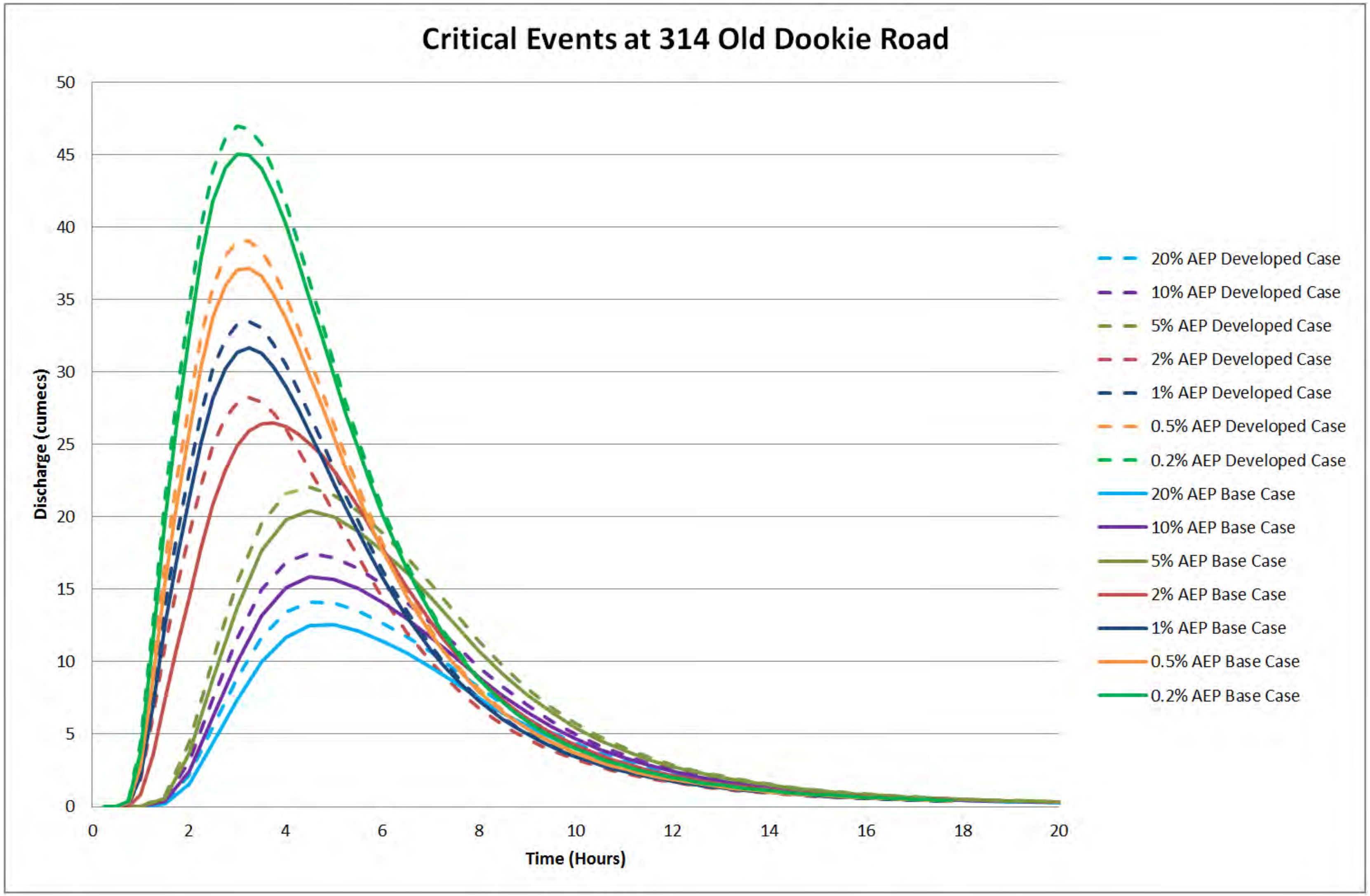


Figure 3-17 RORB Critical Climate Change Hydrographs at 314 Old Dookie Road

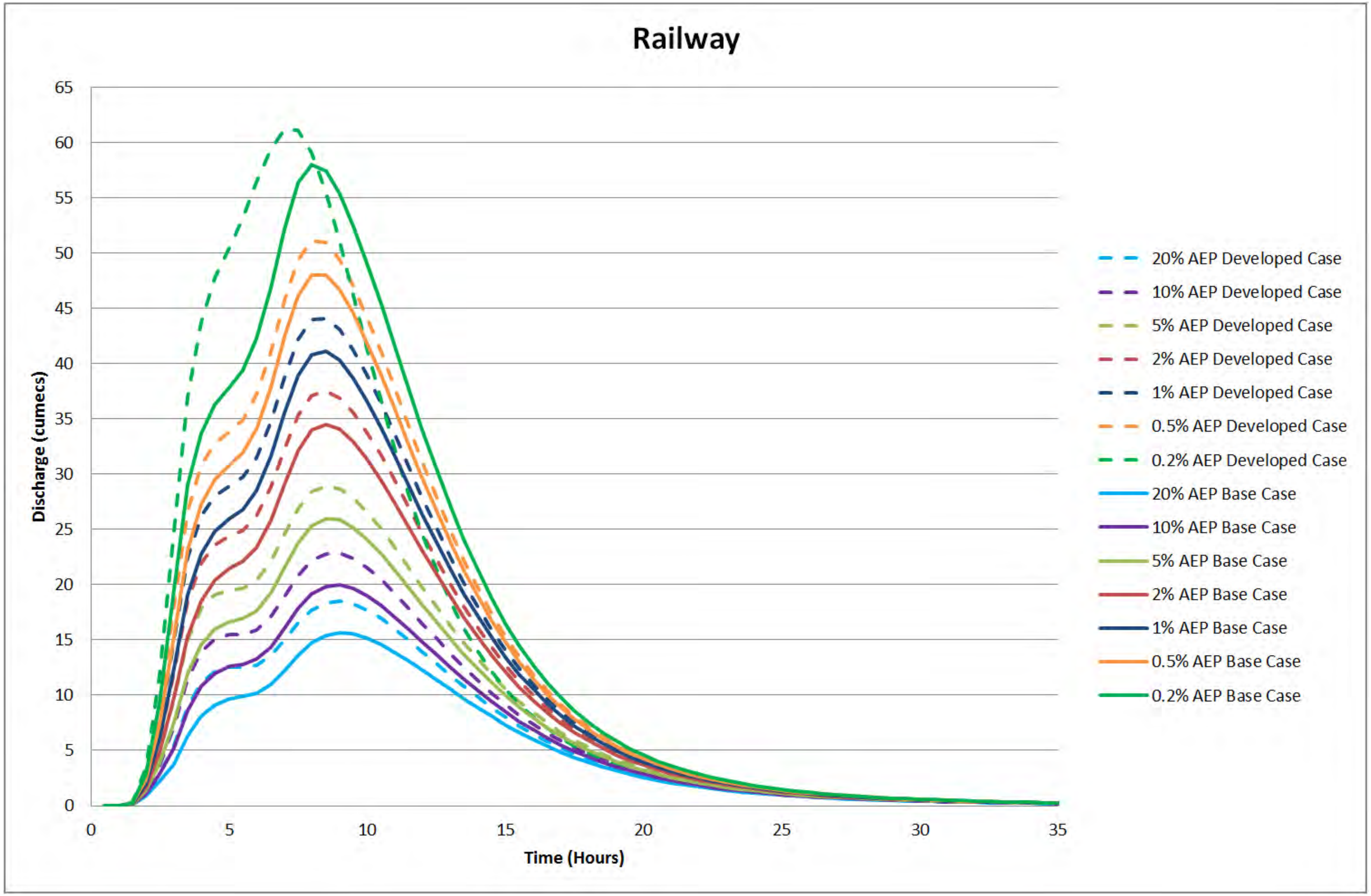


Figure 3-18 RORB Critical Climate Change Hydrographs at Railway

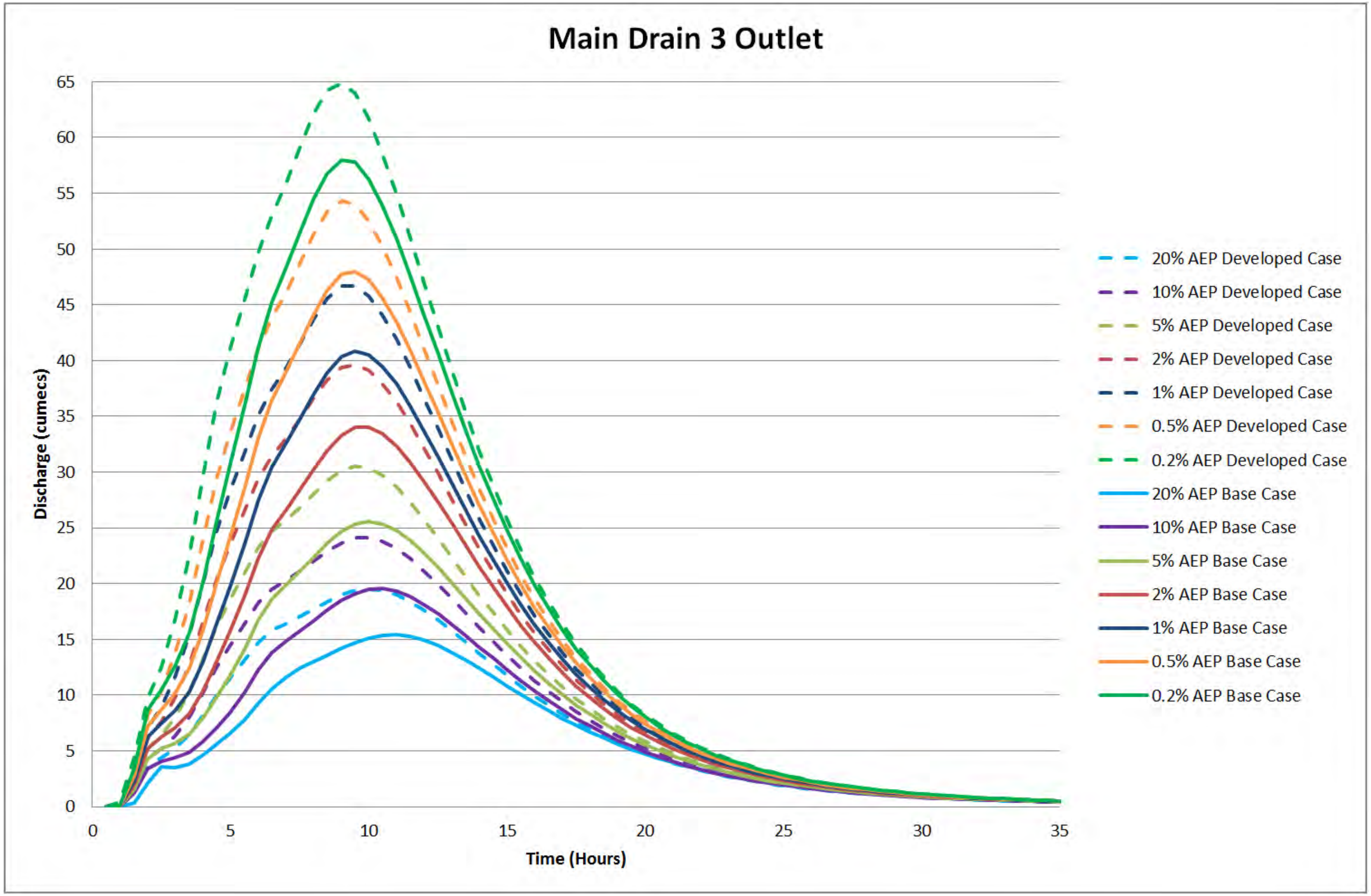


Figure 3-19 RORB Critical Climate Change Hydrographs at Main Drain 3 Outlet

3.3.5 Comparison to Previous Models

There are no known previous hydrologic models within the Shepparton East Overland Urban catchment of sufficient detail to allow comparisons.

3.4 Joint Verification with the Hydraulic Model

This section presents a discussion on the joint verification process undertaken for the flood model (the combined output of the hydrologic and hydraulic model). It has been presented here, ahead of the main discussion on hydraulics in Section 4. The reason for this is that the majority of the effort was involved in updating the rainfall input into the hydrologic model; hence it is convenient to report this work in the hydrology section.

The calibration of a model is a critical stage of the model development process, and it is considered good practice to calibrate models where there is sufficient data. According to the draft chapter on in the Australian Rainfall and Runoff revision (ARR, 2012), model calibration:

- Demonstrates that the model is capable of reproducing flood behaviour within acceptable parameter bounds; and
- Demonstrates the model is capable of adequately representing the physical system and, in doing so, producing reliable results.

Model calibration involves the adjustment of model parameters until an acceptable fit to the recorded flood data is achieved. Model validation on the other hand, uses the parameters determined in the calibration process and applies them to a different flood event. The validation results are then checked to ensure that an acceptable fit to the data has been achieved.

Model verification involves the comparison of modelled results to collected data, but is not as rigorous as model calibrations. Model verification can be a valuable tool in circumstances where the data does not support full model calibration or there are insufficient resources to undertake a full model calibration.

Due to the lack of stream or flow gauges within the catchment it was not possible to undertake the most robust calibration techniques. Fortuitously, a sizable flood event occurred during the Study allowing flood marks to be collected throughout the catchment. The Shepparton East hydrologic and hydraulic models underwent a verification process to fit the model to the observed data from this event.

The models were verified to the flood event that occurred on the 27th and 28th of February 2013. The hydrologic and hydraulic models went through a joint verification process whereby parameters from each were varied with each iteration of either or both of the models. The RORB hydrologic model was verified by maintain the k_c, m and fraction impervious and varying the initial and continuing losses with acceptable tolerances using the observed rainfall. The TUFLOW hydraulic model was verified by varying the model parameters (Manning's n) within acceptable tolerances and, if required, model schematisation.

3.4.1 Joint Verification Process

The joint verification process involves the following steps:

(1) Collect, collate and verify relevant data, including rainfall data, flood marks and anecdotal evidence.

(2) Create the storm event inputs developed in the hydrologic modelling process, using default loss parameters.

(3) Run the hydrologic model to determine inputs to the TUFLOW model

(4) Apply the hydrologic outputs to the TUFLOW model using typical model parameters

(5) Following the initial model runs, iterate both the hydrologic losses and/or the hydraulic model parameters with typical limits until optimised to achieve the best model verification to the observed flood marks.

3.4.2 Rainfall Analysis

Rainfall data was collected and was converted to a rainfall field (the spatial and temporal distribution of rainfall across the catchment) for application to the flood model. This involved the collation and review of the rainfall data in and around the catchment. The process undertaken is described in greater detail below.

Rainfall depth

The rainfall data was plotted and rainfall depths for the total event compared for each of the 20 rain gauges provided as shown in Figure 2-2. In general, the rainfall data was consistent and no data was removed from further analysis.

Once the data has been accepted a rainfall depth grid was created based on the collected data. A number of interpolation techniques were investigated including Triangulation, Inverse Distance Weighting, Kirging, Minimum Curvature and Nearest Neighbour Interpolation using the Vertical Mapper and Encom Discover packages. The Minimum Curvature technique provided the smoothest representation of the rainfall across the study area and for this reason it was the preferred method. The rainfall grid is shown in Figure 3-20.

The rainfall depth for each sub-catchment was determined by taking the average rainfall depth from the created rainfall grid.

Rainfall Timing

There were three sub-daily rainfall gauges in the vicinity of the study area; Shepparton Airport and the gauges operated by IK Caldwell at Grahamvale and Kialla. The temporal patterns from each of these were applied to the nearest sub-catchments as determined by Thiessian polygons. The resulting allocation of sub-catchments to pluviograph stations is shown in Figure 3-21.

Radar data from the Bureau of Meteorology was requested to assist with the spatial distribution of temporal patterns, however, this data was not available.

Annual Exceedance Probability of Rainfall Event

The Annual Exceedance Probability (AEP) of the February 2013 rainfall event at East Shepparton was determined using the Bureau of Meteorology Intensity Frequency Duration (IFD) calculator. Significant spatial variance was noted in the rainfall depths. For the majority of the catchment the rainfall gauges experienced a rainfall event that significantly exceeded the 1% AEP event. Rainfall gauges closer Shepparton Airport and to the south of the catchment experienced intensities in the 10 to 5% AEP range.

3.4.3 Joint Verification Results

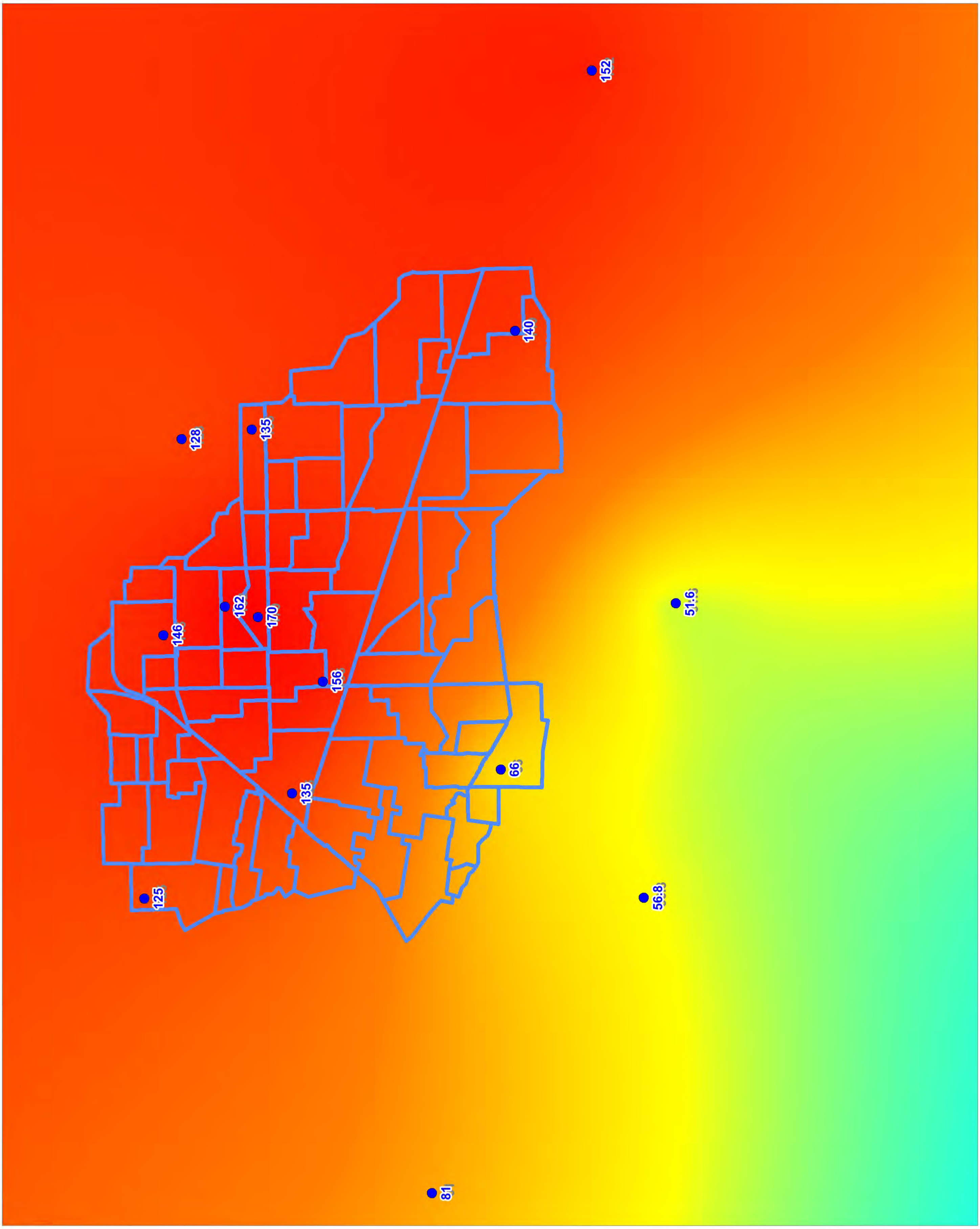
Given the sizable rainfall event it is unsurprising that the peak flow from the hydrologic RORB model at the reporting locations is similarly large. Through the iterative joint verification process it was found that high losses were required to match the recorded flood marks within the catchment. After a number of iterations an initial loss of 60 mm and a continuing loss of 5 mm/hour were found to best match the flood marks. Note the due to the long model run time there was a limit to the number of iterations that could be completed.

In general, the flows at the seven reporting locations were found to be within the 0.5 to 0.2% AEP range, with only Main Drain 2 and Doyles Road reporting flood events less than the 1% AEP. The peak flows and the approximate AEP are tabulated in Table 3-10.

Table 3-14 February 2013 Peak Discharges

Location	Beckham Road	Central Avenue	Doyles Road	Main Drain 2 Outlet	314 Old Dookie Road	Railway	Main Drain 3 Outlet
Peak Flow (m^3/s)	17.8	16.2	20.9	20.1	25.9	36.4	35.6
AEP	Greater than 0.2%	Between 0.5% & 0.2%	Approx. 0.5%	Approx. 1%	Approx. 0.5%	Between 0.5% & 0.2%	Between 0.5% & 0.2%

The hydraulic model results of the joint verification are presented in Section 4.6.



Title:

Shepparton East
February 2013 Rainfall Grid

Figure: **3-20**

Rev: **A**

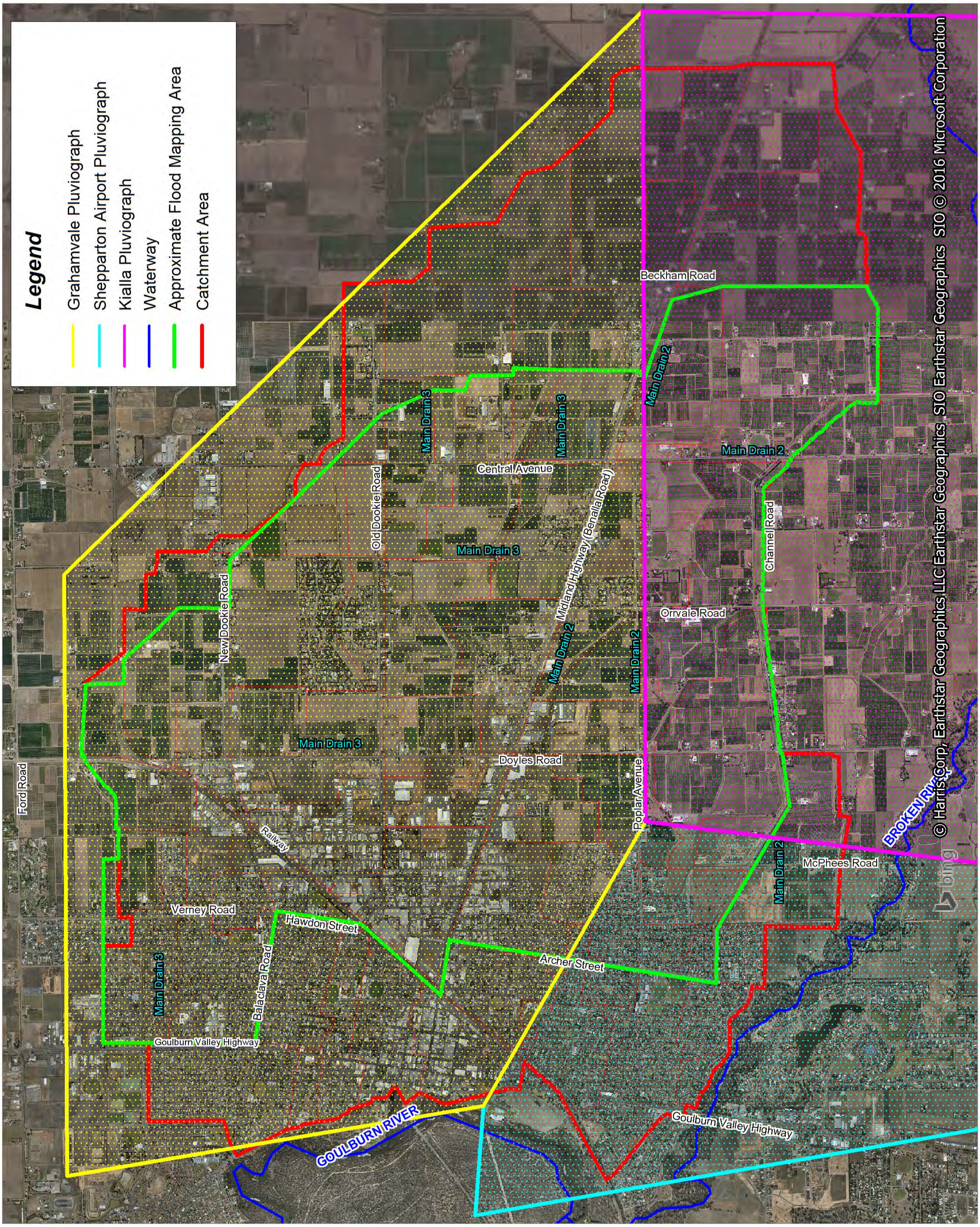
BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 1.25 2.5km
Approx. Scale

BMT WBM
www.bmtwbm.com.au

Filepath : T:\M8415.JL.SheppartonEast_Urban_FS\MapInfo\Drawings\R.M8415.003.00.Final\Fig3-20_RainfallGrid_RevA.wor



Title:

Shepparton East
February 2013 Thiessian Polygons

Figure: 3-21

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 1 2km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : T:\M8415.JL.SheppartonEast_Urban_FS\MapInfo\Drawings\R.M8415.003.00.Final\Fig3-21_ThiessianPoly_Plan_RevA.wor

4 Hydraulic Modelling

This section provides a description of the TUFLOW modelling process undertaken for the catchment. A 1D/2D dynamically linked TUFLOW hydraulic model was developed as part of this study with the aim of flood mapping the catchment for the calibration and design flood events.

The following sections detail the development of the hydraulic model used to produce the flood maps and other flood risk products. This chapter is presented in the following format:

- TUFLOW model development
- Verification of the TUFLOW model
- Design event modelling

4.1 Model Description

In order to produce flood extents, depths, velocities and other hydraulic properties for the study area a hydraulic model was developed. The study area, including the urbanised area of Shepparton as well as the farm zones to the east, were represented in the 2D domain with the drainage network modelled as connected 1D elements.

The model covers the full extent of the available LiDAR. The model extends from Main-Channel 10 to the South to the intersection of Beckham Rd and Channel Rd to the South-East, before heading North-West to the train line, heading west along Hawkins St to the intersection of Packham St. The downstream boundary is the Goulburn River to the West and the Broken River to the South. In total the model covers an area of approximately 40.2 km^2 of the catchment and floodplain, as shown in Figure 4-1.

The downstream boundaries of the hydraulic model, located at the Goulburn and Broken Rivers, are significantly downstream of the project mapping limit. The mapping limit for this Study is bound by Archer St, the Goulburn Valley Highway and the railway line along its western edge. Due to the flatness and relatively poor drainage of the catchment it was deemed necessary to extend the hydraulic model to the rivers to ensure realistic flow patterns by removing boundary affects.

4.1.1 Model Schematisation

As noted above, the model was schematised as a 2D model with embedded 1D elements that represented the underground drainage system as well as the open drains in and around Shepparton.

The floodplain topography and other significant hydraulic features, such as roads and embankments, were represented within the 2D domains. A 2D domain with a 5m grid resolution was used to represent the floodplain.

External inflows boundaries were applied to the model to represent flow from the eastern portion of the catchment that was not included within the hydraulic model domain. The downstream boundaries of the model are the Goulburn and Broken Rivers. Internal inflow boundaries were distributed throughout the model domain to ensure a 'realistic' distribution of runoff across the study area.

Details of the model setup and application are described below and shown in Figure 4-1.

4.2 Hydraulic Modelling

The following sections provide details of the hydraulic modelling methodology and assumptions used to establish the key elements of the hydraulic model.

4.2.1 TUFLOW Model Version

Model runs were performed with the 2013-12-AE-iDP-w64 build of TUFLOW.

4.2.2 Model Extent

As described above, the extent of the hydraulic model is limited to the extent of the high quality LiDAR available for the study. The extent of the LiDAR is shown in Figure 2-1. As such, the hydraulic model domain extended from Main-Channel 10 to the South to the intersection of Beckham Road and Channel Rd to the South-East, before heading North-West to the railway line, heading West along Hawkins St to the intersection of Packham St. The downstream boundary is the Goulburn River to the West and the Broken River to the South. In total the model covers an area of approximately 40.2 km^2 of the catchment and floodplain, as shown in Figure 4-1.

This model extent allows for the flood behaviour within the mapping limit of the study area to be reliably represented without the influence of boundary effects.

4.3 2D Domain

4.3.1 Topography

The geometry of the 2D floodplain and watercourses were established by constructing a uniform grid of square elements from the DEM. This TUFLOW grid provides the topography for the hydraulic model. The DEM used in the hydraulic model was based on the LiDAR provided by GBCMA.

4.3.2 Breaklines

Breaklines are often incorporated into TUFLOW models to add detail to coarser grids, such as gutters, roads, railways, or to ensure that certain aspects of the terrain that would act as hydraulic controls are included, such as levees, embankments or other solid walls.

Given the high resolution of the TUFLOW grid, 5m as discussed below, significant floodplain features such as such as roads and embankments were generally well represented.

However, at a small number of locations it was necessary to reinforce features through the use of breaklines and the like. These locations included the railway embankment, and reinforce embankments of Doyles and Old Dookie Roads. Similarly, it was necessary to reinforce the open spoon drains along the edges of a small number of roads predominately within the farm zones.

4.3.3 Retarding basins

Retarding basins (RB) are designed to attenuate a significant volume of water during flood events. For this reason it is important to correctly represent the capacity of retarding basins in TUFLOW. If applicable, any embankments and spillways should also be accurately detailed to ensure the volume and spill rate from the retarding basin is represented in TUFLOW.

In total 47 RB's exists within the catchment, these are detailed in Appendix A. Of these RB's 5 are privately owned and operated, with the remaining being owned by Greater Shepparton City Council. Due to the general lack of grade within the catchment all but two of these RB's are pumped and as such operate as depression storages rather than as the more typical gravity outlet controlled flow RB.

4.3.4 Grid Resolution

One of the key considerations in establishing a 2D hydraulic model relates to the selection of an appropriate grid element size. Element size affects the resolution, or degree of accuracy, of the representation of the physical properties of the study area as well as the size of the computer model and its resulting run times. Selecting a very small grid element size will result in both higher resolution and longer model run times.

In adopting the grid size for the model, the above issues were considered in conjunction with the final objectives of the study. To ensure accurate representation of flooding within the catchment whilst keeping model runtimes to a reasonable limit a grid size of 5 metres was adopted for model. Each square grid element contains information on ground topography, sampled from the DEM and surface resistance to flow (Manning's 'n' value).

4.3.5 Surface Roughness

The roughness layer, or Manning's 'n' layer, for the floodplain were based on areas of different land-use type determined from the planning scheme, aerial photography and site inspections. These initially values were based on standard texts such as *Open Channel Hydraulics* (Chow 1959). The adopted Manning's 'n' coefficients are summarised in Table 4-1 and the layer is shown in Figure 4-2. These values were determined during the calibration and validation process (Refer to Section 4.6).

Table 4-1 2D Domain Manning's 'n' Coefficients

Land Use	Manning's 'n' – Existing Conditions	Manning's 'n' – Ultimate Conditions
Infrastructure		
Roads - paved	0.020	0.020
Railway	0.035	0.035
Development		
Residential	0.200	0.300
Public building & Commercial and industrial - low density	0.100	0.200
Commercial and industrial - town	0.200	0.400
Schools and Hospitals	0.060	0.060
Parks, Waterways and Agriculture		
Parks & Recreational Zone	0.035	0.035
Conservation with moderate vegetation	0.065	0.065
Unmaintained grass/grazing	0.045	0.045
Orchards	0.060	0.060

4.4 1D Network

4.4.1 Underground Drainage Network

Due to the large uncertainty in the existing underground drainage network within Shepparton a survey was commissioned for the Study.

Key features of the drainage system, including pipes and pits, were modelled in 1D and linked to the 2D domain. A Manning's 'n' of 0.013 was adopted for the stormwater pipes. All supplied council pipes that were in the mapping limit of the study area were modelled. Downstream of the mapping limit only the trunk drains were included to allow water to leave the mapping limit realistically.

Where possible invert levels were adopted from the supplied council GIS pipe data set or the survey. For those pipes where invert level information was not available, inverts were derived from adjacent pipes, by interpolation or by using the ground level on the DEM and an assumed minimum cover depth.

Entry pits that connected to the council pipes within the mapping limit were modelled as boundaries between the 1D network and the 2D domain. They were also assumed to be 900mm wide and have 150mm high kerb inlets.

The 1D domain of the model was run on a 1.0 second timestep. This timestep is within the range recommended by the TUFLOW manual. It is half of the timestep required by the 2D domain which is running at 2.0 seconds.

4.4.2 Drainage Network Losses

Pipe junction losses were modelled using the Engelhund manhole feature of TUFLOW. Additional losses were applied as appropriate to account for entrance and exit losses at the first and final pipes respectively.

4.4.3 Open Drainage Network

The catchment has a large number of major open drains, irrigation channels and road side drains. The vast majority of these drains are less than 10 metres wide bank to bank and are therefore unsuitable for modelling within the 2D domain with a grid cell resolution of 5 metres.

For this reason an imbedded 1D channel was incorporated into the model. These drains are wholly man-made and for the most part regular trapezoidal shaped channels. The cross-section details of these drains were extracted from survey commissioned for the Study. A Manning's n of 0.035 was applied to all open drains which corresponds to a clean strait channel with some stones and weeds (Chow, 1959).

4.5 Boundary Conditions

A hydraulic model requires inflow boundaries and outlet boundaries to allow water into and out of the model in a realistic manner. Often 2D hydraulic models will have external and internal inflow boundaries. The external inflow boundaries accounts for flow generated from outside of the model extents whereas internal boundaries account for the runoff generated from within the model extents. Flow is removed from the model through downstream boundaries, which are generally a fixed water level or a stage discharge relationship.

The Shepparton East TUFLOW model has external inflow boundaries along the eastern edge of the model at the LiDAR extent, internal distributed inflow boundaries and downstream stage fixed water levels. The external and internal inflow boundaries were obtained from the RORB hydrological modelling described in Section 3. The location and distribution of boundaries are shown in Figure 4-1.

4.5.1 External Boundaries

There is generally an upstream and a downstream boundary in hydraulic models. The upstream boundary is usually a flow-time series (or hydrograph) and the downstream boundary is often a level-time series or a rating curve (when there is data available). For the model a fixed water level of 110 m AHD has been adopted for this Study. Due to the distance from the downstream boundary to the mapping limit the levels in the area of interest are not influenced by the level in the Goulburn-Broken system.

The upstream inflows derived from the RORB model were applied as flow versus time boundaries directly to the 2D domain at the appropriate location at the limits of the available LiDAR.

4.5.2 Internal Boundaries

The internal inflow boundaries account for runoff generated within the model domain. The location of these boundaries is shown in Figure 4-1. The internal inflow boundaries used were "excess rainfall" boundaries. These boundaries are the determined rainfall after the initial and continuous losses have been removed. The rainfall excess is taken from the output of the RORB hydrologic model. In total, 92 internal inflow boundaries were applied using a number of application methods. These are described in detail below;

Flow-Time Boundaries to 2D domain

These boundaries were applied in the predominately in the farm zone areas of the model. Within these zones the flows are initially applied to the lowest surface within the 2D domain, should other areas within the sub-area begin to 'wet' then flow is distributed across all 'wet' cells.

Flow-Time Boundaries to Pits

These boundaries were applied in the area immediately upstream of the western mapping limit in the predominately urban areas of the catchment where a significant drainage network exists. In these locations the flow is applied to the surface of the model at the location of any pits, the capacity of the pit is used to determine the volume of water that can enter the pipe, any volume that cannot enter the pit/pipe is applied to the surface of the 2D domain.

Flow-Time Boundaries Distributed over 2D Surface

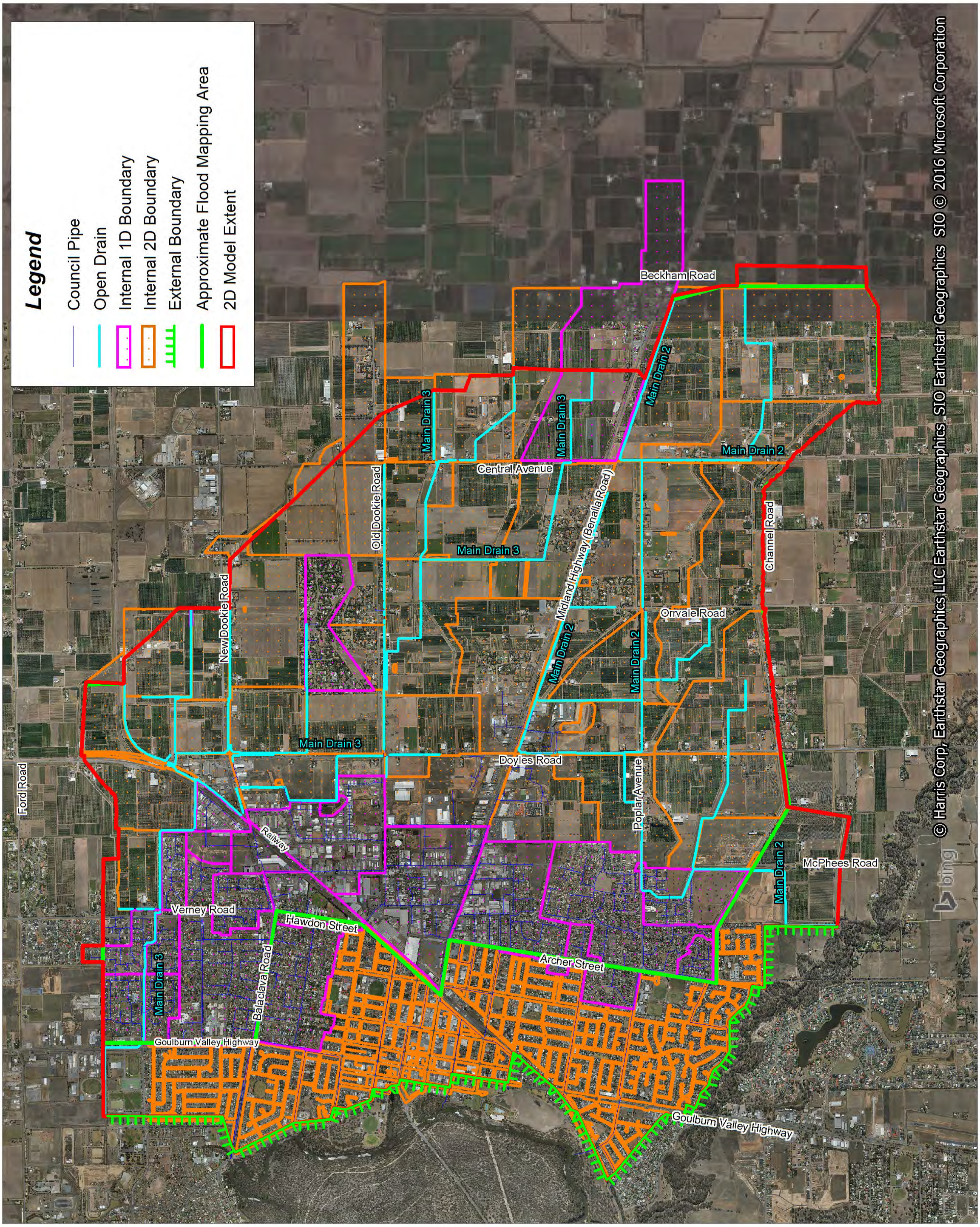
The boundaries distribute water to all cells within the 2D domain, effectively a 'rain-on-grid' technique using rainfall excess from the hydrologic RORB model. These boundaries were applied in two general locations; in retarding basins & downstream of the mapping limit. Within retarding basins all cells will be wet so this is appropriate. As discussed above, flood mapping is limited to the west by Archer St, the railway and the Goulburn Valley Highway. However to minimise boundary effects it was deemed prudent to extend the hydraulic model to the Goulburn and Broken Rivers. To ensure realistic flood conditions between the mapping limit and the downstream boundary of the hydraulic model the 'rain-on-grid' method was deemed most appropriate due to the limited underground drainage network included in the model within these portions of the hydraulic model. The application of flows within this area was limited to the road network however the inflows include the contribution from the lots.

4.5.3 1D / 2D Linking

The 1D network was dynamically linked to the 2D domain through boundary cells. These boundary cells pass water from one domain to the other. In the model 1D/2D linking occurred at the 1D pipe network and the 2D domain at the pits. Accordingly, boundaries were set at these locations in the model.

Similarly, along the banks of the embedded 1D open channel drains, flow was allowed to interchange between the 1D and 2D domains freely. To ensure the correct interchange water level between domains the banks of the open channel drains were reinforced in the 2D domain.

The appropriate entry and exit losses were applied to culverts or pipes that have headwalls, or similar, as their entrance/exit structure were connected directly to the 2D domain.



Title:

Shepparton East TUFLOW Model Layout

Figure: 4-1

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

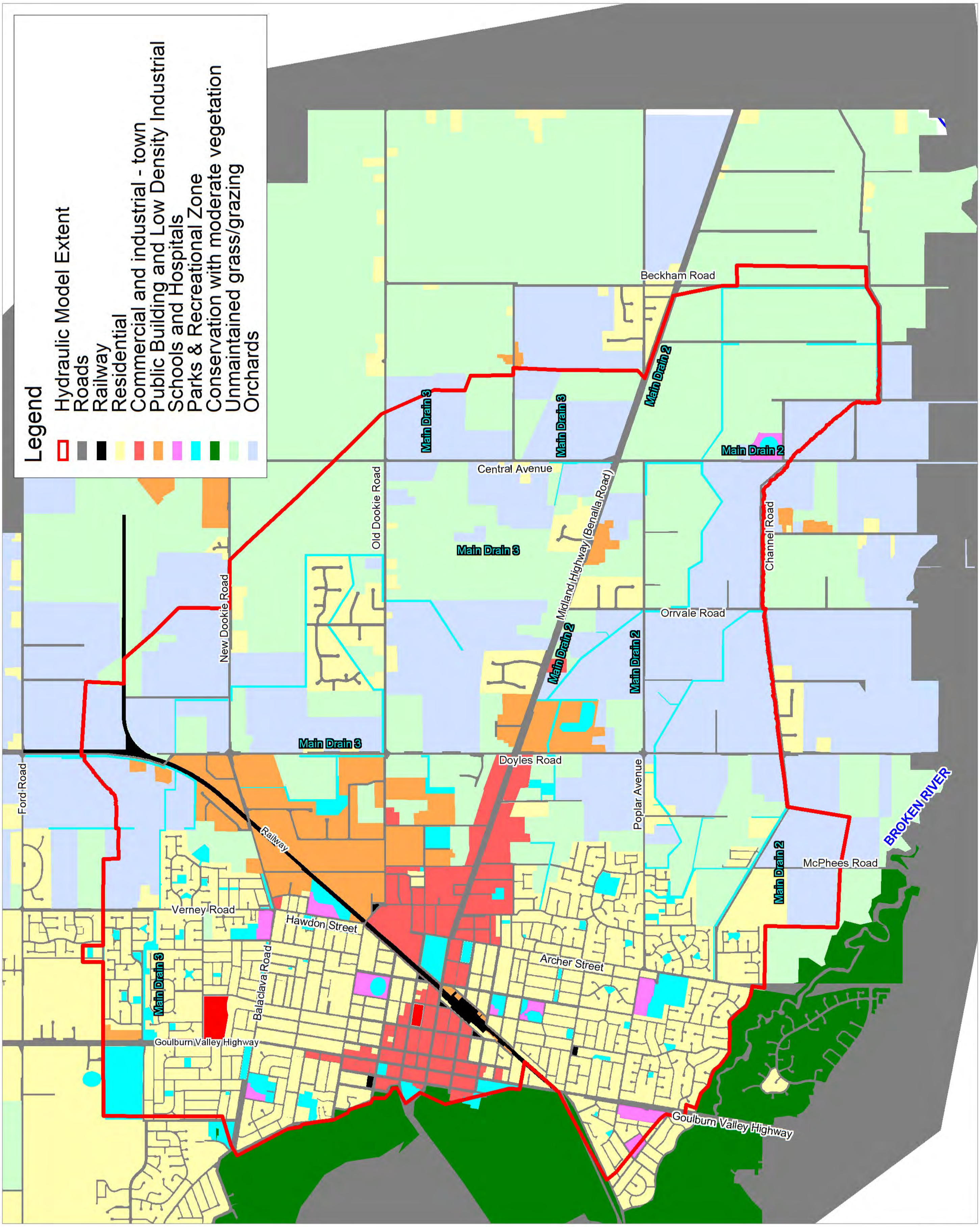
0 1 2km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : T:\M8415.JL.SheppartonEast_Urban_FS\MapInfo\Drawings\R.M8415.003.00.Final\Fig4-1_TUFLOW_RevA.wor



Title:

Shepparton East
Manning's 'n' Roughness Distribution - Existing Case

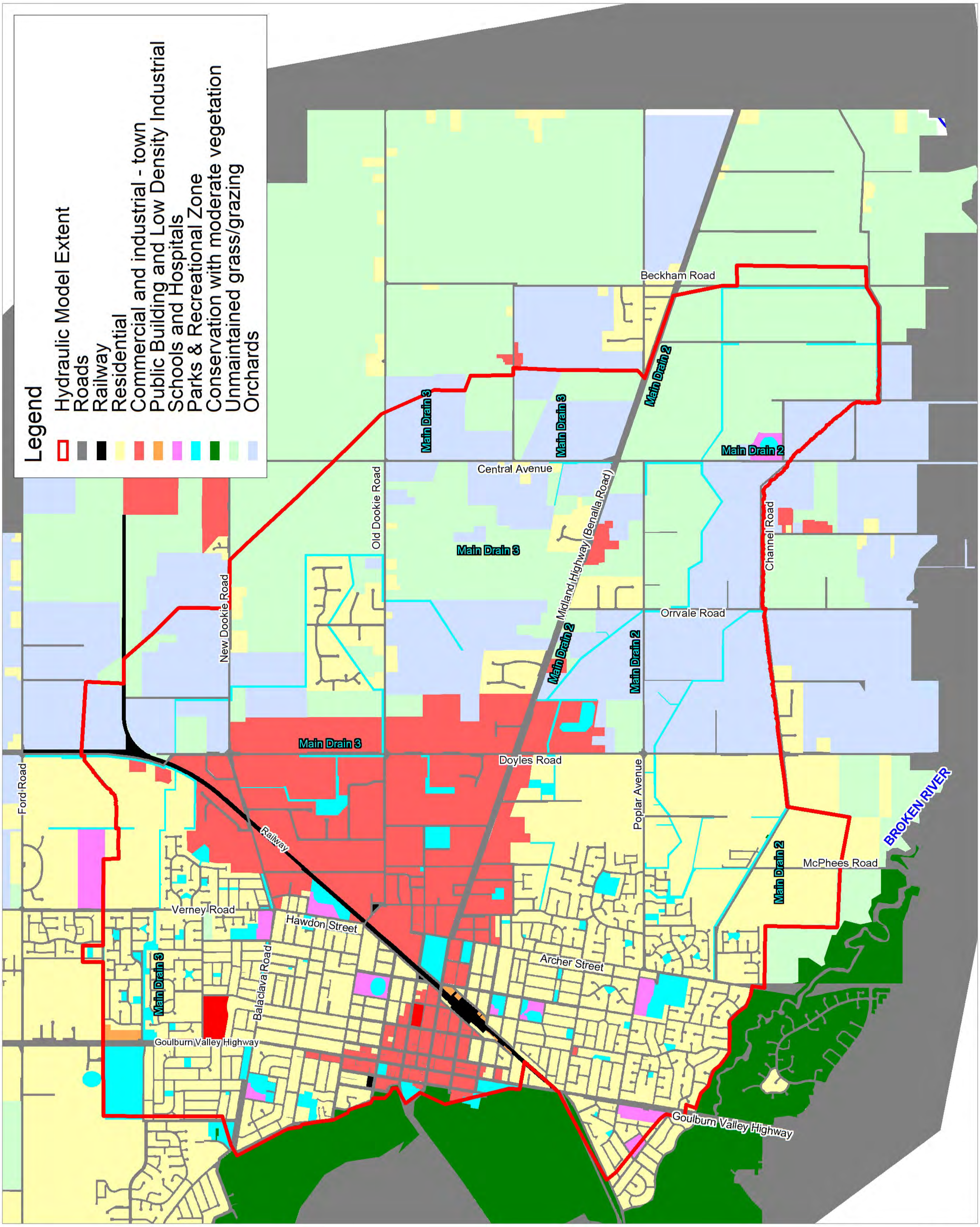
Figure: **4-2**

Rev: **A**

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

BMT WBM
www.bmtwbm.com.au

Filepath : T:\M8415.JL.SheppartonEast_Urban_FS\MapInfo\Drawings\R.M8415.003.00.Final\Fig4-2_E01_Manning's_RevA.wor



Title:

Shepparton East
Manning's 'n' Roughness Distribution - Developed Case

Figure: **4-3**

Rev: **A**

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 1 2km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : T:\M8415.JL.SheppartonEast_Urban_FS\MapInfo\Drawings\R.M8415.003.00.Final\Fig4-3_U01_Manning's_RevA.wor

4.6 Hydraulic Model Verification

As discussed in Section 3.4, the hydraulic model underwent a joint verification with the hydrologic model to the flood event that occurred on the 27th and 28th of February 2013. The TUFLOW model was verified by varying the model parameters (Manning's n) within acceptable tolerances and, if required, model schematisation. As mentioned above, the catchment lacks a stream gauge; as such the verification of the hydraulic model was jointly verified by altering the initial and continuing losses in the hydrologic model of the observed rainfall.

The following sections provide details of the aforementioned processes as well as outline the assumptions made during the hydraulic model calibration and validation process and presents the calibration and validation results.

4.6.1 Verification of the February 2013 Flood Event

As discussed in Section 2.5 in February 2013 the catchment experienced a significant flood with a rarity of between 0.5% and 0.2% AEP. While the available data did not support model calibration or validation it was considered to be important to assess to provide additional certainty of the suitability of the models developed for this Study.

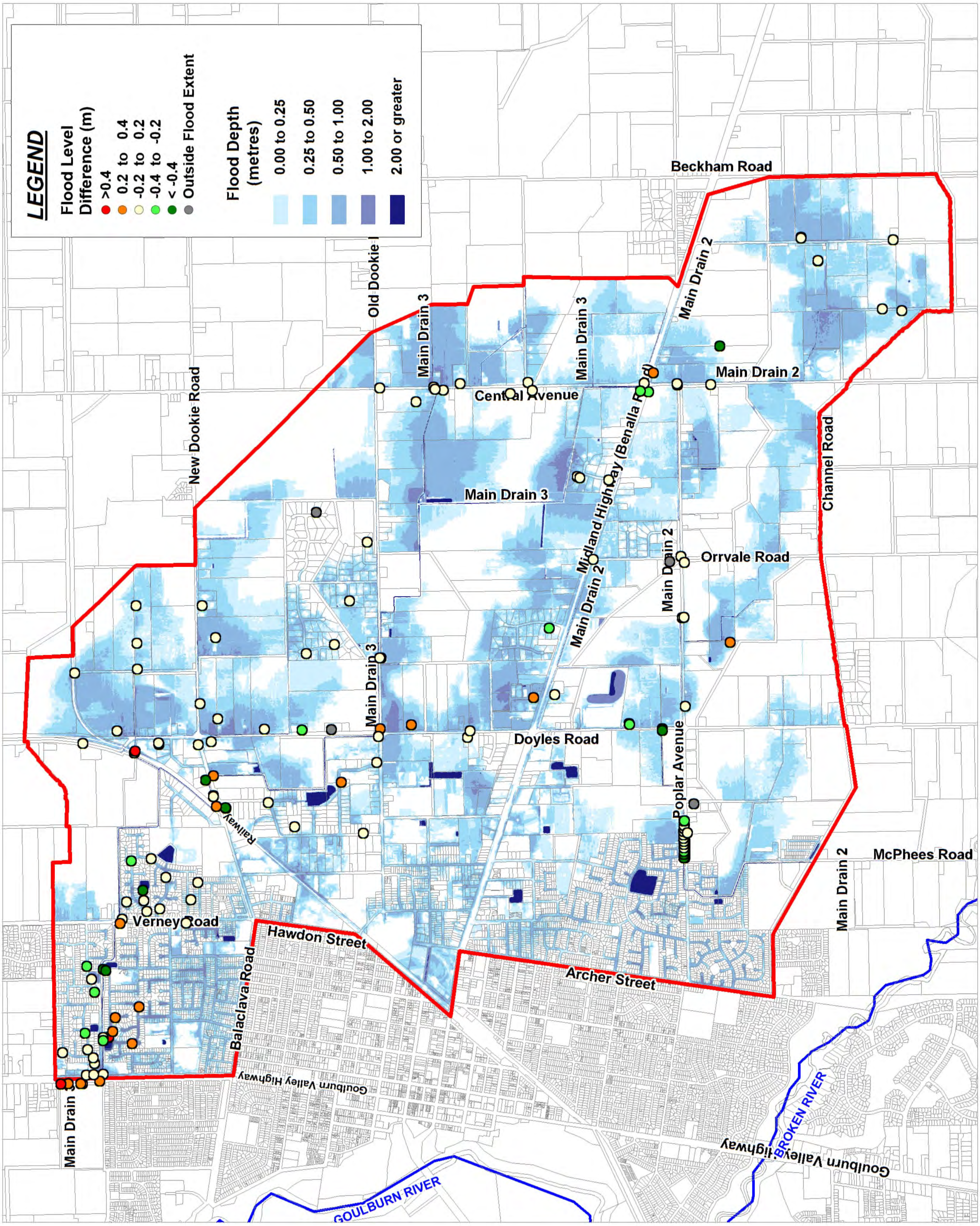
To undertake this verification event, the hydrologic model was run with the calibrated parameters (from the rational method calibration) and the resulting hydrographs applied to the hydraulic model. As described above in Section 3.4.1, depending on the outcome of an individual model simulation both the hydrologic loss parameters and/or the hydraulic roughness parameters were altered. This iterative process was undertaken a number of times until an acceptable fit to the available data were achieved.

The results of the joint verification are presented in Figure 4-4 along with the flood height difference for each flood mark. Overall, given the information available, a good fit to the data was achieved with the majority (92 out of 151) of modelled flood levels within ±0.2 m of the surveyed flood marks.

Table 4-2 Comparison of Floodmarks to Modelled Flood Level

Statistical Measure of Difference (m)	Difference between Floodmarks and Hydraulic model results
Mean	-0.06
Median	-0.04
Standard Deviation	0.25
Lower Quartile	-0.19
Upper Quartile	0.09

This indicates, that the model setup, the parameters and assumptions used in the model are appropriate for use in the design event modelling required for the study. That is, these results taken together, demonstrate as well as possible, that the Shepparton East TUFLOW model is suitable for the purposes of this study.



Title:

Shepparton East
February 2013 Verification Event Peak Flood Depths

Figure: 4-4

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 0.75 1.5km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : T:\M8415.JL.SheppartonEast_Urban_FS\MapInfo\R.M8415.003.00.Final\Fig4-4_CAL_IL60CL5_20130228_039_RevA.wor

4.7 Design Event Modelling

4.7.1 Design Event Modelling

The hydraulic model was run for a number of design events. These design events were used to undertake the four scenario conditions flood mapping and the damages assessments for the Study. The four scenarios included the base case, developed case, climate change and climate change with development. The following events were run in the hydraulic model:

- 20% AEP (5 year ARI) event;
- 10% AEP (10 year ARI) event;
- 5% AEP (20 year ARI) event;
- 2% AEP (50 year ARI) event;
- 1% AEP (100 year ARI) event;
- 0.5% AEP (200 year ARI) event; and
- 0.2% AEP (500 year ARI) event.

4.7.2 Storm Duration Selection

Initially the full suite of existing case design storm durations for all AEPs was modelled in TUFLOW. A peak flood surface was generated from these events and analysis was undertaken to determine the critical flood events.

This analysis indicated that 10 durations resulted in peak flooding throughout the catchment. These events were typically long duration, volume dominated events, which is typical of flat-poor draining catchments. Following this analysis, the 10 storm durations listed in Table 4-3 were modelled for the remaining events and scenarios.

Table 4-3 Storm Durations Modelled for Final Model

Critical Duration in Hours									
1	2	3	4.5	6	9	18	36	48	72

As part of the mapping procedure a peak flood height and extent envelope was developed from the 10 durations and the peak envelope flood surfaces mapped.

5 Modelling Quality Assurance

To ensure that results and outcomes that have determined as part of the Study can be used for any future assessments or works to be undertaken within the Catchment, an extensive Quality Assurance (QA) program has been undertaken. This includes independent review of all modelling and reporting outputs.

A comprehensive independent review was undertaken on the flood model for both the hydrologic and hydraulic modelling components, an overview of which is provided below.

5.1 Hydrologic (RORB) Model Review

The independent hydrologic (RORB) model review included, but is not limited to, the following checks:

- The methodology of the model development and calibration and validation process was checked for suitability and agreed upon.
- The catchment definition, sub-catchment breakup and reach alignments were appropriate for the catchment characteristics.
- That the RORB model was developed correctly to ensure that input data, catchment characteristics and rainfall was appropriately represented in the model.
- A review of the model calibration output results, including a review of the adopted parameters for design event modelling.

5.2 Hydraulic (TUFLOW) Model Review

5.2.1 General Quality Assurance

As part of the quality control of the model, a review of the TUFLOW messages output was carried out. Messages during compiling of the model were reviewed and any issues resolved. Warnings produced by TUFLOW during the run were also investigated. Locations and structures causing recurring warnings were identified and a solution implemented to reduce or remove the cause of the issue.

5.2.2 1D Domain

As part of the QA process for the 1D domain, the following checks were performed:

- Pipe inverts were checked for reverse gradients and pipes generally meeting typical minimum cover requirements. Due to the flat nature of much of the catchment a number of pipes exhibited reverse grades however the vast majority of pipes had a positive gradient.
- 1D/2D links were selecting the correct number of cells required to represent the width of the 1D structure. This involved checking the 1d_to_2d_check file.
- The dH (change in water level) values in the 1d_mmH results file were checked for disproportionate changes in water levels between adjacent pipe elements.

- For the pipe network, the maximum percentage full and percentage of time flowing full were checked using the 1d_ccA results files for all ARIs and durations. During the 100 year ARI event 96% of all pipe assets in the model were found to be running full.
- Pipe flows and velocities were checked against standardised slope discharge graphs and Colebrook White calculations. This comparison indicated a close agreement between the TUFLOW results and other methods.
- Pipe flow time series data was checked using the 1d_Q.csv and TS MID/MIF files.
- The 1D mass balance was checked (please refer to Section 5.2.4 below for details).

5.2.3 2D Domain

As part of the QA process for the 2D domain the following checks were performed:

- A TIN was created from the zpts check file to ensure the 2D cell size resolution was appropriate to reproduce the topography. The TIN was compared to the LiDAR DEM, and the TIN was reviewed to ensure the correct implementation of any breaklines, z-shapes or other terrain altering layers. Key hydraulic controls were reviewed to ensure a continuous and appropriate representation in the model grid. The TIN created from the zpts check file corresponded well to the LiDAR DEM as well as the topographical modifications made (embankments, gully lines, etc).
- Material roughness was checked by importing and thematically mapping the uvpt_check file to ensure surface resistance was applied correctly.
- Initial water levels in the model were checked by reviewing the grd_check file.
- The 2D mass balance was checked (please refer to Section 5.2.4 below for details).

5.2.4 Volume Checks and Mass Conservation

Volume checks and conservation of mass are arguably the most important checks. Volume checks are important as they check that all the input hydrographs are being applied to, and interpreted correctly by, TUFLOW. Mass conservation is important as it's an indicator of model health and therefore the likely accuracy of the computed solution. As part of the QA process, the following checks were performed:

- At external flow boundaries, the hydrograph shapes were checked to ensure they matched with the input flow hydrographs.
- Volume checks of the model are shown for the critical duration 5, 100 year ARI events in Table 5-1. The volume reported by the RORB model was compared to the volume in the TUFLOW model. The volume into the TUFLOW model was determined by calculating the sum of the inflow boundaries in both the 1D and 2D domains. This was compared to the volume leaving the final RORB hydrograph at the catchment outlet. This table indicates a close agreement between the RORB volume and the TUFLOW volume.

Table 5-1 Volume Check

Model	5yr 2hr	100yr 72hr
RORB	1,418,227	3,474,173
TUFLOW	1,413,086	3,485,736
% Difference	0.4%	-0.3%

- Conservation of mass was checked by reviewing the percentage cumulative mass error (%CE) reported by TUFLOW. These values were reviewed for the full range of existing case models and found to be within the ± 1% range typical for a healthy model. A number of the sensitivity test model, i.e. increased developed scenario and climate change models, were found to have mass errors exceeding ± 1%. Following discussion with GBCMA it was decided to accept these %CE as these models form part of the sensitivity analysis and do not significantly alter the outcomes of the Study.
- The 1D and 1D/2D linkage mass balance was also checked by thematically mapping the TSMB and TSMB1d2d MID/MIF files.