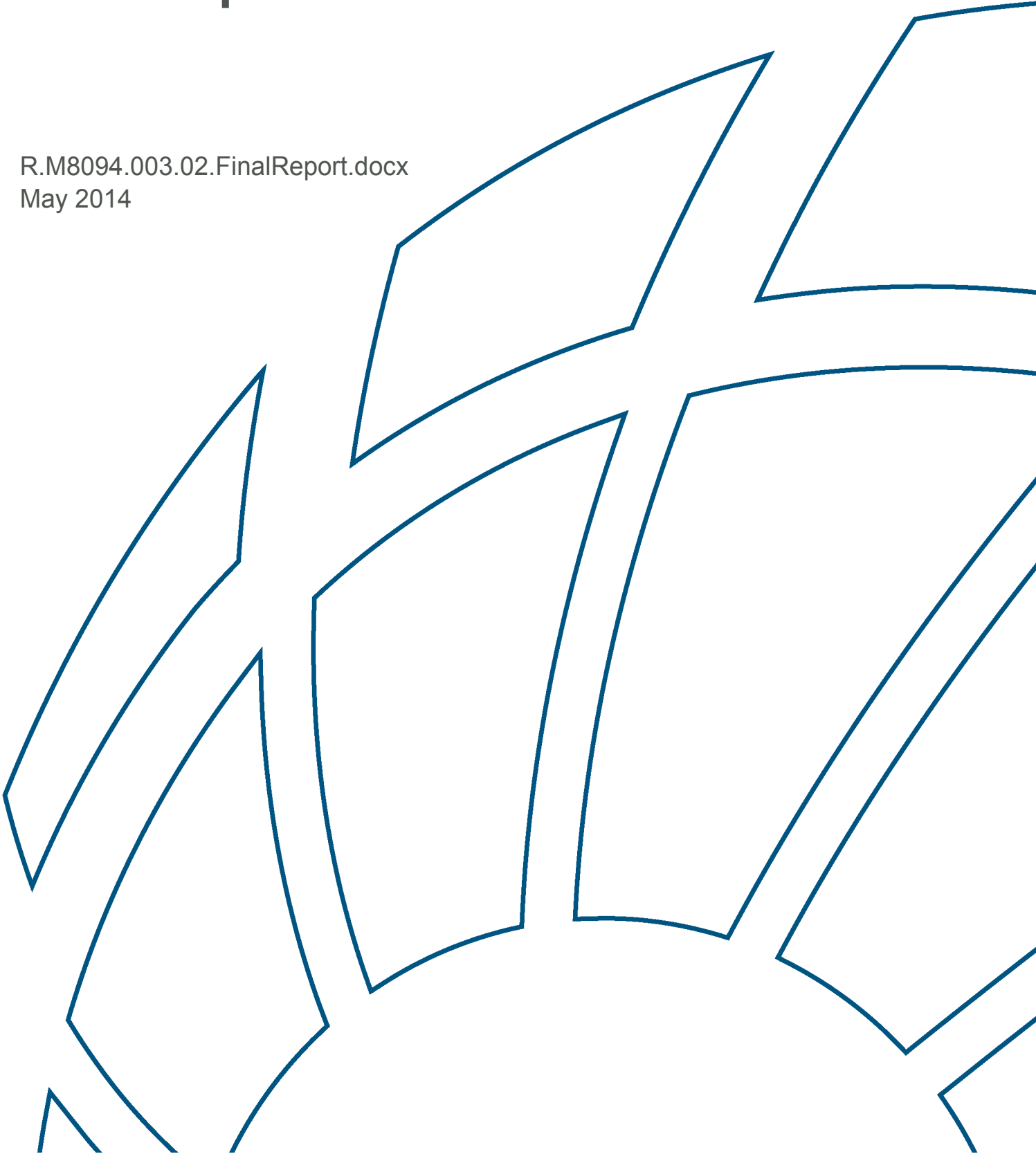


Highton Drainage / Flood Study Final Report

R.M8094.003.02.FinalReport.docx
May 2014



Highton Drainage/Flood Study Final Report

Prepared For: City of Greater Geelong

Prepared By: BMT WBM Pty Ltd (Member of the BMT group of companies)



Offices
Brisbane
Denver
Karratha
Melbourne
Morwell
Newcastle
Perth
Sydney
Vancouver

DOCUMENT CONTROL SHEET

<p>BMT WBM Pty Ltd BMT WBM Pty Ltd Level 5, 99 King Street MELBOURNE VIC 3000 Australia PO Box 604 Collins Street West VIC 8007</p> <p>Tel: +61 3 8620 6100 Fax: +61 3 8620 6105</p> <p>ABN 54 010 830 421 www.wbmpl.com.au</p>	<p>Document : R.M8094.003.02.FinalReport.docx</p> <p>Project Manager : Joel Leister</p> <hr/> <p>Client : City of Greater Geelong</p> <p>Client Contact: Richard Wojnarowski</p> <p>Client Reference C11503</p>
--	--

Title :	Highton Drainage/Flood Study Final Report
Author(s) :	Michael South and Joel Leister
Synopsis :	This report documents the methodology and results for the Highton Drainage / Flood Study.

REVISION/CHECKING HISTORY

REVISION NUMBER	DATE OF ISSUE	CHECKED BY	ISSUED BY
0	25/09/2013	MT	JL
1	21/10/2013	MT	JL
2	08/05/2014	MT 	JL 

DISTRIBUTION

DESTINATION	REVISION			
	0	1	2	3
CoGG	1	6	1	
CoGG (pdf)	1	1	1	
CoGG (doc)	0	0	1	
BMT WBM File	1	1	1	
BMT WBM Library	0	1	1	

EXECUTIVE SUMMARY

Study Objective

The Kardinia Creek Catchment (C 250) is named after the waterway that existed prior to the construction of the main drainage system within the suburbs of Highton, Wandana Heights, Waurn Ponds and Belmont. This catchment has been identified as having a known problem with drainage related or “stormwater” flooding. The City of Greater Geelong has received numerous reports of flooding problems within the Kardinia Creek catchment, especially within the suburb of Highton, in the lower portion of the catchment. The majority of the problems relate to the characteristics of the catchment (topography, development density and age). The removal of the natural waterway and the installation of various main drains (typically built prior to the 1980's) has resulted in limited capacity in the underground pipes, whilst a lack of clear overland flowpaths results in surcharge and excess flows through private property. The primary objectives of the Highton Drainage/Flood Study were to characterise existing flooding and to develop an appropriate flood management strategy to mitigate stormwater flooding in the study area.

Study Methodology

The study was carried out under the following core elements.

1. *Preliminary Tasks* – These were project initiation, including an inception meeting and initial site inspection, along with a data collation and review exercise. The data collation and review phase included an analysis of previous drainage investigations, council policy, aerial photography of the area, topography, GIS datasets, digital plans and design information.
2. *Digital Terrain Model* – Photogrammetry and LiDAR data of the study area was provided by the City of Greater Geelong (CoGG) and used to assist in the hydrological model development. Additional continuous elevation strings representing features of hydraulic importance (such as retarding basin crests) were sourced for use in the modelling.
3. *Hydrological and Hydraulic Modelling, and Mapping of the Existing Conditions* – The hydrologic and hydraulic modelling was undertaken using the traditional approach of applying flow boundaries from the hydrological model (RORB) to the two-dimensional (2D) hydraulic model (TUFLOW). The existing flood characteristics were identified through hydrologic and hydraulic modelling of the 20%, 10%, 5% and 1% Annual Exceedance Probability (AEP) flood events. The flood results were mapped using GIS. An assessment of flood damage was undertaken using the stage-damage curve approach.
4. *Mitigation Option Assessment and Mapping* – A wide range of potential structural and non-structural flood mitigation measures were screened, from which a shortlist of three (3) alternative flood mitigation schemes were selected to be tested using the hydraulic model. Flood damage, scheme cost and benefit-cost ratios were determined for each of the schemes tested. A ‘no structural works’ option was also considered.
5. *Selection and Detailed Mapping of the Preferred Mitigation Scheme* – The mitigation schemes were assessed according to their ability to reduce flood damage. The schemes were ranked according to a range of economic and non-economic factors. A preferred strategy was then selected in consultation

with CoGG. The preferred scheme was mapped using GIS, with hardcopy plans of flood extent and flood levels produced.

The key results from the investigation are summarised in the following sections.

Existing Flooding Characteristics

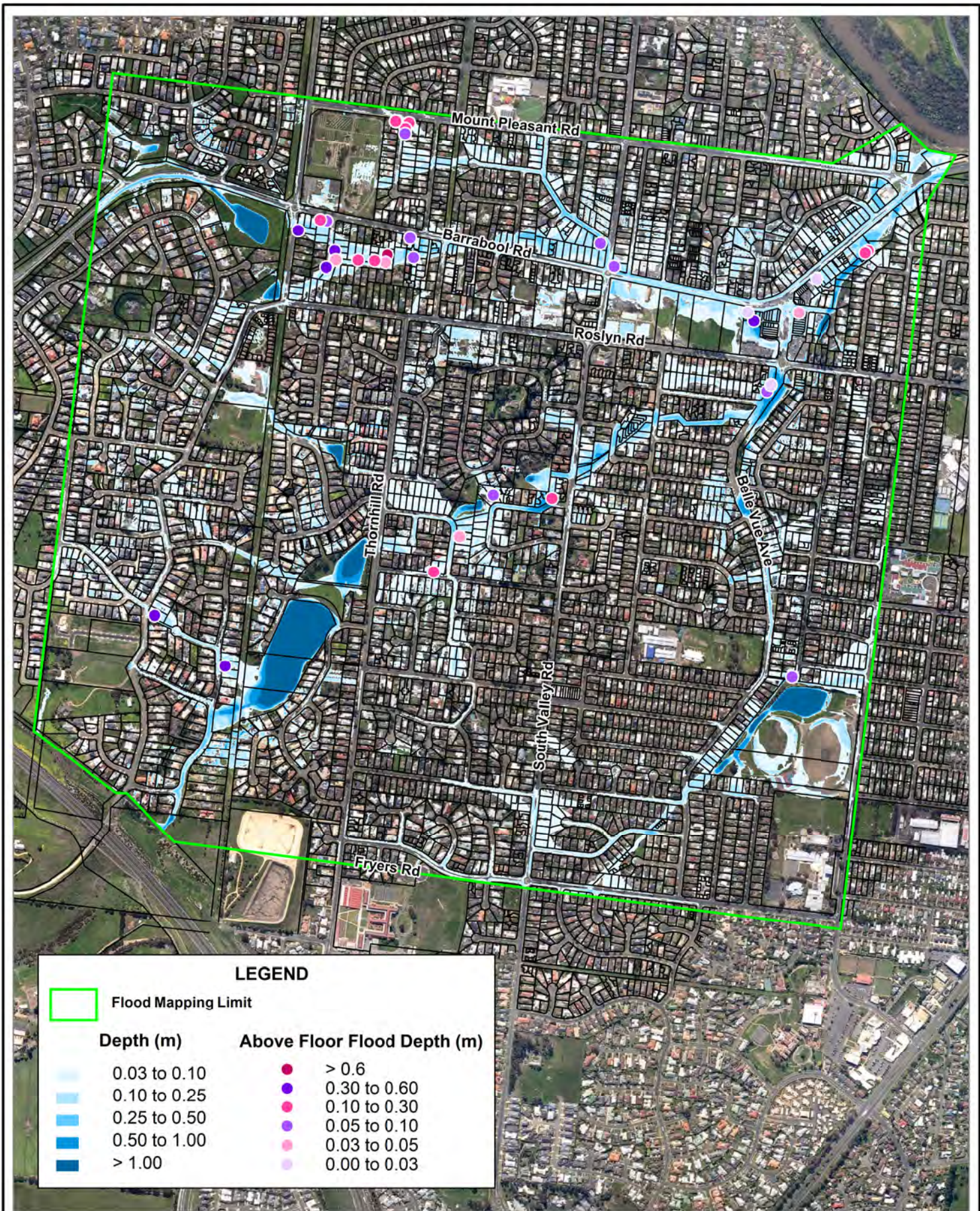
The flood extent of the 1% Annual Exceedance Probability (AEP) flood, i.e. the 100 Year Average Recurrence Interval (ARI) flood, is shown in Figure E-1. The number of flood-affected properties was identified and the average annual flood damage (AAD) was calculated at \$354,000. Table E-1 shows the total number of properties that have floor level information available and are inundated to above floor level in the range of flood events analysed. An analysis was also undertaken to determine the number of properties within the study mapping area, ie, not the full catchment, that have flooding within the property boundaries in the 1% AEP event. This information is also detailed in Table E-1.

Table E-1 Number of Flooded Properties

AEP	Number of Flooded Properties - Existing Conditions	
	Within Property	Above Floor*
20%	1402	14
10%	1719	16
5%	1976	22
1%	2318	35

* Results based on properties surveyed by CoGG.

Hazard mapping was undertaken using the methodology prescribed in the Melbourne Water document *Guidelines for Development in Flood-prone Areas* (Melbourne Water 2008). The analysis is designed to determine if it is safe for people to move about on a property during a flood event. Safety is defined in terms of the depth, velocity and velocity-depth product. The existing 1% AEP hazard mapping for the study area is shown in Figure E-2. As expected, the majority of the main overland flow through the catchments is classified as safe in a 1% AEP event. This is due to the relatively shallow flow depths experienced across the majority of the study area. The majority of the flooding that has been deemed unsafe occurs within the retarding basins or road corridors, however there are other isolated areas deemed unsafe in the 1% AEP event. These include properties on Belle Vue Avenue immediately south of Roslyn Road and on the major drainage path between Roslyn Road and Mount Pleasant Road, adjacent to Barrabool Road.



Title:
Existing Conditions 1% AEP Peak Flood Depth

Figure:
E-1

Rev:
B

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.



0 250 500m
Approx. Scale



Filepath : T:\M8094.JL.Highton_DFS\MapInfo\Drawings\Report_Final\Fig-E-1_Exg_1%_Depth_RevB.WOR



Title:

Existing Conditions 1% AEP Peak Flood Hazard

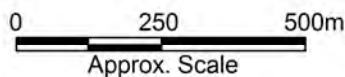
Figure:

E-2

Rev:

B

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.



Mitigation Option Assessment

A full range of structural and non-structural flood mitigation elements were considered when developing the three mitigation schemes. The elements considered ranged from upgraded underground pipe systems through to planning scheme amendments and education and awareness programs. These elements were screened to provide a list of elements that were considered suitable for use in the study area. Through discussion with Council officers, the elements were combined to form the mitigation schemes for detailed modelling and assessment. The 'no structural works' strategy, i.e., the existing flood conditions, was also considered.

The schemes were assessed using the hydraulic model for each flood event. Table E-2 shows the number of flooded properties under each scenario assessed. Table E-3 outlines the benefit (as a result of reduced flooding), the capital and on-going costs and Benefit to Cost Ratio (BCR).

Table E-2 Flood Affected Properties

Scenario	Flood Affected Property Floors *			
	20% AEP	10% AEP	5% AEP	1% AEP
Existing Conditions	14	16	22	35
Scheme One	14	16	21	33
Scheme Two	13	15	21	30
Scheme Three	13	15	20	29
Scheme Four (No Structural Works)	14	16	22	35

* Flood Affected Property Floors are defined as those with flood levels above the surveyed floor level.

Table E-3 Mitigation Option Economic Summary

Scheme	Annual Damages	Average Annual Benefit	Total Benefit (NPV)*	Capital Cost	Ongoing Costs over 30 Years (PA)	Ongoing Costs over 30 Years (NPV)*	Total Option Cost	BCR
One	\$381,000	\$8,000	\$99,000	\$6,694,000	\$161,000	\$1,998,000	\$8,692,000	0.01
Two	\$362,000	\$27,000	\$335,000	\$21,102,000	\$506,000	\$6,279,000	\$27,381,000	0.01
Three	\$363,000	\$26,000	\$323,000	\$26,600,000	\$638,000	\$7,917,000	\$34,517,000	0.01
Four	\$389,000	-	-	-	-	-	-	-

* NPV – Net Present Value discounted at 7% over 30 years

Preferred Mitigation Scheme

Scheme Four is the preferred mitigation scheme for the study area. Through consultation with the CoGG, the preferred scheme was selected as the mitigation works adopted in Schemes One to Three have very low benefit cost ratios (BCRs). The very low BCRs have resulted in high capital costs per floor level saved, to the order of \$4M in capital cost.

Whilst each of the schemes delivers benefits in reducing the above floor flooding, the nature of the flooding within the catchment has meant that large numbers of properties are still inundated during the modelled flood events. The bulk of the calculated flood damages are a result of property inundation rather than above floor flooding, and consequently despite reductions in the above floor flooding, commensurate reductions in the calculated AAD have not been realised.

Whilst structural mitigation measures have not been recommended, the overall flood management strategy recommended in the Highton Drainage/Flood Study comprises the following:

- Further investigation into the feasibility of localised flood mitigation measures, such as lifting footpaths and/or underground drainage augmentation, in order to reduce the flood risk for properties that have been the subject of previous drainage/flooding requests for service that have identified capacity deficiencies rather than blockages. These investigations would be undertaken in accordance with the priority ranking established by applying the City's prioritisation method for drainage investigation/design work.
- Further investigation into the feasibility of property-specific measures to manage flood risk. Potential measures include flood-proofing of individual or groups of buildings/properties by landowners, and property buy-back with on-sell following modifications (where feasible) with conditions known to purchaser.
- Education and awareness program to inform landowners how to minimise the magnitude of damage in a flood event.
- Development controls via designation of areas as liable to flooding in accordance with Building Regulations 2006 and use of flood zones/overlays within the Greater Geelong Planning Scheme.
- Recognition that further development within the catchment has the potential to increase flood risk to people and property. Assessment of rezoning proposals to include application of principle of zero adverse flood impact on adjacent, upstream and downstream areas. Assessment of development and subdivision applications to include application of best practice guidelines for development within or upstream of flood-prone areas.
- Best practice environmental management for stormwater runoff to be encouraged as part of development and subdivision applications in order to reduce runoff and improve water quality, where not a statutory requirement.

CONTENTS

EXECUTIVE SUMMARY	i
Contents	vii
List of Figures	ix
List of Tables	x
1 INTRODUCTION	1-1
1.1 Background	1-1
1.2 Catchment Description	1-1
1.3 History of Flooding	1-1
1.4 Study Area	1-1
1.5 Key Objectives	1-2
2 STUDY APPROACH	2-1
2.1 Data Collation	2-1
2.1.1 Study Inception and Site Visit	2-1
2.1.2 Drainage, Topographic and GIS Data Sets	2-1
2.2 Flood Model Development	2-1
2.3 Flood Mapping	2-2
2.4 Flood Damages Assessment	2-2
2.5 Mitigation Options Assessment	2-2
2.6 Reporting	2-2
3 DATA COLLATION	3-1
3.1 Site Inspection	3-1
3.2 GIS Data	3-1
3.3 Drainage Data	3-1
3.4 Topographic Data	3-1
3.5 Survey Data	3-2
4 FLOOD MODEL DEVELOPMENT	4-1
4.1 Hydrologic Modelling	4-1
4.1.1 RORB Model	4-1
4.1.1.1 Model Description	4-1
4.1.1.2 Sub-Catchment Definition	4-1

4.1.1.3	<i>Global Parameters</i>	4-3
4.1.1.4	<i>IFD Parameters</i>	4-3
4.1.1.5	<i>Loss Parameters</i>	4-4
4.1.1.6	<i>Fraction Impervious</i>	4-4
4.1.1.7	<i>Retarding Basins</i>	4-5
4.1.2	Hydrological Model Verification	4-7
4.1.3	Design Event Modelling	4-9
4.1.3.1	<i>Design Event Probabilities</i>	4-9
4.1.3.2	<i>Design Rainfall</i>	4-9
4.1.3.3	<i>Critical Duration</i>	4-9
4.1.4	Peak Outflows	4-9
4.2	Hydraulic Model	4-14
4.2.1	Model Description	4-14
4.2.2	Model Development	4-16
4.2.2.1	<i>Pipe Network Setup</i>	4-16
4.2.2.2	<i>Pits</i>	4-17
4.2.2.3	<i>Multiple Domain Linking</i>	4-17
4.2.3	Boundary Conditions	4-18
4.2.4	Design Event Modelling	4-18
5	FLOOD MAPPING	5-1
6	FLOOD DAMAGES ASSESSMENT	6-1
6.1	Methodology	6-1
6.1.1	Key Assumptions	6-1
6.1.2	Stage-Damage Curves	6-2
6.1.3	Damage Calculations	6-2
6.2	Existing Conditions Flood Damages	6-3
7	MITIGATION SCHEMES ASSESSMENT	7-1
7.1	Focus Areas	7-1
7.2	Mitigation Option Screening	7-1
7.3	Detailed Assessment	7-2
7.3.1	Non-Structural Options	7-2
7.3.2	Structural Options	7-3
7.3.2.1	<i>Retarding Basin Works</i>	7-3
7.3.2.2	<i>Pipe Works</i>	7-4
7.3.2.3	<i>Pit Works</i>	7-5
7.3.2.4	<i>Further Works</i>	7-5

7.3.3	Hydraulic Assessment	7-10
7.3.3.1	<i>Scheme One</i>	7-10
7.3.3.2	<i>Scheme Two</i>	7-11
7.3.3.3	<i>Scheme Three</i>	7-11
8	MITIGATION OPTION ASSESSMENT	8-1
8.1	Economic Assessment	8-1
8.1.1	Basis of Assessment	8-1
8.1.2	Scheme One	8-3
8.1.3	Scheme Two	8-5
8.1.4	Scheme Three	8-7
8.2	Environmental Assessment	8-10
8.3	Social Assessment	8-11
8.4	Feasibility and Performance Indicators	8-12
9	PREFERRED MITIGATION SCHEME	9-1
9.1	Description of Preferred Scheme	9-1
10	PUBLIC CONSULTATION PROCESS	10-1
11	REFERENCES	11-1
APPENDIX A:	Construction Rates	A-1
APPENDIX B:	Longitudinal Profile Plots	B-1
APPENDIX C:	Public Submissions and Responses	C-1

LIST OF FIGURES

Figure 1-1	Locality Map	1-3
Figure 1-2	Study Area and Flood Mapping Limit	1-4
Figure 3-1	Highton Photogrammetry DEM	3-4
Figure 3-2	Highton LiDAR DEM	3-5
Figure 3-3	Photogrammetry DEM Check	3-6
Figure 3-4	LiDAR DEM Check	3-7
Figure 4-1	RORB Catchment Layout	4-2
Figure 4-2	Thornhill Road Upper Retarding Basin Inflow	4-10
Figure 4-3	Vanessa Avenue Retarding Basin Inflow	4-11
Figure 4-4	Corner of Bellevue Avenue and Maus Street	4-11
Figure 4-5	Corner of Bellevue Avenue and Roslyn Road	4-12

Figure 4-6	Corner of Barrabool Road and Mount Pleasant Road	4-12
Figure 4-7	Catchment Outlet - Barwon River	4-13
Figure 4-8	TUFLOW Model Setup	4-15
Figure 5-1	20% AEP Peak Flood Depth	5-3
Figure 5-2	10% AEP Peak Flood Depth	5-4
Figure 5-3	5% AEP Peak Flood Depth	5-5
Figure 5-4	1% AEP Peak Flood Depth	5-6
Figure 5-5	20% AEP Flood Hazard	5-7
Figure 5-6	10% AEP Flood Hazard	5-8
Figure 5-7	5% AEP Flood Hazard	5-9
Figure 5-8	1% AEP Flood Hazard	5-10
Figure 6-1	Existing Conditions Damages Probability Curve	6-4
Figure 7-1	Scheme One Proposed Mitigation Works	7-7
Figure 7-2	Scheme Two Proposed Mitigation Works	7-8
Figure 7-3	Scheme Three Proposed Mitigation Works	7-9
Figure 7-4	Scheme One 20% AEP Peak Flood Impact	7-12
Figure 7-5	Scheme One 10% AEP Peak Flood Impact	7-13
Figure 7-6	Scheme One 5% AEP Peak Flood Impact	7-14
Figure 7-7	Scheme One 1% AEP Peak Flood Impact	7-15
Figure 7-8	Scheme Two 20% AEP Peak Flood Impact	7-16
Figure 7-9	Scheme Two 10% AEP Peak Flood Impact	7-17
Figure 7-10	Scheme Two 5% AEP Peak Flood Impact	7-18
Figure 7-11	Scheme Two 1% AEP Peak Flood Impact	7-19
Figure 7-12	Scheme Three 20% AEP Peak Flood Impact	7-20
Figure 7-13	Scheme Three 10% AEP Peak Flood Impact	7-21
Figure 7-14	Scheme Three 5% AEP Peak Flood Impact	7-22
Figure 7-15	Scheme Three 1% AEP Peak Flood Impact	7-23
Figure 8-1	Scheme One Probability Damages Curve	8-5
Figure 8-2	Scheme Two Probability Damages Curve	8-7
Figure 8-3	Scheme Two Probability Damages Curve	8-9

LIST OF TABLES

Table 4-1	RORB Parameters	4-3
Table 4-2	IFD Parameters	4-3
Table 4-3	Runoff Coefficients for different AEPs	4-4
Table 4-4	Impervious Fraction for Planning Scheme Zone	4-4
Table 4-5	Thornhill Road Assessment Retarding Basin Details	4-6
Table 4-6	Geelong Ring Road Stage-Storage-Discharge Relationship	4-7
Table 4-7	Barrabool Road Upper and Barrabool Road Lower Retarding Basin Details	4-7

Table 4-8	Comparison of Highton RORB model and Thornhill Road Assessment results	4-8
Table 4-9	Fraction Impervious Comparison for Thornhill Road Retarding Basin Assessment Catchment and Highton Catchment of Equivalent Area	4-8
Table 4-10	Comparison of Highton RORB model and Rational Method results	4-9
Table 4-11	Peak Outflows	4-10
Table 4-12	2D Domain Manning's 'n' Coefficients	4-16
Table 5-1	Number of Flooded Properties	5-2
Table 6-1	Existing Conditions Damages Summary	6-3
Table 7-1	Mitigation Option Element Screening	7-2
Table 7-2	Mitigation Scheme Details	7-3
Table 7-3	Reduction in Flooded Properties – Scheme One	7-10
Table 7-4	Reduction in Flooded Properties – Scheme Two	7-11
Table 7-5	Reduction in Flooded Properties – Scheme Three	7-11
Table 8-1	Present Value of Annual Benefits	8-2
Table 8-2	Scheme One Damages Summary	8-4
Table 8-3	Scheme One Capital Cost Estimates	8-4
Table 8-4	Scheme One BCR Summary	8-4
Table 8-5	Scheme Two Damages Summary	8-6
Table 8-6	Scheme Two Capital Costs	8-6
Table 8-7	Scheme Two BCR Summary	8-6
Table 8-8	Scheme Three Damages Summary	8-8
Table 8-9	Scheme Three Capital Costs	8-8
Table 8-10	Scheme Three BCR Summary	8-8
Table 8-11	Environmental Indicators	8-10
Table 8-12	Social Indicators	8-11
Table 8-13	Feasibility and Performance Indicators	8-12
Table 9-1	Comparison of Scheme One and Scheme Two	9-1

1 INTRODUCTION

1.1 Background

The City of Greater Geelong (CoGG) has engaged BMT WBM Pty Ltd (BMT WBM) to undertake an assessment of stormwater flooding within the Kardinia Creek catchment (C250), and to investigate flood management options to manage and minimise the effects of flooding on the community.

1.2 Catchment Description

The Kardinia Creek catchment is located predominantly within the Geelong suburb of Highton; approximately 4km south west of Geelong's Central Activities Area and on the south side of the Barwon River (Figure 1-1). The catchment drains approximately 1,050 hectares of both rural and urbanised land via overland flow paths and a series of retarding basins into the Barwon River. Approximately 60% of the catchment is urbanised and the rural portion of the catchment is upstream of this urbanised area.

Throughout the catchment, many of the natural flow paths have been rendered ineffective due to the presence of urban development along and within the overland flowpaths. Consequently, floodwaters have been noted to build-up behind road formations and within road reserves.

The existing drainage network is generally undersized and therefore contributes to localised 'stormwater' flooding. Like many drainage systems in areas of a similar age, Highton's drainage network has a limited capacity for the catchment it is draining. The Kardinia Creek catchment is drained by a series of underground pipes and overland flow paths. Eleven retarding basins have also been constructed within the catchment to help alleviate local flooding issues.

1.3 History of Flooding

Council has received numerous reports of flooding problems within the Kardinia Creek catchment. The majority of the problems relate to the characteristics of the catchment (topography, development density and age). The old (pre 1980's) drainage system typically has limited capacity in the underground pipes and a lack of clear overland flowpaths for surcharge and excess flows.

A storm event in 1978 caused significant flood damage and the then City of South Barwon initiated a major drainage augmentation program. This program included the retro-fitting of a number of retarding basins, including the Thornhill Road Upper Basin.

During a storm event in 1993, the Thornhill Road Lower Basin overflowed (partially due to outlet blockage), while the Upper Basin was only partially full. Surcharging of the underground drainage system downstream of the lower basin was observed.

1.4 Study Area

The Highton study area is detailed in Figure 1-2. The study area is modelled in detail using both hydrologic and complex two-dimensional hydraulic models to simulate the flood behaviour within the catchment. The area that is to be flood mapped is also shown in Figure 1-2

1.5 Key Objectives

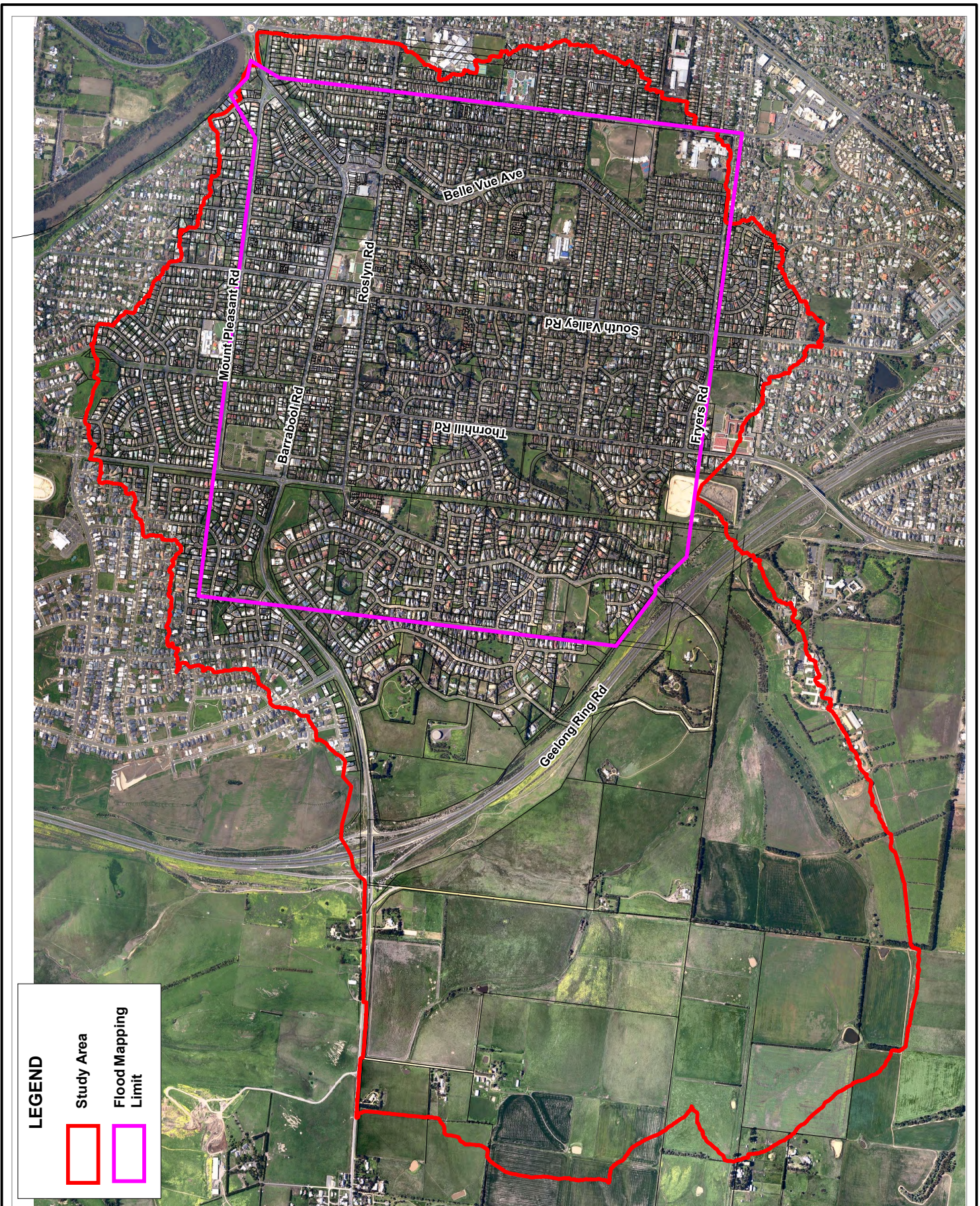
The key objectives of this study are to:

1. develop a Digital Terrain Model (DTM) of the study catchment from digital data captured by Aerometrix in October 2009 and supplied by the City of Greater Geelong;
2. determine the flood extents, depths and associated hazard of the critical 1%, 5%, 10% and 20% annual exceedance probability (AEP) flood events through the use of hydrologic and hydraulic models for existing conditions;
3. identify and assess potential mitigation strategies to reduce damages associated with flooding;
4. determine the flood extents, depths and associated hazard of the critical 1%, 5%, 10% and 20% annual exceedance probability (AEP) flood events through the use of hydrologic and hydraulic models for the preferred mitigation strategy; and
5. produce a report and flood maps detailing the methodology and results from the above four tasks.



© Harris Corp, Earthstar Geographics LLC State of Michigan

<p>Title: Locality Map</p>	<p>Figure: 1-1</p>	<p>Rev: A</p>
<p>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.</p>	<p>Approx. Scale</p>	<p>BMT WBM www.bmtwbm.com.au</p>



LEGEND

Study Area



Flood Mapping Limit

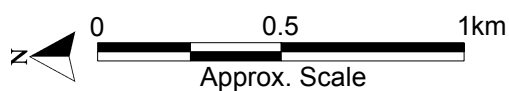


Title:
Study Area and Flood Mapping Limit

Figure:
1-2

Rev:
B

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.



2 STUDY APPROACH

There were six key stages in the study as follows:

- Data collection;
- Flood model development;
- Flood mapping;
- Flood damages assessment;
- Mitigation options assessment; and
- Reporting.

The remainder of Section 2 outlines the adopted approach for each of these stages. A detailed description of the key stages is given in subsequent sections of the report.

2.1 Data Collation

2.1.1 Study Inception and Site Visit

Following commissioning of the study, an inception meeting and site visit were held between representatives from CoGG and BMT WBM. The principal objectives were to confirm the project approach, obtain key and relevant data and to discuss known flooding issues within the catchments.

2.1.2 Drainage, Topographic and GIS Data Sets

All relevant data for the drainage systems was obtained from the CoGG. The data was comprehensively reviewed to identify any significant data gaps and to gain a complete understanding of issues in the study area. Where required, field survey was commissioned to address gaps in available data.

2.2 Flood Model Development

The flood model was developed using the traditional approach of utilising hydrologic and hydraulic computer models. The hydrologic model determines the runoff hydrographs that occur following a particular rainfall event. The hydrographs describe the quantity, rate and timing of the runoff that results from rainfall events. These hydrographs then become a key input into the hydraulic model. The hydraulic model simulates the movement of floodwaters through overland flow paths, storage areas, and hydraulic structures. The hydraulic model calculates flood levels and flow patterns and also models the complex interactions between overland flow paths and underground drainage.

The hydrologic modelling of the catchments was undertaken using RORB. A new RORB hydrological model of the catchments was developed for this flood study. As discussed further in Section 4.1.1.7, although 11 retarding basins exist within the Kardinia Creek drainage catchment, they are included in the RORB model for completeness only. The hydraulic model is used to simulate the behaviour of the retarding basins during a flood event. No calibration data was available for the hydrological model, so for most parameters, typical values appropriate for the catchments characteristics were adopted and the model was then verified against the Rational Method and previous studies within the catchments. The adopted loss model was an initial loss/volumetric runoff coefficient model.

Hydraulic modelling of the catchments was undertaken using the 2D/1D dynamic hydraulic modelling package TUFLOW. The model incorporated both the overland flow paths and the underground trunk drainage system. No data was available for calibration so typical parameter values based on experience and the data collected during the site inspections were applied. TUFLOW was run as an unsteady flow model to ensure reliable representation of the storage within the system and the complex timing and interaction of flows in the drainage network.

2.3 Flood Mapping

Flood maps showing flood extent, depth and height were produced for each design flood analysed. Design floods are hypothetical floods used for planning and floodplain management investigations. A design flood is defined by its probability of occurrence. It represents a flood that has a particular probability of being exceeded in any one year. For example, the 1% Annual Exceedance Probability (AEP) or 100 year Average Recurrence Interval (ARI) flood is a best estimate of a flood magnitude which has 1 chance in 100 of being exceeded in any one year. It should be noted that planning for the 1% AEP flood does not guarantee protection for the next 100 years. Design flood levels were determined for the 20%, 10%, 5% and 1% AEP floods.

2.4 Flood Damages Assessment

The design floods were used to make an assessment of the financial losses to residential properties and public infrastructure. These financial losses were then used as a basis to do an economic assessment of potential mitigation options.

2.5 Mitigation Options Assessment

A range of options designed to mitigate the existing flood impact and associated damages were considered and analysed for effectiveness. The economic impacts of each scenario, as well as a range of non-economic factors, were compared in order to ascertain the most suitable outcome.

2.6 Reporting

Several meetings were held with CoGG during the course of the study to present findings before proceeding to subsequent stages. The findings of the study are presented in this Drainage/Flood Study Report.

3 DATA COLLATION

3.1 Site Inspection

Following commissioning of the study, an inception meeting was held between CoGG representatives and BMT WBM project staff. During this meeting background data was supplied, project documentation was exchanged and the scope of works was discussed and approved. This meeting was followed by a site inspection with Council's representative, where flooding issues throughout the study area were outlined and viewed.

3.2 GIS Data

All relevant data for the drainage systems was obtained from the CoGG. The data was comprehensively reviewed to identify any significant data gaps and to gain a complete understanding of issues in the study area.

Additional project related GIS data was sourced from Council's GIS system. In particular, the following data was supplied:

- cadastral information over the study area;
- planning scheme zones over the catchment; and
- aerial photography.

3.3 Drainage Data

CoGG supplied drainage network data for the catchment in digital formats (as GIS datasets and pdf documents). Data included pipe networks (location and size), drainage pit details and retarding basin locations. Data gaps within the pipe network were identified and in-filled from available data (drawings, etc.) and then through the interpolation of inverts from upstream and downstream information. A survey brief has been issued to fill in the missing data.

3.4 Topographic Data

CoGG provided BMT WBM with new aerial photogrammetry for the area to be flood mapped. The data was supplied in AutoCAD (DWG) format, and was subsequently converted to a Triangulated Integrated Network (TIN), which was imported into MapInfo Professional. The resulting digital elevation model (DEM) is shown in Figure 3-1.

As part of the survey component of the project, verification of the vertical accuracy of the photogrammetry was required. The quoted vertical accuracy of the data is +/- 0.1m. Whilst not specifically quoted in the provided metadata, vertical accuracy is commonly quoted as a vertical accuracy plus one (1) sigma (standard deviation) on either bare earth or hard surfaces. A series of points were captured along road centrelines (hard surfaces) as part of the field survey (refer to Section 3.5) to check the quoted accuracy of the photogrammetry data. Refer to Section 3.5 for details of the accuracy verification undertaken.

CoGG also provided BMT WBM with topographic data from LiDAR flown over the entire municipality's developed areas. The data was supplied in xyz format, and was subsequently converted to a

Triangulated Integrated Network (TIN) using Vertical Mapper, with the resultant file imported into MapInfo Professional. The resulting DEM is shown in Figure 3-2.

The quoted vertical accuracy of the LiDAR data is +/- 0.15m and, like the photogrammetry, was also verified against field survey using the same points captured along the road centrelines (hard surfaces). As noted previously, vertical accuracy is commonly quoted as a vertical accuracy plus one (1) sigma (standard deviation) on bare earth or hard surfaces. Refer to Section 3.5 for details of the accuracy verification.

Within the flood mapping area the sampling resolution for the DEMs is 0.5m. Based on our past experience, we have found that this level of detail is well suited to simulating the topography of urbanised environments for hydraulic modelling and more than adequate for the development of the hydrologic model.

3.5 Survey Data

Following a review of the data provided by the CoGG it was determined that additional field data would be required to fill missing pipe data, confirm the validity of the photogrammetry and LiDAR and capture additional topographic data not present in the DEM. TGM Group Pty Ltd were commissioned on the 7th July 2011 to carry out the required field survey.

TGM Group supplied the requested field survey data on the 12th of September, 2011 in the form of an AutoCAD drawing with an accompanying comma separated value (CSV) text file and site photos.

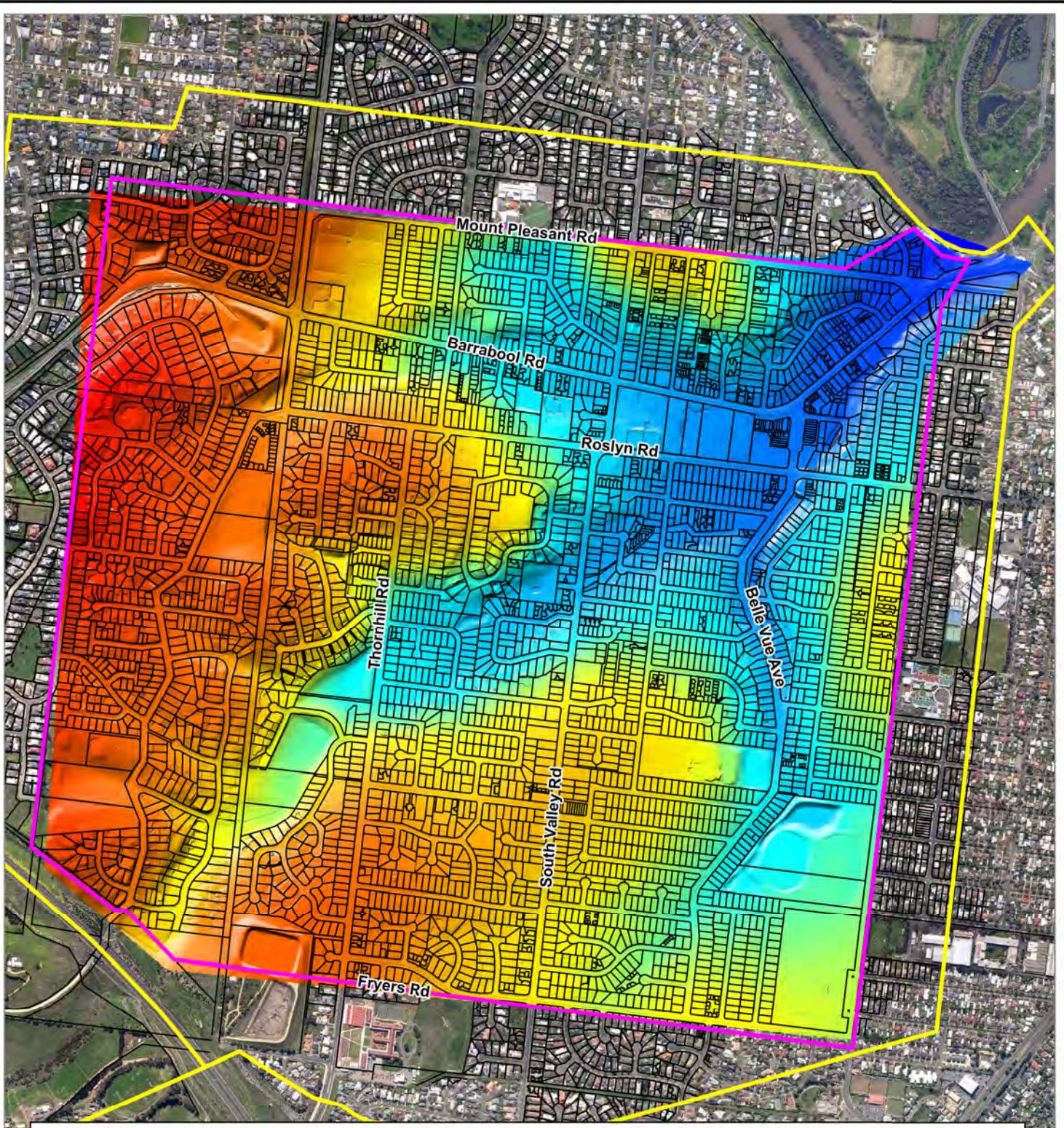
Pipe invert levels at 21 pit locations, where either upstream or downstream invert levels were missing, were surveyed. The inverts at these locations were either unable to be interpolated using the methods described in Section 4.2.2.1 or were considered critical to the completion of the pipe network within the hydraulic model.

Stringlines were taken at the spillway crests for the 10 formal and informal retarding basins within the catchment. The shape and elevation of the spillways is critical to accurately defining the amount of flood storage and flow from the retarding basins. Accordingly, the stringlines were incorporated into the hydraulic model.


A series of spot heights were also taken along a selection of road centrelines throughout the study area (101 spot heights in total) in order to confirm the accuracy of the topographic data provided. The elevations at each point were compared to the levels from the LiDAR and photogrammetry DEMs. The differences in elevation were then reviewed to see how strongly the data sets agreed. Elevation differences within +/- 0.1m were considered reasonable given the stated accuracy of the two survey methods. Figure 3-3 and Figure 3-4 illustrate the results of the checks on the photogrammetry and LiDAR.


As can be seen in Figure 3-3 and Figure 3-4 the surveyed spot heights show good agreement with both the photogrammetry and LiDAR DEMs. Whilst the LiDAR DEM is marginally better (all points inside the acceptable tolerance), when compared to the photogrammetry DEM (95 of 101 points inside the acceptable tolerance), both DEMs are suitable for use in the hydrologic and hydraulic models required for the Drainage/Flood Study.

The LiDAR DEM was used for the development of the hydrologic model, whilst both the LiDAR and photogrammetry DEMs were used for the development of the hydraulic model. The photogrammetry DEM was used for the hydraulic modelling within the flood mapping limit.

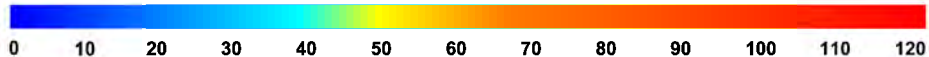


LEGEND

 2D Model Extent

 Flood Mapping Limit

Elevation (mAHD)



0 10 20 30 40 50 60 70 80 90 100 110 120

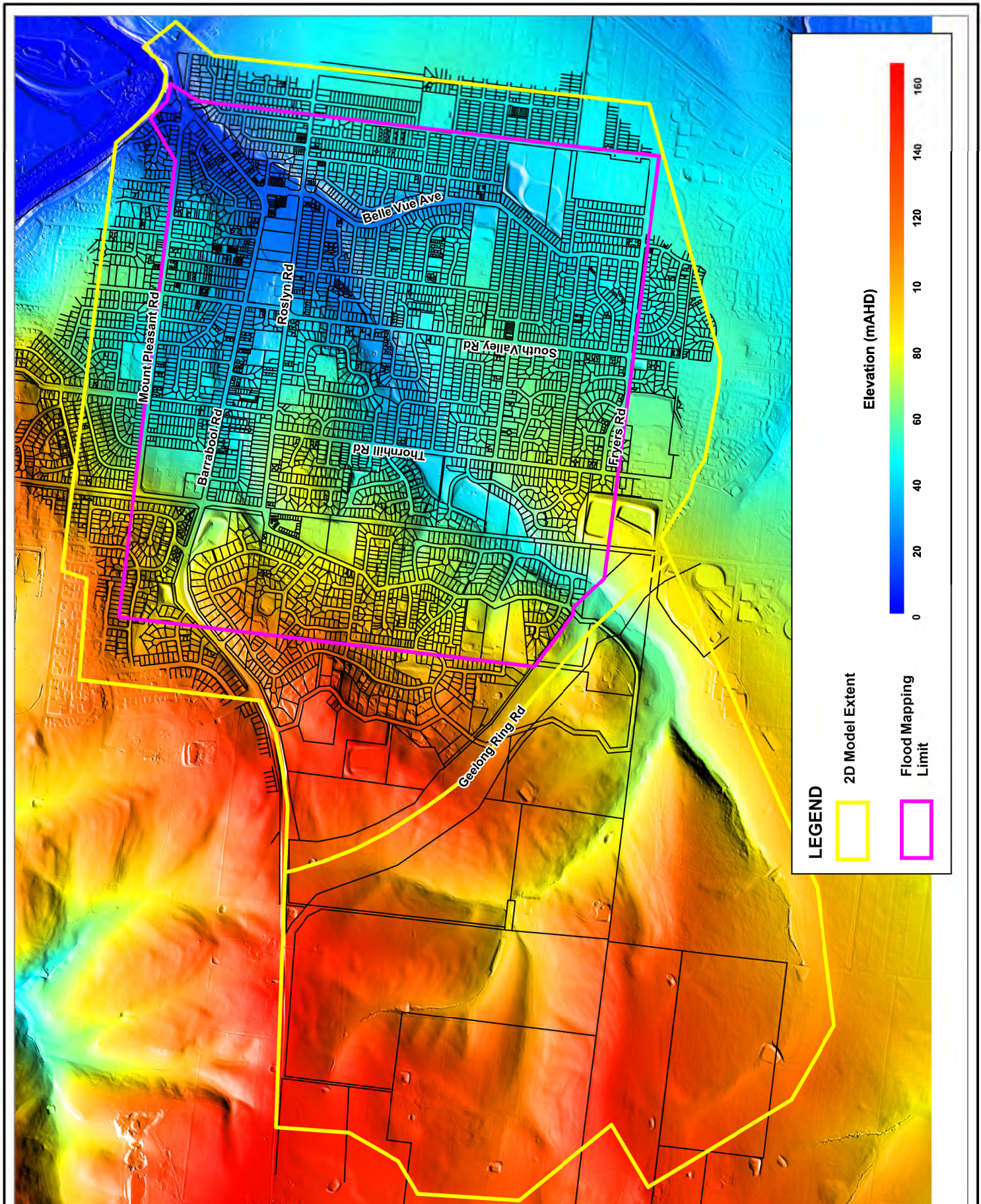
Title:
Highton Photogrammetry Digital Elevation Model

Figure:
3-1

Rev:
B

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.





LEGEND

- 2D Model Extent
- Flood Mapping Limit

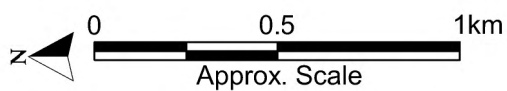


Title:
LiDAR Digital Elevation Model

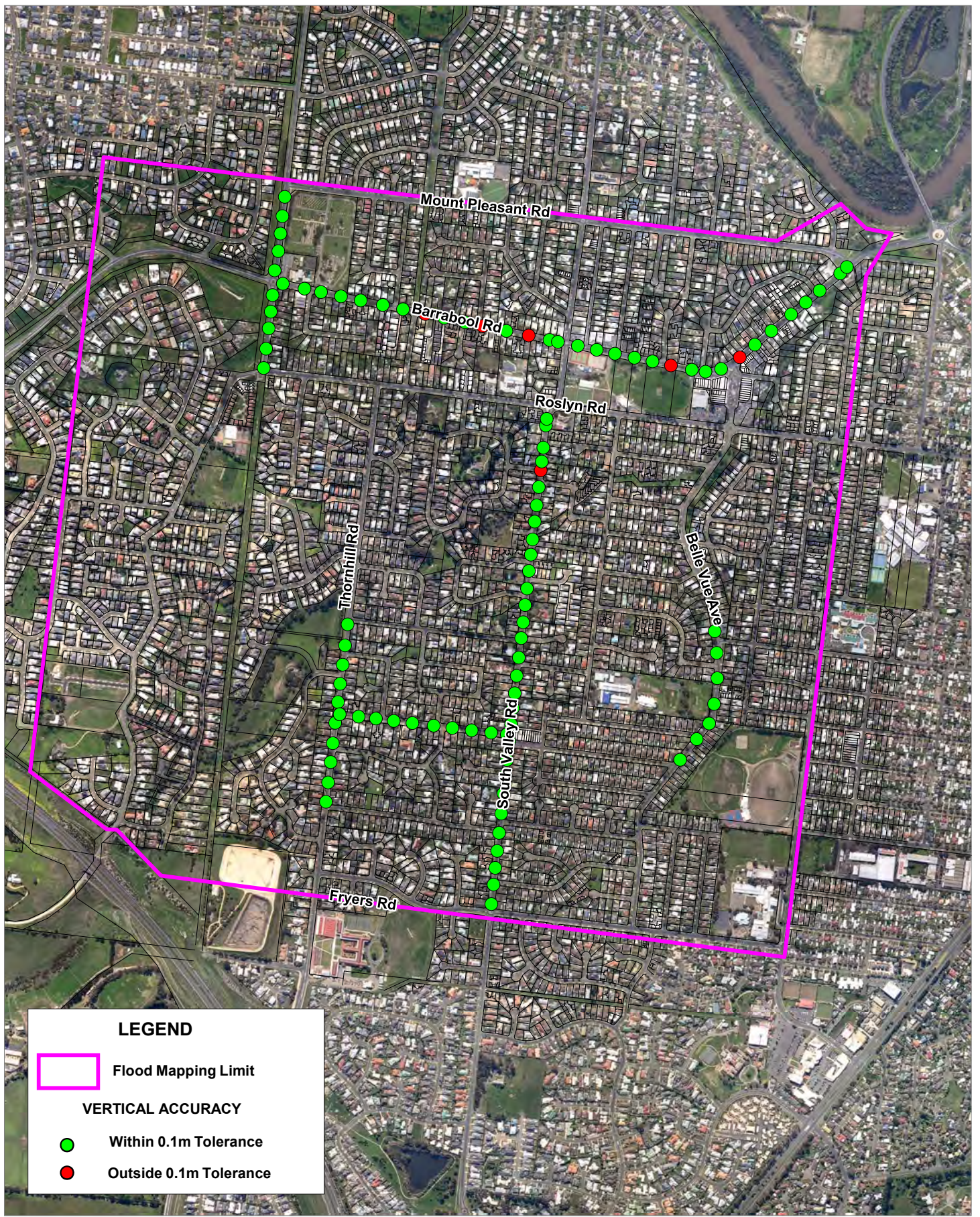
Figure:
3-2

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.



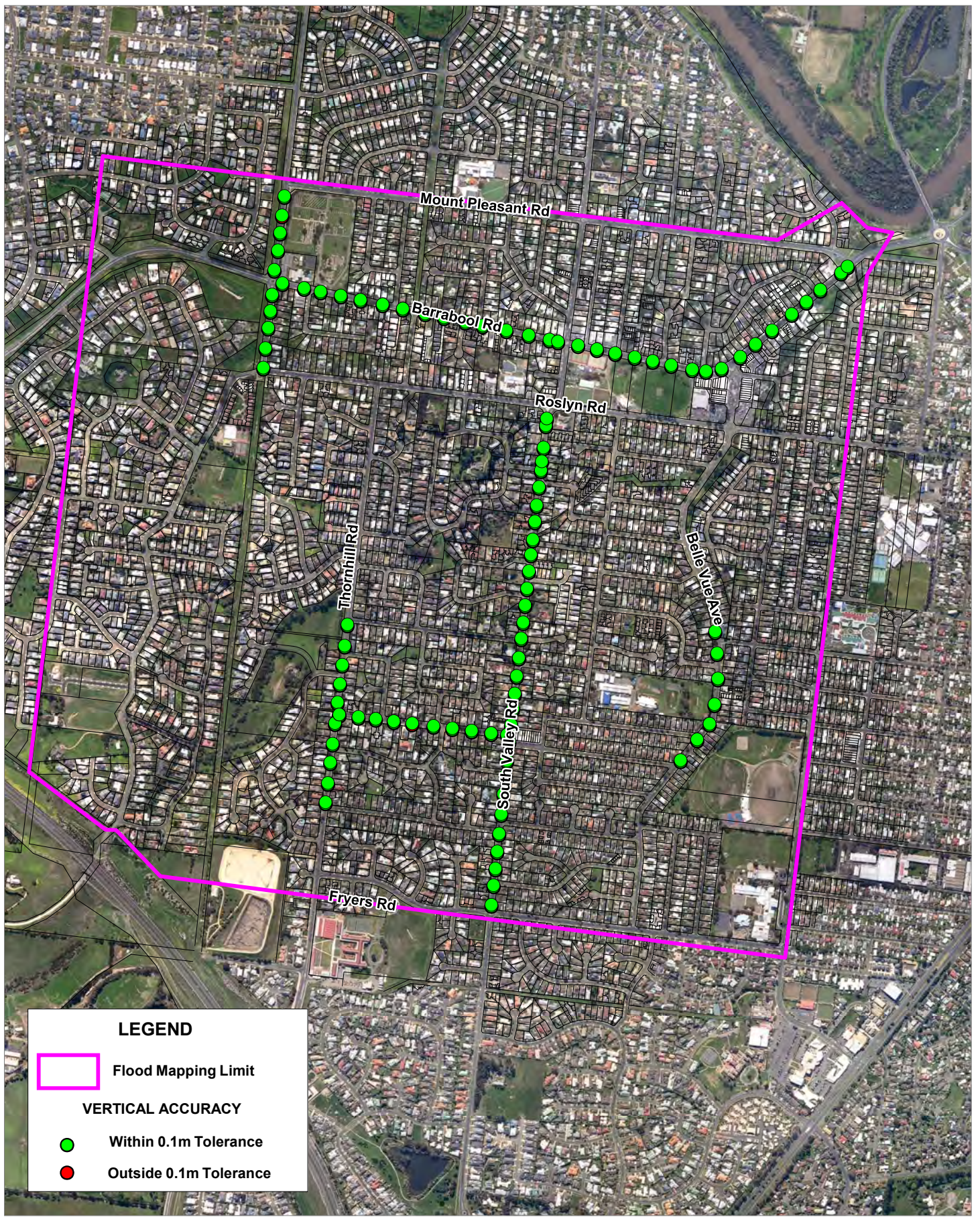
Filepath : T:\M8094.JL.Highton_DFS\MapInfo\Drawings\Report_Final\Fig3-2_LiDAR_DEM_RevA.WOR




Title: Photogrammetry Digital Elevation Model Check	Figure: 3-3	Rev: B
---	-----------------------	------------------

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.







LEGEND

 Flood Mapping Limit

VERTICAL ACCURACY

 Within 0.1m Tolerance

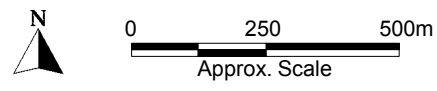
 Outside 0.1m Tolerance

Title:
LiDAR Digital Elevation Model Check

Figure:
3-4

Rev:
B

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.



4 FLOOD MODEL DEVELOPMENT

4.1 Hydrologic Modelling

Hydrologic modelling of the study catchment was undertaken using RORB. A RORB model had previously been developed of the catchment as part of the Thornhill Road Retarding Basin Assessment (WBM 2004). This previously developed RORB model was refined to ensure it could meet the requirements of the current study and subsequently provide total and sub-area hydrographs as boundary conditions for the TUFLOW hydraulic model. The RORB modelling process and results are discussed in the following sections.

4.1.1 RORB Model

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

$$S = 3600kQ^m$$

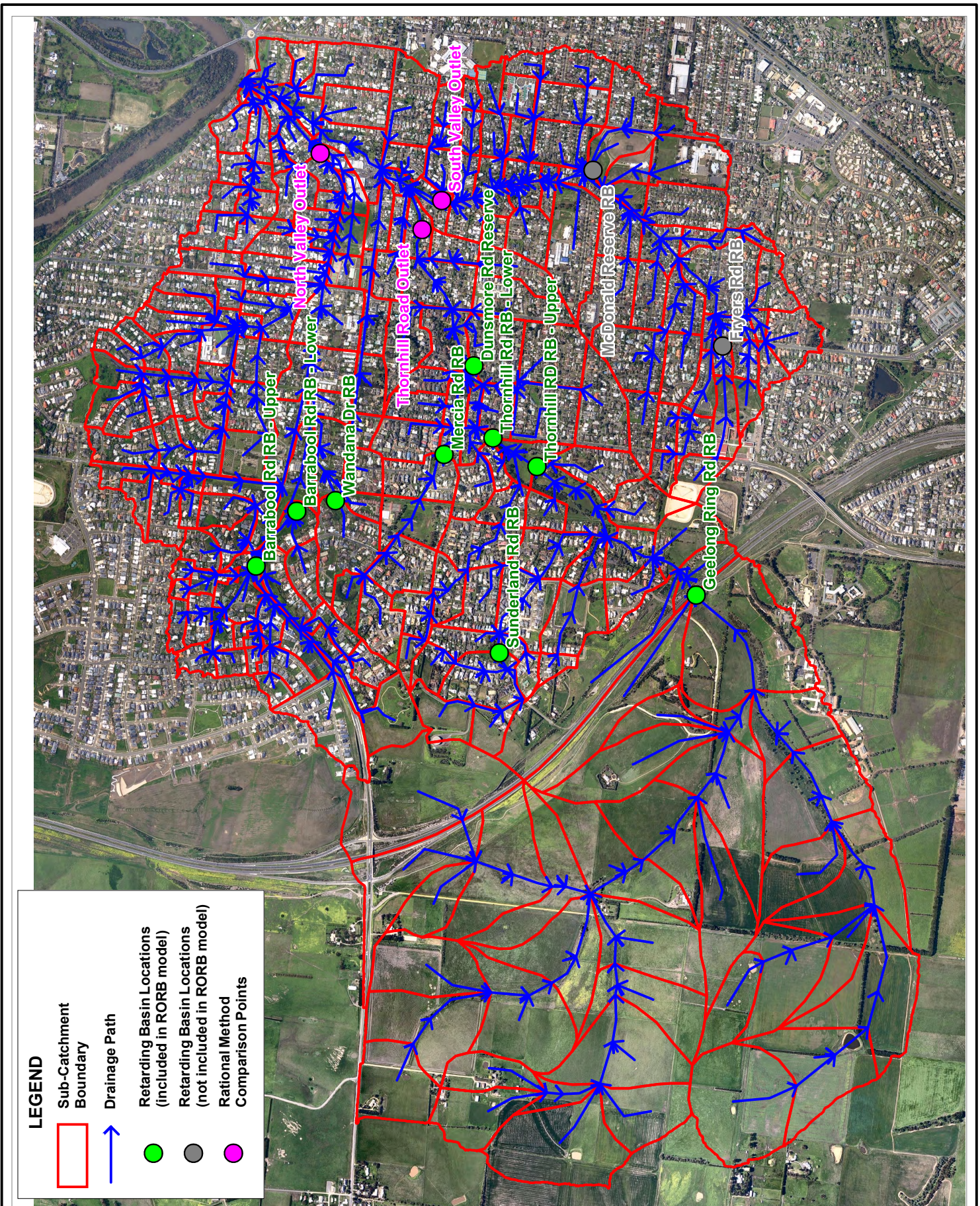
Where 'S' represents the storage (m³), 'Q' is the discharge (m³/s), 'm' is a dimensionless exponent and 'k' is non-dimensional empirical coefficient. 'k' is defined by the product of the catchment value 'k_c' and the individual reach k_r. Both m and k_c are defined as calibration parameters. Based on industry best practice, in the absence of calibration events, 'm' of 0.8 was adopted.

4.1.1.1 Model Description

The RORB model incorporates an area of approximately 10.4 square kilometres, including the entire Highton study area. To ensure accurate representation of the overall catchment and an appropriate distribution of flows for the hydraulic model, the RORB model was divided into 264 individual sub-catchments. Conceptual reaches (approximate overland flow paths) were defined and storage relationships were included for the existing retarding basins within the catchment. The schematic RORB layout is shown in Figure 4-1.

4.1.1.2 Sub-Catchment Definition

The external catchment boundary was determined using the software package CatchmentSim, whilst the internal sub-catchment boundaries were determined based on the LiDAR topographic data and photogrammetry (supplied by CoGG), CoGG drainage plans and the underground drainage network layout. The sub-catchment breakdown is shown in Figure 4-1.



LEGEND

- Sub-Catchment Boundary ▭
- Drainage Path ↑
- Retarding Basin Locations (included in RORB model) ●
- Retarding Basin Locations (not included in RORB model) ●
- Rational Method Comparison Points ●

Title:
RORB Catchment Layout

Figure:
4-1

Rev:
B

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.



4.1.1.3 Global Parameters

RORB model parameters for the Kardinia Creek catchment are summarised in Table 4-1 and are discussed further in Sections 4.1.1.4 to 4.1.1.7.

Table 4-1 RORB Parameters

RORB Parameter	Value
Storm Data	Highton
Catchment Area	10.4 km ²
Initial Loss	15.0 mm
Volumetric Runoff Coefficient	Varies (refer to 4.1.1.4)
m	0.80
k _c	4.94
Fraction Impervious	Varies, as per land use (Table 4-4)
Reach Types	Type 1, 2, 3 and 4

4.1.1.4 IFD Parameters

Storm data was based on IFD parameters sourced from the Bureau of Meteorology, which are based on Figures 1.8 to 6.8 and 7d to 9 of Australian Rainfall and Runoff (AR&R) Volume 2. The adopted values for the catchment are presented in Table 4-2.

Table 4-2 IFD Parameters

IFD Parameter		Adopted Value
Rainfall Intensity (mm/hr)	2 Year ARI, 1 Hour Duration	17.97
	2 Year ARI, 12 Hour Duration	3.25
	2 Year ARI, 72 Hour Duration	0.89
	50 Year ARI, 1 Hour Duration	34.47
	50 Year ARI, 12 Hour Duration	6.03
	50 Year ARI, 72 Hour Duration	1.80
Skew Coefficient		0.42
Geographical Factor F2		4.29
Geographical Factor F50		14.83
Zone		1

4.1.1.5 Loss Parameters

The loss model adopted was the “initial loss/volumetric runoff coefficient” loss model. This modelling approach is consistent with previous flood studies undertaken for CoGG, including the Thornhill Road Retarding Basin Assessment. RORB generates runoff by subtracting losses at each timestep from the rainfall occurring in that time period. The adopted initial loss was 15 mm and the runoff coefficients for pervious areas were adopted as per Melbourne Water recommendations, as shown in Table 4-3. For impervious areas, RORB has a “hardwired” initial loss of 0 mm and runoff coefficient of 0.9.

Table 4-3 Runoff Coefficients for different AEPs

AEP	Runoff Coefficient
20%	0.25
10%	0.35
5%	0.45
1%	0.60

4.1.1.6 Fraction Impervious

The fraction of the catchment that is impervious is a key input to the hydrologic modelling. Impervious fractions for various planning scheme codes were based on advice from CoGG, values contained within Council's design guidelines, inspections of aerial photographs, and values presented in Australian Rainfall and Runoff (1987). Key impervious fractions adopted are reproduced in Table 4-4.

Table 4-4 Impervious Fraction for Planning Scheme Zone

Zone	Impervious Fraction
Residential (< 300 m ²)	0.95
Residential (300 to 400 m ²)	0.6
Residential (400 to 600 m ²)	0.5
Residential (600 to 1 000 m ²)	0.42
Residential (1 000 to 2 000 m ²)	0.4
Commercial	0.95
Industrial	1
Hospitals	1
Open Space / Sports Grounds	0.15
Farmland	0.05
Schools with large sports fields / Developed Parks	0.5
Schools with few fields	0.75
Major Roads	1
Minor Roads	0.8

The planning scheme data was used to establish an area-weighted average of the impervious fractions for each sub-catchment used in the hydrologic model.

4.1.1.7 Retarding Basins

The Kardinia Creek catchment includes 11 individual retarding basins, all of which are located within the TUFLOW hydraulic model extent. The 2D hydraulic model determines the storage and discharge characteristics of the basins based upon the underlying topography and outlet structures, and therefore do not need to be included in the RORB hydrologic model. For the majority of sub-catchments within the hydraulic model extent, only local sub-area inflows are applied, not total hydrographs.

However, as eight of the retarding basin's relationships had previously been defined as part of the Thornhill Road Retarding Basin Assessment (WBM 2004), the Geelong Ring Road Hydraulic Assessment (SKM 2008) and internal CoGG drainage assessments (pers comm), these relationships have been included in the Highton RORB model for completeness. The remaining three retarding basins: Wandana Drive, Burdekin/South Valley Road and McDonald Reserve, were modelled within the hydraulic model only as no stage-storage / storage-discharge relationships (or similar) were available. For each of the basins within the hydraulic model, the LiDAR data effectively described the storage while the outlet structure configuration was based on design drawings supplied by Council.

4.1.1.7.1 Thornhill Road Retarding Basin Assessment

Five of the retarding basins within the Kardinia Creek catchment have previously been modelled in the Thornhill Road Retarding Basin Assessment (WBM 2004). These include:

- Sunderland Road Retarding Basin;
- Close Retarding Basin;
- Vanessa Avenue Retarding Avenue Basin;
- Thornhill Road Upper Retarding Basin; and
- Thornhill Road Lower Retarding Basin.

The parameters for these basins have been taken directly from the Thornhill Road Retarding Basin Assessment and applied to the Highton RORB model using weir and pipe formulas consistent with previous modelling. The adopted basin details are provided in Table 4-5.

Table 4-5 Thornhill Road Assessment Retarding Basin Details

Parameter	Sunderland Road RB	Mercia Close RB	Vanessa Avenue RB	Thornhill Road Upper RB	Thornhill Road Lower RB
Peak storage at weir crest	1700 m ³	3100 m ³	560 m ³	88 600 m ³	4 700m ³
Overflow weir crest	100.0 m AHD	54.2 m AHD	32.2 m AHD	48.0 m AHD	40.4 m AHD
Overflow weir crest length	6 m	10 m	20 m	50 m	50 m
Pipe outlet diameter	1 x 450 mm	1 x 450 mm	1 x 675 mm RCP & 2 x 900x900 mm RCBC	1 x 1050 mm	5 x 525 mm
Pipe outlet length	20 m	30 m	30 m	75 m	45 m
Pipe outlet invert	96.96 m AHD	50.44 m AHD	50.44 m AHD	42.00 m AHD	38.10 m AHD
Pipe outlet grade	2.0 %	0.6%	1.3 %	2.0 %	5.5 %

4.1.1.7.2 Geelong Ring Road Hydraulic Assessment

Details for the Geelong Ring Road Retarding Basin were provided by the City of Greater Geelong as an excerpt of the Wandana Drive Retarding Basin Report (referred to as Ring Road Retarding Basin in this report) undertaken by SKM(2008). The storage discharge table was then used to represent the basin in RORB. The retarding basin stage-storage-discharge relationship provided by CoGG has been reproduced in Table 4-6.

Table 4-6 Geelong Ring Road Stage-Storage-Discharge Relationship

Elevation (m AHD)	Discharge (m ³ /s)	Storage (m ³)
55.90	0.00	0
56.90	1.35	126
57.90	2.23	1840
58.90	2.68	7284
59.90	3.08	16466
60.90	3.43	30872
61.40	3.59	40494
61.90	3.75	51568
62.40	3.90	64410
62.75	4.00	74506
62.90	4.04	79071
62.97	4.06	81250
63.10	4.10	85379
63.40	4.18	95321
63.50	4.21	98760

4.1.1.7.3 Internal CoGG Hydraulic Assessment

The City of Greater Geelong provided an XP-RAFTS model containing pipe outlet data and stage-discharge equations for the Barrabool Road Upper and Barrabool Road Lower Retarding Basins. The pipe outlet data was taken from the XP-RAFTS model and applied to the Highton RORB model using the weir and pipe formula method. Ground elevation and outlet invert data was converted meters AHD from the supplied photogrammetry DEM, using the top of bank for each retarding basin as reference. Table 4-7 provides the adopted basin details.

Table 4-7 Barrabool Road Upper and Barrabool Road Lower Retarding Basin Details

Parameter	Barrabool Road Upper RB	Barrabool Road Lower RB
Peak storage at weir crest	5469 m ³	21469 m ³
Overflow weir crest	84.49m AHD	71.04m AHD
Overflow weir crest length	13 m	30 m
Pipe outlet diameter	1 x 1050 mm	3 x 375 mm
Pipe outlet length	80 m	112 m
Pipe outlet invert	29 m AHD	64 m AHD
Pipe outlet grade	0.55 %	5.4%

4.1.2 Hydrological Model Verification

Due to the lack of historical rainfall and flood height data, calibration of the model to recorded data was not possible. Results from the hydrological model were verified against previous modelling of the portion of the catchment covered by the Thornhill Road Retarding Basin Assessment (WBM 2004). Additional checks were undertaken by comparing the flows generated by the RORB model against

the flows calculated by the Rational Method. The process undertaken to verify the results of the hydrological model are detailed below.

To verify the hydrologic model against the previous Thornhill Road Retarding Basin Assessment (WBM 2004) a RORB model of the Kardinia Creek catchment was developed with the Geelong Ring Road Retarding Basin removed. The peak 1% AEP flows from the RORB model at the inflow of the Thornhill Road Upper Retarding Basin and at the inflow to the Vanessa Avenue Retarding Basin were compared against RORB results from the previous Thornhill Road Retarding Basin Assessment (WBM 2004) model, but with the IFD parameters adjusted to match the overall Kardinia Creek catchment. The runs were completed using a k_c value of 4.94 that maintained the k_c/d_{av} ratio of 1.52 from the previous modelling. These results showed that by maintaining the k_c/d_{av} ratio, the discharges from the Highton modelling were very similar to those of the Thornhill Road Retarding Basin Assessment modelling, as shown in Table 4-8. As a result of this comparison a k_c value of 4.94 has been adopted for the Highton Drainage/Flood Study.

Table 4-8 Comparison of Highton RORB model and Thornhill Road Assessment results

Location	Peak Flow (m ³ /s) RORB Model	Peak Flow (m ³ /s) Thornhill Road Retarding Basin Assessment RORB Model (WBM 2004)	% Difference
Upper Thornhill Road Retarding Basin Inflow	25.8	25.3	1.9%
Dunsmore Road Drainage Reserve Inflow	11.0	10.9	0.9%

To ensure the validity of the comparison between the two hydraulic models, a region inspection of the contributing catchment area and fraction impervious values of the Thornhill Road Retarding Basin Assessment RORB model and the equivalent area of the Highton RORB model was performed. As shown in Table 4-9 there is a slight increase in catchment area and a minor decrease in the area weighted fraction impervious to the Vanessa Avenue Retarding Basin. This indicated that there have been no significant changes in the fraction impervious which would create differences in flows between the two RORB models.

Table 4-9 Fraction Impervious Comparison for Thornhill Road Retarding Basin Assessment Catchment and Highton Catchment of Equivalent Area

Model	Contributing Catchment Area (km ²)	Fraction Impervious (area weighted average)
Thornhill Road Retarding Basin Assessment	5.88	18.9%
Highton (Equivalent Area)	5.89	18.4%

In order to further verify that the adopted k_c value of 4.94 was appropriate to be applied over the entire catchment, the peak flows at other locations within the catchment were compared to a Rational Method calculation. The differences between the Rational Method and the RORB model (without retarding basins) results at the outlet of the three main drainage system branches were of the same order of magnitude and are considered acceptable. The results of the comparison are summarised in

Table 4-10. These results show that adopting a k_c value of 4.94 is appropriate for the entire Kardinia Creek catchment.

Table 4-10 Comparison of Highton RORB model and Rational Method results

Location	Peak Flow (m ³ /s) RORB Model	Peak Flow (m ³ /s) Rational Method	% Difference
North Branch	43.6	45.3	-3.9 %
South Branch	29.0	30.6	-5.5 %
Thornhill Road Branch	67.6	67.9	-0.4 %

4.1.3 Design Event Modelling

4.1.3.1 Design Event Probabilities

Hydrological analysis was undertaken for the 1%, 5%, 10% and 20% Average Exceedance Probability (AEP), i.e. the 100, 20, 10 and 5 year Average Recurrence Interval (ARI) or return period, design storm events. Hydrographs were derived by RORB to provide external and internal boundary conditions to the hydraulic model at a number of locations throughout the catchment.

4.1.3.2 Design Rainfall

Intensity Frequency Duration (IFD) parameters for the Kardinia Creek catchment were determined from the Bureau of Meteorology using a method based on the maps from Volume Two of Australia Rainfall and Runoff (AR&R). These IFD parameters are an input to RORB and are used to generate design rainfall intensities and depths using standard AR&R procedures. The IFD parameters are presented in Table 4-2.

Filtered temporal patterns were used to derive the design storm events. Aerial Reduction Factors (ARF) were not applied due to the catchment's small size. The resulting design storms were run through the RORB model of the catchment and the results summarised to determine the critical durations.

4.1.3.3 Critical Duration

For each design probability, the peak discharge at various locations within the drainage system may be generated by storm events of different durations. Therefore, consideration of peak discharges for a range of durations is important. For example, a 2 hour duration event may result in the peak discharge in the upper portion of a catchment, while a 9 hour duration event could result in the peak discharge at the bottom of a catchment. Alternatively, the peak flood level may be more related to volume than discharge, and a high volume event may be more appropriate for consideration. Accordingly, to assess the peak discharges and volumes over the catchment, events ranging from 10 minute duration to 72 hour duration were modelled.

4.1.4 Peak Outflows

The hydraulic model extent covers almost the entire catchment limit and hence, there are no major external inflows into the hydraulic model. The inflows for the hydraulic model are a series of 'local'

hydrographs that represent the local sub-catchment flows. Table 4-11 summarises the peak outflows from the hydrological model at six locations of hydraulic significance within the study area including the catchment outflow into the Barwon River. The peak outflow hydrographs are also presented in Figure 4-2 to Figure 4-7.

Table 4-11 Peak Outflows

Location	Peak Flow (m ³ /s)			
	20% AEP	10% AEP	5% AEP	1%AEP
Thornhill Road Upper Retarding Basin Inflow	4.0	5.7	8.1	12.4
Vanessa Avenue Retarding Basin Inflow	4.5	5.9	7.6	11.0
Corner of Bellevue Avenue and Maus Street	7.2	9.8	13.2	21.6
Corner of Bellevue Avenue and Roslyn Road	11.2	15.0	21.2	35.5
Corner of Barrabool Road and Mount Pleasant Road	10.1	13.4	17.4	28.6
Catchment Outlet - Barwon River	16.5	21.2	28.2	48.5

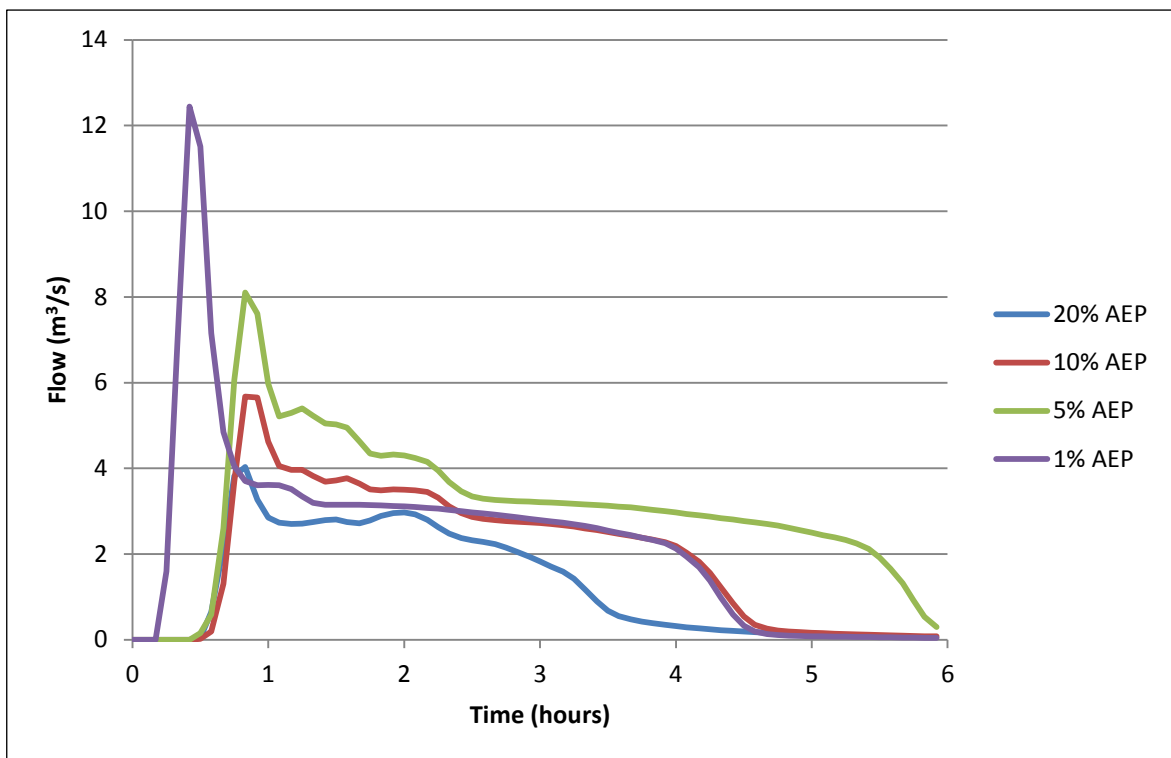


Figure 4-2 Thornhill Road Upper Retarding Basin Inflow

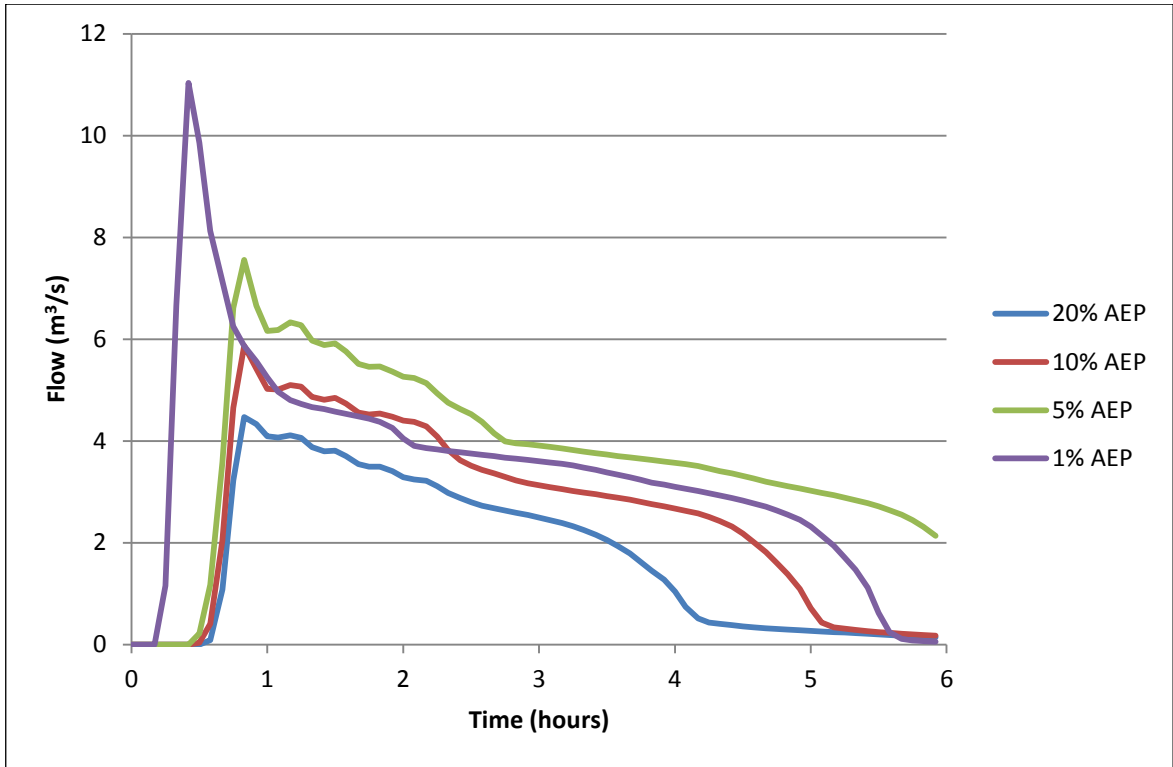


Figure 4-3 Vanessa Avenue Retarding Basin Inflow

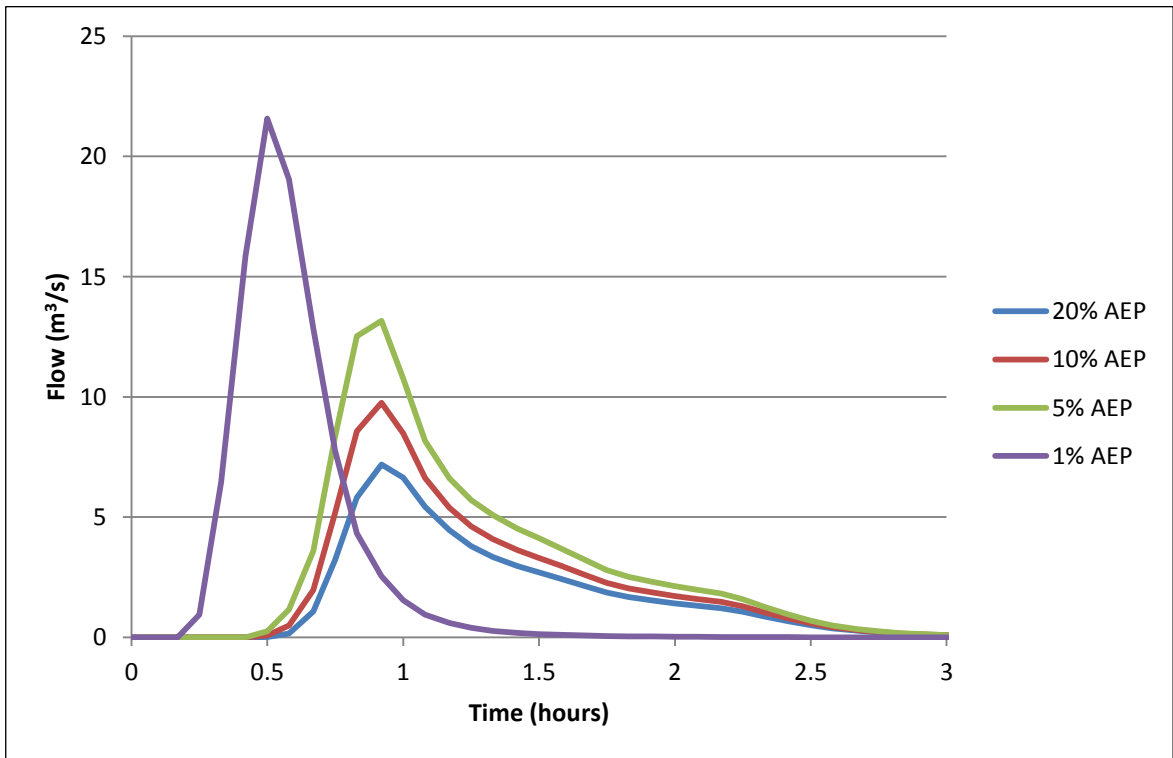


Figure 4-4 Corner of Bellevue Avenue and Maus Street

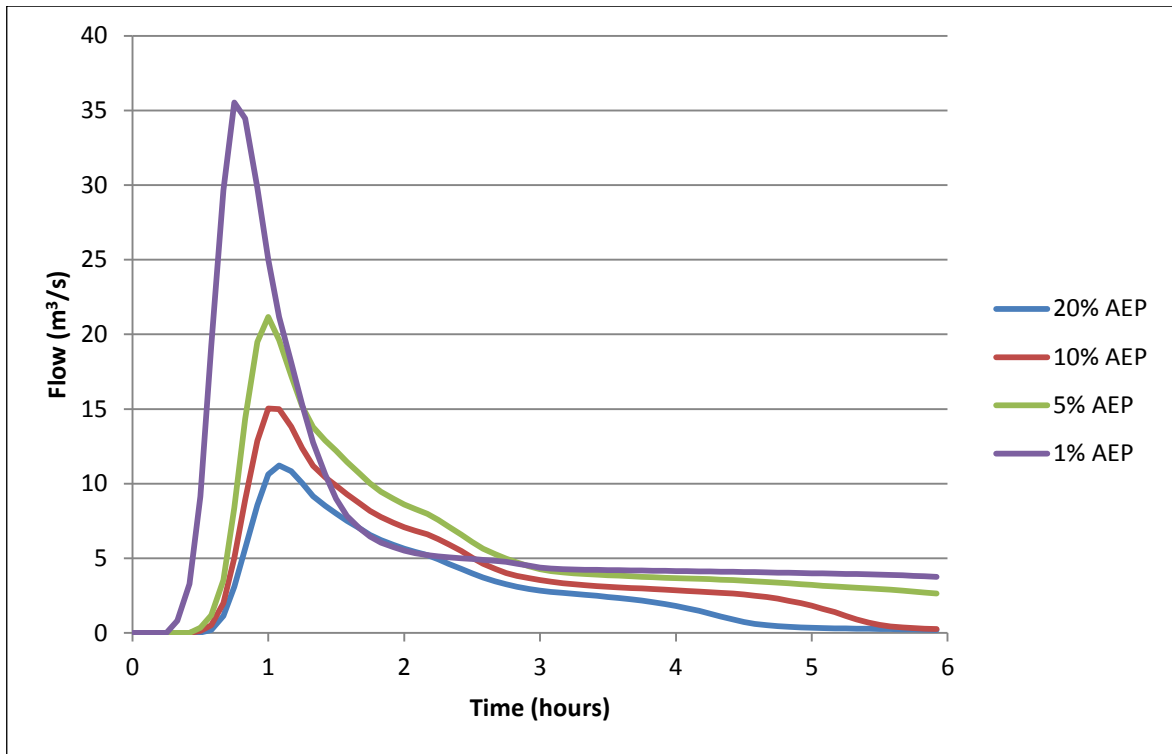


Figure 4-5 Corner of Bellevue Avenue and Roslyn Road

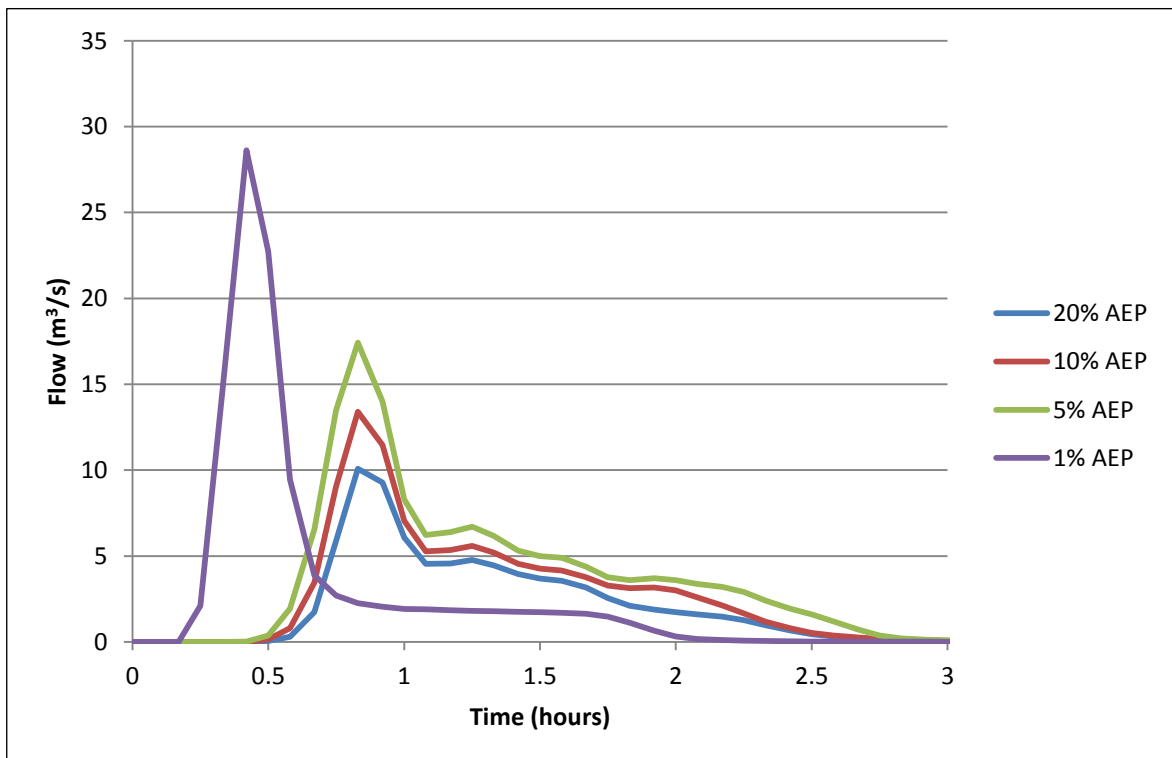


Figure 4-6 Corner of Barrabool Road and Mount Pleasant Road

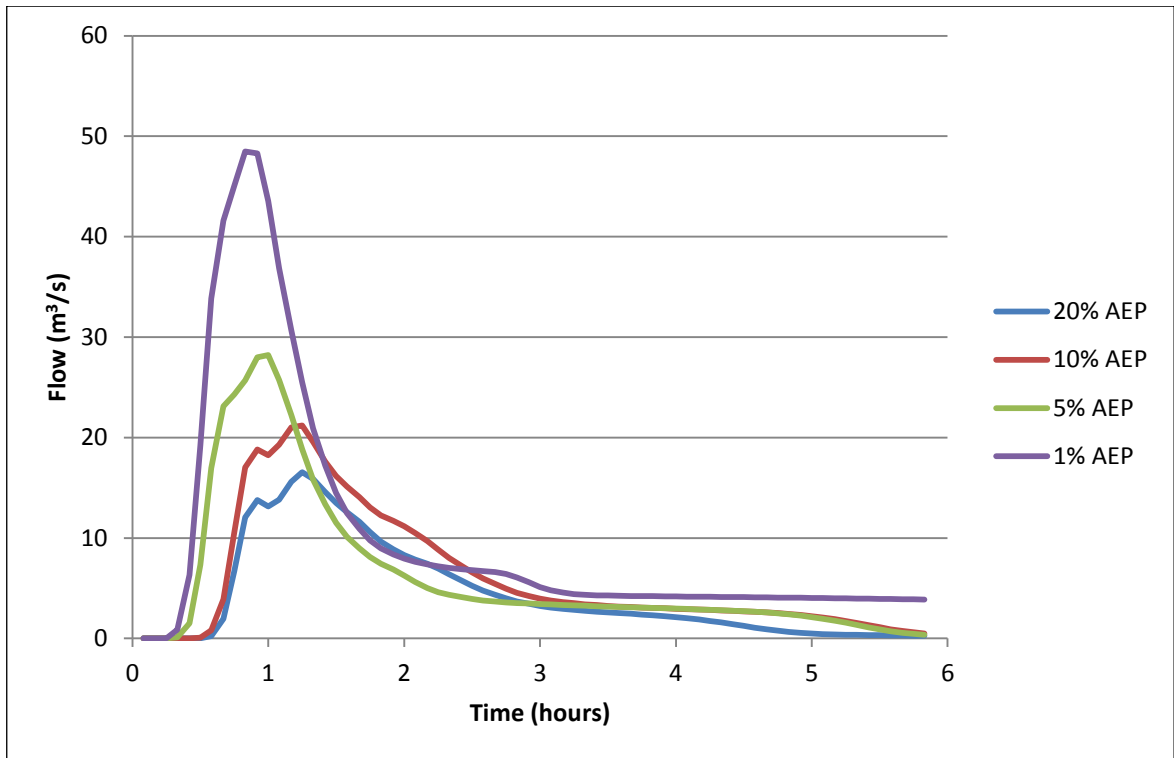


Figure 4-7 Catchment Outlet - Barwon River

4.2 Hydraulic Model

TUFLOW, a fully 2D hydraulic modelling package with the ability to dynamically nest 1D elements, was adopted for this study. This TUFLOW model contains nested 1D channels representing table drains and the open drainage channels, Council's pipe network (DN300 and greater) and stormwater entry pits.

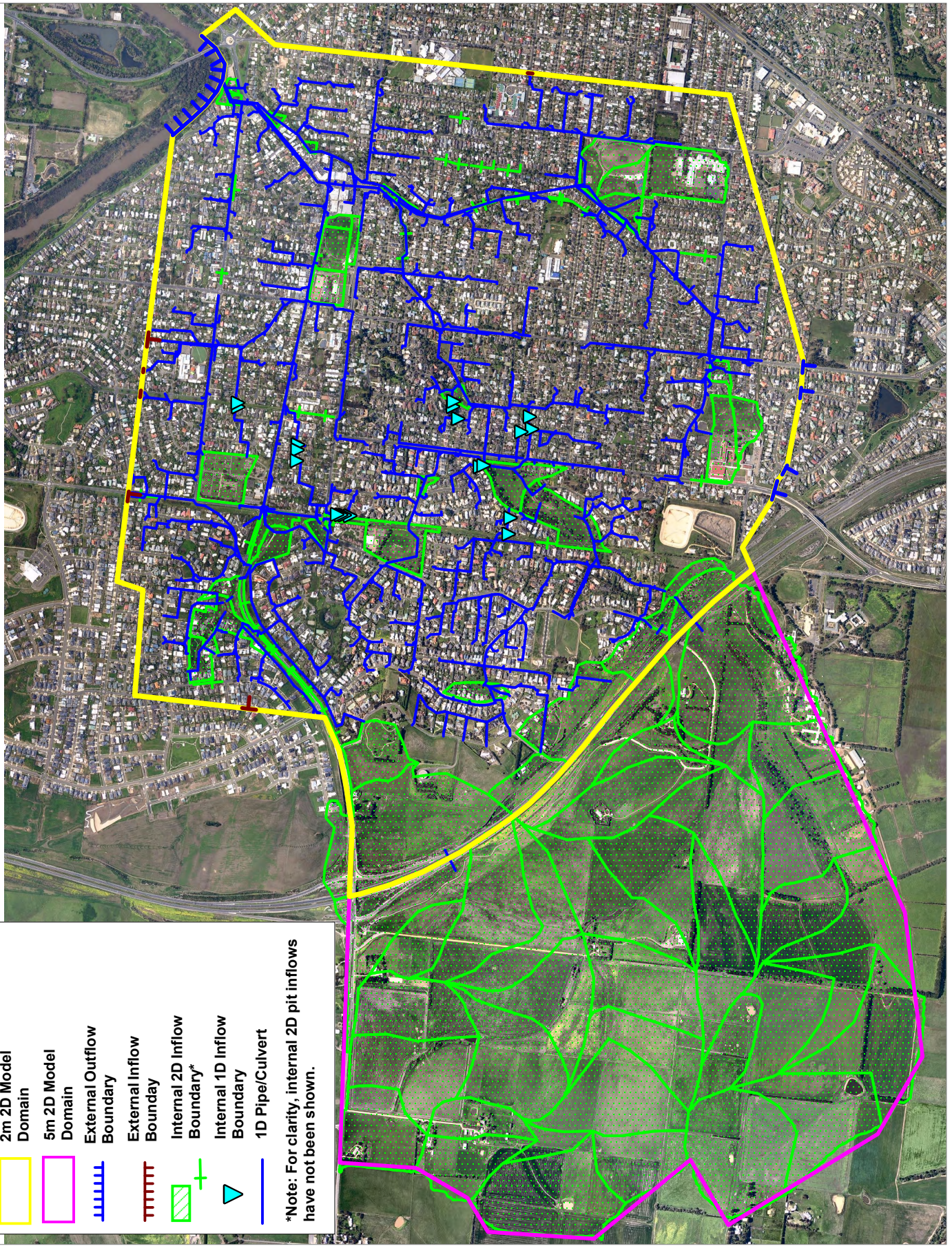
In catchments such as Kardinia Creek, where storage and timing of the rainfall inflows in the catchments are important, modelling using flow varying with time (unsteady state) rather than peak flow (steady state) is required. Accordingly, TUFLOW was run in unsteady state.

4.2.1 Model Description








The 2D model domain extends beyond the limit of the study's flood mapping region, and covers about 10.3 square kilometres of the Kardinia Creek catchment (as shown in Figure 4-8). The geometry of the 2D model was established by constructing two uniform grids of square elements divided by the Geelong Ring Road. 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 element size for the Kardinia Creek catchment, the above issues were considered in conjunction with the final objectives of the study. In order to achieve the final objectives of the study, whilst keeping model run times within acceptable limits, the hydraulic modelling adopted a grid size of 2 metres east of the Geelong Ring Road and a grid size of 5 metres to the west. This allows for a high resolution within the flood mapping limit and also allows for the upper catchment west of the Geelong Ring Road to be modelled in the hydraulic model, removing uncertainties associated with the representation of the informal storages and the performance of the Geelong Ring Road Retarding Basin within the hydrological model. As part of the detailed hydraulic modelling, a number of 1D elements have been embedded into the 2D model to improve the modelling of the catchment. The modelling of these 1D elements (culverts/pipe networks), ensures that the capacity and conveyance of these systems are accurately modelled.

Each square grid element contains information on ground topography, sampled from the DEM at 1 m spacing in the 2 m domain and 2.5 m in the 5 m domain, surface resistance to flow (Manning's 'n' value) and initial water level. Seventeen areas of different land-use type, determined from planning maps, aerial photography and site inspections, were identified for setting Manning's 'n' values. These are summarised in Table 4-12.



LEGEND

	2m 2D Model Domain
	5m 2D Model Domain
	External Outflow Boundary
	External Inflow Boundary
	Internal 2D Inflow Boundary*
	Internal 1D Inflow Boundary
	1D Pipe/Culvert

*Note: For clarity, internal 2D pit inflows have not been shown.

Title:
TUFLOW Model Layout

Figure:
4-8

Rev:
B

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.

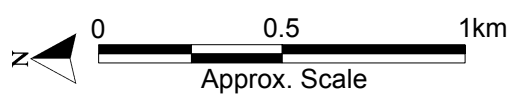


Table 4-12 2D Domain Manning's 'n' Coefficients

Land use	Manning's n
Low Density Residential	0.15
Residential	0.2
High Density Residential	0.4
Commercial/High Density Industrial	0.4
Building Envelope	1
Open Space – Maintained Grass	0.035
Open Space – Unmaintained Grass	0.05
Open Space – Low Density Vegetation	0.55
Open Space – Medium Density Vegetation	0.65
Open Space – High Density Vegetation	0.1
Sports Ovals	0.03
Easements	0.045
Developed Parks/School Fields	0.05
Schools and Public Areas of Similar Type	0.2
Cemetery	0.1
Roads	0.025
Open Water	0.03

4.2.2 Model Development

4.2.2.1 Pipe Network Setup

Pipe elements within the Highton drainage area of 300mm diameter/width and above have been included as 1D elements within the model. The 1D pipe network (Figure 4-8) was developed using data supplied by the CoGG (refer to Section 3.3). There were many gaps in the supplied GIS data which required filling before the pipe network could be represented accurately within the 2D model. The steps and assumptions made to complete the 1D pipe network are detailed below:

1. Circular pipes of less than 300mm diameter and rectangular box culverts of less than 300mm width were removed from the pipe network. As result of this there was a number of "stand alone" pipes present which did not connect to the remaining pipe network. These were also removed on a case by case basis.
2. Missing pipe dimensions and inverts were filled using information from adjacent pipes.
3. Where possible missing inverts and dimensions were interpolated.
4. All plans supplied by the CoGG were reviewed to either fill missing data or to confirm the accuracy of present data.

During this process it became evident that plans that were in imperial measurements and some that were in metric measurements had not had their datum converted to m AHD. Where possible datums were adjusted to m AHD. This was done by several methods including; matching to downstream pipe networks, using depths from plans or GIS data and using known datum conversions (GW&ST).

5. Following the review of the plans, remaining inverts were interpolated assuming a minimum of 450mm cover for drains within easements and 600mm for those within road reserves.
6. To verify the infilled inverts, field survey was required (refer to Section 3.5). The survey was taken at selected pits which would allow for a section of pipe network to have its assumed inverts, as determined by the previously mentioned assumptions, verified.

4.2.2.2 Pits

In order to connect the 1D pipe network with the 2D domain hydraulic connectors are required. For the Highton drainage/flood study this has been achieved using pit connections. All side entry and grated entry pits that connect to pipes modelled were included in the model as connectors. Side entry pits were assumed to be 1200mm wide and 150mm high kerb inlets. For double and triple side entry the width was adjusted accordingly. Grated pits were assumed to have a 900mm x 900mm square inlet.

In order to represent the inflow/discharge capacity of the above mentioned pits, curves have been developed specifying a depth – inflow/discharge to model the conveyance of the pit given the depth of water at an individual pit within the 2D domain. The inlet pits were derived by adapting previous work undertaken by BMT WBM for the Bankstown City Council in NSW (BMT WBM 2009) and adapted to suit the dimensions of the pits found within the Highton model. The derived curves assume that there is no blockage at the pit entries and have been sensibility checked using standard hydraulic calculations.

Other connection types such as wing wall entries or exits and structures within retarding basins were modelled as appropriate on a case by case basis.

All pits within the model, including sealed junction pits, which were not modelled as connections, have been assigned an appropriate form loss using the Engelhund loss approach, a new feature in TUFLOW that automatically assigns losses based on the characteristics of the drainage network. Where there are complex hydraulic structures such as retarding basin inflows and outflows losses have been specified based on the characteristics of the structure. These losses are based on those described in Melbourne Water's *Land Development Manual* (Melbourne Water 1998).

4.2.2.3 Multiple Domain Linking

The Highton hydraulic model was developed using multiple 2D domains to represent the floodplain. As shown in Figure 4-1 a 2 metre grid element size was used on the east side of the Geelong Ring Road where the area of interest for this study is located and a 5 metre grid element size was used on the west side of the Geelong Ring Road. The 5 metre domain was included within the hydraulic model in order to remove the uncertainties associated with applying the routed flow from the hydrologic model downstream of the Geelong Ring Road. These include the lack of representation of

the informal storages ie. farm dams, natural depressions, etc and the performance of the Geelong Ring Road retarding Basin within the hydrologic model.

As shown in Figure 4-1, the two 2D domains are linked together via 1D pipe elements representing the Geelong Ring Road Retarding Basin outlet and a drainage culvert under the road to the north. No 2D2D linking has been used in this model as the domains join along the centre of the Geelong Ring Road which is immune to flooding in a 1% AEP flood event. The Wandana Drive underpass was also not modelled as it will remain dry in the 1% AEP event (documented in provided technical report and supported by preliminary hydraulic modelling).

Limited details of the topography of the Geelong Ring Road were supplied for this study; therefore some interpretation of “current” ground elevations within the area was required. Topographic data was supplied for the west face and the road surface of the embankment adjacent to the Geelong Ring Road Retarding basin. These known elevations were then used to create the topography of the entire length of highway using aerial photography to define the embankment extents and match the elevated elevations with the DEM elevations.

4.2.3 Boundary Conditions

The TUFLOW model has been developed using a fixed water level of 4.85 m AHD for the downstream boundary condition. This level was supplied by the CoGG and equates to the 5% AEP flood level in the Barwon River at the catchment outlet.

4.2.4 Design Event Modelling

The 1%, 5%, 10% and 20% AEP design storm events were modelled in the initial TUFLOW models for a wide range of storm durations. Model results were reviewed and it was determined that the 15 minute, 20 minute, 25 minute, 1 hour, 1.5 hour, 2 hour, 9 hour, 24 hour and 72 hour duration storms were critical. These storms were run for subsequent TUFLOW simulations.

The critical storm duration varies across the study area and with AEP. In the 1% AEP event the 15 minute and 25 minute duration events are generally the critical events where flooding has occurred at the upper reaches of the drainage network, i.e. smaller diameter feeder pipes, across the study area. The major drainage path along Barrabool Road the 1 hour duration event is critical from Scenic Road to the catchment outlet. The 24 hour duration event is critical in the Thornhill Road retarding basin; however the critical storm decreases in duration along the major drainage path until it intersects with Belle Vue Avenue where the 1 hour duration event is critical. A peak flood height envelope was developed from the 9 durations and the peak envelope for each AEP event was mapped. The mapping is presented in Figure 5-1 to Figure 5-4. These flood events also formed the basis of the hazard assessment as discussed in Section 5.

As no data was available to calibrate the hydraulic model, a sensibility check was undertaken by comparing the flood extents with historical flooding patterns. Preliminary flood extents for each of the design runs were provided to CoGG. CoGG reviewed the extents in the context of their experience with historical flooding problems in the study area and advised that the flooding patterns indicated by the model were consistent with their understanding of historical flooding in the catchment.

5 FLOOD MAPPING

This section provides a brief overview of the floodplain mapping process used in the investigation and the flood extent map for each of the AEP events presented.

TUFLOW produces a geo-referenced data set defining peak water levels throughout the model domain at the corners of its computational cells. For a given AEP flood event, the peak flood level from each of the storm durations was selected for each computational cell to generate an envelope of peak flood levels. These data were imported into GIS to generate a DEM of the flood surface. Contours of flood height (relative to AHD), depth and hazard were extracted directly from the flood surface.

The nature of flooding within the study area resulted in large areas of quite shallow sheet flow, or runoff, across the catchment. To provide a more realistic estimate of the extent of flooding within the catchment, following consultation with CoGG a “cut off” of 30 mm was adopted for the flood mapping. The flood depth for existing conditions is mapped for the 20%, 10%, 5% and 1% AEP events in Figure 5-1 to Figure 5-4 respectively.

Flooding within the study area above the cut off depth of 30 mm is restricted to the major drainage paths along Barrabool Road, downstream of the Thornhill Road retarding basin and Belle Vue Avenue. Water depths in excess of 2 metres are observed in some of the retarding basins, including the Ring Road Basin, Thornhill Road Upper Retarding Basin and the Wandana Drive Retarding Basin.

Hazard mapping was undertaken using the methodology prescribed in the Melbourne Water document *Guidelines for Development in Flood-prone Areas* (Melbourne Water 2008). The analysis is designed to determine if it is safe for people to move about on a property during a flood event. Safety is defined in terms of the depth and velocity as follows:

- depth should be no more than 0.35m;
- velocity should be no more than 1.5 m/s; and
- the velocity depth product should be no more than $0.35\text{m}^2/\text{s}$

Hazard maps for the four AEP flood events are presented in Figure 5-5 to Figure 5-8. As expected, the majority of the main overland flow through the catchment is classified as safe in a 1% AEP event. This is due to the relatively shallow flow depths experienced across the majority of the study area. The majority of the flooding that has been deemed unsafe occurs within the retarding basins or road corridors, however there are other isolated areas deemed unsafe in the 1% AEP event. These include properties on Belle Vue Avenue immediately south of Roslyn Road and on the major drainage path between Roslyn Road and Mount Pleasant Road, adjacent to Barrabool Road.

During the 20% AEP flood, areas considered unsafe are similar to those outlined above in the 1% AEP event.

An estimate of the number of properties with flooding within the property boundary based on the 30 mm mapping cut off depth has been determined and these figures are shown in Table 5-1. The location of properties with flooding above floor for each AEP is shown Figure 5-1 to Figure 5-4.

Table 5-1 Number of Flooded Properties

AEP	Flooding Occurs Within Property Boundary	Flooding Occurs Above Flood Level*
20%	1402	14
10%	1719	16
5%	1976	22
1%	2318	35

*Results based on properties surveyed by CoGG.



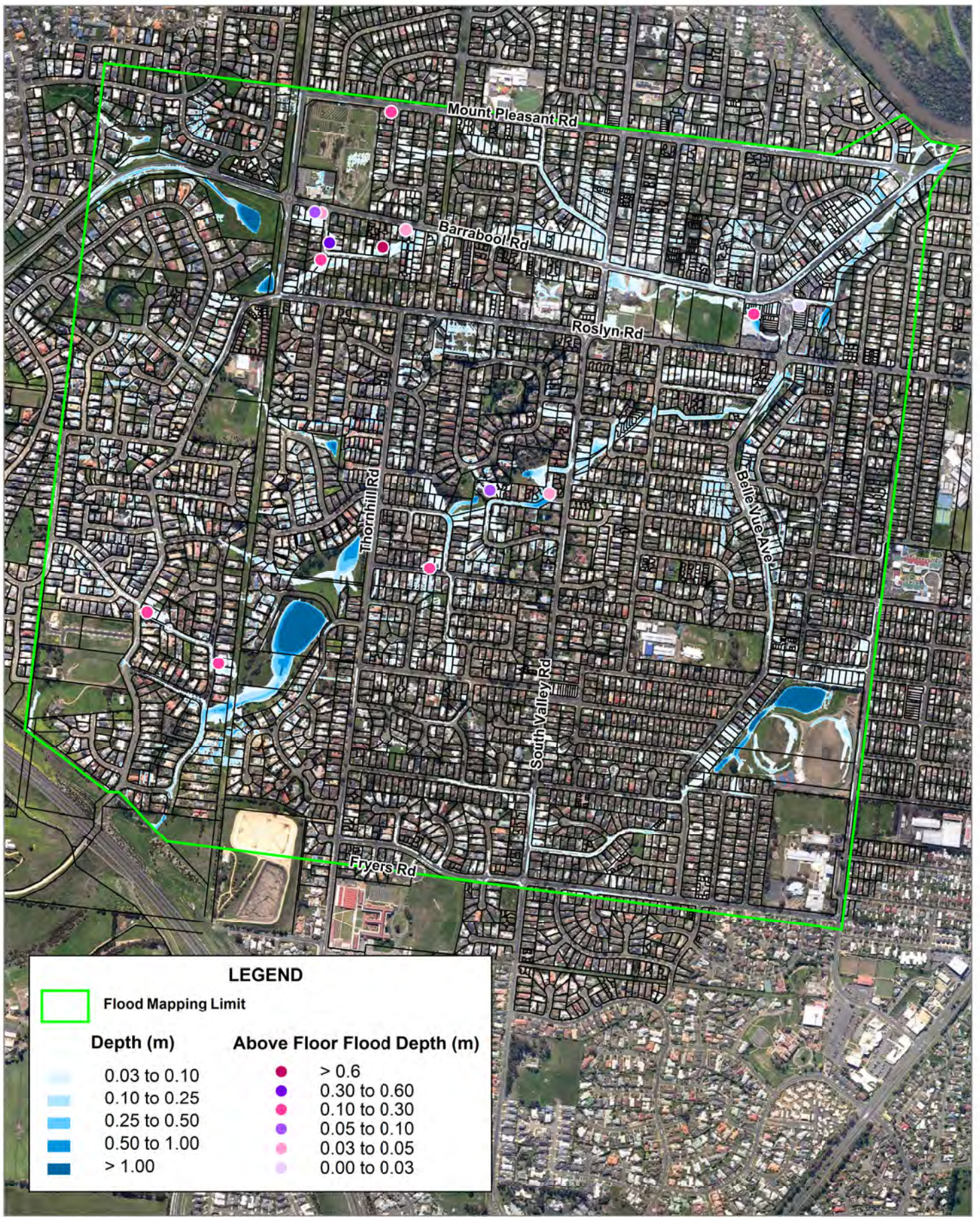
Title:
Existing Conditions 20% AEP Peak Flood Depth

Figure:
5-1

Rev:
B

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.





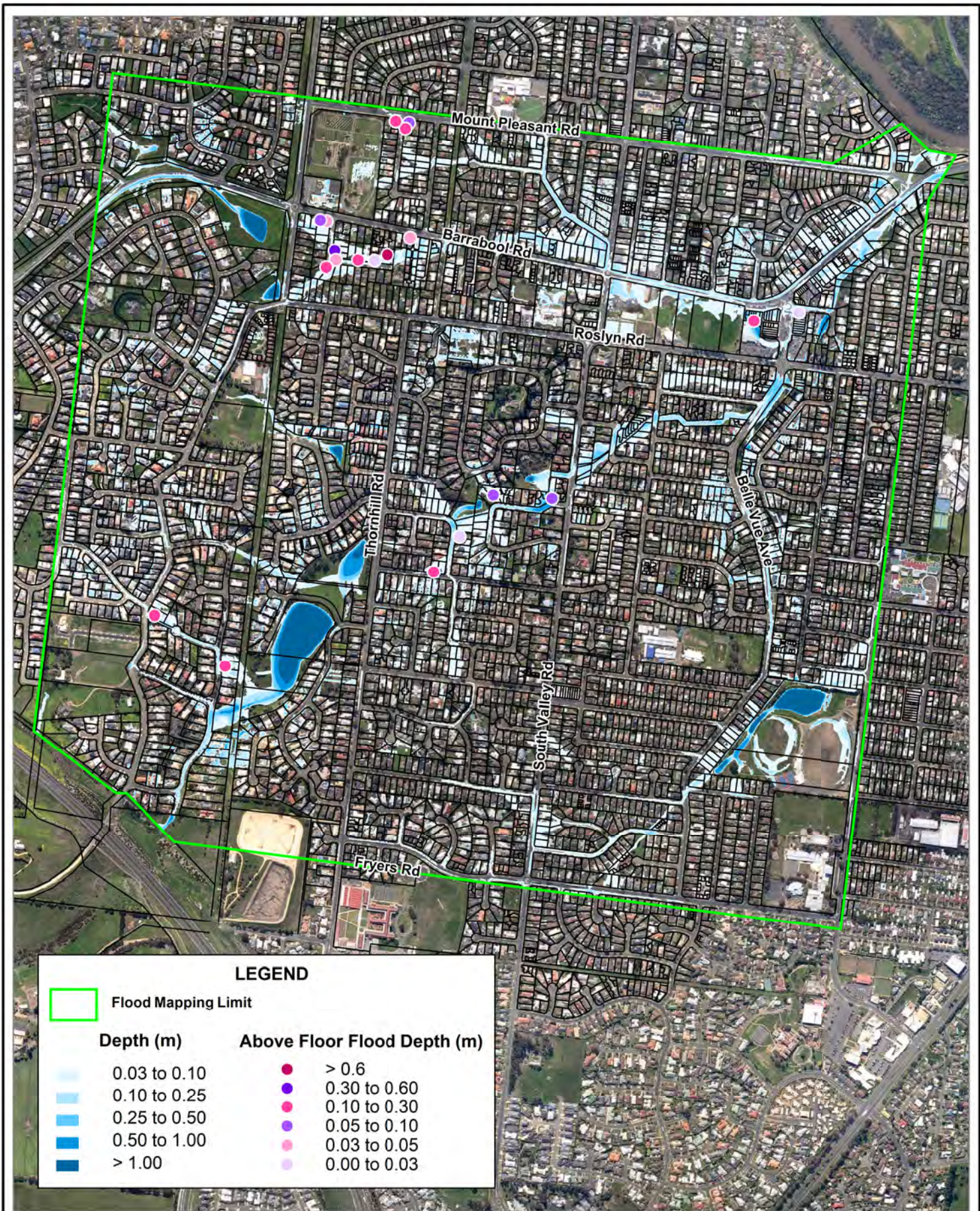
Title:
Existing Conditions 10% AEP Peak Flood Depth

Figure:
5-2

Rev:
B

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.





Title:
Existing Conditions 5% AEP Peak Flood Depth

Figure:
5-3

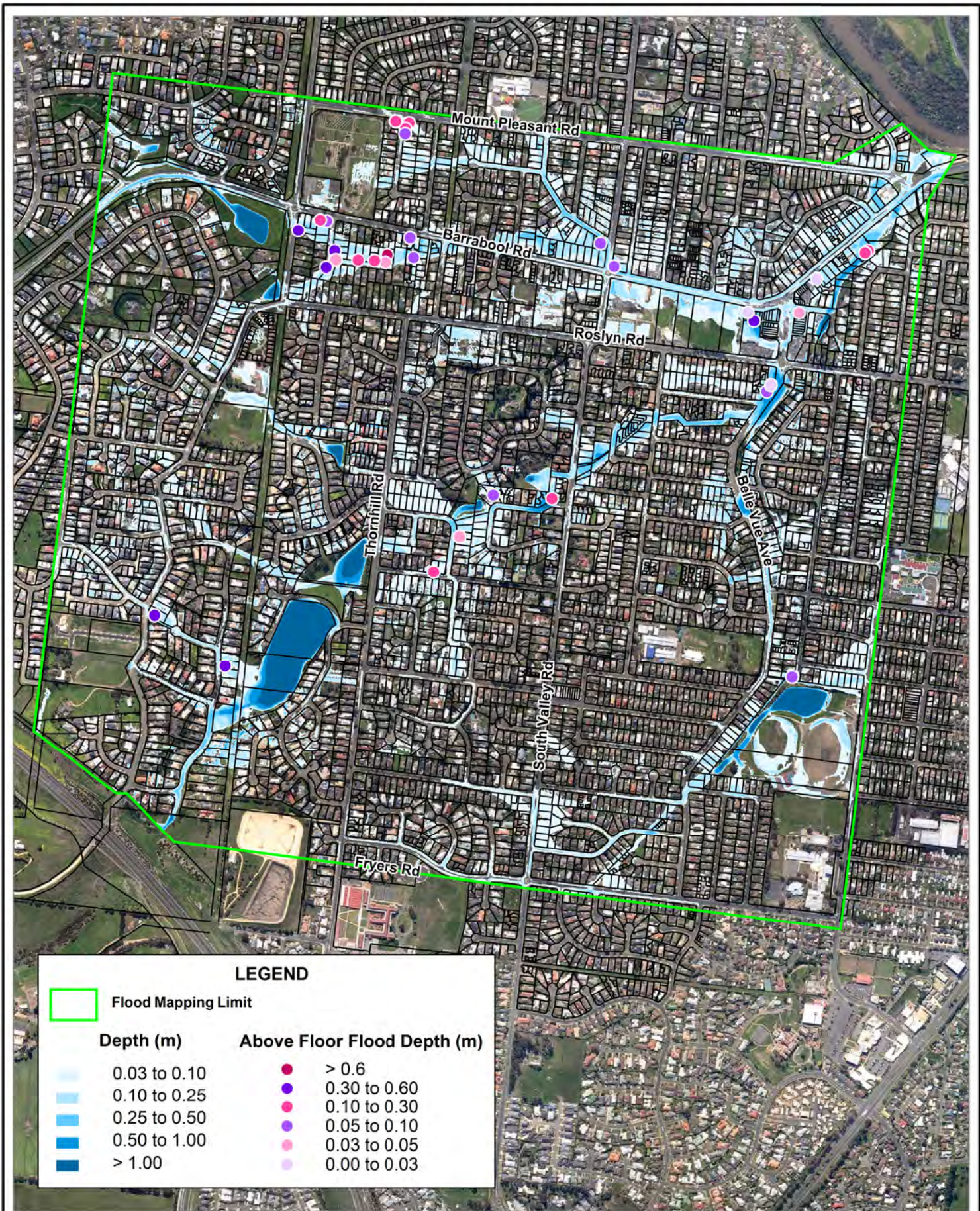
Rev:
B

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.



0 250 500m
 Approx. Scale





Title:
Existing Conditions 1% AEP Peak Flood Depth

Figure:
5-4

Rev:
B

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.




0 250 500m
 Approx. Scale



Filepath : T:\M8094.JL.Highton_DFS\MapInfo\Drawings\Report_Final\Fig5-4_Exg_1%_Depth_RevB.WOR



LEGEND

 Flood Mapping Limit

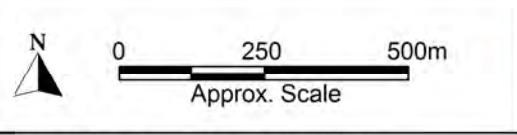
HAZARD

 Safe

 Unsafe

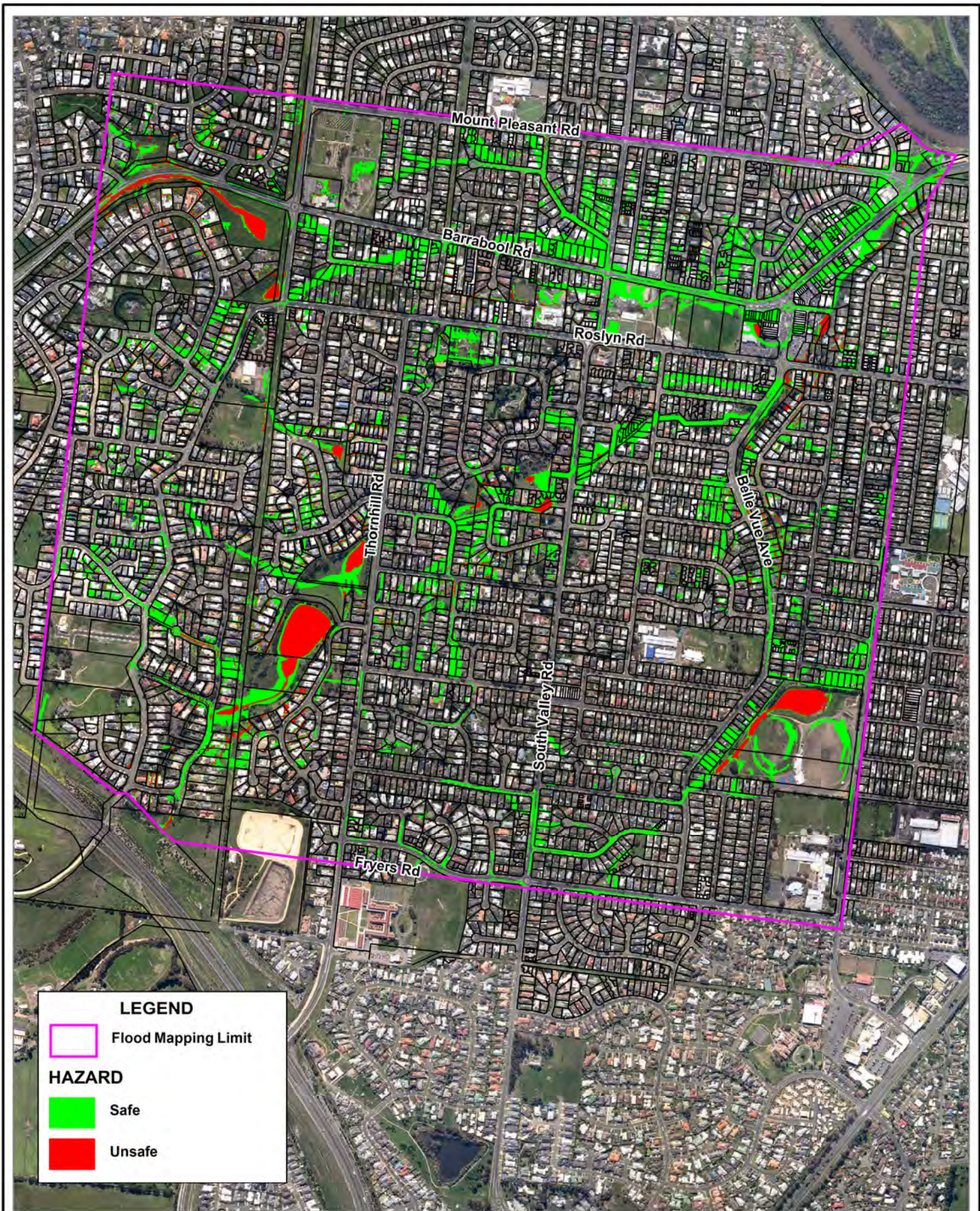
<p>Title:</p> <p>Existing Conditions 20% AEP Peak Flood Hazard</p>	<p>Figure:</p> <p>5-5</p>	<p>Rev:</p> <p>B</p>
---	----------------------------------	-----------------------------

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



LEGEND

 Flood Mapping Limit

HAZARD

 Safe

 Unsafe

Title:
Existing Conditions 10% AEP Peak Flood Hazard

Figure:
5-6

Rev:
B

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.



0 250 500m
 Approx. Scale





LEGEND

 Flood Mapping Limit

HAZARD

 Safe

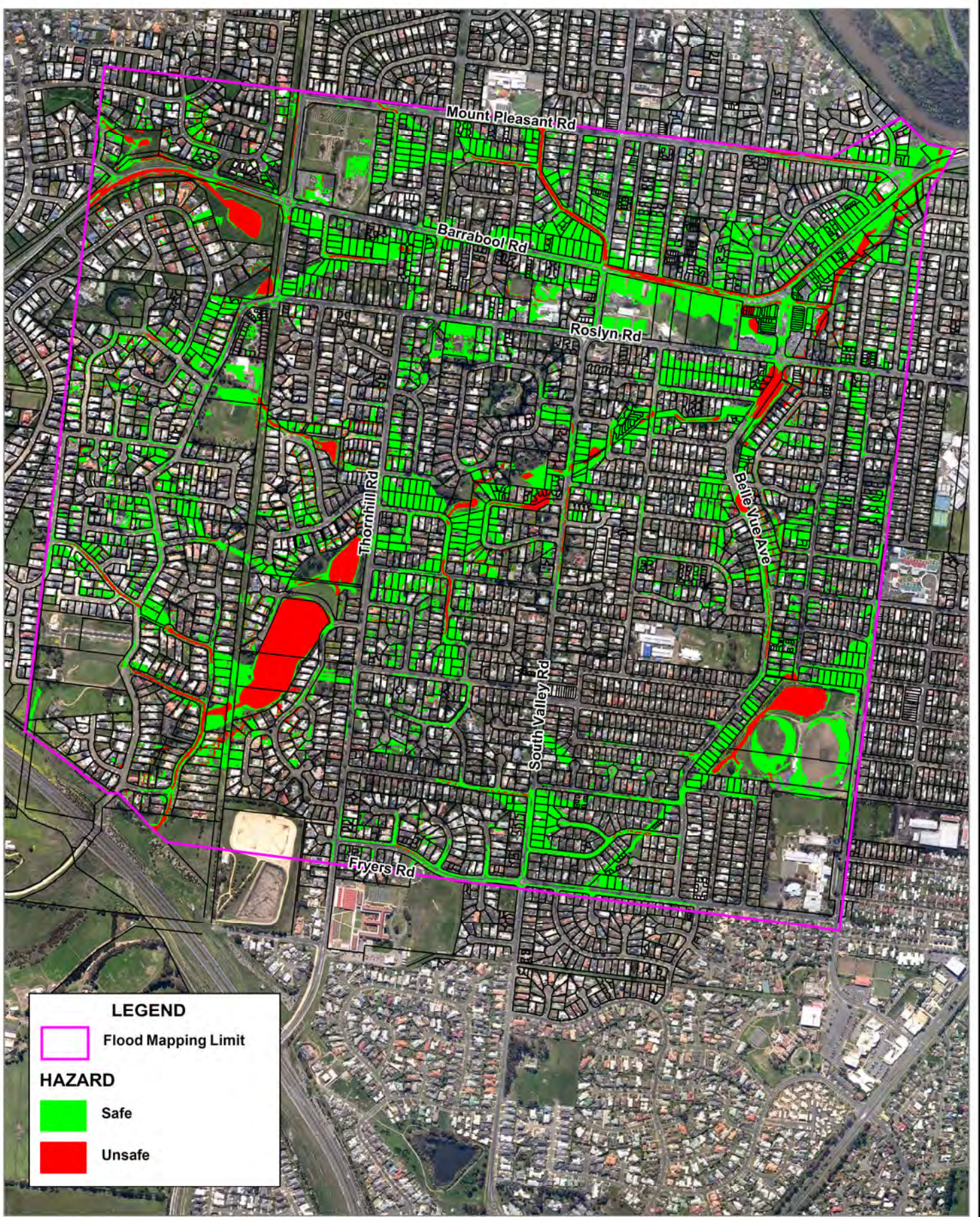
 Unsafe

Title:	Figure:	Rev:
Existing Conditions 5% AEP Peak Flood Hazard	5-7	B

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



LEGEND

 Flood Mapping Limit

HAZARD

 Safe

 Unsafe

Title: Existing Conditions 1% AEP Peak Flood Hazard	Figure: 5-8	Rev: B
---	-----------------------	------------------

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