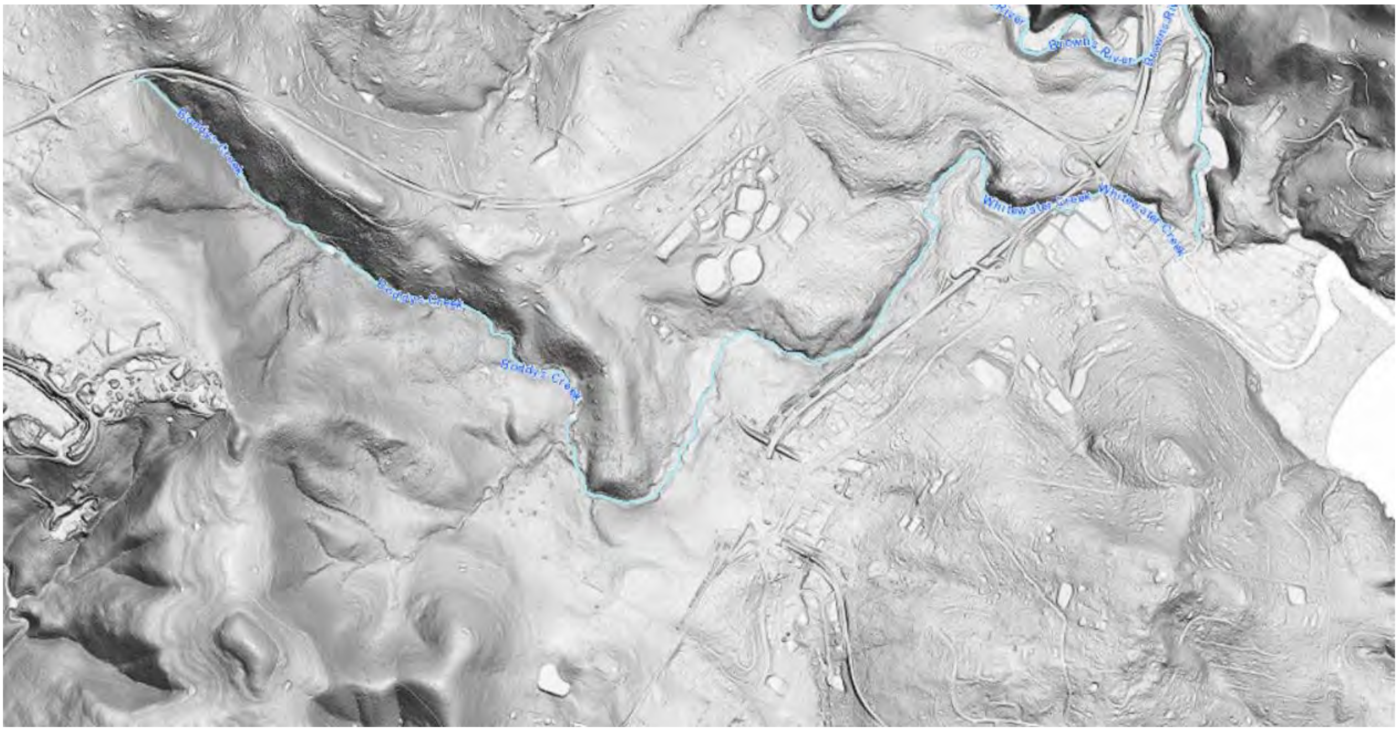
KINGBOROUGH COUNCIL

KINGSTON CBD CATCHMENT RESILIENCE PROGRAM

FINAL REPORT



APRIL 2020

101 West Fyans Street
Newtown, VIC, 3220

Tel: (02) 9299 2855
Fax: (02) 9262 6208
Email: wma@wmawater.com.au
Web: www.wmawater.com.au

KINGSTON CBD CATCHMENT RESILIENCE PROGRAM

FINAL REPORT

APRIL 2020

Project KINGSTON CBD CATCHMENT RESILIENCE PROGRAM	**Project Number** **119088**
Client KINGBOROUGH COUNCIL	**Client's Representative** Alan H Walker & Alexander Aronsson
Project Manager Mark Colegate	

Revision History

Revision	Description	Distribution	Authors	Reviewed by	Date
0	Draft Report, Issued to Council for review		Yuan Li, Mark Colegate		MAR 20
1	Final Report, Issued to Council	Alan Walker, Kingborough Council	Yuan Li, Mark Colegate	Fiona Ling, Mark Colegate	APR 20
2					

KINGSTON CBD CATCHMENT RESILIENCE PROGRAM

TABLE OF CONTENTS

PAGE

LIST OF TABLES

APPENDICES:

LIST OF FIGURES

APPENDICES:

LIST OF PHOTOGRAPHS

LIST OF DIAGRAMS

LIST OF ACRONYMS

ADR	Australian Disaster Resilience
AEP	Annual Exceedance Probability
ARI	Average Recurrence Interval
ARR	Australian Rainfall and Runoff
BOM	Bureau of Meteorology
CBD	Central Business District
DRM	Direct Rainfall Method
DEM	Digital Elevation Model
GIS	Geographic Information System
GPS	Global Positioning System
IFD	Intensity, Frequency and Duration (Rainfall)
IL/CL	Initial Loss / Continues Loss
LIST	Land Information System Tasmania
m AHD	meters above Australian Height Datum
PMF	Probable Maximum Flood
SRMT	Shuttle Radar Mission Topography
TUFLOW	one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software (hydraulic model)
WBNM	Watershed Bounded Network Model (hydrologic model)

ADOPTED TERMINOLOGY

Australian Rainfall and Runoff (ARR, ed Ball et al, 2019) recommends terminology that is not misleading to the public and stakeholders. Therefore, the use of terms such as “recurrence interval” and “return period” are no longer recommended as they imply that a given event magnitude is only exceeded at regular intervals such as every 100 years. However, rare events may occur in clusters. For example, there are several instances of an event with a 1% chance of occurring within a short period, for example the 1949 and 1950 events at Kempsey. Historically the term Average Recurrence Interval (ARI) has been used.

ARR 2016 recommends the use of Annual Exceedance Probability (AEP). Annual Exceedance Probability (AEP) is the probability of an event being equalled or exceeded within a year. AEP may be expressed as either a percentage (%) or 1 in X. Floodplain management typically uses the percentage form of terminology. Therefore a 1% AEP event or 1 in 100 AEP has a 1% chance of being equalled or exceeded in any year.

ARI and AEP are often mistaken as being interchangeable for events equal to or more frequent than 10% AEP. The table below describes how they are subtly different.

For events more frequent than 50% AEP, expressing frequency in terms of Annual Exceedance Probability is not meaningful and misleading particularly in areas with strong seasonality.

Therefore, the term Exceedances per Year (EY) is recommended. Statistically a 0.5 EY event is not the same as a 50% AEP event, and likewise an event with a 20% AEP is not the same as a 0.2 EY event. For example, an event of 0.5 EY is an event which would, on average, occur every two years. A 2 EY event is equivalent to a design event with a 6-month Average Recurrence Interval where there is no seasonality, or an event that is likely to occur twice in one year.

The Probable Maximum Flood is the largest flood that could possibly occur on a catchment. It is related to the Probable Maximum Precipitation (PMP). The PMP has an approximate probability. Due to the conservativeness applied to other factors influencing flooding a PMP does not translate to a PMF of the same AEP. Therefore, an AEP is not assigned to the PMF.

This report has adopted the approach recommended by ARR and uses % AEP for all events rarer than the 50 % AEP and EY for all events more frequent than this.

Frequency Descriptor	EY	AEP (%)	AEP (1 in x)	ARI
Very Frequent	12			
	6	99.75	1.002	0.17
	4	98.17	1.02	0.25
	3	95.02	1.05	0.33
	2	86.47	1.16	0.5
	1	63.21	1.58	1
Frequent	0.69	50	2	1.44
	0.5	39.35	2.54	2
	0.22	20	5	4.48
	0.2	18.13	5.52	5
	0.11	10	10	9.49
Rare	0.05	5	20	19.5
	0.02	2	50	49.5
	0.01	1	100	99.5
Very Rare	0.005	0.5	200	199.5
	0.002	0.2	500	499.5
	0.001	0.1	1000	999.5
	0.0005	0.05	2000	1999.5
Extreme	0.0002	0.02	5000	4999.5
			↓	
			PMP/ PMP Flood	

EXECUTIVE SUMMARY

WMAwater was engaged by Kingborough Council to develop a catchment resilience program for Kingston CBD Catchment in Tasmania. The study comprises the development of hydrologic and hydraulic models to define design flood behaviour and establish the flood risk for the 5% AEP, 1% AEP and 0.5% AEP design storms and 2050 and 2100 Climate Change scenarios in the Kingston CBD Catchment.

The primary aim is to provide Council with flood intelligence that can be used in the preparation of planning controls for development applications, understanding the flood risks associated with a range of event probabilities, and developing catchment resilience strategies, including mitigation measures.

Kingston Rivulet, the main water course of Kingston CBD Catchment, is a tributary of Whitewater Creek. A coupled hydrologic and hydraulic model was developed for the entire Whitewater Creek Catchment, and flood behaviour in Kingston CBD catchment was extracted from the results of this model. The modelling programs used in the study are:

- WBNM (Hydrologic) for the upper rural area of Whitewater Creek Catchment – the model converts rainfall to runoff and the flow hydrographs are input into the TUFLOW model.
- TUFLOW (Hydraulic) for the lower urbanised area of Whitewater Creek Catchment including the Kingston CBD area – The 1D/2D hydraulic model was established to assess the complex overland flow regimes of the urban catchments to analyse flooding behaviour in the study area.

The models were calibrated to the May 2018 flood event, using scaled pluviograph records and registered flood marks. The models were used to assess design flood behaviour for a range of events, including the 5% AEP, 1% AEP and 0.5% AEP events. Comprehensive mapping of design flood information across Kingston CBD Catchment is provided, including peak flood extents, levels, velocities, depths, as well as hydraulic hazards and categories.

Sensitivity analyses were undertaken in terms of climate change (2050 and 2100 scenarios), surface roughness, and drainage and key structure blockage. Model results were sensitive to increased rainfall intensity (climate change) and were generally not sensitive to surface roughness and blockage variations.

The modelling results and mapping, including current climate and climate change conditions, provide flood behaviour and intelligence information for Council to use for planning purpose.

Flood resilience measures are summarised for consideration by Council. Structural and non-structural flood resilience measures have been discussed and preliminarily investigated. Some non-structural measures are recommended, e.g., promoting flood awareness education, development of emergency management plan, and implementation of flood overlays to inform planning, due to their low cost, high feasibility, and reasonable effectiveness, in urbanised areas such as Kingston CBD. Structural measures are typically expensive in urbanised area. Several structural measures were assessed in this study. The most effective option, which will significantly reduce the flood risk in Channel Court and some other downstream hotspots, is Option C (Section 9.1.2.2) – construction of infrastructure (including diversion wall and stormwater trunk drain) to capture and convey stormwater flows around the CBD and discharge to Browns River. However, the cost will be very high. Detailed cost benefit analysis and feasibility analysis are required if Council consider proceeding with any of the potential structural measure.

1. INTRODUCTION

Kingborough Council (Council) commissioned WMAwater to develop a catchment resilience program for the Kingston CBD area in response to the May 2018 flood event, which caused severe flooding issues for residences as well as commercial premises and community facilities throughout the Kingborough municipality.

The study includes the development of hydrologic and hydraulic models to define design flood behaviour and test potential flood mitigation/management measures, and then be used to establish a catchment resilience program for the Kingston CBD area.

The resilience program will provide Council with a detailed understanding of the catchment characteristics, the natural, underground and impeded flow paths as well as the likely causes of the severe flooding in the CBD area occurring on May 2018. In addition, the resilience program will also provide Council with strategies to improve, mitigate, relieve or ameliorate future flooding impacts of the CBD area.

Study outputs include maps of flood extent, depth, velocity and hazard for flood events with a range of Annual Exceedance Probabilities (AEPs), identification, assessment and indicative costing of flood mitigation options, reports detailing the study methods, investigations and conclusions, hydrologic and hydraulic models, and digital datasets.

The specific tasks undertaken for the study were as follows:

- the collection and collation of existing information relevant to the study, which includes the data already held by Council as well as other information, such as development, topographic, GIS and rainfall data
- the preparation of hydrologic and hydraulic models capable of defining the flood behaviour for the study area for a wide range of design flood probabilities
- undertaking sensitivity analysis
- the interpretation and presentation of model results to describe and categorise flood behaviour and hazard for a range of design storm events for the existing catchment conditions
- investigating and determining the flood risk in the Kingston CBD area
- analysis of hotspots
- identification and consideration of flood mitigation opportunities
- modelling assessment of selected mitigation opportunities
- indicative costing of mitigation opportunities
- development of a catchment resilience program.

A discussion of terminology and a glossary of other flood-related terms is provided in APPENDIX A.

2. BACKGROUND

2.1. Study Area

The Kingston CBD Catchment is situated in the southeast coastal area of Tasmania, covering approximately 1.11 km^2. Kingston Rivulet, a downstream tributary to Whitewater Creek, is the main historical water course in the Catchment (Figure 1).

Kingston Rivulet flows from south to north through the Kingston CBD. Elevations range from 2 m AHD to 170 m AHD (mapping of the topography from LiDAR aerial survey is shown in Figure 2).

The Kingston CBD Catchment is highly urbanised with a mix of residential, commercial, and industrial land uses. The topography is moderate steep; the average slope of the Kingston Rivulet is approximately 6.4% and the hillslope grades range from 2% to 10% in the majority of the area. Drainage elements in the catchment include natural creek channels, kerbs and gutters, and pits and pipes.

2.2. Historical Flooding

Flood events in the Kingston area are listed in the Kingston Beach Flood Study (Kingborough Council, 2015, Reference 1). Since that flood study was completed, a significant flood event occurred on 10th – 11th May 2018. Very high rainfalls occurred in the south of Tasmania on the evening of the 10th May 2018. The heavy rainfalls were due to a highly active line of thunderstorms that trained over Hobart and surrounding areas over a number of hours, with each thunderstorm following a similar path as it moved in from the east. Much of the rainfall fell within approximately 6 hours, leading to flash flooding in many streams, including Whitewater Creek. During this event, Kingston (Greenhill Drive) daily rainfall site recorded the highest rainfall in the 18 years of record. The 24-hour rainfall is estimated to be approximately a 0.5% AEP event. Shorter duration rainfalls are likely to be rarer. The pluviograph site at Hobart recorded a 2-hour rainfall that was approximately a 1 in 2000 AEP event. The 24-hour rainfall total at Kingston was larger than that recorded at Hobart.

The 2018 flood event resulted in significant damage to Kingston CBD, including Channel Court shopping centre (Photo 1 and Photo 2).

2.2.1. Previous Studies

The Kingston Beach Flood Study (2015) (Reference 1) included hydraulic modelling of the Kingston Beach Area, downstream of the confluence of Browns River and Whitewater Creek. The Whitewater Creek, including the Kingston Rivulet tributary, were analysed through hydrologic modelling.

Whitewater Creek Flood Study (2020) (Reference 2), covering the entire Whitewater Creek Catchment, including Kingston CBD area, is a parallel study with this Kingston Catchment Resilience Program conducted by WMAwater.

Photo 1: Damage to Channel Court Shopping Centre due to May 2018 flood (https://www.abc.net.au/news/2018-05-14/flood-clean-up-inside-channel-court-kingston/9758324)

Photo 2: Entry to Channel Court Shopping Centre showing damage due to May 2018 flood (https://www.themercury.com.au/business/hobart-floods-kingston-cleanup-begins-after-night-of-drama/news-story/5c17096873811b050c78889c8f0ab57d)

3. DATA

This project was conducted concurrently with Whitewater Creek Flood Study (2020) (Reference 2). As Kingston Rivulet joins the downstream end of Whitewater Creek before entering to Browns River, therefore, a single flood model was set up for Whitewater Creek Catchment, including Kingston CBD Catchment, to make the best use of the downstream boundary condition (Browns River) data extracted from Kingston Beach Flood Study (2015) (Reference 1). Therefore, data summarised below cover the whole Whitewater Creek Catchment area and were ultimately used for the establishment and calibration of the entire model.

3.1. Overview

The first stage in the investigation of flooding matters is to establish the nature, size and frequency of the problem. On larger river systems there may be stream height and historical records dating back over a considerable period, in some cases over one hundred years. However, in smaller catchments, such as the Kingston CBD Catchment, stream gauges and/or official historical records are generally not available, and there is more uncertainty about the frequency and magnitude of flood problems. Additionally, overland flooding in urban areas like this, is highly dependent on localised changes to development, intensification of development (i.e. increased building sizes and more paved surfaces), and localised drainage features such as kerbs and guttering in roadways. These features are subject to relatively frequent modification and renewal, making it difficult to compare flood behaviour over time.

There is one rain gauge, Kingston (Greenhill Drive), within the catchment that recorded rainfall data for the May 2018 flood event. However, only daily data are available at this site and there are no sub-daily pluviograph records. The closest rain gauge with sub-daily records is Blackmans Bay Treatment Plant situated 4 km southeast of Kingston CBD. The pluviograph data from Blackmans Bay gauge for the 2018 event was scaled according to the ratio of event total rainfall (two-day total) between Kingston and Blackmans Bay. An understanding of historical flooding was obtained from an examination of rainfall records, photos and CCTV.

Airborne Light Detection and Ranging (LiDAR) data acquired in 2011 was utilised for catchment delineation and hydraulic modelling. Design and survey data supplied as part of the study, as well as the survey conducted for Kingston CBD during this project, were of mixed usability, and were used for updating LiDAR-based Digital Elevation Model (DEM) and informing other parameter setups. There were gaps in other datasets, including the Council GIS database where inverts of pits and pipes were only partially available. Such gaps are common for flood studies, since collection of detailed information about drainage networks is expensive and time consuming, and often beyond the resources available to Council. As part of this study, analysis of the available data along with site visits were undertaken to address the limitations of the data in key areas.

It should be recognised that while the information about the drainage system for this study is not perfect, this is often not a critical issue, since the majority of runoff cannot be contained within the formal drainage network, especially for the events modelled for this study. Sub-surface drainage networks are typically only designed to cater for the 20% to 5% AEP flow. Therefore, caution must be exercised when applying the broad catchment modelling results at individual properties, particularly for smaller floods or in areas where the pit/pipe drainage network plays a significant role in the flood behaviour.

3.2. Data Sources

Data utilised in the study has been collated from a variety of sources. Data provided by Council and collected from other sources are summarised in Table 1.

Table 1: Summary of Data

Data	Format	Comments	Source
Bridges	.tab	Point layer with limited dimensional information available	Kingborough Council
Culverts	.tab	Point layer with no cross-section information available; not covering all key culverts	Kingborough Council
Stormwater_Pit	.tab	Point layer with type information; no invert level information	Kingborough Council
Stormwater_Pipe	.tab	Line layer with diameter and limited invert level information; no cross-section type information, e.g., circulate or rectangular	Kingborough Council
Propmap	.tab	Property boundary layer (cadastre)	Kingborough Council
Easements	.tab	Easement layer	Kingborough Council
Local_Gov_Reserve	.tab	Local government reserves	Kingborough Council
planning_zone	.tab	Planning zone layer	Kingborough Council
Subdivisions	.tab	Approved subdivisions	Kingborough Council
Contour_5m	.tab	5m surface contours	Kingborough Council
Survey_Control	.tab	Survey control points	Kingborough Council
Spring_Farm_proposed_boundary	.tab	Property boundary of Spring Farm	Kingborough Council
Spring_Farm_proposed_easements	.tab	Easement layer of Spring Farm	Kingborough Council
municipality_kingborough	.tab; .shp	Kingborough municipality region	The LIST
list_hydline_kingborough	.tab; .shp	Watercourse	The LIST
LiDAR	.asc	Mt Wellington LiDAR data; 1m resolution; created on 20-01-2011	The LIST
DEM for Twin Ovals	.asc	0.14m resolution	Kingborough Council
Kingston Park Designs and TINs	.dwg; .pdf	Design for Kingston Park development with surface TIN information; proposed land fill TIN at northeast of the site	Kingborough Council
Whitewater Park	.dwg	Design for Stage 1 to Stage 3 with land fill contours and road strings	Kingborough Council
Spring Farm Designs	.dwg; .pdf	Design for Stage 1 to Stage 8 with land fill contours and road strings; no TIN file for design surface; pdf for Stage 8A	Kingborough Council
Java Head Road Bridge	.pdf	Design for Bridge at Java Head Road in Spring Farm	Kingborough Council
Bridge Drawings - B1260 – Channel Hwy	.pdf	Design for Bridge at Channel Highway	Kingborough Council

Bridge Drawings - B5713 Southern Outlet	.pdf	Design for Bridge at Southern Outlet	Kingborough Council
Walk bridge DS Summerleas Rd	.dwg; .pdf	Design for two Bridges downstream of Summerleas Road	Kingborough Council
Walk bridge DS Huon Hwy	.dwg; .pdf	Design for Bridge downstream of Huon Highway	Kingborough Council
Survey for Channel Court	.e57; .asc	Laser scan survey for flood path through Channel Court	Swanson Surveying
Flood height outputs from Kingston Beach Flood Study	.csv	Flood height outputs at confluence of Whitewater Creek and Browns River used as downstream boundary conditions	Kingborough Council
Flood photos for May 2018 event	.jpg	Flood photos for May 2018 event along Whitewater Creek and in Kingston CBD area	Kingborough Council
Site visit photos	.jpg	Photos taken during site visit on 01 and 02 Oct 2019	WMAwater
CCTV in Channel Court	.mp4	CCTV in Channel Court for 2018 event	Kingborough Council
Rainfall Daily	.csv	Rain gauge records in/around the catchment including Kingston (Greenhill Drive), for May 2018 event	Bureau of Meteorology
Rainfall Pluviograph	.csv	Rain gauge pluviograph records in/around the catchment including Blackmans Bay for May 2018 event	Bureau of Meteorology
Aerial imagery	.jpg	Nearmap Aerial imagery	Nearmap

3.3. Topography

3.3.1. LiDAR Data

Mt Wellington LiDAR, covering the Whitewater Creek Catchment and its immediate surroundings, was obtained from Land Information System Tasmania (LIST) managed by Land Tasmania, a division of Department of Primary Industries, Parks, Water and Environment (DPIPWE). It was indicated that the data were collected in 2011. These data typically have accuracy in the order of +/- 0.15 m (for 70% of points) in the vertical direction on bare earth. The accuracy of the LiDAR data can be influenced by the presence of open water or vegetation (tree or shrub canopy) at the time of the survey.

The LiDAR-based DEM data, as shown in Figure 2, was used as the primary data set for hydrologic catchment delineation and hydraulic modelling.

The LiDAR was flown in 2011, therefore, it does not accurately reflect morphology under the current state of development. The last nine years have seen an increase in residential development and road infrastructure within the Kingston CBD Catchment and the other part of urbanised area of Whitewater Creek Catchment, resulting in relatively significant changes to hydrology and hydraulics. The aerial imageries shown in Diagram 1 illustrate the land development from 2011 – 2019.

Diagram 1: Aerial Imagery (Nearmap) in 2011 and 2019. Cyan lines indicate the main areas of development between 2011-2019.

3.3.2. Design and Survey

To compensate for the lack of representation of current topography by the LiDAR-based DEM, information from the design drawings, additional DEM, and field survey were extracted and integrated. These include:

- design drawings for Whitewater Park, Spring Farm Development, and Kingston Park provided by Council
- additional DEM for Twin Ovals provided by Council
- laser scan survey for flow path through Channel Court, which was conducted by Swanson Surveying for this study.

Based on the above datasets, DEMs for those developed areas were constructed and were then used to update LiDAR-based DEM for hydraulic modelling. Figure 3 and Figure 4 illustrate the constructed DEMs for the whole Whitewater Creek Catchment and for Kingston CBD, respectively.

3.3.2.1. Whitewater Park

Three as constructed design drawings (.dwg) for Whitewater Park were provided, hereby called Stages 1 to 3. The following information was extracted from the drawings to create up-to-date topographic data:

- landfill contours (filled depth ≥ 0.3 m), which indicate the land to be filled for the development;
- road strings, including kerb Invert, kerb lip, kerb back, footpath, etc.

Due to the lack of a completed design surface, the landfill contours were used to update 2011 LiDAR-based DEM. Road strings were interpolated into the DEM to reflect the completed road surface. It should be noted that the majority of the landfill areas were within/around road reserves and only landfill with filled depth ≥ 0.3 m were provided, therefore, only limited value was added to the road strings by including land-fill contours.

Based on the assessment of aerial imageries (Nearmap) acquired on 06/03/2011, 06/03/2018, and 22/12/2019, drawings for Stage 1 was used to update surface topography to May 2018 conditions for calibration event modelling, and drawings for Stages 1 – 3 were used to update surface topography to existing conditions for design events modelling, as shown in Figure 3.

3.3.2.2. Spring Farm

The as constructed design drawings for Stages 1 – 8 were provided in DWG format, while the drawing for Stage 8A was provided in PDF format. Similar to procedure applied for Whitewater Park, the landfill contours (filled depth ≥ 0.3 m) and road strings for Spring Farm Development were extracted and used to create up-to-date topographic data.

Drawings for Stages 1 – 5 were used to update surface topography to May 2018 conditions for calibration event modelling, and drawings for Stages 1 – 8A were used to update surface topography to existing conditions for design events modelling as shown in Figure 3.

The civil design for Spring Farm Development (up to Stage 8A) is illustrated in Diagram 2 as an example.

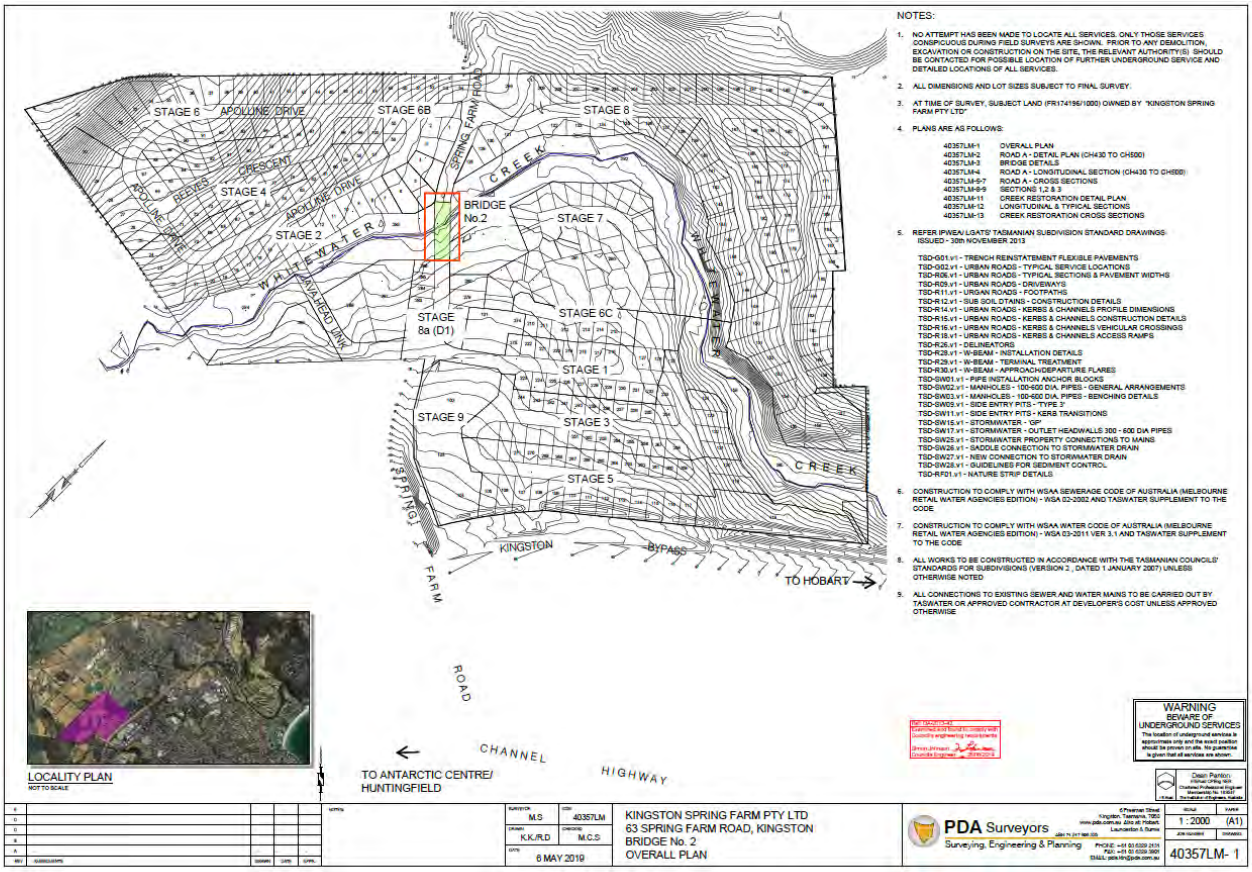


Diagram 2: Concept Plan for Spring Farm Development (PDA Surveyors).

3.3.2.3. Kingston Park

In addition to the design drawings, illustrated in Diagram 3 as an example, the surface design TIN file for Kingston Park Development and the TIN file for the proposed landfill at the northeast part of the site were provided.

The surface design TIN file was directly used to create the existing conditions DEM for this area. The landfill TIN file was not included in existing conditions modelling but was assessed for flood impacts as future developed conditions. The created DEM was illustrated in Figure 3.

3.3.2.4. Twin Ovals

The addition DEM covering the area from Twin Ovals to Drysdale Avenue Park was provided by Council with grid size of 0.143 m. A comparison between Twin Ovals DEM and LiDAR-based DEM indicated that the two are relatively consistent with each other with the Twin Ovals DEM showing more details in some area, e.g., road reserve. However, it was found that the LiDAR-based DEM showed better representation of a minor tributary between Nolan Crescent and Willowbend Road, therefore, the tributary area was trimmed from Twin Ovals DEM, as shown in Figure 3.

Diagram 3: Concept Plan for Kingston Park.

3.3.2.5. Channel Court

Channel Court, in the CBD of Kingston, was flooded in 2018 flood event. According to the aerial imageries as shown in Diagram 4, there was some development from 2011 – 2019, especially for the shopping centre at the southwest of Channel Court. Considering the lack of design/survey information and significance of flooding issues in this area, a Laser Scan survey was conducted in January 2020 by Swanson Surveying engaged by WMAwater, on behalf of Council.

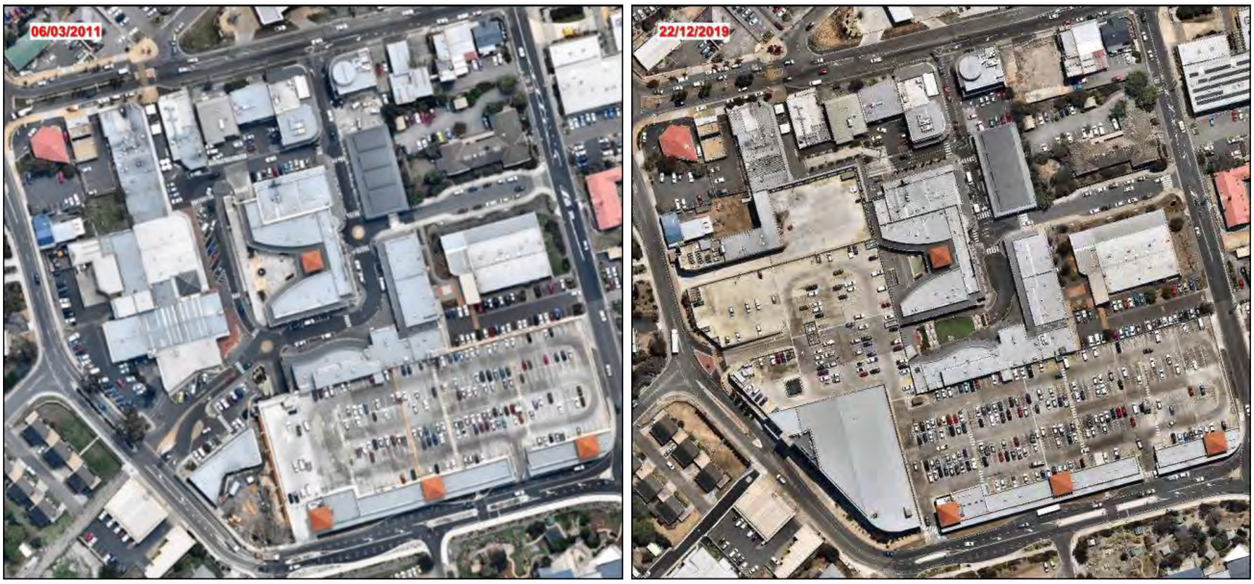


Diagram 4: Aerial Imagery (Nearmap) in 2011 and 2019 – Channel Court.

The DEM for the main flow path, including the ground floor within the shopping centre, was constructed based on the survey data and used for updating LiDAR-based DEM in this area, as shown in Figure 4.

3.4. Hydraulic Structures

Structures including bridges and culverts can have a significant impact on flood behaviour. Therefore, appropriate representation of these structures is essential for the accuracy of the hydraulic model.

Infrastructure characteristics are partially documented in the GIS dataset provided by the Council, however, some key dimensions, i.e., invert levels, cross-sectional area, etc. are missing. Design information were provided by Council for the following structures along Whitewater Creek:

- Java Head Road bridge in Spring Farm;
- Spring Farm Road bridge in Spring Farm;
- two footbridges downstream of Summerleas Rd;
- Southern Outlet box culvert
- Channel Highway bridge

The identification of key bridge and culverts and their representation in hydraulic model are detailed in Section 4.3.5.1.

3.5. Underground Drainage

GIS information pertaining to the underground drainage system, including pits and pipes, was provided by Council. Pipe diameters are generally provided while only part of the pipes/pits have invert level information available.

Additional pits and pipes information for stormwater assets within Kingston Plaza, which was known to be not flooded during 2018 event, were extracted from a photocopy of the design drawings, as shown in Diagram 5, to properly model the drainage capacity in this area.

The integration of pits and pipes for hydraulic modelling was detailed in Section 4.3.5.2.

3.6. Historical Rainfall Data

Rainfall data is recorded either daily (24-hour rainfall totals to 9:00 am) or continuously (pluviometers measuring rainfall in small increments – less than 1 mm). In many locations, long periods of daily rainfall data is available. However, pluviometers have generally only been installed for widespread use since the 1970s at limited locations. Together these records provide a picture of when and how often large rainfall events have occurred in the past.

Care must be taken when interpreting historical rainfall measurements. Rainfall records may not provide an accurate representation of past flooding due to a combination of factors including local site conditions, human error or limitations inherent to the type of recording instrument used.

Diagram 5: Civil Design for Kingston Plaza (Gandy & Roberts Consulting Engineers).

Rain gauges with rainfall records available from Australian Bureau of Meteorology (BoM) are shown in Diagram 6. There is one rain gauge, Kingston (Greenhill Drive), within the catchment with rainfall data for the May 2018 flood event. However, only daily data are available and there are no pluviograph records. Red and blue circles in Diagram 6 highlight gauges with pluviograph records for the May 2018 event. For this study, the pluviograph record from Blackmans Bay Treatment Plant, which is the closest pluviometer (4 km away from Kingston CBD) to the study area, was selected to reconstruct the May 2018 rainfall event.

As shown in Table 2, the two-day total rainfalls (9am 9/5/2018 – 9am 11/5/2018) based on BoM's daily rainfall data, covering the major period of the event, are 180.2 mm at Kingston and 149.8 mm at Blackmans Bay, respectively. The large differences in rainfalls at the two sites means that the data from Blackmans Bay cannot be applied directly to the study area. Therefore, the pluviographic data from Blackmans Bay for May 2018 event was scaled according to the rate of two-day total between Kingston and Blackmans Bay, i.e., 180.2 mm / 149.8 mm, to be implemented as catchment wide pluviographic data for modelling.

It should be noted that there was small amount of rainfall recorded between 9am and 4pm on 11/5/2018 at Blackmans Bay pluviograph, however that amount was not recorded in daily rainfall at either Kingston or Blackmans Bay. Therefore, it is assumed that the rate of two-day rainfall (9am 9/5/2018 – 9am 11/5/2018) is the most appropriate information and can be used to scale the pluviographic data.

Table 2: Total Rainfall at Kingston and Blankmans Bay

Station Number	Station Name	Two-day total based daily data (9am 9/5/2018 – 9am 11/5/2018)	Event total based on pluviograph data (8am 10/5//2018 – 4pm 11/5/2018)
094222	Kingston (Greenhill Drive)	180.2 mm	-
094163	Blackmans Bay Treatment Plant	149.8 mm	124.6 mm

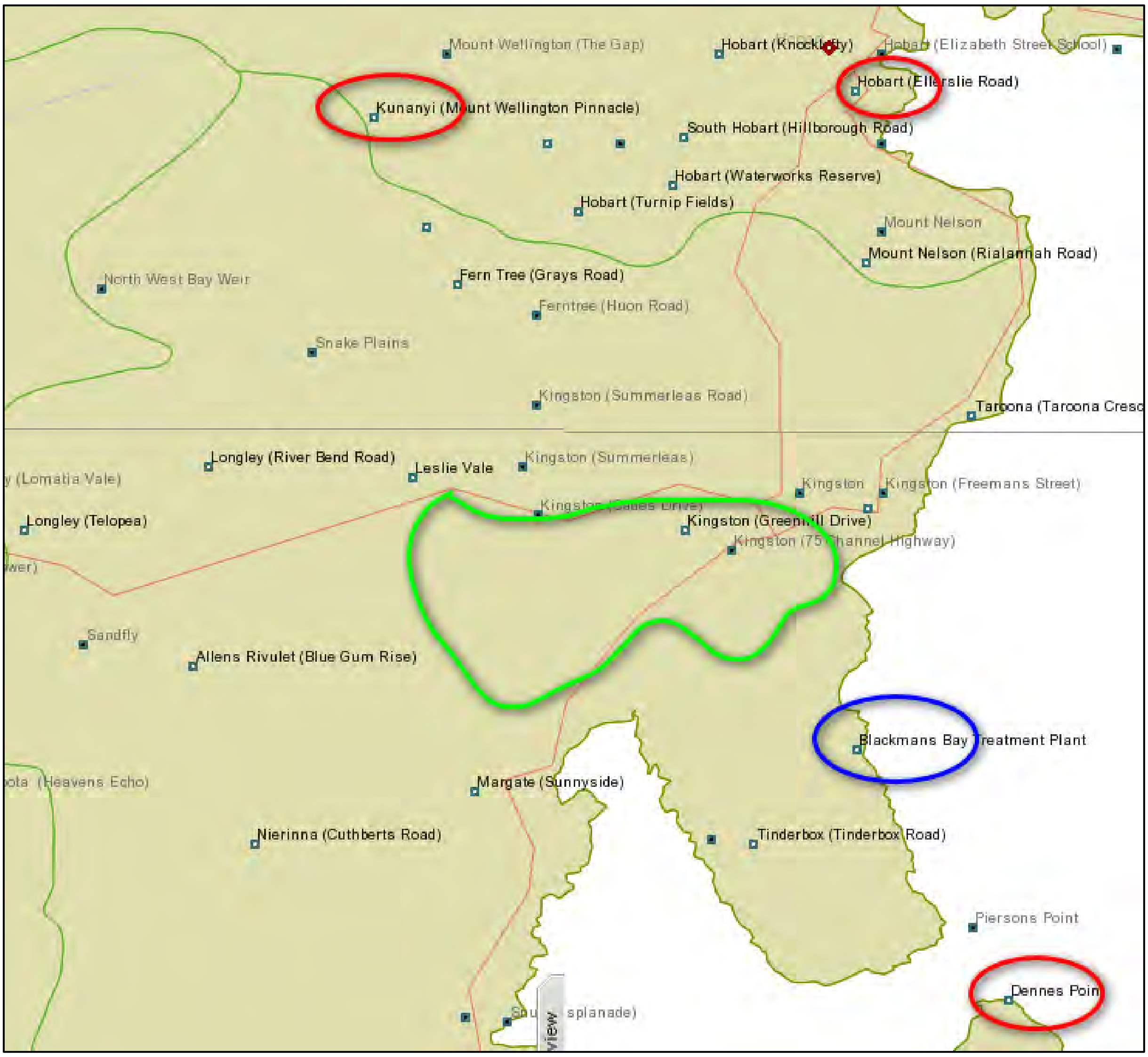


Diagram 6: Rain Gauges within and near the Study Area. Green line indicates the Whitewater Creek Catchment. Red and blue circles highlight gauges with pluviograph records for May 2018 event, while blue circle indicates the pluviograph data selected for use.

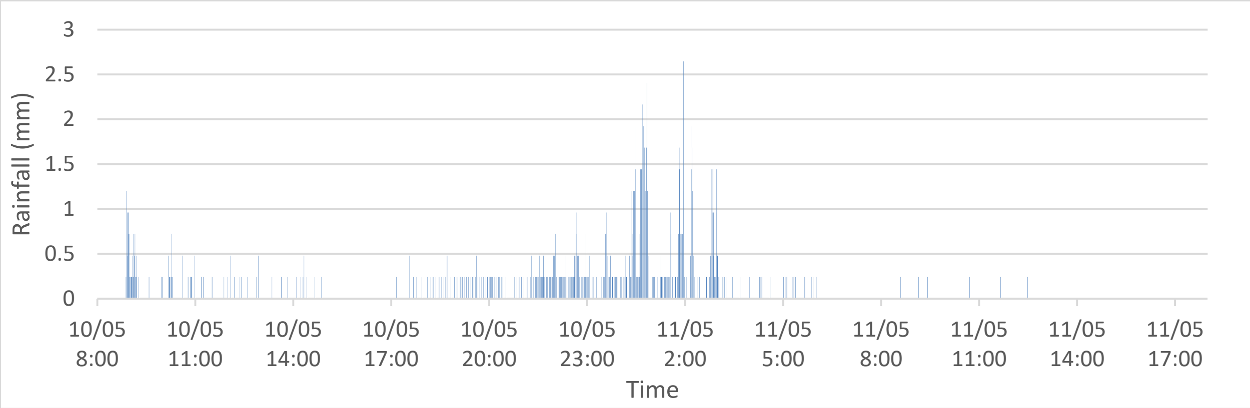


Diagram 7: Constructed Pluviograph at Kingston (Greenhill Drive) for May 2018 Event.

3.7. Design Rainfall and Losses

The Whitewater Creek Catchment is covered by six (6) design rainfall intensity-frequency-duration (ARR 2016 IFD) grids, as illustrated in Diagram 8. The IFDs downloaded from BoM's 2016 IFD data page are shown in APPENDIX B.

The rural loss parameters were obtained from the ARR datahub and are provided in Table 3. These values were assessed and used for hydrologic and hydraulic modelling, detailed in Sections 4.2.2 and 4.3.1, respectively.

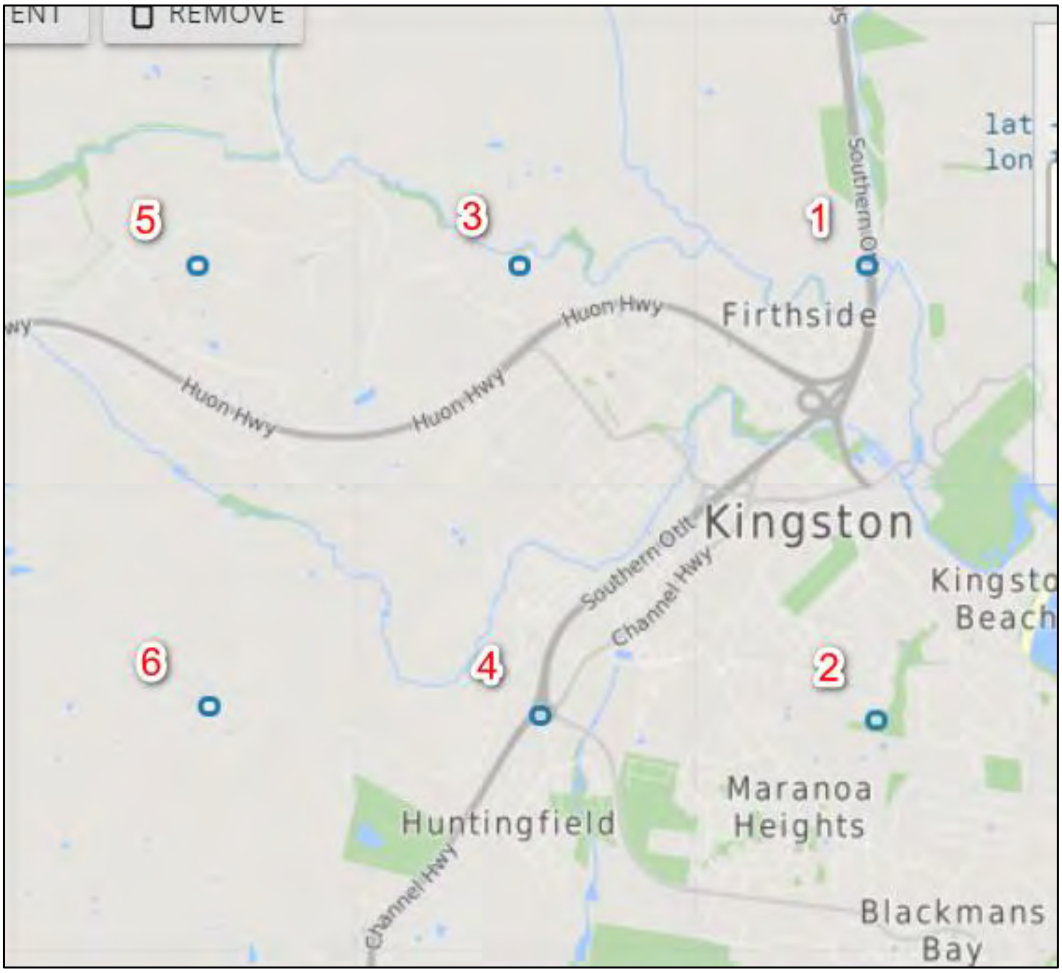


Diagram 8: BoM 2016 IFD Grids Covering the Whitewater Creek Catchment.

Table 3: ARR Losses

Storm Initial Losses (mm)	Storm Continuing Losses (mm)
28.0	3.4

3.8. Photos and Videos

Photos provided by the Council for the May 2018 event and obtained during the site visit were geographically registered in the MapInfo workspace, as illustrated in Figure 5. Those photos were used to identify key hydraulic features, and photos with flood marks were used for model calibration.

CCTV in Channel Court during May 2018 event was provided by Council and was used for model validation purpose.

4. MODEL SETUP

As mentioned before, the project was conducted in parallel with Whitewater Creek Flood Study (2020) (Reference 2). As Kingston Rivulet joins the downstream end of Whitewater Creek before entering to Browns River, therefore, a single flood model was set up for Whitewater Creek Catchment, including Kingston CBD Catchment, to make the best use of the downstream boundary condition (Browns River) data extracted from Kingston Beach Flood Study (2015) (Reference 1).

This section details the model setup for the whole catchment.

4.1. Model Schematisation

The Whitewater Creek Catchment, including Kingston CBD, was split into an upper catchment and a lower catchment. The upper catchment is a rural catchment covered by forests, pastures, and rural resources, whilst the lower catchment, including the Kingston CBD Catchment, is urbanised with a mix of pervious and impervious surfaces and piped and overland flow drainage systems.

A coupled hydrologic-hydraulic model was developed to address the complex runoff generation and routing processes in the catchment, with the upper catchment simulated by a hydrologic model, i.e., the Watershed Bounded Network Model (WBNM), and the lower catchment simulated by a hydraulic model, i.e., a Direct Rainfall Method (DRM) based TUFLOW model. The output hydrographs of the upper catchment were used as upstream boundary condition for the lower catchment. Figure 6 illustrates the model schematisation of the whole catchment.

4.2. Hydrologic Model

Inflow hydrographs serve as inputs at the boundaries of the hydraulic model. In a flood study where long-term gauged streamflow records are not available, a hydrologic model (simulating rainfall-runoff and runoff routing processes) is generally used to provide these inflows. A range of hydrologic models are available as described in ARR 2019 (Reference 3). These models allow the rainfall depth to vary both spatially and temporarily over the catchment and readily lend themselves to calibration against recorded data.

Hydrologic modelling was undertaken using WBNM (Reference 4), a widely utilised hydrologic modelling software. The WBNM model includes a relatively simple but well supported method, where the routing behaviour of the catchment is primarily assumed to be correlated with the catchment area.

The WBNM model can be calibrated to streamflow data through adjustment of various model parameters including the stream lag factor, storage lag factor, and/or rainfall losses. Due to the absence of streamflow data it was not possible to perform an independent calibration of the hydrologic model to observed flows.

A hydrologic model for the upper catchment was created and used to calculate upstream boundary inflows for lower catchment hydraulic model.

4.2.1. Sub-catchment delineation

Delineation of sub-areas was carried out by applying a mathematical algorithm called Terrain analysis using Digital Elevation Models (TauDEM, Reference 5) to topographic data sets.

TauDEM is a suite of DEM tools for the extraction and analysis of hydrologic information from topography as represented by a DEM. LiDAR-based DEM was used for TauDEM analysis as there has not been notable development in the upper catchment since 2011. Please refer to Section 3.3.1 for a detailed description of the LiDAR-based DEM used here.

TauDEM provides the distinct advantage of applying an objective technique to calculate the stream flow paths and directions, the contributing areas using both single and multiple flow direction methods, as well as to delineate the catchments and sub-catchments draining to each stream segment.

The LiDAR-based DEM, analysed in TauDEM, extended far enough to ensure that the entire contributing catchment area was defined.

The upper catchment covered by the hydrologic model is approximately 6.2 km^2. This was delineated into 32 sub-catchments with an average sub-catchment size of 19.44 hectares. The sub-catchment delineation is shown in Figure 6.

4.2.2. Losses and WBNM Lag Parameters

Methods for modelling the proportion of rainfall that is “lost” to infiltration are outlined in ARR 2019 (Reference 3). The methods are of varying degrees of complexity, with the more complex options only suitable if sufficient data are available. The method most typically used for design flood estimation is to apply an initial loss (IL) and continuing loss (CL) to the rainfall. The initial loss represents the wetting of the catchment prior to runoff starting to occur and the continuing loss represents the ongoing infiltration of water into the saturated soils while rainfall continues.

Rainfall losses from a paved or impervious area are considered to consist of only an initial loss (a sufficient amount to wet the pavement and fill minor surface depressions). Losses from grassed and vegetated areas are comprised of an initial loss and a continuing loss. Based on the assessment of the planning zone GIS layer and the latest aerial imagery (Nearmap), the upper catchment is a purely rural catchment covered by forest, pasture, and environmental resources. Therefore, 100% fractional pervious was assumed and the rural losses from ARR data hub as detailed in Table 3 were directly used for hydrologic modelling.

WBNM requires a catchment lag parameter and a stream lag factor to be selected which describes the average travel time for runoff from the catchment surface. The WBNM parameters selected are summarised in Table 4. A value of 1.6 was selected for catchment lag to reflect relative steep slope in the upper catchment. Those parameters were validated in calibration (Section 5).

Table 4: Adopted WBNM Parameters for Calibration and Design

WBNM Parameters	Value
Lag Parameter (C)	1.6
Stream Lag Factor (natural channels)	1.0

4.3. Hydraulic Model

Hydraulic modelling was undertaken for the lower Whitewater Creek Catchment, including Kingston CBD Catchment (Figure 6) using TUFLOW HPC (build 2018-03-AC-iSP-w64) with Graphics Processing Unit (GPU) solver (Reference 6), a widely utilised 1D and 2D flood simulation software. Hydrographs from the WBNM hydrologic model at the interface between upper and lower catchments were input as upstream inflow into the TUFLOW model. Rainfall was directly applied onto the lower catchment as internal boundary conditions. Hydraulic modelling was carried out on a fixed 2 m grid.

The TUFLOW modelling package includes a finite difference numerical model for the solution of the depth averaged shallow water flow equations in two dimensions. The TUFLOW software is produced by BMT and has been widely used for a range of similar projects. The model is capable of dynamically simulating complex overland flow regimes. It is especially applicable to the hydraulic analysis of flooding in urban areas which is typically characterised by short duration events and a combination of supercritical and subcritical flow behaviour, and interactions between overland flow and the sub-surface drainage network.

In addition to 2D modelling of overland flows, TUFLOW can model drainage elements (pipes) as 1D elements as well as modelling creeks or open channels in 1D if required. The 1D and 2D components of the model can be dynamically linked during the simulation. In TUFLOW the ground topography is represented as a uniformly spaced grid with a ground elevation and a Manning's '*n*' roughness value assigned to each grid cell. The grid cell size is determined as a balance between the model result definition required and the computer run time (which is largely determined by the total number of grid cells, and the number of "wet" cells). A cell size of 2 m by 2 m was found to provide an appropriate balance for this study.

The TUFLOW hydraulic model extends upstream to where Whitewater Creek enters the Whitewater Park and Spring Farm area, and downstream to the confluence with Browns River. The total area included in the 1D/2D model covers 7.2 km^2 and the extents of the TUFLOW model are shown in Figure 6.

4.3.1. Rainfall

Rainfall records were directly applied to the lower catchment. Pre-burst and burst rainfall were both used for modelling.

For May 2018 event, the pre-burst and burst rainfall was constructed by scaling pluviograph data from Blackmans Bay to the Whitewater Creek Catchment by multiplying the rate of two-day rainfall between Kingston (Greenhill Drive) and Blackmans Bay, as detailed in Section 3.6.

For design events, burst rainfall for each event was constructed by applying the temporal pattern downloaded from ARR data hub to BoM 2016 IFD. The pre-burst for each event obtained from ARR data hub was uniformly distributed within 1hr a priori the burst, to allow the hydraulic model to simulate the pre-burst with enough flow propagation time. For instance, a 4.5-hour event was actually modelled with 5.5-hour rainfall input, i.e., 1-hour pre-burst plus 4.5-hour burst.

As shown in Diagram 8, the lower catchment, which was modelled through hydraulic model, was covered by four IFD grids, i.e., Grids 1 – 4. Therefore, the average IFDs of Grids 1 – 4 were used for hydraulic modelling for design events.

4.3.2. Losses

Since pre-burst rainfall was modelled directly in the hydraulic model, losses estimated for the lower catchment were also directly applied without subtracting pre-burst. Application of losses in the DRM hydraulic modelling differs from that for hydrologic modelling. The differences are in two aspects:

- hydraulic model will account for part of the storage loss by itself; and
- the spatial variation cannot be represented through sub-catchments.

4.3.2.1. Storage Loss by Hydraulic Model

As detailed in Chapter 11 of ARR 2016 Project 15 (Reference 7), in the process of rainfall becoming runoff and flow, catchment water losses occur due to a number of processes, including interception, infiltration, evaporation, transpiration and storages. It is expected that surface topography employed in DRM hydraulic model will account for part of the Initial Loss (IL) caused by storage. Therefore, the initial loss should be lower in a direct rainfall model when compared with a traditional initial and continuing loss hydrological model.

To quantify the IL in the hydraulic model, a synthetic DRM modelling assessment was conducted for the upper catchment. The upper rural catchment was used for assessment to avoid any impact by urban impervious area. A 1-hour 1% AEP event was modelled and the IL and CL were both set to 0. The model was run for 24 hours to ensure all rainfall was converted and routed to the outlet of the catchment except for the storage loss accounted for by the surface topography. The storage loss accounted for by the surface topography was quantified to be **2.46 mm**, through the following equation:

$$\text{Storage Loss}_{\text{modelled}} = \text{Rainfall Depth} - \text{Runoff Depth} \qquad \text{Equation 1}$$

The IL of pervious area for lower catchment DRM hydraulic model was then quantified to be **25.54 mm**, through subtracting the storage loss accounted by the model from the rural IL obtained from ARR data hub (**28 mm**), i.e.,

$$\text{IL}_{\text{DRM}} = \text{IL}_{\text{ARR}} - \text{Storage Loss}_{\text{modelled}} \qquad \text{Equation 2}$$

The CL of previous area for lower catchment DRM hydraulic model was set to be **3.4 mm**, adopted directly from ARR data hub CL.

4.3.2.2. Losses Based on Planning Zones

The IL $_{DRM}$ / CL quantified above are for 100% pervious areas. Urban area, such as the lower catchment, typically has a mix of pervious and impervious surfaces, and impervious surfaces normally have significant lower IL/CL. Based on the methodology in ARR 2019 (Reference 3), IL/CL were set for three different surface types, i.e., Pervious Area, Indirectly Connected Area, and Effective Impervious Area, as shown in Table 5.

Table 5: Losses and Assumptions for Three Surface Types

Surface Type	IL (mm)	CL (mm)
Pervious Area	**25.54** (IL $_{ARR}$ – Storage Loss $_{modelled}$**)**	**3.4** (ARR data hub)
Indirectly Connected Area	**17.14** (0.7 × IL $_{ARR}$ – Storage Loss $_{modelled}$)	**2.5** (ARR suggestion)
Effective Impervious Area	**0** (IL accounted by Storage Loss $_{modelled}$)	**0** (ARR suggestion)

It is very difficult to accurately delineate the three types of surfaces for the modelling extent. In this study, a single IL/CL was estimated for each planning zone based on the estimated percentages (%) of the three surface types, as shown in Table 6. The percentages (%) of the three surface types for each planning zone were estimated by visual inspection of sample aerial imageries (Nearmap), as shown in Table 7.

Table 6: Estimated Percentage (%) of Surface Types and Adopted Losses for Planning Zones

Planning Zone	IL (mm)	CL (mm)	Effective Impervious Area (%)	Indirectly Connected Area (%)	Pervious Area (%)
General Residential	11.12	1.59	40	50	10
Inner Residential	5.98	0.84	70	20	10
Low Density Residential	17.09	2.40	15	55	30
Rural Living	23.42	3.14	5	10	85
Environmental Living/Forest	25.54	3.40	0	0	100
Urban Mixed Use	17.07	2.36	20	40	40
Community Purpose	11.96	1.68	40	40	20
Recreation	22.58	3.05	5	20	75
Open Space	24.70	3.31	0	10	90
Local Business	5.98	0.84	70	20	10
General Business	5.98	0.84	70	20	10
Central Business	1.71	0.25	90	10	0
Commercial	5.98	0.84	70	20	10
Light Industrial	5.98	0.84	70	20	10
Rural Resource	25.12	3.36	0	5	95
Utilities / Road Reserve	7.70	1.09	60	30	10
Environmental Management	25.54	3.40	0	0	100

Table 7: Sample Imageries (Nearmap) for Planning Zones

 General Residential	 Inner Residential
 Low Density Residential	 Rural Living
 Environmental Living/Forest	 Urban Mixed Use
 Community Purpose	 Recreation

 Open Space	 Local Business
 General Business	 Central Business
 Commercial	 Light Industrial
 Rural Resource	 Utilities / Road Reserve

 Environmental Management	

The planning zone GIS layer provided by the Council was firstly stamped by road reserve from the cadastre, and then refined against most recent aerial imagery to produce an up-to-date planning zone database for losses schematisation, as shown in Figure 7.

4.3.3. Boundary Conditions

Flows from sub-catchments C028, C031, and C032, including their upstream sub-catchments contribution were used as upstream inflow to the hydraulic model. The locations of the three upstream inflow locations are shown in Figure 8. Rainfall was applied within the lower catchment as internal boundary conditions.

Two different type of downstream boundary conditions (Figure 8) were utilised in the model:

- **HQ Boundaries** – The outflow from this boundary is dependent on water level, using a rating curve in which the topographic gradient is assumed to equal the water level gradient (i.e. uniform flow); and
- **HT Boundary** – The water level at the boundary, which can be specified as a static or a varying water level over time.

The 5% AEP and 1% AEP peak flood levels at the confluence of Whitewater Creek and Browns River were extracted from the Kingston Beach Flood Study (Reference 1). The extracted 5% AEP peak flood level was used as a static downstream HT boundary condition at Browns River for 5%, 1%, and 0.5% AEP design events modelling, while the extracted 1% AEP peak flood level was used as downstream boundary condition for May 2018 flood event modelling. While limitations exist when using static flood levels from previous study (ARR 1987) as downstream boundary conditions, it was found that the boundary conditions had only a limited effect on modelling results upstream of Huon Highway.

Model extent was set slightly wider than the lower catchment extent, to minimize the impact of inter-catchment flow. HQ boundaries were applied around the model extent except for the confluence of Whitewater Creek and Browns River, so that the flow towards the neighbour catchments can flow out of the model extent freely.

4.3.4. Surface Roughness

The hydraulic efficiency of the flow paths within the TUFLOW model is represented in part by the hydraulic roughness or friction factor formulated as Manning's '*n*' values. This factor describes the net influence of bed roughness and incorporates the effects of vegetation and other features which may affect the hydraulic performance of the flow path.

The Manning's '*n*' values were applied according to planning zones described in Section 4.3.2.2 with certain update. The updates of the planning zones were in two aspects:

- The schematisation of Manning's '*n*' within the Channel Court shopping centre was refined with survey information, e.g., flow path on ground floor was assigned a low value while the shelves in Woolworth were assigned a high value; and
- The urbanised area outside the inundated (Whitewater Creek and Kingston CBD Tributary) area was extracted and a single low value was assigned.

The revised planning zones used for Manning's '*n*' schematisation are shown in Figure 9. The adopted Manning's '*n*' value for each zone is summarised in Table 8. These values have been adopted based on aerial imagery and site inspection, past experience in similar floodplain environments, and suggestions in ARR 2016 Project 15 (Reference 7).

Table 8 Manning's '*n*' Coefficient

Planning Zone	**Manning's '*n*' (constant or depth varying)**
General Residential	0, 0, 0.03, 0.02, 0.1, 0.15
Inner Residential	0, 0, 0.03, 0.02, 0.1, 0.15
Low Density Residential	0, 0, 0.03, 0.04, 0.1, 0.10
Rural Living	0, 0, 0.03, 0.08, 0.1, 0.04
Environmental Living/Forest	0.12
Urban Mixed Use	0.05
Community Purpose	0.045
Recreation	0, 0, 0.03, 0.08, 0.1, 0.035
Open Space	0, 0, 0.03, 0.06, 0.1, 0.04
Local Business	0, 0, 0.03, 0.02, 0.1, 0.15
General Business	0, 0, 0.03, 0.02, 0.1, 0.15
Central Business	0, 0, 0.03, 0.02, 0.1, 0.20
Commercial	0, 0, 0.03, 0.02, 0.1, 0.20
Light Industrial	0, 0, 0.03, 0.02, 0.1, 0.15
Rural Resource	0, 0, 0.03, 0.08, 0.1, 0.04
Utilities / Road Reserve	0.03
Environmental Management	0.10
Urban Non-inundated Area	0.02
Channel Court Ground Floor	0.016

NOTE: For depth varying Manning's '*n*', the six values represent – depth (m), '*n*', depth (m), '*n*', depth (m), '*n*'

It should be noted that the large Urban Non-inundated Area (Figure 9 was assigned a Manning's '*n*' of 0.02 based on the advice contained in ARR 2016 Project 15 (Reference 7) for DRM hydraulic models. This assumes that most of the rainfall falling on roofs and other impervious areas will be directly routed to the ground (kerb and channel) and underground (pipes) drainage systems with low roughness and quick routing. ARR 2016 Project 15 suggested a Manning's '*n*' of 0.015 to 0.02 should be applied to non-inundated buildings. As planning zones were used to assign Manning's '*n*', the upper value, i.e., 0.02, was adopted.

Sealed roads are typically assigned a Manning's '*n*' of 0.18 to 0.02. However, the Utilities / Road Reserve zone in our schematisation covers buffer areas (i.e., lawn in front of properties) of road reserves, as illustrated in Table 7. Therefore, a Manning's '*n*' of 0.03 was adopted.

The adopted values were validated during the calibration process (Section 5).

4.3.5. Hydraulic Structures

4.3.5.1. Bridges and Culverts

Ten main structures, 5 culverts and 5 bridges, along Whitewater Creek were identified during the site inspection and initial modelling assessment. The locations of the structures are illustrated in Figure 10. These culverts and bridges were partially documented in the GIS dataset provided by the Council, however, some key dimensions, i.e., invert levels, depth, and/or cross-sectional area, were missing. There was limited useful information from the GIS database.

As described in Section 3.4, design information of six (6) structures, e.g., 5 bridges and 1 culvert, were provided by Council. The design information was used to setup the structures in hydraulic model. Where no design information available, i.e., for the other 4 culverts; approximation was made based on visual inspection of photos taken during site visit. Table 9 shows the setup of the 5 bridges in hydraulic model, while Table 10 shows the setup of the 5 culverts in hydraulic model. The photos/aerial imageries and design drawings of the 10 structures used to extract/estimate key dimensions can be seen in Table 11.

Table 9: Hydraulic Model Parameters for Bridges

Parameters		Java Head Rd Bridge	Spring Farm Rd Bridge	Foot Bridge I	Foot Bridge II	Channel Hwy Bridge
Obvert (m AHD) / Depth (m)	L1 Obvert	49.4 - 49.8	47.2 - 47.8	25.6	24.9	2.17
	L2 Depth	1.1	0.8	0.06	0.06	0.2
	L3 Depth	1.0	1.0	1.0	1.0	1.0
Blockage (%)	L1	0	0	6	6	5
	L2	100	100	100	100	100
	L3	25	25	30	30	25
Form Loss Coefficient	L1	0	0	0.02	0.02	0.05
	L2	0.18	0.18	0.13	0.13	0.18
	L3	0.1	0.1	0.06	0.06	0.1

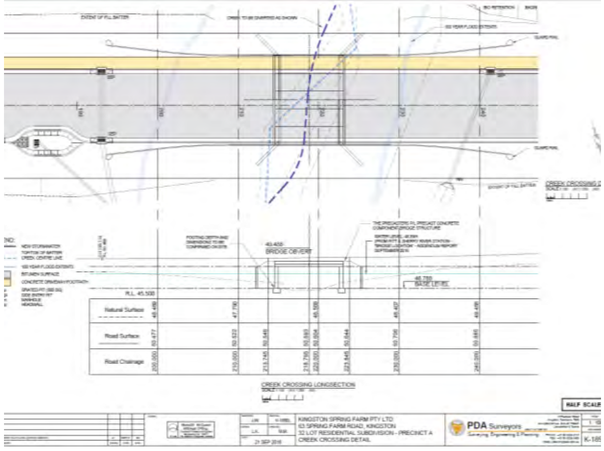
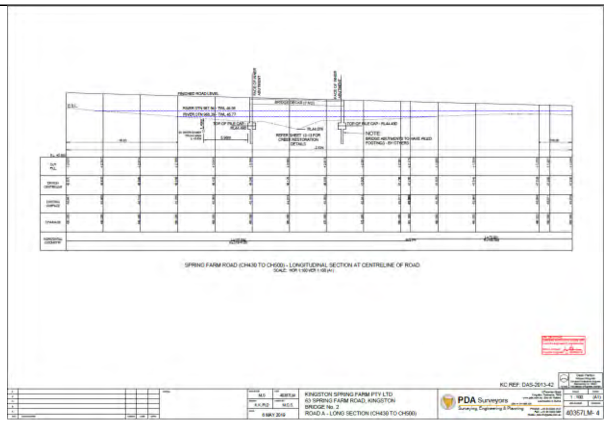
NOTE: Modifiers (2d_zsh) were used to update DEM to the invert levels provided in design drawings. L1 obverts were defined either constant or spatially varying using 2d_lfcsh_p.

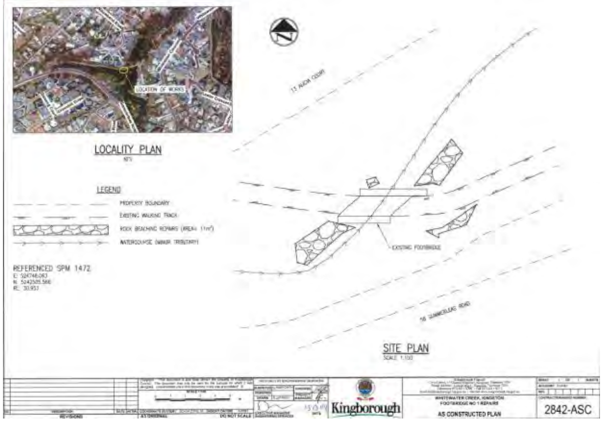
Table 10: Hydraulic Model Parameters for Culverts

Parameters	Summerleas Rd Culvert	Whitewater Cres Culvert	Sourthern Outlet Tunnel	Sourthern Outlet Culvert	Huon Hwy Culvert
Type	R (Box)	I (Arch)	R (Box)	R (Box)	R (Box)
Width (m)	2	7	4	3	2.5
Height (m)	2	2.8	2.5	3	2.5
Number	2	1	1	1	1

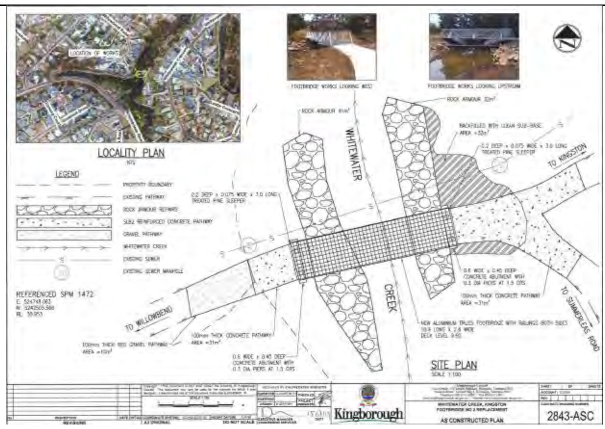
NOTE: Upstream and downstream invert levels were set in accordance the DEM. HW x-section was estimated using width and height based on typical arched culvert assumption for Whitewater Cres Culvert. Widths and heights were estimated based on visual inspection for all culverts, except for Southern Outlet Culvert, where information was extracted from design plan.

Table 11: Photos/Aerial Imageries and Design Drawings for Hydraulic Structures

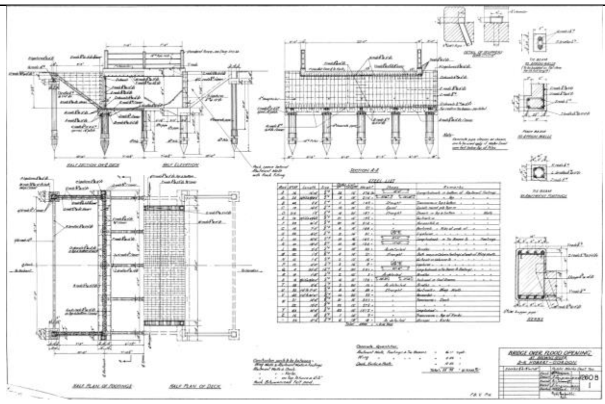
	
Java Head Road Bridge	
	
Spring Farm Road Bridge	



Foot Bridge I d/s Summerleas Rd



Foot Bridge II d/s Summerleas Rd



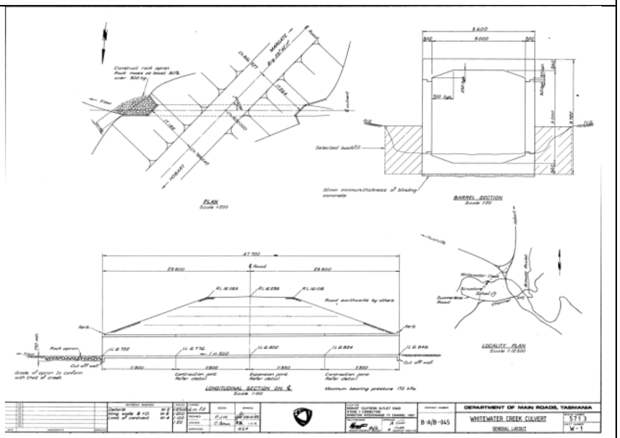
Channel Highway Bridge

Summerleas Road Culvert

Whitewater Crescent Culvert

Southern Outlet Tunnel

Huon Highway Culvert



Southern Outlet Culvert

4.3.5.2. Pits and Pipes

The underground stormwater drainage network was modelled in TUFLOW as a 1D network dynamically linked to the 2D overland flow domain. As the scope of this study was focused on large flood events, i.e., 5%, 1%, and 0.5% AEPs, only major pipes (diameter > 450 mm) were modelled, except for a few certain areas, such as Kingston Plaza, where minor pipes (diameter ≤ 450 mm) were included. The schematisation of the stormwater network is illustrated in Figure 10.

Details of the 1D solution scheme for the pit and pipe network are provided in the TUFLOW user manual (Reference 6). For the modelling of inlet pits the "R" pit channel type was utilised, which requires a width and height dimension for the inlet in the vertical plane. The width dimension represents the effective inlet length exposed to the flow, and the vertical dimension reflects the depth of flow where the inlet becomes submerged, and the flow regime transitions from the weir equation to the orifice equation. For lintel inlets, the width was based on the length of the opening which was assumed to be 1.2 m for all inlet pits. As only major pipes were included, inlet pits connected to minor pipes were clustered to connect to major pipe system.

In cases where invert level data were not available, invert levels at the start and end points of the pipe system were estimated based on pipe diameter and minimum depth. Invert levels in the middle of the pipe systems were interpolated by TUFLOW.

4.3.5.3. Road Kerbs and Gutters

LiDAR typically does not have sufficient resolution to adequately define the kerb and gutter system within roadways. The density of the aerial survey points is in the order of one per square metre, and the kerb/gutter feature is generally of a smaller scale than this, so the LiDAR does not pick up a continuous line of low points defining the drainage line along the edge of the kerb.

To deal with this issue, Reference 7 provides the following guidance:

> *"Stamping a preferred flow path into a model grid/mesh (at the location of the physical kerb/gutter system) may produce more realistic model results, particularly with respect to smaller flood events that are of similar magnitude to the design capacity of the kerb and gutter. Stamping of the kerb/gutter alignment begins by digitising the kerb and gutter interval in a GIS environment. This interval is then used to select the model grid/mesh elements that it overlays in such a way that a connected flow path is selected (i.e. element linkage is orthogonal). These selected elements may then be lowered relative to the remaining grid/mesh."*

The road gutter network plays a key role for overland flow in urbanised area, e.g., the lower catchment. In order to model the system effectively, the gutters were stamped into the mesh using the method described above. The method used was to digitise breaklines along the gutter lines and reduce the ground levels along those model cells by 0.1 m, creating a continuous flow path in the model (Figure 11). This was not applied to areas with design or feature survey data, e.g., Spring Farm, Whitewater Park, Kingston Park, and Channel Court.

For Spring Farm and Whitewater Park, road strings were modelled in hydraulic model (Figure 11) together with DEM constructed based on design drawings (Figure 3). For Kingston Park and Channel Court, only DEM constructed based on design TIN or Survey data were used for modelling (Figure 3).

4.3.6. Building Representation

Buildings play a significant role in urban flooding in two ways: 1) high imperviousness and runoff generation rate and 2) impact on flood propagation. The first aspect is typically treated in the hydrologic part of a flood model; in this case, it was represented through the losses parameterisation in direct rainfall, as detailed in Section 4.3.2.

There are several approaches to representing building effects on flood propagation in traditional hydraulic flood modelling, including:

- modifying elevation of building footprints to floor level, which requires floor level survey
- raising elevation of building footprints to prevent flow through
- deactivating building footprints from the model to prevent flow through
- implementing high roughness values to slow down flow velocity.

For a DRM hydraulic model, it is not optimal to directly apply the above methods, due to the fact that rainfall is applied everywhere, including the building footprints. In this case, the following procedures were implemented to represent building effects on flood propagation:

- Low roughness was applied to urban zones in non-inundated areas to represent rainfall falling on roofs (Section 4.3.4).
- Depth-varying roughness was applied to urban zones in inundated areas to represent building effects on flood propagation (Section 4.3.4).
- For Channel Court and Kingston Plaza, the following modifications were applied to ensure a detailed representation of building effects:
    - Building footprints were digitized and deactivated from the model
    - Rainfall on deactivated buildings was distributed on a 2 m buffer area along the edge of these buildings by adding SA Rainfall layer
    - The internal ground floor of Channel Court Main Mall was kept active in the model to allow flood propagation through the Mall; however, rainfall was distributed along the edge of the Main Mall rather than directly on the ground floor
    - The effects of shops and Woolworths on the Main Mall ground floor were represented by adding internal walls.

The building representation for the Channel Court and Kingston Plaza area is illustrated in Figure 12. It should be mentioned that the methodology implemented at Channel Court and Kingston Plaza can be applied through the whole catchment for future investigation, which was outside the scope of this study.

5. MODEL CALIBRATION

As a part of the model establishment process, the calibration was conducted for the whole modelling area covering the Whitewater Creek and Kingston CBD catchments.

5.1. Objectives

The objective of the calibration process is to build a robust hydrologic and hydraulic modelling system that can replicate historical flood behaviour in the catchment being investigated. If the modelling system can replicate historical flood behaviour, then it can more confidently be used to estimate design flood behaviour.

Typically, in urban areas calibration/validation information is lacking. For this study, the model was calibrated to a recent extreme event, the May 2018 event, as described in Section 2.2.

5.2. Approach

As there was no streamflow data available within the catchment for May 2018 event, photos with flood marks and CCTV were used as the main information to validate the model. Due to the lack of information, the model was parameterised with reasonable details, e.g., integrating detailed design and survey information (Section 3.3.2), developing a detailed loss quantification and schematisation methodology for DRM hydraulic model (Section 4.3.2), and incorporating depth-varying Manning's '*n*', before it was evaluated using data from the historical event. The calibration was conducted essentially in a joint "validation" manner for hydrologic and hydraulic models.

There are four "registered" flood water levels based on flood marks after May 2018 event, two along Whitewater Creek (U3/30 Lester Crescent and 34 Lester Crescent) and two within Kingston CBD Catchment (16 Freeman Street and 15 Channel Highway), as shown in Photo 3 to Photo 6. These water levels were used together as the primary source to validate the entire model for Whitewater Creek and Kingston CBD. Additional water marks (not measured) and CCTV in Channel Court Shopping Centre were also used as approximate references to further evaluate the Kingston CBD part of the model, as shown in Photo 5 to Photo 16.

Photo 3: High Water Mark (approx. **1.5 m** above ground) at U3/30 Lester Crescent, Kingston

Photo 4: Debris Mark Measured at **1.17 m** above Ground (**RL 27.5 m** from DA Plans 2010) opposite 16 Freeman Street, Kingston

Photo 5: High Water Mark (approx. **1.2 m** above ground) at 34 Lester Crescent, Kingston

Photo 6: High Water Mark in Emergency Exit Door **0.25 m** above Floor Level (Ground Floor Level = RL **15.0m** in 1996 Original Drawings) at 15 Channel Highway, Kingston (Kingborough Civic Centre)

Photo 7: Flood Marks in Channel Court (The Main Mall Ground Floor)

Photo 8: Flood Marks in Channel Court (Priceline at the Main Mall Ground Floor)

Photo 9: CCTV at 11-05-2018 00:08:58 in Channel Court Main Mall (Mr Johnson)

Photo 10: CCTV at 11-05-2018 00:31:14 in Channel Court Main Mall (Mr Johnson)

Photo 11: CCTV at 11-05-2018 00:09:04 in Channel Court Main Mall (Millers to Habitat)

Photo 12: CCTV at 11-05-2018 00:24:28 in Channel Court Main Mall (Millers to Habitat)

Photo 13: CCTV at 11-05-2018 00:00:24 in Channel Court Main Mall (Woolworths)

Photo 14: CCTV at 11-05-2018 00:27:16 in Channel Court Main Mall (Woolworths)

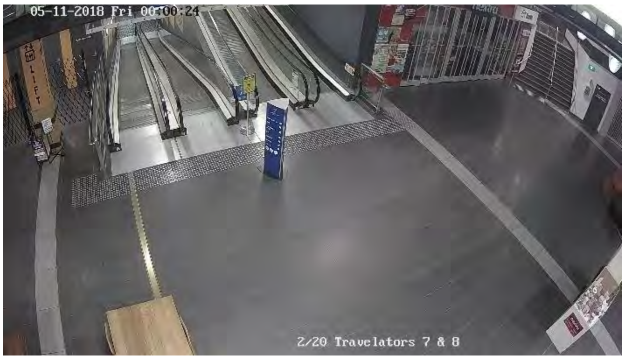


Photo 15: CCTV at 11-05-2018 00:14:43 in Channel Court Main Mall (Travelators)

Photo 16: CCTV at 11-05-2018 00:31:13 in Channel Court Main Mall (Travelators)

5.3. Calibration results

The May 2018 event was simulated using hydrologic and hydraulic modelling detailed in Section 4. Peak flood depth map is shown in Figure 14. A comparison of modelled and the four recorded flood levels is presented in Table 12. The modelled water levels are 0.06 m – 0.16 m higher than recorded levels, which are within tolerance levels and indicate a reasonable fit between model estimations and observations.

Modelled levels on the ground floor inside the Main Mall of Channel Court were also presented in Table 12. The floor level is 24.94 m AHD based on survey. The modelled peak flood depth in front of Woolworths and in the middle of the ground floor are 0.42 m and 0.53 m, respectively, which are considered to be reasonable based on the flood marks (Photo 7 and Photo 8) and CCTV records (Photo 9 to Photo 16). The locations of the validation points listed in Table 12 are illustrated in Figure 14.

The parameters detailed in Section 4 remained unchanged after calibration/validation and adopted for design event modelling.

Table 12: Comparison of Modelled and Recorded Flood Levels

Location	Recorded Level (m AHD)	Modelled Level (m AHD)	Difference (Modelled - Recorded) (m)
Unit 3/ 30 Lester Cres	15.81	15.88	0.06
34 Lester Cres	15.79	15.89	0.09
16 Freeman St	28.70	28.86	0.16
15 Channel Hwy	15.26	15.32	0.06
Channel Court – Woolworths	25.34	25.36	0.02
Channel Court – Ground Floor in Mall	25.41	25.47	0.06

NOTE: Recorded levels at 16 Freeman St and 15 Channel Hwy are based on DEM-based floor levels. Recorded levels at Unit 3/ 30 Lester Cr and 34 Lester Cr are based on registered floor levels provided with Photo 4 and Photo 6. Recorded levels in Channel Court were obtained through comparison of CCTV footage and laser scanned levels.

6. DESIGN EVENT MODELLING

6.1. Temporal Patterns and Durations Selection

Temporal patterns are a hydrologic tool that describe how rainfall falls over time and are often used in hydrograph estimation. Advice in ARR 1987, was to adopt a single burst temporal pattern for each rainfall event duration. However, ARR 2019 (Reference 3) discusses the potential inaccuracies with adopting a single temporal pattern and recommends an approach where an ensemble of temporal patterns is investigated.

An ensemble of 10 temporal patterns is applicable across AEP ranges for durations ranging from 10 mins to 7 days. However, assessment of all durations and patterns in the hydraulic model is inefficient in terms of run time and data storage, especially when multiple iterations and scenarios were conducted for this study and there will be possible future applications by Council. Therefore, critical temporal patterns and durations were selected based on an initial modelling experiment.

For each duration, the temporal pattern producing the flood level closest to the mean of all patterns at a given location is typically deemed as being the representative pattern at that location. The duration producing the highest flood level at the given location is deemed as being the critical duration at that location.

To determine the critical storm duration(s) and select representative temporal pattern(s) for various parts of the catchment, modelling of the 1% AEP event was undertaken for a range of design storm durations from 15 minutes to 6 hours, with the consideration of the catchment size and previous experience.

Each duration utilised ten temporal patterns from ARR 2019 (Reference 3). The following process was undertaken in order to determine the critical duration(s) and representative pattern(s):

1. Run hydrologic and hydraulic models of 10 temporal patterns for each duration for the 1% AEP event. The hydraulic model was run with a 3 m × 3m grid size for this purpose to reduce the run time.
2. Determine the mean peak level from the 10 model runs at all hydraulic grids within the catchment from each duration modelled.
3. Select the critical duration(s), producing the maximum mean peak level for representative areas, Whitewater Creek area and Kingston CBD area in this case.
4. For each critical duration, select a single temporal pattern that produces the closest peak level to the mean peak level in representative areas.
5. Examine the representativeness of selected critical durations and temporal patterns outside the representative areas, to ensure that they produce peak flows close enough to the maximum mean peak level, e.g., within ± 0.1m, over most of the catchment.

It was found that the 4.5-hour duration was critical for Whitewater Creek and 30 min duration was critical for Kingston CBD and some other urbanised areas for the 1% AEP event. Temporal patterns #6614 and #6777 (ARR 2019 pattern numbers) were selected for 4.5-hr and 30 min durations, respectively. The patterns and durations selected for 1% AEP were extended to 5% and 0.5% AEP events modelling.

6.2. Design Results

Model establishment, calibration, as well as temporal pattern and critical duration selection were conducted for the entire catchment covering Whitewater Creek and Kingston CBD. However, the results presented below are only for Kingston CBD Catchment, to support the development of Kingston CBD Catchment Resilience Program.

The modelling results for the Kingston CBD Catchment are presented in Appendix D as:

- Peak flood extent and levels in Figure C1 to Figure C3
- Peak flood velocities in Figure C4 to Figure C6
- Peak flood depths in Figure C7 to Figure C9
- Hydraulic hazard in Figure C10 to Figure C12
- Hydraulic categories in Figure C13 to Figure C15

The results were provided in digital format compatible with Council's Geographic Information Systems. The digital data should be used in preference to the figures in this report as they provide more detail. Please note that all flood maps and tables below are presented for flood depth ≥ 0.05 m. Areas with flood depth ≤ 0.05 m are treated as non-inundated area.

6.2.1. Summary of Results

A number of reporting locations were digitalized to obtain flood levels, depths, and flows from TUFLOW, which were provided in csv files together with the model and other result files. Table 13, Table 14, and Table 15 summarise results at key locations (as shown in Figure 15), a subset of the original reporting locations. These key locations coincide with the key locations used for the sensitivity analysis discussed in Section 7.

Table 13: Peak Flood Levels (m AHD) at Key Locations (depth ≥ 0.05 m)

ID	Location	5% AEP	1% AEP	0.5% AEP
Point01	16 Freeman St (Loading Bay)	-	27.65	28.00
Point02	Channel Court - Entrance from Freeman St	26.99	27.62	27.96
Point04	Channel Court - Woolworths	-	-	25.05
Point06	Channel Court - Ground Floor	-	25.01	25.16
Point11	Channel Court - Entrance from Central	-	24.71	24.81
Point22	15 Channel Hwy (West)	15.27	15.28	15.29
Point24	15 Channel Hwy (South)	15.26	15.29	15.30
Point26	Kingston Plaza Central Car Park	-	11.23	11.23
Point31	Kingston Plaza South Car Park	11.61	11.73	11.78
Point36	3/14 Channel Hwy	6.16	6.29	6.31
Point62	16 Freeman St	27.94	28.21	28.30
Point64	Unit 6/ 20-22 Freeman St	31.21	31.39	31.47
Point66	12 Sherburd St	36.06	36.14	36.18

Table 14: Peak Depths (m) at Key Locations (depth ≥ 0.05 m)

ID	Location	5% AEP	1% AEP	0.5% AEP
Point01	16 Freeman St (Loading Bay)	-	0.39	0.73
Point02	Channel Court - Entrance from Freeman St	0.17	0.81	1.15
Point04	Channel Court - Woolworths	-	-	0.10
Point06	Channel Court - Ground Floor	-	0.08	0.22
Point11	Channel Court - Entrance from Central	-	0.07	0.18
Point22	15 Channel Hwy (West)	0.24	0.26	0.26
Point24	15 Channel Hwy (South)	0.35	0.38	0.39
Point26	Kingston Plaza Central Car Park	-	0.08	0.08
Point31	Kingston Plaza South Car Park	0.19	0.31	0.36
Point36	3/14 Channel Hwy	0.11	0.23	0.25
Point62	16 Freeman St	0.39	0.65	0.75
Point64	Unit 6/ 20-22 Freeman St	0.43	0.60	0.68
Point66	12 Sherburd St	0.17	0.25	0.28

Table 15: Peak Flows (m^3/s) at Key Cross-sections

ID	Location	5% AEP	1% AEP	0.5% AEP
XS07	Channel Court U/S	3.51	6.40	7.97
XS16	Harris Ct D/S	1.88	3.84	4.81
XS18	Sherburd St U/S	3.82	6.45	8.23
XS19	Channel Court D/S	1.01	1.51	1.77
XS21	Channel Court Entrance from Freeman St	0.00	0.62	2.39

6.2.2. Hydraulic Hazard

Hazard classification plays an important role in informing floodplain risk management in an area. Provisional hazard categories have been determined for the Whitewater Creek catchment in accordance with the Australian Disaster Resilience Handbook Collection (Reference 12).

In recent years, there have been a number of developments in the classification of hazards. Research has been undertaken to assess the hazard to people, vehicles and buildings based on flood depth, velocity and velocity depth product. The Australian Disaster Resilience Handbook Collection deals with floods in Handbook 7 (Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia). The supporting guideline 7-3 (Reference 12) contains information relating to the categorisation of flood hazard. A summary of this categorisation is provided in Diagram 9.

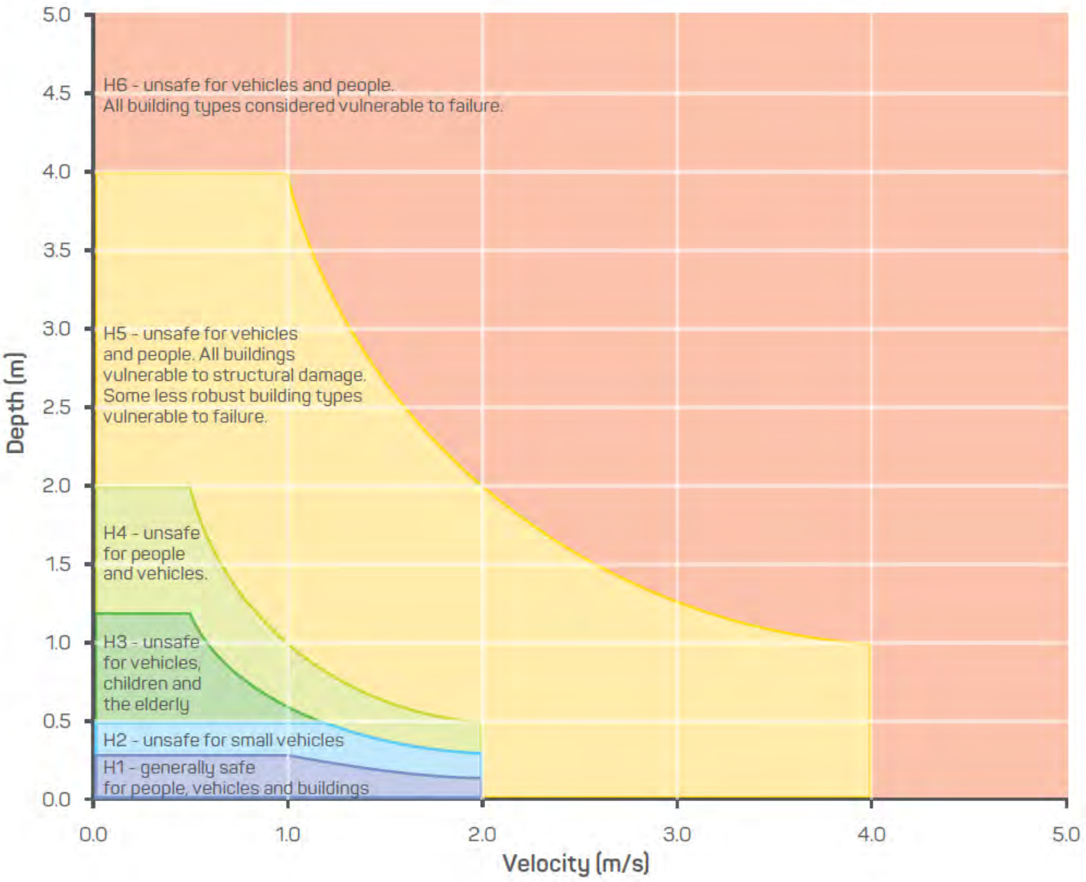


Diagram 9: General Flood Hazard Vulnerability Curves (ADR)

This classification provides a more detailed distinction and practical application of hazard categories, identifying the following 6 classes of hazard:

- H1 – No constraints, generally safe for vehicles, people and buildings;
- H2 – Unsafe for small vehicles;
- H3 – Unsafe for all vehicles, children and the elderly;
- H4 – Unsafe for all people and all vehicles;
- H5 – Unsafe for all people and all vehicles. All building types vulnerable to structural damage. Some less robust building types vulnerable to failure. Buildings require special engineering design and construction; and
- H6 – Unsafe for all people and all vehicles. All building types considered vulnerable to failure.

The hazard maps created using the Australian Disaster Resilience (ADR) classification are presented in Figure C10 to Figure C12 for the 5% AEP, 1% AEP, and 0.5% AEP events.

6.2.3. Hydraulic Categorisation

Floodplains can be classified into the following hydraulic categories depending on the flood function:

- Floodways
- Flood Storage and
- Flood Fringe.

There is no quantitative definition of these three categories or accepted approach to differentiate between the various classifications. The delineation of these areas is somewhat subjective based on knowledge of an area and flood behaviour, hydraulic modelling and previous experience in categorising flood function. A number of approaches are available, such as the method defined by Howells *et al* (Reference 13).

For this study, hydraulic categories were defined by the following criteria, which has been tested and is considered to be a reasonable representation of the flood function of this catchment.

- Floodway is defined as areas where:
  - o the peak value of velocity multiplied by depth (V x D) > 0.25 m^2/s, **AND** peak velocity > 0.25 m/s, **OR**
  - o peak velocity > 1.0 m/s **AND** peak depth > 0.1 m.

The remainder of the floodplain is either Flood Storage or Flood Fringe,

- Flood Storage comprises areas outside the floodway where peak depth > 0.2 m, and
- Flood Fringe comprises areas outside the Floodway where peak depth ≤ 0.2 m.

Figure C13 to Figure C15 show the provisional hydraulic categorisations for the Whitewater catchment for the 5% AEP, 1% AEP, and 0.5% AEP events.

7. SENSITIVITY ANALYSIS

7.1. Overview

A number of sensitivity analyses were undertaken for 1% AEP events to establish the variation in design flood levels and flow that may occur if different parameter assumptions were made. These sensitivity scenarios are summarised in Table 16.

Table 16: Overview of Sensitivity Analyses

Scenario	Description
Climate Change	Sensitivity to climate change assessed for: • Year 2050 scenario with 10% IFD increase • Year 2100 scenario with 30% IFD increase
Manning's '*n*'	Sensitivity to hydraulic roughness assessed for: • Manning's '*n*' decreased by 20% • Manning's '*n*' increased by 20%
Blockage	Sensitivity to blockage assessed for: • 50% blockage of bridge and culverts • 50% blockage of all inlet pits • 50% blockage of bridge and culverts, and all inlet pits

7.2. Climate Change

The increase in rainfall intensities due to climate change adopted for this study were those used in Kingston Beach Flood Study (Reference 1). Rainfall intensities were assumed to increase 10% and 30% by Year 2050 and Year 2100, respectively. Flood depth mapping is presented in Figure D1 and Figure D2. The climate change sensitivity results at key locations are shown in Table 17.

Table 17: Results of Climate Change Analysis for 1% AEP (depth ≥ 0.05 m)

ID	Location	Peak Flood Level (m AHD)			Difference (m)	
		Existing	Y2050	Y2100	Y2050 - Existing	Y2100 - Existing
Point01	16 Freeman St (Loading Bay)	27.65	27.91	28.32	0.26	0.67
Point02	Channel Court - Entrance Freeman St	27.62	27.88	28.29	0.26	0.67
Point04	Channel Court - Woolworths	-	25.03	25.15	-	-
Point06	Channel Court - Ground Floor in Mall	25.01	25.12	25.28	0.11	0.27
Point11	Channel Court - Entrance from Central	24.71	24.79	24.89	0.08	0.19
Point22	15 Channel Hwy (West)	15.28	15.29	15.30	0.00	0.02
Point24	15 Channel Hwy (South)	15.29	15.30	15.31	0.01	0.02
Point26	Kingston Plaza Central Car Park	11.23	11.23	11.24	0.00	0.01
Point31	Kingston Plaza South Car Park	11.73	11.77	11.92	0.04	0.18
Point36	3/14 Channel Hwy	6.29	6.30	6.33	0.01	0.04
Point62	16 Freeman St	28.21	28.28	28.43	0.07	0.22
Point64	Unit 6/ 20-22 Freeman St	31.39	31.45	31.56	0.06	0.17
Point66	12 Sherburd St	36.14	36.17	36.24	0.03	0.09

The increase in rainfall results in an increase in peak flood levels at the majority of the locations analysed. Peak flood level increases on Freeman Street upstream of Channel Court are most notable (Points 1 and 2), with peak flood level increases of 0.26 m and 0.67 m, for the Year 2050 and Year 2100 climate scenarios respectively. This is because the drainage system under Channel Court restricts the flow in Kingston Rivulet, which resulted in significant flooding in May 2018 event. This is likely to cause more serious issues if a similar probability event happens under future climate scenarios.

7.3. Roughness Variations

Flood depth mapping for roughness variations is presented in Figure D3 and Figure D4. The results at key locations are shown in Table 18.

Overall peak flood level results were shown to be relatively insensitive to 20% variations in the roughness parameter. Varying the roughness parameter by 20% typically resulted in a peak flood height difference within ± 0.1 m. A slightly greater change in peak flood levels occurred on Freeman Street upstream of Channel Court (Points 1 and 2). This is likely because the entire contributing area upstream of Channel Court is highly urbanised, and the catchment response is fast. In this area, the change in the roughness results in a relatively larger change in response time, hence the flow detention on Freeman Street in front of Channel Court.

Table 18: Results of Roughness Sensitivity Analysis for 1% AEP (depth ≥ 0.05 m)

ID	Location	Peak Flood Level (m AHD)			Difference (m)	
		Existing	- 20%	+ 20%	- 20%	+ 20%
Point01	16 Freeman St (Loading Bay)	27.65	27.77	27.53	0.11	-0.13
Point02	Channel Court - Entrance Freeman St	27.62	27.73	27.49	0.12	-0.13
Point04	Channel Court - Woolworths	-	-	-	-	-
Point06	Channel Court - Ground Floor in Mall	25.01	25.06	-	0.05	-
Point11	Channel Court - Entrance from Central	24.71	24.74	-	0.03	-
Point22	15 Channel Hwy (West)	15.28	15.28	15.29	-0.01	0.00
Point24	15 Channel Hwy (South)	15.29	15.28	15.29	0.00	0.00
Point26	Kingston Plaza Central Car Park	11.23	11.23	11.23	0.00	0.00
Point31	Kingston Plaza South Car Park	11.73	11.72	11.73	-0.01	0.00
Point36	3/14 Channel Hwy	6.29	6.28	6.30	-0.01	0.01
Point62	16 Freeman St	28.21	28.20	28.21	-0.01	0.00
Point64	Unit 6/ 20-22 Freeman St	31.39	31.36	31.41	-0.03	0.02
Point66	12 Sherburd St	36.14	36.12	36.16	-0.02	0.02

7.4. Blockage Variations

There are multiple factors to be considered in assessing the potential for blockage of drainage systems, e.g. the type and size of the structure, the type of mobility of debris causing blockage, and catchment land use. In this study, 50% blockage was applied to bridges and culverts for open channels, inlet pits for underground drainage, or both. Flood depth mapping for blockage variations is presented in Figure D5 to Figure D7. The results at key locations are shown in Table 19.

Table 19: Results of Blockage Sensitivity Sensitivity Analysis for 1% AEP (depth ≥ 0.05 m)

ID	Location	Peak Flood Level (m AHD)				Difference (m)		
		Existing	50% Block Bridge, Culverts	50% Block Pits	50% block Bridge, Culverts Pits	50% Block Bridge, Culverts	50% Block Pits	50% block Bridge, Culverts Pits
Point01	16 Freeman St (Loading Bay)	27.65	27.65	27.70	27.70	0.00	0.04	0.04
Point02	Channel Court - Freeman St	27.62	27.62	27.67	27.67	0.00	0.05	0.05
Point04	Channel Court - Woolworths	-	-	-	-	-	-	-
Point06	Channel Court - Ground Floor	25.01	25.01	25.04	25.03	0.00	0.02	0.02
Point11	Channel Court - from Central	24.71	24.70	24.72	24.72	0.00	0.02	0.02
Point22	15 Channel Hwy (West)	15.28	15.28	15.28	15.28	0.00	0.00	0.00
Point24	15 Channel Hwy (South)	15.29	15.29	15.29	15.29	0.00	0.00	0.00
Point26	Kingston Plaza Centre Parking	11.23	11.23	11.25	11.25	0.00	0.02	0.02
Point31	Kingston Plaza South Parking	11.73	11.73	11.73	11.73	0.00	0.00	0.00
Point36	3/14 Channel Hwy	6.29	6.29	6.28	6.28	0.00	-0.01	-0.01
Point62	16 Freeman St	28.21	28.21	28.23	28.24	0.00	0.03	0.03
Point64	Unit 6/ 20-22 Freeman St	31.39	31.39	31.45	31.45	0.00	0.06	0.06
Point66	12 Sherburd St	36.14	36.14	36.15	36.15	0.00	0.00	0.00

Peak flood levels at most locations were found to be relatively insensitive to blockage. There is no change of flood levels caused by bridge and culvert blockage, which is due to the fact that all bridge and culverts incorporated in the model are located along Whitewater Creek, not in CBD area.

8. FLOODING HOTSPOTS

Some of the key areas where flooding is problematic, sometimes referred to as “hotspots,” are discussed below. Figure E1 provides an overview of the locations discussed.

8.1. Harris Court

Harris Court residential block is located on the main waterway (Kingston Rivulet), with main trunk pipe underneath, which was designed to convey stormwater for approximately 20% to 10% AEP events only. The surface drainage, i.e., Kerb and Channel along Harris Court, conveys stormwater down grade towards southwest during flooding; however, the modelling shows that water does not remain confined within the road reserve but flows towards northeast, as shown in Photo 17, which causes flooding in the residential area, as shown in Figure E2.

Design flood levels at a sampling point (23 Harris Court), as well as inflows and outflows through this area, are summarised in Table 20. Figure E2 shows design flood behaviour for the 1% AEP event and the key reporting locations for flood levels and flows.

During 5% AEP event, the trunk pipe conveys 1.77 m^3/s, approximately 47.5% of the inflow, through Harris Court, which does not increase much during rarer events, i.e., 1% and 0.5% AEP events. This results in significant overland flow through this area, e.g., 4.47 m^3/s inflow during 0.5% AEP event, which leads to inundation at 6 properties with 0.43 m peak depth at 23 Harris Court (Table 20).

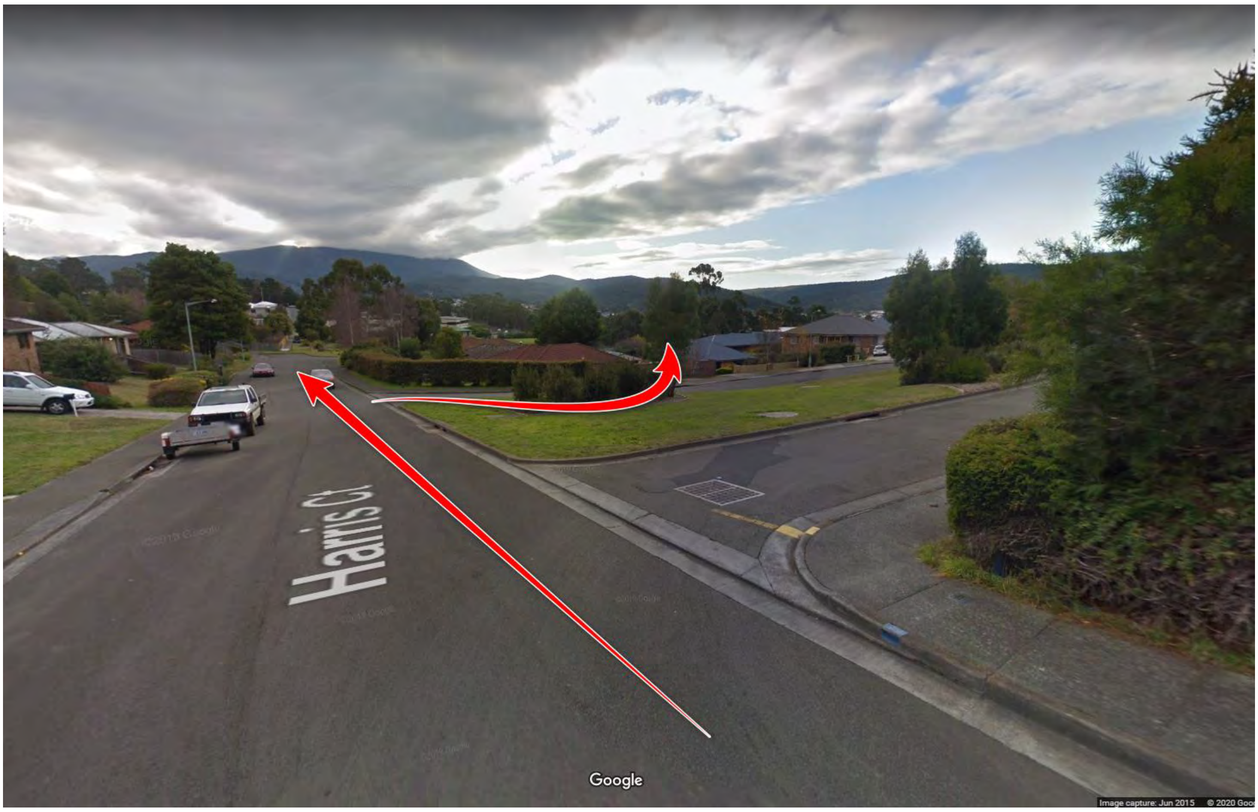


Photo 17: Harris Court (Google street view)

Table 20: Design Flood Behaviour near Harris Court

Event	Peak Level (m AHD)	Peak Depth (m)	Peak Inflow (m^3/s)		Peak Outflow (m^3/s)	
	23 Harris Court		Surface	Pipe	Surface	Pipe
5% AEP	58.53	0.27	1.96	1.77	1.86	1.72
1% AEP	58.63	0.38	3.60	1.84	3.80	1.73
0.5% AEP	58.67	0.42	4.47	1.85	4.75	1.73

8.2. Sherburd Street to Freeman Street

The residential block, surrounded by Sherburd Street, Freeman Street, and Denison Street, is located to the southwest of Channel Court, with Kingston Rivulet flowing through (Figure E1). Several calls were received by Council during and after the May 2018 event around this region according to the map provided by Council. Photo 18 shows the erosion along Kingston Rivulet within this area after May 2018 event.

Photo 18: Erosion along Kingston Rivulet between Sherburd Street to Freeman Street

Design flood levels at residential lots along Kingston Rivulet, as well as surface and underground inflows and outflows through this block, are summarised in Table 21. Figure E3 shows design flood behaviour for the 1% AEP event and the key reporting locations for flood levels and flows.

As indicated by Figure E3, all residential lots are subject to flooding issue to various extents. At the reporting locations at 12 Sherburd Street, Unit 6/ 20-22 Freeman Street, and 16 Freeman Street, the water depth can be up to 0.75 m in the waterway during 0.5% AEP event.

Table 21: Design Flood Behaviour near Sherburd Street to Freeman Street

Event	Peak Level (m AHD)	Peak Depth (m)	Peak Level (m AHD)	Peak Depth (m)	Peak Level (m AHD)	Peak Depth (m)	Peak Inflow (m³/s)		Peak Outflow (m³/s)	
	12 Sherburd St		Unit 6/ 20-22 Freeman St		16 Freeman St		Surface	Culvert	Surface	Culvert
5% AEP	36.06	0.17	31.21	0.43	27.94	0.39	3.83	2.57	1.89	3.40
1% AEP	36.14	0.25	31.39	0.60	28.21	0.65	6.46	2.67	5.55	3.91
0.5% AEP	36.18	0.28	31.47	0.68	28.30	0.75	8.25	2.71	7.46	4.20

8.3. Channel Court

Channel Court shopping centre is located at the centre of Kingston CBD, with Kingston Rivulet flowing through. The newly upgraded Main Mall blocked the surface flow path of Kingston Rivulet, as indicated in Photo 19. The underground trunk stormwater pipe underneath the Main Mall was upgraded into a 2.4m × 0.9m box culvert, as shown in Diagram 10, which was however connected to a cascade of existing 1.8m × 0.9m box culvert and 1.5m circular culvert. The blocked surface flow path results in significant threat to the Main Mall during flooding once the flow rate exceeds the capacity of the underground drainage. For instance, during May 2018 event, Freeman Street in front of Channel Court was significantly inundated and water broke the glass door and flowed through the Main Mall, causing significant damage, as illustrated in Photo 7 to Photo 16.

Photo 19: Freeman Street in front of Channel Court (Google street view)

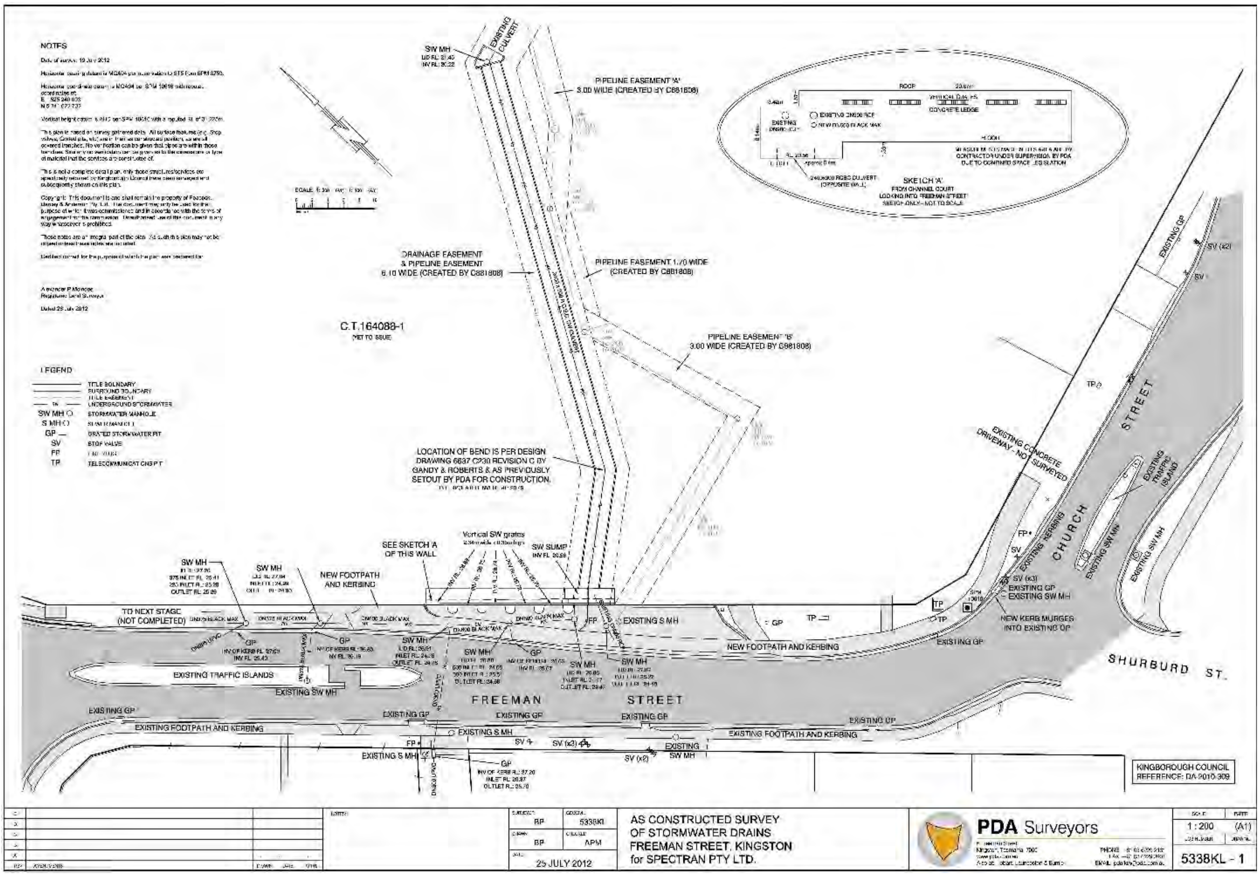


Diagram 10: As Constructed Survey of Stormwater Drains underneath Channel Court.

Design flood levels on Freeman Street and on the ground floor of Channel Court, inflows and outflows through the ground floor of the Main Mall, as well as flows through underground drainage, are summarised in Table 22. Figure E4 shows design flood behaviour for the 1% AEP event and the key reporting locations for flood levels and flows.

As shown in Table 22, there is up to 1.15 m of inundation on Freeman Street in front of the Main Mall entrance and the ground floor is subject to 0.22 m depth of inundation during 0.5% AEP flood events.

Table 22: Design Flood Behaviour near Channel Court

Event	Peak Level (m AHD)	Peak Depth (m)	Peak Level (m AHD)	Peak Depth (m)	Peak Level (m AHD)	Peak Depth (m)	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Pipe Flow (m^3/s)
	Loading Bay		Mall Entrance		Mall Ground Floor		Mall Ground Floor		Culvert
5% AEP	Not flooded		26.99	0.17	Not flooded		0.00	0.00	6.59
1% AEP	27.65	0.39	27.62	0.81	25.01	0.08	0.66	0.15	9.81
0.5% AEP	28.00	0.73	27.96	1.15	25.16	0.22	2.42	0.89	9.24

8.4. Kingborough Civic Centre

The Kingborough Civic Centre is located at 15 Channel Highway, on the southeast side of the main water course. The Centre is subject to flooding risk due to the relatively low elevation within the centre footprint and the overland flow from Hutchins Street overtopping the kerb, as indicated in Photo 20. The Centre was flooded during May 2018 event.

Design flood levels on the west and south sides of the Civic Centre, as well as inflows and outflows are summarised in Table 23. Figure E5 shows design flood behaviour for the 1% AEP event and the key reporting locations for flood levels and flows.

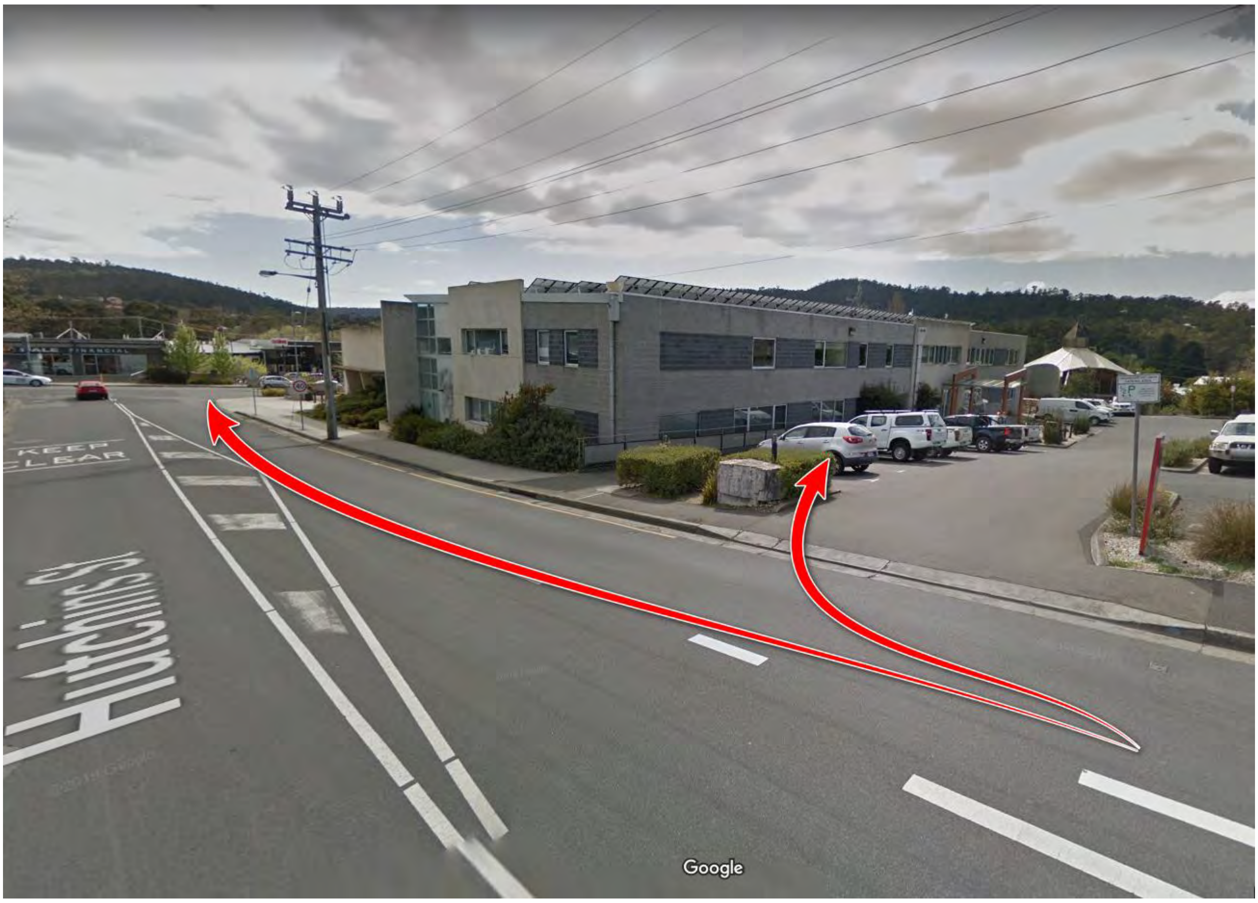


Photo 20: The Civic Centre (Google street view)

Table 23: Design Flood Behaviour near Civic Centre

Event	Peak Level (m AHD)	Peak Depth (m)	Peak Level (m AHD)	Peak Depth (m)	Peak Inflow (m^3/s)	Peak Outflow HWY (m^3/s)	Peak Outflow East (m^3/s)
	Civic Centre South		Civic Centre West		Surface	Surface	Surface
5% AEP	15.26	0.35	15.27	0.24	0.98	0.61	0.30
1% AEP	15.29	0.38	15.28	0.26	1.44	1.00	0.41
0.5% AEP	15.30	0.39	15.29	0.26	1.68	1.51	0.48

It is shown that the main building is subject to different level of inundation during 5%, 1% and 0.5% AEP events. The flood depth does not vary notably among different AEPs, indicating that the inundation is likely caused by the local topography. An improved understanding of the detailed flood behaviour around the Civic Centre can be potentially achieved with detailed survey information.

8.5. Good Price Pharmacy Warehouse

The Good Price Pharmacy Warehouse (3/14 Channel Highway) is located close to the end of the Kingston Rivulet, which partially flow through the Warehouse and Kingston wetlands before joining Whitewater Creek. It is understood that the Warehouse was flooded during May 2018 event. Photo 21 illustrates the flow path through the Warehouse.

Design flood levels in front of the Warehouse, as well as inflows and outflows for this area are summarised in Table 24. Figure E6 shows design flood behaviour for the 1% AEP event and the key reporting locations for flood levels and flows.

As shown in Table 24 and Figure E6, the surface flow is impeded by the Warehouse and diverted towards northeast and southeast. There is up to 0.39 m^3/s of inflow coming from the southwest during 0.5% AEP event, while 0.13 m^3/s is forced towards northeast and the rest flows to the southeast. The south side of the Warehouse is subject to up to 0.33 m depth of inundation during 0.5% AEP flood event.

Photo 21: The Good Price Pharmacy Warehouse Kingston (Google street view)

Table 24: Design flood behaviour near Good Price Pharmacy Warehouse

Event	Peak Level (m AHD)	Peak Depth (m)	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)
	Warehouse		Creek	Creek
5% AEP	6.17	0.19	0.12	0.01
1% AEP	6.30	0.31	0.33	0.09
0.5% AEP	6.31	0.33	0.39	0.13

As the southwest side of the Warehouse is subjected to inflow from Kingston Rivulet and the northeast side of the Warehouse is directly adjacent to the Kingston Wetland, the whole Warehouse is at high risk of inundation during flooding.

9. FLOOD RESILIENCE MEASURES

Catchment flood resilience program requires development of a set of flood resilience measures (FReM), also known as floodplain risk management measures, that may be put in place to avoid the realisation of flood risk. FReM will need to be designed to -

a. reduce the vulnerability of the built environment and/or reduce the exposure without negative impact on the hydrological system.
b. support the recovery of the community after an extreme flood and thus stand for the improvement of resiliency of the whole system.

FReM include structural solutions (e.g. retarding basins, levees) and non-structural (e.g. land-use planning, early warning systems). It can be classified under the following flood resiliency categories, as summarised by Biemans *et al.,* (Reference 14):

- Awareness (or capacity building of stakeholders) is a resilience strategy aimed at promoting the concept of "living with floods" rather than fighting floods.
- Avoidance (or land use planning) defines the development of land use strategies to best meet current and future needs, according to the land's capabilities.
- Alleviation (or flood preparedness) aims at alleviating the effects of floods, including structural flood modification measures.
- Assistance (or contingency planning) encompasses all activities and resources in place in preparation for a major flood event.

A list of types of FReM and correlation to the categories, is detailed in Table F1.

The following section analyses potential structural and non-structural measures designed to provide flood protection to key hotspots within the Kingston CBD.

9.1. Structural Measures

Structural flood resilience measures are designed to protect people and property by counteracting the flood event in order to reduce the hazard or to influence the course or probability of occurrence of the event.

For this study, structural measures were considered to manage flooding at the hotspots identified within the Kingston CBD, being those that are most susceptible to flood impact. Retardation and flow diversion opportunities were assessed in this study to relieve the pressure on drainage systems and direct flood flows away from high risk areas.

The morphology of the Kingston CDB catchment creates a well-defined primary flow path (channel) that originates below the ridgeline in the north-west quadrant, around Marigold Court. The primary flow path travels west (approximately 0.5 km) towards Harris Court before heading north (approximately 1.25 km) through Denison Street reserve, Channel Court and Kingston CBD and finally discharging to Whitewater Creek and Browns River.

Throughout the Kingston CBD, the built environment has encroached heavily into the primary and secondary drainage flow paths. In fact, the main drainage line through the CBD has recently (within the last 8 years) been severed by the upgrades of Channel Court shopping centre. The overland flow path has been built out and surface flows are forced into underground drainage systems.

Unfortunately, the topographic and land use characteristics of the upstream catchment produces a large amount of debris with high mobility, resulting in the potential for severe blockage of stormwater infrastructure.

During the 2018 flood event the inlet pits to the underground drainage network beneath Channel Court became blocked and could not convey the volume of flood flow required. The outcome was the significant flood inundation of the Channel Court shopping centre and surrounding buildings, resulting in a significant material damage.

The lack of a clear overland flow path coupled with a drainage system that exhibits low conveyance capacity, a high risk of blockage and a concentration of flood impacts, restricts the locations available to integrate structural features such as detention and diversion measures.

Therefore, the following structural measures were analysed at these locations –

- **Harris Court**
  - **Option A** – Kerb raising and road regrading to provide additional capacity within the road reserve to capture and convey flood flows away from critical areas.
- **Denison Street Reserve** (between Calvin Christian School and Kingston Primary School)
  - **Option B** – Augmentation of the existing basin configuration to increase detention capacity and mitigate flow rates downstream.
  - **Option C** – Construction of infrastructure (including diversion wall and stormwater trunk drain) to capture and convey stormwater flows around the CBD and discharge to Browns River.
- **Hutchins Street North** (Kingborough Civic Centre)
  - **Option D** – Raise kerb and east footpath to increase capacity within Hutchins Street road reserve.

Kerb raising and regrading of road reserve and footpath at the Harris Court and Hutchins Street locations are designed to mitigate the impacts of flooding on residential properties and Kingborough Council offices, respectively. These measures are local flood risk management measures.

Proposed works for Denison Street Reserve are designed to alleviate regional flood impacts extending downstream through the CBD to Huon Highway. This includes addressing the significant flood impacts experienced through Channel Court.

The proposed structural measures are shown in Figure G1.

9.1.1. Harris Court

9.1.1.1. Option A – Raised Kerb

The majority of flood flows are conveyed within the Harris Court road reserve. Harris Court, for the most part, follows the primary flow path alignment. About halfway along Harris Court, the stormwater flows are redirected into the Harris Court crescent where they continue through residential property to the Calvin Christian School sports oval. The affected Harris Court properties experience flooding above floor level, with depths over 450 mm during the 1% AEP flood event.

The longitudinal grade of Harris Court (excluding the Crescent) is approximately 5.4%. Proposed flood management works involve raising the north kerb (from Crescent reserve) approximately 150 mm and constructing a raised 'hump' at the mouth of the Crescent to contain the stormwater flows within the east-west alignment of Harris Court. Flows will then discharge to an open drain along the west boundary of the residential properties. The concept layout can be seen in Figure G1.

9.1.1.2. Flood Protection Capability

The impact of Harris Court flood management works are presented in Change in Flood Height (Figure G2 and Figure G4) and Change in Flood Velocity (Figure G3 and Figure G5) mapping. Preliminary modelling suggests the measures can provide an improved level of flood protection for the affected properties within Harris Court, in flood events up to and including the 0.5% AEP, by diverting flows around the residential property within the road reserve.

9.1.1.3. Discussion

Under the estimated existing 0.5% AEP flood event, there are six (6) affected properties and all have an associated risk to buildings. The raised kerb works appear to remove the risk to building within one of the six properties, and reduce the risk to the other five properties, as shown in Figure G4. Detailed assessment with civil design can be conducted to further explore the effectiveness and cost benefit of proposed measures.

An indicative estimation of the cost for the civil work and related contingencies is $58,520 (Excl. GST) for Option A, and the breakdown is provided in APPENDIX H.

9.1.2. Denison Street Reserve

Denison Street Reserve is located within the primary catchment flow path. The reserve is situated upstream of the Channel Court shopping complex and Kingston CBD. The reserve location offers a good opportunity to integrate a regional flood risk management measure within the primary flow path.

The reserve currently contains two 'basins', operating as wetlands on the primary flow path alignment. The wetland basins are connected by a 100 mm culvert and discharge to the existing 1050 mm trunk stormwater main beneath the primary flow path, via a 100 mm culvert. The existing basin configuration does not provide flood storage and or detention capabilities during flood events.

Two (2) design options were assessed for integration within Denison Street reserve.

9.1.2.1. Option B – Basin Augmentation

Option B looks at detention opportunities. This option involves augmentation of the existing wetland basin chain to provide increased flood storage potential. Flood storage capacity of the basins would be increased through minor earthworks and redesign of the basin outlet arrangement, to control discharge flow rates to the downstream drainage network.

The proposed works can be seen in Figure G1.

The design concept will reduce the volumetric flowrate within the primary flow path alignment to allow downstream drainage infrastructure to better accommodate flood flows.

Option B maintains the flow path through Channel Court and Kingston CBD. The effectiveness of Option B relies heavily on maintaining operational capacities of stormwater inlet infrastructure. It is noted that blockage of stormwater inlet pits during a flood event will reduce effectiveness to mitigate flood risk and likely result in flood impact similar to existing conditions.

9.1.2.2. Option C – Stormwater Diversion Main

Option C will focus on capturing and diverting runoff volumes around the CBD by constructing a stormwater main that conveys flood flows from Denison Street Reserve to Browns River.

The design option includes the construction of a dam wall across the primary flow path, or augmentation of the existing basins, to capture and divert stormwater flows into a 1200 mm diameter stormwater trunk system. The inlet can be designed to prevent blockage.

Option C infrastructure can be seen in Figure G1.

9.1.2.3. Flood Protection Capability

The impacts of basin augmentation (Option B) are presented in Figure G6 to Figure G9, while the impacts of diversion main (Option C) are presented in Figure G10 to Figure G13, in terms of Change in Flood Height and Change in Flood Velocity. Preliminary modelling suggests both measures can provide an improved level of flood protection downstream of Denison Street Reserve, including the Channel Court, in flood events up to and including the 0.5% AEP.

9.1.2.4. Discussion

Benefits are observed for both options. Option B shows reduction of flood levels and extents downstream of Denison Street Reserve and the benefit extends to Huon Highway. However, the Main Mall of Channel Court is still flooded during 0.5% AEP event after the implementation of Option B, and the Good Price Warehouse does not benefit from Option B. Option C shows more profound effect on flood mitigation downstream of Denison Street Reserve. The Main Mall is completely free of inundation during 0.5% AEP event and there is also a notable flood level reduction at Good Price Warehouse. This is mainly because Option B only detains the flood peak, while Option C provides both flow detention and volume mitigation through the stormwater diversion main. However, construction costs associated with the stormwater diversion main (Option C) are much higher than the detention wall construction only option (Option B).

An indicative estimation of the cost for the civil work and related contingencies is $2,470,720 (Excl. GST) for Option C, and the breakdown is provided in APPENDIX H.

For Option B, due to the lack of detailed design, only costs for construction of earthwork bund were estimated based on the estimated volume of filling required. The estimated cost is $143,312 (Excl. GST) or $150,768 (Excl. GST), for basin augmented to cater 1% or 0.5% AEP event, respectively. Design and construction of outlet are excluded. Details are provided in APPENDIX H.

9.1.3. Hutchins Street

9.1.3.1. Option D – Raised Kerb and Footpath

The Kingborough Civic Centre experiences above floor flooding during the 1% AEP flood event. This appears to be caused by the accumulation of flood water at a low point near the west entrance. The accumulation of flood flows within the low point are a result of overtopping of the kerb and footpath (including driveway layback) along the east side of Hutchins Street.

Raising the kerb profile and footpath will assist in containing the flood flows within the Hutchins Street road reserve and directing flows to Channel Highway to alleviate flood impact on the Kingborough Civic Centre.

The kerb and footpath were raised by 100 mm as shown in Figure G1 and tested through modelling.

9.1.3.2. Flood Protection Capability

The impacts of Hutchins Street works are presented in Change in Flood Height (Figure G14 and Figure G16) and Change in Flood Velocity (Figure G15 and Figure G17) mapping. Preliminary modelling suggests the measures can provide an improved level of flood protection for the affected Civic Centre on the east side of Hutchins Street, in floods up to and including the 0.5% AEP event, by containing the flood flows within the Hutchins Street road reserve and directing flows to Channel Highway.

9.1.3.3. Discussion

The measure shows notable reduction in terms of flood depth and extent on the west and north west side of the Civic Centre building. There is no benefit to the inundation issue within the car park at the south side of the Civic Centre building, indicating that this issue was more likely caused

by local stormwater accumulation rather than flow from Hutchins Street.
An indicative estimation of the cost for the civil work and related contingencies is $81,900 (Excl. GST) for Option D, and the breakdown is provided in APPENDIX H.

9.1.4. Summary

The effectiveness of the options can be seen in the change in flood characteristics detailed in Table 25, as well as flood impact mapping (Figure G2 to Figure G17). It is noted that Options A and D have local impacts on reducing flood levels at affected properties. Both Options B and C have positive impacts for area downstream of Denison Street Reserve; however, the flood level reductions by Option C are more significant at key locations across the catchment than the reductions provided by Option B.

Table 25: Change in Flood Height (m) at Key Locations

	Options	**A**		**B**		**C**		**D**	
Hot spot	Location	1% AEP	0.5% AEP	1% AEP	0.5% AEP	1% AEP	0.5% AEP	1% AEP	0.5% AEP
1	23 Harris Court	-0.10	-0.10	0.00	0.00	0.00	0.00	0.00	0.00
2	16 Freeman St	0.00	0.00	-0.14	-0.14	-0.54	-0.61	0.00	0.00
	Unit 6/ 20-22 Freeman St	0.00	0.00	-0.13	-0.13	-0.49	-0.56	0.00	0.00
	12 Sherburd St	0.00	0.00	-0.07	-0.06	No longer flooded	No longer flooded	0.00	0.00
3	Mall Entrance	0.00	0.00	-0.50	-0.40	-0.64	-0.98	0.00	0.00
	Loading Bay	0.00	0.00	-0.32	-0.40	-0.32	-0.66	0.00	0.00
	Ground Floor	0.00	0.00	No longer flooded	-.015	No longer flooded	No longer flooded	0.00	0.00
4	Civic Centre West	0.00	0.00	0.00	0.00	0.00	0.00	-0.03	-0.03
5	Good Price Warehouse	0.00	0.00	-0.01	-0.01	-0.12	-0.13	0.00	0.00

NOTE: “No longer flooded” indicates that the location is flooded under unmitigated conditions but dry under mitigated conditions.

Change in Flood Height mapping for Year 2050 and Year 2010 1% AEP conditions is also presented for the four options in Figure G18 to Figure G25.

For Harris Court, the raised kerb (Option A) can reduce flood level by approximately 100 mm in a large part of the inundated area in Harris Court, in both Year 2050 and Year 2100 conditions. However, the raised kerb does not prevent affected properties in Harries Court from inundation. For rarer event under future climate conditions, e.g., 0.5% AEP Year 2100 conditions, the flood inundation can still be hazardous.

Option B can detain stormwater within Denison Street Reserve so as to reduce flood peak downstream. However, as it does not reduce the volume, the effectiveness is less significant under future climate conditions. Option C mitigates the flood volume and reroutes water directly to Browns River, so it has more profound effect in future climate conditions compared with Option B. It is shown that Option B can reduce the flood depth on Freeman Street and Channel Court, however, the Main Mall of Channel Court is still flooded during 1% AEP Year 2100 event. Option C can prevent the Main Mall from inundation under 1% AEP Year 2100 conditions.

The flood level reduction at the west side of Kingborough Civic Centre provided by Option D is between 50 to 100 mm and it does not change significantly in future climate conditions. Therefore, the effectiveness of the flood mitigation become less significant when the rainfall intensity increases.

9.1.5. Other Potential Structural Measures

The above structural measures were selected for modelling assessment due to their relatively high potential for implementation and flood risk reduction. Additional structural measures, raised during communication with Council but not modelled in this study, are discussed below.

9.1.5.1. Main Underground Pipe Upgrade

Underground drainage systems are typically designed to cater for stormwater for event probabilities more frequent than 5% AEP. Significant flooding occurred in Channel Court during the May 2018, where the main surface flow path was blocked by the upgraded Main Mall of Channel Court and the flow rate exceeded the capacity of the main underground pipe.

One potential structural option is to upgrade the main underground pipe under and downstream of Channel Court to cater for a rarer event, e.g., 1% AEP. However, this option will be very costly, especially for the sections of pipes under existing buildings, such as Channel Court. Council can further investigate this option in terms of its cost and benefit, however, it is not recommended based on the current modelling results and existing details available for assessment.

The idea of Option C (Section 9.1.2.2) is similar to upgrading existing main pipes, i.e., to convey stormwater downstream through underground drainage to reduce the flood risk for Channel Court and downstream properties. The modelled potential benefits of Option C provide an indication of what can be expected by upgrading existing main pipes, though it would be more expensive and technically difficult to update the existing pipes underneath significant structures such as Channel Court.

9.1.5.2. Inlet Pits Upgrade

Related to the above option (Section 9.1.5.1), the effectiveness and efficiency of the main underground pipes is also restricted by the inlet capacities of these piped systems. Many inlets in the urban area are old and lack capacity to accept flows due to various of reasons, including blocked inlets, opening too small, slope too steep, or systems too shallow resulting in restricted hydraulic efficiency. One example of this is the low grates on the Freeman Street wall at Channel

Court that were blocked during May 2018 event and likely contributed to the flooding through the shopping centre.

Peak flood extents and levels were generally found to be not sensitive to inlet pits blockage according to the sensitivity analysis (Section 7.4); nevertheless, it was found that 50% of inlet pits blockage could lead to 50 mm to 60 mm increase of peak flood level on Freeman Street during 1% AEP event (Table 19). This can be worsened if the blockage percentage is higher and/or during a rarer event.

One mitigation measure is to upgrade existing inlets, which can be relatively expensive depending on the type of inlets. Another more feasible option is to install blockage prevention devices at key inlet locations, e.g., the low grids on the Freeman Street wall at Channel Court, which can be less costly and more technically feasible. However, these are never 100% effective and, in some cases, may accentuate the problem by acting as a debris collector themselves. The cost of trash racks or bollards varies greatly depending upon the nature of the structure. An indicative cost is $5,000 to $20,000 per item. Photo 22 illustrates an example of blockage prevention device.

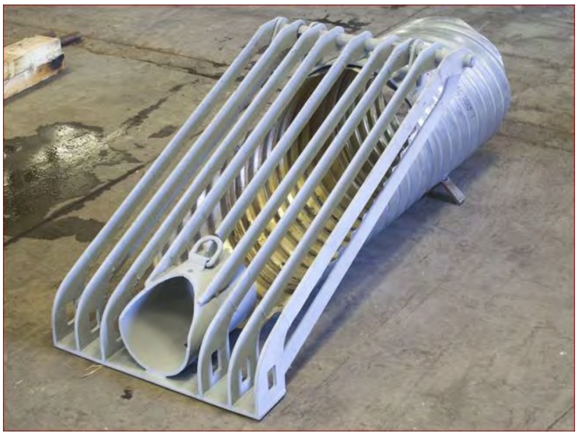


Photo 22: Example of Blockage Prevention Device

9.1.6. Limitations of Structural Measures

Structural flood management measures often are not an adequate answer. The disadvantage of this strategy is its finiteness of effectiveness. For flood events above the design flood structures lose their containment function and may result in a more significant flood impact through the breaching or failure of flood management measures.

The probability of these events of failure is likely to increase in the future due to climate change. However, the projections of climate change are too uncertain to be used as the basis for deriving assured design high water levels. Designing for less frequent floods is prudent to cover off on increased flood levels due to climate change.

Flood management structural measures are no longer regarded as necessarily being the best solution to manage flooding. In fact, flood response strategies (non-structural measures) that response to the vulnerability of the built environment, infrastructure and population are often favoured.

9.2. Non-structural Measures

Non-structural measures are a set of mitigation and/or adaptation measures that do not make use of traditional structural flood defence measures. They are designed to reduce damage without having a physical influence on the flood event.

These measures include:

- information, education and communication tools (flood maps, public presentations, collaborative platforms etc.)
- spatial planning (flood risk adapted land use)
- building regulation and improvement of building flood resistance (wet-proofing and dry-proofing)
- flood action plans at a local scale (infrastructure maintenance)
- financial preparedness (insurance of residual risk and reserve funds)
- emergency response (evacuation and rescue plans, forecasting and warning services)
- recovery measures (disaster recovery plans, financial provisions of government).

9.2.1. Flood Planning and Controls

Council has the opportunity to implement planning measures to ensure future development will be designed to have flood resilience and will not exacerbate current flood issues. Examples of planning scheme measures are map overlays that identify land subject to flooding.

The purpose of overlays is to minimise the effects of overland flows and flooding on new buildings and to ensure new developments don't adversely affect existing properties. Flood related overlays provide information on drainage issues that can be addressed at the beginning of the development proposal and/or design process.

Flood overlays can be categorised as land that is subject to flooding from –

- urban drainage systems (i.e., Special Building Overlays)
    - control measure: set appropriate design conditions to address flood risk, i.e., floor levels
- waterways and open drainage systems, flood depth <1 metre (i.e., Land Subject to Inundation Overlays)
    - control measure: Development works must consider a range of flood impacts and design criteria
- waterways and open drainage systems actively conveying flood flows, depths >1 metre (i.e., Floodway Overlay)
    - control measure: Development not encouraged
- major urban overland flow path (i.e., Urban Floodway Zone)
    - control measure: Development is typically prohibited in these areas.

Flood overlays can be determined based on flood modelling results. Figure G26 illustrate flood overlays generated based on the flood depth outputs for 1% AEP design event. The following criteria were used to produce flood overlays:

- Special Building Overlay: main waterway area with depth between 0.05 m and 0.5 m and area outside main waterway area with depth ≥ 0.05 m
- Land Subject to Inundation Overlay: main waterway area with depth between 0.5 m and 1.0 m
- Floodway Overlay: main waterway area with depth ≥ 1.0 m.

Council can investigate further to derive its own flood overlays based on modelling results. Figure G26 is intended to provide an example to show how this can be derived.

Based on the implemented flood overlays, Council can revise its planning policy to provide stricter development controls in high risk areas. It is recommended that Council reviews the past/existing planning policy to identify any defects, e.g., the reason for approving Channel Court upgrade which totally blocked the surface flow path. The new policy needs to address such issues and avoid its occurrence in future planning and development. Greater consideration should also be given to the development controls that are applicable to overland and mainstream flooded areas and whether there should be a total preclusion of development where there is a risk to life or significant flood damages.

9.2.2. Creek and Drainage Maintenance Program

Maintenance of the drainage network is important to ensure it is operating with maximum efficiency and to reduce the risk of blockage or failure. There are two different types of measures to address the blockage issues, including 1) installation of blockage prevention devices (structural measure detailed in Section 9.1.5.2) and 2) implementation of a creek and drainage maintenance program (non-structural measure detailed below).

A maintenance program should involve regularly removing unwanted vegetation and other debris from the drainage network. A common issue with all residents in flood liable areas is the perceived lack of maintenance within the creek or piped drainage systems. This perception arises as residents see the build-up of debris either before during or after the event and think that this is a major contributor to flooding. The following guidelines are proposed to develop a maintenance program:

- ensure that as far as possible, significant amounts of debris (natural and manmade) are regularly removed from the drainage system and particularly at culvert, bridge crossings, and key inlets to the main underground pipes, e.g., the low grids on the Freeman Street wall at Channel Court;
- ensure man made debris will not enter the creek and drainage system. This may include inspecting the creek system to ensure potential debris providing locations are identified and controlled. For example, a timber yard should not be allowed to store timber in the floodplain without adequate fencing;
- following each flood, undertake a survey of the creek system and contact residents to establish where significant blockages have occurred;
- remind residents to take photos and to advise Council of any debris build up in the pit and pipe or creek systems. This can be done online or by contacting Council, and will ensure that reported problem areas can be addressed and repeated areas at risk of blockage

added to the regular cleaning cycle;
- develop an educational community action program, e.g., “Save your City by Keeping Flow paths clear”, to improve the community’s understanding of the impacts of putting impediments in the way of flows in a major storm event and the importance of keeping appropriate areas free of gardens, vegetation, features or structures to reduce impacts and loss in a major storm event. This can be done through community consultation processes together with the owner contribution program (Section 9.2.5);
- implementing structural measures, e.g., blockage prevention devices (Section 9.1.5.2), together with the above non-structure program to minimize the blockage risk at key locations.

Some Councils have introduced silt and vegetation management plans to address this issue. However, it is acknowledged that these schemes are costly for Councils to operate and must be continued indefinitely to be effective. These schemes are generally welcomed by the residents who appreciate that Council is listening and addressing their concerns.

9.2.3. Flood Emergency Management

There are two key components in flood emergency management, including evacuation and recovery.

It may be necessary for a number of residents to evacuate their homes during or following a major flood. This would be undertaken under the direction of the lead agency (the SES). Some residents may choose to leave of their own accord based on flood information from the radio or other warnings and may be assisted by local residents. The main problems with all flood evacuations are:
- they must be carried out quickly and efficiently
- there can be confusion about ‘ordering’ evacuations, with rumours and well-meaning advice from other residents taking precedence over official directions which can only come from the lead agency, the SES
- they are hazardous for both rescuers and the evacuees
- residents are generally reluctant to leave their homes, causing delays and placing more stress on the rescuers, and
- people (residents and visitors) do not often appreciate the dangers of crossing floodwaters.

It should be noted that the amount of time for evacuation depends on the available warning time, and this catchment is small with a very quick response time. This limits the value of installing a sophisticated flood warning system. The Bureau of Meteorology (BoM) is responsible for providing flood warnings on major river systems. BoM will issue general flood watches and severe weather warnings for a larger area. Flash flood warning (catchment response time of 6 hours or less) is the responsibility of Councils. The efficiency of evacuation in Kingston CBD area highly depends on the flood awareness by the community and the evacuation preparedness by the authorities, which this is addressed in Section 9.2.4.

The SES has the skills and experience to undertake the necessary evacuations should they be required. However, during major storm events it is likely that all emergency services will be fully occupied in the local area and the SES should not be relied upon for immediate assistance.

Another key part of any flood emergency is the recovery arrangements; a well thought out and carefully managed recovery will ensure that residents and the community are able to be "back on their feet" as quickly as possible. This phase is very important and requires input from many different authorities.

The Council should work with SES to review their flood emergency management approach and ensure that the required response for the study area is up to date and includes feedback from recent flood events, including the May 2018 event. Priority should be given to the implementation of this process once completed, which will continue to involve ongoing community education and awareness. The SES should also note key areas of concern as provided in this study.

9.2.4. Raising Flood Awareness

The success of flood emergency management depends on the following:

- *Flood Awareness:* How aware is the community of the threat of flooding? Has the community been adequately informed and educated?
- *Flood Preparedness:* How prepared is the community to react to the threat of flooding? Do they (or the SES) have damage minimisation strategies (such as sandbags, raising possessions) that can be implemented?
- *Flood Evacuation:* How prepared are the authorities and the residents to evacuate households and businesses to minimise damages and the potential risk to life during a flood? How will the evacuation be done, where will the evacuees be moved to?

The above can be improved upon through the implementation of an effective Council and SES run flood awareness program. The extent of the program can vary from year to year depending upon the circumstances.

For risk management to be effective it must become the responsibility of the whole community. It is difficult to accurately assess the benefits of an awareness program, but it is generally considered that the benefits far outweigh the costs. The perceived value of the information and level of awareness diminishes as the time since the last flood increases.

A major hurdle is often convincing residents that major floods (larger than the recent events) will occur in the future. Also, once they have experienced what they consider to be a large flood, e.g., the May 2018 event, then they can have perception that another will not occur for a long time thereafter. This viewpoint is incorrect as a 1% AEP (1 in 100 year) event has the same chance of occurring next year, regardless of the magnitude of the event that may have recently occurred. A similar analogy is after “tossing” a coin 5 times and coming up with “heads” each time, the chance of “heads” on the next throw is still 50:50.

The memories of the May 2018 significant flooding are still fresh for many residents. However, as time passes since the last significant flood, the direct experience of the community with historical floods will diminish. It is important that a high level of awareness is maintained through implementation of a suitable flood awareness program that would include flood safe brochures as well as advice provided on the Council and SES websites. Council and the SES are encouraged to actively and continuously update their flood information for the catchment. Table F2 provides examples of various flood awareness methods that can be employed.

The specific flood awareness measures that are implemented will need to be developed by Council considering the views of the local community, funding considerations and other awareness programs within the Council area. The details of the exact measures would need to be developed in consultation with affected communities.

9.2.5. Owner Contribution to Flood Mitigation

Flood resilience at each flood affected property may require contributions from both the owner and relative authorities. Owners' contributions can be particularly effective due to their in-depth knowledge and direct control of their own properties.

It is recommended that an educational program is undertaken, facilitated by community consultancy sessions. This would enhance the participation and contribution by owners of flood affected properties and encourage them to implement ideas or processes to protect their assets without causing negative impact on their abutting and downstream neighbours. Knowledge and opinions on lot scale mitigation measures should be encouraged and collected, e.g., installation of temporary flood barriers during flooding, consideration of removing impermeable fencing which might increase flood risk on the dwelling, flood proofing for future development, etc.

The modelling of lot scale resilience measures requires more detailed information, which was not within the scope of this study. However, the Council may initiate further modelling exercises to provide guidance on how Council and owners can contribute to lot scale flood risk management.

9.2.6. Improved Flood Access, Road Closures and Notifications

Access in times of flood is important in all flood liable areas to ensure that residents can travel safely to higher ground. In urban areas flood access is not as critical as in rural areas as the duration of closure is short (less than 2 hours) and there are generally alternative routes. Also, in urban areas vehicle incidents (breakdowns and accidents) as well as the effects of storm damage (such as fallen trees) mean that it is not possible to guarantee that any road (whether inundated or not) will be passable in a severe storm event.

In rural areas early warning of road closures is important to ensure drivers make informed choices. In urban areas the short available warning time means that early warning is often not possible, and drivers must rely on their own experience (heavy rain falling) or listen to the media.

On minor roads, enlarging of culverts or raising of the road would ensure less frequency of overtopping. These works should be considered when upgrading roads, or for any works are proposed on flood liable routes.

No specific road raising works to improve flood access are proposed as part of this study. Depth indicators at road crossings are an appropriate cost-effective measure to advise drivers of the depth of flood waters. However, advice from the SES is that drivers should not enter any flooded road crossing as even at shallow depths vehicles can be moved and potentially be swept into floodwaters or crashing thus presenting a significant risk to life.

10. CATCHMENT RESILIENCE PROGRAM

10.1. Multi-criteria Assessment of Flood Resilience Measures

A number of possible resilience measures were developed and evaluated in this study taking into account a range of parameters (Section 9). Various methods are available for judging the relative merits of competing measures. The benefit/cost (B/C) approach has long been used to quantify the economic worth of each option, enabling ranking against similar projects in other areas. The benefit/cost ratio is the ratio of the net present worth (the total present value of a time series of cash flows) of the project over its life. It is a standard method using the time value of money to compare the reduction in flood damages (benefit) with the capital and ongoing cost of the works. Generally, the ratio expresses only the reduction in tangible damages as it is difficult to accurately include intangibles (such as anxiety, risk to life, ill health and other social and environmental effects).

The potential environmental or social impacts of any proposed flood mitigation measure must be considered in the assessment of any management measure and these cannot be evaluated using the classical B/C approach. For this reason, a matrix type assessment has been used which enables a value (including non-economic worth) to be assigned to each measure. A multi-variate decision matrix was developed for the Kingston CBD catchment, allowing B/C estimates, community involvement in determining social and other intangible values, and assessment of environmental impacts.

10.1.1. Management Matrix

The criteria assigned a value in the management matrix are:

- impact on flood behaviour (reduction in flood level, hazard or hydraulic categorisation) over the range of flood events
- number of properties benefited by measure
- technical feasibility (design considerations, construction constraints, long-term performance)
- likely community acceptance and social impacts
- economic merits (capital and recurring costs versus reduction in flood damages)
- financial feasibility to fund the measure
- environmental and ecological benefits
- impacts on the State Emergency Services
- political and/or administrative issues
- long-term performance given the likely impacts of climate change
- risk to life.

The colour coded scoring system for the above criteria is provided in Table 26 and largely relates to the impacts in a 1% AEP event. Table 27 indicates the score assigned to each measure, however these may be adjusted in the light of local conditions and future community consultations.

Table 26: Colour Coded Matrix Scoring System

	-3	-2	-1	0	1	2	3
Impact on Flood Behaviour	>100mm increase	50 to 100mm increase	<50mm increase	no change	<50mm decrease	50 to 100mm decrease	>100mm decrease
Number of Properties Benefitted	>5 adversely affected	2-5 adversely affected	<2 adversely affected	none	<2	2 to 5	>5
Technical Feasibility	major issues	moderate issues	minor issues	neutral	moderately straight forward	straight forward	no issues
Community Acceptance	majority against	most against	some against	neutral	minor	most	majority
Economic Merits	major disbenefit	moderate disbenefit	minor disbenefit	neutral	low	medium	high
Financial Feasibility	major disbenefit	moderate disbenefit	minor disbenefit	neutral	low	medium	high
Environmental and Ecological Benefits	major disbenefit	moderate disbenefit	minor disbenefit	neutral	low	medium	high
Impacts on SES	major disbenefit	moderate disbenefit	minor disbenefit	neutral	minor benefit	moderate benefit	major benefit
Political/administrative Issues	major negative	moderate negative	minor negative	neutral	few	very few	none
Long Term Performance	major disbenefit	moderate disbenefit	minor disbenefit	neutral	positive	good	excellent
Risk to Life	major increase	moderate increase	minor increase	neutral	minor benefit	moderate benefit	major benefit

Table 27: Matrix of Resilience Measures Investigated in Study (sorted by rank)

Option	Section in Study	Impact on Flood Behaviour	Number of Properties Benefited	Technical Feasibility	Community Acceptance	Economic Merits	Financial Feasibility	Environmental / Ecological Benefits	Impact on SES	Political / Admin Issues	Long Term Performance	Risk to Life	Total Score	Rank (Total)
Review Flood Emergency Management	9.2.3		1	3	3	2	3		3		2	3	20	1
Flood Planning and Control	9.2.1			3	2	3	3	1		2	3		17	2
Flood Awareness Program	9.2.4		1	3	2	2	2		3		2	1	16	3
Owner Contribution to Flood Mitigation	9.2.5	1	1	1		3	3	1	1		1	1	13	4
Consider Depth Indicators on Roads	9.2.6			3	2	2	2		1	-1	1	2	12	5
Creek and Drainage Maintenance	9.2.2	1	1	2	3		1	1			-2		7	6
Kerb Rasing at Harris Court	9.1.1	1	1			1				-1	3	1	6	7
Stormwater Diversion Main from Denison Street Reserve	9.1.2.2	3	3	-2	-1	1	-2	-1		-1	3	3	6	7
Kerb Rasing at Hutchins Street	9.1.3	1	1							-1	3	1	5	9
Basin Augmentation at Denison Street Reserve	9.1.2.1	2	2	-1	-1	1	-1	-1		-1	2	2	4	10
Inlet Pits Upgrade	9.1.6.2	1	1	-1			1			-1	2	1	4	10
Main Underground Pipe Upgrade	9.1.6.1	2	2	-3		-2	-3			-1	3	2	0	12

10.2. Flood Resilience Program for Kingston CBD

The recommendations on proposed measures are described in Table 28 according to the ranking in Table 27. However a high rank in Table 27 may not necessarily be a high priority measure for implementation as, for example, funds may not be available and it will depend upon the ease of implementation (agreement between agencies, responsibility etc.).

Key points for each measure based on the assessment in Section 9 are summarised in Table 29 according to the ranking.

Table 28: Recommended Management Measures in Plan

Option	Section in Study	Priority	Responsibility	Costing	Timeframe	Rank (Total)
Review Flood Emergency Management	9.2.3	High	Council / SES	Low	Short	1
Flood Planning and Control	9.2.1	High	Council	Low	Short	2
Flood Awareness Program	9.2.4	Medium	Council / SES	Medium	Medium	3
Owner Contribution to Flood Mitigation	9.2.5	High	Landowner	Low	Medium	4
Consider Depth Indicators on Roads	9.2.6	Medium	Council	Low	Short	5
Creek and Drainage Maintenance	9.2.2	Medium	Council	Medium	Short	6
Kerb Raising at Harris Court	9.1.1	Medium	Council	Medium	Long	7
Stormwater Diversion Main from Denison Street Reserve	9.1.2.2	Low	Council	High	Long	7
Kerb Raising at Hutchins Street	9.1.3	Medium	Council	Medium	Long	9
Basin Augmentation at Denison Street Reserve	9.1.2.1	Low	Council	High	Long	10
Inlet Pits Upgrade	9.1.6.2	Low	Council	Medium	Long	10
Main Underground Pipe Upgrade	9.1.6.1	Low	Council	High	Long	12

Table 29: Key Points of Recommended Management Measures for Kingston CBD

MEASURE	PURPOSE	COMMENT
Non-Structural Measures:		
Review Flood Emergency Management (Section 9.2.3)	Effective planning for emergency response is a vital way of reducing risk to life and property.	• The cost to undertake this measure is small and will provide a high benefit/cost ratio. • A range of measures are provided and supported.
Flood Planning and Control (Section 9.2.1)	Define the boundaries of the flood planning area and implementing flood related planning controls.	• Flood overlays need to be developed for planning purpose. Examples are provided. • It is recommended that planning policy is revised to provide stricter development controls in high risk areas.
Flood Awareness Program (Section 9.2.4)	Educate people to prepare themselves and their properties for floods, to minimise flood damages and reduce the risk.	• A cheap and effective method but requires continued effort as floods are infrequent events. • It is important that a high level of awareness is maintained. • Community Consultation is suggested.
Owner Contribution to Flood Mitigation (Section 9.2.5)	Encourage and implement owners' knowledge and ideas to protect their assists.	• Educational program to encourage owner to implement ideas or processes to protect their assets without causing negative impact on their abutting and downstream neighbours. • Further flood modelling at lot scales can be beneficial to inform and guide lot scale measure implementation.
Consider Depth Indicators on Roads (Section9.2.6)	To ensure safe and reliable access during times of flood and to reduce the risk to life of vehicles entering flood waters.	• Flood hazard cannot be eliminated. • No specific road raising works to improve flood access are proposed. • Depth indicator is an appropriate cost-effective measure to advise drivers of the depth of flood waters.
Creek and Drainage Maintenance (Section 9.2.2)	To ensure drainage is operating with maximum efficiency and to reduce the risk of blockage or failure.	• Maintenance is costly and requires ongoing investment. • Engaging community through educational program can be effective. • Implementation with structural measures can be considered, e.g., blockage prevention facilities.
Structural Measures:		
Kerb Raising at Harris Court (Section 9.1.1)	To restrict discharge within the road reserve along the west boundary of the residential properties.	• The measure involves raising the north kerb approximately 150 mm and constructing a raised 'hump' at the mouth of the Crescent. • It can prevent one property from inundation and reduce flood level by approximately 100 mm across the other five affected properties. • Less costly among structural measures.

MEASURE	PURPOSE	COMMENT
Stormwater Diversion Main from Denison Street Reserve (Section 9.1.2.2)	Detain stormwater in Denison Street Reserve and divert directly to Browns River through underground Pipe.	• The measure involves construction of a detention wall and a 1200 mm (as modelled) diversion pipe. • Provides high level of flood protection for Channel Court during flood events up to and including the 1% AEP event under projected 2100 climate conditions • Provides a high level of flood resilience to the Kingston CBD. Resolves major flooding issues within CBD catchment • Significant capital works cost
Kerb Raising at Hutchins Street (Section 9.1.3)	To restrict discharge within the road reserve along the west boundary of the Civic Centre.	• The kerb and footpath need to be raised by 100 mm. • It is shown to lead to notable reduction of flood depth and extent on the west and north west side of the Civic Centre but no benefit to the issue within the car park at the south side. • Less costly among structural measures.
Basin Augmentation at Denison Street Reserve (Section 9.1.2.1)	To provide additional detention storage in two Denison Street Basins.	• It requires to either augment or reconstruct Denison Street Basins to provide additional detention. • It is costly, but can prevent Channel Court free from inundation during 1% AEP event under existing conditions and solve the flooding issue across downstream area to certain extent.
Inlet Pits Upgrade (Section 9.1.5.2)	To increase inlet capacity for existing underground drainage systems.	• The measure can be either upgrading the existing inlet structure or installation of blockage prevention devices. • It can be costly pending on the number of inlets to be upgraded. • Priority should be given to low grates on the Freeman Street wall at Channel Court if this measure is considered.
Main Underground Pipe Upgrade (Section 9.1.5.1)	To increase capacity of existing underground drainage systems.	• Flooding issue at Channel Court may be reduced by increasing the size of the main pipe under and downstream of Channel Court. • It is very costly to do construction work under significant existing buildings, such as Channel Court. • Further detailed modelling needs to be carried out to assess the impact.

11. CONCLUSIONS AND RECOMMENDATIONS

11.1. Conclusions

Hydrologic and hydraulic models have been established to define design flood behaviour and establish the flood risk for the 5%, 1% and 0.5% AEP design storms under current climate and 2050 and 2100 Climate Change scenarios, in the Kingston CBD catchment. Based on the design flood modelling results, flood risk at key locations (hotspots) and associated potential resilience measures were investigated.

Several structure measures were modelled, and the indicative costs were estimated, including:

- Kerb raising at Harris Court to reduce flood inundation in residential block
- Kerb and Footpath raising at Hutchins Street to reduce flood inundation at Kingborough Civic Centre
- Augmentation of existing basins in Denison Street Reserve to alleviate flood risk downstream
- Detaining and Diverting stormwater from Denison Street Reserve direct to Browns River through underground main to alleviate flood risk downstream.

The results indicated that kerb and/or footpath raising at Harris Court and Hutchins can reduce local flood inundation issues to certain extent. Both basin augmentation and stormwater diversion main show reduction of flood levels and extents downstream of Denison Street Reserve and the benefit extends to Huon Highway. However, the stormwater diversion main shows more profound effect on flood mitigation and resilience downstream of Denison Street Reserve. This option results in Channel Court being free of inundation during flood events up to and including the 0.5% AEP.

It should be noted that for highly urbanised catchment like Kingston CBD, it can be difficult to implement structural flood resilience measures. In most cases, implementation of structural measures means modification or demolition of existing infrastructure and construction of new infrastructure. Major upgrade works typically command high costs and create social disruptions during construction, which can impact on project feasibility. Funding through government grants, developer contributions and or rate payers may need to be considered.

The kerb and/or footpath raising are moderate costly, while the other two structural measures tested are quite expensive. Stormwater diversion main is the most effective option to reduce flood risk through Kingston CBD, but also the most expensive one.

The multi-criteria assessment of resilience measures indicates that the non-structural flood resilience measures can be easier to be implemented in a relatively short term with relatively low cost. Some non-structural measures can be particularly beneficial in the study area, including:

- implementation of flood overlays to inform planning decisions
- owner participation and contribution to flood mitigation
- development of an emergency management plan
- promoting flood awareness education.

The cost, timeframe and priority of each assessed measure are summarized in Table 28. The relatively priorities of those measures are based on the multi-criteria assessment matrix, as shown in Table 27, which has been developed mainly from the Council perspective to build an improved flood resilient community. Therefore, there have been more emphasis on residential properties than commercial properties, with the assumption that commercial properties such as Channel Court Shopping Centre are more at the owners' responsibility to manage flood risks. This may have brought scores and priorities down for some of the expensive but high beneficial structural measures, such as Stormwater Diversion Main, considering the low financial feasibility through government funding. Recommendations on future actions for Council to proceed are summarized in below section.

11.2. Recommendations

Structural and non-structural flood resilience measures have been discussed and preliminarily investigated. Based on the initial assessment, the catchment resilience measures are prioritised in Table 28 and further commented in Table 29. The prioritised list of catchment resilience measures is provided as an indicative guidance for Council to pursue and allocate its funding and resources for future investigation. Detailed assessment and plan will need to be conducted before the implementation any of the measures.

Recommendations are summarized in Table 30.

Table 30: Recommendations for Management Measures

MEASURE	RECOMMENDATION
Non-Structural Measures:	
Review Flood Emergency Management (Section 9.2.3)	A vital way of reducing risk to life and property with low cost and short timeframe; Suggest implementing directly with high priority.
Flood Planning and Control (Section 9.2.1)	An effective way with low cost and short timeframe which can bring huge benefit and avoid significant damage for future development; Suggest implementing directly with high priority.
Consider Depth Indicators on Roads (Section9.2.6)	An appropriate measure with low cost and short timeframe, with reasonable benefit; Suggest implementing directly with median priority.
Owner Contribution to Flood Mitigation (Section 9.2.5)	Low cost and medium timeframe with high benefit; Suggest pursuing with high priority but in two steps: • Community consultancy program to obtain opinions and wellness of owners; • Setup owner participation/contribution program/policy for implementation.
Flood Awareness Program (Section 9.2.4)	Median cost and medium timeframe with high benefit; Suggest implementing an on-going program including regular educational sessions to maintain high level of flood awareness with median priority.
Creek and Drainage Maintenance (Section 9.2.2)	Short timeframe with reasonable benefit, requiring ongoing investment; Public education (with flood awareness program) is suggested with high priority; Vegetation and debris maintenance is suggested to be considered with median priority if funding is available.
Structural Measures:	
Kerb Raising at Harris Court (Section 9.1.1)	Medium cost and long timeframe, with reasonable benefit; Suggest further investigation, including detailed costing and functional design if funding available.
Kerb Raising at Hutchins Street (Section 9.1.3)	Medium cost and long timeframe, with reasonable benefit; Suggest further investigation, including detailed costing and functional design if funding available.
Stormwater Diversion Main from Denison Street Reserve (Section 9.1.2.2)	High cost and long timeframe, however, can be the most effective to solve the flood inundation issue across the CBD, including Channel Court; Suggest further investigation, including detailed cost benefit analysis and functional design if funding available.
Basin Augmentation at Denison Street Reserve (Section 9.1.2.1)	High cost and long timeframe, with reasonable benefit; Suggest considering with low priority with further investigation.
Inlet Pits Upgrade (Section 9.1.5.2)	High cost and long timeframe, with limited benefit; Suggest considering with lowest priority.
Main Underground Pipe Upgrade (Section 9.1.5.1)	High cost and long timeframe, with limited benefit; Suggest considering with lowest priority.

12. ACKNOWLEDGEMENTS

WMAwater has prepared this document for Kingborough Council, with financial and technical assistance from the Tasmania Government through its Community Recovery and Resilience Grants program. The assistance of the following in providing data, survey, and guidance to the study is gratefully acknowledged:

- Kingborough Council;
- Land Information System Tasmania, Tasmania Government;
- Bureau of Meteorology;
- Swanson Surveying;
- PDA Surveyors;
- JSA Consulting Engineers; and
- Residents of the catchment.

13. REFERENCES

1. **Kingston Beach Flood Study**
   Kingborough Council, Australia, 2015

2. **Whitewater Creek Flood Study**
   WMAwater, Australia, 2020

3. Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors)
   Australian Rainfall and Runoff: A Guide to Flood Estimation
   Commonwealth of Australia, Australia, 2019

4. **WBNM User Guide**, June 2012
   WBNM, July 2011

5. Tarboton, D. G.
   A New Method for the Determination of Flow Directions and Contributing Areas in Grid Digital Elevation Models
   Water Resources Research, 33(2): 309-319, 1997

6. **TUFLOW User Manual**, 2018-03-AD
   BMT WBM, 2018

7. Engineers Australia
   Australian Rainfall and Runoff Revision Project 15: Two Dimensional Modelling in Urban and Rural Floodplains
   Department of Climate Change and Energy Efficiency, November 2012

8. Weeks, W., Witheridge, G., Rigby, E., Barthelmess, A. and O'Loughlin, G.
   Australian Rainfall and Runoff: Revision Project 11: Blockage of Hydraulic Structures (Stage 2 Report)
   Engineers Australia, February 2013

9. Pilgrim DH (Editor in Chief)
   Australian Rainfall and Runoff – A Guide to Flood Estimation
   Institution of Engineers, Australia, 1987.

10. Bureau of Meteorology
    The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method
    Bureau of Meteorology, June 2003

11. New South Wales Government
    Floodplain Development Manual
    NSW State Government, April 2005

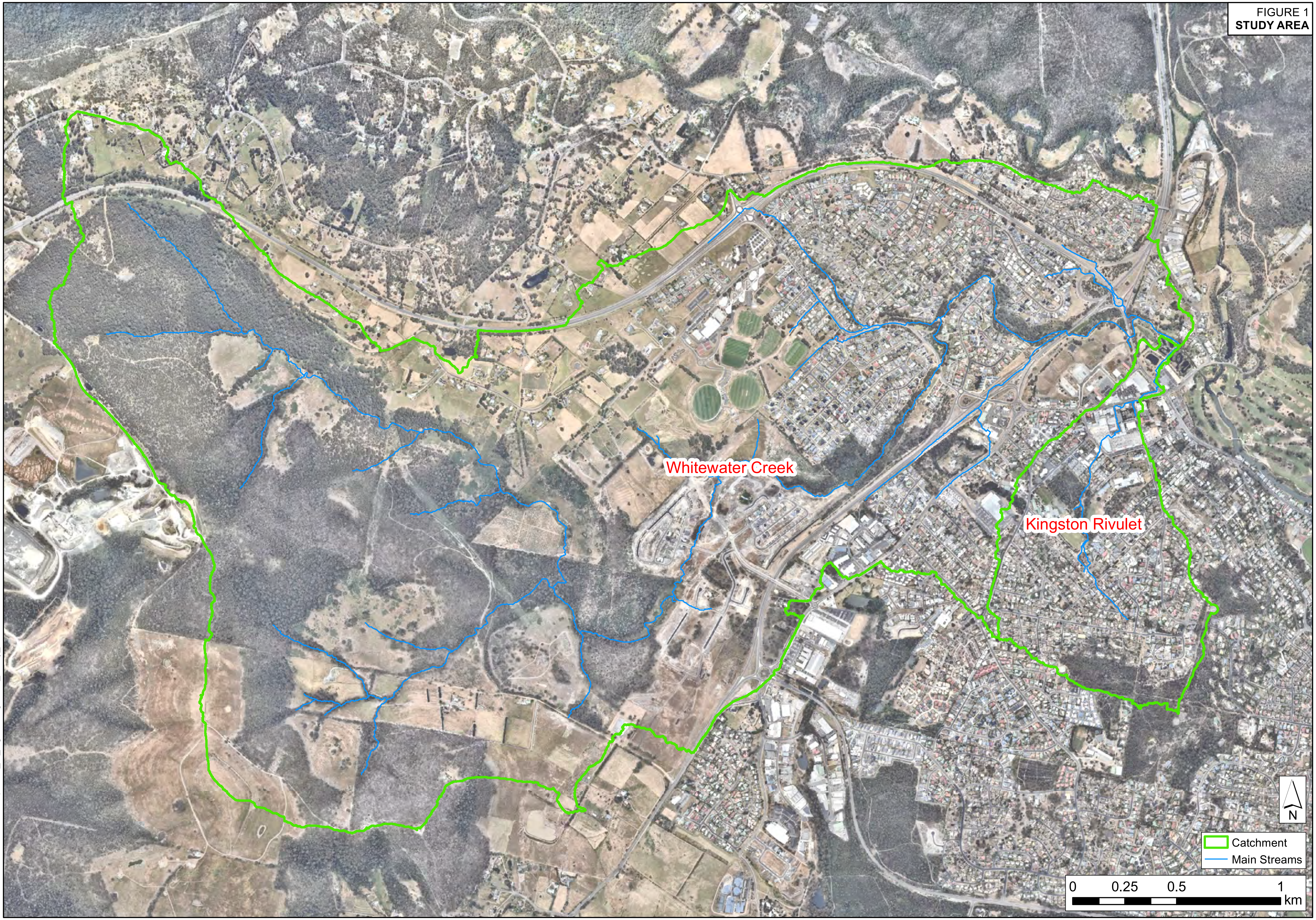
12. Australian Institute for Disaster Resilience
    Australian Disaster Resilience Guideline 7-3 Flood Hazard
    Supporting document for the implementation of Australian Disaster Resilience

Handbook 7 Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia
Australian Government, 2017

13. Howells, L., McLuckie, D., Collings, G. and Lawson, N.
Defining the Floodway – Can One Size Fit All?
Floodplain Management Authorities of NSW 43rd Annual Conference, Forbes
February 2003

14. Biemans, H.; Bresser, T.; et al
Water and Climate risks: A Plea for Climate Proofing of Water Development Strategies and Measure
UNESCO-IHE, 2006

Figures



J:\Jobs\119087\ArcGIS\ArcMaps\List_of_Figures\Figure01_Study_Area.mxd

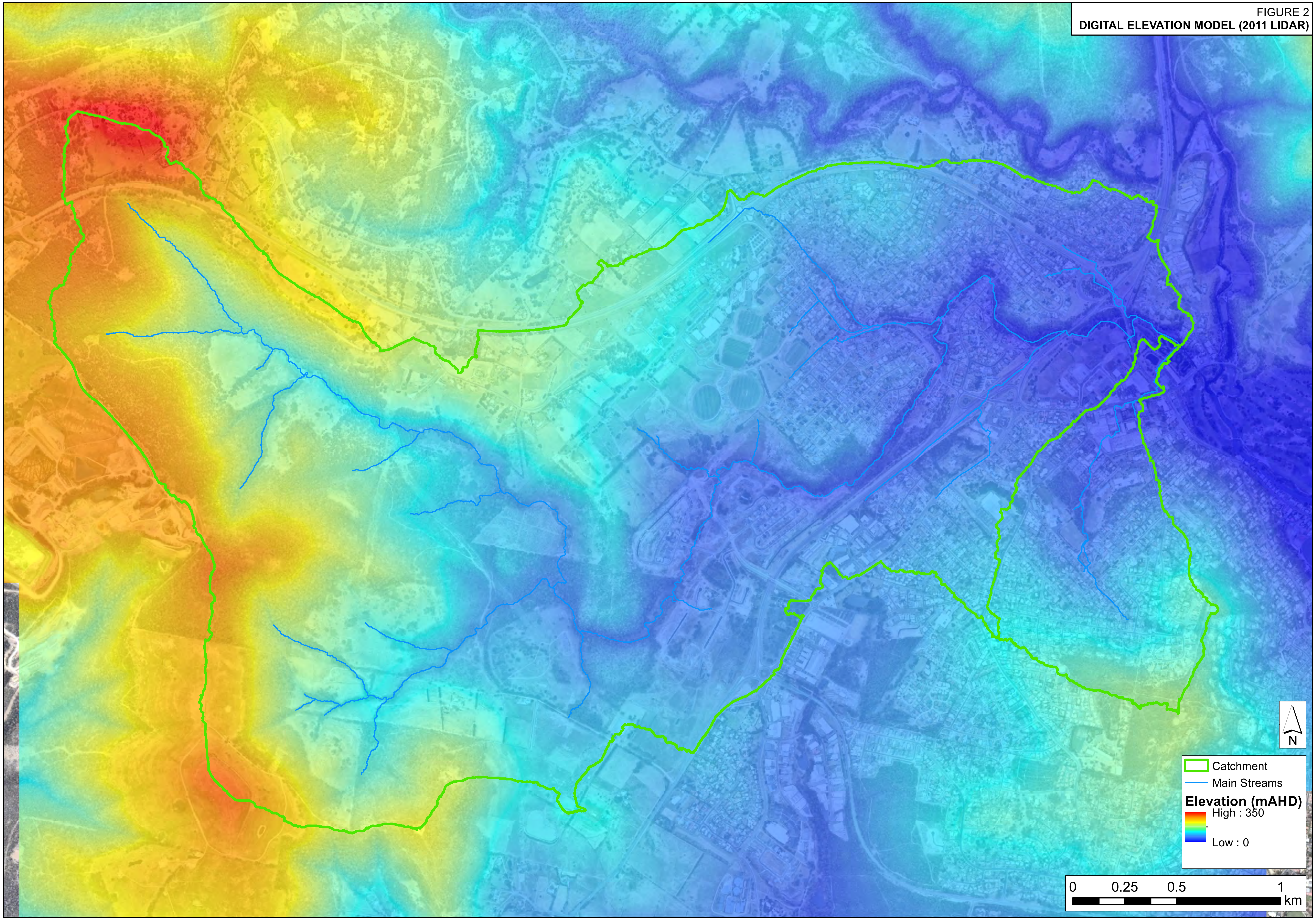
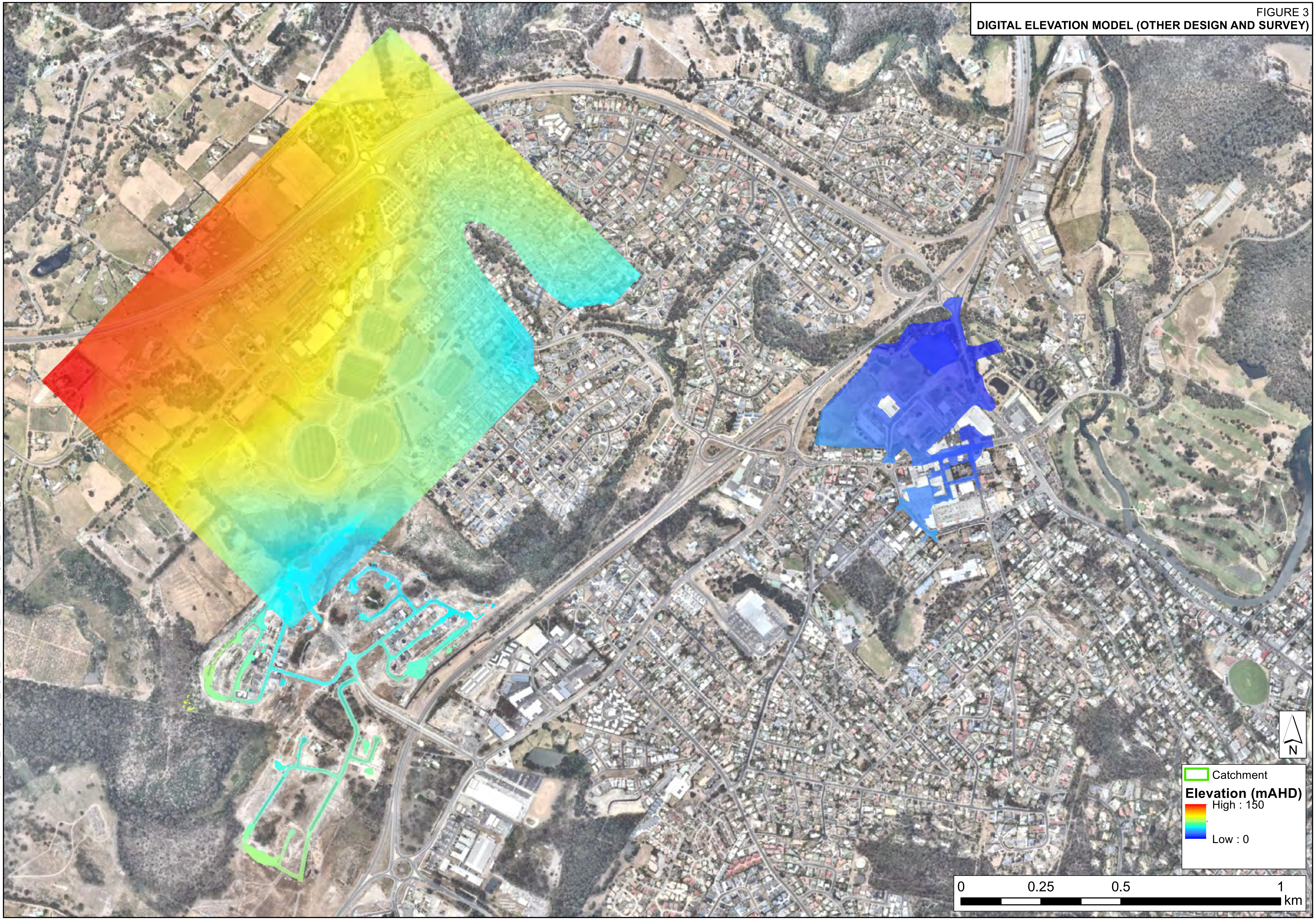


FIGURE 2
DIGITAL ELEVATION MODEL (2011 LIDAR)

FIGURE 3
DIGITAL ELEVATION MODEL (OTHER DESIGN AND SURVEY)



J:\Jobs\119088\ArcGIS\ArcMap\Figures_List\Figure03_Digital_Elevation_Model_Design_and_Survey_Data.mxd

J:\Jobs\119088\ArcGIS\ArcMap\Figures_List\Figure04_Digital_Elevation_Model_Design_and_Survey_Data_Kingston_CBD.mxd

FIGURE 5
LOCATIONS OF PHOTOS AND CCTV

J:\Jobs\119088\ArcGIS\ArcMap\Figure05_Locations_of_Photos_and_CCTV.mxd

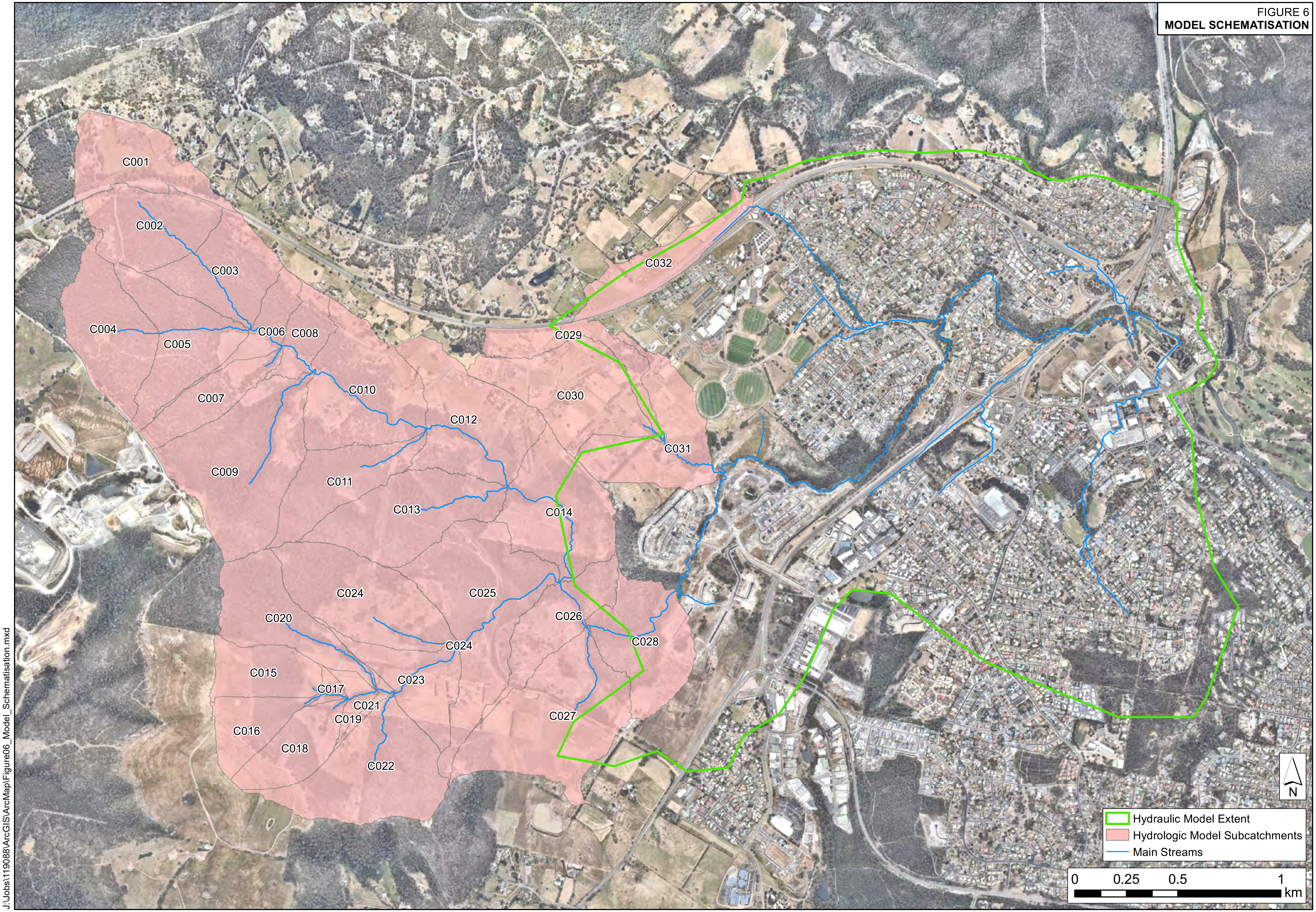
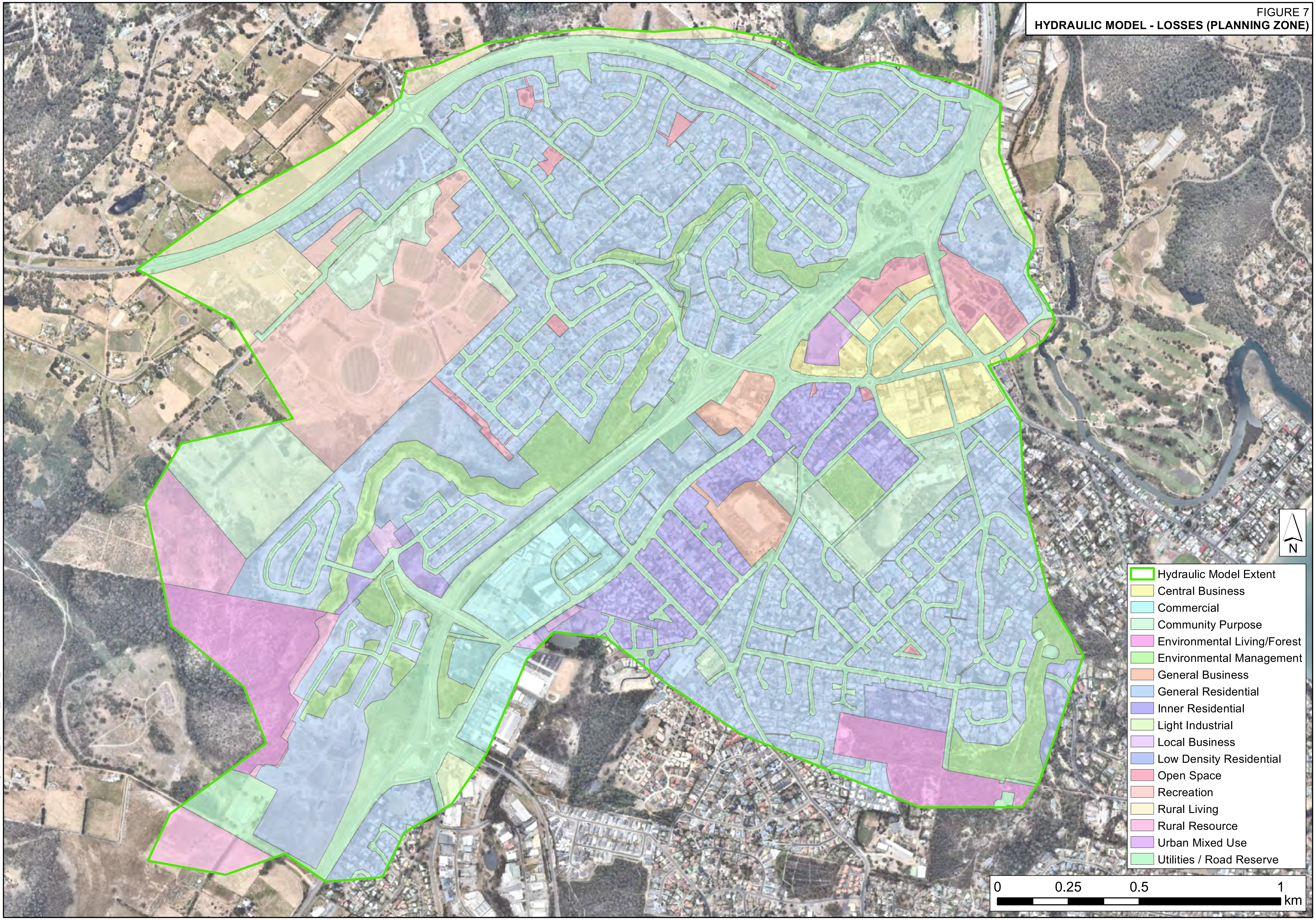


FIGURE 6
MODEL SCHEMATISATION
C001
C002
C003
C004
C005
C006
C007
C008
C009
C010
C011
C012
C013
C014
C015
C016
C017
C018
C019
C020
C021
C022
C023
C024
C025
C026
C027
C028
C029
C030
C031
C032
N
Hydraulic Model Extent
Hydrologic Model Subcatchments
Main Streams
0
0.25
0.5
1
km
J:\Jobs\119088\ArcGIS\ArcMap\Figure06_Model_Schematisation.mxd

FIGURE 7

HYDRAULIC MODEL - LOSSES (PLANNING ZONE)

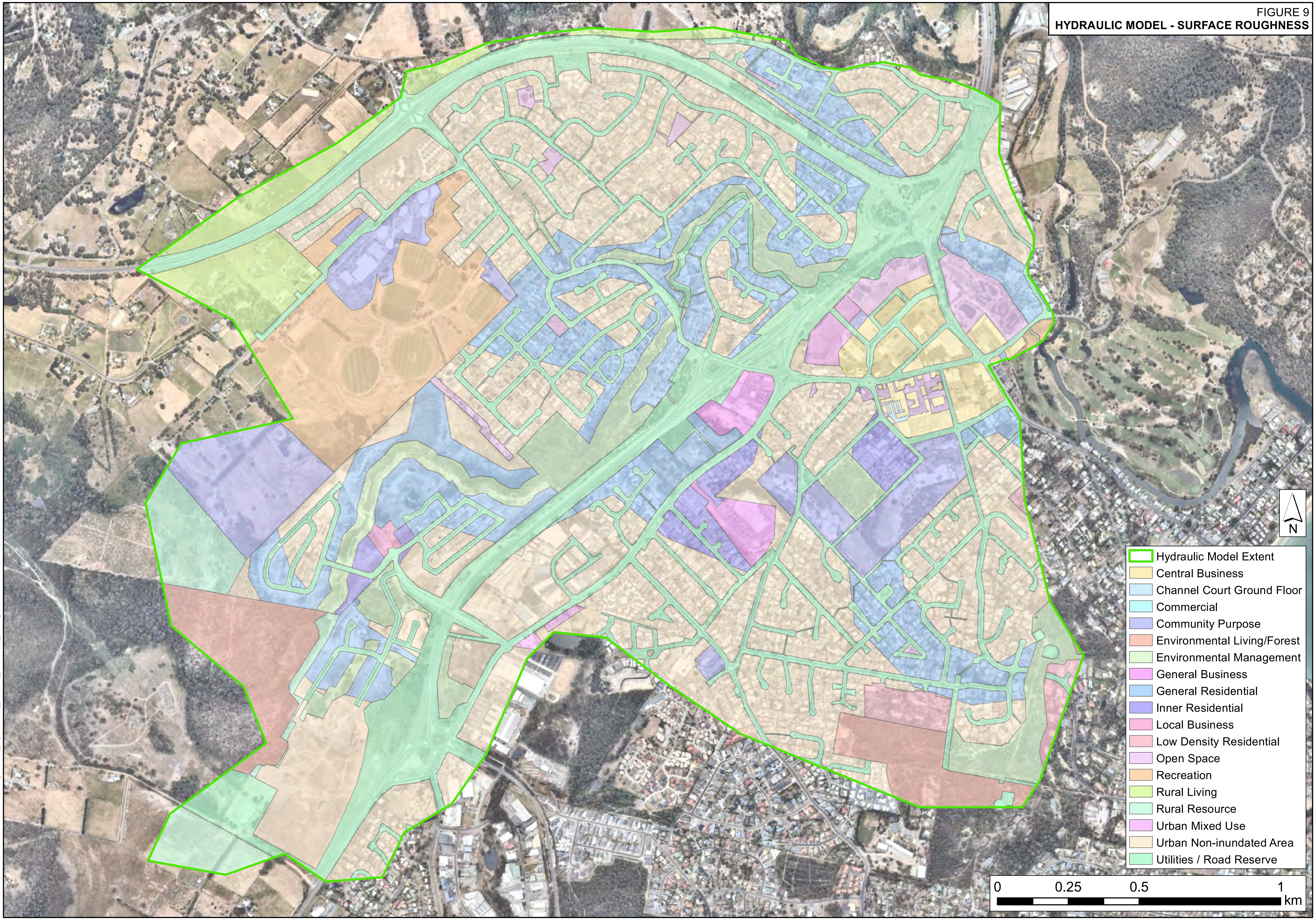


J:\Jobs\119088\ArcGIS\ArcMap\Figure07_Hydraulic_Model_Losses.mxd

FIGURE 8
HYDRAULIC MODEL - BOUNDARY CONDITIONS

J:\Jobs\119088\ArcGIS\ArcMap\Figure08_Hydraulic_Model_Boundary_Conditions.mxd

FIGURE 9
HYDRAULIC MODEL - SURFACE ROUGHNESS



J:\Jobs\119088\ArcGIS\ArcMap\Figure09_Hydraulic_Model_Surface_Roughness.mxd

FIGURE 10
HYDRAULIC MODEL - DRAINAGE

J:\Jobs\119088\ArcGIS\ArcMap\Figure10_Hydraulic_Model_Drainage.mxd

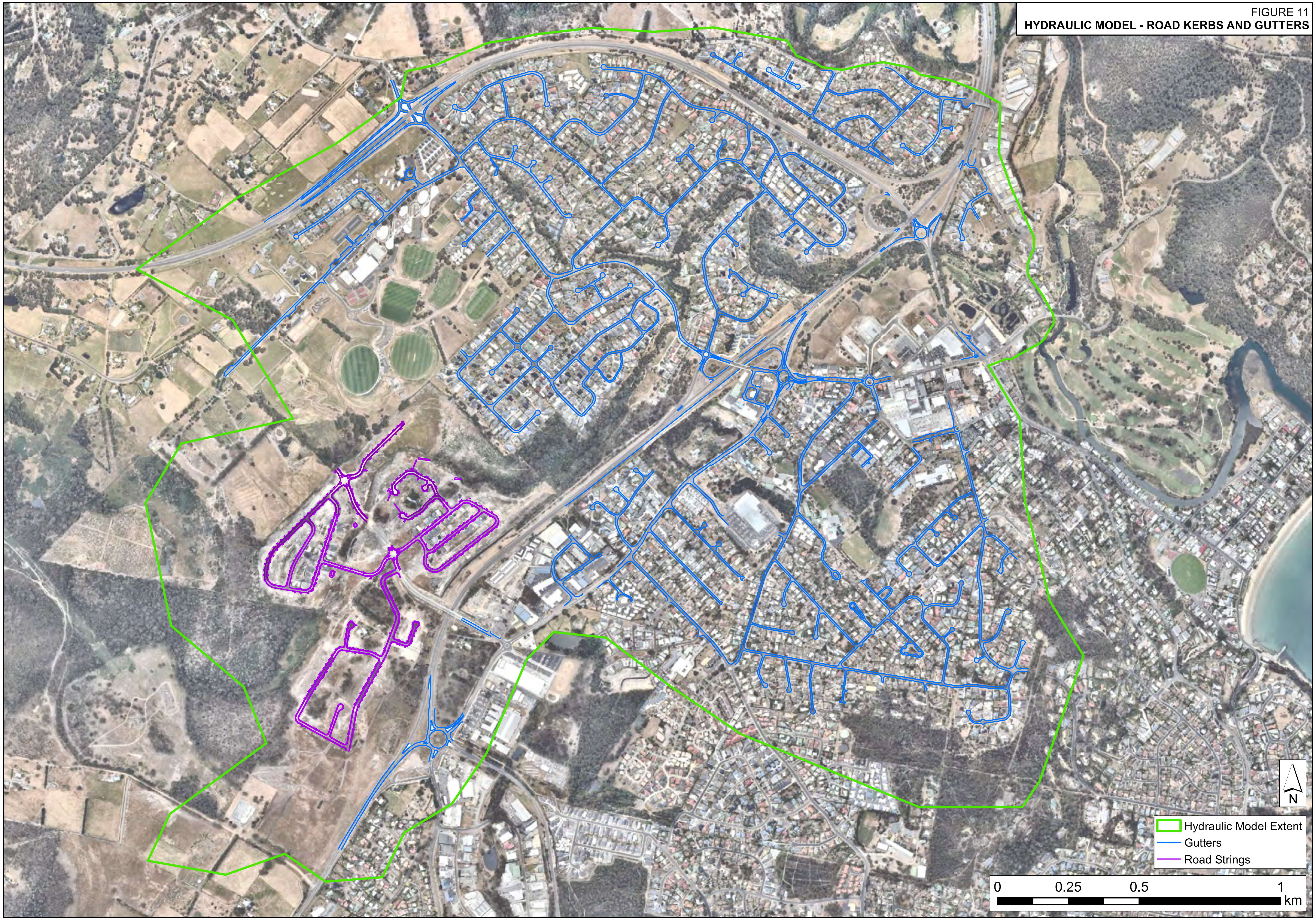


FIGURE 11
HYDRAULIC MODEL - ROAD KERBS AND GUTTERS
N
Hydraulic Model Extent
Gutters
Road Strings
0
0.25
0.5
1
km
J:\Jobs\119088\ArcGIS\ArcMap\Figure11_Hydraulic_Model_Road_Kerbs_Gutters.mxd

FIGURE 12
BUILDING REPRESENTATION

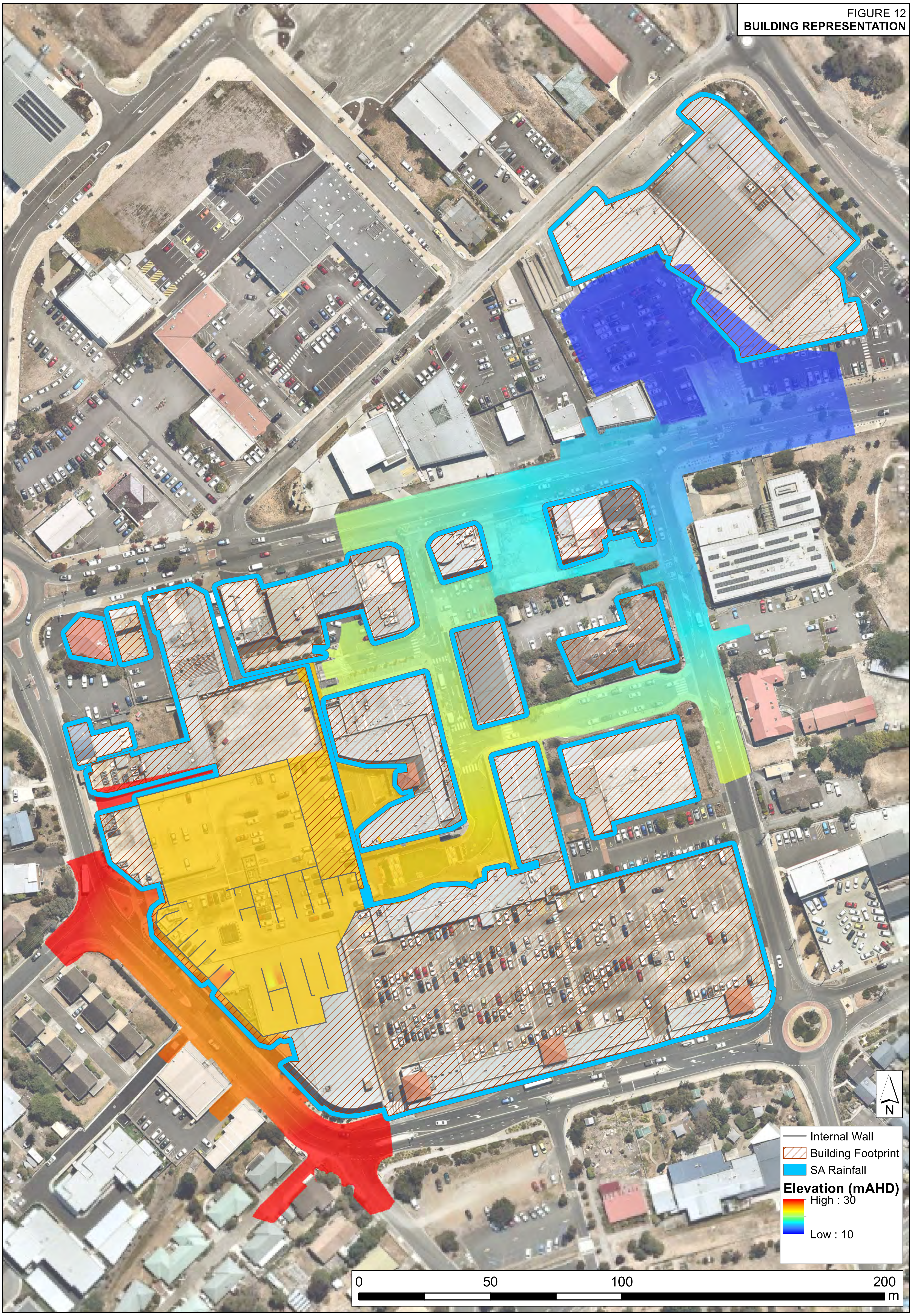
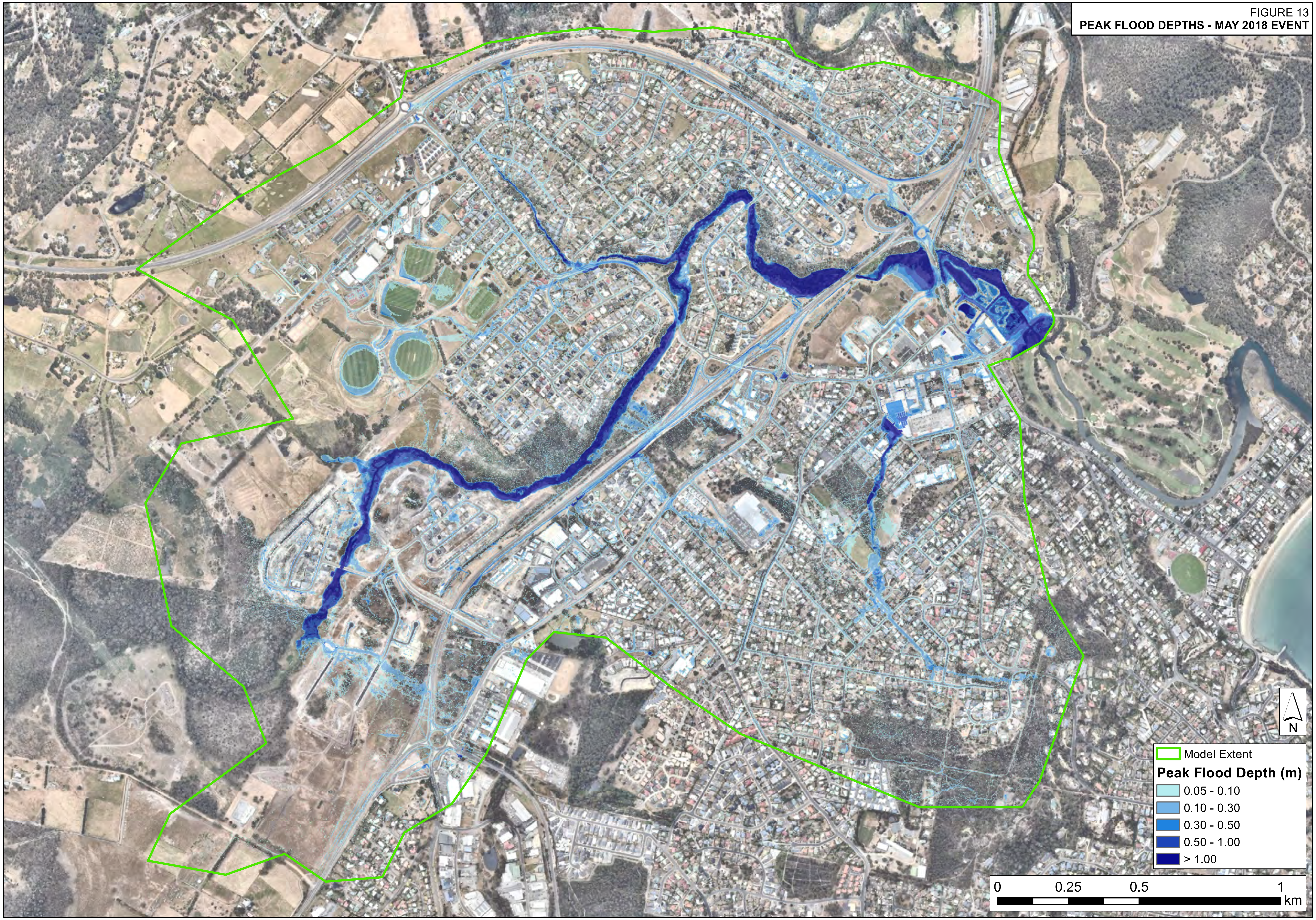


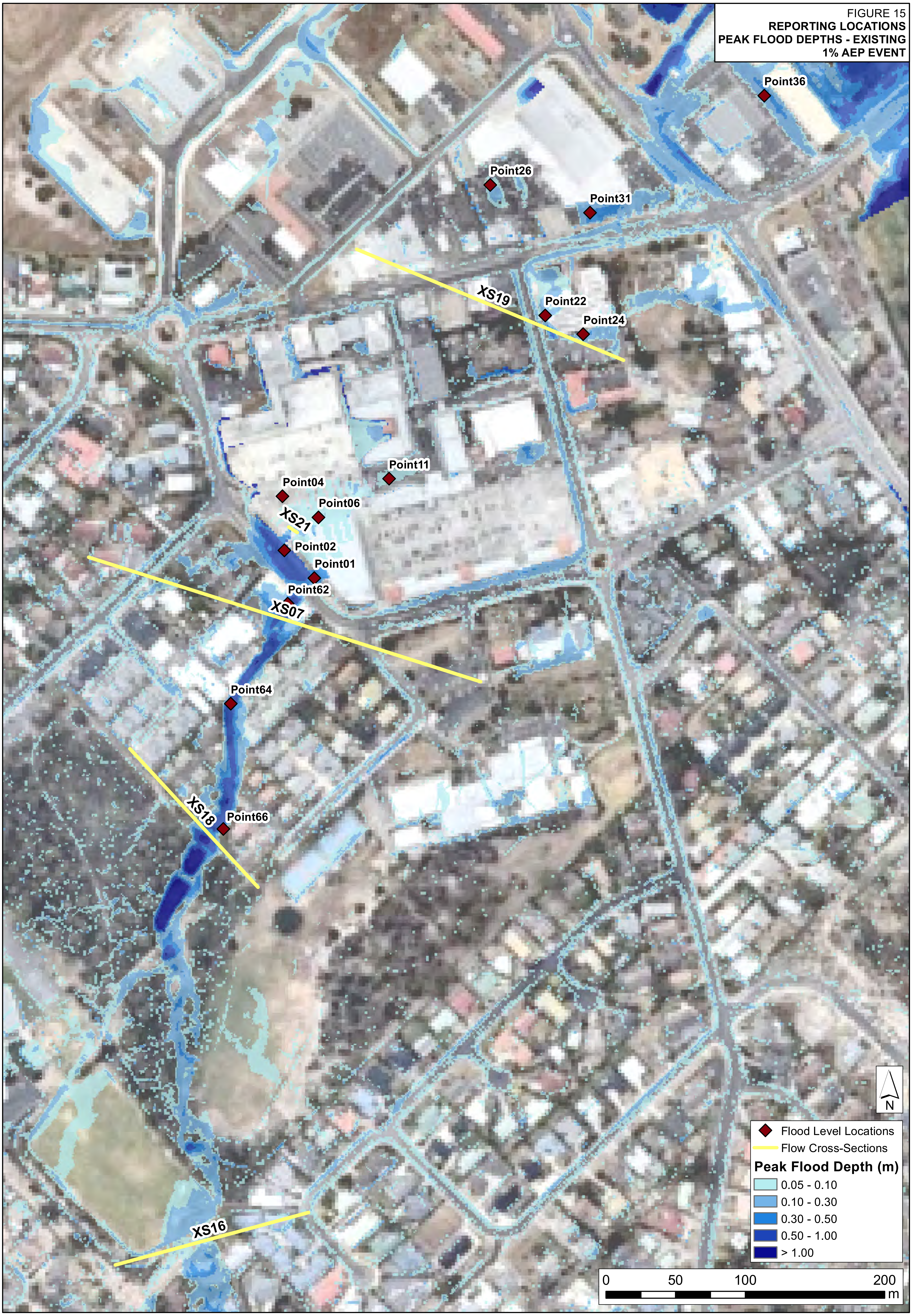
FIGURE 13
PEAK FLOOD DEPTHS - MAY 2018 EVENT



J:\Jobs\119088\ArcGIS\ArcMap\Figures_List\Figure13_PeakFloodDepths_May 2018_Event.mxd

FIGURE 14
VALIDATION LOCATIONS - MAY 2018 EVENT

J:\Jobs\119088\ArcGIS\ArcMap\Figures_List\Figure14_Validation_Locations_May 2018_Event.mxd



J:\Jobs\119088\ArcGIS\ArcMap\Figures_List\Figure15_Reporting_Locations_1pctAEP_Event.mxd

Appendix A

APPENDIX A. GLOSSARY

Taken from the Floodplain Development Manual (April 2005 edition)

acid sulfate soils	Are sediments which contain sulfidic mineral pyrite which may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual published by Acid Sulfate Soil Management Advisory Committee.
Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Annual Damage (AAD)	Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
Average Recurrence Interval (ARI)	The long term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
caravan and moveable home parks	Caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the LG Act.
catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
consent authority	The Council, government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the Council, however legislation or an EPI may specify a Minister or public authority (other than a Council), or the Director General of DIPNR, as having the function to determine an application.
development	Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act). **infill development:** refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development. **new development:** refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power.

redevelopment: refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services.

disaster plan (DISPLAN)	A step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.
discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
ecologically sustainable development (ESD)	Using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act 1993. The use of sustainability and sustainable in this manual relate to ESD.
effective warning time	The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.
emergency management	A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.
flash flooding	Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
flood awareness	Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.
flood education	Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves an their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.
flood fringe areas	The remaining area of flood prone land after floodway and flood storage areas have been defined.
flood liable land	Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).
flood mitigation standard	

	The average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.
floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
floodplain risk management options	The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
floodplain risk management plan	A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammetic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
flood plan (local)	A sub-plan of a disaster plan that deals specifically with flooding. They can exist at State, Division and local levels. Local flood plans are prepared under the leadership of the State Emergency Service.
flood planning area	The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the Aflood liable land@ concept in the 1986 Manual.
Flood Planning Levels (FPLs)	FPL=s are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the Astandard flood event@ in the 1986 manual.
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.
flood readiness	Flood readiness is an ability to react within the effective warning time.
flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. **existing flood risk:** the risk a community is exposed to as a result of its location on the floodplain. **future flood risk:** the risk a community may be exposed to as a result of new development on the floodplain. **continuing flood risk:** the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.
flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood

	storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.
freeboard	Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
habitable room	**in a residential situation:** a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom. **in an industrial or commercial situation:** an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.
hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Manual.
hydraulics	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
hydrograph	A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
hydrology	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
local drainage	Are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.
mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
major drainage	Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purpose of this manual major drainage involves: - the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or - water depths generally in excess of 0.3 m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or

- major overland flow paths through developed areas outside of defined drainage reserves; and/or

- the potential to affect a number of buildings along the major flow path.

mathematical/computer models The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.

merit approach The merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well being of the State=s rivers and floodplains.

The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into Council plans, policy and EPIs. At a site specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local floodplain risk management policy and EPIs.

minor, moderate and major flooding Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood:

minor flooding: causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded.

moderate flooding: low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered.

major flooding: appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.

modification measures Measures that modify either the flood, the property or the response to flooding. Examples are indicated in Table 2.1 with further discussion in the Manual.

peak discharge The maximum discharge occurring during a flood event.

Probable Maximum Flood (PMF) The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.

Probable Maximum Precipitation (PMP) The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.

probability A statistical measure of the expected chance of flooding (see AEP).

risk Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.

runoff The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.

stage Equivalent to Awater level@. Both are measured with reference to a specified datum.

stage hydrograph A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.

survey plan A plan prepared by a registered surveyor.

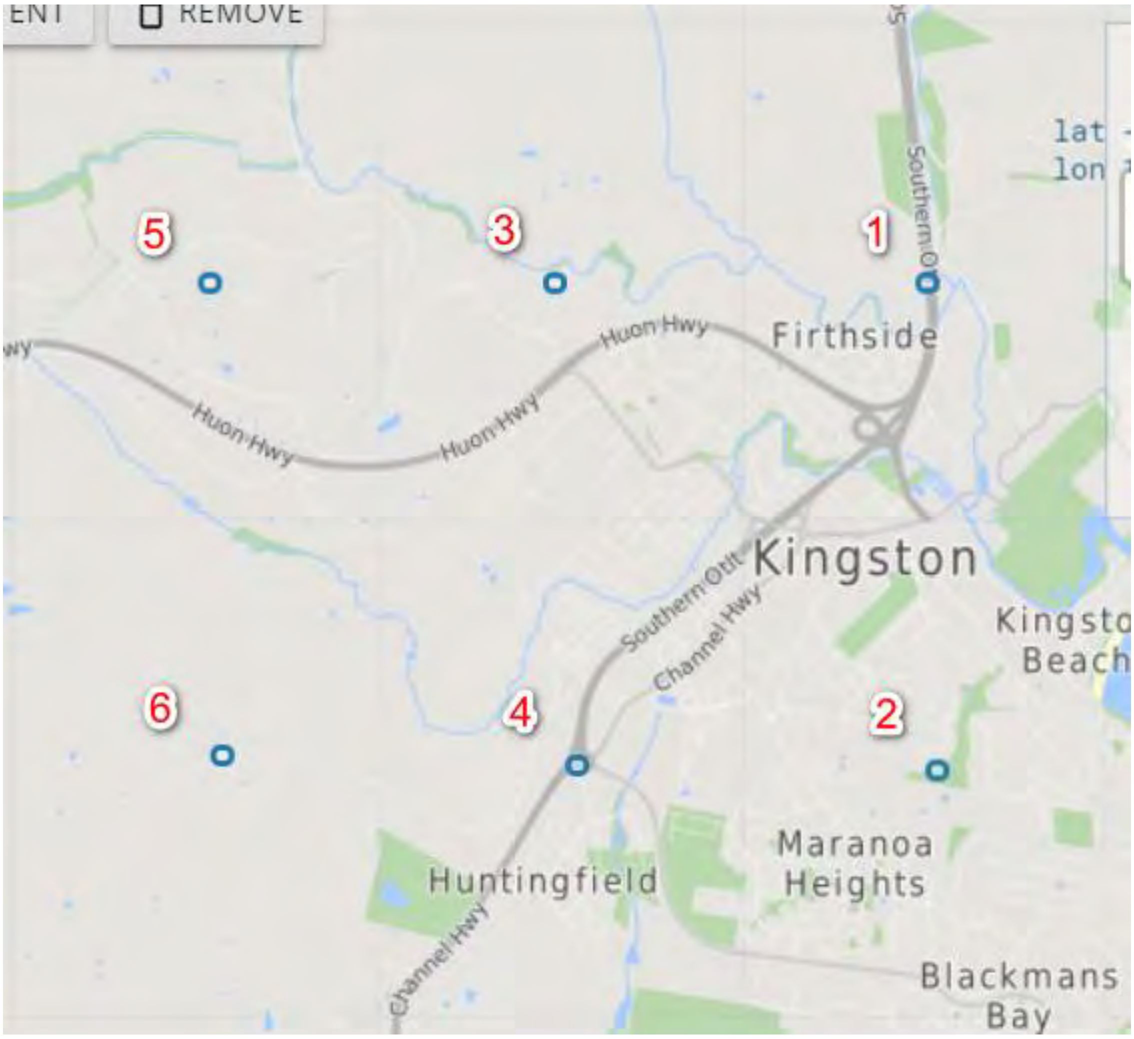
water surface profile A graph showing the flood stage at any given location along a watercourse at a particular time.

wind fetch The horizontal distance in the direction of wind over which wind waves are generated.

APPENDIX B. IFDs

Appendix B

B.1. IFD Grids


REMOVE
5
3
1
Firthside
Huon Hwy
Huon Hwy
Huon Hwy
Southern Otlt
Kingston
Southern Otlt
Channel Hwy
Kingston Beach
6
4
2
Maranoa Heights
Huntingfield
Channel Hwy
Blackmans Bay

B.2. IFD Tables

Table B1: BoM 2016 IFD for Grid 1

Grid 1	Annual Exceedance Probability (AEP) Rainfall intensity in mm/h									
Duration	**63.20 %**	**50%#**	**20%***	**10%**	**5%**	**2%**	**1%**	**1 in 200**	**1 in 500**	**1 in 1000**	**1 in 2000**
1 min	1.04	1.18	1.66	2.01	2.38	2.9	3.34	3.8	4.41	4.9	5.41
2 min	1.79	2.02	2.75	3.26	3.77	4.43	4.94	5.6	6.49	7.21	7.98
3 min	2.37	2.68	3.69	4.4	5.11	6.06	6.8	7.71	8.95	9.94	11
4 min	2.85	3.23	4.48	5.38	6.29	7.53	8.52	9.68	11.2	12.5	13.8
5 min	3.26	3.7	5.16	6.22	7.31	8.83	10.1	11.4	13.3	14.8	16.3
10 min	4.71	5.36	7.57	9.22	11	13.5	15.6	17.8	20.6	22.9	25.3
15 min	5.71	6.5	9.18	11.2	13.3	16.4	19	21.6	25.1	27.9	30.8
20 min	6.51	7.41	10.4	12.7	15.1	18.5	21.4	24.4	28.3	31.5	34.8
25 min	7.2	8.18	11.5	14	16.5	20.2	23.3	26.5	30.8	34.2	37.8
30 min	7.82	8.87	12.4	15	17.8	21.7	24.9	28.3	32.9	36.5	40.4
45 min	9.39	10.6	14.8	17.8	20.9	25.2	28.7	32.7	37.9	42.1	46.6
1 hour	10.7	12.2	16.8	20.2	23.5	28.2	31.9	36.2	42	46.7	51.6
1.5 hour	13	14.7	20.3	24.2	28.1	33.3	37.3	42.5	49.3	54.7	60.5
2 hour	15	17	23.4	27.8	32.2	37.9	42.3	48.1	55.8	62	68.5
3 hour	18.3	20.9	28.9	34.2	39.4	46.2	51.4	58.5	67.9	75.4	83.4
4.5 hour	22.5	25.7	35.8	42.5	49	57.4	63.8	72.7	84.4	93.7	104
6 hour	25.9	29.8	41.8	49.7	57.4	67.4	75	85.6	99.4	110	122
9 hour	31.5	36.4	51.6	61.8	71.6	84.7	94.7	108	125	139	154
12 hour	35.9	41.6	59.4	71.5	83.2	99.1	111	127	147	164	181
18 hour	42.4	49.3	71.2	86.3	101	121	137	156	182	202	223
24 hour	47.1	54.8	79.6	96.8	114	137	156	178	206	229	253
30 hour	50.6	58.9	85.7	104	123	149	170	194	225	250	276
36 hour	53.4	62.1	90.3	110	130	158	180	205	237	264	292
48 hour	57.4	66.6	96.7	118	140	169	193	219	253	282	312
72 hour	62.3	72	104	126	149	180	205	230	267	297	329
96 hour	65.5	75.4	107	130	152	183	208	234	273	303	336
120 hour	68	78	110	132	155	185	209	237	276	307	340
144 hour	70.2	80.4	113	135	156	186	210	238	279	310	343
168 hour	72.3	82.8	115	137	159	188	212	240	281	313	346

Note:
 # The 50% AEP IFD does not correspond to the 2 year Average Recurrence Interval (ARI) IFD. Rather it corresponds to the 1.44 ARI.
** The 20% AEP IFD does not correspond to the 5 year Average Recurrence Interval (ARI) IFD. Rather it corresponds to the 4.48 ARI.*

Table B2: BoM 2016 IFD for Grid 2

Grid 2	**Annual Exceedance Probability (AEP) Rainfall intensity in mm/h**										
Duration	**63.20 %**	**50%#**	**20%***	**10%**	**5%**	**2%**	**1%**	**1 in 200**	**1 in 500**	**1 in 1000**	**1 in 2000**
1 min	1.04	1.19	1.67	2.02	2.39	2.92	3.36	3.82	4.43	4.92	5.44
2 min	1.79	2.03	2.77	3.28	3.79	4.45	4.97	5.63	6.53	7.26	8.03
3 min	2.38	2.7	3.71	4.42	5.14	6.09	6.84	7.76	9	10	11.1
4 min	2.87	3.25	4.51	5.41	6.32	7.58	8.58	9.74	11.3	12.6	13.9
5 min	3.27	3.72	5.19	6.26	7.36	8.89	10.1	11.5	13.4	14.8	16.4
10 min	4.73	5.39	7.61	9.27	11	13.6	15.7	17.8	20.7	23	25.4
15 min	5.74	6.53	9.22	11.2	13.4	16.5	19.1	21.7	25.2	28	31
20 min	6.54	7.44	10.5	12.8	15.2	18.6	21.5	24.5	28.4	31.6	34.9
25 min	7.23	8.21	11.5	14	16.6	20.3	23.4	26.6	30.9	34.4	38
30 min	7.85	8.91	12.5	15.1	17.9	21.8	25	28.5	33	36.7	40.5
45 min	9.43	10.7	14.9	17.9	21	25.4	28.9	32.8	38.1	42.3	46.8
1 hour	10.8	12.2	16.9	20.3	23.7	28.4	32.1	36.4	42.3	47	52
1.5 hour	13.1	14.9	20.5	24.4	28.3	33.6	37.7	42.8	49.7	55.2	61
2 hour	15.1	17.1	23.7	28.1	32.5	38.3	42.8	48.6	56.4	62.7	69.3
3 hour	18.5	21.1	29.2	34.7	40	47	52.2	59.4	69	76.6	84.7
4.5 hour	22.8	26.1	36.4	43.3	49.9	58.6	65.1	74.1	86.1	95.6	106
6 hour	26.3	30.3	42.6	50.8	58.6	69	76.8	87.5	102	113	125
9 hour	32.1	37.2	52.8	63.3	73.5	87.1	97.4	111	129	143	158
12 hour	36.7	42.6	61.1	73.5	85.7	102	115	131	152	169	186
18 hour	43.5	50.7	73.4	89	104	125	142	161	187	208	230
24 hour	48.4	56.4	82.1	100	118	142	161	184	213	237	262
30 hour	52.1	60.7	88.5	108	128	154	176	201	232	258	286
36 hour	55	64	93.3	114	135	163	186	212	246	273	302
48 hour	59.2	68.8	100	122	144	175	200	226	262	291	323
72 hour	64.4	74.5	107	130	154	186	211	238	276	307	340
96 hour	67.7	78	111	134	157	189	215	242	282	314	347
120 hour	70.3	80.7	114	137	160	191	216	245	285	317	351
144 hour	72.7	83.2	117	139	162	193	217	246	288	320	355
168 hour	74.9	85.7	119	142	164	195	219	248	291	323	358

Table B3: BoM 2016 IFD for Grid 3

Grid 3	Annual Exceedance Probability (AEP) Rainfall intensity in mm/h										
Duration	**63.20 %**	**50%#**	**20%***	**10%**	**5%**	**2%**	**1%**	**1 in 200**	**1 in 500**	**1 in 1000**	**1 in 2000**
1 min	1.04	1.19	1.67	2.03	2.4	2.93	3.37	3.83	4.45	4.94	5.46
2 min	1.8	2.03	2.78	3.3	3.81	4.49	5.01	5.69	6.59	7.32	8.1
3 min	2.39	2.7	3.73	4.44	5.17	6.13	6.89	7.83	9.07	10.1	11.1
4 min	2.87	3.25	4.52	5.43	6.35	7.62	8.63	9.8	11.4	12.6	14
5 min	3.27	3.72	5.2	6.28	7.38	8.93	10.2	11.6	13.4	14.9	16.5
10 min	4.73	5.39	7.62	9.29	11	13.6	15.7	17.9	20.7	23	25.5
15 min	5.73	6.53	9.23	11.3	13.4	16.5	19.1	21.8	25.3	28.1	31
20 min	6.54	7.44	10.5	12.8	15.2	18.7	21.6	24.5	28.5	31.7	35
25 min	7.23	8.22	11.6	14	16.7	20.4	23.5	26.7	31	34.5	38.1
30 min	7.84	8.91	12.5	15.2	17.9	21.9	25.1	28.6	33.1	36.8	40.7
45 min	9.43	10.7	14.9	18	21.1	25.5	29	33	38.3	42.5	47
1 hour	10.8	12.2	17	20.4	23.8	28.5	32.3	36.7	42.5	47.3	52.3
1.5 hour	13.1	14.9	20.6	24.5	28.5	33.8	37.9	43.1	50	55.6	61.4
2 hour	15.1	17.2	23.7	28.2	32.7	38.5	43.1	49	56.8	63.1	69.8
3 hour	18.5	21.2	29.3	34.8	40.2	47.2	52.5	59.8	69.4	77.1	85.2
4.5 hour	22.8	26.1	36.5	43.4	50.1	58.8	65.4	74.4	86.4	96	106
6 hour	26.3	30.3	42.6	50.9	58.8	69.2	77.1	87.7	102	113	125
9 hour	32.1	37.1	52.8	63.3	73.5	87.1	97.4	111	129	143	158
12 hour	36.6	42.5	60.9	73.4	85.5	102	115	130	152	168	186
18 hour	43.4	50.5	73	88.5	104	125	141	161	187	207	229
24 hour	48.2	56.2	81.6	99.3	117	141	160	182	212	235	260
30 hour	51.9	60.4	87.9	107	126	153	174	199	231	256	284
36 hour	54.8	63.7	92.6	113	134	162	185	210	244	271	300
48 hour	59	68.4	99.1	121	143	173	198	224	260	289	320
72 hour	64.2	74	106	129	152	184	209	236	274	304	337
96 hour	67.5	77.5	110	133	156	188	213	240	279	311	344
120 hour	70.1	80.3	113	136	159	190	214	242	283	314	348
144 hour	72.5	82.9	116	138	161	192	216	244	285	317	351
168 hour	74.8	85.5	119	142	164	194	218	245	288	320	354

Table B4: BoM 2016 IFD for Grid 4

Grid 4	**Annual Exceedance Probability (AEP) Rainfall intensity in mm/h**										
Duration	**63.20 %**	**50%#**	**20%***	**10%**	**5%**	**2%**	**1%**	**1 in 200**	**1 in 500**	**1 in 1000**	**1 in 2000**
1 min	1.04	1.19	1.67	2.02	2.39	2.92	3.36	3.82	4.43	4.93	5.45
2 min	1.79	2.03	2.77	3.28	3.79	4.46	4.98	5.66	6.55	7.28	8.06
3 min	2.38	2.7	3.71	4.42	5.14	6.1	6.85	7.79	9.03	10	11.1
4 min	2.86	3.25	4.5	5.4	6.32	7.58	8.59	9.76	11.3	12.6	13.9
5 min	3.27	3.71	5.18	6.25	7.35	8.89	10.1	11.5	13.4	14.9	16.4
10 min	4.72	5.37	7.59	9.26	11	13.5	15.7	17.8	20.7	23	25.4
15 min	5.72	6.51	9.2	11.2	13.4	16.5	19.1	21.7	25.2	28	31
20 min	6.53	7.42	10.5	12.7	15.1	18.6	21.5	24.4	28.4	31.6	34.9
25 min	7.22	8.2	11.5	14	16.6	20.3	23.4	26.6	30.9	34.4	38
30 min	7.83	8.89	12.5	15.1	17.8	21.8	25	28.4	33	36.7	40.6
45 min	9.41	10.7	14.9	17.9	21	25.4	28.9	32.8	38.1	42.4	46.9
1 hour	10.8	12.2	16.9	20.3	23.7	28.4	32.1	36.5	42.3	47.1	52.1
1.5 hour	13	14.8	20.5	24.4	28.3	33.6	37.7	42.9	49.8	55.3	61.2
2 hour	15	17.1	23.6	28.1	32.5	38.4	42.9	48.7	56.6	62.9	69.5
3 hour	18.4	21	29.2	34.7	40	47	52.3	59.5	69.1	76.8	84.9
4.5 hour	22.6	26	36.3	43.2	49.9	58.6	65.2	74.2	86.2	95.8	106
6 hour	26.2	30.1	42.5	50.7	58.6	69	76.9	87.5	102	113	125
9 hour	31.9	36.9	52.6	63.1	73.3	86.9	97.3	111	129	143	158
12 hour	36.4	42.2	60.7	73.2	85.4	102	114	130	151	168	186
18 hour	43.1	50.2	72.8	88.4	104	125	141	161	187	207	229
24 hour	47.9	55.9	81.4	99.1	117	141	160	182	212	235	260
30 hour	51.6	60.1	87.7	107	126	153	174	199	231	256	284
36 hour	54.4	63.4	92.4	113	133	162	185	210	243	271	300
48 hour	58.7	68.2	98.9	121	143	173	198	223	259	288	319
72 hour	63.9	73.8	106	129	151	183	208	235	273	303	336
96 hour	67.3	77.3	110	132	155	186	212	239	278	310	343
120 hour	69.9	80.1	113	135	157	188	213	241	281	313	347
144 hour	72.2	82.6	115	138	160	190	214	242	284	316	350
168 hour	74.5	85.2	118	141	162	193	217	243	287	319	353

Table B5: BoM 2016 IFD for Grid 5

Grid 5	Annual Exceedance Probability (AEP) Rainfall intensity in mm/h										
Duration	**63.20 %**	**50%#**	**20%***	**10%**	**5%**	**2%**	**1%**	**1 in 200**	**1 in 500**	**1 in 1000**	**1 in 2000**
1 min	1.06	1.21	1.71	2.08	2.46	3.01	3.46	3.93	4.57	5.08	5.61
2 min	1.83	2.08	2.86	3.41	3.95	4.65	5.2	5.89	6.86	7.62	8.43
3 min	2.44	2.77	3.84	4.59	5.35	6.35	7.14	8.1	9.42	10.5	11.6
4 min	2.93	3.33	4.65	5.6	6.56	7.87	8.91	10.1	11.8	13.1	14.5
5 min	3.34	3.81	5.35	6.46	7.61	9.2	10.5	11.9	13.8	15.4	17
10 min	4.81	5.49	7.79	9.51	11.3	13.9	16.1	18.3	21.2	23.6	26.1
15 min	5.83	6.65	9.43	11.5	13.7	16.9	19.6	22.3	25.8	28.7	31.8
20 min	6.64	7.57	10.7	13.1	15.5	19.1	22.1	25.1	29.1	32.4	35.8
25 min	7.35	8.37	11.8	14.4	17.1	20.9	24.1	27.4	31.8	35.3	39.1
30 min	7.98	9.08	12.8	15.5	18.4	22.4	25.8	29.3	34	37.8	41.8
45 min	9.62	10.9	15.3	18.5	21.7	26.3	29.9	34	39.5	43.9	48.5
1 hour	11	12.6	17.5	21	24.6	29.5	33.4	37.9	44.1	49	54.2
1.5 hour	13.5	15.4	21.4	25.5	29.7	35.2	39.5	44.9	52.2	58	64.1
2 hour	15.6	17.8	24.8	29.5	34.2	40.4	45.2	51.3	59.6	66.3	73.3
3 hour	19.4	22.2	30.9	36.8	42.5	49.9	55.6	63.2	73.3	81.6	90.2
4.5 hour	24.1	27.7	38.8	46.2	53.4	62.7	69.8	79.4	92.1	102	113
6 hour	28	32.4	45.7	54.5	63	74.3	82.8	94.2	109	122	134
9 hour	34.5	40	57	68.4	79.5	94.2	105	120	139	155	171
12 hour	39.7	46.1	66.1	79.7	92.9	111	125	142	164	183	202
18 hour	47.4	55.2	79.8	96.8	114	136	154	176	204	227	251
24 hour	52.9	61.6	89.4	109	128	155	176	200	232	258	286
30 hour	57.1	66.4	96.5	118	139	169	192	220	255	283	313
36 hour	60.4	70.1	102	124	147	179	204	233	270	299	332
48 hour	65.2	75.4	109	133	158	192	219	249	289	320	354
72 hour	71.1	81.8	117	143	169	204	232	261	304	338	374
96 hour	75	85.8	122	147	174	209	237	266	309	345	382
120 hour	78.1	89.2	125	151	177	212	239	268	312	349	386
144 hour	81	92.4	129	155	180	215	242	271	314	352	390
168 hour	83.9	95.7	133	159	184	218	246	274	315	356	394

Table B6: BoM 2016 IFD for Grid 6

Grid 6	Annual Exceedance Probability (AEP) Rainfall intensity in mm/h									
Duration	**63.20 %**	**50%#**	**20%***	**10%**	**5%**	**2%**	**1%**	**1 in 200**	**1 in 500**	**1 in 1000**	**1 in 2000**
1 min	1.07	1.22	1.72	2.09	2.48	3.02	3.48	3.96	4.59	5.11	5.65
2 min	1.84	2.09	2.87	3.42	3.96	4.67	5.21	5.92	6.88	7.64	8.46
3 min	2.45	2.78	3.85	4.61	5.36	6.37	7.16	8.14	9.46	10.5	11.6
4 min	2.94	3.34	4.67	5.62	6.58	7.9	8.95	10.2	11.8	13.1	14.5
5 min	3.36	3.82	5.37	6.49	7.64	9.24	10.5	12	13.9	15.5	17.1
10 min	4.83	5.51	7.82	9.55	11.4	14	16.2	18.4	21.4	23.8	26.3
15 min	5.85	6.67	9.47	11.6	13.8	17	19.7	22.4	26	28.9	32
20 min	6.67	7.6	10.8	13.1	15.6	19.2	22.2	25.2	29.3	32.6	36.1
25 min	7.38	8.4	11.9	14.4	17.1	21	24.2	27.5	32	35.5	39.3
30 min	8.01	9.12	12.8	15.6	18.4	22.5	25.9	29.4	34.2	38	42.1
45 min	9.66	11	15.4	18.5	21.8	26.4	30	34.2	39.7	44.1	48.8
1 hour	11.1	12.6	17.6	21.1	24.7	29.6	33.5	38.1	44.3	49.2	54.5
1.5 hour	13.6	15.4	21.5	25.6	29.8	35.4	39.7	45.2	52.5	58.4	64.6
2 hour	15.7	17.9	24.9	29.7	34.4	40.7	45.4	51.7	60	66.8	73.8
3 hour	19.5	22.3	31.2	37.1	42.8	50.3	56	63.7	74	82.4	91.1
4.5 hour	24.3	27.9	39.2	46.7	54	63.4	70.6	80.3	93.3	104	115
6 hour	28.3	32.7	46.2	55.2	63.9	75.2	83.9	95.5	111	123	136
9 hour	35	40.6	57.9	69.5	80.8	95.8	107	122	142	158	174
12 hour	40.3	46.8	67.3	81.1	94.7	113	127	145	168	187	206
18 hour	48.2	56.2	81.4	98.8	116	140	158	180	209	232	257
24 hour	53.9	62.8	91.4	111	131	159	180	205	238	265	293
30 hour	58.2	67.8	98.7	121	143	173	197	225	261	290	321
36 hour	61.6	71.6	104	127	151	183	209	239	277	307	340
48 hour	66.6	77.1	112	137	162	197	225	255	296	328	364
72 hour	72.7	83.7	120	146	173	209	238	268	312	347	384
96 hour	76.7	87.9	125	151	178	214	243	273	317	354	392
120 hour	79.9	91.3	128	155	181	217	245	276	320	358	397
144 hour	82.9	94.5	132	158	184	220	248	278	321	362	400
168 hour	85.9	97.9	136	162	188	223	251	281	323	365	404

APPENDIX C. Design Flood Mapping

Appendix C

FIGURE C1
PEAK FLOOD LEVELS
EXISTING (DEPTH ≥ 0.05M)
5% AEP EVENT

J:\Jobs\119088\ArcGIS\ArcMap\Appendix_C\FigureC01_PeakFloodLevel_5pctAEP_Event.mxd

J:\Jobs\119088\ArcGIS\ArcMap\Appendix_C\FigureC02_PeakFloodLevel_1pctAEP_Event.mxd

FIGURE C3
PEAK FLOOD LEVELS
EXISTING (DEPTH ≥ 0.05M)
0.5% AEP EVENT
Model Extent
Major Contours (5.0m Intervals)
Minor Contours (1.0m Intervals)
Flood Extent
N
0
100
200
400
m
J:\Jobs\119088\ArcGIS\ArcMap\Appendix_C\FigureC03_PeakFloodLevel_0.5pctAEP_Event.mxd

J:\Jobs\119088\ArcGIS\ArcMap\Appendix_C\FigureC04_PeakFloodVelocity_5pctAEP_Event.mxd

J:\Jobs\119088\ArcGIS\ArcMap\Appendix_C\FigureC05_PeakFloodVelocity_1pctAEP_Event.mxd


FIGURE C6
PEAK FLOOD VELOCITY
EXISTING (DEPTH ≥ 0.05M)
0.5% AEP EVENT
N
Model Extent
Velocity (m/s)
< 0.1
0.1 to 0.2
0.2 to 0.5
0.5 to 1
1 to 2
2 to 3
3 to 5
> 5
0
100
200
400
m
J:\Jobs\119088\ArcGIS\ArcMap\Appendix_C\FigureC06_PeakFloodVelocity_0.5pctAEP_Event.mxd

J:\Jobs\119088\ArcGIS\ArcMap\Appendix_C\FigureC07_PeakFloodDepth_5pctAEP_Event.mxd


FIGURE C8
PEAK FLOOD DEPTHS
EXISTING (DEPTH ≥ 0.05M)
1% AEP EVENT
N
Model Extent
Peak Flood Depth (m)
0.05 - 0.10
0.10 - 0.30
0.30 - 0.50
0.50 - 1.00
> 1.00
0
100
200
400
m
J:\Jobs\119088\ArcGIS\ArcMap\Appendix_C\FigureC08_PeakFloodDepth_1pctAEP_Event.mxd

J:\Jobs\119088\ArcGIS\ArcMap\Appendix_C\FigureC09_PeakFloodDepth_0.5pctAEP_Event.mxd


FIGURE C10
HYDRAULIC HAZARD
EXISTING (DEPTH ≥ 0.05M)
5% AEP EVENT
N
Model Extent
Hydraulic Hazard
H1 - No constraints
H2 - Unsafe for small vehicles
H3 - Unsafe for all vehicles, children and the elderly
H4 - Unsafe for all people and all vehicles
H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction
H6 - Unconditionally dangerous
0
100
200
400
m
J:\Jobs\119088\ArcGIS\ArcMap\Appendix_C\FigureC10_Hydraulic_Hazard_5pctAEP_Event.mxd

FIGURE C11
HYDRAULIC HAZARD
EXISTING (DEPTH ≥ 0.05M)
1% AEP EVENT

J:\Jobs\119088\ArcGIS\ArcMap\Appendix_C\FigureC11_Hydraulic_Hazard_1pctAEP_Event.mxd


FIGURE C12
HYDRAULIC HAZARD
EXISTING (DEPTH ≥ 0.05M)
0.5% AEP EVENT
N
Model Extent
Hydraulic Hazard
H1 - No constraints
H2 - Unsafe for small vehicles
H3 - Unsafe for all vehicles, children and the elderly
H4 - Unsafe for all people and all vehicles
H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction
H6 - Unconditionally dangerous
0
100
200
400
m
J:\Jobs\119088\ArcGIS\ArcMap\Appendix_C\FigureC12_Hydraulic_Hazard_0.5pctAEP_Event.mxd

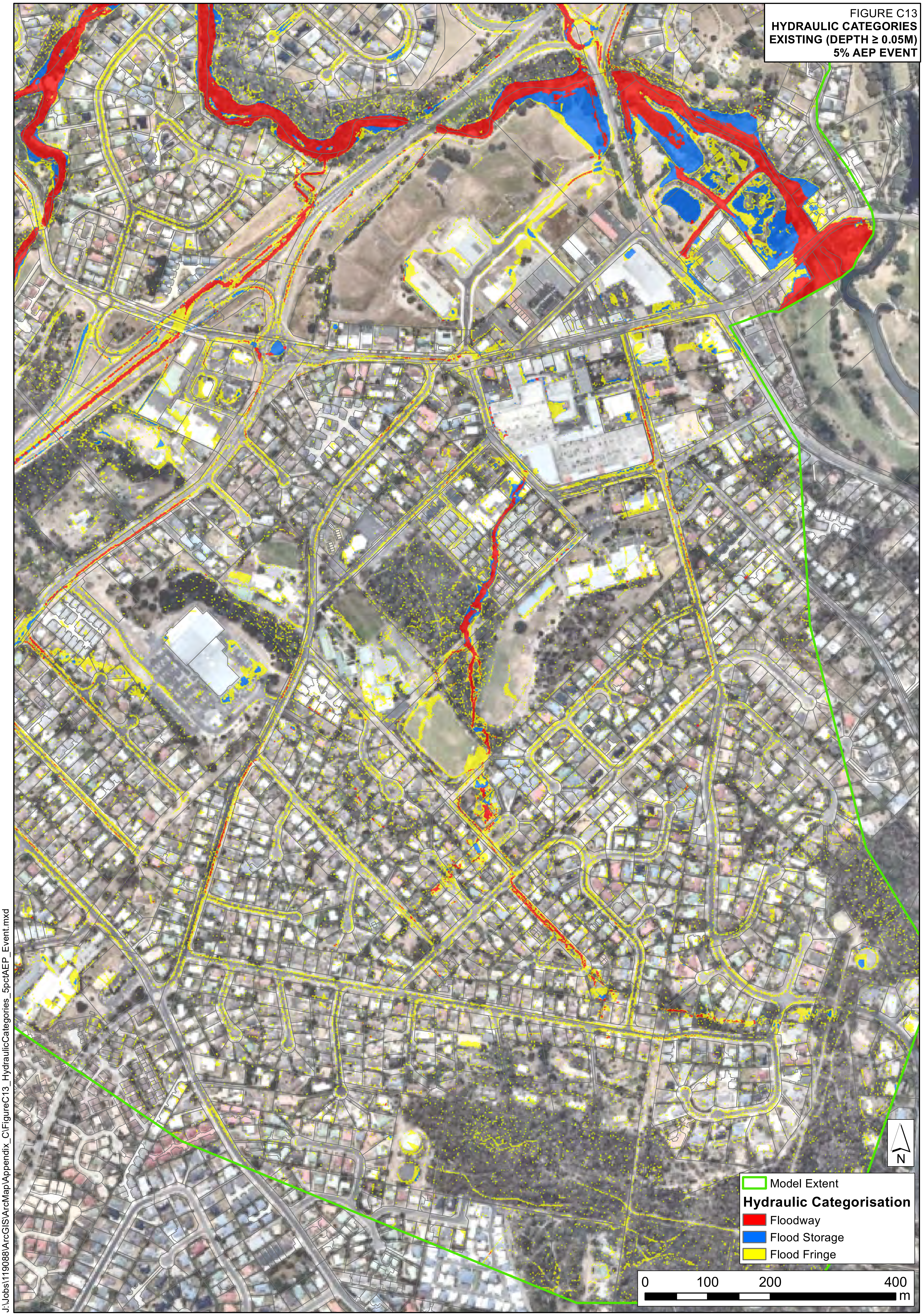


FIGURE C13
HYDRAULIC CATEGORIES
EXISTING (DEPTH ≥ 0.05M)
5% AEP EVENT
N
Model Extent
Hydraulic Categorisation
Floodway
Flood Storage
Flood Fringe
0
100
200
400
m
J:\Jobs\119088\ArcGIS\ArcMap\Appendix_C\FigureC13_HydraulicCategories_5pctAEP_Event.mxd

J:\Jobs\119088\ArcGIS\ArcMap\Appendix_C\FigureC14_HydraulicCategories_1pctAEP_Event.mxd

J:\Jobs\119088\ArcGIS\ArcMap\Appendix_C\FigureC15_HydraulicCategories_0.5pctAEP_Event.mxd

APPENDIX D. Sensitivity Flood Mapping

Appendix D

FIGURE D1
PEAK FLOOD DEPTH
Y2050 (DEPTH ≥ 0.05M)
1% AEP EVENT

J:\Jobs\119088\ArcGIS\ArcMap\Appendix_D\FigureD01_PeakFloodDepths_Existing_climate_2050_1pctAEP_Event.mxd


FIGURE D2
PEAK FLOOD DEPTH
Y2100 (DEPTH ≥ 0.05M)
1% AEP EVENT
N
Model Extent
Peak Flood Depth (m)
0.05 - 0.10
0.10 - 0.30
0.30 - 0.50
0.50 - 1.00
> 1.00
0
100
200
400
m
J:\Jobs\119088\ArcGIS\ArcMap\Appendix_D\FigureD02_PeakFloodDepths_Existing_climate_2100_1pctAEP_Event.mxd


FIGURE D3
PEAK FLOOD DEPTH
20% ROUGHNESS DECREASE (DEPTH ≥ 0.05M)
1% AEP EVENT
N
Model Extent
Peak Flood Depth (m)
0.05 - 0.10
0.10 - 0.30
0.30 - 0.50
0.50 - 1.00
> 1.00
0
100
200
400
m
J:\Jobs\119088\ArcGIS\ArcMap\Appendix_D\FigureD03_PeakFloodLeveldepth_1pctAEP_Event.mxd


FIGURE D4
PEAK FLOOD DEPTH
20% ROUGHNESS INCREASE (DEPTH ≥ 0.05M)
1% AEP EVENT
N
Model Extent
Peak Flood Depth (m)
0.05 - 0.10
0.10 - 0.30
0.30 - 0.50
0.50 - 1.00
> 1.00
0
100
200
400
m
J:\Jobs\119088\ArcGIS\ArcMap\Appendix_D\FigureD4_PeakFloodLeveldepth_1pctAEP_Event.mxd


FIGURE D5
PEAK FLOOD DEPTH
50% BRIDGE AND CULVERTS BLOCKAGE (DEPTH ≥ 0.05M)
1% AEP EVENT
N
Model Extent
Peak Flood Depth (m)
0.05 - 0.10
0.10 - 0.30
0.30 - 0.50
0.50 - 1.00
> 1.00
0
100
200
400
m
J:\Jobs\119088\ArcGIS\ArcMap\Appendix_D\FigureD05_PeakFloodLeveldepth_1pctAEP_Event.mxd

J:\Jobs\119088\ArcGIS\ArcMap\Appendix_D\FigureD06_PeakFloodLeveldepth_1pctAEP_Event.mxd

FIGURE D7
PEAK FLOOD DEPTH
50% BRIDGE, CULVERTS AND INLET PITS BLOCKAGE (DEPTH ≥ 0.05M)
1% AEP EVENT

J:\Jobs\119088\ArcGIS\ArcMap\Appendix_D\FigureD07_PeakFloodLeveldepth_1pctAEP_Event.mxd

APPENDIX E. Hot Spot Mapping

Appendix E

J:\Jobs\119088\ArcGIS\ArcMap\Appendix_E\FigureE01_Hotspot_Locations.mxd

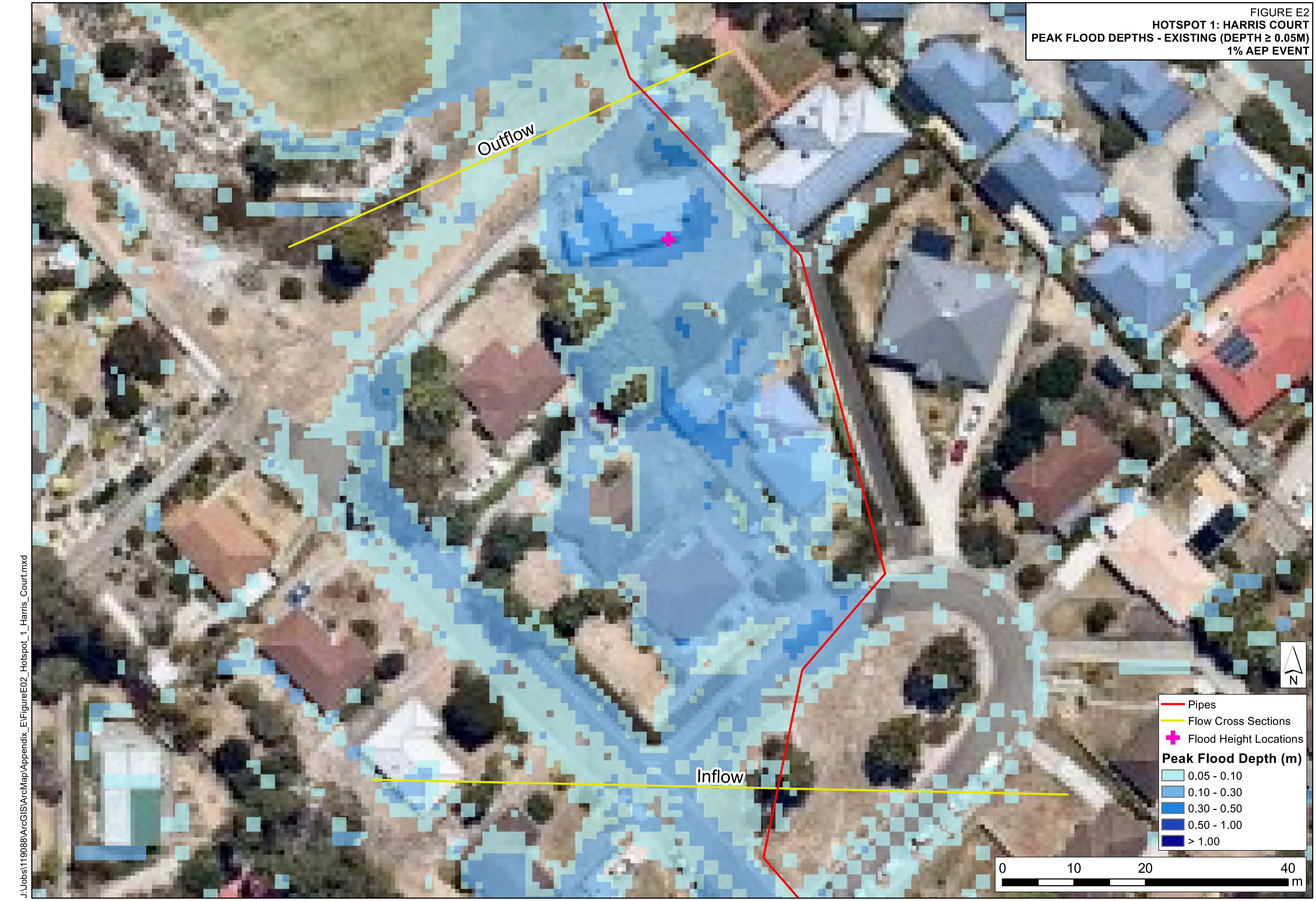
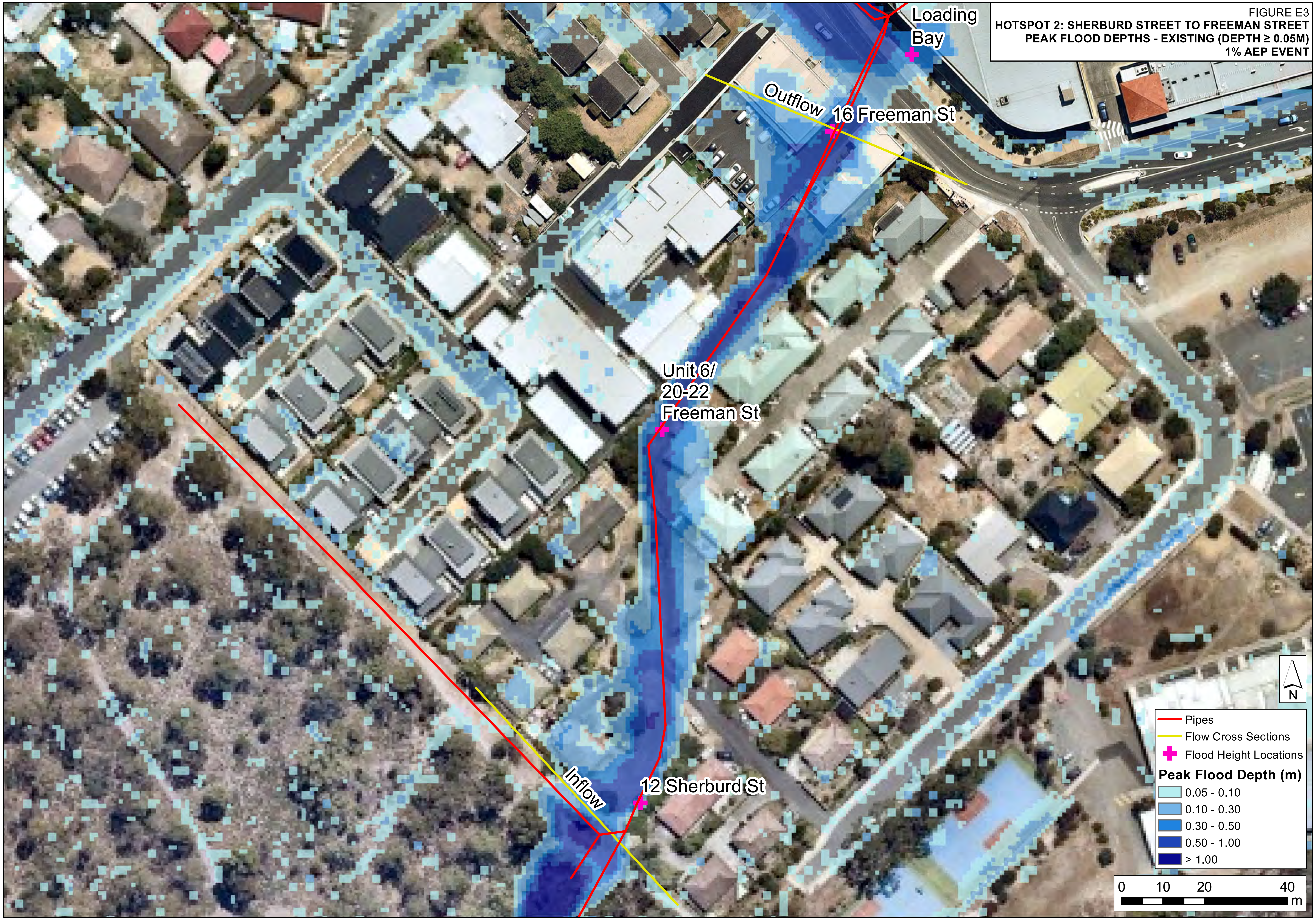


FIGURE E2
HOTSPOT 1: HARRIS COURT
PEAK FLOOD DEPTHS - EXISTING (DEPTH ≥ 0.05M)
1% AEP EVENT
Outflow
Inflow
N
Pipes
Flow Cross Sections
Flood Height Locations
Peak Flood Depth (m)
0.05 - 0.10
0.10 - 0.30
0.30 - 0.50
0.50 - 1.00
> 1.00
0
10
20
40
m
J:\Jobs\119088\ArcGIS\ArcMap\Appendix_E\FigureE02_Hotspot_1_Harris_Court.mxd

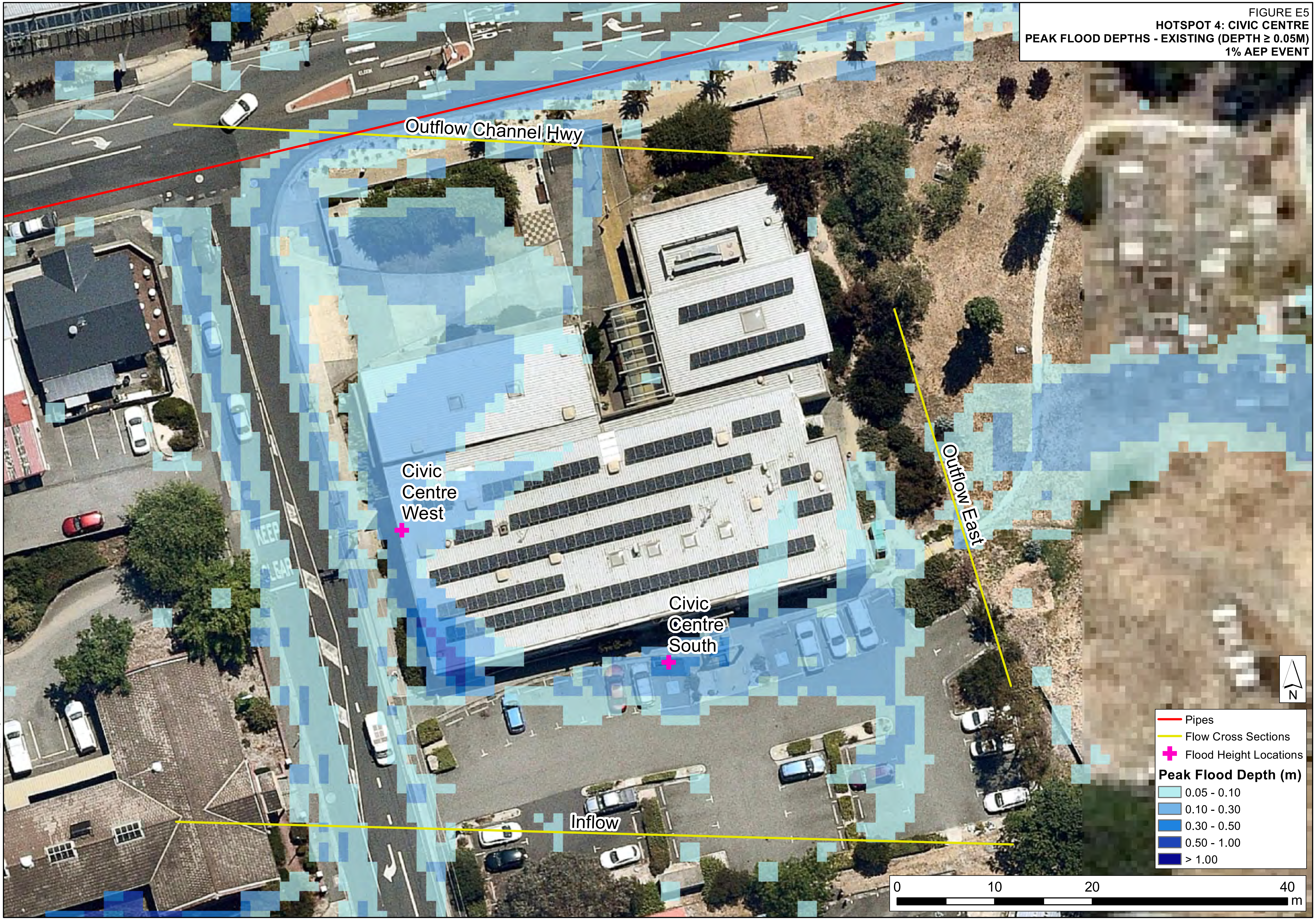
FIGURE E3
HOTSPOT 2: SHERBURD STREET TO FREEMAN STREET
PEAK FLOOD DEPTHS - EXISTING (DEPTH ≥ 0.05M)
1% AEP EVENT



J:\Jobs\119088\ArcGIS\ArcMap\Appendix_E\FigureE03_Hotspot_2_Sherburd_St_Freeman_St.mxd

FIGURE E4
HOTSPOT 3: CHANNEL COURT
PEAK FLOOD DEPTHS - EXISTING (DEPTH ≥ 0.05M)
1% AEP EVENT

J:\Jobs\119088\ArcGIS\ArcMap\Appendix_E\FigureE04_Hotspot_3_Channel_Court.mxd



J:\Jobs\119088\ArcGIS\ArcMap\Appendix_E\FigureE05_Hotspot_4_Civic_Centre.mxd

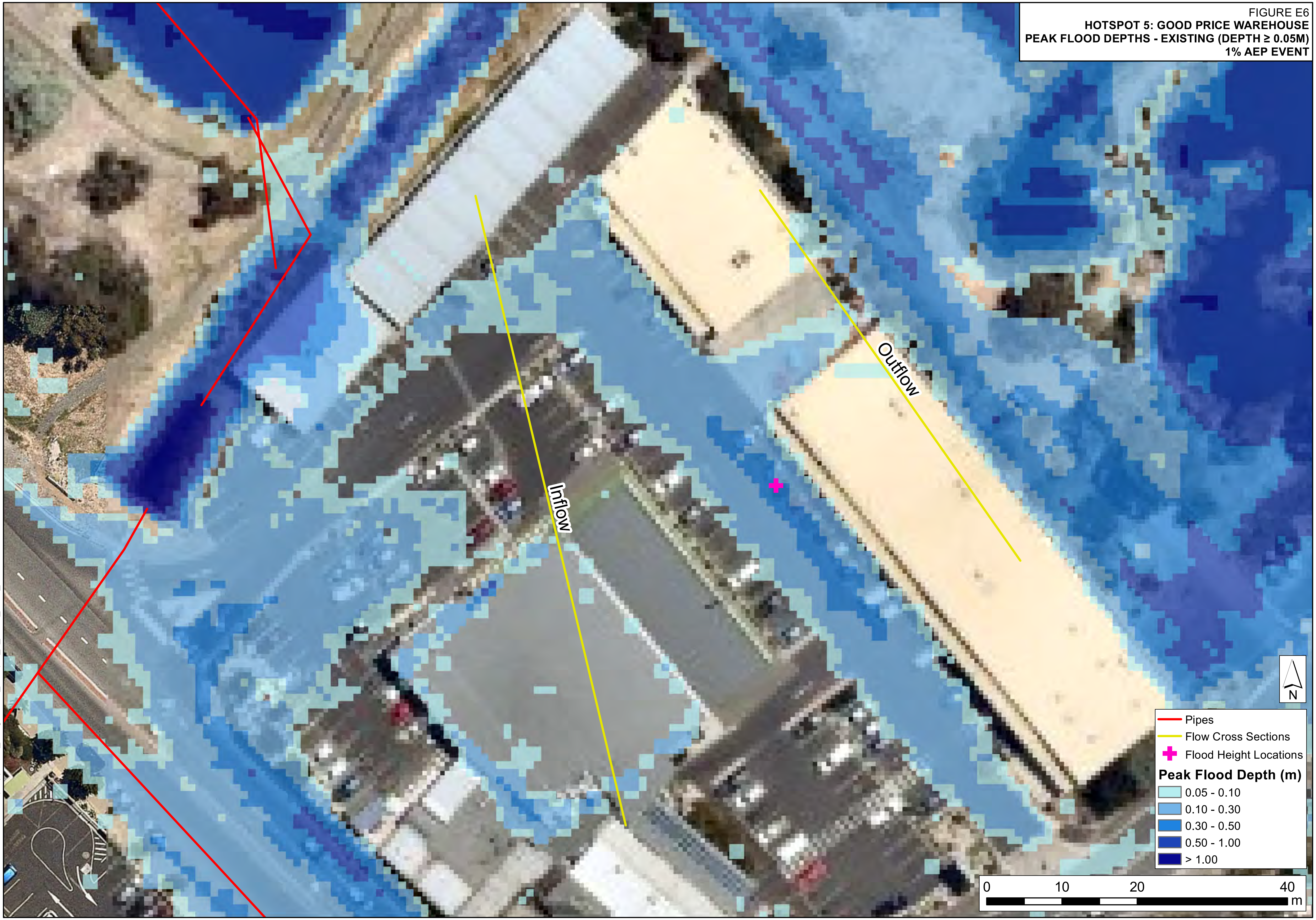


FIGURE E6
HOTSPOT 5: GOOD PRICE WAREHOUSE
PEAK FLOOD DEPTHS - EXISTING (DEPTH ≥ 0.05M)
1% AEP EVENT
Inflow
Outflow
N
Pipes
Flow Cross Sections
Flood Height Locations
Peak Flood Depth (m)
0.05 - 0.10
0.10 - 0.30
0.30 - 0.50
0.50 - 1.00
> 1.00
0
10
20
40
m
J:\Jobs\119088\ArcGIS\ArcMap\Appendix_E\FigureE06_Hotspot_5_Good_Price_Warehouse.mxd

APPENDIX F. Flood Resilience Measures

Appendix F

Table F1: Flood Resilience Measures

FReM	Type of measure
Capacity building of stakeholders	Information
	Flood maps (Inundation and Risk)
	Info material (brochures, public presentations, internet portals etc
A1: Awareness of flood risk	Education - Communication
	Face-to-face learning
	Web-based learning
	Training
	Collaborative platforms
Land use control	Spatial Planning
	Flood risk adapted land use
A2: Avoidance of the risk where possible	Building regulations
	Building codes
	Zoning ordinances
Flood preparedness	Flood Resistant buildings
	Wet proofing
A3: Alleviation of the effects of the flood	Dry proofing
	Flood action plan (local scale)
	Infrastructure maintenance
Contingency measures	Financial Preparedness
	Insurance of residual risk
A4: Assistance in the event of difficulties	Reserve funds
	Emergency Response:
	Evacuation and rescue plans
	Forecasting and warning services
	Control Emergency Operations

	Providence of emergency response staff
	Emergency infrastructure
	Allocation of temporary containment structures
	Telecommunications network
	Transportation and evacuation facilities
	Recovery: Disaster recovery plans, pecuniary provisions of government

Table F2: Flood Awareness Methods

Method	Comment
Letter/pamphlet from Council	These may be sent (annually or biannually) with the rate notice or separately. A Council database of flood liable properties/addresses makes this a relatively inexpensive measure which can be effective if residents take the time to absorb and apply the suggestions. The pamphlet can inform residents of ongoing implementation of the Risk Management Plan, changes to flood levels, climate change or any other relevant information.
Council website	Council should continue to update and expand their website to provide both technical information on flood levels as well as qualitative information on how residents can make themselves flood aware. This would provide an excellent source of knowledge on flooding within the study area (and elsewhere in the LGA) as well as on issues such as climate change. It is recommended that Council's website continue to be updated as and when required.
Community Working Group	Council could initiate a Community Working Group framework (undertaken in other catchments elsewhere) and this would provide a valuable two-way conduit between the residents and Council.
School project or local historical society	This provides an excellent means of informing the younger generation about flooding and climate change. It may involve talks from various authorities and can be combined with topics relating to water quality, floodplain management, etc.
Displays at key locations or similar	This is an inexpensive way of informing the community and may be combined with related displays.
Historical flood markers and flood depth markers	Signs or marks can be prominently displayed on telegraph poles or such like to indicate the level reached in previous floods. Depth indicators advise of potential hazards. These are inexpensive and effective but in some flood communities not well accepted as it is considered that they affect property values.
Articles in local newspapers	Ongoing articles in the newspapers will ensure that the flood and climate change issues are not forgotten. Historical features and remembrance of the anniversary of past events are interesting for local residents.
Collection of peak water level data from future floods	Collection of data (photographs) assists in reinforcing to the residents that Council is aware of the problem and ensures that the design flood levels are as accurate as possible. This might also include establishment of peak water level marker poles and which house floors are inundated.
Types of information available	A recurring problem is that new owners consider they were not adequately advised that their property was flood affected on the 10.7 Certificate during the purchase process. Council may wish to advise interested parties, when they inquire during the property purchase process, regarding flood information currently available, how it can be obtained and the cost. This information also needs to be provided to all tenants and visitors who may rent for a period. Some Councils have conducted "briefing" sessions with real estate agents and conveyancers.
Establishment of a flood affectation effects database	A database would provide information on (say) which houses require evacuation, which public structures will be affected (e.g. telephone or power cuts). This database should be reviewed after each flood event. It is already being part developed as part of this present study. This database should be updated following each flood with input from the community.
Flood preparedness program	Providing information to the community regarding flooding helps to inform it of the problem and associated implications. However, it does not necessarily adequately prepare people to react effectively to the problem. A Flood Preparedness Program would ensure that the community is adequately prepared. The SES would take a lead role in this.

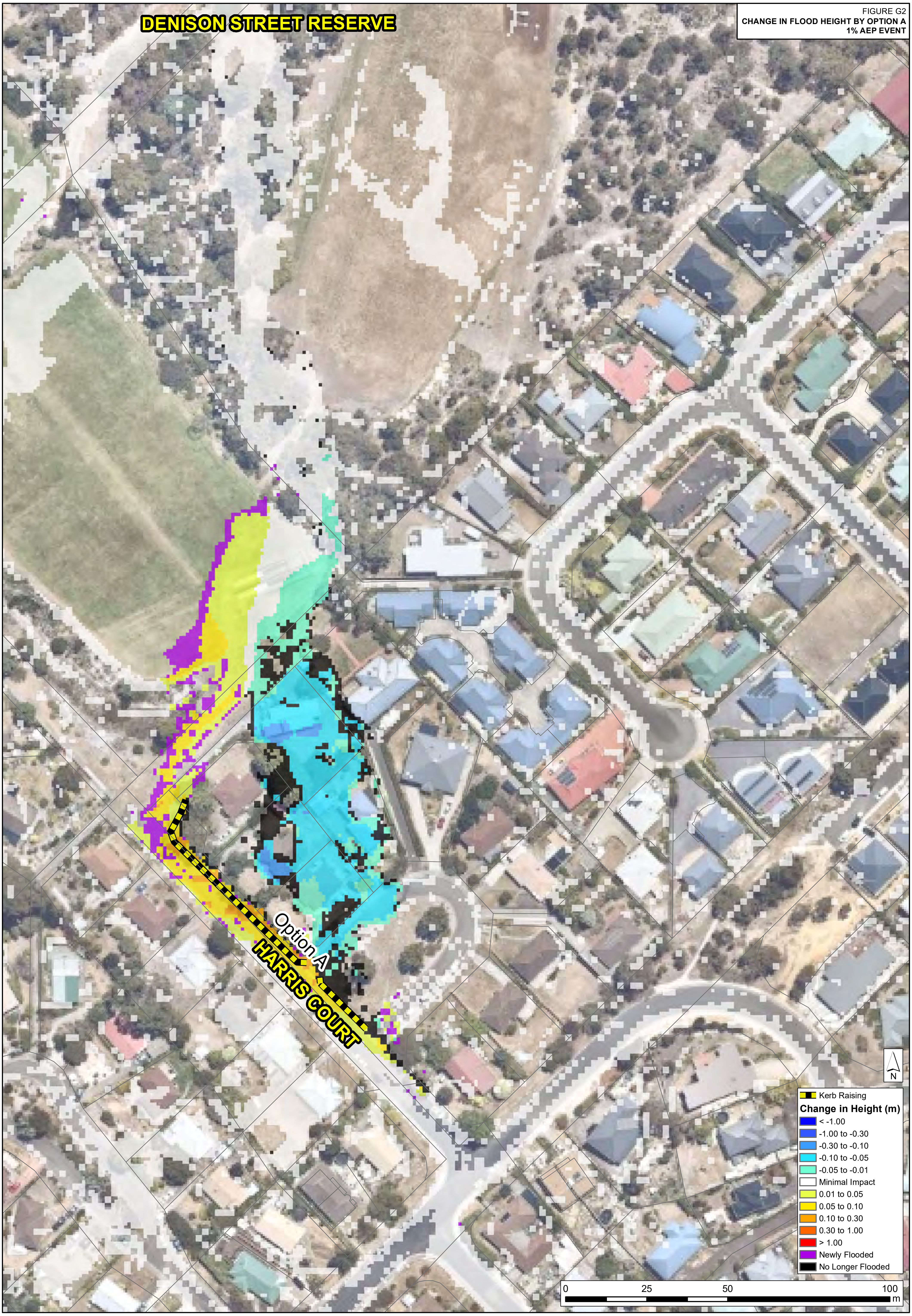
Develop approaches to foster community ownership of the problem	Flood damages in future events can be minimised if the community is aware of the problem and takes steps to find solutions. The development of approaches that promote community ownership should therefore be encouraged. For example, residents should be advised that they have a responsibility to advise Council if they see a problem such as debris blockage or such like. This process can be linked to water quality or other water related issues including estuary management. The specific approach can only be developed in consultation with the community. Consideration and reference should be made to engaging the community as per the community engagement International Association for Public Participation spectrum framework and associated methods and activities, which seeks to promote and improve the practice of public participation or community and stakeholder engagement, incorporating individuals, governments, institutions and other entities that affect the public interest (https://www.iap2.org.au/Home).

APPENDIX G. Flood Impact Mapping

Appendix G

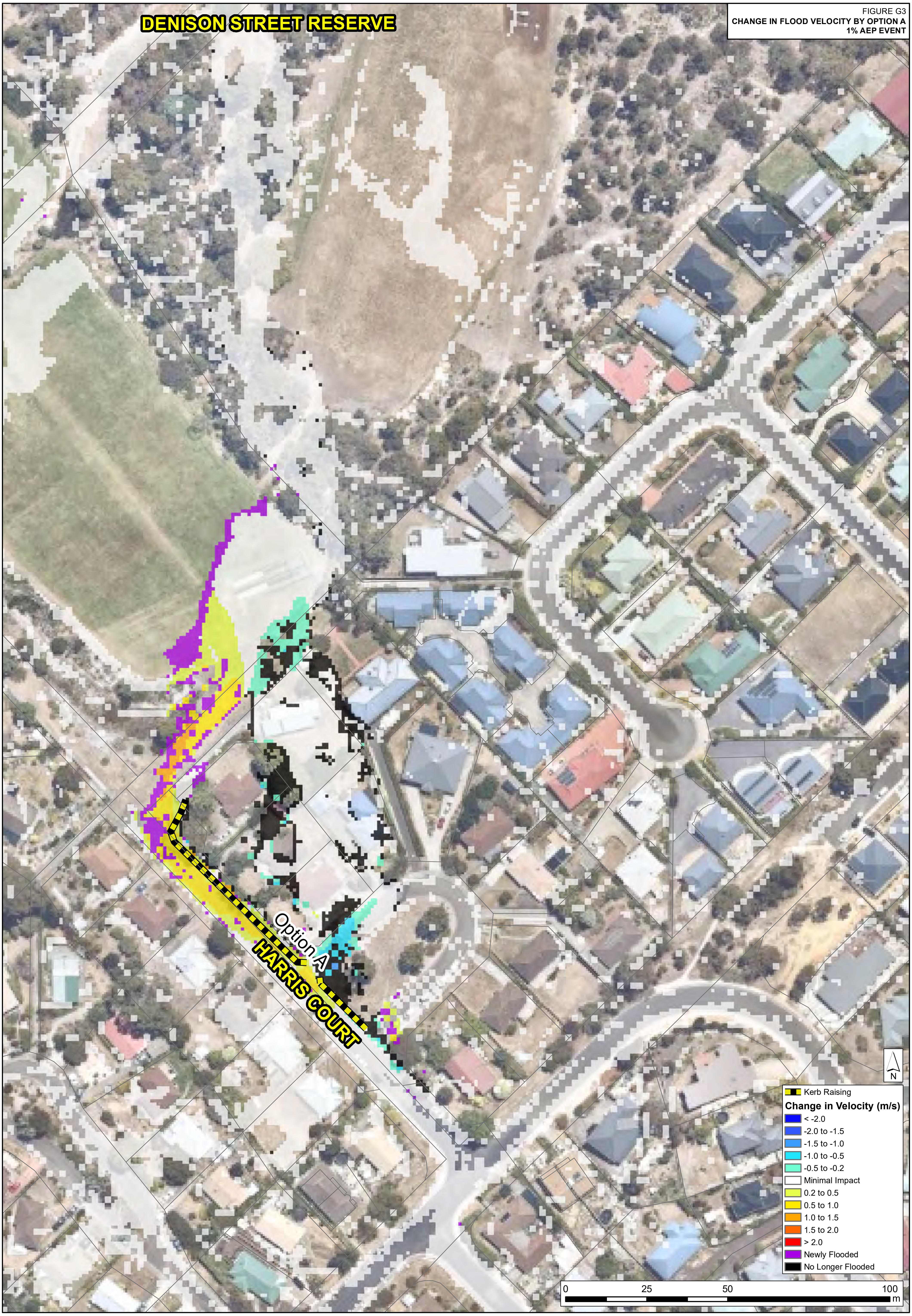
FIGURE G1
STRUCTURAL FLOOD MANAGEMENT

J:\Jobs\119088\ArcGIS\ArcMap\Appendix_G\FigureG01_Structural_Flood_Management.mxd



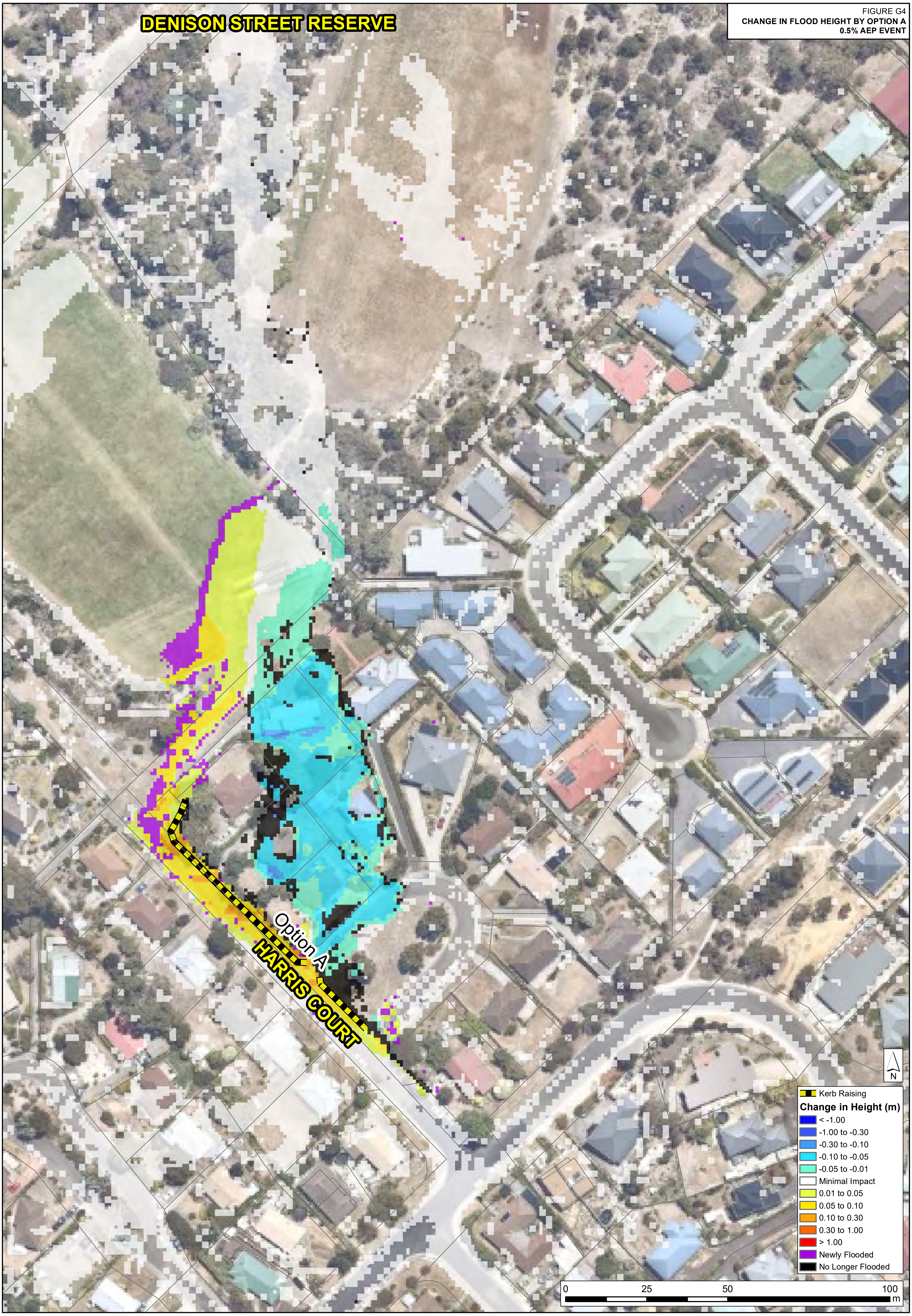
DENISON STREET RESERVE
FIGURE G2
CHANGE IN FLOOD HEIGHT BY OPTION A
1% AEP EVENT
Option A
HARRIS COURT
N
Kerb Raising
Change in Height (m)
< -1.00
-1.00 to -0.30
-0.30 to -0.10
-0.10 to -0.05
-0.05 to -0.01
Minimal Impact
0.01 to 0.05
0.05 to 0.10
0.10 to 0.30
0.30 to 1.00
> 1.00
Newly Flooded
No Longer Flooded
0
25
50
100
m
J:\Jobs\119088\ArcGIS\ArcMap\Appendix_G\FigureG02_Impact_Option_A_1pct_AEP_Event.mxd

FIGURE G3
CHANGE IN FLOOD VELOCITY BY OPTION A
1% AEP EVENT



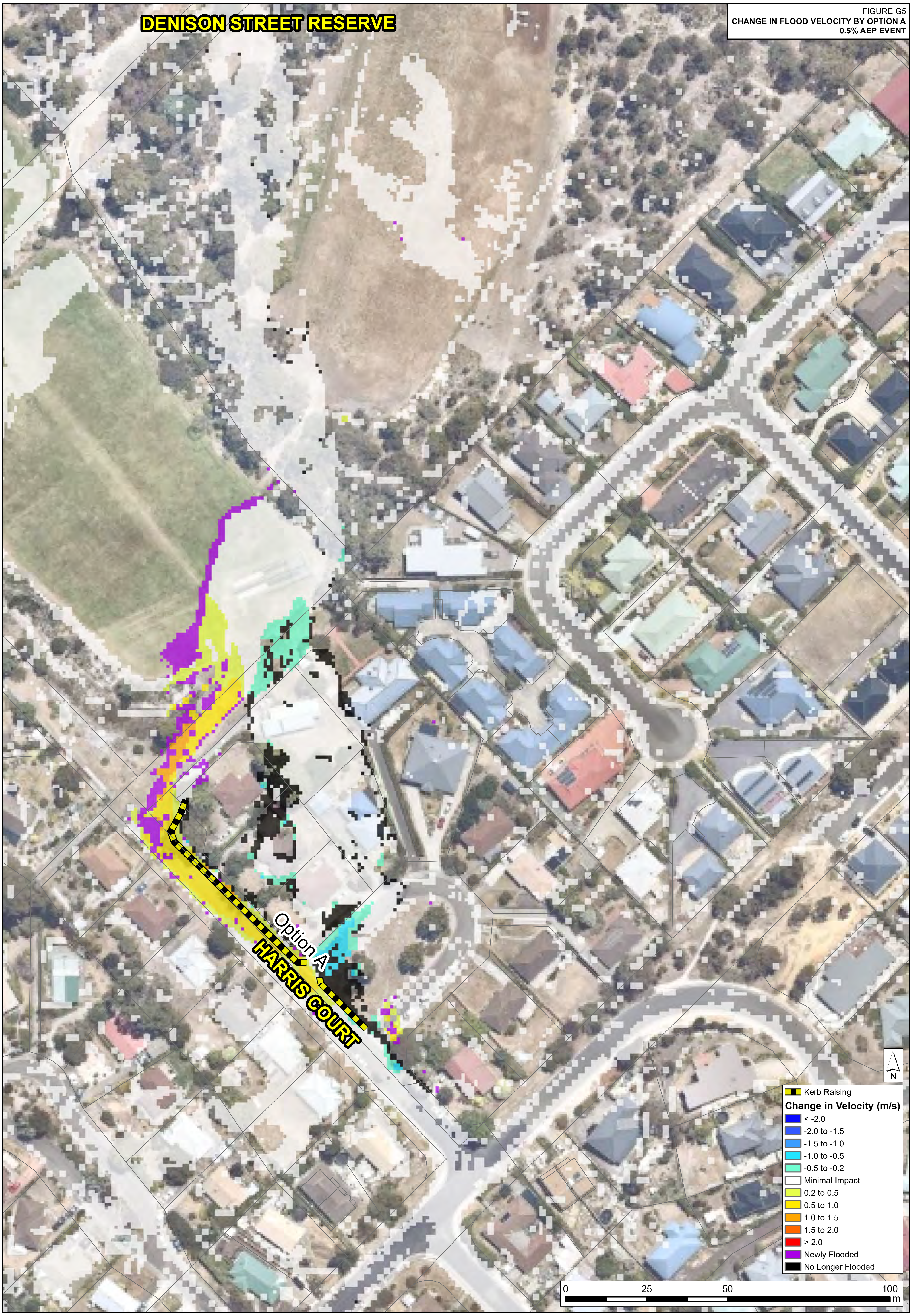
J:\Jobs\119088\ArcGIS\ArcMap\Appendix_G\FigureG03_Impact_Velocity_Option_A_1pct_AEP_Event.mxd

FIGURE G4
CHANGE IN FLOOD HEIGHT BY OPTION A
0.5% AEP EVENT



J:\Jobs\119088\ArcGIS\ArcMap\Appendix_G\FigureG04_Impact_Option_A_0.5pct_AEP_Event.mxd

FIGURE G5
CHANGE IN FLOOD VELOCITY BY OPTION A
0.5% AEP EVENT



J:\Jobs\119088\ArcGIS\ArcMap\Appendix_G\FigureG05_Impact_Velocity_Option_A_0.5pct_AEP_Event.mxd

J:\Jobs\119088\ArcGIS\ArcMap\Appendix_G\Figure G06_Impact_Option_B_1pct_AEP_Event.mxd

J:\Jobs\119088\ArcGIS\ArcMap\Appendix_G\FigureG07_Impact_Velocity_Option_B_1pct_AEP_Event.mxd

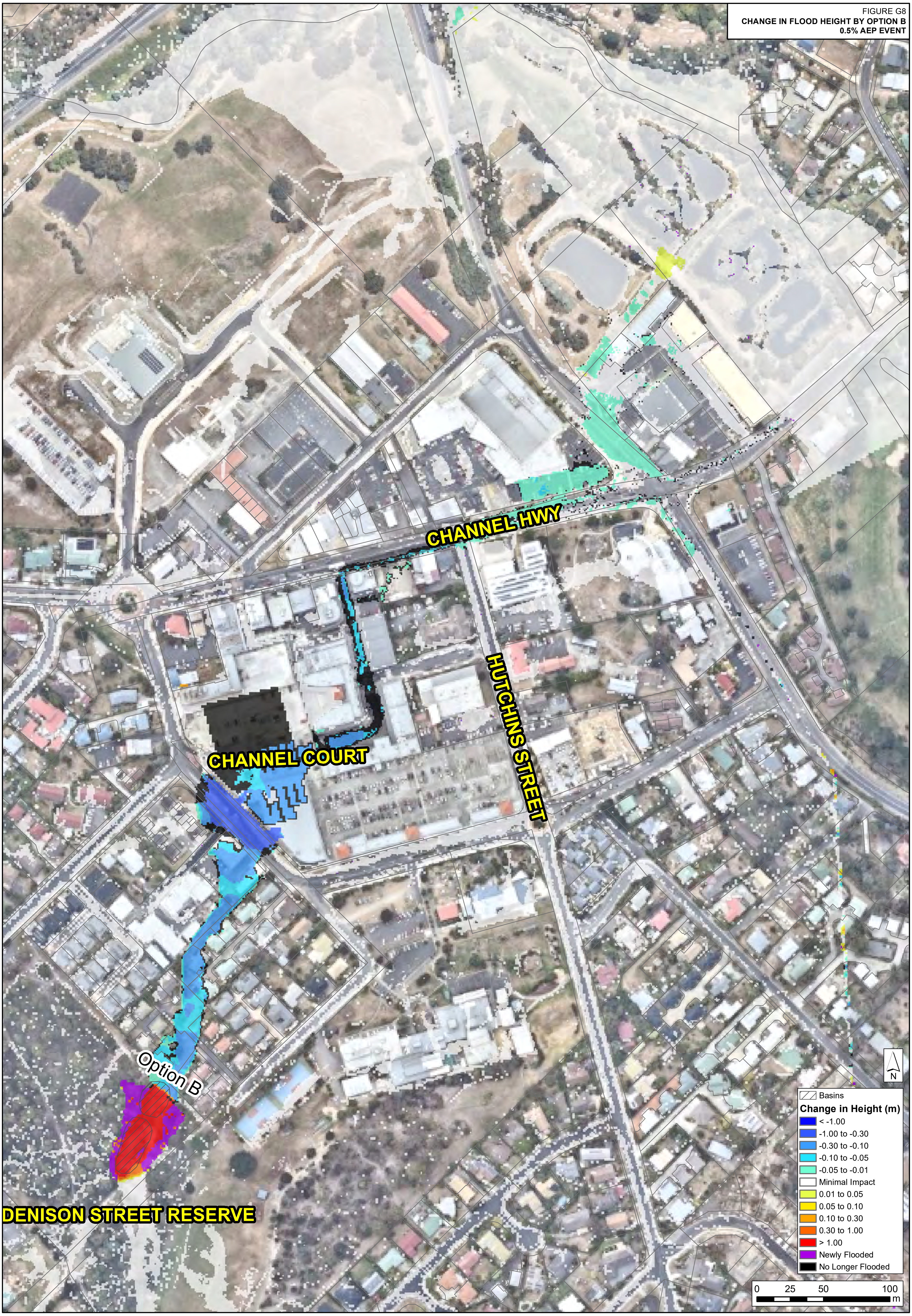


FIGURE G8
CHANGE IN FLOOD HEIGHT BY OPTION B
0.5% AEP EVENT
CHANNEL HWY
HUTCHINS STREET
CHANNEL COURT
Option B
DENISON STREET RESERVE
Basins
Change in Height (m)
< -1.00
-1.00 to -0.30
-0.30 to -0.10
-0.10 to -0.05
-0.05 to -0.01
Minimal Impact
0.01 to 0.05
0.05 to 0.10
0.10 to 0.30
0.30 to 1.00
> 1.00
Newly Flooded
No Longer Flooded
0 25 50 100
m
N
J:\Jobs\119088\ArcGIS\ArcMap\Appendix_G\FigureG08_Impact_Option_B_1pct_AEP_Event.mxd

FIGURE G9
CHANGE IN FLOOD VELOCITY BY OPTION B
0.5% AEP EVENT

J:\Jobs\119088\ArcGIS\ArcMap\Appendix_G\FigureG09_Impact_Velocity_Option_B_05pct_AEP_Event.mxd

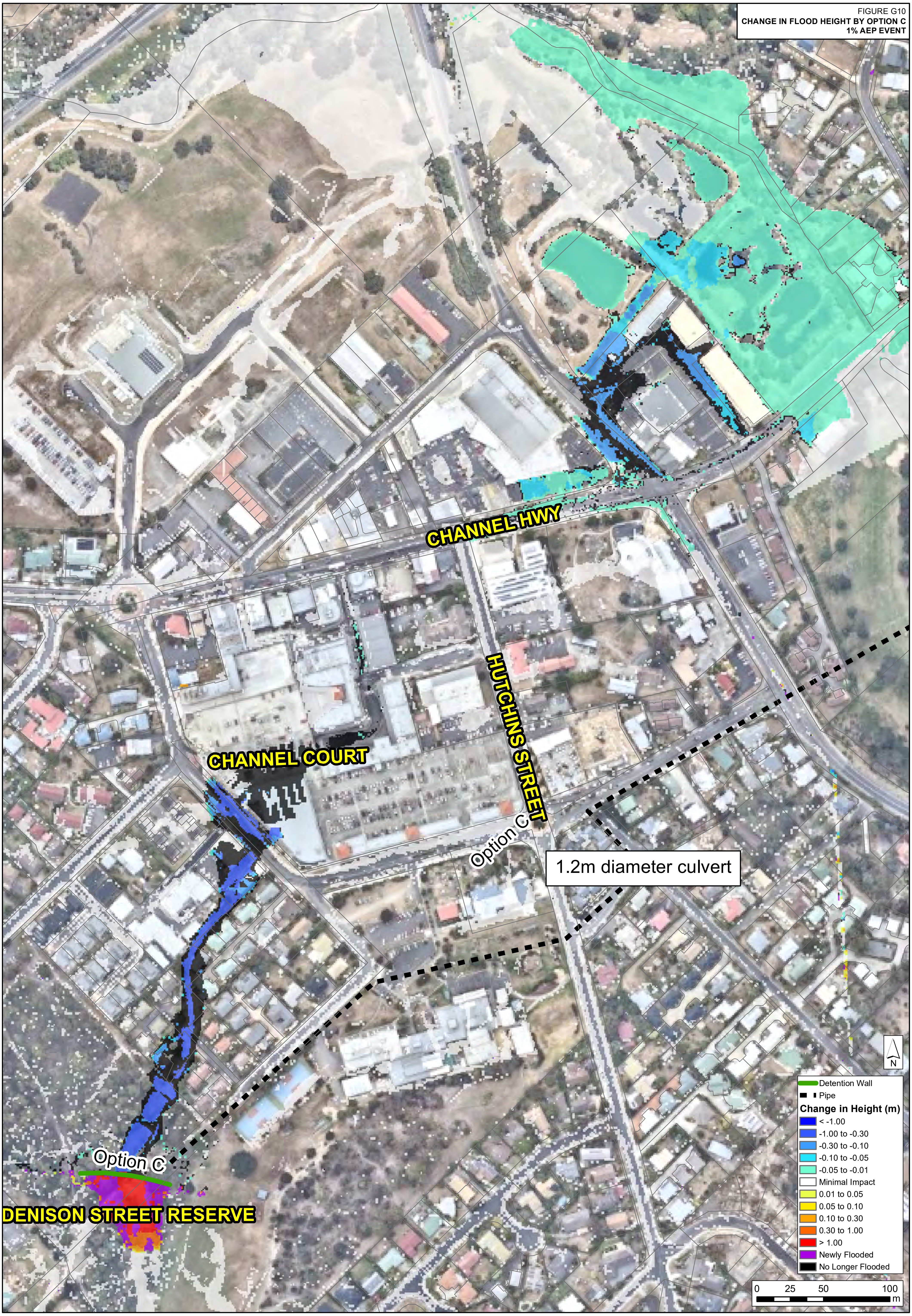


FIGURE G10
CHANGE IN FLOOD HEIGHT BY OPTION C
1% AEP EVENT
CHANNEL HWY
HUTCHINS STREET
CHANNEL COURT
Option C
1.2m diameter culvert
Option C
DENISON STREET RESERVE
N
Detention Wall
Pipe
Change in Height (m)
< -1.00
-1.00 to -0.30
-0.30 to -0.10
-0.10 to -0.05
-0.05 to -0.01
Minimal Impact
0.01 to 0.05
0.05 to 0.10
0.10 to 0.30
0.30 to 1.00
> 1.00
Newly Flooded
No Longer Flooded
0 25 50 100
m
J:\Jobs\119088\ArcGIS\ArcMap\Appendix_G\FigureG10_Impact_Option_C_1pct_AEP_Event.mxd

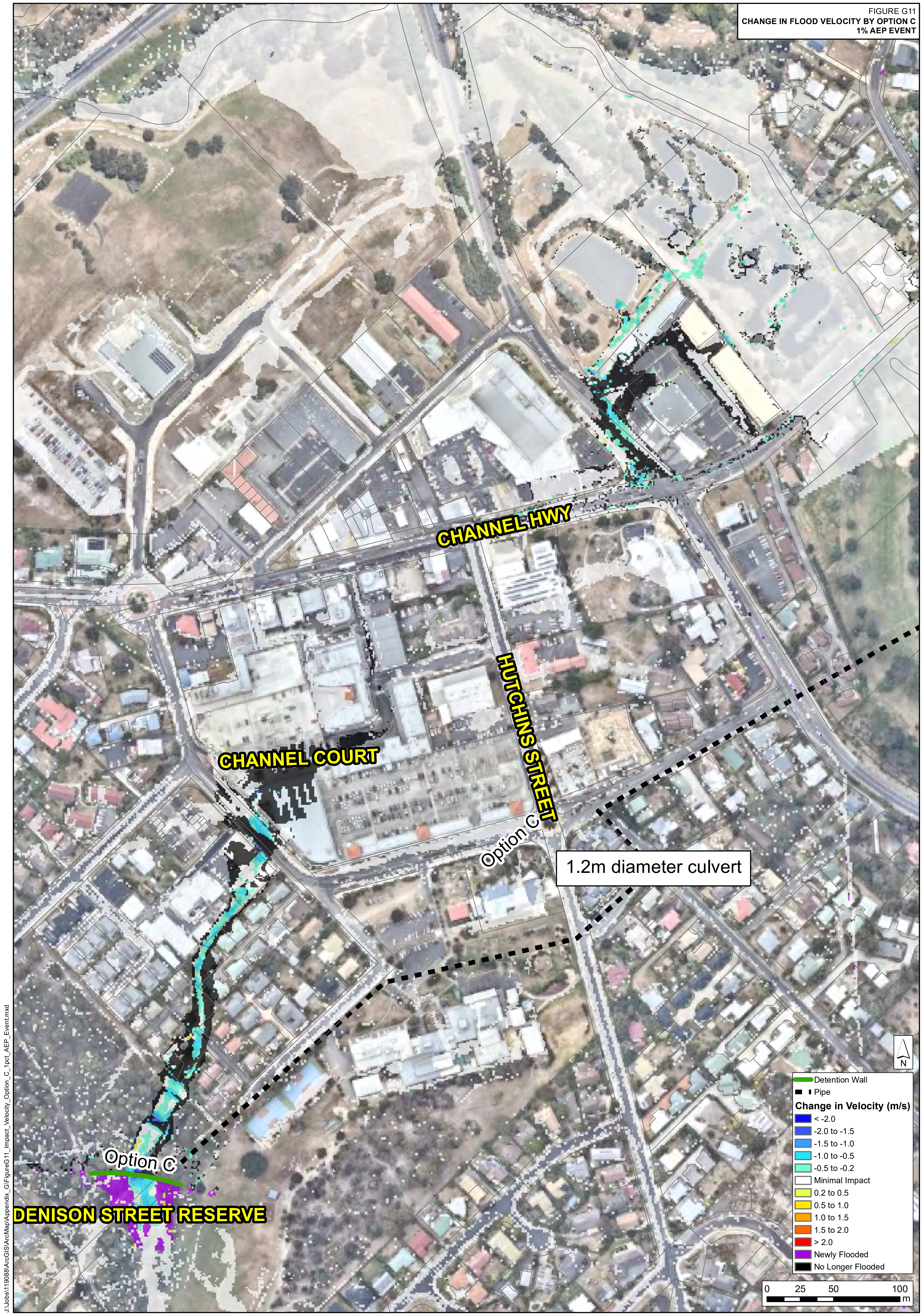
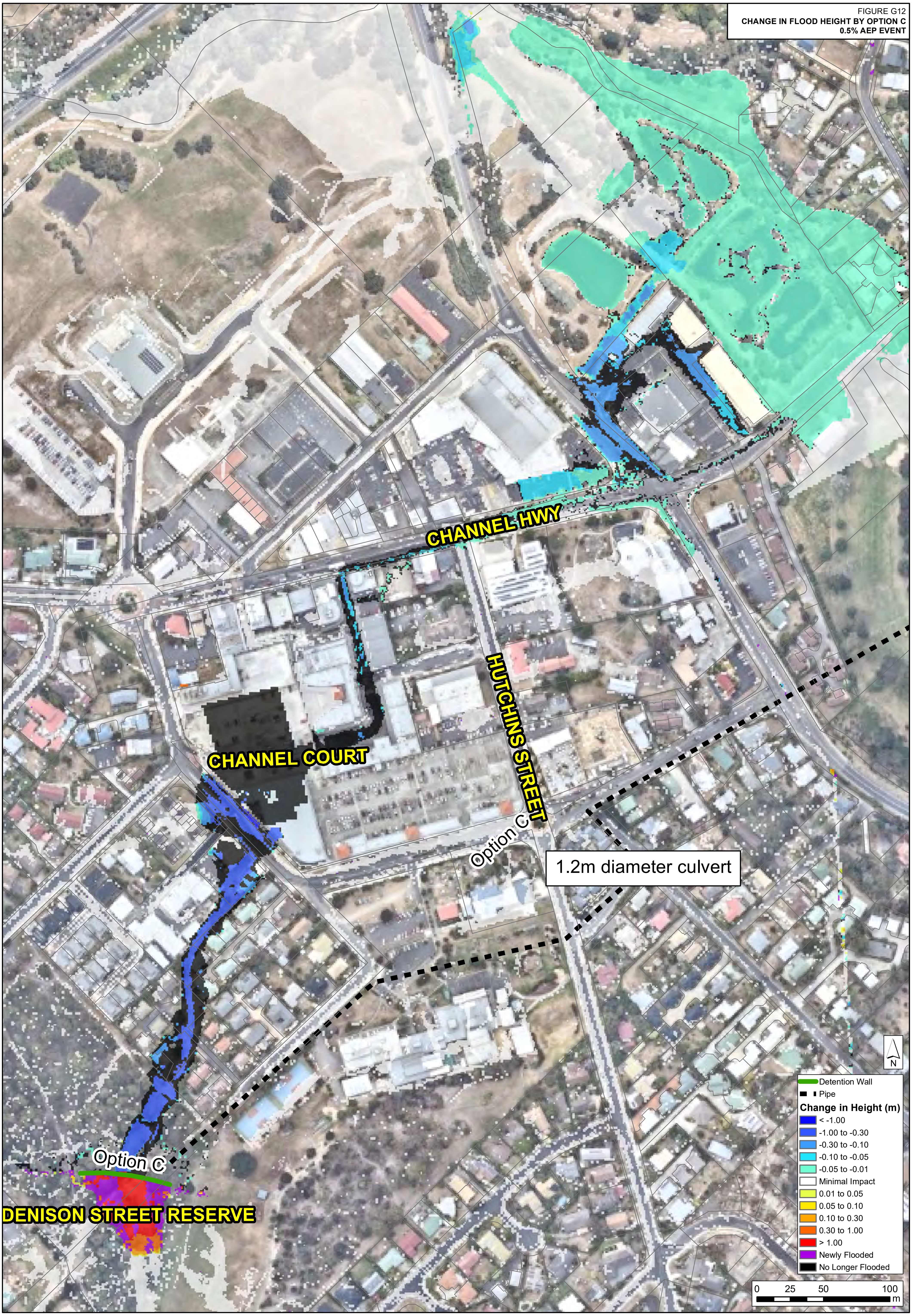
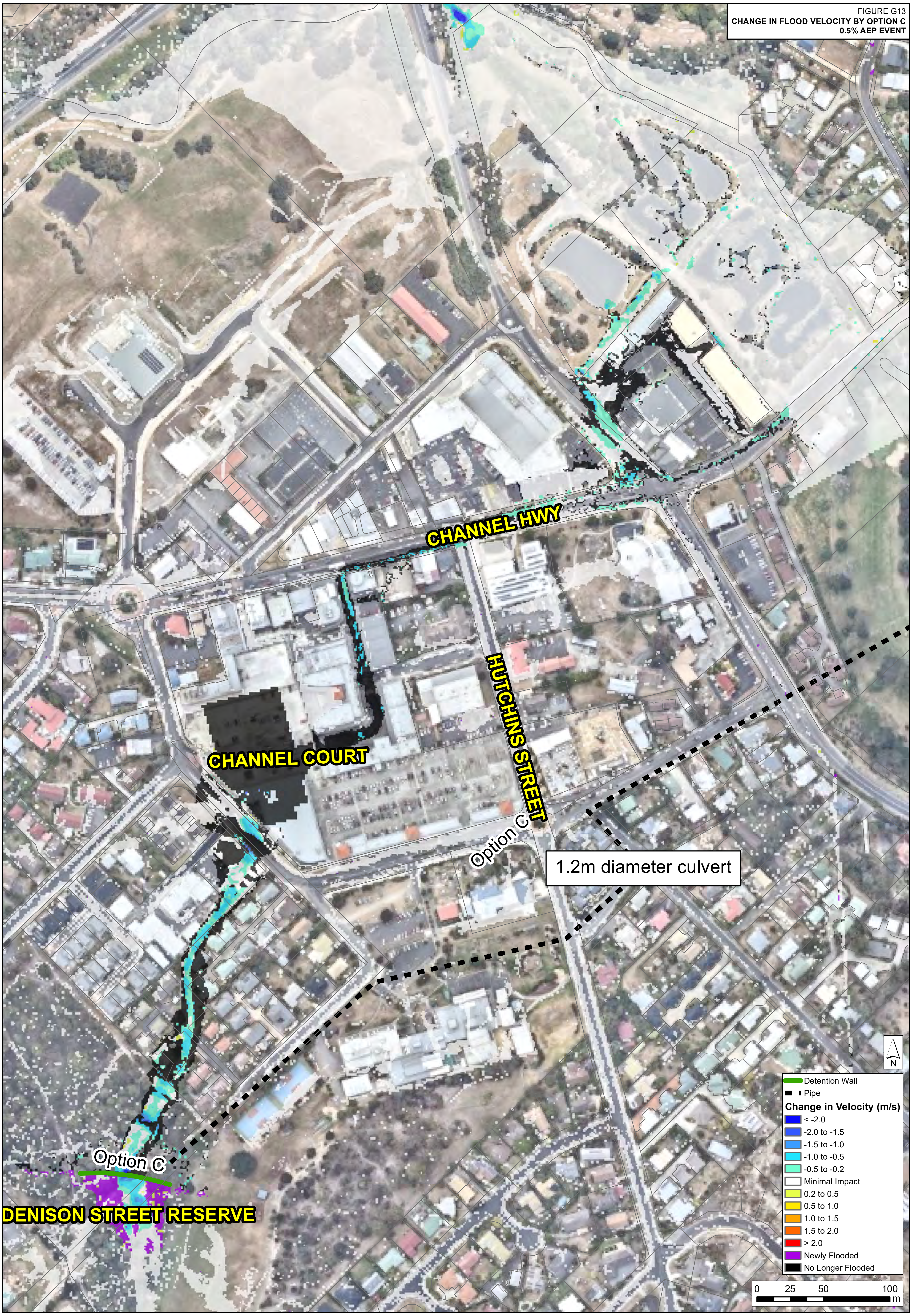


FIGURE G11
CHANGE IN FLOOD VELOCITY BY OPTION C
1% AEP EVENT
CHANNEL HWY
HUTCHINS STREET
CHANNEL COURT
Option C
1.2m diameter culvert
Option C
DENISON STREET RESERVE
Detention Wall
Pipe
Change in Velocity (m/s)
< -2.0
-2.0 to -1.5
-1.5 to -1.0
-1.0 to -0.5
-0.5 to -0.2
Minimal Impact
0.2 to 0.5
0.5 to 1.0
1.0 to 1.5
1.5 to 2.0
> 2.0
Newly Flooded
No Longer Flooded
0 25 50 100
m
N
J:\Jobs\119088\ArcGIS\ArcMap\Appendix_G\FigureG11_Impact_Velocity_Option_C_1pct_AEP_Event.mxd

FIGURE G12
CHANGE IN FLOOD HEIGHT BY OPTION C
0.5% AEP EVENT

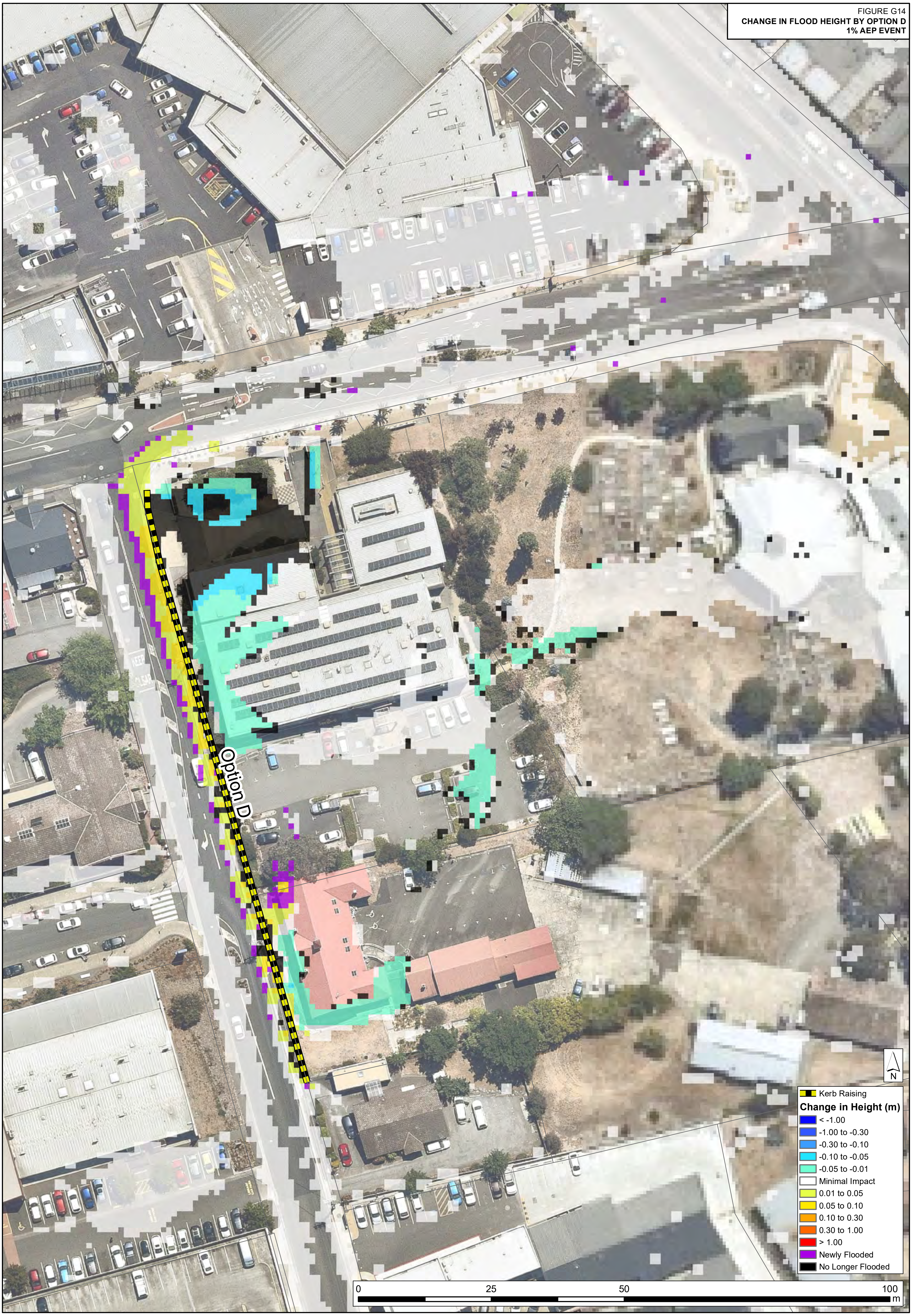


J:\Jobs\119088\ArcGIS\ArcMap\Appendix_G\FigureG12_Impact_Option_C_0.5pct_AEP_Event.mxd



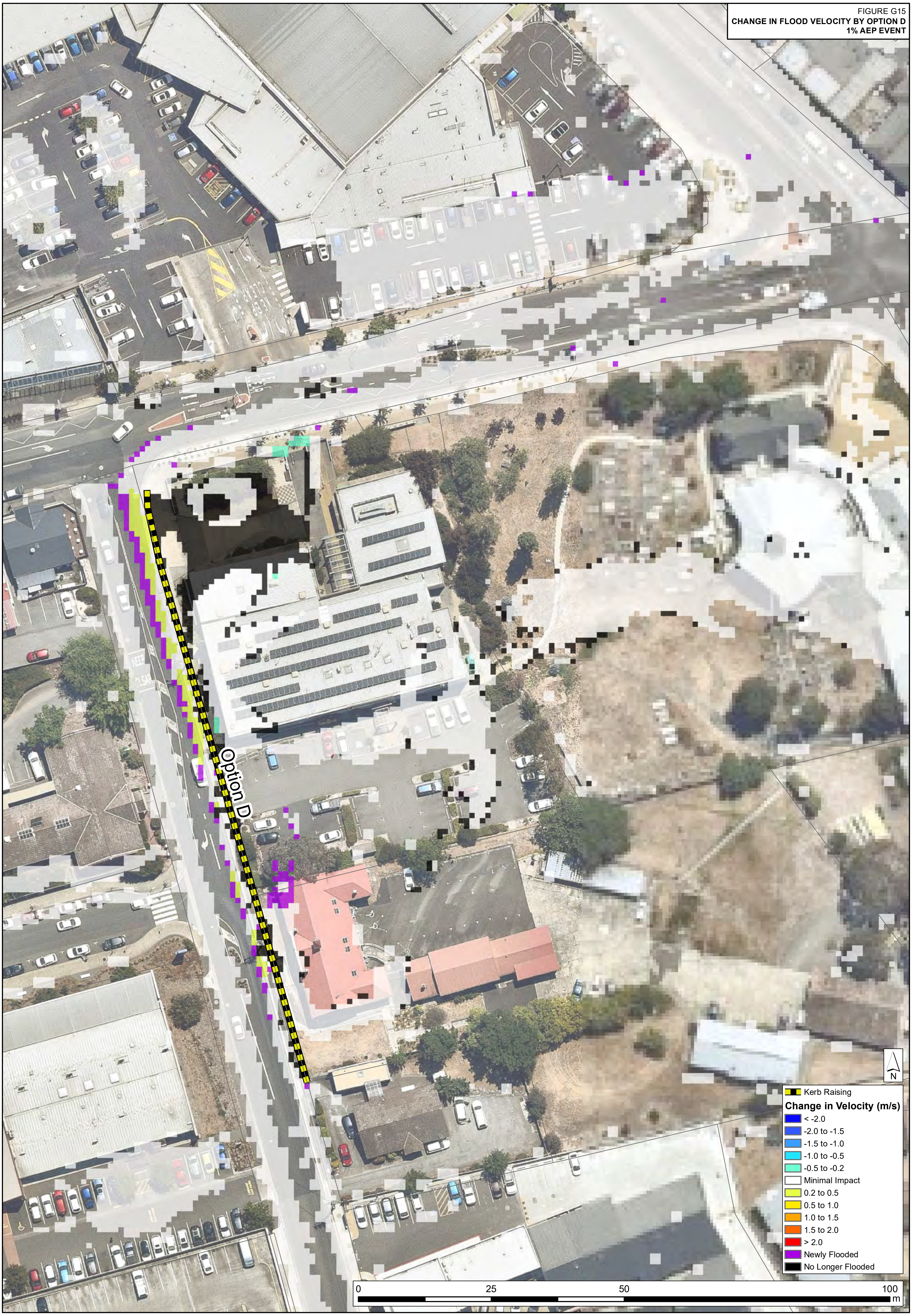
J:\Jobs\119088\ArcGIS\ArcMap\Appendix_G\FigureG13_Impact_Velocity_Option_C_0.5pct_AEP_Event.mxd

FIGURE G14
CHANGE IN FLOOD HEIGHT BY OPTION D
1% AEP EVENT



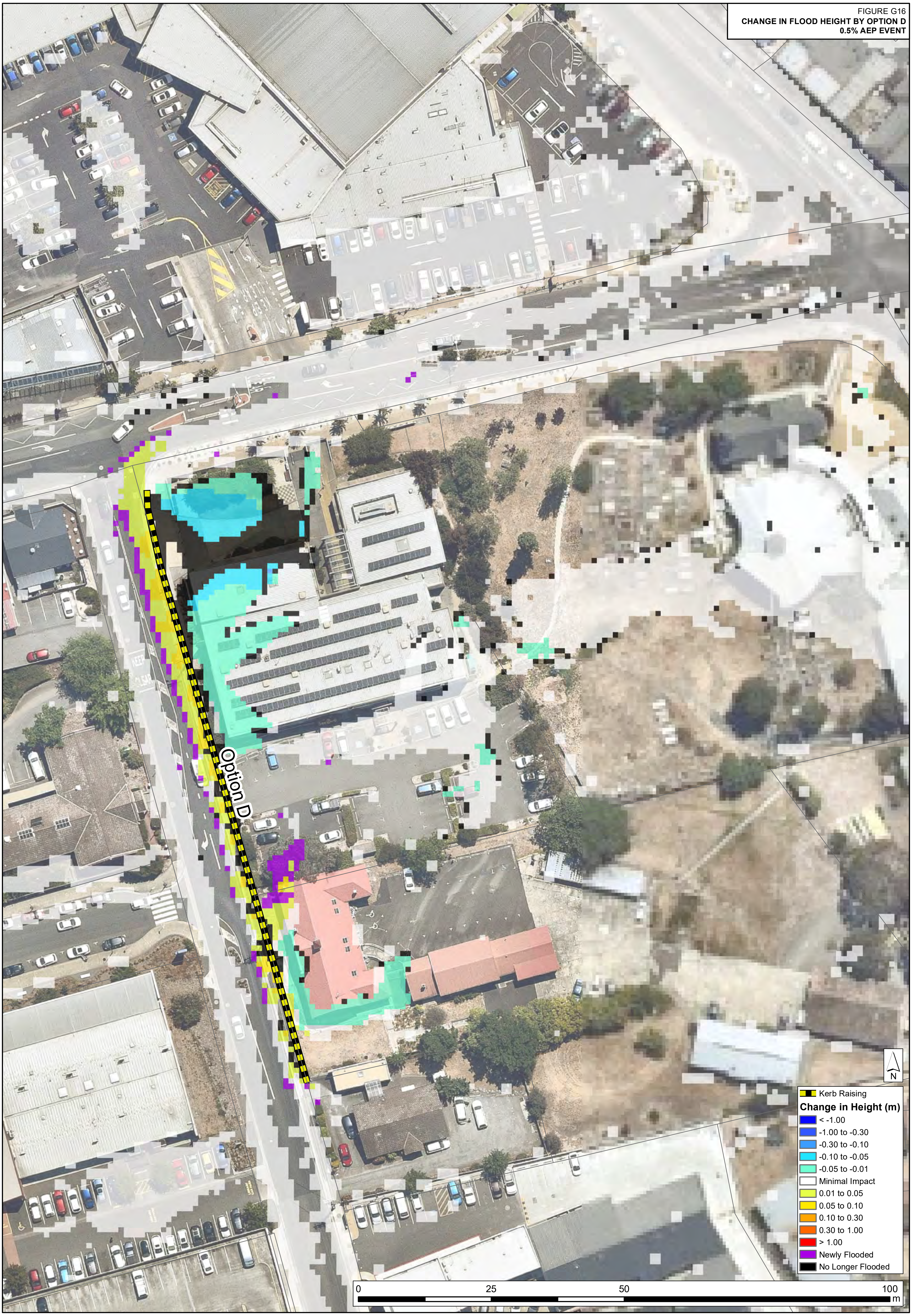
J:\Jobs\119088\ArcGIS\ArcMap\Appendix_G\FigureG14_Impact_Option_D_1pct_AEP_Event.mxd

FIGURE G15
CHANGE IN FLOOD VELOCITY BY OPTION D
1% AEP EVENT



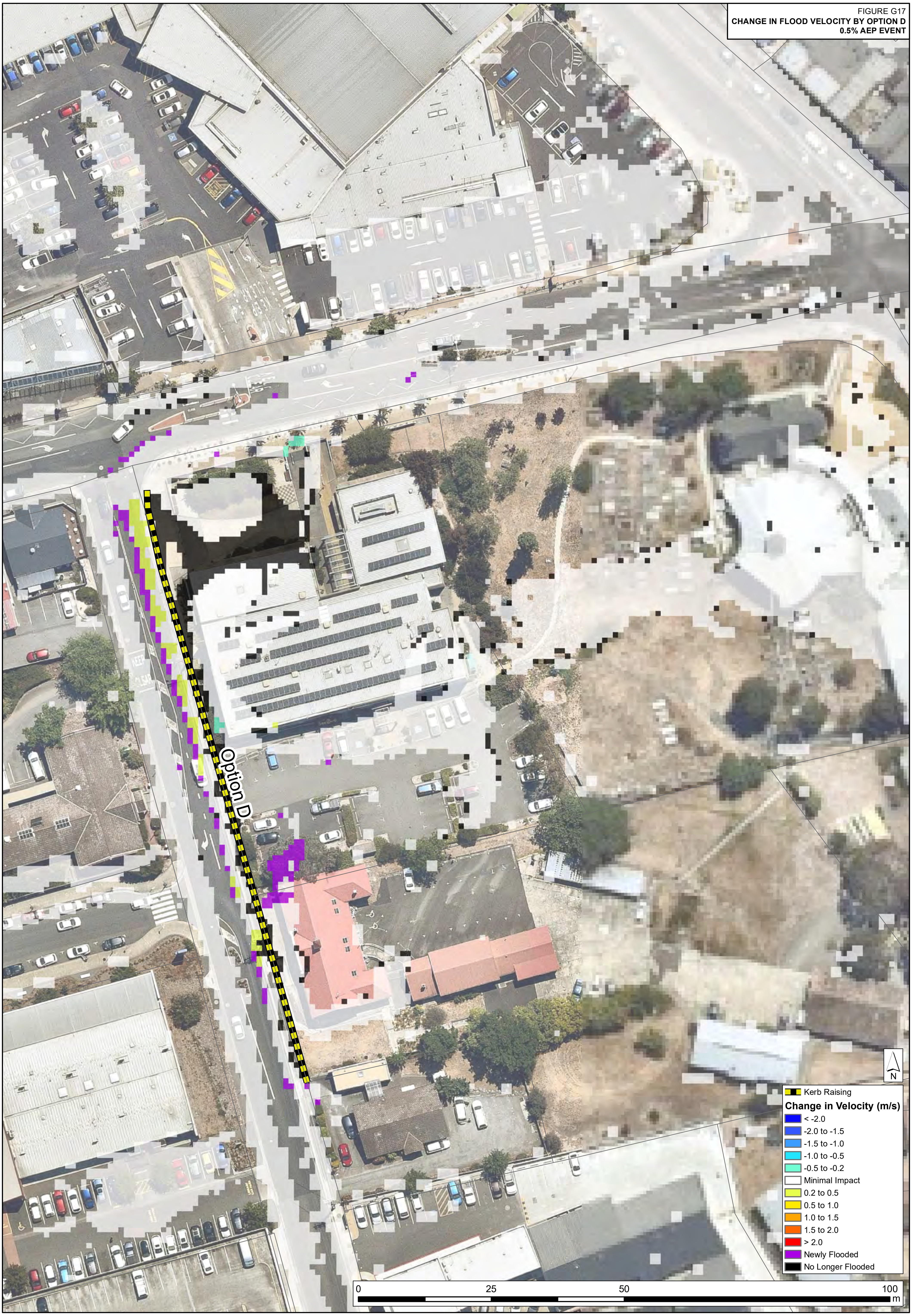
J:\Jobs\119088\ArcGIS\ArcMap\Appendix_G\FigureG15_Impact_Velocity_Option_D_1pct_AEP_Event.mxd

FIGURE G16
CHANGE IN FLOOD HEIGHT BY OPTION D
0.5% AEP EVENT



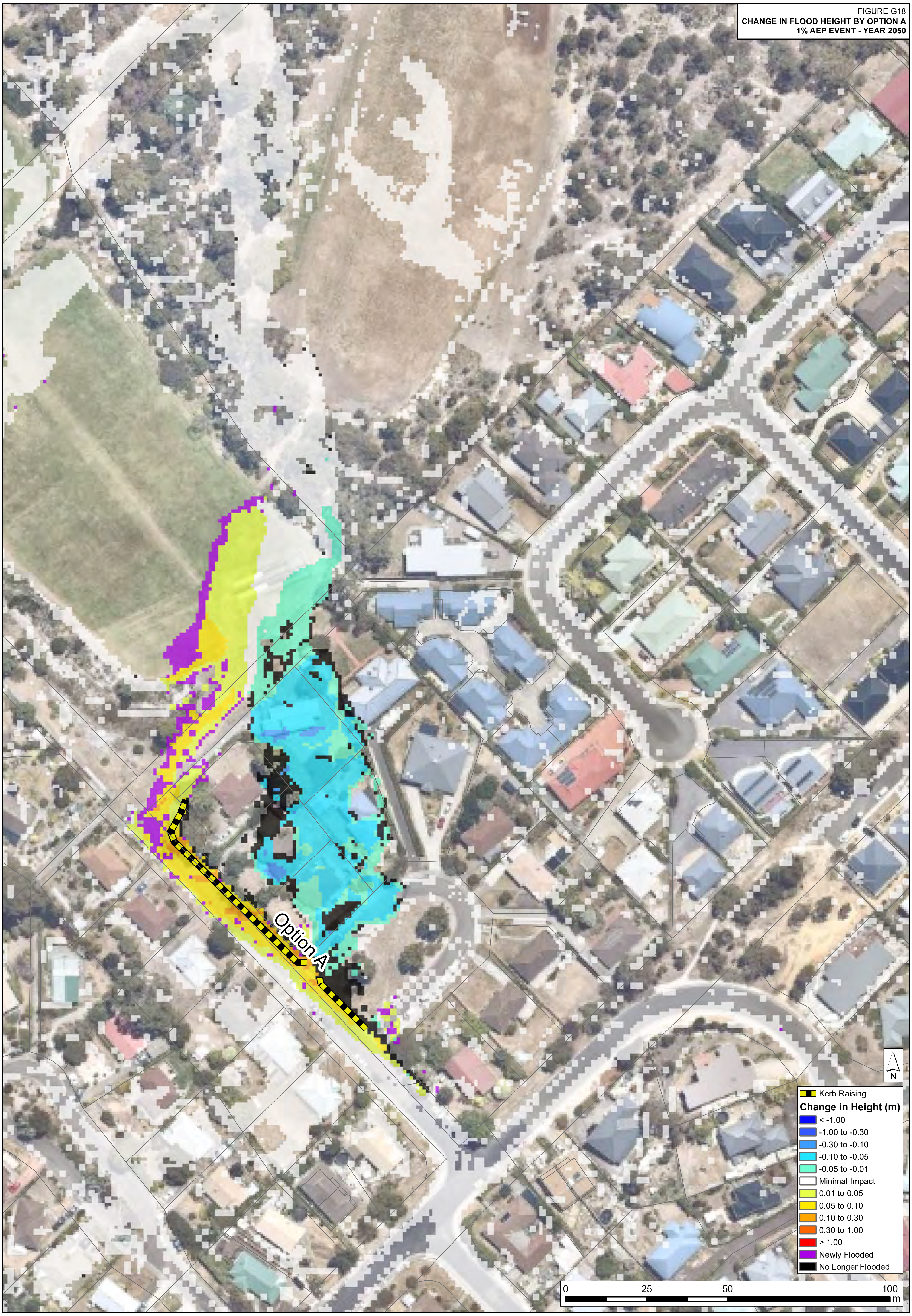
J:\Jobs\119088\ArcGIS\ArcMap\Appendix_G\FigureG16_Impact_Option_D_0.5pct_AEP_Event.mxd

FIGURE G17
CHANGE IN FLOOD VELOCITY BY OPTION D
0.5% AEP EVENT

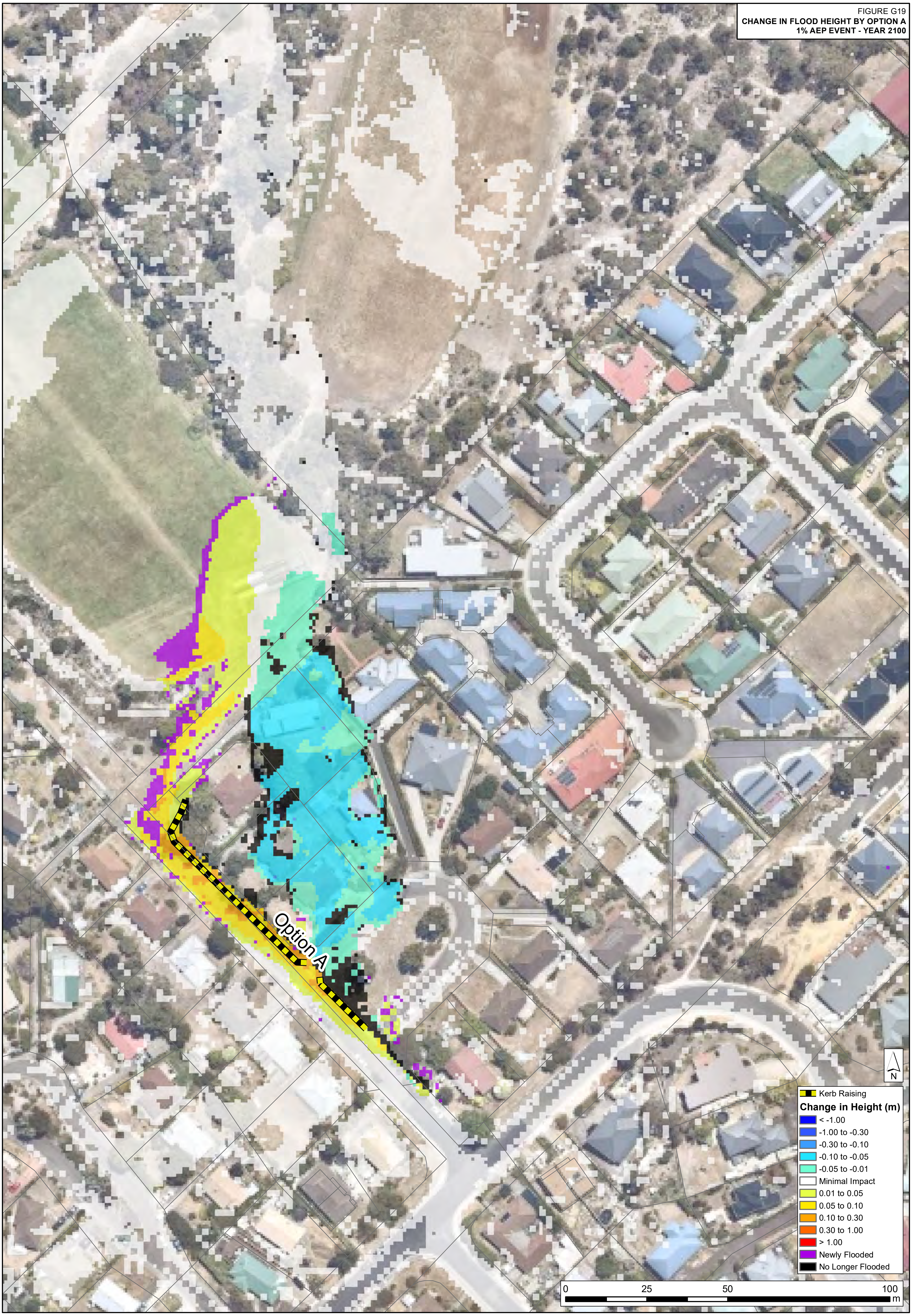


J:\Jobs\119088\ArcGIS\ArcMap\Appendix_G\FigureG17_Impact_Velocity_Option_D_0.5pct_AEP_Event.mxd

FIGURE G18
CHANGE IN FLOOD HEIGHT BY OPTION A
1% AEP EVENT - YEAR 2050

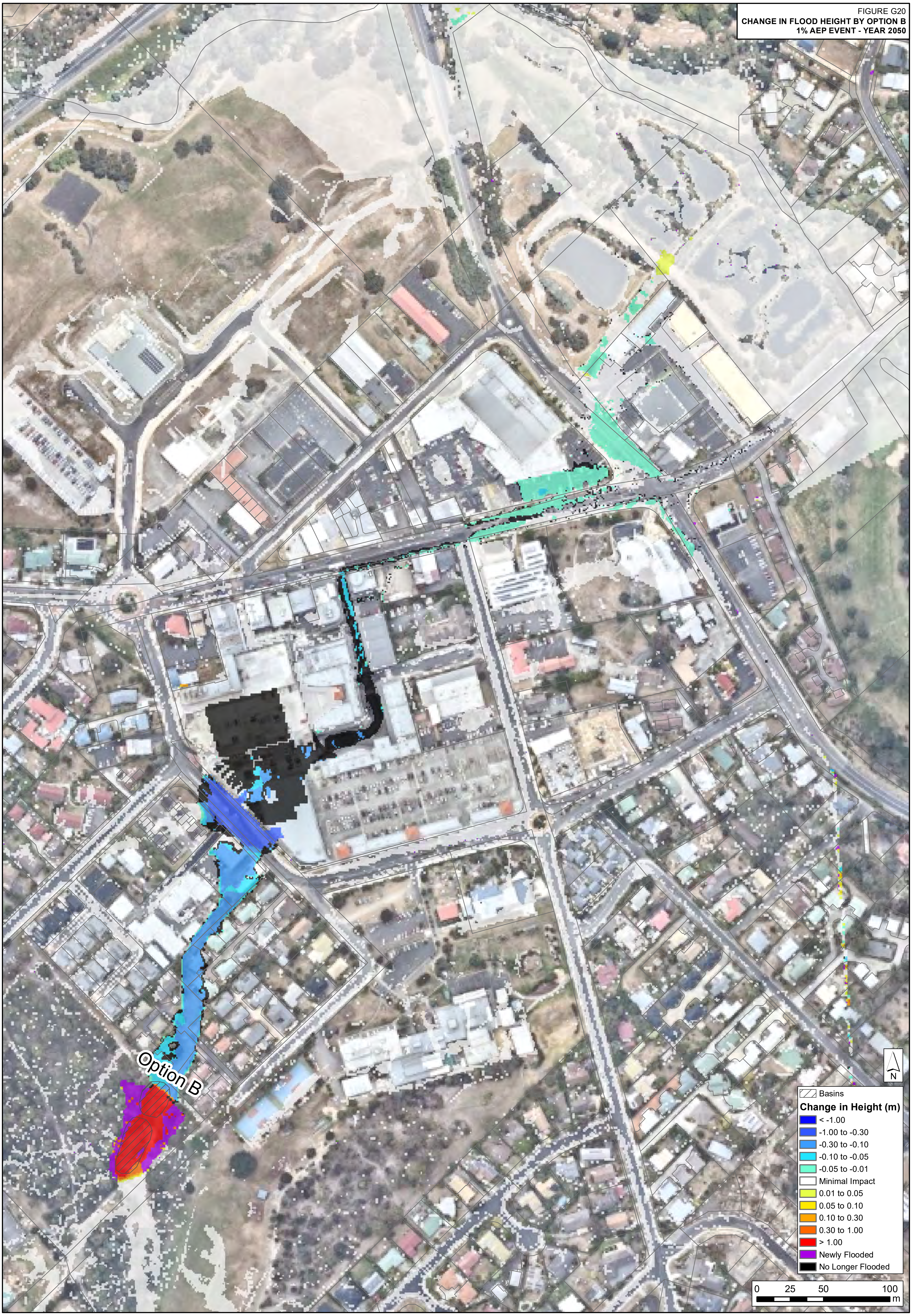


J:\Jobs\119088\ArcGIS\ArcMap\Appendix_G\FigureG18_Impact_Option_A_1pct_AEP_Event_CC2050.mxd



J:\Jobs\119088\ArcGIS\ArcMap\Appendix_G\FigureG19_Impact_Option_A_1pct_AEP_Event_CC2100.mxd

FIGURE G20
CHANGE IN FLOOD HEIGHT BY OPTION B
1% AEP EVENT - YEAR 2050



J:\Jobs\119088\ArcGIS\ArcMap\Appendix_G\FigureG20_Impact_Option_B_1pct_AEP_Event_CC2050.mxd

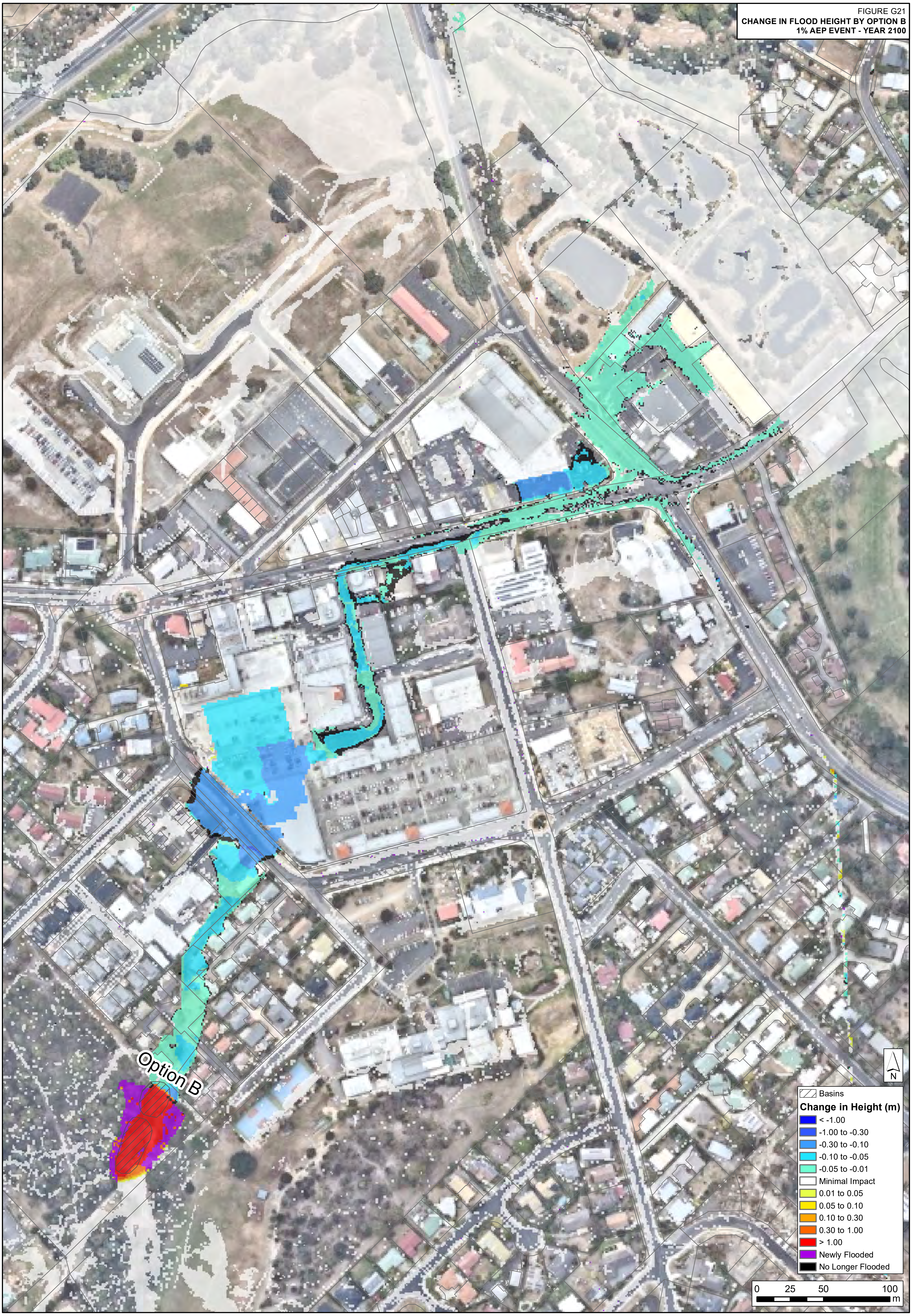
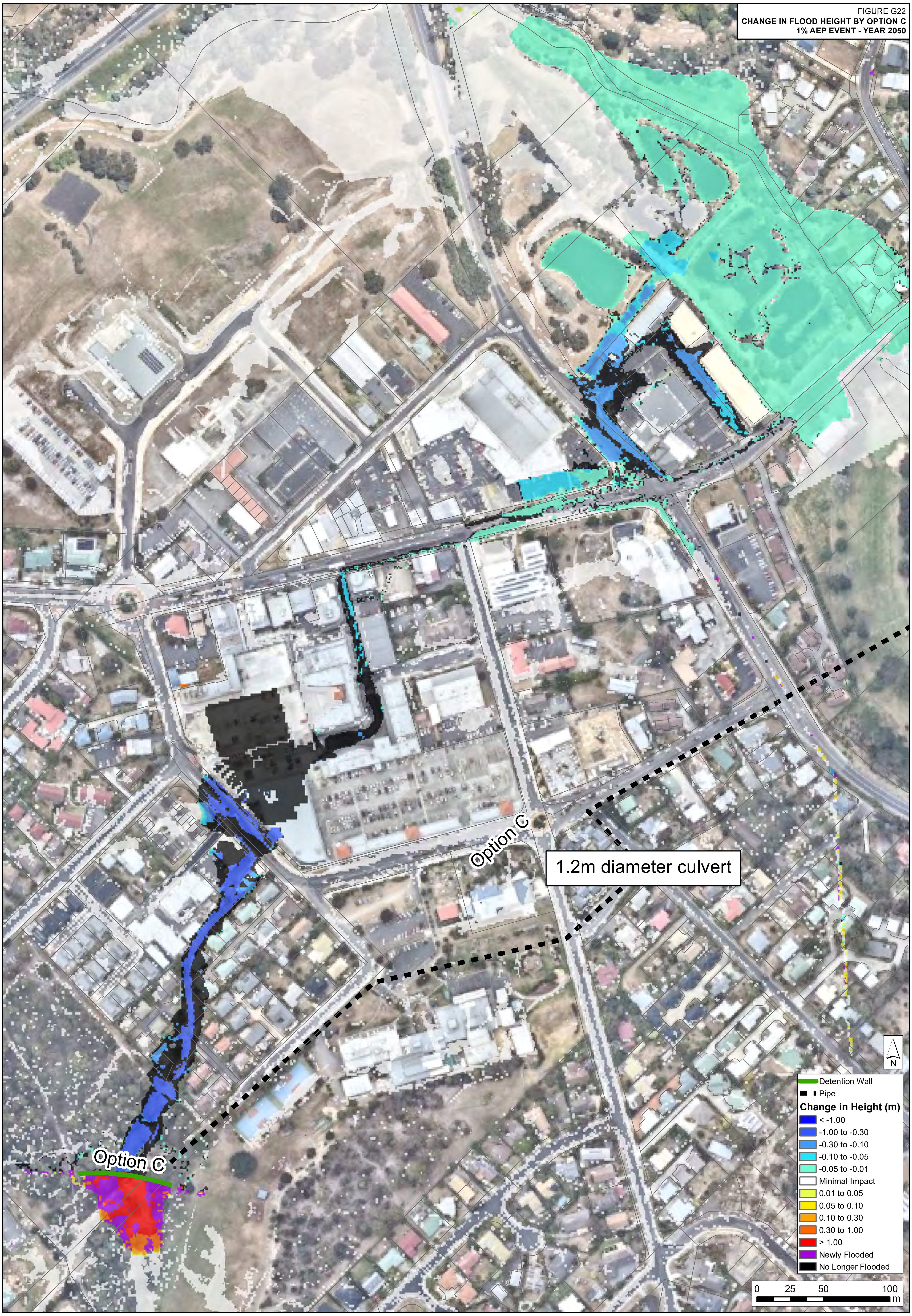


FIGURE G21
CHANGE IN FLOOD HEIGHT BY OPTION B
1% AEP EVENT - YEAR 2100
Option B
Basins
Change in Height (m)
< -1.00
-1.00 to -0.30
-0.30 to -0.10
-0.10 to -0.05
-0.05 to -0.01
Minimal Impact
0.01 to 0.05
0.05 to 0.10
0.10 to 0.30
0.30 to 1.00
> 1.00
Newly Flooded
No Longer Flooded
0 25 50 100
m
N
J:\Jobs\119088\ArcGIS\ArcMap\Appendix_G\FigureG21_Impact_Option_B_1pct_AEP_Event_CC2100.mxd



J:\Jobs\119088\ArcGIS\ArcMap\Appendix_G\FigureG22_Impact_Option_C_1pct_AEP_Event_CC2050.mxd

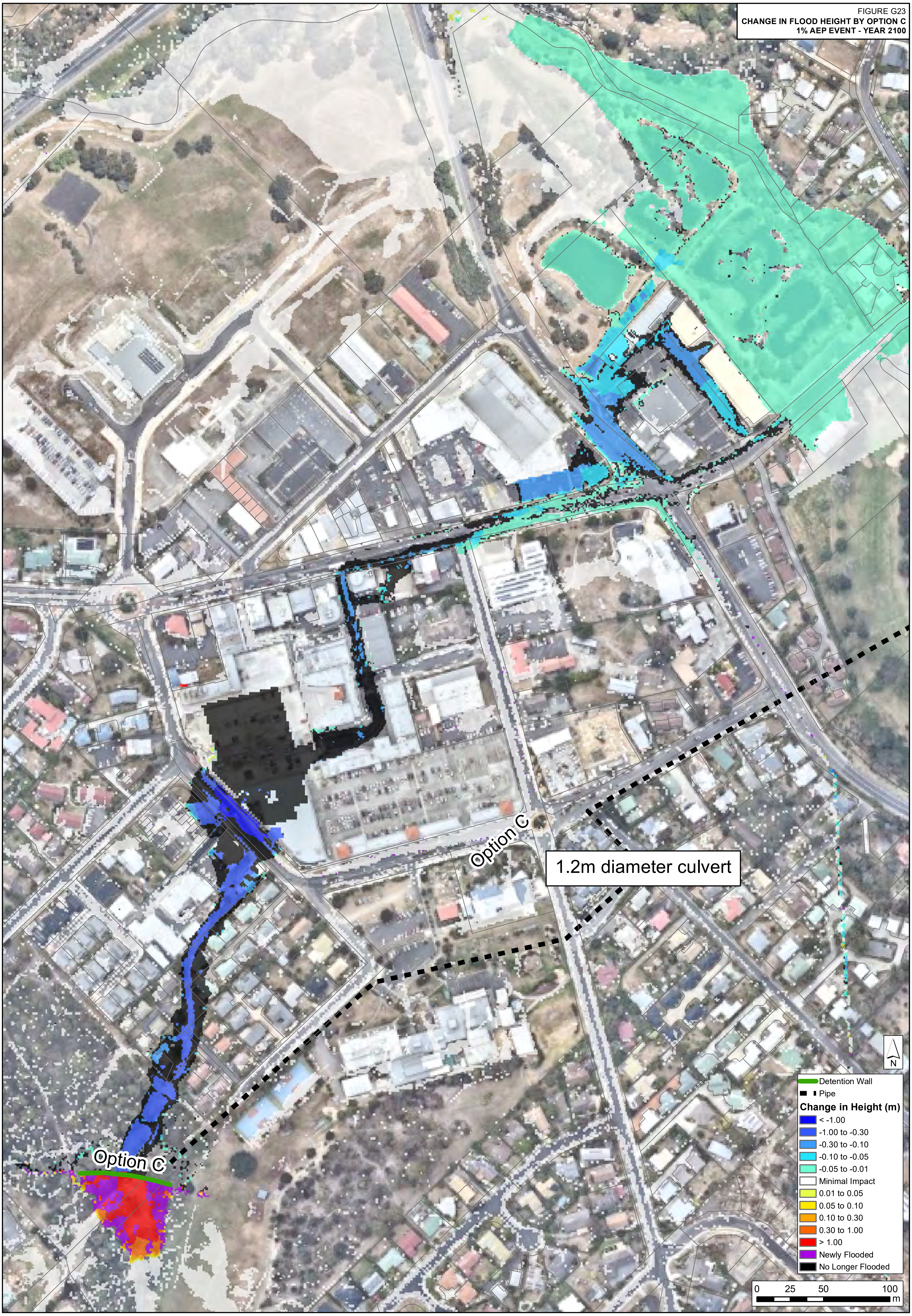
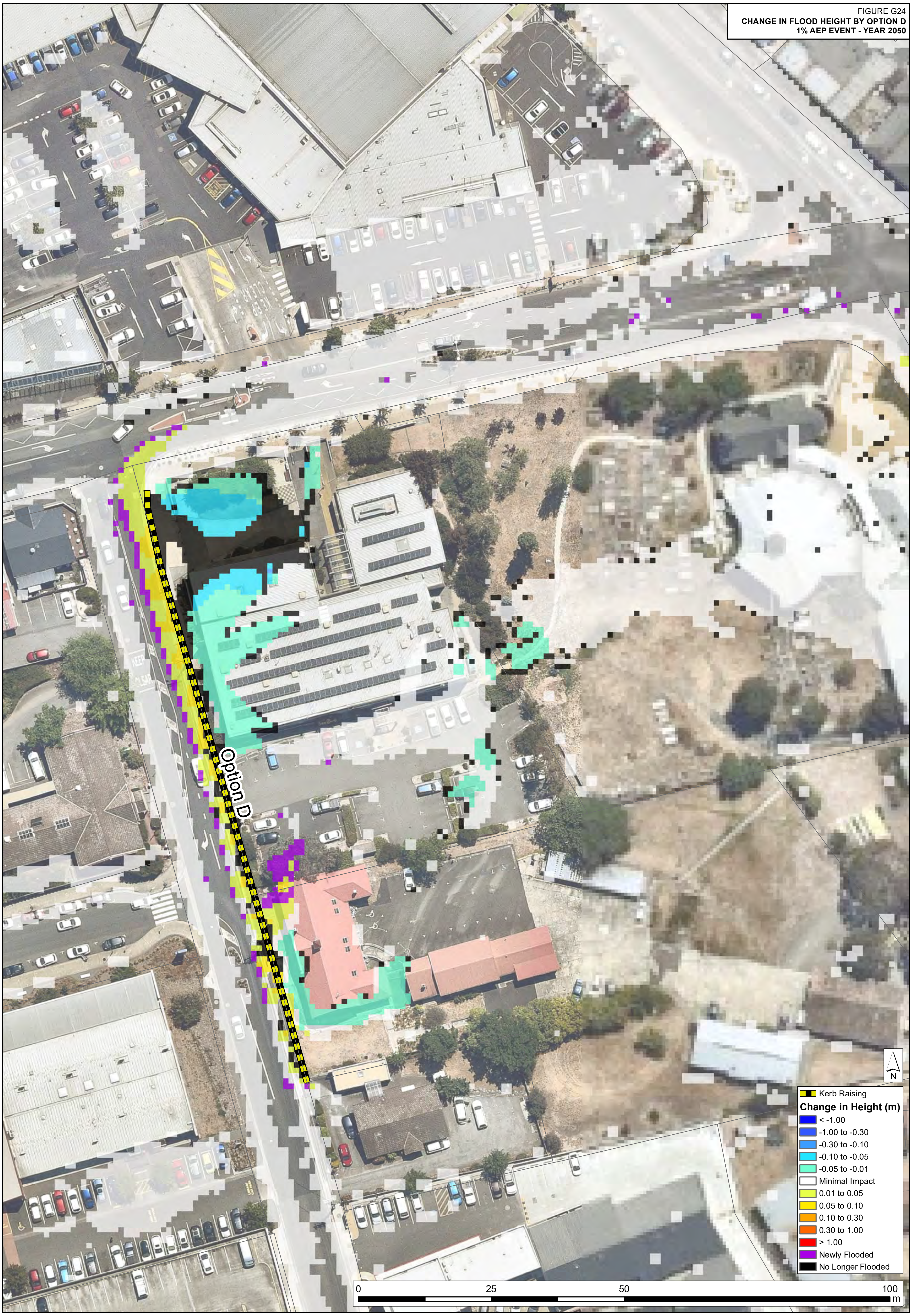


FIGURE G23
CHANGE IN FLOOD HEIGHT BY OPTION C
1% AEP EVENT - YEAR 2100
Option C
1.2m diameter culvert
Option C
N
Detention Wall
Pipe
Change in Height (m)
< -1.00
-1.00 to -0.30
-0.30 to -0.10
-0.10 to -0.05
-0.05 to -0.01
Minimal Impact
0.01 to 0.05
0.05 to 0.10
0.10 to 0.30
0.30 to 1.00
> 1.00
Newly Flooded
No Longer Flooded
0 25 50 100
m
J:\Jobs\119088\ArcGIS\ArcMap\Appendix_G\FigureG23_Impact_Option_C_1pct_AEP_Event_CC2100.mxd

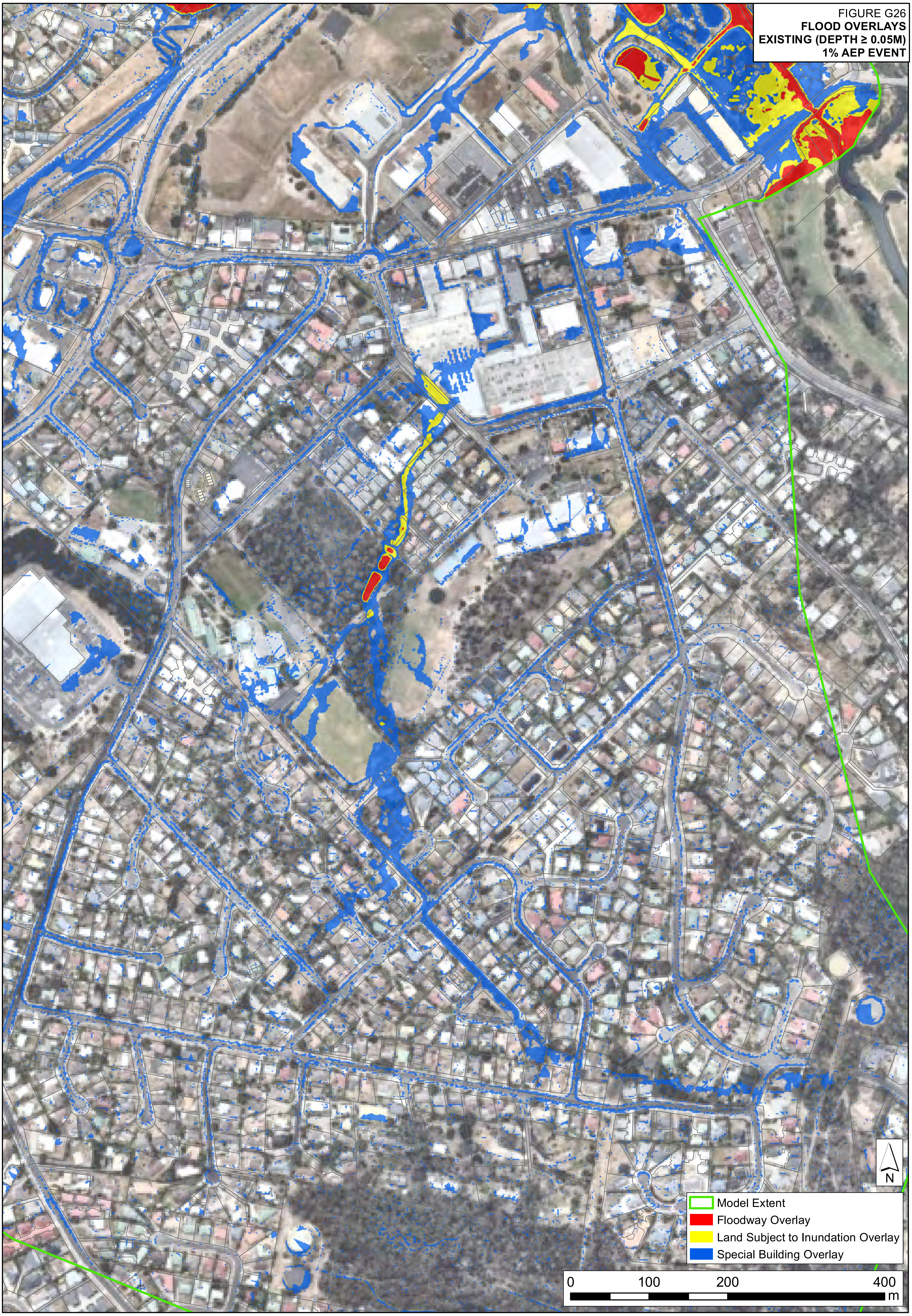
FIGURE G24
CHANGE IN FLOOD HEIGHT BY OPTION D
1% AEP EVENT - YEAR 2050



J:\Jobs\119088\ArcGIS\ArcMap\Appendix_G\FigureG24_Impact_Option_D_1pct_AEP_Event_CC2050.mxd

FIGURE G25
CHANGE IN FLOOD HEIGHT BY OPTION D
1% AEP EVENT - YEAR 2100

J:\Jobs\119088\ArcGIS\ArcMap\Appendix_G\FigureG25_Impact_Option_D_1pct_AEP_Event_CC2100.mxd



J:\Jobs\119088\ArcGIS\ArcMap\Appendix_G\FigureG26_Flood_Overlays_1pctAEP_Event.mxd

APPENDIX H. Costing

Appendix H

Option A					
Item No	**Description**	**QTY**	**Unit**	**Rate**	**Amount**
A	**CIVIL WORKS (General)**				
1.1	Site establishment, Construction Management Plan and Environmental management Plan	1	Item	$8,000.00	$8,000.00
1.2	Traffic Control in accordance with Council requirements for works	1	Item	$6,000.00	$6,000.00
A	**CIVIL WORKS**				
1.3	As-Constructed' Survey	1	Item	$1,000.00	$1,000.00
1.4	Proving of existing services	1	Item	$1,000.00	$1,000.00
1.5	Demolition inclusive of existing pavement and kerb etc.	1	Item	$15,000.00	$15,000.00
1.6	Re-instatement of non-standard B2 kerb (raised top) and channel 450mm wide, inclusive of spoon drain and layback crossings, Class 3 FCR bedding 50mm thick extending 150mm behind kerb.	100	m	$100.00	$10,000.00
1.7	re-sheeting and regrading of existing road pavement after construction of Crescent 'hump'	16	m^2	$50.00	$800.00
A	**TOTAL CIVIL WORKS**				$41,800.00
B	**PROVISIONAL ITEMS AND CONTINGENCIES**				
2.1	PROVISIONAL ITEM Contigencies (30%)	1	Item		$12,540.00
2.2	PROVISIONAL ITEM Design, documentation, contract administration and superivision of works (10%)	1	Item		$4,180.00
B	**TOTAL CONTINGENCIES**				$16,720.00
A	**CIVIL WORKS**				**$41,800.00**
B	**PROVISIONAL ITEMS AND CONTINGENCIES**				$16,720.00

SUBTOTAL:	$58,520.00
GST:	$5,852.00
TOTAL AMOUNT (Including GST):	$64,372.00

Option B					
Item No	**Description**	**QTY**	**Unit**	**Rate**	**Amount**
A	**Bund and Basin works**				
	Construction and excavation of Bund/ Basin (58m length)				
1% AEP	(i) Construction of Earthwork Bund inclusive of compaction requirements, stripping and stockpiling of topsoil, excavation of basins and side batters, placing, watering and compacting approved clay filling, side batters, *compaction testing* , inclusive of stockpiling of all surplus spoil, construction waste and rubbish.	3582.80	m^3	$40.00	$143,312.00
0.5% AEP	(i) Construction of Earthwork Bund inclusive of compaction requirements, stripping and stockpiling of topsoil, excavation of basins and side batters, placing, watering and compacting approved clay filling, side batters, *compaction testing* , inclusive of stockpiling of all surplus spoil, construction waste and rubbish.	3769.20	m^3	$40.00	$150,768.00
	PROVISIONAL ITEM (ii) Re-instatement of Landscaping		m^2	$10.00	
	PROVISIONAL ITEM (iii) Tree Removal		Item	$10,000.00	

Option C					
Item No	**Description**	**QTY**	**Unit**	**Rate**	**Amount**
A	**CIVIL WORKS**				
1.1	Site establishment, Construction Management Plan and Environmental management Plan	1	Item	$50,000.00	$50,000.00
1.2	Traffic Control in accordance with Council requirements for works	1	Item	$75,000.00	$75,000.00
1.3	As-Constructed' Survey	1	Item	$10,000.00	$10,000.00
1.4	Proving of existing services	1	Item	$50,000.00	$50,000.00
1.5	Demolition inclusive of existing pavement, Shared paths and kerb etc.	1	Item	$150,000.00	$150,000.00
1.6	Construction of bund/retaining wall at across primary flow path in Denison Street Reserve to divert flows to pipe inlet structure	300	m^3	$40.00	$12,000.00
1.7	Excavation and refilling trenches, supply, laying and jointing inclusive of pipe bedding, re-instatement of surfaces, compacted **Class 2 FCR backfill** in trenches under pavement and behind kerb and disposal of spoil as specified.				
	(i) 1200mm dia. RCP RRJ	660	m	$1,150.00	$759,000.00
1.8	Excavation and refilling trenches, supply, laying and jointing inclusive of pipe bedding, re-instatement of surfaces, compacted **Ordinary backfill** in trenches under pavement and behind kerb and disposal of spoil as specified.				
	(i) 1200mm dia. RCP RRJ	185	m	$1,000.00	$185,000.00
1.9	CCTV of all drainage pipes at completion of works	800	m	$11.00	$8,800.00
1.10	Re-instatment of existing asphalt road pavement 2m wide after construction of drainage alignment inclusive of crushed rock and compaction testing.	81	m^2	$150.00	$12,150.00
1.11	Coldplanning and re-sheeting of existing road pavement (entire width) after construction of drainage alignment	81	m^2	$50.00	$4,050.00
1.12	Concrete Junction Pit, internal dimensions , to Council details, inclusive of supply and fitting Class 'D' concrete cover as detailed on drawings, and pipe connections, as specified.				
	(i) 900mm x 1200mm	4	No.	$3,500.00	$14,000.00
1.13	Supply and install rock beaching at endwall outlets, inclusive of excavation and disposal of spoil (size and area of rock to be confirmed).	1	Item	$5,000.00	$5,000.00
1.14	Endwall to suit 1200mm dia. RCP RRJ	1	No.	$7,000.00	$7,000.00
1.15	Removal of existing trees as required	1	Item	$10,000.00	$10,000.00
1.16	Re-instatement of landscaping and irrigation	1	Item	$70,000.00	$70,000.00
1.17	125mm thick concrete footpath inclusive of SL72 mesh reinforcement 50mm/20mm Class 2 FCR bedding and construction joints, as specified.	408	m^2	$200.00	$81,600.00
1.18	Re-instatement of B2 kerb and channel 450mm wide, inclusive of spoon drain and pram crossings, Class 3 FCR bedding 50mm thick extending 150mm behind kerb as specified.	408	m	$150.00	$61,200.00
1.19	Alteration of drainage alignment to avoid existing services. Involves altering the drainage to an alignment that is less ideal (i.e. deeper or less direct route)	1	Item	$100,000.00	$100,000.00
1.20	Relocation/alteration to existing service to suit proposed drainage alignment	1	Item	$100,000.00	$100,000.00
	TOTAL CIVIL WORKS				$1,764,800.00
B	**PROVISIONAL ITEMS AND CONTINGENCIES**				

2.1	PROVISIONAL ITEM Contigencies (30%)	1	Item		$529,440.00
2.2	PROVISIONAL ITEM Design, documentation, contract administration and superivision of works (10%)	1	Item		$176,480.00
	TOTAL CONTINGENCIES				$705,920.00
A	**CIVIL WORKS**				**$1,764,800.00**
B	**PROVISIONAL ITEMS AND CONTINGENCIES**				$705,920.00

SUBTOTAL:	$2,470,720.00
GST:	$247,072.00
TOTAL AMOUNT (Including GST):	$2,717,792.00

Option D					
Item No	**Description**	**QTY**	**Unit**	**Rate**	**Amount**
A	**CIVIL WORKS (General)**				
1.1	Site establishment, Construction Management Plan and Environmental management Plan	1	Item	$8,000.00	$8,000.00
1.2	Traffic Control in accordance with Council requirements for works	1	Item	$6,000.00	$6,000.00
A	**CIVIL WORKS**				
1.3	As-Constructed' Survey	1	Item	$1,000.00	$1,000.00
1.4	Proving of existing services	1	Item	$1,000.00	$1,000.00
1.5	Demolition inclusive of existing pavement and kerb etc.	1	Item	$15,000.00	$15,000.00
1.6	Re-instatement of non-standard B2 kerb (raised top) and channel 450mm wide, inclusive of spoon drain and layback crossings, Class 3 FCR bedding 50mm thick extending 150mm behind kerb.	110	m	$100.00	$11,000.00
1.7	re-sheeting and regrading of existing road pavement after construction of kerb	330	m^2	$50.00	$16,500.00
1.8	Lift existing drainage pit to match proposed levels.	3	Item	$3,000.00	$9,000.00
A	**TOTAL CIVIL WORKS**				$58,500.00
B	**PROVISIONAL ITEMS AND CONTINGENCIES**				
2.1	PROVISIONAL ITEM Contigencies (30%)	1	Item		$17,550.00
2.1	PROVISIONAL ITEM Design, documentation, contract administration and superivision of works (10%)	1	Item		$5,850.00
B	**TOTAL CONTINGENCIES**				$23,400.00
A	**CIVIL WORKS**				**$58,500.00**
B	**PROVISIONAL ITEMS AND CONTINGENCIES**				$23,400.00

SUBTOTAL:	$81,900.00
GST:	$8,190.00
TOTAL AMOUNT (Including GST):	$90,090.00