Throsby, Styx & Cottage Creek Flood Study

Draft

City of Newcastle

RR-05-1468-00

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Foreword

The primary objective of the New South Wales (NSW) Government's Flood Prone Land Policy is to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods, utilising ecologically positive methods wherever possible.

Through the NSW Department of Planning and Environment (DPE) and the NSW State Emergency Service (SES), the NSW Government provides specialist technical assistance to local government on all flooding, flood risk management, flood emergency management and land-use planning matters.

The *Flood Risk Management Manual, the policy and manual for the management of flood liable land* (DPE, 2023) (the **Manual**) is provided to assist councils to meet their obligations through the preparation and implementation of floodplain risk management plans, through a staged process. **Figure F1**, taken from this manual, documents the process for plan preparation, implementation and review.

The Manual is consistent with Australian Emergency Management Handbook 7: *Managing the floodplain: best practice in flood risk management in Australia* (AEM Handbook 7) (AIDR 2017).

Figure F1. The Floodplain Risk Management Process (DPE, 2023)

The City of Newcastle has committed to prepare a comprehensive flood study for the study area in accordance with the Manual (DPE, 2023). This document relates to the data collection and flood study phase of the process.

Executive Summary

Study Overview and Purpose

The Throsby, Styx and Cottage Creek Flood Study (the **Flood Study**) has been prepared for the City of Newcastle in accordance with the New South Wales (NSW) Flood Prone Land Policy and the principles of the *Flood Risk Management Manual, the policy and manual for the management of flood liable land* (Department of Planning and Environment, 2023) (the **Manual**).

Multiple flood investigations have already been undertaken within the study area; some were only localised studies looking at individual developments. The previous flood study covering this study area was completed in 2008 (BMT WBM, 2008a).

This Flood Study seeks to revise and update the 2008 flood study. It improves upon the understanding of flood behaviour and associated impacts of flooding on the community. The study will inform the ongoing management of flood risk in the study area.

This revised flood study utilises the most recent methodologies outlined in *Australian Rainfall and Runoff 2019* (ARR2019) (Ball et al, 2019), using more contemporary modelling techniques and technologies, and incorporates additional rainfall and flooding data gathered after the completion of the 2008 flood study.

Study Area and Scope

The study area covers the catchments of Styx Creek, Throsby Creek, Cottage Creek and the Newcastle central business district (CBD) with a focus on understanding the flood behaviour and flood risk in these catchments. The study area is shown in **Map G101** (provided in Appendix A of this study and replicated within this executive summary).

The study is a comprehensive technical investigation of flood behaviour that provides the foundation for the development of robust guidance for management of flood risk within the context of a floodplain risk management study and plan. It aims to provide a better understanding of the full range of flood behaviour and consequences. It involves consideration of the local flood history, available flood data, and the development of hydrologic and hydraulic models that are calibrated and verified against historic flood events and extended, where appropriate, to determine the full range of flood behaviour.

Consultation

Comprehensive community engagement was undertaken at key points in the study. This involved:

- A public survey in April 2021 requesting information on the community's experiences of and attitudes towards flooding.
- Collation of public and stakeholder data gathered from previous flood related studies, including a collection of flood observations from the June 2007 "Pasha Bulker" flood event.

The results of the community consultation and flood data collection have been important in assisting with the flood model calibration.

Public exhibition of this draft document will be undertaken to obtain feedback from the community and other stakeholders. The community members which participated in the 2021 public survey and registered their contact details, have been invited directly (via email) to provide feedback on this Draft Flood Study during public exhibition.

Flood Model Development and Calibration

The flood model established as part of the *Throsby, Cottage and CBD Flood Study* (BMT WBM, 2008a) was provided by the City of Newcastle as a base for establishing an updated flood model.

This flood model was updated with the following key datasets:

- Light Detection and Ranging (LiDAR) collected in 2014 and 2021. These data contain both ground elevations in the form of a digital elevation model (DEM) and point cloud data which categorises data based on ground cover (vegetation, roofs, paved surfaces, etc.).
- Ground survey of Waterdragon Creek.
- Updated intensity-frequency-duration (IFD) rainfall data and losses from the Australian Rainfall and Runoff (ARR) data hub (http://data.arr-software.org/).
- Updated stormwater pit and pipe survey information collected in 2020.
- Revised oceanic boundary conditions for coincidence of ocean and catchment flooding based on guidance from the Department of Planning and Environment (DPE).

The hydrologic model was established using the Watershed Bounded Network Model (WBNM) software package, while the two-dimensional (2D) hydraulic modelling package utilised was the TUFLOW software.

The updated flood model was also used to estimate historic flood behaviour using data sourced from local rainfall and water level gauges as well as community observations of flooding (surveyed and estimated). The following flood events were considered when calibrating and validating the flood model:

- Model calibration event: June 2007
- Model validation events: February 1990 and April 1988.

Results of from the June 2007 calibration event showed that the flood model could reproduce observed flood levels within 0.3 m for almost 90% of more than 1,000 data points. **Map G203** (provided in Appendix A of this study and also replicated within this executive summary) illustrates the flood depths modelled for the June 2007 event.

Design Flood Modelling Results

The hydrological and 2D hydraulic models were used to analyse a range of design events, including the Probable Maximum Flood (PMF), 1% annual exceedance probability (AEP), 2% AEP, 5% AEP and 10% AEP events. Storm durations were considered ranging from 10 minutes to 24 hours, using the 10 temporal pattern ensemble approach detailed in ARR2019.

Two climate change scenarios were also modelled considering future increases in rainfall intensity and sea level rise. The 1% AEP event in 2050 was estimated by modelling the 0.5% AEP event with a sea level rise of 0.4 m and the 1% AEP event in 2100 as estimated by modelling the 0.2% AEP event with a sea level rise of 0.9 m.

The City of Newcastle has proposed to adopt the 1% AEP event in 2050 as the Defined Flood Event for flood planning purposes, where development is subject to catchment flash flooding.

The design flood depths and flood levels for the 1% AEP in 2050 and the PMF events, respectively are shown in **Maps G320 and G308** (provided in Appendix A of this study and replicated within this executive summary). In general, flooding in the study area is driven by catchment-generated runoff in the higher elevation areas while oceanic conditions dictate flooding near the foreshore areas; however, there is a significant degree of interaction between these two sources of flooding in the low-lying portions of the study area and along portions of Throsby, Styx and Cottage Creeks.

Blockage of hydraulic structures (i.e. culverts and bridges) was considered in the design event flood modelling. A risk-based approach, using guidance from ARR2019, was adopted to apply a blockage factor based on the likelihood of debris being generated from the catchment draining to each structure and the ability of the watercourse to carry that debris to the structure. Adopted blockage rates increase with the magnitude of the flood event.

Flood Model Sensitivity

A number of assumptions are made when establishing flood models that influence the quantity and timing of flow generated from rainfall, and the resulting flood behaviour. The calibration and validation modelling assists in the selection of suitable modelling parameters. However, sensitivity testing of the models is also undertaken to better understand the confidence in the results.

The established flood model was tested for the sensitivity of results to multiple input parameters including catchment storage and lag, hydrologic model inflows, rainfall losses, hydraulic structure blockage, bridge and culvert losses, and surface roughness. Each of these parameters were varied and the flood model run to test their effect on flood levels in the 1% AEP in 2050 event and/or the June 2007 calibration event.

Results of this sensitivity testing indicated that the flood model is most sensitive to blockage assumptions, with flood levels increasing more than +0.2 m over large sections of the lower lying portions of the study area when the ARR2019 risk-based blockage approach is changed to a blanket 90% blockage rate applied to all hydraulic structures. Conversely, flood levels dropped up to -0.2 m when a 0% blockage rate was applied to all hydraulic structures.

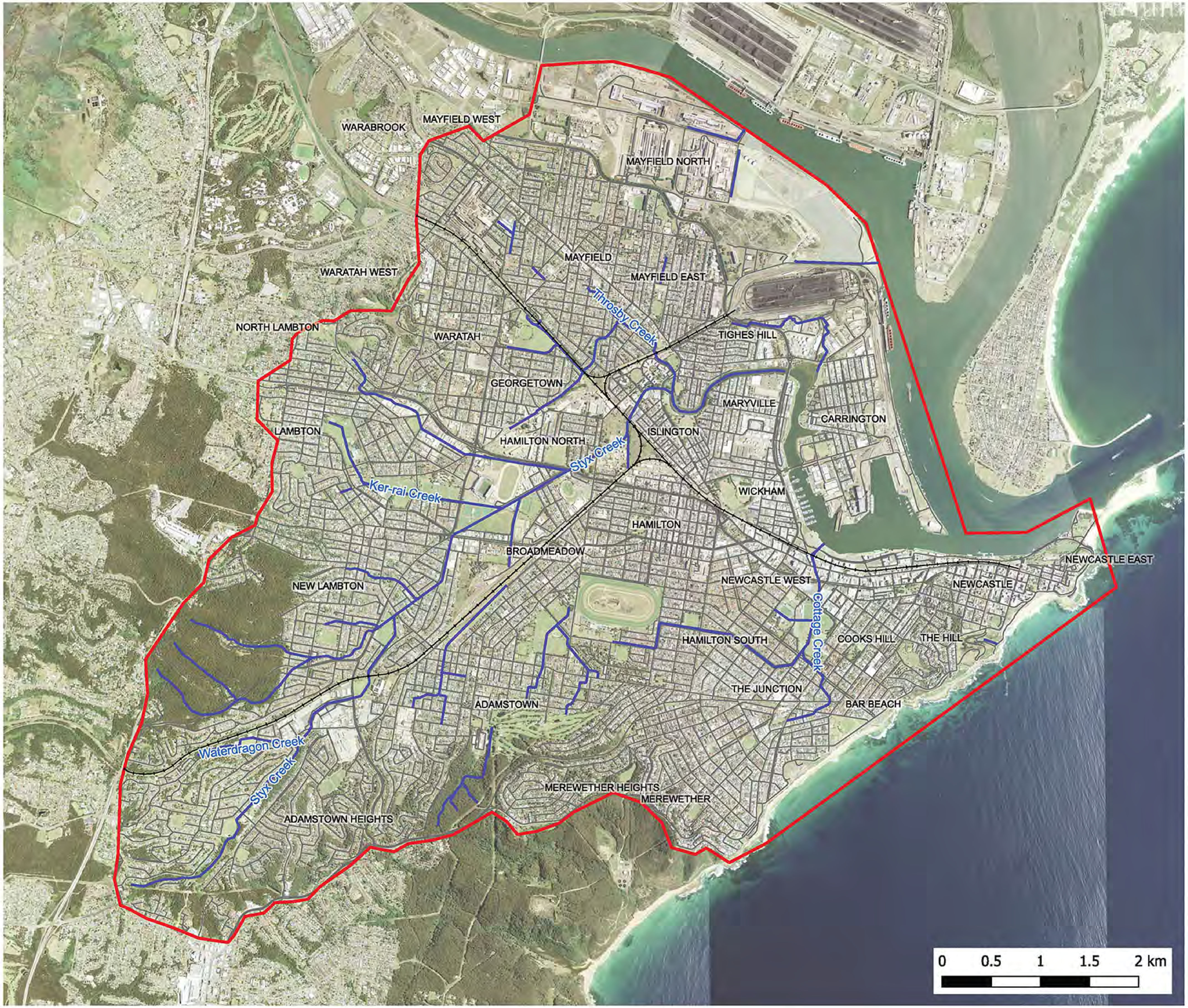
The flood model is also sensitive to the adopted surface roughness, for both the 2D ground surface portion of the model and the one-dimensional (1D) pipe and concrete channels. Flood levels varied from +0.2 m to -0.2 m, although this is largely limited to areas of higher velocity flows. Widespread changes to flood levels across the study area were generally limited to +/- 0.05 m.

The model was not particularly sensitive to the remaining parameters tested (i.e. less than a +/- 0.1 m impact).

The results of the sensitivity testing provides confidence that the model parameters selected accurately represent flood behaviour in the study area.

Conclusion

This flood study provides an understanding of the flood risk within the study area and provides the City of Newcastle with the tools for flood-related planning. This information and the flood models prepared for this flood study can be used to assess and recommend flood management strategies as part of a Floodplain Risk Management Study and Plan.



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Map G101

Throsby, Styx and Cotage Creek Flood Study

Study Area

Legend

- Study Area
- Rail Line
- Roads
- Watercourses (Creeks, Channels, and Drains)

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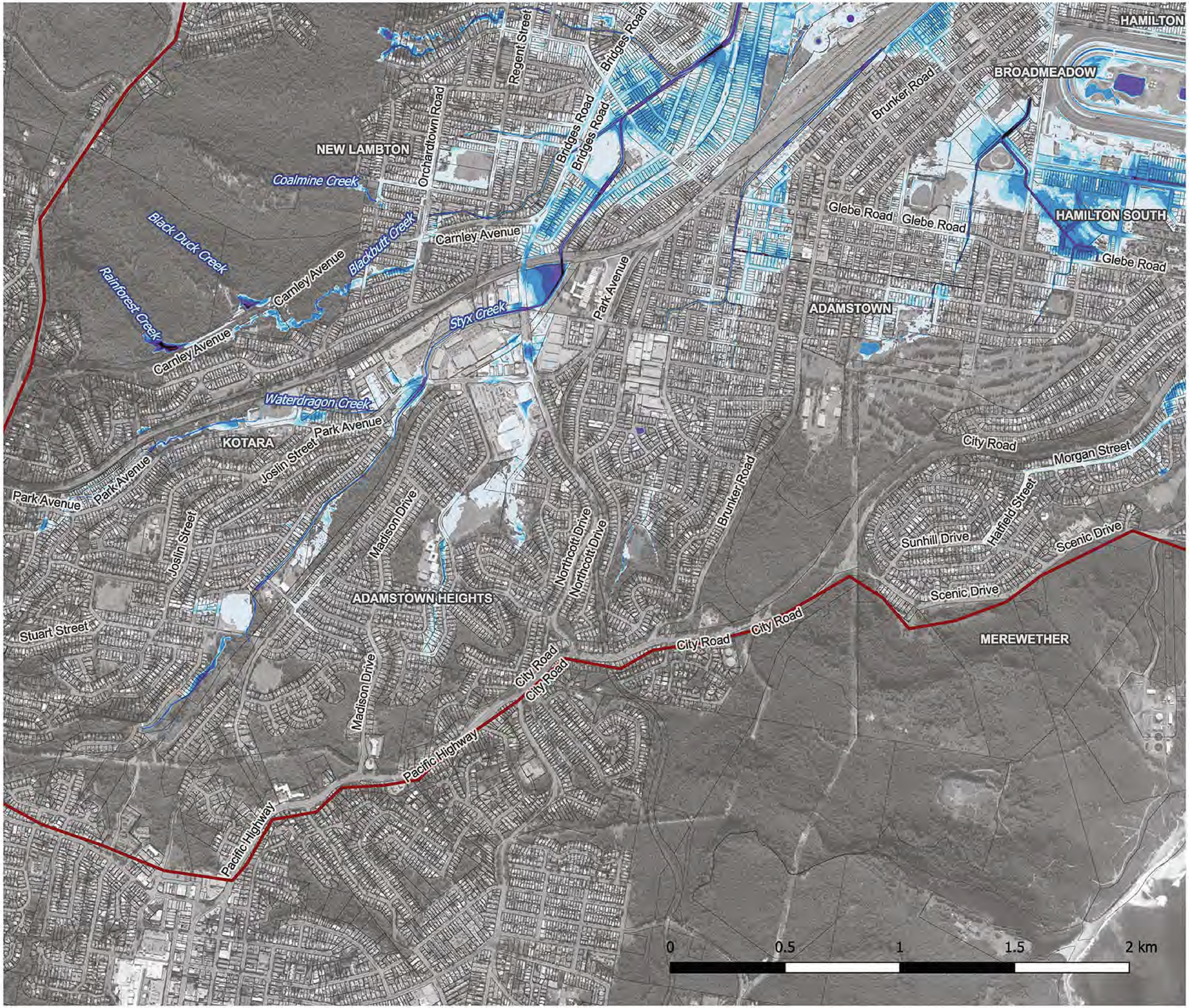

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Map G203a

Throsby, Styx and Cottage Creek Flood Study

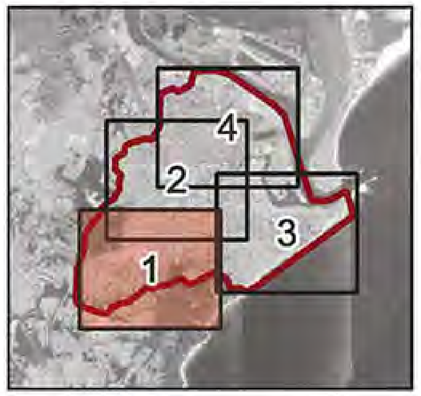
Modelled Flood Depth and Elevation
2007 Flood Event - Calibration
Map 1 of 4

Legend

- Study Area
- Cadastre

Peak Flood Depth (m)

- <= 0.01
- 0.01 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- 3 - 4
- > 4



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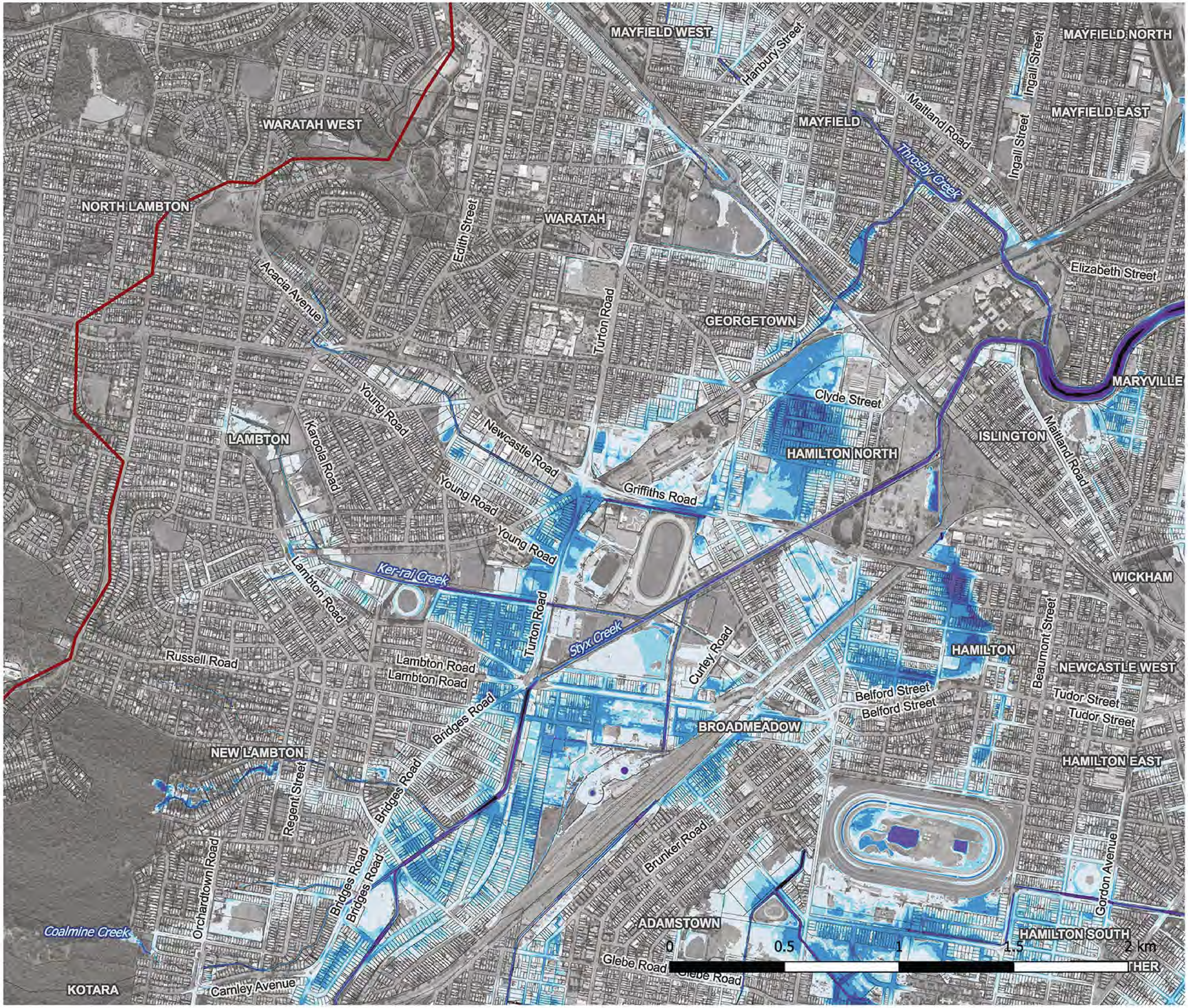

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Map G203b

Throsby, Styx and Cottage Creek Flood Study

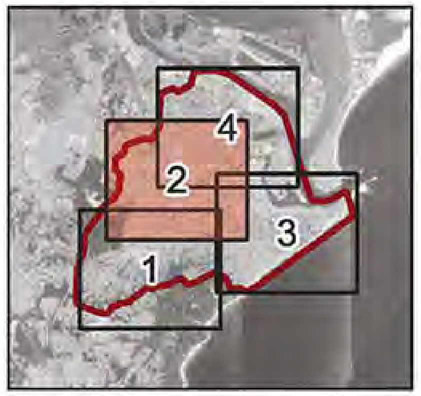
Modelled Flood Depth and Elevation
2007 Flood Event - Calibration
Map 2 of 4

Legend

- Study Area
- Cadastre

Peak Flood Depth (m)

- <= 0.01
- 0.01 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- 3 - 4
- > 4



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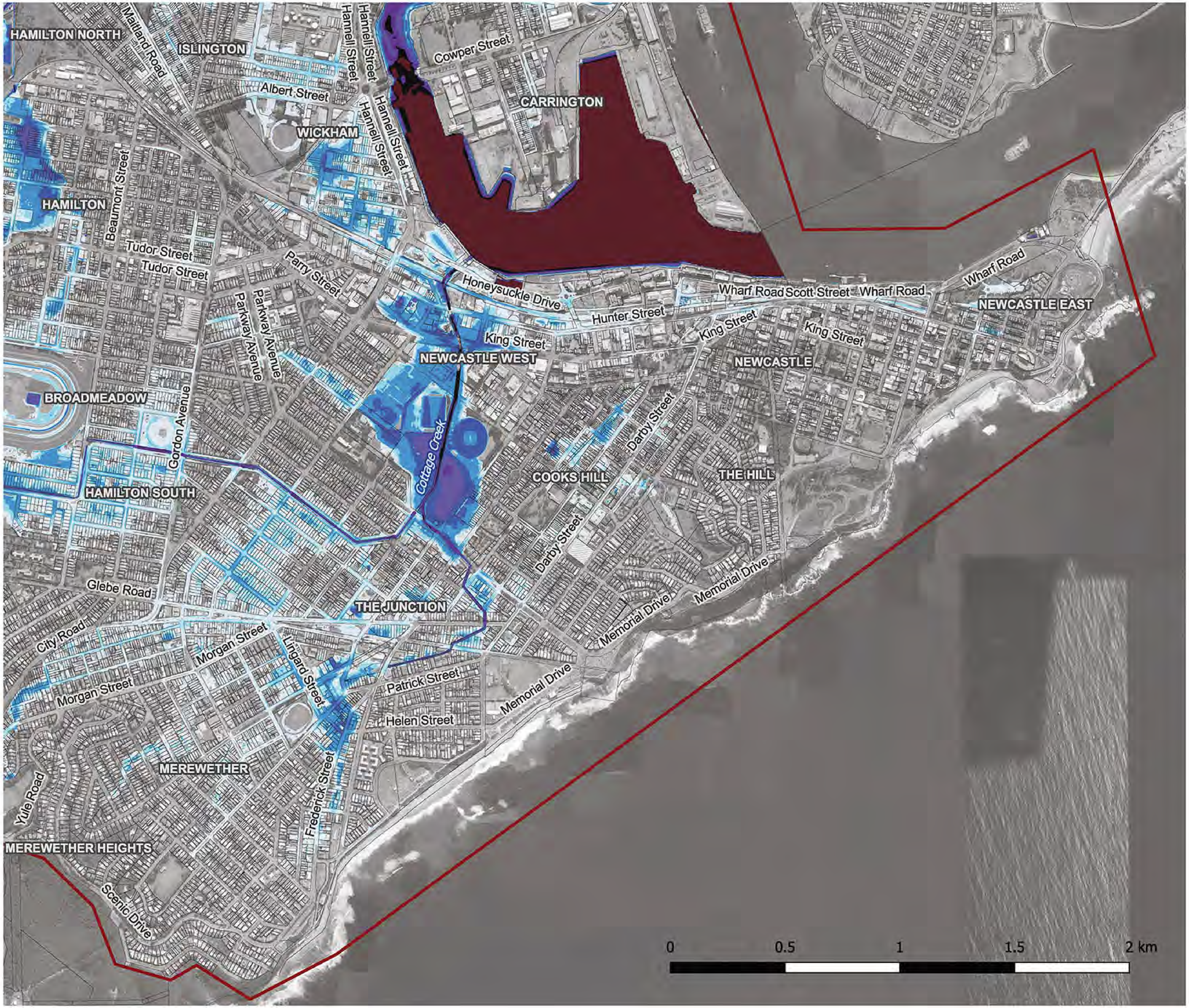

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Map G203c

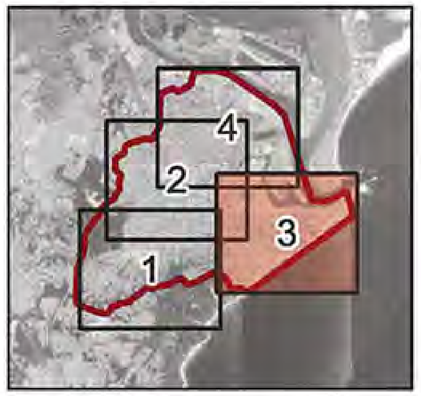
Throsby, Styx and Cottage Creek Flood Study

Modelled Flood Depth and Elevation 2007 Flood Event - Calibration Map 3 of 4

Legend

Study Area
Cadastre

Peak Flood Depth (m)
- <= 0.01
- 0.01 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- 3 - 4
- > 4



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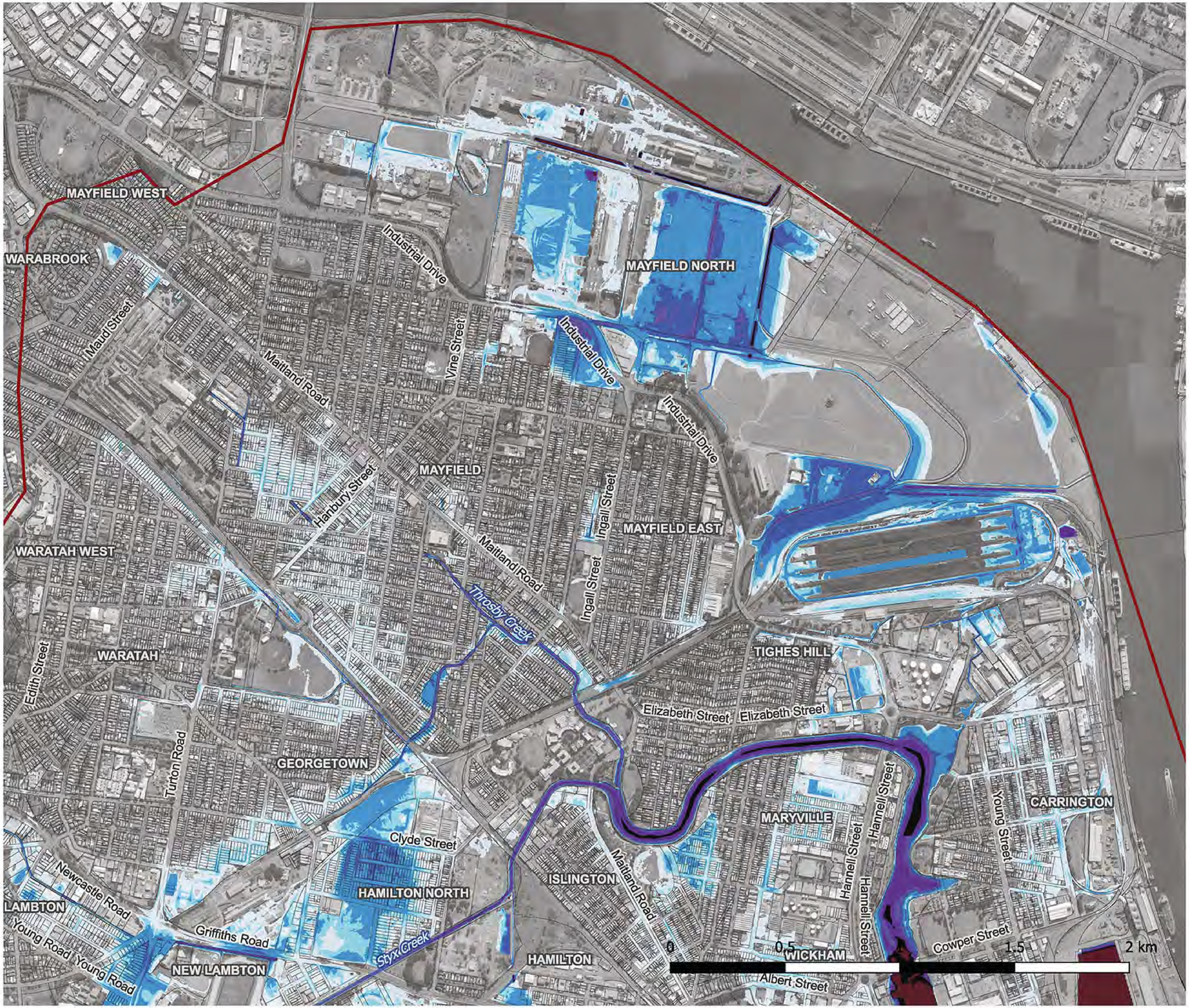

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Map G203d

Throsby, Styx and Cottage Creek Flood Study

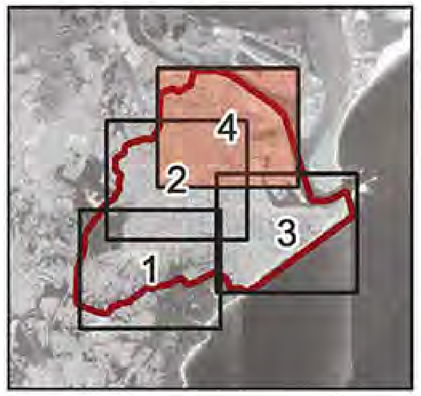
Modelled Flood Depth and Elevation 2007 Flood Event - Calibration Map 4 of 4

Legend

- Study Area
- Cadastre

Peak Flood Depth (m)

- <= 0.01
- 0.01 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- 3 - 4
- > 4



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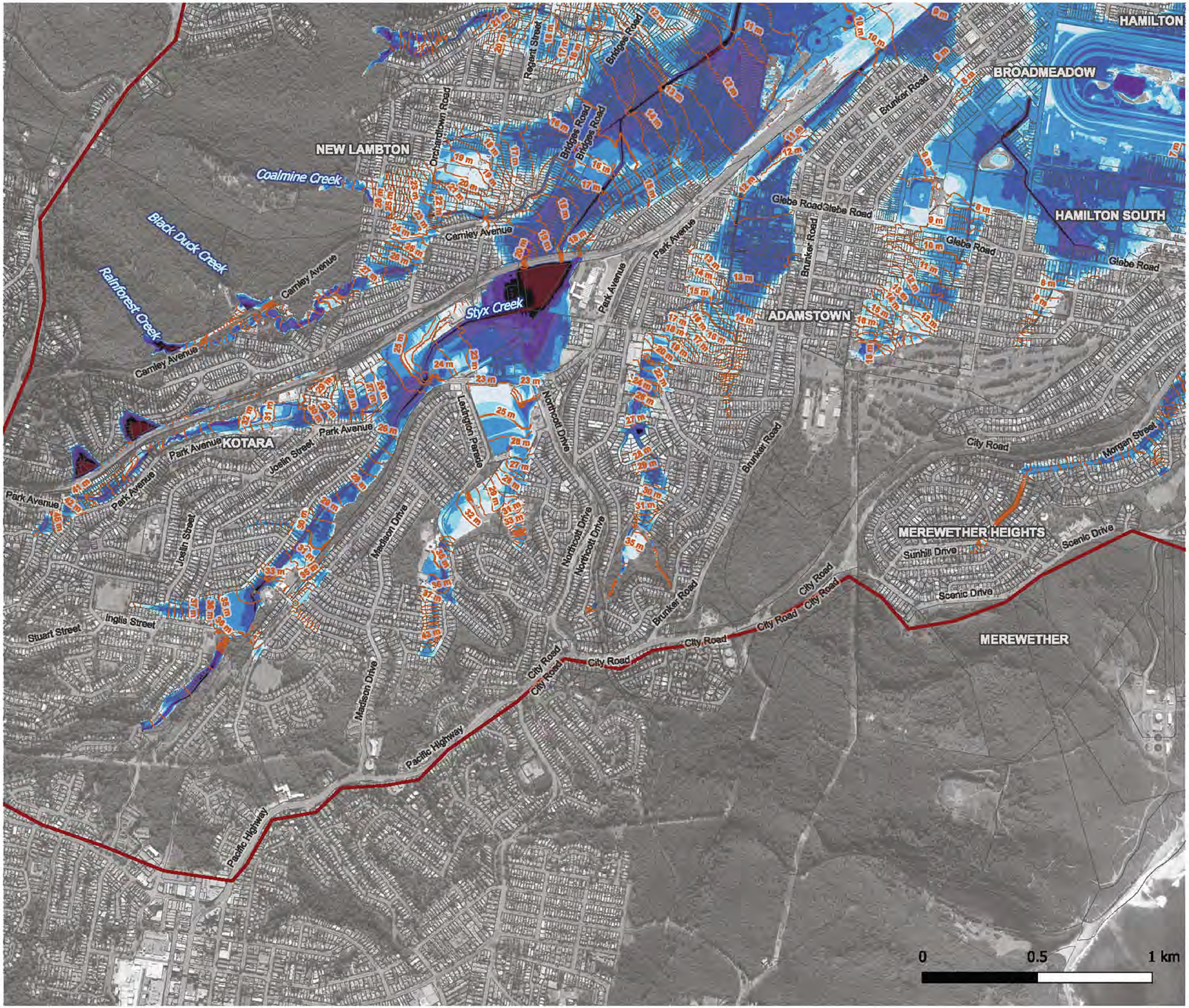

Map G308a

Throsby, Styx and Cottage Creek Flood Study

Peak Flood Depth and Elevation
PMF
Map 1 of 4

Legend

- Study Area
- Cadastre

Water Level Contours
- 5m
- 1m

Peak Flood Depth (m)
- <= 0.01
- 0.01 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- 3 - 4
- > 4

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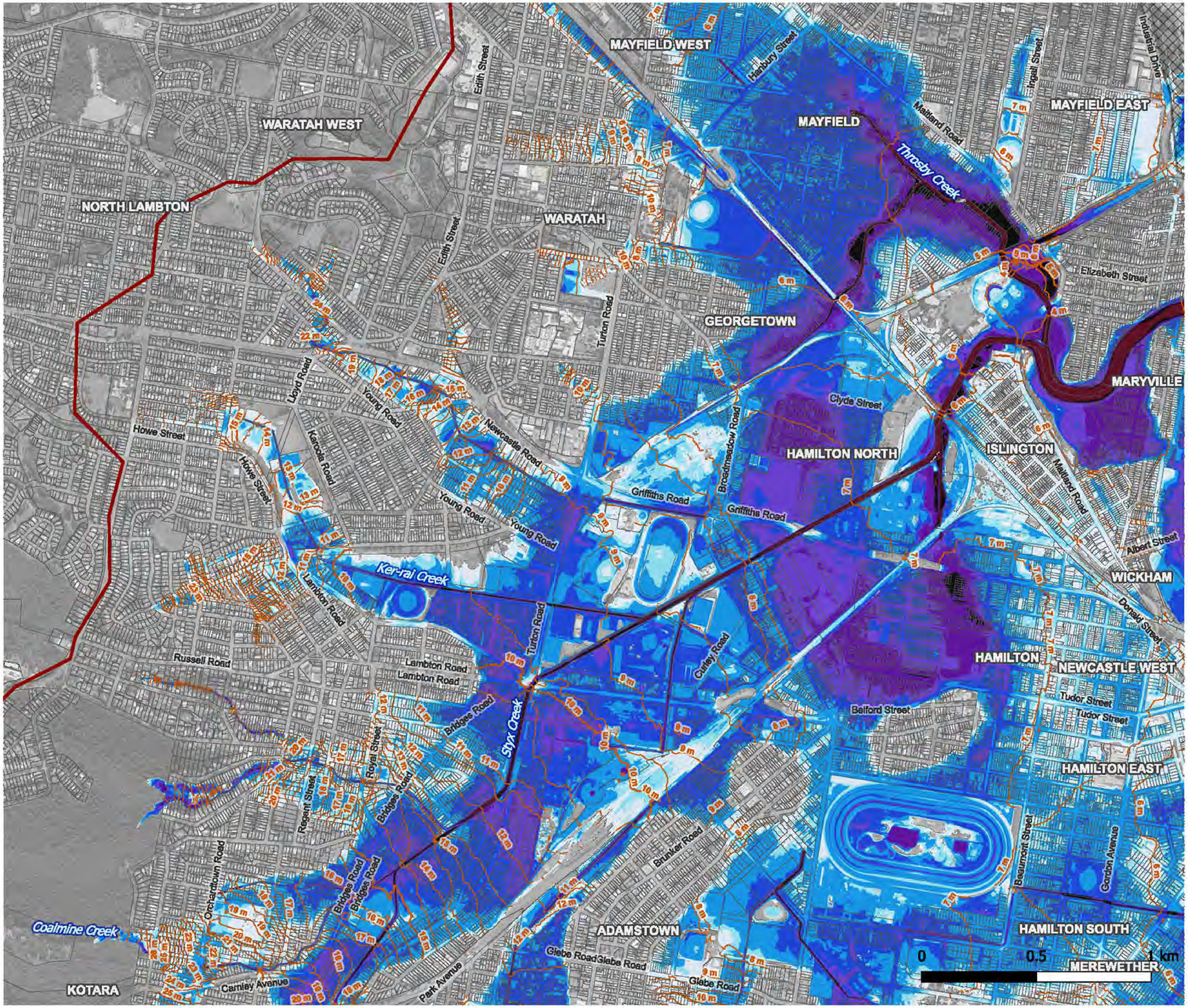


Map G308b

Throsby, Styx and Cottage Creek Flood Study

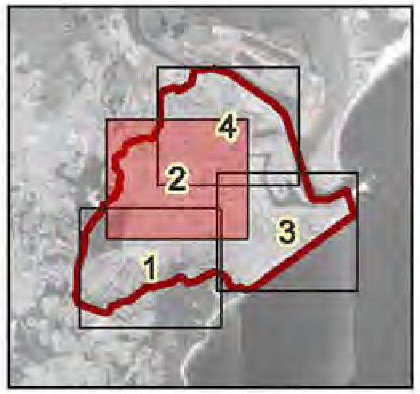
Peak Flood Depth and Elevation
PMF
Map 2 of 4

Legend

Study Area
Cadastre

Water Level Contours
5m
1m

Peak Flood Depth (m)
<= 0.01
0.01 - 0.3
0.3 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 3
3 - 4
> 4



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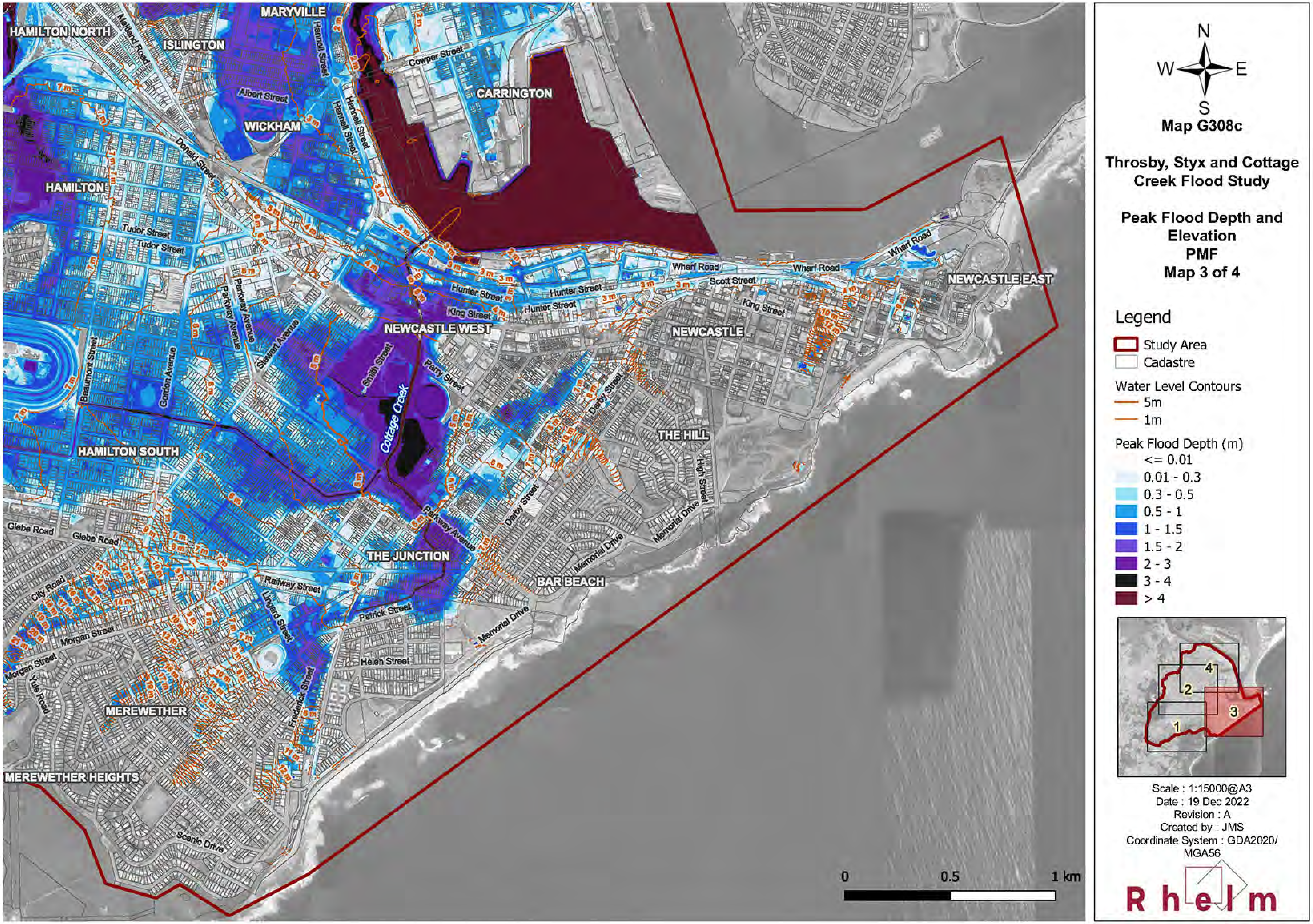

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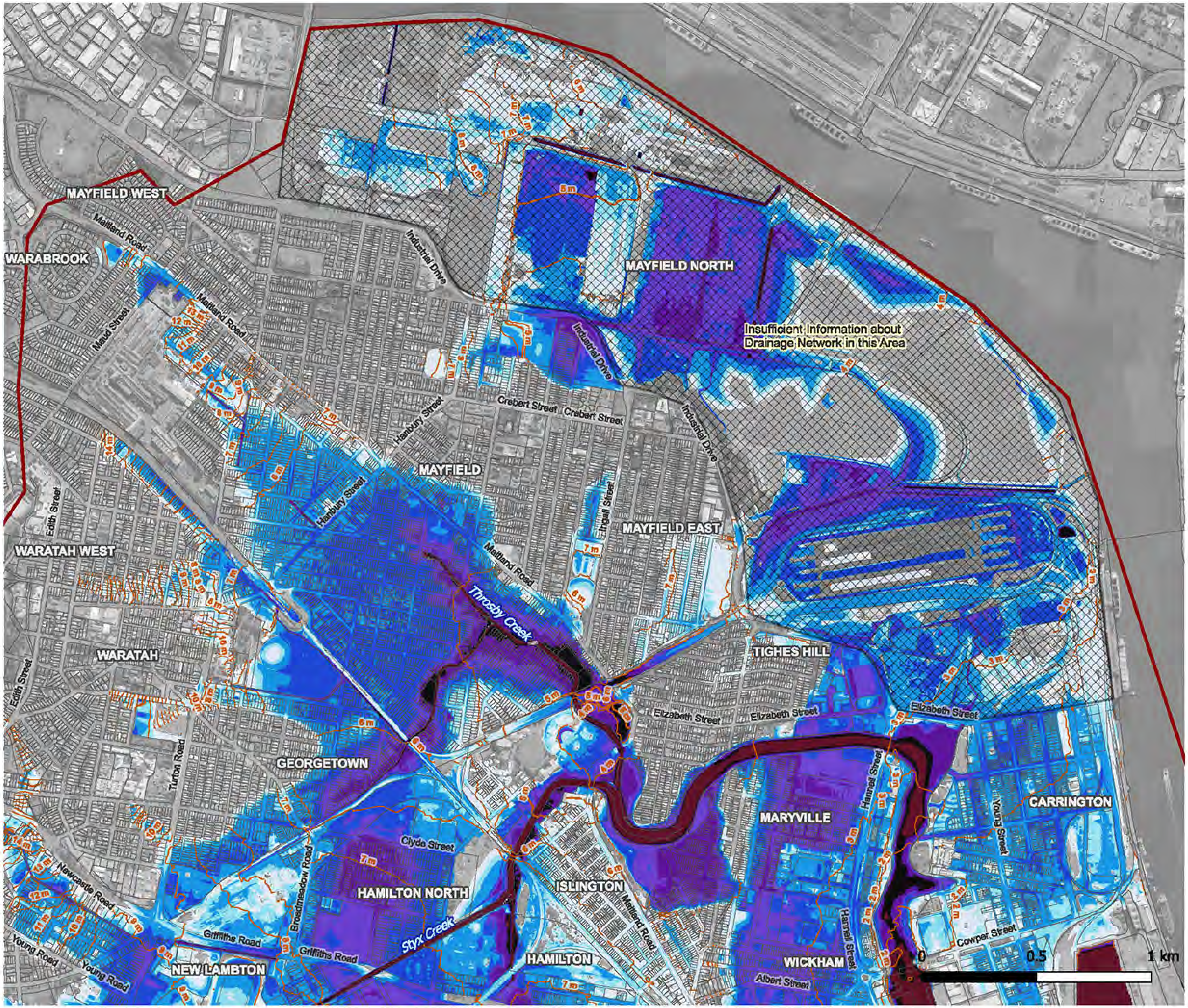
Map G308c
Throsby, Styx and Cottage Creek Flood Study
Peak Flood Depth and Elevation
PMF
Map 3 of 4
Legend
Study Area
Cadastre
Water Level Contours
5m
1m
Peak Flood Depth (m)
<= 0.01
0.01 - 0.3
0.3 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 3
3 - 4
> 4
Scale : 1:15000@A3
Date : 19 Dec 2022
Revision : A
Created by : JMS
Coordinate System : GDA2020/ MGA56
Rhelm
0
0.5
1 km
HAMILTON NORTH
MARYVILLE
ISLINGTON
CARRINGTON
WICKHAM
HAMILTON
NEWCASTLE WEST
NEWCASTLE
NEWCASTLE EAST
THE HILL
HAMILTON SOUTH
THE JUNCTION
BAR BEACH
MEREWETHER
MEREWETHER HEIGHTS
Cottage Creek



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Map G308d

Throsby, Styx and Cottage Creek Flood Study

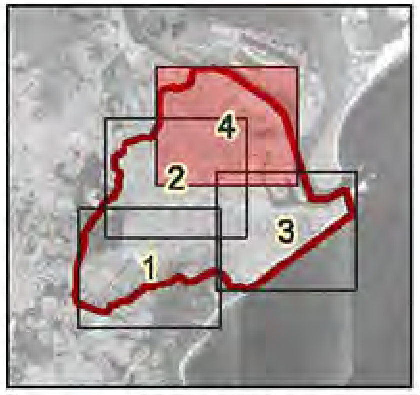
Peak Flood Depth and Elevation
PMF
Map 4 of 4

Legend

Study Area
Cadastre

Water Level Contours
5m
1m

Peak Flood Depth (m)
<= 0.01
0.01 - 0.3
0.3 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 3
3 - 4
> 4



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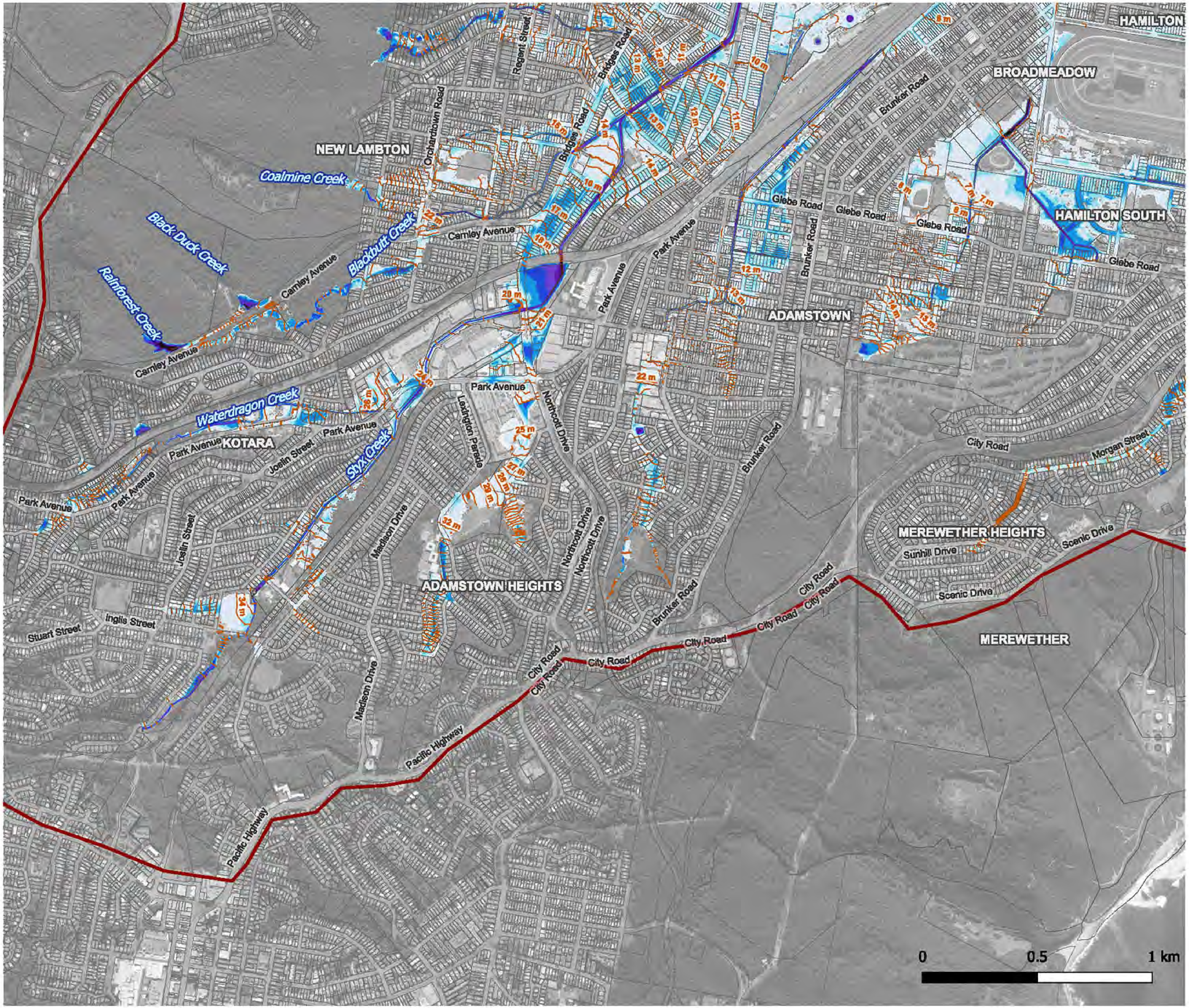

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Map G320a

Throsby, Styx and Cottage Creek Flood Study

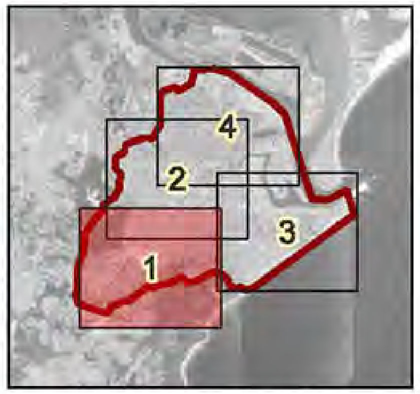
Peak Flood Depth and Elevation
1% AEP in 2050 (0.5% AEP, 0.4m SLR)
Map 1 of 4

Legend

Study Area
Cadastre

Water Level Contours
5m
1m

Peak Flood Depth (m)
<= 0.01
0.01 - 0.3
0.3 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 3
3 - 4
> 4



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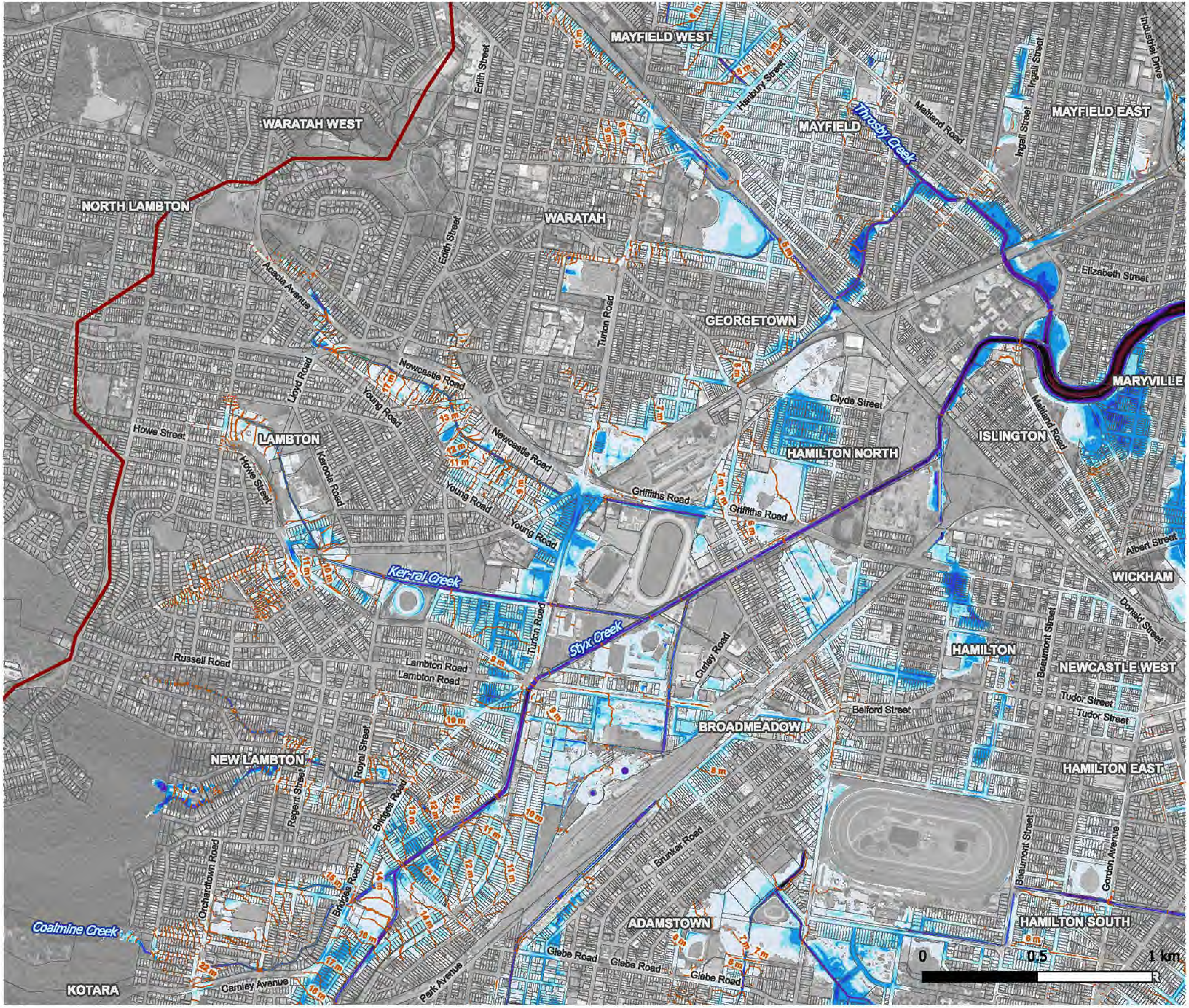

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Map G320b

Throsby, Styx and Cottage Creek Flood Study

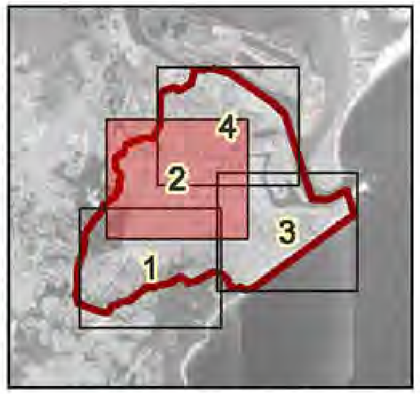
Peak Flood Depth and Elevation
1% AEP in 2050 (0.5% AEP, 0.4m SLR)
Map 2 of 4

Legend

- Study Area
- Cadastre

Water Level Contours
- 5m
- 1m

Peak Flood Depth (m)
- <= 0.01
- 0.01 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- 3 - 4
- > 4



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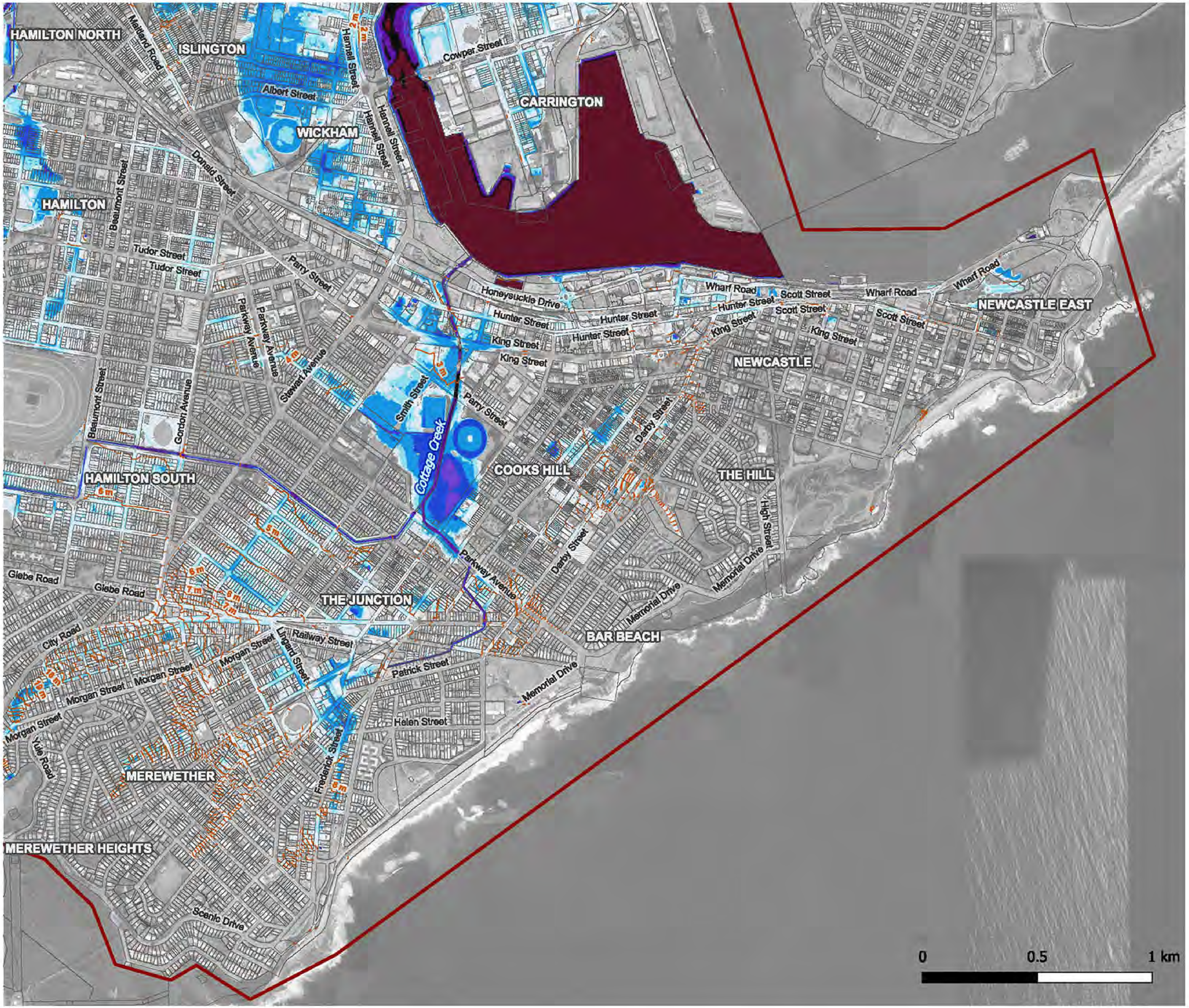


Map G320c

Throsby, Styx and Cottage Creek Flood Study

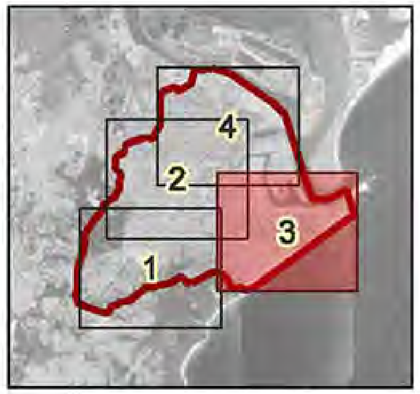
Peak Flood Depth and Elevation
1% AEP in 2050 (0.5% AEP, 0.4m SLR)
Map 3 of 4

Legend

- Study Area
- Cadastre

Water Level Contours
- 5m
- 1m

Peak Flood Depth (m)
- <= 0.01
- 0.01 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- 3 - 4
- > 4



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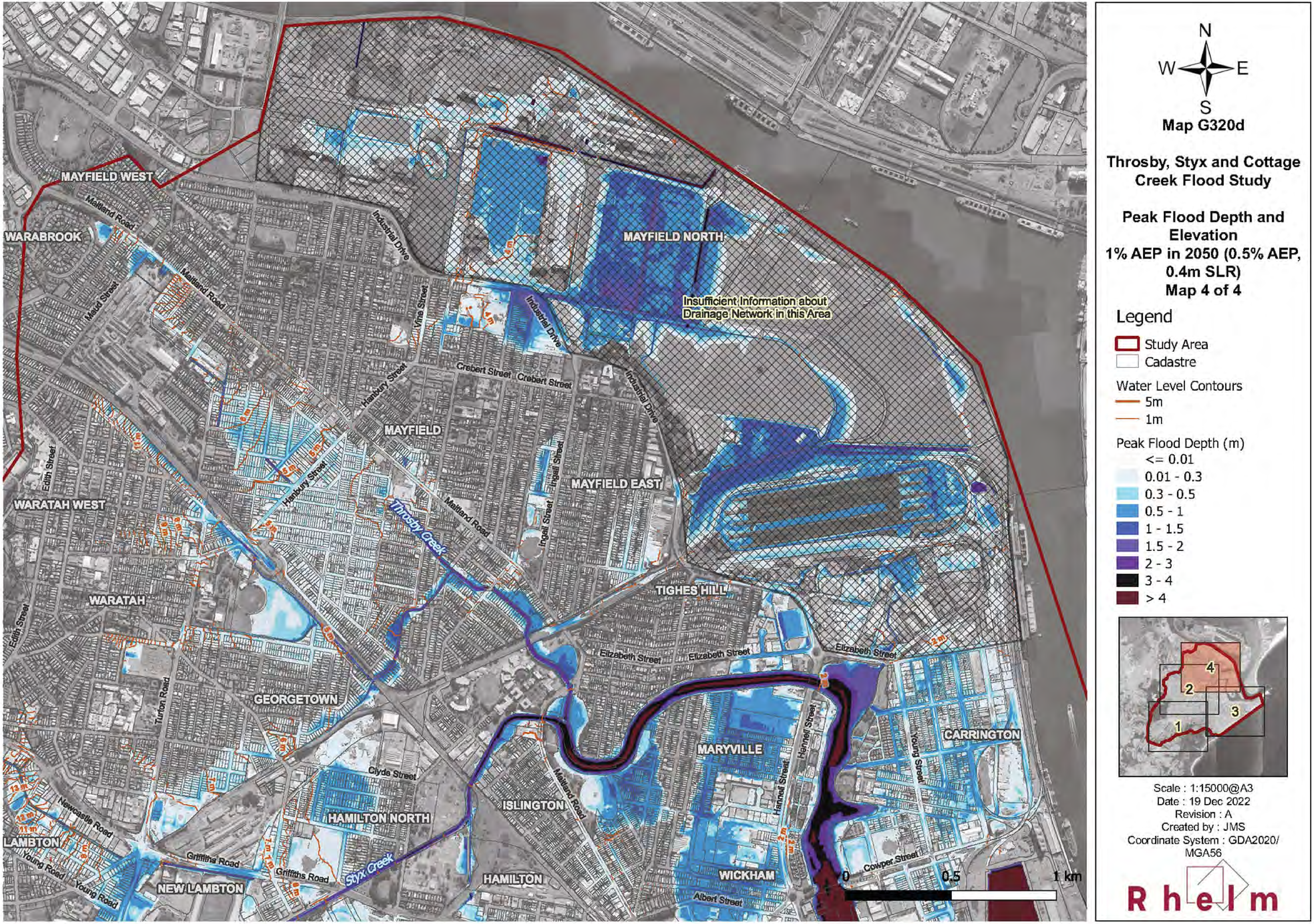
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Map G320d
Throsby, Styx and Cottage Creek Flood Study
Peak Flood Depth and Elevation
1% AEP in 2050 (0.5% AEP, 0.4m SLR)
Map 4 of 4
Legend
Study Area
Cadastre
Water Level Contours
5m
1m
Peak Flood Depth (m)
<= 0.01
0.01 - 0.3
0.3 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 3
3 - 4
> 4
1
2
3
4
Scale : 1:15000@A3
Date : 19 Dec 2022
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Insufficient Information about Drainage Network in this Area
MAYFIELD WEST
WARABROOK
MAYFIELD NORTH
MAYFIELD
MAYFIELD EAST
WARATAH WEST
WARATAH
TIGHES HILL
GEORGETOWN
CARRINGTON
MARYVILLE
ISLINGTON
HAMILTON NORTH
LAMBTON
NEW LAMBTON
HAMILTON
WICKHAM
Maitland Road
Industrial Drive
Maud Street
Vine Street
Crebert Street
Hanbury Street
Ingall Street
Edith Street
Throsby Creek
Elizabeth Street
Turton Road
Clyde Street
Newcastle Road
Young Road
Griffiths Road
Styx Creek
Hannell Street
Young Street
Cowper Street
Albert Street
0
0.5
1 km

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Glossary

Annual exceedance probability (AEP)	The chance of a flood of a given size (or larger) 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 (i.e. a 1 in 20 chance) of a peak discharge of 500 m^3/s (or larger) occurring in any one year (see also average recurrence interval).
Australian Height Datum (AHD)	National survey datum corresponding approximately to mean sea level.
Catchment	The catchment, at a particular point, is the area of land that drains to that point.
Defined Flood Event (DFE)	The flood event selected as a general standard for the management of flooding to development. This aims to reduce the frequency of flooding but does not remove all flood risk.
Design flood	A hypothetical flood representing a specific likelihood of occurrence (for example the 1% AEP flood).
Development	In accordance with the Environmental Planning and Assessment Act 1979, development is considered to be: the use of land, the subdivision of land, the rection of a building, the carrying out of a work, the demolition of a build or work, or any other act, matter or thing that may be controlled by an environmental planning instrument.
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).
Flood	Relatively high river or creek flows, which overtop the natural or artificial banks, and inundate floodplains and/or coastal inundation resulting from super elevated sea levels and/or waves overtopping coastline defences.
Flood fringe	Land that may be affected by flooding but is not designated as floodway or flood storage.
Flood hazard	An assessment of how hazardous the physical conditions produced by a flood can be to people, cars, infrastructure and buildings if they were exposed to the flood event, independent of the population at risk. The degree of flood hazard varies with circumstances across the full range of flood events.
Flood level	The height or elevation of floodwaters relative to a datum (typically the Australian Height Datum). Also referred to as “stage”.
Floodplain	Area of land which is subject to floods up to and including the probable maximum flood.
Flood planning level (FPL)	The level of the defined flood event plus an additional freeboard as advocated in the Flood Risk Management Manual. For purposes of this study, the design flood is the 1% 2050 Annual Exceedance Probability flood, and the freeboard is generally 500mm.

Flood prone land	Land susceptible to inundation by the probable maximum flood (PMF) event. Under the merit policy, the flood prone definition should not be seen as necessarily precluding development. Floodplain Risk Management Plans should encompass all flood prone land (i.e. the entire floodplain).
Flood storage	Floodplain area that is important for the temporary storage of floodwaters during a flood.
Floodway	A flow path (sometimes artificial) that carries significant volumes of floodwaters during a flood.
Freeboard	A factor of safety usually expressed as a height above the adopted defined flood event level thus determining the flood planning level. Freeboard tends to compensate for factors such as wave action, localised hydraulic effects and uncertainties in the design flood levels.
Gauging (tidal and flood)	Measurement of flows and water levels during historic tides or flood events.
Hazard	A source of potential harm or a situation with a potential to cause loss.
Historical flood	A flood that has actually occurred.
Hydraulic	The term given to the study of water flow in rivers, estuaries and coastal systems, in particular the evaluation of flow parameters such as water level and velocity.
Hydrograph	A graph showing how a river or creek's discharge changes with time.
Hydrologic	Pertaining to rainfall-runoff processes in catchments.
Hydrology	The term given to the study of the rainfall-runoff process in catchments, in particular, the evaluation of peak flows and flow volumes. .
Isohyet	Equal rainfall contour.
Peak flood level, flow or velocity	The maximum flood level, flow or velocity that occurs at a specified location during a flood event.
Pluviometer	A rainfall gauge capable of continuously measuring rainfall intensity.
Probable maximum flood (PMF)	An extreme flood deemed to be the maximum flood that could conceivably occur. Usually as a result of probable maximum precipitation.
Probable maximum precipitation (PMP)	The greatest depth of precipitation (rainfall) for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of year. It is the primary input into the probable maximum flood.
Probability	A statistical measure of the likely frequency or occurrence of flooding.
Riparian	The interface between land and waterway. Literally means "along the river margins".
Runoff	The amount of rainfall from a catchment that actually ends up as flowing water in the river or creek.
Stage	See flood level.
Topography	The shape and elevation of the surface features of land.

Velocity	The speed at which the floodwaters are moving. A flood velocity predicted by a 2D computer flood model is quoted as the depth averaged velocity, i.e. the average velocity throughout the depth of the water column. A flood velocity predicted by a 1D or quasi-2D computer flood model is quoted as the depth and width averaged velocity, i.e. the average velocity across the whole river or creek section.

Terminology in this Glossary has been adapted from the Flood Risk Management Manual (DPE, 2023) where available.

Abbreviations

1D	One Dimensional
2D	Two Dimensional
AHD	Australian Height Datum
AEP	Annual Exceedance Probability
ARR	Australian Rainfall and Runoff
ARR2019	Australian Rainfall and Runoff 2019
BoM	Bureau of Meteorology
CBD	Central Business District
DEM	Digital Elevation Model
DFE	Defined Flood Event
DPE	Department of Planning and Environment
FPL	Flood Planning Level
FRMP	Floodplain Risk Management Plan
FRMS	Floodplain Risk Management Study
Ha	hectare
Km	kilometres
km^2	square kilometres
LGA	Local Government Area
LiDAR	Light Detection and Ranging
m	metre
m^2	square metres
m^3	cubic metres
m AHD	metres to Australian Height Datum
mm	millimetres
m/s	metres per second
NSW	New South Wales
OEH	Office of Environment and Heritage (NSW)
PMF	Probable Maximum Flood
SES	State Emergency Service (NSW)

1 Introduction

The Throsby, Styx and Cottage Creek Flood Study has been prepared for the City of Newcastle to define flood behaviour within the Throsby, Styx and Cottage Creek catchments and the Newcastle central business district (CBD).

1.1 Study Background

Historically, a significant portion of Newcastle has been developed on a floodplain and is subject to flooding. This flooding has been exacerbated by the modification of existing creeks into undersized concrete lined channels which, at the time of construction, were designed using now outdated practices. These lined channels are known to overtop their banks relatively frequently and flows are directed into the surrounding streets and properties. Compounding the flooding problem is the occurrence of elevated sea levels during storm events associated with weather systems along the coast of NSW.

Multiple flood investigations have been undertaken in the past, both from an individual development and catchment wide perspective. The previous flood study covering the study area was the *Throsby, Cottage and CBD Flood Study* (BMT WBM, 2008a). However, due to updates to flood assessment methodologies and modelling techniques, design flood levels may be different than those adopted in the 2008 flood study resulting in the need to produce a revised flood study (this document). This revised flood study utilises the most recent methodologies outlined in Australian Rainfall and Runoff 2019 (ARR2019), contemporary modelling techniques and technologies, and incorporates additional rainfall and flooding data gathered after the completion of the 2008 flood study.

Although the study area is already highly urbanised, it is expected that the city's population will continue to increase in the coming decades, and with this there will be pressure on housing in the form of new infill developments and generally an overall increase in catchment imperviousness. In addition to this, since the 2008 flood study was published, significant development has occurred (and continues to progress) in Newcastle, particularly within the central business district, Newcastle West, Wickham and Broadmeadow. The foreshore areas have especially been subject to redevelopment as the city transitions from its industrial heritage towards a more modern urban environment.

1.2 Project Objectives

The objective of this flood study is to:

- improve understanding of flood behaviour,
- improve understanding of flood impacts,
- improve community resilience to climate change impacts, and
- better inform management of flood risk in the study area in consideration of the available information and relevant standards and guidelines.

This study provides an understanding of, and information on, flooding and flood risk to inform:

- The community, including residents, businesses and visitors,
- Flood risk management planning for existing and future development,
- Impact of climate change enabling planning response to improve community resilience,
- Relevant government information systems,
- Government and strategic decision makers on flood risk,

- Strategic and development scale flood risk management planning to reduce risk to life and property for existing and future development, and
- Other key stakeholders on flood risk, including utility providers, emergency response providers, and the insurance industry.

Outputs of the study provide a better understanding of:

- Flood behaviour in the study area,
- Impacts for a range of flood events on the existing community,
- Impacts of climate change on flood risk.

These outputs will inform decision making for investing in the floodplain in the management of flood risk through prevention, preparedness, response and recovery activities.

The end users of this study have varying needs and the outcomes aim to support this. These key end user groups are:

- High-level strategic decision makers,
- Community members (residents, businesses, visitors, etc.),
- Flood risk management professionals,
- Engineers involved in designing, constructing and maintaining mitigation works,
- Emergency management planners,
- Emergency services such as the State Emergency Services and Office of Emergency Management,
- Land-use planners for strategic planning and planning controls,
- Hydrologists and meteorologists involved in flood prediction and forecasting,
- Insurers, and
- Developers.

2 Study Area

The study area includes the catchments of Throsby Creek, Styx Creek and Cottage Creek. These combined catchments are bounded by the Hunter River to the North, the coastline to the east, Scenic Drive and the Pacific Highway to the South and Lookout Road to the west. It includes the Newcastle CBD, Merewether, Kotara, Broadmeadow. Mayfield and Carrington. The total study area is approximately 52 km^2. Refer to **Figure 2-1** for the study location and **Figure 2-2** for the general study area.

Flooding in the Newcastle local government area (LGA) can be caused by three main sources:

- Catchment flooding - the focus of this Flood Study
- Hunter River flooding
- Ocean storm flooding.

Often significant flooding occurs when two or more of these sources of flooding coincide within the study area. Although this is not a prerequisite.

Multiple flood events have been recorded in the study area, dating back to the early 1800s; however, pertinent to this study are three recent events where rainfall on the catchment contributed significantly to flooding:

- June 2007 ('Pasha Bulker' storm). Over 300 mm of rainfall within 24 hours and high levels of blockage along channels.
- February 1990. Approximately 300 mm of rainfall over a 48 hour period.
- April 1988. Varied rainfall across the catchment, with up to 141 mm over a 48 hour period.

The catchments of the three main creeks considered in this study are highly urbanised with only a few smaller portions of their upper catchments still retaining bushland. Furthermore, the form of the creeks have historically been converted from natural creeks in low lying swamp areas to concrete lined channels, culverts and pipes. Most sections of these urbanised creeks have been under designed and flood flows can break out into residential, commercial and industrial areas during flood events as frequent as the 10% AEP event. Compounding the flood risk issue, in some locations the channel has been piped under urban areas with no direct overland flow path retained and private structures have been constructed close to channel edges.

Figure 2-1. Study Location

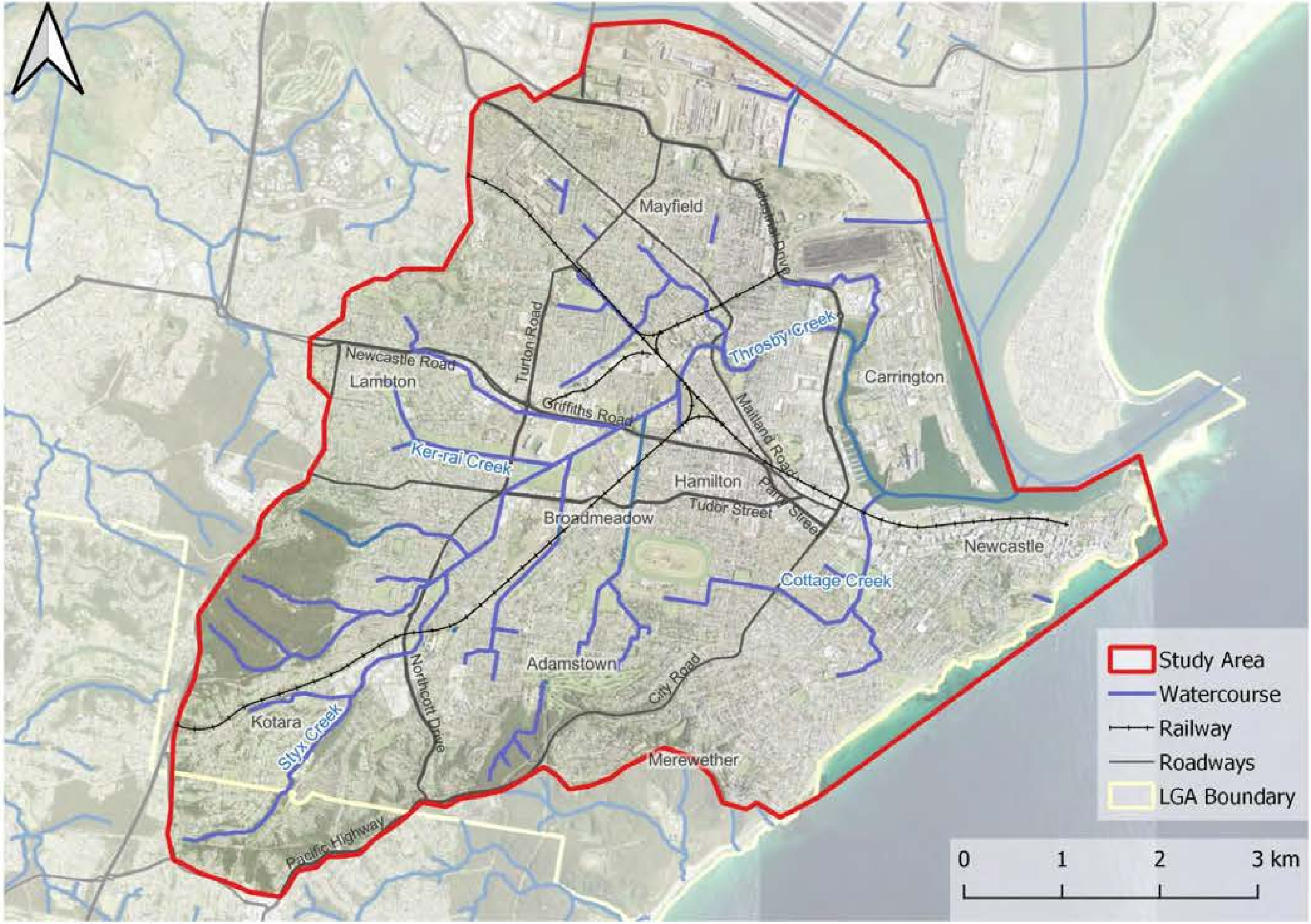

Figure 2-2. Study Area

3 Review of Available Data

There have been a number of studies previously undertaken within the catchment, covering either the overall catchment or smaller sub-sections. These, together with more up to date information, formed the basis for flood modelling as part of this project.

The available data reviewed for this current study includes:

- Previous studies and reports – various reports and studies that have been undertaken within the study area
- Previous flood modelling – flood models that have been developed within the study area, generally to support the above studies and reports
- Calibration Data – information available for the calibration and verification of the flood models, including observations of flooding from historical events
- Survey information – available survey for the study area
- GIS data – spatial information available for the study area
- Future development – information on future developments within the floodplain.

3.1 Previous Studies and Reports

A number of studies have been previously undertaken that are relevant to the preparation of this flood study. The studies provide information on available data, historical flood behaviour as well as previous estimates of design flood behaviour. These studies have informed the establishment of the hydrologic and hydraulic models used to define flood behaviour in this flood study. A list of these studies is given in **Table 3-1** and corresponding map giving the approximate locations of smaller studies in **Map G102**.

In addition to the reports, various data and models from these studies have also been provided and are detailed in the subsequent sections.

Table 3-1. Previous Studies, Reports and Drawings

Document	Relevance to Study
Newcastle City-Wide Flood Studies, Data Collection Studies (WBM Oceanics, 2000)	This study outlines the data collected for historic flooding events in the Newcastle area at the time of publication. Specific data contained within the report and associated GIS files includes: • Previous flood level data including source, date, levels, depths, and data value grade. • Approximate flood extents of the 1988 and 1990 events. • Historic flood photos (taken during the flood events) and photos taken during the flood level survey collection. • Locations and metadata of streamflow, water level and rainfall gauges. Not all gauges were operated in the proposed calibration and validation events. No gauge data was included. This information has been utilised for validation modelling of flood levels throughout the study area.

Document	Relevance to Study
Throsby, Cottage and CBD Flood Study (BMT WBM, 2008a)	This is the previous flood study completed for the majority of the study area and is a key reference for the current project. It did not include in its study area Mayfield North, Newcastle East or the smaller coastal catchments draining to Merewether Beach, Bar Beach and Newcastle Beach (which are included in the current Flood Study area). The study's purpose was to define flood behaviour within the study area. A WBNM hydrologic model and 1D/2D TUFLOW hydraulic model were established and calibrated to the 1990 flood event and validated with the 1988 flood event. Note that the hydrologic calibration was indirect, as no appropriate stream flow gauge data were available for these events. Raw tabular data for gauges (rainfall, streamflow, water level) in the study area were not included in the report or associated data transfer. This information is only shown as graphs and figures in the report, although rainfall data has been received from Hunter Water to inform the current Flood Study. Streamflow and tidal data were digitised for use in this current Flood Study. Design storm events were modelled for the 50%, 20%, 10%, 5%, 2%, 1%, and 0.5% AEP events as well as the PMF. These design events were defined using the then current version of Australian Rainfall and Runoff 1987. The current Flood Study is being prepared as an update to the 2008 flood study. The 2008 flood study report has been essential in assisting with identifying existing flooding issues, model schematisation and previous model calibration parameters. This study was used for general context of the Throsby, Styx and Cottage Creek Flood Study, as well as identifying existing flooding issues, issues with calibration and validation of the previous modelling, and data availability for the calibration and validation events.
Newcastle Flash Flood, 8 June 2007 (the Pasha Bulker Storm) Flood Data Compendium (BMT WBM, 2008b)	This report summarises the 2007 flood event in which severe flooding was experienced in Newcastle LGA and surrounding areas. It also details the post-event data gathering exercises and the results of these. It includes a detailed description of the impacts of the event based on photographs, surveyed flood marks, and interviews and questionnaires returned from the community. Modelling, using the previously established 2008 flood study TUFLOW model, was undertaken to estimate flood behaviour of the 2007 event. A full set of compendium documentation was provided to the City of Newcastle. This study was useful for identifying and categorising all of the historical flood data received for the July 2007 event.
Lower Hunter River Flood Study (DHI, 2008)	This report and associated mapping details the flood modelling of the lower Hunter River, from just upstream of Raymond Terrace to the port of Newcastle. Of particular interest to this flood study is the outcome that flood levels in Newcastle Harbour are generally governed by tidal conditions rather than discharge from the Hunter River. This study was used for general context of the Throsby, Styx and Cottage Creek Flood Study.
Analysis of Extreme Ocean Water Levels at the Hunter River Entrance (DHI, 2008)	This report outlines modelling methodologies and subsequent design flood levels at the entrance of the Hunter River to the Pacific Ocean (i.e. within Newcastle Harbour). Flood planning levels from oceanic flooding are based on the results of this study.

Document	Relevance to Study
Newcastle City-Wide Floodplain Risk Management Study and Plan (BMT WBM, 2012)	This study was completed following the 2008 flood study. It also included information on the 2007 storm event. The study outlines the existing flood risk to the study area from the Hunter River, ocean flooding and catchment flooding. It also gives an account of the historical flooding in the area. Multiple options for mitigation of flood risk are included, as well as a plan for the City of Newcastle to implement the options. This study was used for general context of the Throsby, Styx and Cottage Creek Flood Study.
Wharf Road Catchment – Newcastle East, Drainage Study (Royal HaskoningDHV, 2014)	This was a drainage study undertaken within the east end of Newcastle. This study was used to cross check flood modelling results of the Throsby, Styx and Cottage Creek Flood Study.
Cooks Hill Drainage Study (Royal HaskoningDHV, 2015)	This is a drainage study within the Cooks Hills suburb of Newcastle. This study was not used to inform the Throsby, Styx and Cottage Creek Flood Study, outside of the model information provided and described in **Table 3-2**.
Westfield Kotara – Development Application for Eastern Mall Expansion (Northcott Avenue / Cynthia Street) Flooding Considerations (GCA Engineering Solutions, 2016)	This letter report outlines the flooding consideration for expansion of the Westfield Kotara, including details on flooding through the ground floor level carpark. This information included drawings which were used to roughly inform the flowpath though the carpark in the Throsby, Styx and Cottage Creek Flood Study flood modelling.
Newcastle Light Rail Detailed Design Report, System Wide – Flood Study (WSP/Parsons Brinkerhoff, 2017)	This study determines the catchment flood risk and climate change flood risk along the light rail corridor through Newcastle, as well as determining the off-site impacts from the development. This study assisted in identifying the extent of the light rail network in the Newcastle CBD.
Newcastle International Hockey Stadium – Flood Study (BMT WBM, 2018)	This letter report details the impacts on flood behaviour of the proposed works in Broadmeadow. This study was not used to inform the Throsby, Styx and Cottage Creek Flood Study.
Honeysuckle Redevelopment Area Flood Study (BMT WBM, 2018)	This study was provided for the Hunter Development Corporation to update flood risk for the Honeysuckle Redevelopment Area where Cottage Creek outlets into Newcastle Harbour. This study assisted in identifying the future Honeysuckle development areas.
Darby Plaza, Newcastle, Flood Impact Assessment (BMT WBM, 2019)	This report details the impacts on flood behaviour of the proposed private development works at the corner of Hunter Street and Darby Street. This study was used in the Throsby, Styx and Cottage Creek Flood Study to inform the stormwater network data (pits and pipes) in the flood model.
Newcastle Knights Centre of Excellence Flood Impact Assessment (BMT WBM, 2019)	This report details the impacts on flood behaviour of the proposed development works at MacDonald Jones Stadium and District Park, adjacent to Styx Creek. This study was not used to inform the Throsby, Styx and Cottage Creek Flood Study.

Document	Relevance to Study
Newcastle Knights Centre of Excellence Development Application Drawings (GHD, 2019)	This drawing set outlines the proposed Newcastle Knights Centre of Excellence development, but only the carpark area has details shown. It does give an overall indication of the extent of the development. This study was not used to inform the Throsby, Styx and Cottage Creek Flood Study.
Summary Report on the Assessment of the Mayfield East Catchment (Urban Water Sycle Solutions, 2019)	This study assessed the drainage and flooding behaviour and issues in East Mayfield, as well as provide advice on mitigation of these drainage problems. In particular, the report highlights the flooding is dependent on runoff volume and storages in the catchment, as well as blockage along the rail corridor. This study assisted in understanding the underlying causes for flooding in Mayfield and to cross check flood modelling results of the Throsby, Styx and Cottage Creek Flood Study.
Newcastle Light Rail, As-Built Drawings (Aurecon, 2019)	These drawings contain some of the as-built drainage information for the Newcastle Light Rail, inclusive of long-sections detailing pipe inverts and sizes. This study was not used to inform the Throsby, Styx and Cottage Creek Flood Study.
Nesca Park Detention Basins – Dam Safety Assessment (Royal HaskoningDHV, 2020)	This is a follow-on report from the Cooks Hill Drainage Study (Royal HaskoningDHV, 2015) detailing the dam safety assessment of proposed detention basins in Nesca Park. A TUFLOW model has also been provided with this study. This study was used in the Throsby, Styx and Cottage Creek Flood Study to inform the stormwater network data (pits and pipes) in the flood model.
2021 Broadmeadow Rezoning Workshop	This one-page map shows the potential proposed zoning for the redevelopment of Broadmeadow. This study was not used to inform the Throsby, Styx and Cottage Creek Flood Study.
Hunter Street Mall Streetscape Revitalisation Package – Detailed Design (Northrop, 2021)	This civil works package details some of the proposed civil works for the Hunter Street Mall. It does contain some proposed stormwater drainage works, although none of this has been constructed as of the date of this Flood Study report. This study was not used to inform the Throsby, Styx and Cottage Creek Flood Study.

3.2 Previous Flood Modelling

As part of this study, the City of Newcastle has provided a number of flood models covering the study area which have been completed to inform flood risk and evaluate potential flood mitigation works in the past. These models assisted in the development of the current hydrologic and hydraulic model development by providing model inputs and parameters.

In particular, the WBNM hydrological model and TUFLOW hydraulic model from the *Throsby, Cottage and CBD Flood Study* (BMT WBM, 2008a) formed the basis of modelling for this Flood Study. It has a similar model extent and purpose.

Table 3-2 outlines the details of models collated and information relevant to this current study.

Table 3-2. Previous Flood Modelling and Data

Associated Report	Model Types	Results Provided?	Relevant Information for Current Flood Study
Throsby, Cottage and CBD Flood Study (BMT WBM, 2008a)	Hydrology – WBNM Hydraulics – TUFLOW	Yes, (design events only)	• Forms the basis of data for the updated flood study modelling. All data is assumed to be suitable for re-use apart from where superseded data has been provided.
Cooks Hill Drainage Study (Royal HaskoningDHV, 2015)	Hydrology – Drains Hydraulics – TUFLOW	Yes	• Survey data of pit and pipe network. • Results can be used to check existing flooding in this area, if needed. • Assist to inform selection of hydraulic model parameters.
Hamilton Catchment Modelling (No associated report)	Hydraulic – TUFLOW	Yes (options only)	• Results can be used to check existing flooding in this area, if needed. • Assist to inform selection of hydraulic model parameters. • Supplement pit and pipe input data.

3.3 Calibration Data

3.3.1 Historical Flood Level Observations

3.3.1.1 Newcastle City-Wide Flood Studies, Data Collection Studies (WBM Oceanics, 2000)

This study, commissioned by the City of Newcastle, was undertaken to collect, analyse and present historical flood data for the Newcastle LGA. It was the first step in the process for producing the Newcastle City-Wide Floodplain Risk Management Study and Plan (BMT WBM, 2012), with this data collection providing the necessary information basis for the *Throsby, Cottage and CBD Flood Study* (BMT WBM, 2008a).

This data collection is provided in GIS format and covers the current study area, and critical to this study, provides a flood record data base for the 1988 and 1990 flood model validation events. Pertinent to this Flood Study, the information on the 1988 and 1990 events included in the data set are:

- Records of flooding – Location, source, description of flooding, certainty of date, survey photo, post-event photo, data value grading, and any associated flood damages. These are all provided in GIS format.
- Gauge Data – Rainfall data (daily and sub-daily rainfall), streamflow data, river level data. It is important to note that the GIS data included only identifies the gauge locations. The raw tabular data is not included, but identification of their location and operator is.
- Historical Flooding – A search of historical sources for documented flood data.
- Approximate extents for the 1988 and 1990 flood events.

3.3.1.2 Newcastle Flash Flood, 8 June 2007 (the Pasha Bulker Storm) Flood Data Compendium (BMT WBM, 2008b)

Following the June 2007 storm event (commonly associated with the grounding of the Pasha Bulker freight ship), which produced significant flooding within the study area, various government agencies commissioned the collection of data to document the storm's impacts.

This data compendium is extensive and covers multiple aspects of flooding and flood risk from the 2007 event. It contains information such as flood behaviour, gauge data, and photos, but also contains information on emergency services and flood risk including SES requests for assistance, community questionnaires, and news reports.

While there is a large amount of data included, the primary information which is used in this Flood Study from the 2007 Data Compendium includes:

- Meteorological Data:
  - Bureau of Meteorology:
    - Rainfall gauge data (hourly, 3-hour pluviograph, daily)
    - Rainfall maps
    - GIS radar data
  - Hunter Water:
    - Rainfall gauge data (pluviograph)
  - Manly Hydraulics Laboratory:
    - Water level gauge data for the Hunter River
  - Newcastle Port Corporation:
    - Tidal gauge data
- Flood Data Records:
  - Post-event or during event flood photos from multiple sources
  - GIS flood data points
  - Flooding questionnaire responses
  - Survey of flood marks (completed by BMT WBM and the City of Newcastle)
- GIS Data:
  - Bridge and culvert photos, locations and measurements
  - Hunter Water stormwater asset locations
  - Creek lines
  - Property boundaries
  - Various layers for map preparation.

The flood data records and meteorological data were interrogated further during the calibration model establishment stage (**Section 6**).

3.3.2 Rainfall Gauges

Refer to **Map G105** for locations of known rainfall gauges within the study area.

A total of 12 rainfall gauges within the study area were identified in the *Newcastle City-Wide Flood Studies, Data Collection Studies* (WBM Oceanics, 2000) and the *Newcastle Flash Flood, 8 June 2007 (the Pasha Bulker Storm) Flood Data Compendium* (BMT WBM, 2008b). In addition to this, nine others were located adjacent (within one or two kilometres) to the study area. Of these 21 rainfall gauges, three were not listed as being active during the 1988, 1990 or 2007 events.

Rainfall gauge operators include Hunter Water, the Bureau of Meteorology, and the University of Newcastle. Twelve of the gauges have pluviograph data while the rest record daily rainfall depths.

No isohyet information was included in the supplied information from the previously listed data sets, studies or associated models.

There were no rainfall gauge data provided for the 1988 and 1990 events in the Newcastle City-Wide Flood Studies, Data Collection Studies (WBM Oceanics, 2000). This information was sourced from Hunter Water in October 2021, although it only contained raw data and had not been reviewed or quality coded.

3.3.3 Downstream Water Level Gauges

Refer to **Map G105** for locations of known water level gauges within the study area.

Water level gauges within the Hunter River can provide an understanding of the downstream boundary conditions for the study area during historical flood events.

Water level gauges have been provided as part of the *Newcastle City-Wide Flood Studies, Data Collection Studies* (WBM Oceanics, 2000) and the *Newcastle Flash Flood, 8 June 2007 (the Pasha Bulker Storm) Flood Data Compendium* (BMT WBM, 2008b) along the Hunter River. Three of the four gauges are operated by Manly Hydraulics Laboratory including at the Hexham Bridge, Sandgate and Stockton Bridge. These locations are relatively close to the study area; however, Stockton Bridge is located along the North Arm of the Hunter River; Hexham Bridge is far enough upstream of the Hunter River to be influenced by discharge in the river, rather than raised ocean levels; and the gauge at Sandgate was only in operation during the early 1900s. Therefore, they may not be entirely representative of the downstream conditions for the study area.

The most representative downstream water level information comes from the Newcastle Port Corporation (now amalgamated into the Port Authority of NSW) sourced in the *Newcastle Flash Flood, 8 June 2007 (the Pasha Bulker Storm) Flood Data Compendium* (BMT WBM, 2008b). This contains tidal gauge information that is likely to be more representative. Although the data provided does not contain GIS data on its location, the BoM lists two gauge stations within the Port of Newcastle:

- Pilot Station, Newcastle (Primary – East)
- Pilot Station, Newcastle (Secondary – West).

Both of these stations are listed as being 1.5 km inside of the harbour break wall.

3.3.4 Flow Gauges

No flow gauges were provided as part of the data handover.

The 2008 Flood Study notes that streamflow gauge data was available from Hunter Water (locations at Litchfield Park, Bates Street, Jellicoe Parade, Jenner Parade and Bruce Street) but the actual level data may not be reliable with an unknown datum and high flood velocities interfering with readings. The water level data presented in the 2008 Flood Study has been used to qualitatively assess the timing of the discharge peaks at Jenner Parade.

3.4 Survey Information

3.4.1 Aerial Survey

A number of aerial survey data sets is available for the study area. These data sets are summarised in **Table 3-3**. These data sets cover the entirety of the study area.

Table 3-3. LiDAR Data and Reported Accuracy

Year	Source	Formats	Average Point Separation (m)	Horizontal Accuracy (m)	Vertical Accuracy (m)
2018	ELVIS website	Point cloud	Not reported	Not reported	Not reported
2014	ELVIS website	1 m DEM, Point cloud	1.7	0.8 @ 95% confidence interval	0.3 @ 95% confidence interval
2021	City of Newcastle	1 m DEM, Point cloud	Not reported	0.8 @ 95% confidence interval	0.1 @ 95% confidence interval

Where noted above, data is available on the ELVIS – Elevation and Depth – Foundation Spatial Data website (https://elevation.fsdf.org.au/).

The ground levels from these data sets are used to define the digital elevation model (DEM) for this Flood Study.

3.4.2 MLS Data

The multi-directional laser scanning (MLS) data covers a majority of the streets in the Newcastle CBD area. It was collected in 2021. This can, among its many uses, provide ground levels along roadways in areas where finer definition is required over LiDAR-defined ground levels.

3.4.3 Ground Survey

A survey of Waterdragon Creek in Kotara was undertaken by Craig & Rhodes in March 2022. Creek cross sections were acquired between upstream of Howell Street and the rear of 298 Park Avenue, approximately 1,200 m along the length of the creek. This area has historically flooded relatively frequently, and the upstream section of the creek lies within private property where development has reduced the creek's hydraulic capacity. The survey was commissioned so that this Flood Study can adequately define flooding and flood risk for this area. Refer to **Appendix B** for the survey report, including photographs and locations of each cross section.

Cross sections of existing concrete channels within Throsby Creek, Styx Creek and Cottage Creek reaches are included in the TUFLOW model provided and established as part of the *Throsby, Cottage and CBD Flood Study* (BMT WBM, 2008a). With no major creek modification works noted by the City of Newcastle since the 2008 Flood Study, it is assumed the sections within the model still provide an accurate representation of these channels.

3.4.4 Bathymetric Survey

Bathymetric survey data has been provided by the Newcastle Port Authority, through the City of Newcastle. No date for this data has been included in the information received.

Its extent ranges from the harbour break walls and upstream along the Hunter River South Arm to approximately Warabrook, along the Hunter River North Arm to approximately Hexham, and along Throsby Creek to the confluence with Styx Creek. There are sections of data missing in the Throsby Creek bathymetry, particularly west of Carrington. In these locations, data has been supplemented by the bathymetry data within the existing TUFLOW model from the *Throsby, Cottage and CBD Flood Study* (BMT WBM, 2008a) or, if necessary, interpolated between the adjacent bathymetric survey data points.

3.4.5 Structures

No existing explicit hydraulic structure survey or as-built drawings were provided as part of the data review. However, an extensive investigation of bridge and culvert data was undertaken as part of the *Newcastle Flash Flood, 8 June 2007 (the Pasha Bulker Storm) Flood Data Compendium* (BMT WBM, 2008b). This contains useful information such as the hydraulic structure opening width and length. There was no indication of the opening height or shape of the opening, apart from the included photographs.

The TUFLOW model from the *Throsby, Cottage and CBD Flood Study* (BMT WBM, 2008a) was used as a basis for the hydraulic structures within the study. Almost all of these are located within the 1D model domain. It is inclusive of pit and pipe information as well as culvert and bridge data.

GIS data provided by the City of Newcastle also included information on the stormwater drainage network. This was compared with the network from the TUFLOW model from the *Throsby, Cottage and CBD Flood Study* (BMT WBM, 2008a) to identify where the network has been updated since that study.

A significant pit and pipe survey was undertaken in 2020 by the City of Newcastle. It includes the pit cover levels as well as inlet pipe and outlet pipe invert levels for major pipes covering a significant portion of the study area. This data was taken as precedent over the information provided within the TUFLOW model from the *Throsby, Cottage and CBD Flood Study* (BMT WBM, 2008a) and the City of Newcastle's GIS stormwater database.

3.5 GIS Data

Digitally available information such as aerial photography, cadastral boundaries, topography, watercourses, drainage networks, land zoning, vegetation communities and soil landscapes were provided by the City of Newcastle in the form of GIS datasets.

3.6 Future Development

Details of potential future or recent development (potentially not reflected in the City of Newcastle's land zoning GIS data or the most up to date LiDAR data) provided by the City of Newcastle covers the following areas:

- Broadmeadow rezoning
- Honeysuckle redevelopment
- Wickham
- Newcastle Light Rail
- Hunter Street Mall.

This information is provided as PDF format drawings and can be used to infer changes to the existing land use or topography if it falls within the floodplain.

Map G103 gives an approximate indication of the location and extent of future development in the study area.

3.7 Data Gaps

The following data are not completely necessary to produce an accurate flood study but would provide significant value to the outcomes of the study (i.e. model calibration/validation and community acceptance of the outcomes):

- Historical streamflow gauge records for the 2007, 1990 and 1988 storm events. This information is not available in the City of Newcastle records and could not be sourced from Hunter Water
- Additional digital ground surveys, particularly for areas within the floodplain
- Details of growth corridors or significant future development.

Future flood studies in the study area should consider these data when assessing flood behaviour.

4 Consultation and Engagement

4.1 Background

Phase 1 of the engagement program to support the flood study was held between 7 June -2 July 2021. The key objective of this engagement was to improve the City of Newcastle's understanding of flood behaviour and flood risk in the Throsby, Styx and Cottage Creek catchments.

A summary of the results of this engagement are below.

4.2 Engagement Methods

In 2021, the community were asked to share their experiences of flooding in the Newcastle area via an interactive map via Social Pinpoint, displayed on the City of Newcastle's Have Your Say webpage (https://haveyoursay.newcastle.nsw.gov.au/), and to complete a short survey.

The community and key stakeholders were informed of the opportunity to provide their feedback on this Flood Study by a letterbox notification, social media posts, media release and articles, and the consultation period was promoted through the City of Newcastle's website and Have Your Say newsletter. The City of Newcastle also developed Frequently Asked Questions (FAQs) which were displayed on their Have Your Say website.

4.3 Engagement Results

There were a total of 124 responses to the survey received, and the survey can be found in **Appendix D**. Responses were received from across the Newcastle LGA, with the highest number of responses received from New Lambton (10%), followed by Mayfield (9%) and Carrington (6%).

A summary of the responses received across all suburbs is provided in **Figure 4-1**.

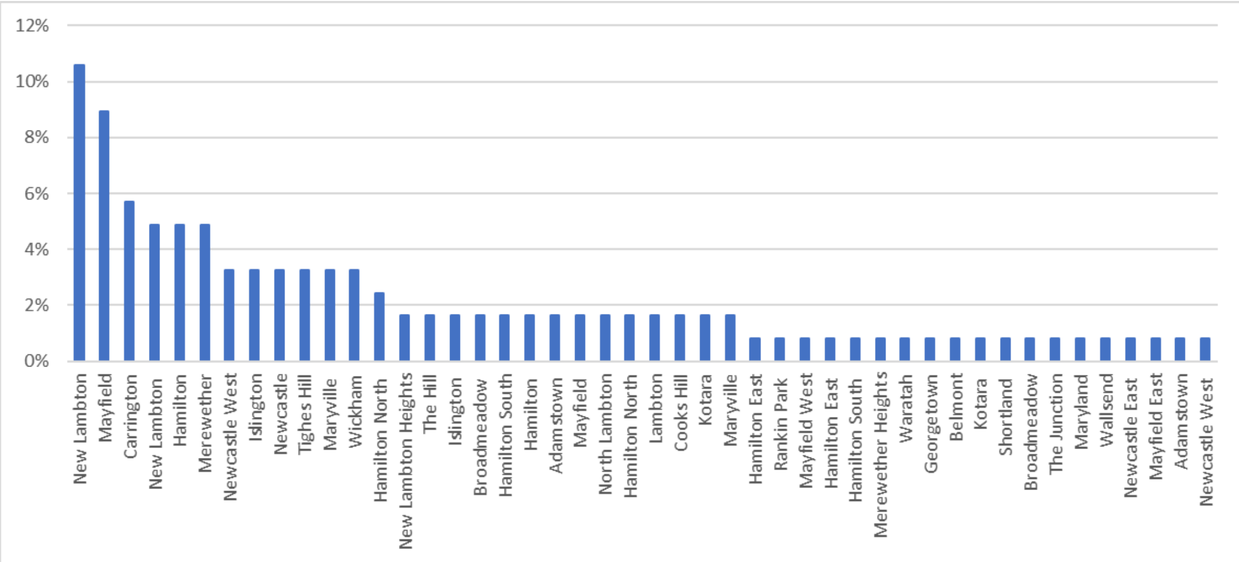

Figure 4-1. Survey Respondent Percentage by Suburb

When respondents were asked of their awareness of flooding within the study area, 79% were aware of flooding, 16% had some knowledge of flooding and only 5% were not aware of flooding within Newcastle. **Figure 4-2** provides a summary of these responses.

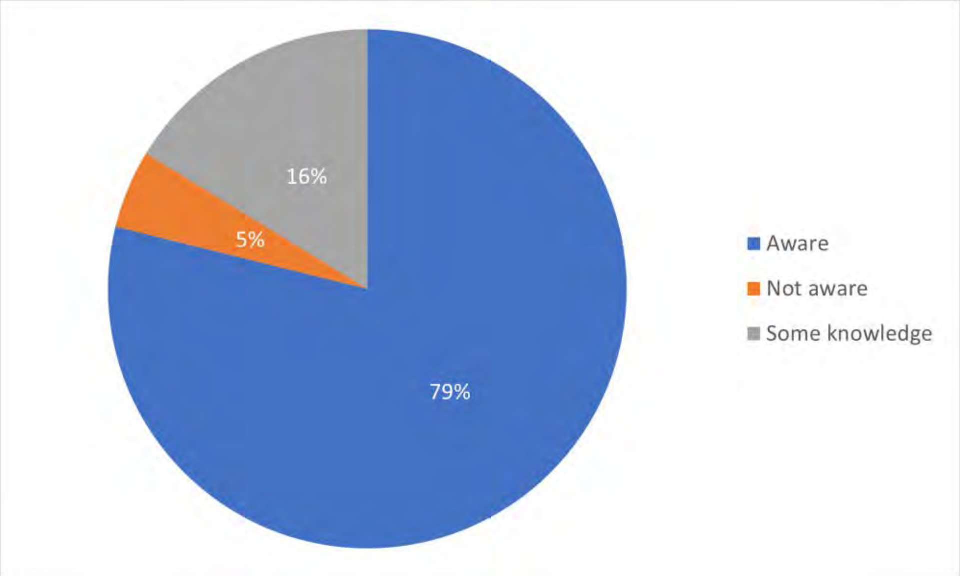

Figure 4-2. Respondent Awareness of Flooding in Study Area

Almost half of the survey respondents (46%) have lived, worked and/or visited the study area for more than 20 years. With only 4% of respondents living, working and/or visiting the study area for less than 12 months. A summary of these responses are shown in **Figure 4-3**.

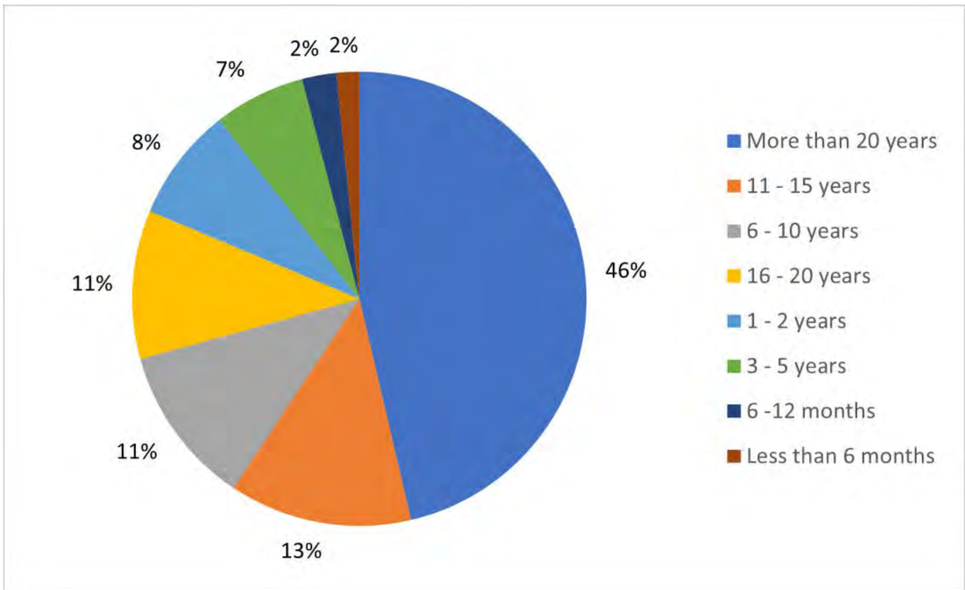

Figure 4-3. Time Spent in the Study Area

Survey respondents were asked to select all the locations where they had seen flooding in the study area. The most common location was on a local road (84 references), local park (60 references), other location (50 references) followed by their home or property (44 references). **Figure 4-4** provides a summary of these responses. Some of the other common locations included King Street, Marketown, Broadmeadow, Lambton Road, The Junction and at Wallsend.

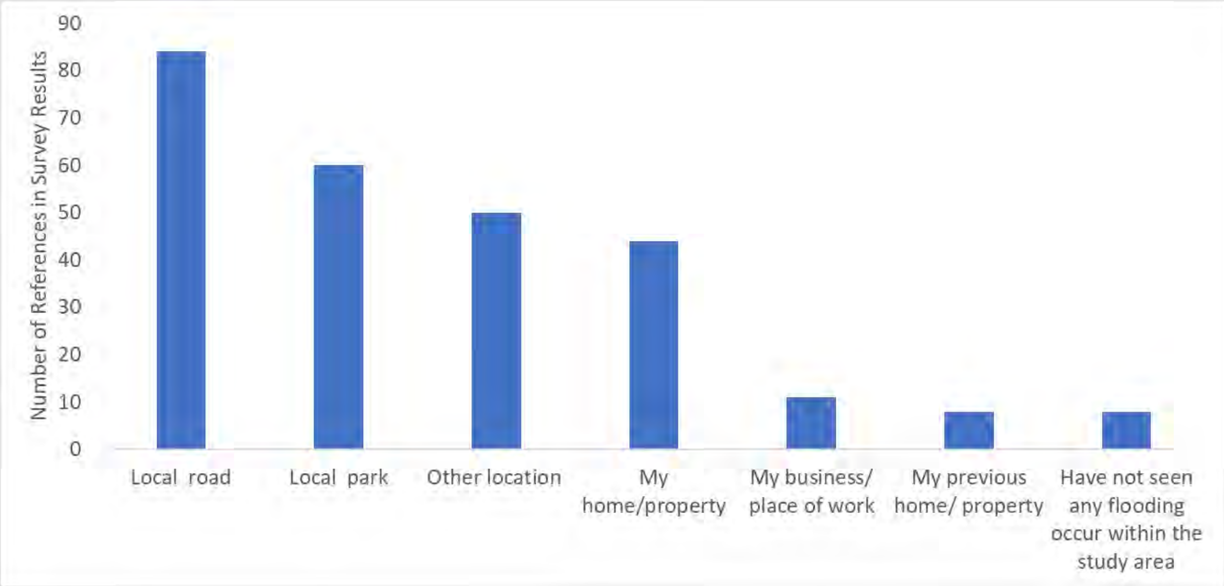

Figure 4-4. Types of Flooding Observations in the Study Area

The community were also encouraged to share their experience and knowledge of flooding on an interactive map using the Social Pinpoint platform on the City of Newcastle website. A visual representation of the geographical locations where flooding experiences was known is demonstrated in **Figure 4-5**.

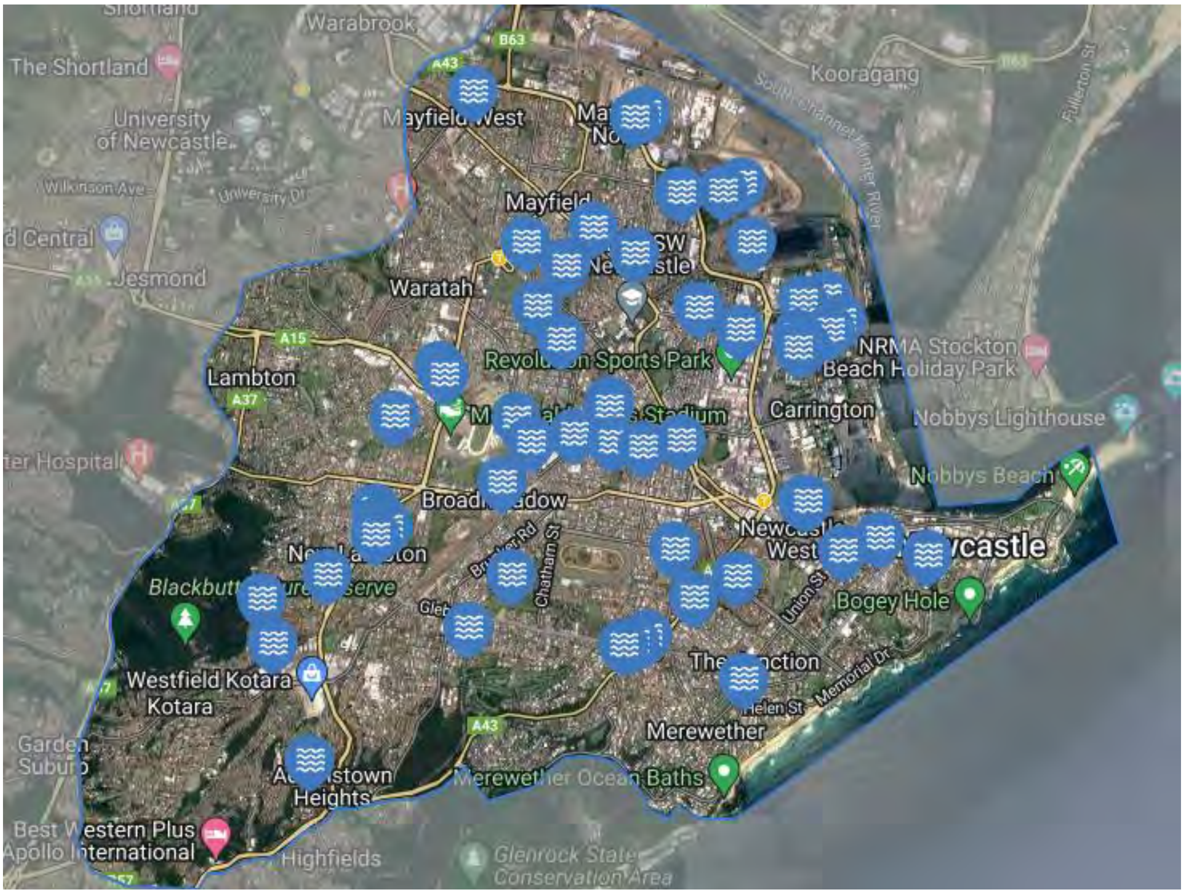

Figure 4-5. Social Pinpoint Flooding Locations

The most often reporting year that flooding occurred was in 2007 with many respondents mentioning the Pasha Bulker storm, this was then followed by July 2020 and March 2021. The flooding occurred at the individuals' properties and at various locations in their local area including, but not limited to, the areas of Mayfield, New Lambton, Maryville, Carrington, Islington, Hamilton North, Merewether, the Junction, Adamstown, and Broadmeadow.

Across all responses, the depth of the flood waters observed varied from 0.01 m to approximately 1.5 m. Twelve people mentioned that the speed of the floodwater was at a running pace, whilst ten stated the flood water was stationary, six people said it was at a walking pace and nine people were unsure or didn't know the speed of the flood waters. **Figure 4-6** provides a summary of these responses.

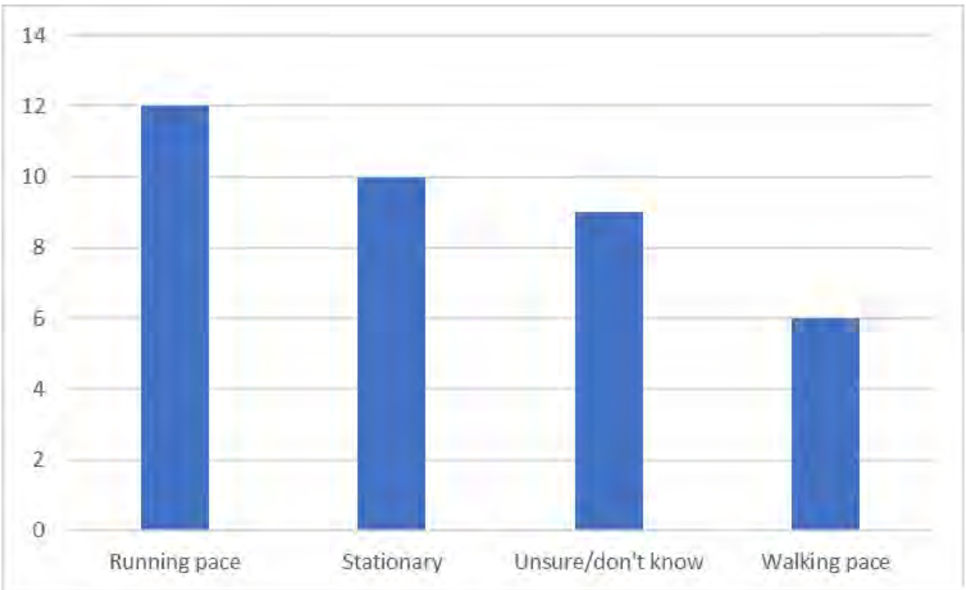

Figure 4-6. Observed Floodwater Speed

The source of the flooding most often mentioned was from drainage including the overflow of drains and gutters within the study area, at Styx Creek and from heavy rain or flooding. Some people mentioned they were unsure of the source of the flooding. Almost 80% of respondents stated there had been damage caused by the flooding, 16% were unsure and 5% were unsure or didn't know if damage was caused by the flooding.

4.4 Next Steps

The next stage of engagement is the Public Exhibition period where community members and stakeholders will have an opportunity to provide comments on the study.

5 Modelling Methodology

5.1 Hydrologic Model

5.1.1 Overview

This project involved the update of the *Throsby, Cottage and CBD Flood Study* (BMT WBM, 2008a) WBNM hydrologic model. This hydrologic model was used to generate the inflows for the 1D/2D TUFLOW hydraulic model, which was originally calibrated to the 1990 flood event and validated with the 1988 flood event. It is noted that the hydrologic model was indirectly calibrated within the hydraulic model, as no appropriate stream flow gauge data was available for these events.

The *Throsby, Cottage and CBD Flood Study* (BMT WBM, 2008a) WBNM hydrologic model has been updated to include the revised study area considered in this flood study, which now includes Mayfield North, Newcastle East and the smaller coastal catchments draining to Merewether Beach, Bar Beach and Newcastle Beach. Additionally, the model updates took into consideration the most up to date information and modelling techniques available, including guidance from ARR2019.

Key updates to the hydrologic model for the purposes of calibration and validation include:

- Inclusion of additional sub-catchments;
- Refinement of the sub-catchment delineation; and
- Updates in calculation of impervious areas and rainfall loss parameters.

A summary of model updates is provided in the following sections.

5.1.2 Subcatchment Delineation

As described in **Section 5.1.1**, the study area considered in the *Throsby, Cottage and CBD Flood Study* (BMT WBM, 2008a) did not include Mayfield North, Newcastle East or the smaller coastal catchments draining to Merewether Beach, Bar Beach and Newcastle Beach. The sub-catchments corresponding to these areas were delineated and included in the updated model.

Modification to the subcatchment delineation from the previous *Throsby, Cottage and CBD Flood Study* (BMT WBM, 2008a), was undertaken manually using the available terrain data (2021 and 2014 LiDAR datasets), reference to aerial imagery, existing GIS stormwater network, and engineering judgement.

Subcatchment delineation is provided in **Map G150**.

5.1.3 Subcatchment Imperviousness

Impervious areas present different runoff characteristics to pervious areas. Impervious areas can include roads, roofs, footpaths and many other features that have no or low depression storage and result in runoff with minimal rainfall loss. However, a key challenge in the definition is that not all impervious areas are directly connected to the drainage and creek systems. For example, while a road may be connected to the pipe drainage system, a paved area in a backyard will often run off onto a pervious area first (such as grass or garden areas).

In this study, the effective impervious area (EIA) is the parameter considered in the runoff estimation. The EIA is calculated as a percentage of the total impervious area (TIA) and is generally considered representative of the area of the catchment that generates a rapid runoff response in rainfall events. The ARR2019 guidelines recommend a value between 50% and 70% for the TIA/EIA ratio. However, the guidelines identify that it may be appropriate to adopt higher ratios for highly impervious industrial or commercial areas.

Table 5-1 summarises the TIA percentages for each land-use type. Note that these values refer only to the areas within the subcatchment not covered by roadways (and rooftops in some zones) as these areas are included in overall subcatchment TIA calculation.

Table 5-1. TIA Percentages, Based on Land Zoning Classification*

Land Zoning Classification	Land Zoning Code	Total Impervious Areas
National Parks and Nature Reserves	E1	0%
Environmental Conservation	E2	0%
Environmental Management	E3	0%
Unzoned Land	UL	0%
Deferred Matter	DM	10%
Public Recreation	RE1	10%
Private Recreation	RE2	10%
Low Density Residential	R2	25%
Medium Density Residential	R3	25%
Transition	RU6	50%
Infrastructure	SP2	50%
High Density Residential	R4	60%
Neighbourhood Centre	B1	70%
Tourist	SP3	70%
Local Centre	B2	80%
Commercial Core	B3	90%
Mixed Use	B4	90%
Business Development	B5	90%
General Industrial	IN1	90%
Light Industrial	IN2	90%
Heavy Industrial	IN3	90%
Special Activities (Newcastle Port)	SP1	90%
Recreational Waterways	W2	100%

** Land use classification as at January 2023, prior to changes in B and IN classifications in mid 2023*

5.2 Hydraulic Model

5.2.1 Overview

The TUFLOW hydraulic model originally developed by BMT WBM as part of the 2008 Flood Study covers the lower 28.2 km^2 of the Throsby, Styx and Cottage Creek catchment areas. This model is a combined 1D/2D model with major channels and hydraulic structures represented as 1D elements nested within a 2D domain with a grid resolution of 10m.

One-dimensional components of the 2008 model were found to be largely suitable for use in the current study.

Significant updates were made to the 2D model domain to incorporate the latest available data and modelling techniques. These model updates included:

- Utilisation of the TUFLOW HPC computational engine
- Extended hydraulic model boundary to include the Mayfield North, Merewether Beach, Bar Beach and Newcastle Beach areas, as well as the upper reaches of the Styx Creek catchment
- Updated digital elevation model based on 2021 LiDAR data
- Improved model resolution and terrain definition using TUFLOW HPC's quadtree and sub-grid sampling features
- Updated surface roughness delineation based on the latest available City of Newcastle GIS data and LiDAR point cloud data
- Additions and modifications to the stormwater drainage network based on the latest available City of Newcastle GIS data, large pipe survey data and completed flood studies in the study area
- Conversion of bridge structures likely subject to significant blockage to culvert structures with an equivalent waterway area to enable the application of blockage factors.

The details of the hydraulic model developed for the current study are provided in the following sections.

5.2.2 Digital Elevation Model

The DEM was primarily based on 2021 LiDAR data provided by the City of Newcastle (refer **Section 3.4.1**). The bathymetry of the Hunter River and Newcastle Harbour was defined using elevation data provided by Newcastle Port Authority (refer **Section 3.4.4**) and supplemented with elevation points from the 2008 TUFLOW model for areas not covered by the Newcastle Port Authority data.

Ridge breaklines were incorporated to ensure critical road crests and the top of channel banks were captured accurately in the model.

The model topography is shown in **Maps G106** (existing conditions)**, G107** (2007 conditions) and **G108** (1988/1990 conditions).

5.2.3 Grid Resolution

TUFLOW model grid sizes were selected to provide an appropriate representation of flood behaviour in the study area, without demanding excessive model run times. The base 2D model grid resolution was set at 8 m across the hydraulic model domain. Using TUFLOW HPC's quadtree feature, the resolution was increased to 4 m for areas where a finer grid was considered necessary to accurately define overland flow behaviour. This included areas such as road reserves, between large buildings and natural channels/depressions in the 2D model domain.

Adopted grid resolutions across the hydraulic model extent are shown in **Map G110**.

5.2.4 Roughness

Roughness zones over the hydraulic model extent were defined using surface type classification from the 2021 point cloud data (refer **Section 3.4.1**) and overlayed with GIS layers sourced from the City of Newcastle's GIS database (refer **Section 3.5**) and the 2008 TUFLOW model.

The delineated roughness zones are shown in **Map G109**.

Adopted Manning's n roughness values for each zone are shown in **Table 5-2.**

Table 5-2. 2D Surface Roughness Values

Land Use Zone	Manning's 'n'
Grass / Gravel	0.030
Light Vegetation / Bare Earth	0.045
Medium Vegetation	0.060
Dense Vegetation	0.090
Riparian Vegetation	0.100
Roads / Railway / Open Concrete	0.020
Buildings	1.000
Urban (incl. buildings)	0.300
Urban (excl. buildings)	0.100
Open Water	0.022
Concrete Channel	0.018

A special case is adopted for the overland flow path through the ground level carpark at the Kotara shopping centre. In this location, flows are restricted by a combination of handrails, short walls, concrete piers and small undulations in the surface (e.g. wheel stops and speed humps). The Manning's n roughness value adopted here is 0.020.

5.2.5 1D Hydraulic Structures

The location of all elements in the 1D domain are shown in **Map G151** and are discussed in the following sections.

5.2.5.1 Open Channels

The majority of watercourses within the study area are man-made concrete lined channels. These types of features are better represented in the 1D domain as the 2D domain is not well suited to represent the near vertical side walls of concrete lined channels. The 1D open channel network from the *Throsby, Cottage and CBD Flood Study* (BMT WBM, 2008a) model was considered suitable for re-use in the updated model, with minor modifications made to suit the revised model extents and to improve model stability.

5.2.5.2 Bridges and Weirs

Given the major channels in the Throsby, Styx and Cottage Creek catchment are represented as 1D elements, hydraulic controls across these channels such as bridges and weirs have also been modelled as 1D elements.

Weir structures from the *Throsby, Cottage and CBD Flood Study* (BMT WBM, 2008a) model were considered suitable for re-use in the updated model.

Manning's n roughness values for bridge and weir structures were updated from 0.012 (in the 2008 model) to 0.015 to better reflect the roughness of slightly degraded concrete.

5.2.5.3 Pits, Pipes and Culverts

The existing drainage network (pits, pipes, and culverts) in the study areas has been represented in the model as a 1D network integrated within the 2D environment.

The stormwater network data included in the model comprises pipes of 750mm diameter and above as well as equivalently sized box culverts and multi-cell conduits. For locations where sections of pipe of 750mm diameter and above are followed by smaller diameter pipes downstream, these smaller diameter pipes were also included in the model. For rare occurrences where sections of the City of Newcastle's GIS stormwater network appear to be missing, pipe sizing was assumed using upstream diameters.

Similar to the bridges and weirs, Manning's n roughness values for the concrete pipes and culverts were updated from 0.012 (in the 2008 model) to 0.015.

5.2.5.4 Blockages

A risk-based approach has been taken for design event blockage in accordance with guidance in ARR2019.

Blockage has been applied to culvert openings using a blockage matrix approach which assigns varying blockage factors based on the structure opening width and design storm frequency. A high debris potential has been adopted for this study area due to the high level of structure blockage reported during the historic 2007 flood event. Use of a high blockage factor for this study area is also supported by the model calibration and validation assessment. **Table 5-3** shows the adopted blockage values based on this blockage matrix strategy. The length of the largest 10% of debris (L_{10} value) was assumed to be 1.5 m given the urban nature of the catchment.

Bridges that were not converted to culvert structures were left un-blocked, consistent with the assumptions of the *Throsby, Cottage and CBD Flood Study* (BMT WBM, 2008a). Blockage of these structures is considered unlikely due to the significant span widths.

Table 5-3 Culvert Blockage Factors

Clear Opening Width (m)	AEP Adjusted Debris Potential at Structure		
	High (AEP<=5%)	Medium (AEP>5%)	Low (not utilised)
W < 1.5m	100%	50%	25%
1.5m < W < 4.5m	20%	10%	0%
W > 4.5m	10%	0%	0%

5.2.6 Boundary Conditions

Flows generated by the WBNM hydrologic model were input into the TUFLOW model via a combination of:

- Point inflows at the upstream end of 1D elements,
- 1D inflows distributed evenly along sections of pipe and/or channel networks falling within 1D boundary condition polygons, and
- 2D inflows distributed evenly over wet cells falling within source-area polygons.

The extents of the 1D boundary condition polygons and 2D source-area polygons generally align with the sub-catchment delineation in the WBNM model. The locations of model inflow boundaries are shown in **Map G152**.

The model contains one downstream boundary. This is an oceanic boundary applied to both the water levels in Newcastle Harbour and extending from Newcastle Beach to the southern end of Merewether Beach.

This study does not consider the effects of flooding from the Hunter River on Throsby, Styx and Cottage Creek. Newcastle harbour has a trained entrance with break walls on the north and south sides. This entrance is regularly dredged to allow safe passage of vessels in and out of the harbour. It also permits flows from the Hunter River to pass through the harbour with minimal raising of flood levels (compared to ocean storm flooding) near the outlets of Throsby Creek and Cottage Creek. It is assumed that oceanic flooding governs the flood levels at the downstream boundary of the study area.

6 Model Calibration and Validation

6.1 June 2007 Calibration Event

6.1.1 Rainfall Data

Sub-daily rainfall data was used from 12 rainfall gauges within and surrounding the study area. The total rainfall at these gauges for the June 2007 event ranged from 428 mm south of the study area in Charlestown (TR106) to 107 mm west of the study area in Wallsend (R14). Generally higher rainfall was experienced in the southern portion of the catchment and along the coast as far north at the Nobby's lighthouse gauge (61055). The gauge that recorded the highest rainfall depth within the catchment (350 mm) is located in Merewether (R8).

The gauged rainfall records within the study area are shown in **Figure 6-1** (gauge locations shown on **Map G200**).

The storm burst occurred roughly between 12:00pm on 8 July and 2:00am on 9 July. This main storm burst was utilised as the inflow for the model calibration. The significantly smaller first storm burst, with an approximate maximum depth of 50 mm, lasted from 2:00am to 6:00am on 7 July and is assumed to have largely drained from the catchment by the time the main storm burst occurred 30 hours later.

Isohyets produced to reflect total rainfalls across the study area are shown in **Map G200** for the June 2007 flood event.

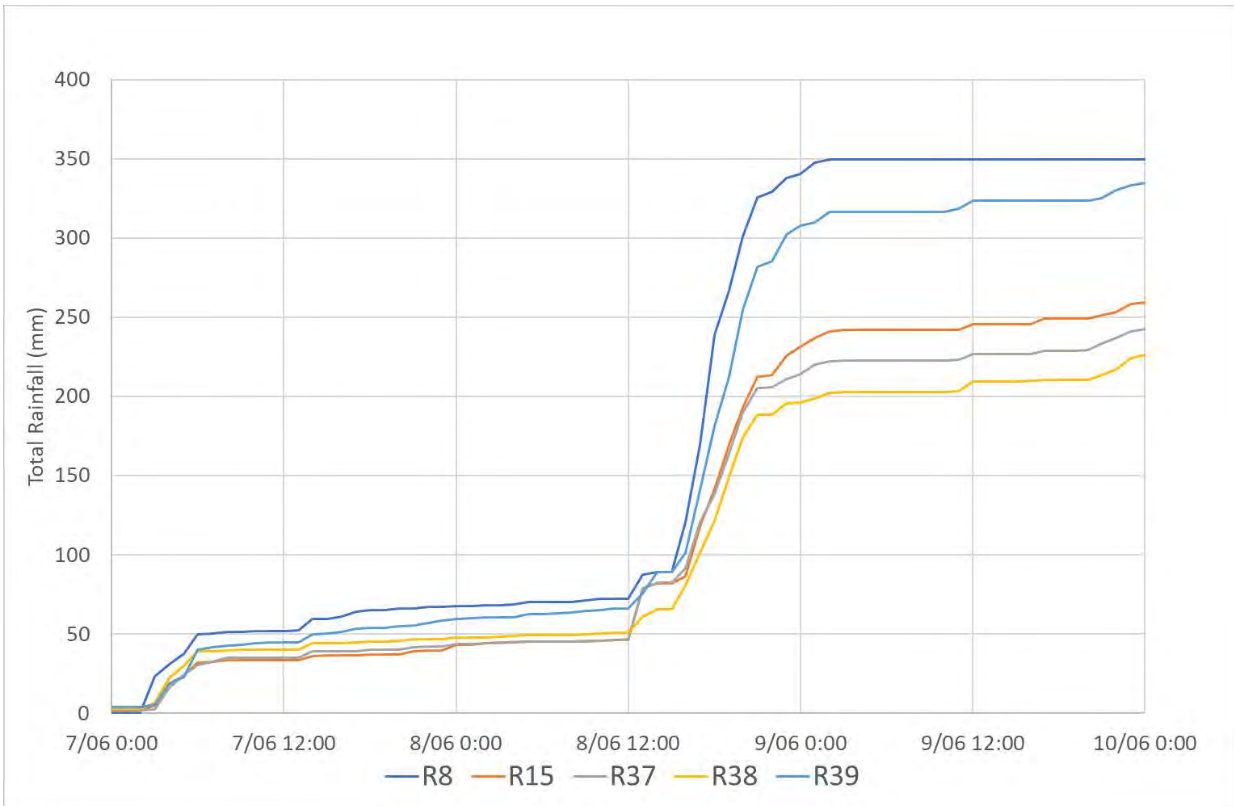

Figure 6-1. Cumulative Rainfall Gauge Recordings in the Study Area – June 2007 Event

6.1.2 Downstream Boundary Condition

The Newcastle Port Corporation water level gauge on the Hunter River (refer **Section 3.3.3**) was used to set the oceanic boundary conditions for the June 2007 event. This is considered sufficiently representative of water levels along the northern model boundary. Water levels along the eastern (Bar Beach/Merewether Beach) boundary would be impacted by wave action; however, the eastern portion of the model is sufficiently elevated such that variations in boundary conditions as a result of such processes would not impact modelled flood behaviour.

The tidal timeseries within the Hunter River at the Newcastle Port Corporation gauge during the June 2007 event is shown in **Figure 6-2**.

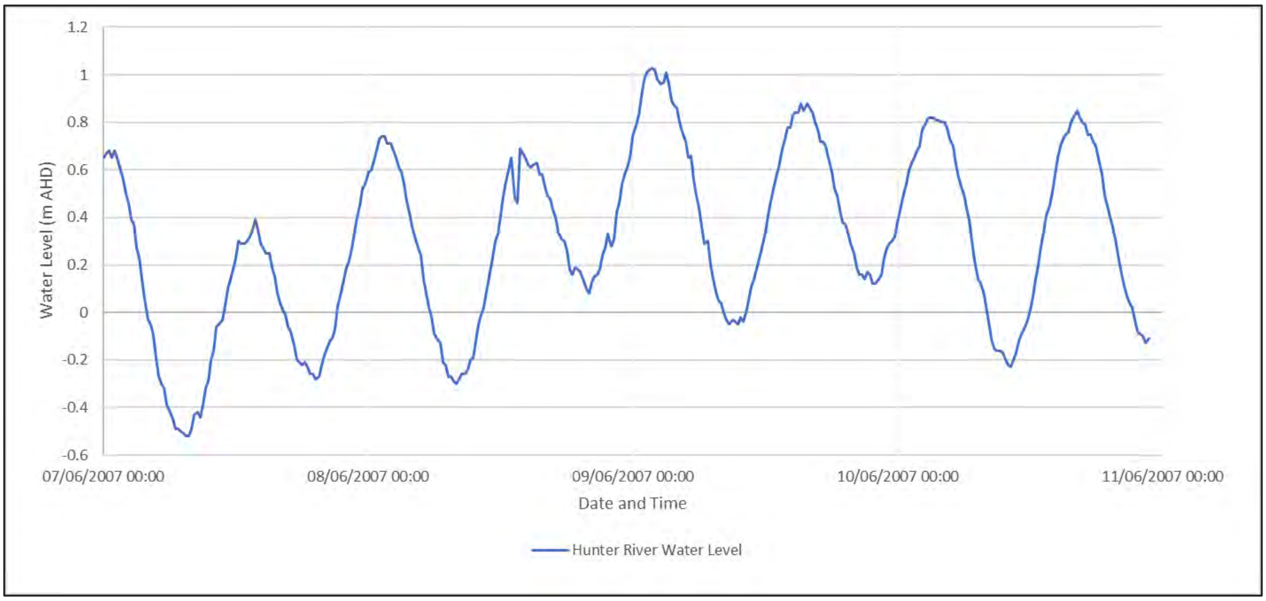

Figure 6-2. Hunter River Water Levels – June 2007 Event

6.1.3 Historic Flood Observations

As mentioned in **Section 3.3.1.2**, a significant quantity of flood observations were recorded following the June 2007 'Pasha Bulker' storm event. This included a number of spatially coded flood data points based on field work undertaken by BMT WBM in the aftermath of the event as well as a widespread dataset of surveyed flood levels by the City of Newcastle. BMT WBM's dataset ranked the degree of confidence in the flood observations from 1 (high confidence flood mark at the peak of flooding) to 4 (low confidence flood mark, not at the peak of flooding); however, information is only provided on flood depths relative to somewhat unknown datums (floor levels, garage levels etc.) as opposed to surveyed flood levels. The City of Newcastle's dataset includes surveyed flood levels but does not provide any information regarding the reliability of the observations. In the absence of stream gauge data, this historic flood level information has been relied upon to inform the calibration process.

For the purpose of model calibration, statistical analysis was undertaken on the City of Newcastle's surveyed flood levels at locations corresponding to the Grade 1 data points from BMT WBM's field survey. These represent points with the highest degree of confidence. Separate analysis was undertaken for the City of Newcastle's complete database of surveyed flood level points which would likely contain a mix of high confidence and low confidence observations. Results of the analysis are discussed in **Section 6.1.5.**

6.1.4 Hydrologic Modelling

Without any streamflow gauge data, for this or any other historic rainfall event considered in this study, the hydrologic model was not able to be directly calibrated. Indirect calibration was undertaken through the 2D hydraulic model.

Initial and continuing losses adopted for this modelled event are shown in **Table 6-1**. The 10 mm initial loss and 2 mm/hr continuing loss was adopted from the *Throsby, Cottage and CBD Flood Study* (BMT WBM, 2008a). Testing on variation of the initial and continuing losses revealed very minor impacts to modelled flood behaviour, which can be attributed to the high degree of urbanisation and impervious areas in the catchment. In accordance with guidance from ARR2019, the losses for indirectly connected areas were assumed to be 70% of the pervious loss values.

Table 6-1 Losses Adopted for July 2007 Event

Type of Area	Initial Loss (mm)	Continuing Loss (mm/hr)
Pervious Areas	10	2
Indirectly Connected Impervious Areas	7	1.4
Effective Impervious Areas	1	0

To adjust the model to represent the level of development across the study area in 2007, the 2021 LiDAR point cloud data was used to estimate the individual subcatchment rooftop areas. Sensitivity checks were then undertaken on rooftop areas defined by the 2014 (earliest available data set) and 2021 LiDAR point cloud data, and associated impacts on sub-catchment peak discharge.

The LiDAR comparison indicated that there was an increase of approximately 10% in roof top area from the 2014 to 2021. This difference appears to be mostly driven by less accurate surface classification in the 2014 data, indicating the true increase in rooftop area from 2014 to 2021 is lower than 10%. However, 10% is likely to be a reasonable estimate of increase in rooftop area since 2007.

When the sensitivity test was undertaken for a maximum 10% decrease, the model showed a minor (approximately 2%) decrease in catchment peak discharge and a low impact on modelled flood levels (approximate maximum 0.02 m decrease). Given the true increase in rooftop areas since 2007 is likely less than the 10% modelled, and the low impact this maximum increase has on the peak discharge and modelled flood levels, the change in development density was not considered to have a significant impact on model outputs, supporting use of the 2021 LiDAR data across the majority of the study area for the 2007 calibration event.

Outputs from the hydrologic model were applied to the 2D and 1D domains of the hydraulic model consistent with the methodology described in **Section 5.2.6**.

6.1.5 Hydraulic Modelling

6.1.5.1 Model Updates

The TUFLOW hydraulic model setup described in **Section 5.2** was updated in a number of areas to reflect catchment conditions during the 2007 event. Model updates included:

- Updating the model topography with the 2014 DEM at select locations to remove significant development that has occurred since 2007 (**Map G107**).

- Updating surface roughness classification in select locations (same locations as shown in **Map G107**) based on 2007 aerial photography.
- Increasing structure blockages in areas of known blockage during the 2007 event and for structures where significant blockage is expected to have occurred based on recorded flood levels in the vicinity of the structure. Notable blockages in the 2007 event which have been reflected in the model include a shipping container blocking the outlet of Cottage Creek (**Figure 6-3**) and a number of cars lodged in the Cottage Creek culvert at the corner of Beaumont Street and Darling Street (**Figure 6-4**). Significant blockage was also assumed for a number of bridge structures in the middle to upper reaches of Styx Creek due to the presence of debris in photographs taken shortly after the event and to better match observed flood levels upstream of the subject bridges.

Given that rainfall depths for the June 2007 event were of similar magnitude to the 1% AEP design event, matrix blockage assumptions for events less frequent than a 5% AEP were adopted for structures where blockage was not directly input.

Figure 6-3. Structure blockage near outlet of Cottage Creek (Source: BMT WBM, 2008a)

Figure 6-4. Culvert blockage at Beaumont Street (Source: BMT WBM, 2008a)

6.1.5.2 Results

TUFLOW modelled flood depth results of the June 2007 event are presented in **Maps G203** to **G203**. The results show widespread inundation due to channel breakouts at a number of locations along Throsby, Styx and Cottage Creek and their associated tributaries as well as extensive overland flooding, particularly in the lower lying areas toward the north-eastern portion of the study area.

Results of the statistical analysis comparing modelled and observed flood levels in the June 2007 event are presented in **Table 6-2. Map G204** shows the difference in modelled and observed 2007 flood levels across the study area for Grade 1 observations.

Table 6-2. Model Calibration Statistics - June 2007 Event

Statistic	Grade 1 Points	All Points
Total number of observation points[1]	219	1148
Percentage of points within 0.1m	52%	45%
Percentage of points within 0.2m	80%	73%
Percentage of points within 0.3m	89%	87%
Average deviation (m)	-0.08	-0.07

Tabulated results of the calibration data points and model results can be found in **Appendix C**.

6.2 February 1990 Validation Event

6.2.1 Rainfall Data

Sub-daily rainfall data was used for nine rainfall gauges within and surrounding the study area. The total rainfall at these gauges ranged from 323 mm south of the study area in Charlestown to 265 mm in Merewether. Rainfall experienced across the catchment was relatively consistent, with only slightly higher total rainfall depths experienced in the western portion of the catchment.

The storm burst occurred during the 24 hour period roughly between 8:00am on 2 February to 8:00am on 3 February.

The gauged rainfall records within the study area are shown in **Figure 6-5** (gauge locations shown on **Map G202**).

Isohyets produced to reflect total rainfalls across the study area are shown in **Map G202** for the February 1990 flood event.

[1] Only includes observation points within the modelled flood extents.

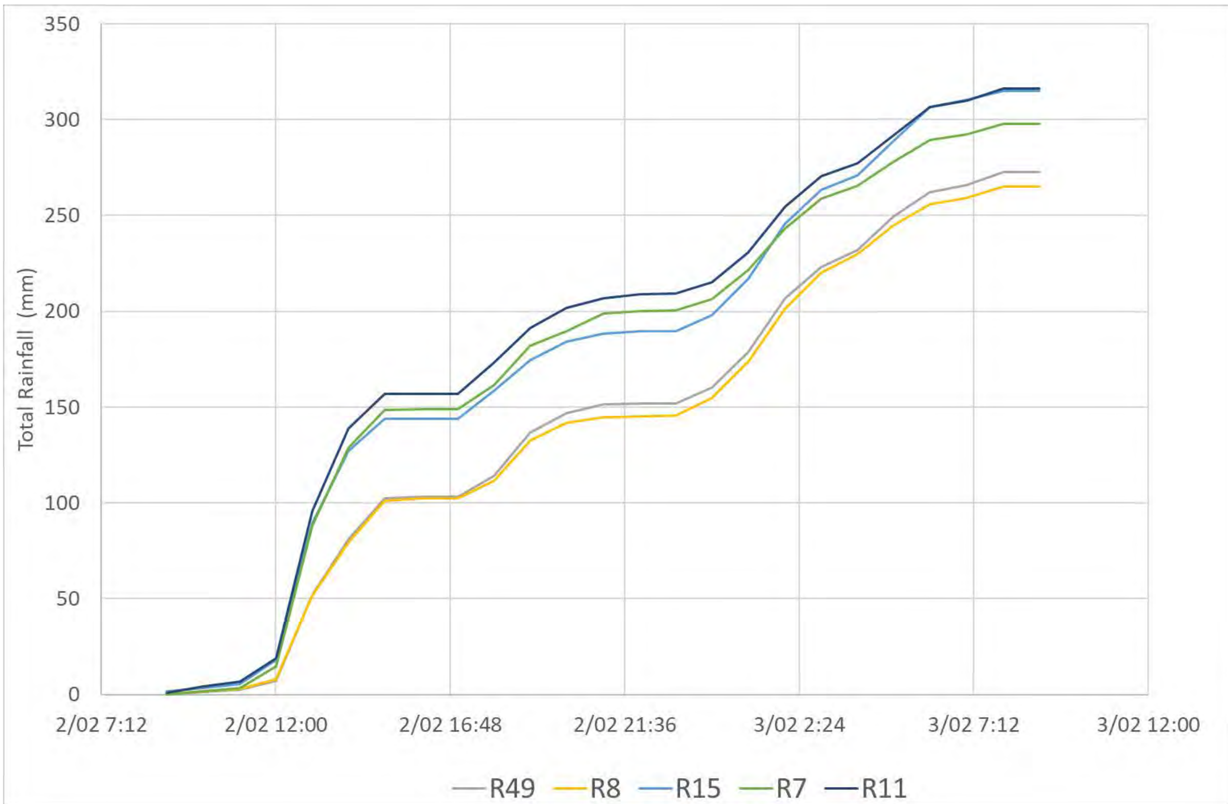

Figure 6-5. Cumulative Rainfall Gauge Recordings – February 1990 Event

6.2.2 Downstream Boundary Condition

Downstream boundary conditions for the February 1990 event were obtained directly from the *Throsby, Cottage and CBD Flood Study* (BMT WBM, 2008a) TUFLOW model for this event. The tidal timeseries used at the downstream boundaries is shown in **Figure 6-6**.

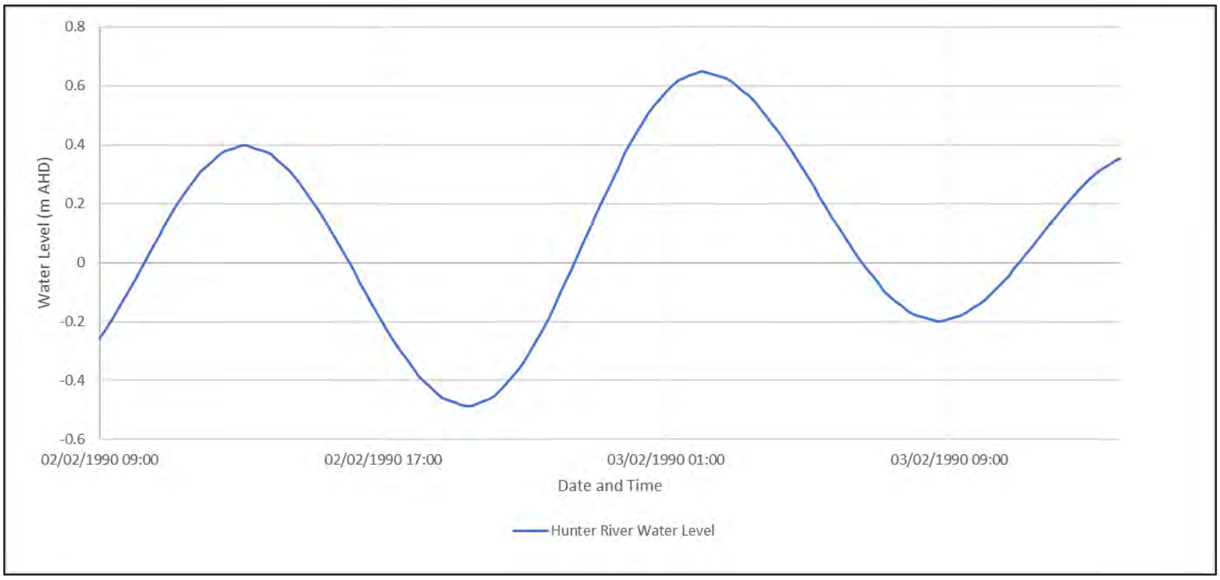

Figure 6-6. Hunter River Water Levels – February 1990 Event

6.2.3 Historic Flood Observations

Spatially located flood data points containing surveyed flood levels were provided by the City of Newcastle for the purpose of model validation against the February 1990 event. Similar to the July 2007 observations, these data points contain gradings from 1 (high confidence flood mark at the peak of flooding) to 4 (low confidence flood mark, not at the peak of flooding).

Figure 5-1 of the *Throsby, Cottage and CBD Flood Study* (BMT WBM, 2008a) provides time series water level data for five Hunter Water owned stream gauges in the study area that were operational during the February 1990 event (and decommissioned later in the 1990s). This water level data was also used for model validation against the February 1990 event; however, this data is not considered to be as reliable as the surveyed Grade 1 observations due to uncertainties in gauge datums and recording issues with the Bastes Street gauge, as discussed in Section 5.2.2 of the *Throsby, Cottage and CBD Flood Study* (BMT WBM, 2008a).

A comparison of observed February 1990 flood levels against model results is provided in **Section 6.2.5.2.**

6.2.4 Hydrologic Modelling

Rainfall depths were applied to each subcatchment within the hydrologic model based on the isohyets created in **Map G202**.

All remaining hydrologic modelling parameters for this event were consistent with **Section 6.1.4**. No variation of the adopted losses was considered necessary given the low level of modelled flood behaviour sensitivity to this parameter.

6.2.5 Hydraulic Modelling

6.2.5.1 Model Updates

The TUFLOW hydraulic model was updated in a number of areas to reflect catchment conditions during the 1990 event. Model updates included:

- Updating the model topography at key areas where surface elevations are known to have changed since 1990 (**Map G108**).
- Updating surface roughness classification in select locations based on 1990 aerial photography (same locations as shown in **Map G108**).

Given that rainfall depths for the February 1990 event were between a 1% and 2% AEP design event, matrix blockage assumptions for events less frequent than a 5% AEP were adopted.

6.2.5.2 Results

TUFLOW model results of the February 1990 event are presented in **Map G206** and show a similar extent of inundation to the June 2007 event. Inundation extents slightly exceed the 2007 event in some areas due to a more widespread distribution of high rainfall intensity (refer **Section 6.2.1**) and are less than the June 2007 event in select areas where increased blockages were applied for the 2007 event (refer **Section 6.1.5.1**).

Results of the statistical analysis comparing modelled and observed flood levels in the February 1990 event are presented in **Table 6-3**. **Map G207** shows the difference in modelled and observed 1990 flood levels across the study area.

Table 6-4 compares modelled flood levels and approximated stream gauge levels based on Figure 5-1 of the *Throsby, Cottage and CBD Flood Study* (BMT WBM, 2008a). Generally, the modelled flood levels are higher than the observed flood levels. This may be either because the gauge rating curve is not reliable at higher levels (i.e. outside the banks of the channels) where the floodplain extends beyond the immediate vicinity of the gauge, or that the gauge did not function properly during the event and did not record the peak flood level.

Table 6-3. Model Validation Statistics - February 1990 Event

Statistic	Grade 1 Points	All Points
Total number of observation points[2]	36	80
Percentage of points within 0.1m	31%	25%
Percentage of points within 0.2m	50%	39%
Percentage of points within 0.3m	72%	60%
Average deviation (m)	+0.17	-0.04

Tabulated results of the validation data points and model results can be found in **Appendix C**.

Table 6-4. Stream Gauge Levels - February 1990 Event

Gauge	Observed Level[3] (m AHD)	Model Level (m AHD)
Litchfield Park	2.1	2.6
Bates Street	3.8	4.7
Jellicoe Parade	9.2	9.7
Bruce Street	2.7	3.2
Jenner Parade	2.5	3.5

6.3 April 1988 Validation Event

6.3.1 Rainfall Data

Sub-daily rainfall data was used for seven rainfall gauges within and surrounding the study area. The total rainfall at these gauges ranged from 141 mm near the John Hunter Hospital down to only 23 mm in Merewether. This event was characterised by high intensity rainfall along the western portion of the catchment, primarily flowing into Styx and Throsby Creeks.

The storm burst occurred during 4 hours roughly between 7:00pm and 10:00am on 27 April.

The gauged rainfall records within the study area are shown in **Figure 6-7** (gauge locations shown on **Map G201**).

Isohyets produced to reflect total rainfalls across the study area are shown in **Map G201** for the April 1988 flood event.

[2] Only includes observation points within the modelled flood extents.

[3] In the absence of raw stream gauge data, levels have been approximated from Figure 5-1 of the *Throsby, Cottage and CBD Flood Study* (BMT WBM, 2008a).

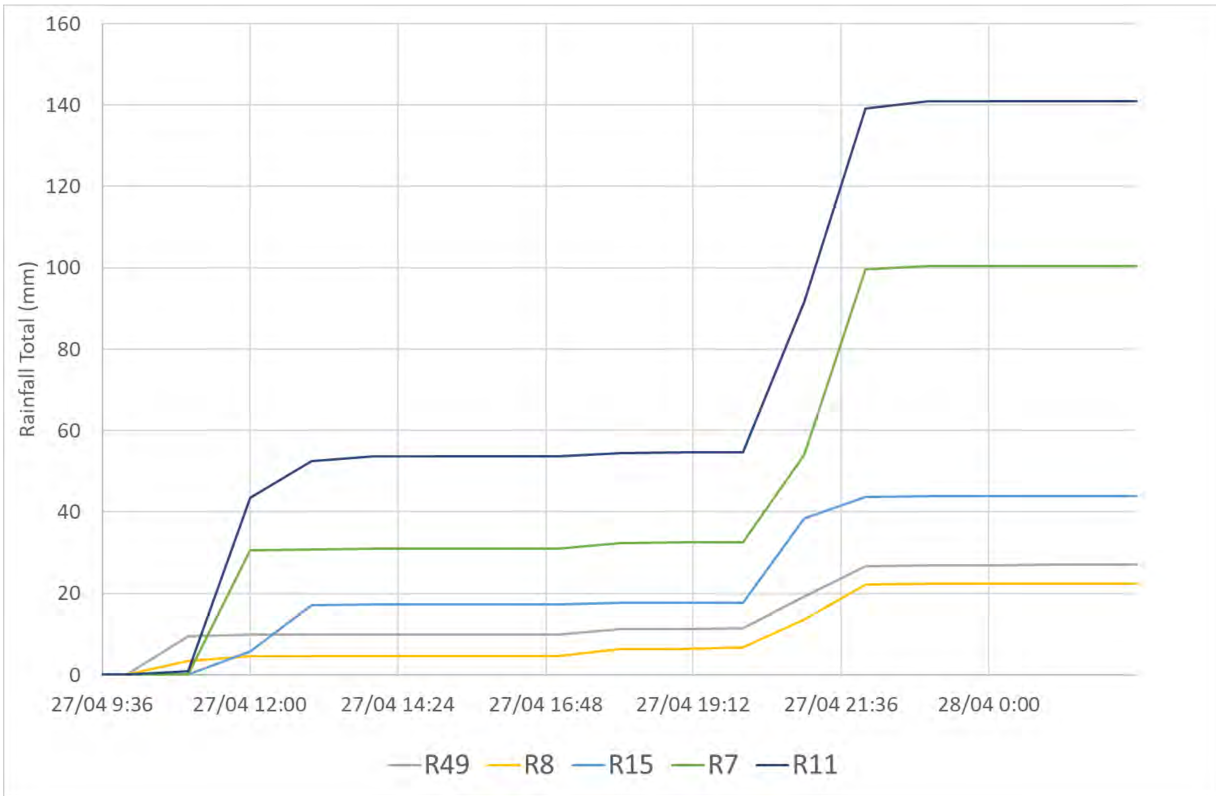

Figure 6-7. Cumulative Rainfall Gauge Recordings – April 1988 Event

6.3.2 Downstream Boundary Condition

Downstream boundary conditions for the April 1988 event were obtained directly from the *Throsby, Cottage and CBD Flood Study* (BMT WBM, 2008a) TUFLOW model for this event. The tidal timeseries at the downstream boundaries is shown in **Figure 6-8** below.

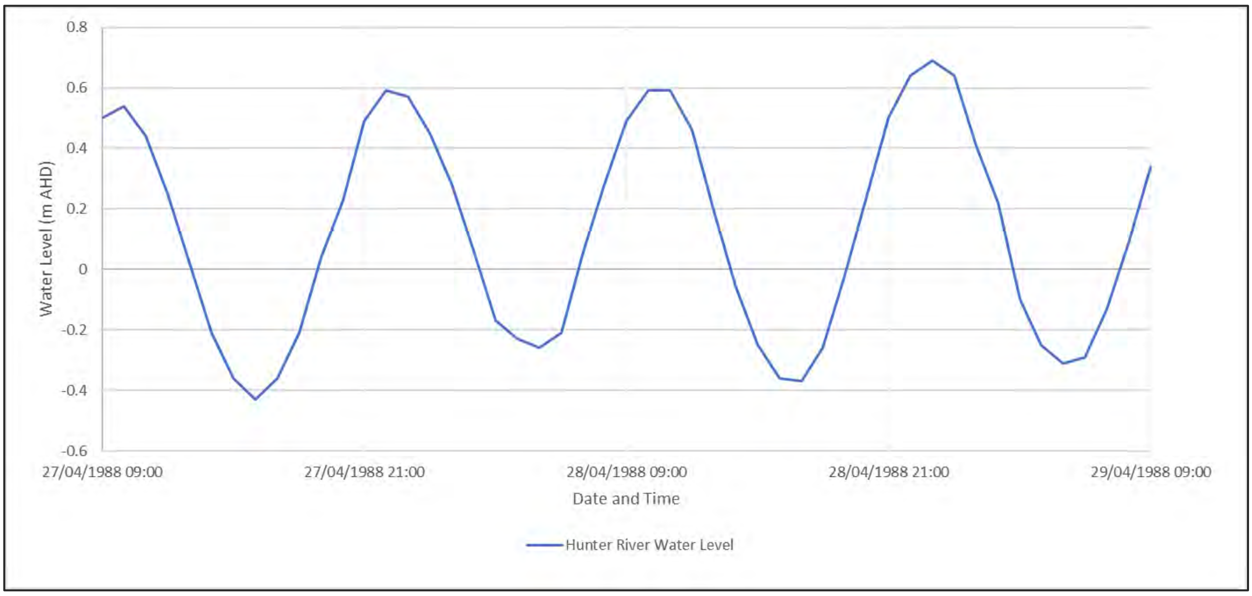

Figure 6-8. Hunter River Water Levels – April 1988 Event

6.3.3 Historic Flood Observations

Spatial data points containing surveyed flood levels were provided by the City of Newcastle for the purpose of model validation against the April 1988 event. Similar to the 2007 and 1990 observations, these data points contain gradings from 1 (high confidence flood mark at the peak of flooding) to 4 (low confidence flood mark, not at the peak of flooding).

Time series water level data from the Hunter Water stream gauge at the Jellicoe Parade gauge is provided in Figure 5-3 of the *Throsby, Cottage and CBD Flood Study* (BMT WBM, 2008a); however, as previously mentioned (**Section 6.3.3**), this data is not considered to be as reliable as the surveyed Grade 1 observations.

A comparison of observed April 1988 flood levels against model results is provided in **Section 6.3.5.2.**

6.3.4 Hydrologic Modelling

Rainfall depths were applied to each subcatchment within the hydrologic model based on the isohyets created in **Map G201**.

All remain hydrologic modelling parameters for this event were consistent with **Section 6.1.4**. No variation of the adopted losses was considered necessary given the low level of modelled flood behaviour sensitivity to this parameter.

6.3.5 Hydraulic Modelling

6.3.5.1 Model Updates

The same TUFLOW model topography and roughness updates from the 1990 validation model were applied to the April 1988 model. No additional modifications were made to the topography or roughness due to the lack of 1988 aerial imagery to identify areas where any significant development may have occurred during the 2 year period between 1988 and 1990.

Given that rainfall depths for the April 1988 event were approximately equivalent to a 10% AEP event, where rainfall was the highest along the western boundary of the catchment, matrix blockage assumptions for events more frequent than a 5% AEP were adopted.

6.3.5.2 Results

TUFLOW model results of the April 1988 event are presented in **Map G208**. TUFLOW model results for this event show far less flooding than the 1990 and 2007 events, with the majority of flooding occurring in the mid to upper reaches of Styx Creek. A significant number of flood observation points are located outside of the modelled flood extents for this event. These are generally located in the upper portions of the catchment where flooding was possibly due to overland flow that is not represented in this model.

Results of the statistical analysis comparing modelled and observed flood levels in the April 1988 event are presented in **Table 6-5. Map G209** shows the difference in modelled and observed 1988 flood levels across the study area.

Table 6-6 compares modelled flood levels and approximated stream gauge levels at the Jellicoe Parade Gauge based on Figure 5-3 of the *Throsby, Cottage and CBD Flood Study* (BMT WBM, 2008a).

Table 6-5. Model Validation Statistics – April 1988 Event

Statistic	Grade 1 Points	All Points
Total number of observation points[4]	33	67
Percentage of points within 0.1m	30%	28%
Percentage of points within 0.2m	42%	54%
Percentage of points within 0.3m	61%	67%
Average deviation (m)	-0.20	-0.04

Tabulated results of the validation data points and model results can be found in **Appendix C**.

Table 6-6. Stream Gauge Levels – April 1988 Event

Gauge	Observed Level[5] (m)	Model Level (m)
Jellicoe Parade	9.1	9.5

6.4 Model Sensitivity

To understand a potential range for the estimated flood levels in the July 2007 calibration event modelling, a sensitivity analysis was undertaken. This individually varied key parameters of the hydrologic and hydraulic models to determine their impact on the resulting flood behaviour.

Four model parameters were chosen for the sensitivity analysis across both the hydraulic and hydrologic calibration models. These are summarised in **Table 6-7**.

Table 6-7. Sensitivity Analysis Parameters

Model	Parameter	Low Range	High Range
Hydrologic (WBNM)	Catchment Lag	1.4	1.8
	Initial & Continuing Losses	-20%	+20%
Hydraulic (TUFLOW)	Bridge/Culvert Blockage	0%	90%
	Bridge/Culvert Losses	-20%	+20%
	Surface Roughness	-20%	+20%

6.4.1 Catchment Lag

In **Maps G250** and **G251**, fluctuation of the WBNM catchment lag factor did not significantly impact the estimated July 2007 flood levels. When the lag factor was increased to 1.8, flood levels generally decreased in the upper elevations of the catchment, generally by no more than 50 mm. The inverse occurred when decreasing the lag factor to 1.4, with increases in flood levels up to 50 mm in similar areas. The exception to this was in the upstream extents of Throsby Creek near Waratah, where flood levels changed by up to 100 mm.

[4] Only includes observation points within the modelled flood extents.

[5] In the absence of raw stream gauge data, levels have been approximated from Figure 5-3 of the *Throsby, Cottage and CBD Flood Study* (BMT WBM, 2008a).

6.4.2 Losses

As originally mentioned in **Section 6**, determination of the adopted losses in the calibration model included a preliminary assessment on the impact of this parameter; of which there was relatively little. **Maps G252** and **G253** further illustrate this with sporadic smaller changes of approximately +/- 50 mm across the study area. Impacts were more significant, but still minor (up to 100 mm), in Waratah where subcatchment slopes are fairly flat.

6.4.3 Blockage

Maps G254 and **G255** outline the impacts to estimated flood levels that significant changes in blockage levels have. Unsurprisingly, with the number of culverts and bridges crossing the major creeks in the study area, this parameter has a major impact on the hydraulic model results.

When blockage levels are reduced to 0% (fully unblocked), the calibration model flood levels are generally reduced within areas of lower gradients where blocked bridges and culverts can cause widespread breakout of flows from the concrete channels. Suburbs subject to lowered flood levels (up to and greater than 200 mm) as a result of reduced blockages include Broadmeadow, Hamilton, Hamilton South, New Lambton, Kotara and Newcastle West. Flood levels increased, as a result of reduced blockages, by up to 200 mm, in Throsby and Styx Creeks, downstream of Broadmeadow.

To represent a scenario with significant widespread blockage across the catchment, a 90% blockage rate was applied to bridges and culverts. A 90% blockage rate was considered more realistic than a 100% blockage rate while still representing a “worst-case” blockage scenario. In general, flood levels increased significantly (a maximum of more than 200 mm) over the entire catchment. The high blockage levels hold back runoff before discharging into the harbour, effectively creating significantly more flood storage volume in the study area. Of greater importance may be that significantly increased blockage may result in many areas which did not experience flooding in the July 2007 event now being inundated. The sensitivity analysis shows this to occur as a result of increased blockage in the vicinity of Hamilton, Islington, Hamilton South, Waratah, Newcastle and Newcastle West.

6.4.4 Bridge and Culvert Losses

When increasing and decreasing the expansion and contraction coefficient losses applied to the modelled bridges and culverts, there was little to no impact on the estimated flood levels for the July 2007 event.

Maps G256 and **G257** present the difference in estimated flood levels for this sensitivity analysis.

6.4.5 Surface Roughness

Increasing the surface roughness (the Manning’s n roughness parameter) in any 1D or 2D model generally has the effect of slowing down flood velocities and increasing flood depths for the area in which this change happens, generally resulting in decreasing flood depths downstream. In this study area, the same is generally true. Increasing the roughness values across the entire area, resulted in an increase in estimated flood depths in the upper portions of the catchment by 100 mm, and up to 200 mm in some isolated areas. Along Styx Creek, some locations experienced greater flood levels (more than 200 mm).

The sensitivity analysis exploring the effects of decreasing roughness had the expected effect of decreasing estimated flood levels in the upper portions of the catchment (maximum of approximately

100 mm) and increasing flood levels in the downstream and flatter portions of the catchment (greater than 200 mm in some areas).

Maps G258 and **G259** highlight the difference in estimated flood levels for increases and decreases in surface roughness, respectively.

7 Understanding Flood Behaviour

7.1 Design Flood Behaviour

Using the hydrologic and hydraulic flood models established as part of the calibration and validation process, and design storm data from the ARR Data Hub (https://data.arr-software.org/), flood behaviour has been estimated for a range of design storm events.

This study focuses on the definition of flood levels within the study area from catchment flooding. For flood levels resulting from ocean storm events, reference should be made to the *Analysis of Extreme Ocean Water Levels at the Hunter River Entrance* (DHI, 2008). Ocean flood levels (and resultant flood planning levels) may take precedence in the low-lying portions of the study area.

Peak flood depths (with water level contours) and velocities are provided in **Maps G300** to **G309**. Maps have been prepared for the 10% AEP, 5% AEP, 2% AEP, 1% AEP and PMF events. Further mapping of climate change scenarios in **Maps G320** to **G323** have been undertaken utilising the 0.5% AEP and 0.2% AEP rainfalls as proxies for increased 1% AEP rainfall intensity in 2050 and 2100, respectively.

7.1.1 Hydrologic Modelling

The WBNM model uses input data provided by the ARR Data Hub such as design rainfall and initial and continuing losses. **Figure 7-1** provides the Intensity-Duration-Frequency (IFD) information for the study area and was sourced from http://www.bom.gov.au/water/designRainfalls/revised-ifd/.

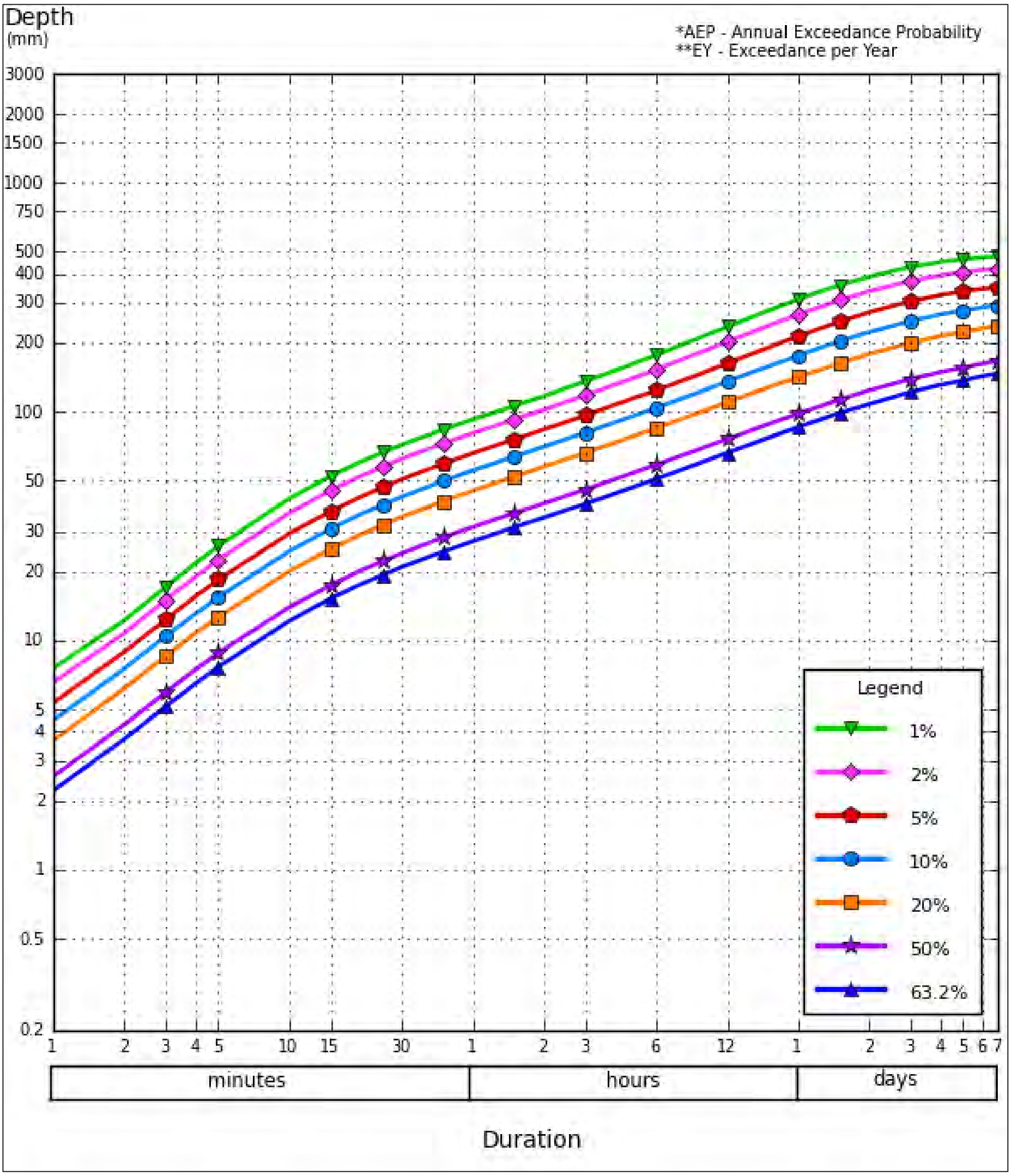

Figure 7-1. Intensity-Duration-Frequency Chart for the Study Area (Source: Bureau of Meteorology)

No further changes to the WBNM model were made to adjust the hydrologic parameters.

The NSW-specific guidance for ARR2019 recommends that in the absence of calibrated catchment loss values, the probability neutral losses should be used to determine design storm flood behaviour. Probable Maximum Precipitation (PMP) was estimated using guidance from *The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method* (Bureau of Meteorology, 2003).

7.1.2 Hydraulic Modelling

7.1.2.1 DEM Modifications

The TUFLOW 2D hydraulic model DEM was updated to reflect current conditions in the study area. Based on information received and locations identified by the City of Newcastle, the following significant changes were made to the hydraulic model with respect to the built environment affecting flood behaviour:

- Newcastle City
    - The outlet of Cottage Creek into Newcastle Harbour. In 2007, the stretch of Cottage Creek between the railway alignment and the harbour was partially an open channel and partially and underground culvert. As part of the development of the Honeysuckle foreshore, the channel has been modified, two new bridges constructed (the Honeysuckle Drive bridge and pedestrian bridge), and the downstream end converted to an open channel.
    - While the Newcastle Light Rail has been a significant development in the city since 2007, ground levels remain similar to those from the 2021 LiDAR data. The only significant update to the hydraulic model included the incorporation of significant public drainage assets (i.e. pits and pipes greater than 600 mm in diameter).
    - The Honeysuckle foreshore itself has undergone significant change since 2007 with the construction of multiple-storey mixed use buildings north of Hunter Street, between Watt Street and Stewart Avenue.
    - West of Stewart Avenue, in Wickham, individual lots have undergone changes with respect to demolition and construction of new buildings. This was particularly evident along the railway corridor from the Newcastle Interchange to Hamilton Station.
    - Additional significant stormwater infrastructure (pits and pipes) was added to Nesca Park as a result of the detention basin works.
- Broadmeadow. The area south of Styx Creek and north of Perth Road has undergone development with the construction of multiple sports fields and the Newcastle Knights Centre of Excellence. While ground levels have not been significantly altered, buildings in the floodplain have been incorporated.
- Waterdragon Creek. Higher up in the Styx Creek catchment is the tributary Waterdragon Creek, which has been subject to development even prior to 2007. Survey of the reach from approximately Nereida Close to Howell Street was acquired in March 2022 to reflect the modified creek sections and to better define design storm flood behaviour following surrounding development and flood mitigation works in Kotara Park.

The current conditions DEM and 2D roughness mapping can be found in **Maps G106** and **G109**, respectively.

7.1.2.2 Downstream Boundary Condition

Water levels in Newcastle Harbour were altered to reflect the joint occurrence which was determined using the guidelines provided by the former Office of Environment and Heritage (OEH, 2015). A static level was adopted for the boundary condition in the hydraulic model.

The corresponding joint occurrences for storm frequencies are summarised in **Table 7-1**.

Table 7-1. Design Storm Boundary Conditions

Catchment Flood Scenario	Ocean Boundary Scenario	Ocean Water Level (m AHD)
10% AEP	HHWS(SS)[6]	1.25
5% AEP	HHWS(SS)[8]	1.25
2% AEP	5% AEP	1.40
1% AEP	5% AEP	1.40
0.5% AEP (proxy for 1% AEP in 2050)	1% AEP plus 0.4 m sea level rise	1.85
0.2% AEP (proxy for 1% AEP in 2100)	1% AEP plus 0.9 m sea level rise	2.35
PMF	1% AEP	1.45

The ocean levels adopted for the modelled calibration and validation events (refer **Sections 6.1.2, 6.2.2 and 6.3.2**) differ significantly from the values adopted for design event modelling. For example, while the June 2007 event produced rainfall similar to a 1% AEP rainfall event, the observed peak level in Newcastle Harbour was approximately 1.0 m AHD compared to the design 1% AEP event where the downstream boundary water level is 1.40 m AHD. The reason for this is that the calibration event model uses real world data to attempt to replicate an historic flood event, and the design flood event needs to consider conditions which make flooding worse but are still statistically possible.

7.1.2.3 Blockage Approach

Similar to the calibration and validation flood estimates, a risk-based blockage approach was adopted to estimate the degree of blockage experienced by culverts and bridges. Refer to **Section 5.2.5.4** and **Table 5-3** for the values adopted for each flood frequency and reasoning for selection. Flood level sensitivity to blockage was conducted for the 2007 calibration event (refer **Section 6.4.3**).

Blockage is highly variable for every independent flood event and can occur to different degrees at different locations throughout the catchment due to a range of factors and debris loads during a particular event. Therefore, the blockage factors used in the model were adopted as a reasonable estimate of the most likely blockage level for culverts and bridges.

7.1.3 Results

Refer to **Maps G300 to G309** for peak flood depths, elevations and velocities of the design event flood events.

Across all modelled events, significant flooding is experienced caused by breakout of flows along each of Throsby, Styx and Cottage Creeks.

7.1.3.1 Throsby Creek Catchment

In Mayfield, flooding is observed primarily where the Throsby Creek alignment has been undergrounded through culverts and overland flow paths have been heavily restricted through urban development. This flooding extends west of Roe Street to Gavey Street in the 10% AEP with a peak flood depth of approximately 0.5 m. Flood depths here increase to approximately 0.7 m in the 1% AEP and extents are more widespread, covering between Maitland Road and the rail line at Waratah Station.

[6]High High Water Springs (Spring Solstice)

The suburb of Waratah is also subject to significant flooding, most notably in the residential blocks surrounding Waratah Park (with depths up to 0.4 m in the 1% AEP) and the north end of Turton Road near Platt Street (maximum of 0.9 m in the 1% AEP). Flood waters appear to be trapped between Prince Street and the rail line; however, this may be caused by the absence of privately owned drainage infrastructure in the rail corridor.

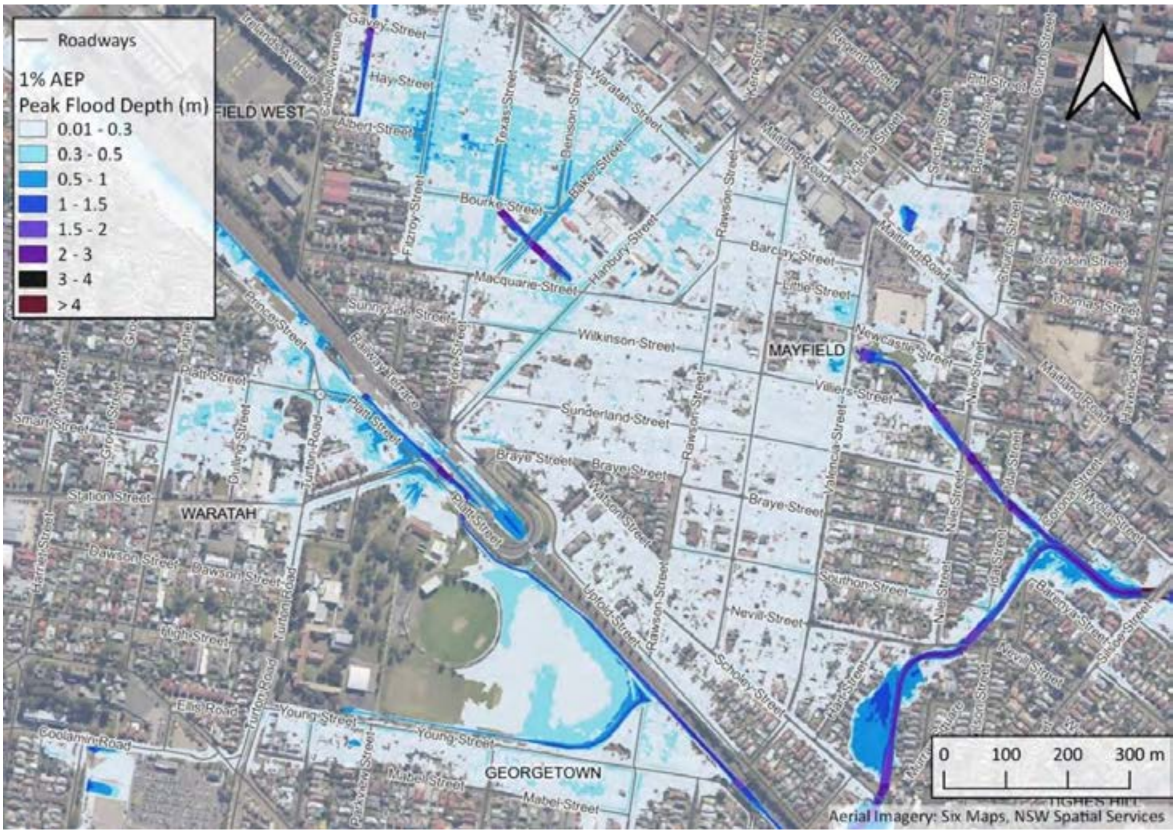

Figure 7-2. 1% AEP Flood Depth - Throsby Creek, Mayfield and Waratah

Mayfield North is a predominately industrial area. It is a relatively flat and low-lying area and flood depths can be substantial up to a maximum of approximately 1.8 m in the 1% AEP. However, this is predominantly associated with the lack of drainage and stormwater asset information in this area. Ponding may be occurring behind earthen embankments or against roadways where no cross drainage is defined in the hydraulic model. Flood results in this area should be treated as preliminary and further refinement would be needed to determine more appropriate flood behaviour.

7.1.3.2 Styx Creek Catchment

In the suburb of Kotara, mainstream flooding is generally confined to waterways in the 10% AEP. The exception being areas adjacent to Nesbitt Park, upstream extents of Waterdragon Creek and south of Hudson Park. In events up to the 1% AEP, flood water generally affects the same locations but extends to a larger area. Flood depths reach up to 1.3 m along Northcott Drive near the Kotara Homemaker Centre in the 1% AEP and flooding in private properties are up to 0.9 m in multiple locations where creek flows have broken out of their banks. The most significant hydraulic control in this area is the rail line north of the Kotara Homemaker Centre. Styx Creek crosses via culverts adjacent to St. Pius Xavier High School, and relief overflow discharges via the underpass to the west along Northcott Drive (**Figure 7-3**).

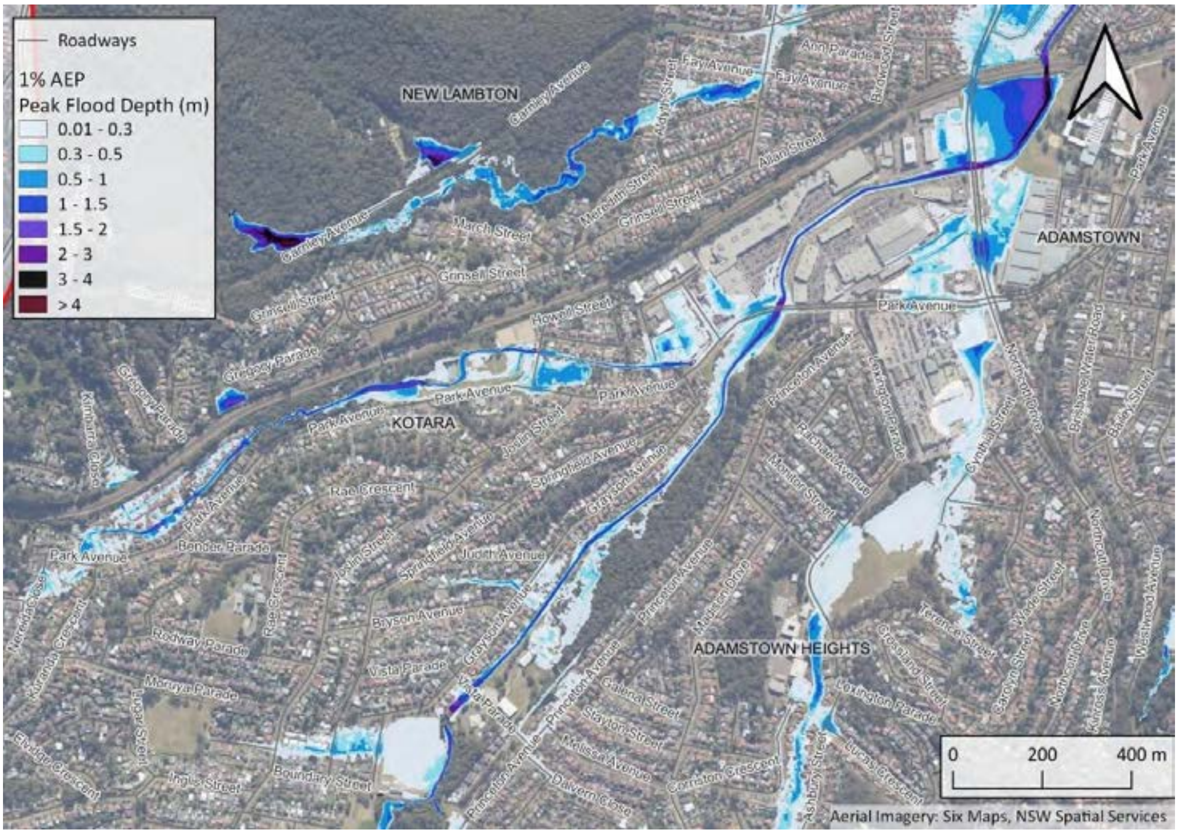

Figure 7-3. 1% AEP Flooding, Styx Creek, Kotara

Flooding in Adamstown tends to be overland flow, where runoff cannot adequately be directed into local tributaries of Styx Creek and Cottage Creek. In the 1% AEP, these flows become far wider with significant inundation from Fletcher Street north to the rail line, and between the Merewether Golf Club and Myers Park. Peak flood depths are up to 0.8 m in residential areas in the 1% AEP event. **Figure 7-4** illustrates flooding in this area.

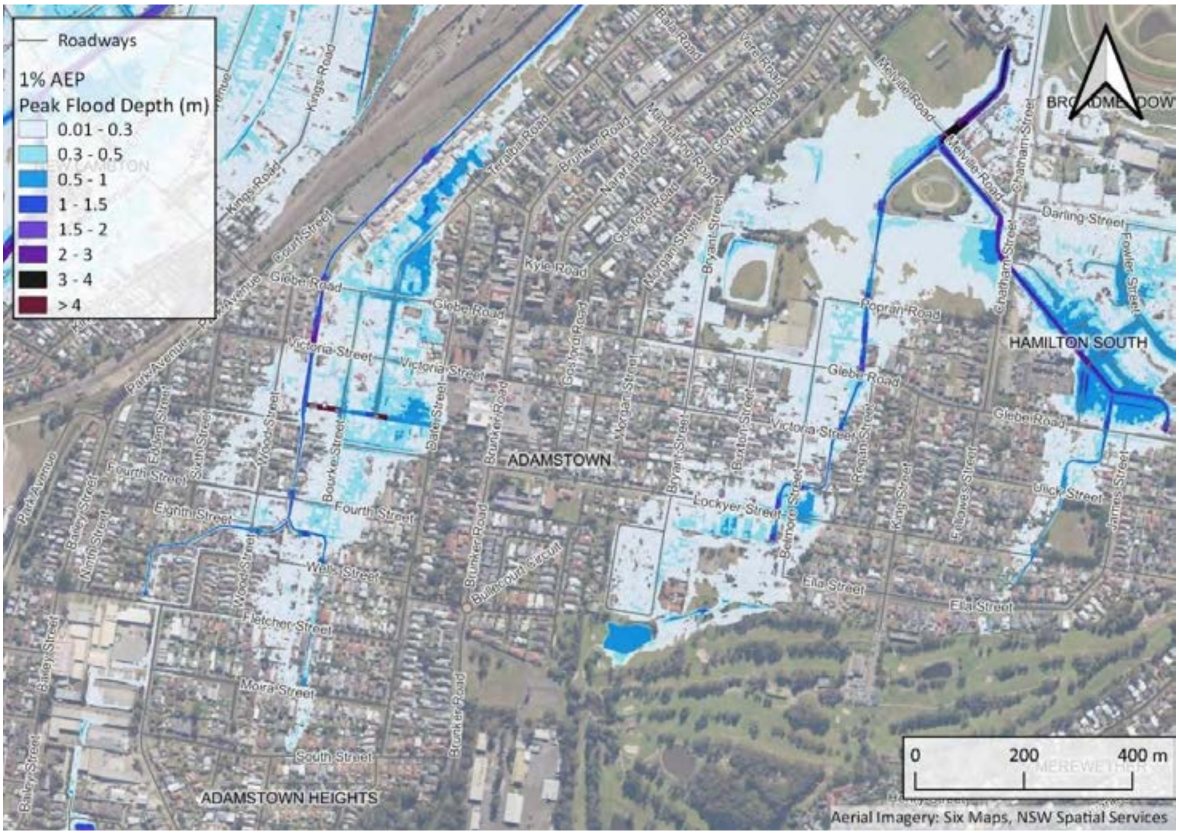

Figure 7-4. 1% AEP Flood Depths - Styx Creek, Adamstown

The confluence of Ker-rai Creek and Styx Creek is located in Broadmeadow. This also tends to be where catchment and creek gradients flatten out, relative to their upstream areas. This causes significant and widespread flooding in these areas. In smaller events the area west of the rail line and east of Bridges Road contains many residential and commercial properties subject to flood depths of up to 0.5 m in isolated locations in the 10% AEP. Flood waters are generally contained by road embankments such as Turton Road and Lambton Road. Behind these road embankments ponding of flood waters affects residential areas. In the 1% AEP, flood conditions worsen with water breaking out of multiple creek banks. Peak flood depths in this event are up to 1.2 m in some isolated locations and Turton Road, near McDonald Jones Stadium, is inundated by up to 0.8 m at the road crown. **Figure 7-5** shows flooding in this area.

Hamilton is affected by overland flows in events as frequent as the 10% AEP where low points cannot convey flood flows into Styx Creek. In this area, the rail line embankment represents a significant impediment to conveying runoff into Styx Creek.

In Hamilton North, Wickham and Maryville there are multiple locations where the local topography does not allow overland flows to reach Styx Creek, Throsby Creek or Newcastle Harbour. Existing stormwater pipes do not have enough capacity to adequately drain these low-lying areas and in the 1% AEP event flood depths rise up to approximately 0.8 m. **Figure 7-6** provides an overview of flooding at this location.

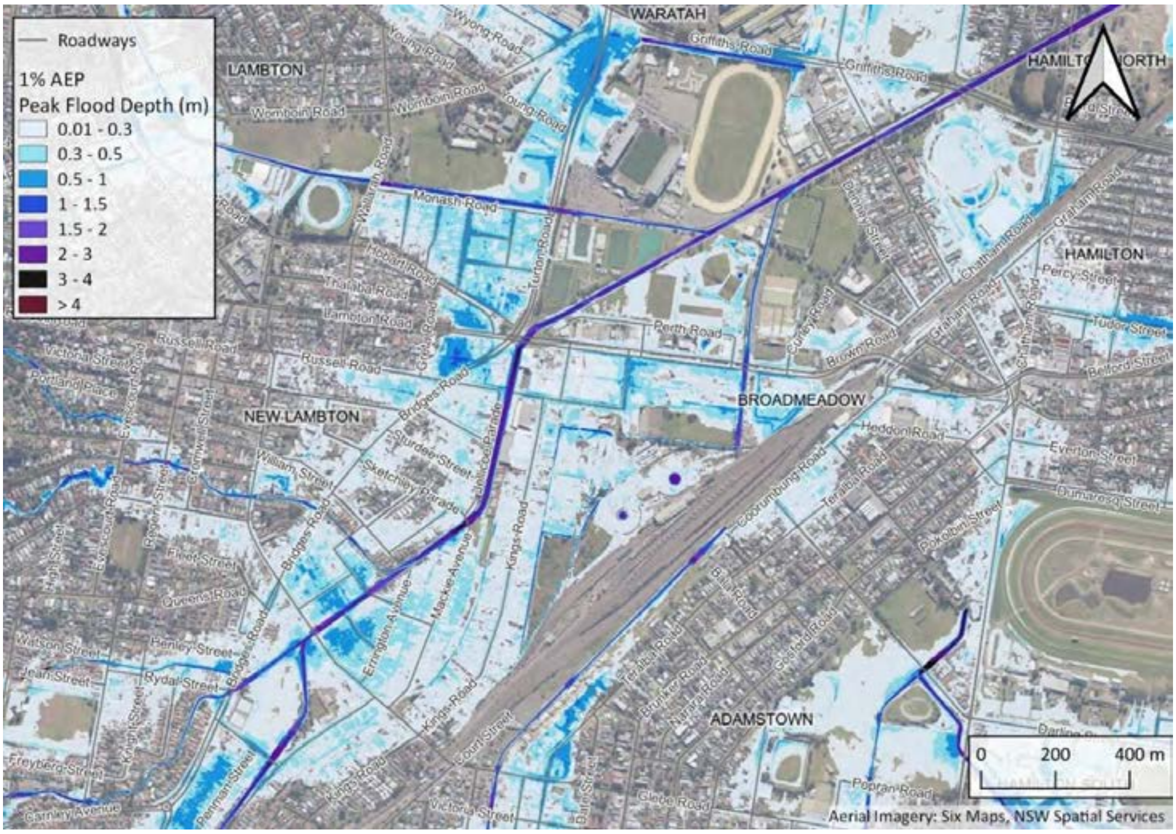

Figure 7-5. 1% AEP Flood Depth - Styx Creek, Broadmeadow

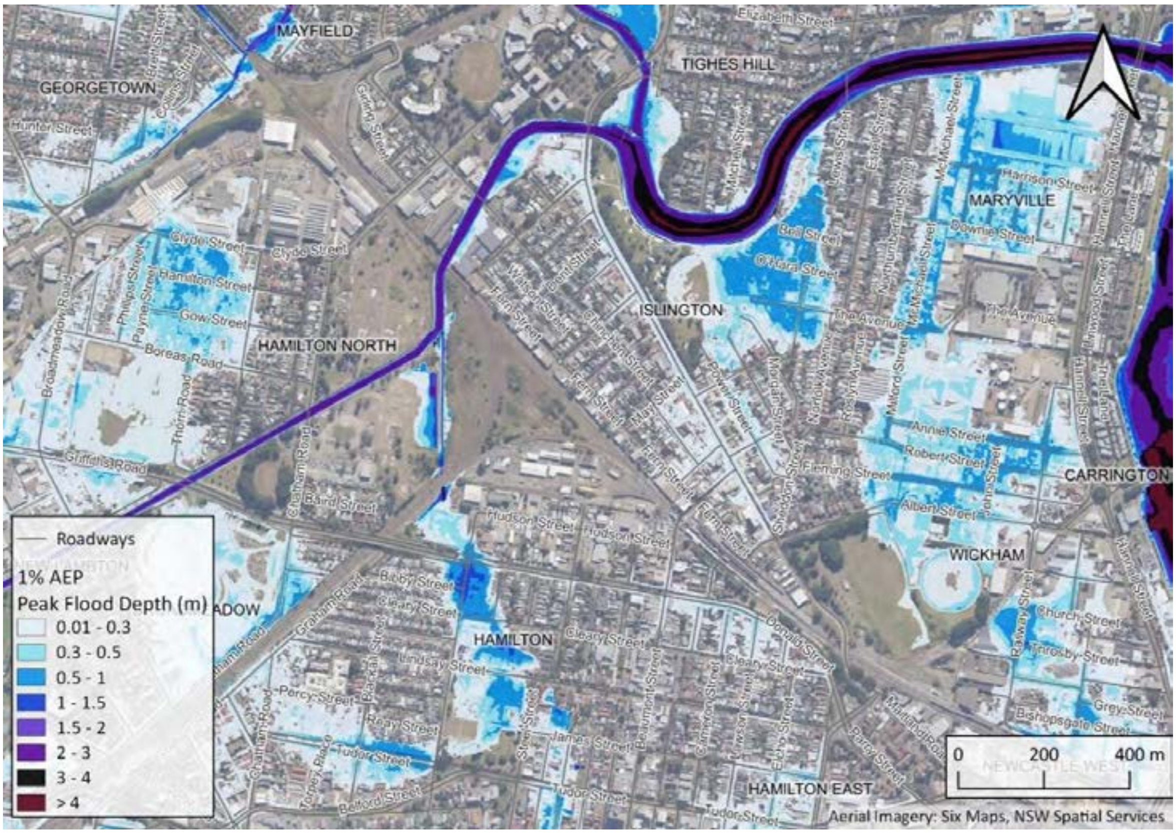

Figure 7-6. 1% AEP Flood Depth - Styx Creek, Hamilton and Wickham

7.1.3.3 *Cottage Creek Catchment*

In the Cottage Creek catchment, overland flows are experienced through Merewether which are generally aligned south of City Road and Frederick Street where depths in the 1% AEP flood can exceed 1.0 m. These overland flows generally discharge north through The Junction and Hamilton South before entering Cottage Creek along Jenner Parade. **Figure 7-7** illustrates flooding in this location.

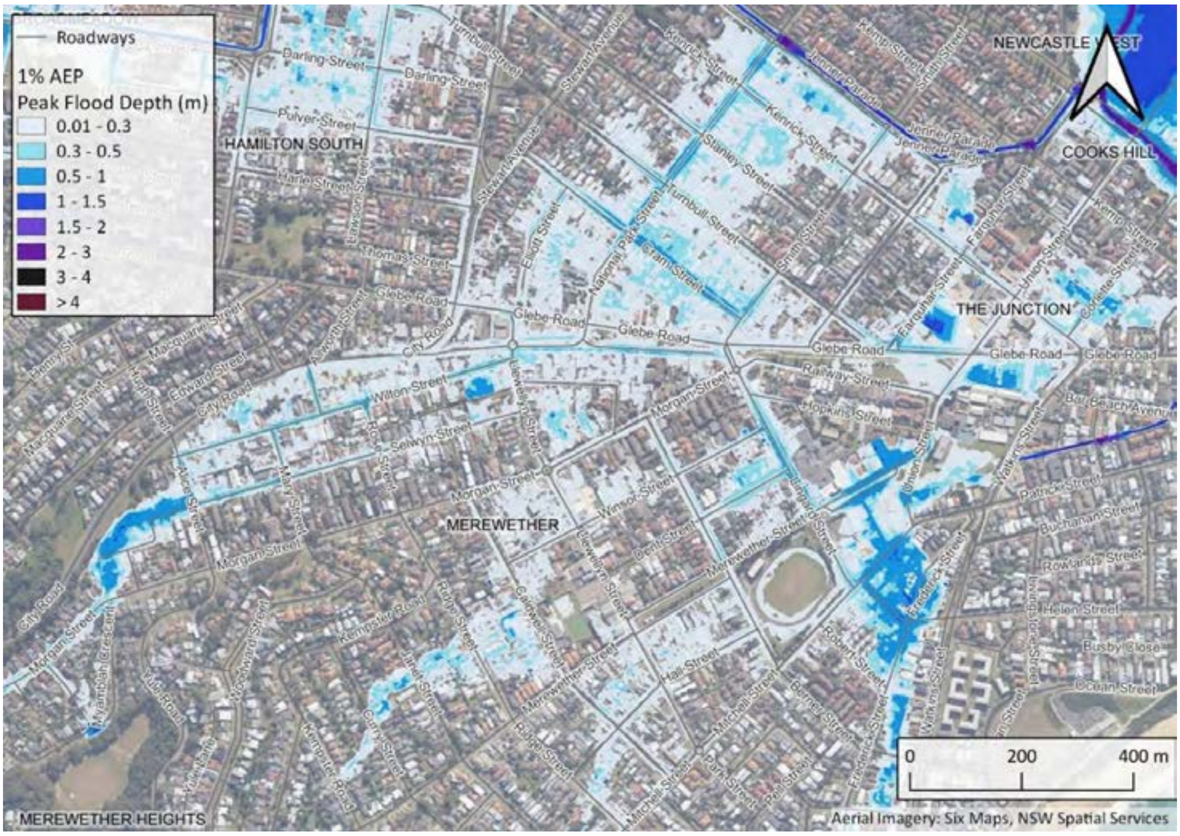

Figure 7-7. 1% AEP Flood Depth - Cottage Creek, Merewether

Cottage Creek breaks its banks primarily within the National Park Sportsground area. This provides significant flood storage for the catchment. In some locations, flooding begins to encroach into adjacent residential or commercial areas in events as frequent as the 10% AEP. Peak flood depths within the recreational area reach up to 1.8 m during the 1% AEP event. Prior to discharging into Newcastle Harbour, flows from Cottage Creek also inundate the commercial area from Parry Street to approximately Hunter Street. **Figure 7-8** shows flooding in this area.

Other locations within the study area subject to significant overland flows and ponding include Cooks Hill from Parry Street to Council Street, and the central area in Carrington.

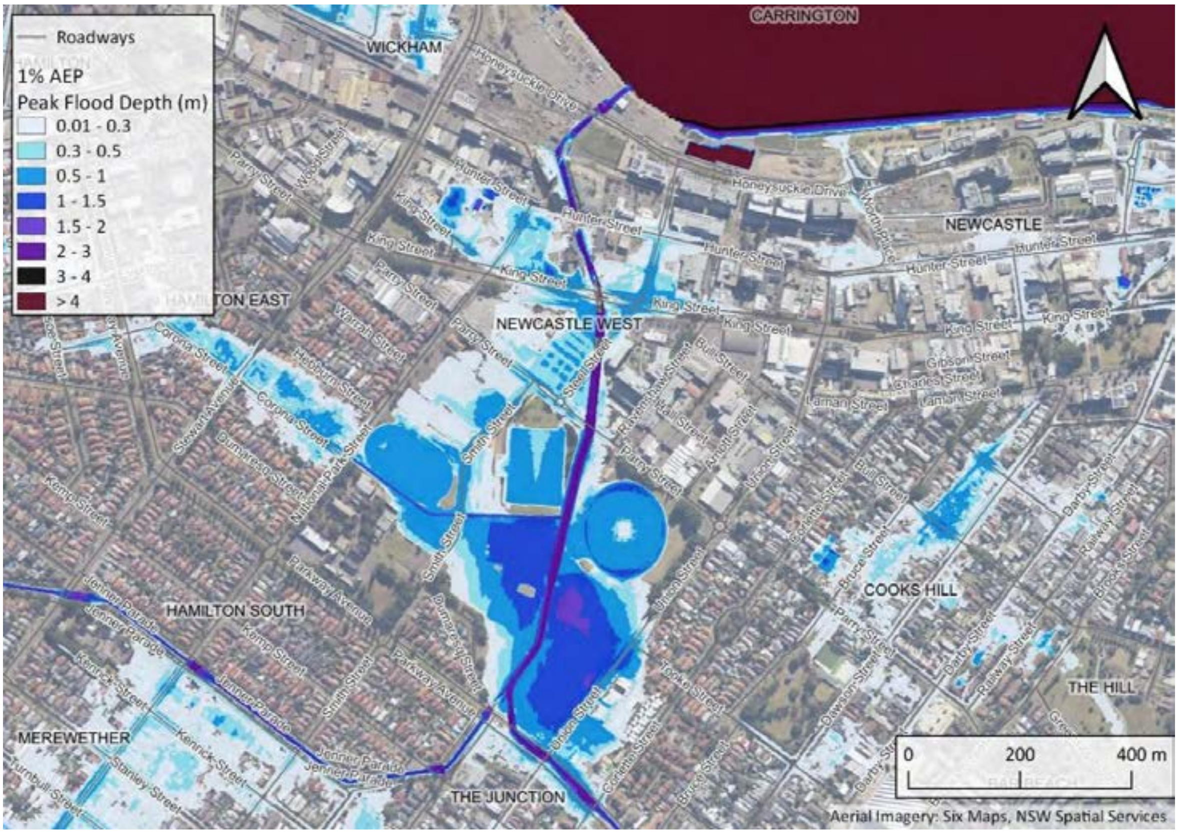

Figure 7-8. 1% AEP Flood Depth - Cottage Creek, Newcastle West

7.2 Climate Change Impacts

The impacts of future sea level rise and rainfall intensity on the study area was assessed in the model for:

- 0.40 m sea level rise, with 0.5% AEP rainfall. This was considered to represent a 1% AEP event in 2050. Rainfall depths for the 0.5% AEP are approximately up to 15% greater than the 1% AEP.
- 0.90 m sea level rise, with 0.2% AEP rainfall. This was considered to represent a 1% AEP event in 2100. Rainfall depths for the 0.2% AEP are approximately 35% greater than the 1% AEP.

Nomination of these parameters as representative of future sea level rise conditions was undertaken in consultation with the City of Newcastle. All other model parameters remained as per the design event runs.

To inform the selection of sea level rise values, guidance from the *Technical Note: Derivation of the NSW Government sea level rise planning benchmarks* (DECCEW, 2009) was adopted. This was based on the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4), published in 2007.

The results for the 2050 1% AEP scenario are shown in **Maps G320** and **G321**, and for the 2050 1% AEP scenario are shown in **Maps G322** and **G323**.

As expected, in the 1% AEP climate change scenario for 2100, increases in flood levels are observed across the study area. This is pronounced in areas which are generally hydraulically controlled by road and rail embankments as the increased rainfall results in deeper ponding before flowing downstream. The areas where catchment flood depths increase by at least 0.3 m in this scenario include:

- Broadmeadow, west of Turton Road and south of Lambton Road;
- Kotara, south of the rail line and adjacent to Northcott Drive, and east of Kotara High School;
- Adamstown, south of the Newcastle Racecourse;
- Hamilton, west and north of Gregson Park; and
- Hamilton North, between Boreas Road and Clyde Street.

Locations closer to the harbour and subject to the effects of increased sea levels, showed far greater increases in peak flood depths. These areas were subject to increases of up to 0.9 m in some locations caused by a combination of sea level rise and increased catchment runoff.

For the 1% AEP climate change scenario in 2050, a similar extent of increased flood levels was observed; however, the peak increases were generally less than 0.3 m across the study area affected by catchment flooding and a maximum of 0.5 m in areas subject to flooding from the ocean and harbour.

The City of Newcastle has advised that the Defined Flood Event (DFE) for this Flood Study should be selected as the 1% AEP in 2050 where development is subject to catchment flash flooding. Future flood planning levels will use this event as a basis plus an appropriate freeboard depth. Using this event as the DFE will make allowance for sea level rise and reduce risk for development planning horizons to 2050.

7.3 Sensitivity Analysis

Assumptions can be made when establishing flood models that influence the quantity and timing of flow generated from rainfall, and the resulting flood behaviour. Parameters adopted in the flood model may differ from their true values because they are unknown or vary across the study area. The calibration and validation modelling assists in the selection of suitable modelling parameters. However, sensitivity testing of the models is also undertaken to better understand the confidence, or variability, in the results.

The sensitivity of the hydraulic model to inflows, roughness and bridge and culvert losses was assessed for the 1% AEP event in 2050 (i.e. the 0.5% AEP with 0.4m sea level rise). The results are shown in:

- **Map G330** for an increase in flows, informed by sensitivity analysis of the hydrologic model parameters;
- **Map G331** for a decrease in flows, informed by sensitivity analysis of the hydrologic model parameters;
- **Map G332** for a 20% increase in 1D and 2D roughness;
- **Map G333** for a 20% decrease in 1D and 2D roughness;
- **Map G334** for a 20% increase in bridge and culvert losses; and
- **Map G335** for a 20% decrease in bridge and culvert losses.

Results are generally consistent with the sensitivity analysis undertaken for the June 2007 calibration event modelling described in **Section 6.4**.

A sensitivity analysis on rainfall changes alone was not undertaken, given that this was assessed as a part of the climate change assessment in **Section 7.2.** **Section 7.2** provides an understanding on the relative sensitivity of the model results to changes in rainfall (from climate change or other factors).

7.3.1 Hydrologic Model Inflows

A sensitivity analysis was undertaken on the hydrologic model by adjusting the catchment lag parameter (C=1.4 and C=1.8) and pervious surface initial and continuing losses (+/- 20%).

The higher range and lower range results from the hydrologic model sensitivity analysis were applied to the hydraulic model. Refer to **Maps G330** and **G331** for results. The impacts of the higher range flows on modelled flood levels is an overall increase in flood levels across the study area although this is generally limited to 0.05 m. Key exceptions include locations within channels or locations with upstream catchments where there are higher proportions of pervious surfaces (e.g. the Blackbutt Nature Reserve west of New Lambton). Although even in these locations, increases are limited to approximately 0.1 m.

Similarly, when inflows are decreased, flood levels decrease across the study area by 0.05 m with isolated locations experiencing slightly greater decreases up to 0.1 m.

7.3.2 2D Roughness

This sensitivity analysis modified the hydraulic model 2D surface roughness to understand the impacts on flood behaviour. Surface roughness represents the effects of ground cover on flood flow behaviour. This can include surfaces such as grassed open spaces and roadways, but the values selected can also represent large scale land use areas and averaged to include items such as buildings and fences. It also applies to the internal roughness of stormwater pipes and concrete open channels. Over time, the roughness of a particular surface can vary. Examples include increased or decreased vegetation cover, concrete surfaces being eroded, or additional building density in residential land uses.

When surface roughness is increased by 20%, velocities along overland flow paths and mainstream channels are marginally decreased, causing a reciprocal increase in flood depths in generally higher elevations or upper catchment extents (up to approximately 0.1 m). This also has the effect of altering the timing of discharge reaching downstream areas where tributaries converge, with a reduced peak flood level exhibited in areas around Broadmeadow, Kotara, Hamilton North, and The Junction (down to a maximum of approximately 0.2 m).

Decreasing surface roughness has the opposite effect. In the upper catchment and steep sections of the study area, flood flows have a higher velocity, decreasing flood depths up to approximately 0.1 m. This increase in velocity of flood flows in the upper catchment results in an increase of flood depths in the flatter downstream sections of the catchment, generally greater than 0.2 m along the downstream reaches of Styx and Throsby Creeks. Flood levels in the mid sections of the catchment around Broadmeadow, Kotara, Hamilton North and The Junction are increased up to approximately 0.2 m.

7.3.3 Bridge and Culvert Losses

Hydraulic structure modelling (typically bridges and culverts) includes estimation of energy loss which impact on flood levels immediately upstream and downstream of the structure. This is where flows will contract at the upstream end and expand again at the downstream end. Characteristics of a structure which affect energy loss can include openings of the bridge or culvert, piers (if any) and creek geometry.

The impact of bridge and culvert loss coefficients on flood levels was marginal. Structures with higher approach velocities are more affected, but the impacts were limited to +/- 0.1 m with relatively small areas of coverage.

7.4 Flood Hazard

Flood hazard is a combination of depth and velocity at a single point within a floodplain. It varies depending on localised flood behaviour across different sized flood events.

It is important to understand the varying degree of hazard and the drivers for the hazard, as these may require different management approaches. Characterising flood hazard informs emergency and flood risk management for existing communities, and strategic and development scale planning for future areas of development.

The criteria and descriptions for hazard categories mapped in this study are summarised in **Table 7-2** and **Figure 7-9**. These are based on the categories defined in the AIDR (2017) guideline.

Table 7-2. Flood Hazard Category Description

Hazard Category	Description
H1	Generally safe for vehicles, people and buildings.
H2	Unsafe for small vehicles.
H3	Unsafe for vehicles, children and the elderly.
H4	Unsafe for vehicles and people.
H5	Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust building types vulnerable to failure.
H6	Unsafe for vehicles and people. All building types considered vulnerable to failure.

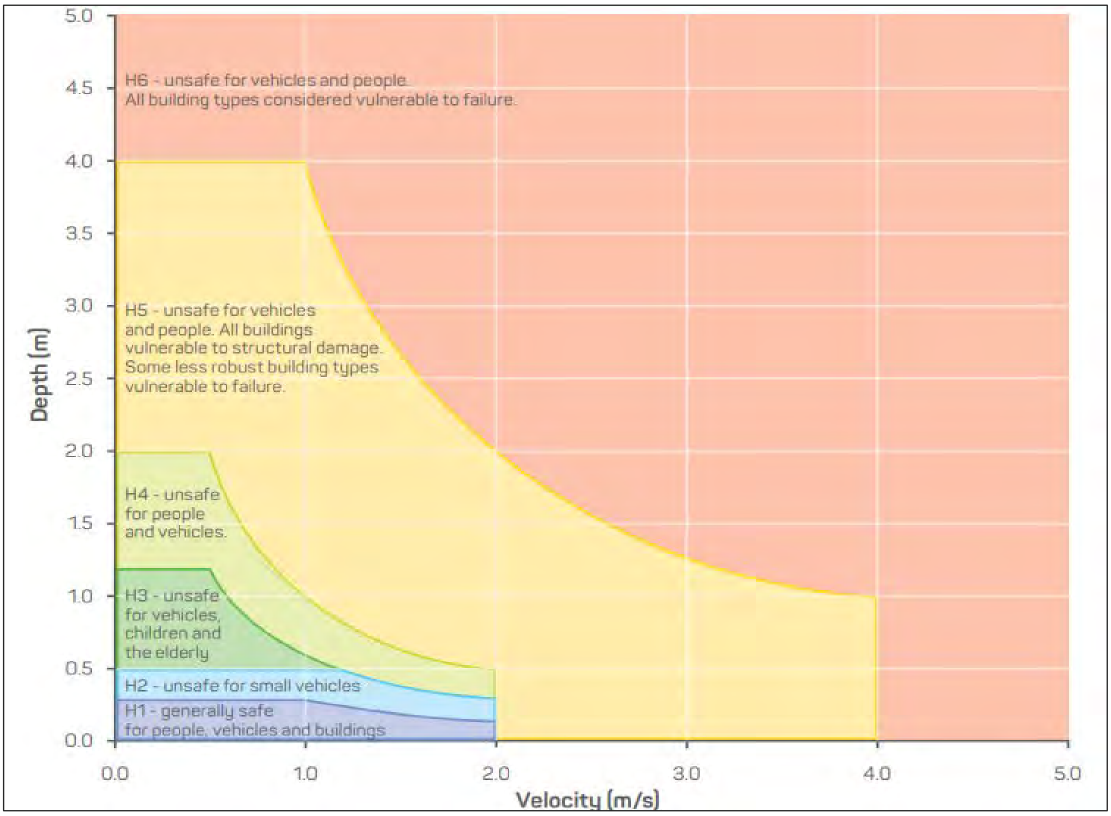

Figure 7-9. Flood Hazard Categories (AIDR, 2017)

Flood hazard mapping is provided for the 1% AEP 2050 climate change scenario (i.e. the 0.5% AEP event with 0.4 m sea level rise) and PMF events in **Maps G340** and **G341**.

Results of flood hazard assessment in this study indicate that hazard is driven by both high velocity flows and high flood depths.

Along all of Throsby, Styx and Cottage Creeks and most of their tributaries, peak hazard categories in the 1% AEP 2050 climate change scenario and the PMF are H5 and H6. With many of these creeks being concrete lined, greater flood velocities are experienced during these high magnitude events.

During the 1% AEP 2050 climate change scenario event, ponding and low velocity flows in storage areas produces peak hazard categories up to H3 and H4. Multiple major roads become non-trafficable for all vehicle types including portions of Turton Road, King Street, Griffiths Road, Bridges Road and Industrial Drive.

In the PMF, the extent of area affected by the H6 flood hazard category is generally limited to creek banks, ponded areas, and some roadways (for example, Bridges Road north of the rail line). The H5 flood category is experienced widely across the study area and extends into land use areas where buildings may be subject to structural failure. Large proportions of urban areas will not have access to roadways (subject to H2 to H4 hazard category) and those areas higher in elevation, but not bordering on the western or southern catchment extents, are likely to become isolated in such an extreme flood event.

7.5 Rate of Rise Assessment

The nature of flooding in the study area is highlighted by relatively quick catchment reaction times (i.e. peak flows and flood levels generated from shorter duration events) and flash flooding is a key concern for any future significant rainfall events. It is important to understand how quickly flood waters can rise within the catchment creeks, break their banks, and potentially cut off roadways and inundate homes.

An assessment on the rate of rise for key areas within the catchment has been undertaken for the 10% AEP, 5% AEP and the 1% AEP for the 2050 climate change scenario.

To identify which storm events resulted in the fastest rise in flood levels, and have the least warning time for evacuation and / or local flood plans to be enacted, the aforementioned storms were reanalysed in the hydrologic model to understand which temporal patterns include a more "front-loaded" storm.

Indicative measurement point locations were selected to ensure:

- a spread across the study area,
- representation of areas experiencing significant flooding in each event, and
- consideration of local evacuation routes.

Figure 7-10 illustrates the location of measurement points selected in the study area.

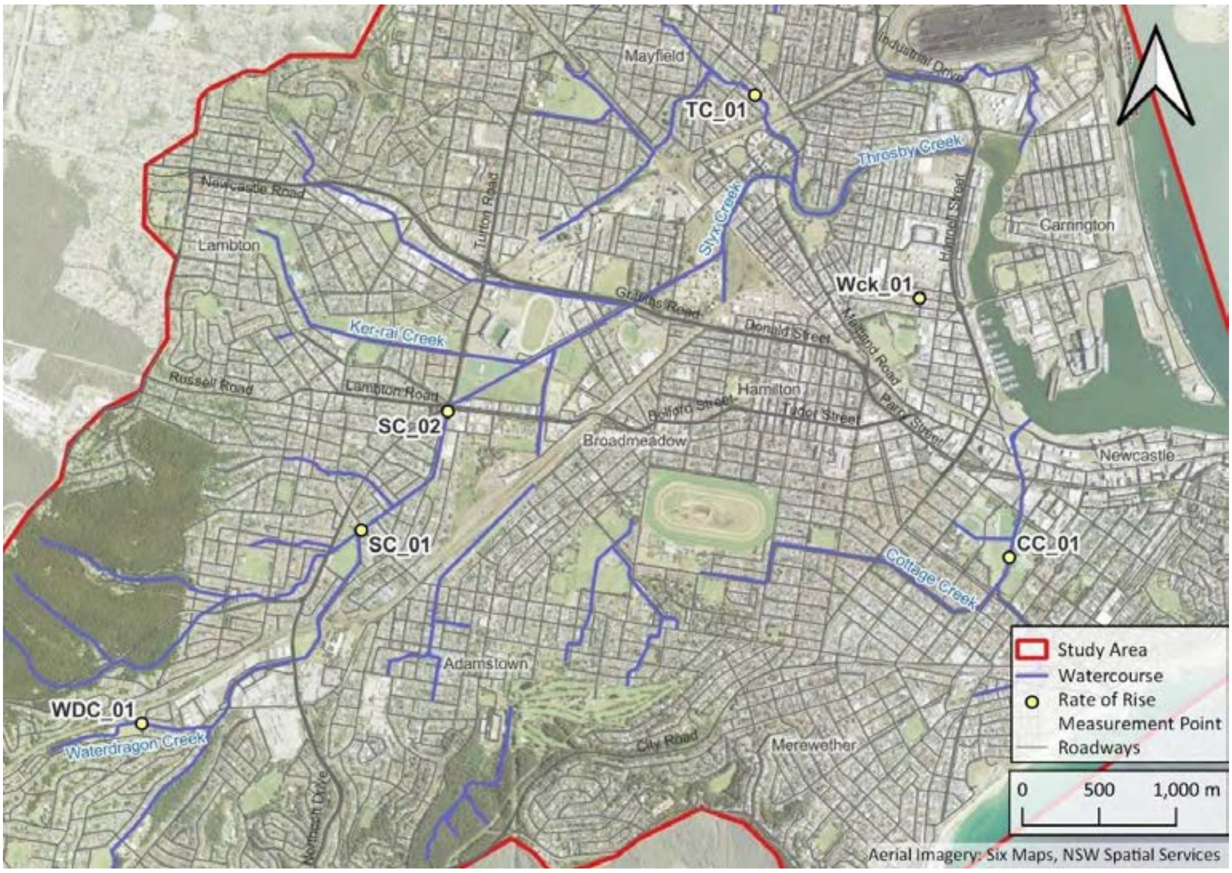

Figure 7-10. Rate of Rise Assessment Locations

Results of the assessment in **Table 7-3** show the maximum rate of raise for each event across the noted measurement locations. These were approximated from the beginning of the increase in flood levels to where flood level increases begin to flatten off after rising to the peak level and include locations within creek banks where flood levels rise quickly.

Table 7-3. Maximum Rate of Rise Results

		Rate of Water Level Rise (m/hr)		
Location	**Description**	**10% AEP**	**5% AEP**	**1% AEP in 2050**
WDC_01	Cottage Creek, in National Park Sportsground, Newcastle West	2.6	3.2	3.6
SC_01	Styx Creek and Blackbutt Creek confluence, St. James Road, New Lambton	6.2	6.4	7.9
SC_02	Styx Creek, intersection of Lambton Road and Bridges Road, Broadmeadow	2.3	2.8	4.7
TC_01	Throsby Creek, upstream of rail crossing at Litchfield Park, Mayfield	1.4	1.7	1.1

Location	Description	Rate of Water Level Rise (m/hr) 10% AEP	5% AEP	1% AEP in 2050
Wck_01	Waterdragon Creek, intersection of Park Avenue and Howell Street, Kotara	0.3	0.4	0.1
CC_01	Wickham, intersection of Robert Street and John Street	1.5	1.7	1.1

7.6 Flood Function

Maintaining the flood function (or hydraulic categorisation) of the floodplain is a key objective of best practice in flood risk management in Australia, because it is essential to managing flood behaviour. The flood function of areas of the floodplain will vary with the magnitude in an event. An area which may be dry in small floods may be part of the flood fringe or flood storage in larger events and may become an active flow conveyance area in an extreme event. Preliminary flood function mapping is provided for the PMF and the 1% AEP in 2050 events in **Maps G350** and **G351**. It is stressed that these flood function definitions are preliminary and will be reviewed and finalised as part of the next steps of the floodplain management process, being the preparation of a Floodplain Risk Management Study and Plan.

The flood function categories relevant to the study area, as defined in the Manual (DPE, 2023), are:

- Floodway - Generally areas which convey a significant portion of water during floods and are particularly sensitive to changes that impact flow conveyance. They often align with naturally defined channels.
- Flood Storage - Areas outside of the floodway and are generally areas that store a significant proportion of the volume of water and where flood behaviour is sensitive to changes that impact on the storage of water during a flood.
- Flood Fringe - Areas within the extent of flooding for the event but are outside floodway and flood storage areas. They therefore do not play a significant role in flood storage or conveyance. Flood fringe areas are not sensitive to changes in either flow conveyance or storage.

It is noted that there is no "one size fits all approach" to hydraulic category / flood function definition. Preliminary encroachment testing has been undertaken on the mapped flood function.

Results of the flood function assessment indicate that the existing concrete channels along Throsby, Styx and Cottage Creeks and their tributaries are primarily floodway areas. When flood flows break out of the channel banks, the surrounding roadways also become floodway areas and convey a significant quantity of flow for both the DFE and PMF.

8 Consequences of Flooding on the Community

With flooding being widespread across the study area and considering expansive development which has occurred in the floodplain for more than a century, it is important to understand not only the behaviour of flood waters but how they impact residents living in the floodplain. This section identifies some of the noteworthy results from the flood modelling and analysis. The 10% AEP, 1% AEP in 2050 (or the DFE) and the PMF results have been included in this analysis as a representative spread of different flood magnitudes.

The modelled area of the floodplain (i.e. the PMF extent) is approximately 44% of the total study area. The total area of flooding for the selected events in listed in **Table 8-1**.

Table 8-1. Total Area Flooded

Event	Area Flooded (km^2)
10% AEP	7.2
1% AEP in 2050	12.6
PMF	23.3

Total flood extent does not always paint the whole picture of flooding and flood risk. Much of the study area is also covered by roads, open space as well as creeks and channels which are intended to store or convey flood flows without serious risk to life and property. Results were analysed to estimate the total number of residential, commercial and industrial properties (using cadastral data identified in **Section 3.5**) within the study area which are inundated by flood waters. Note that a property which is considered 'inundated' only overlaps with the modelled flood extent and there is no discernment regarding the area of which a property or any building within it are flooded. **Table 8-2** outlines the number of properties flooded, as well as further analysis into the number of residential properties subject to inundation and residential properties impacted by H5 and H6 flood hazard categories (Refer **Section 7.4** for further information on defining flood hazard categories). Buildings subject to H5 and H6 flood hazard categories are at risk of structural damage and may be vulnerable to failure.

Table 8-2. Properties Subject to Flooding[7]

Event	Total Lots Flooded	Residential Lots Flooded	Residential Lots Subject to H5 and H6 Hazard Categories
10% AEP	8,707	7,473	181
1% AEP in 2050	13,406	11,328	324
PMF	19,970	16,843	2,664

Quantification of tangible flood damages is not covered in the scope of this flood study but would be considered in a future floodplain risk management study (FRMS).

Flood risk also considers the effect flooding has on transportation routes with respect to emergency access and evacuation. **Figure 8-1** identifies major roadways which are subject to flooding in events as frequent as the 10% AEP, and **Table 8-3** provides peak flood depths at these locations. These depths

[7] All lots zoned as commercial, residential, or industrial overlapping the estimated flood extents

are measured from the nominated roadway crests and deeper flooding may be present along outer lanes and kerb lines. It is important to note that while Industrial Drive would also be considered a major transportation route within the study area, modelled flood levels here are affected by the lack of drainage information available within the Mayfield North industrial area. Reporting of design event flood depths here have therefore not been included in this analysis.

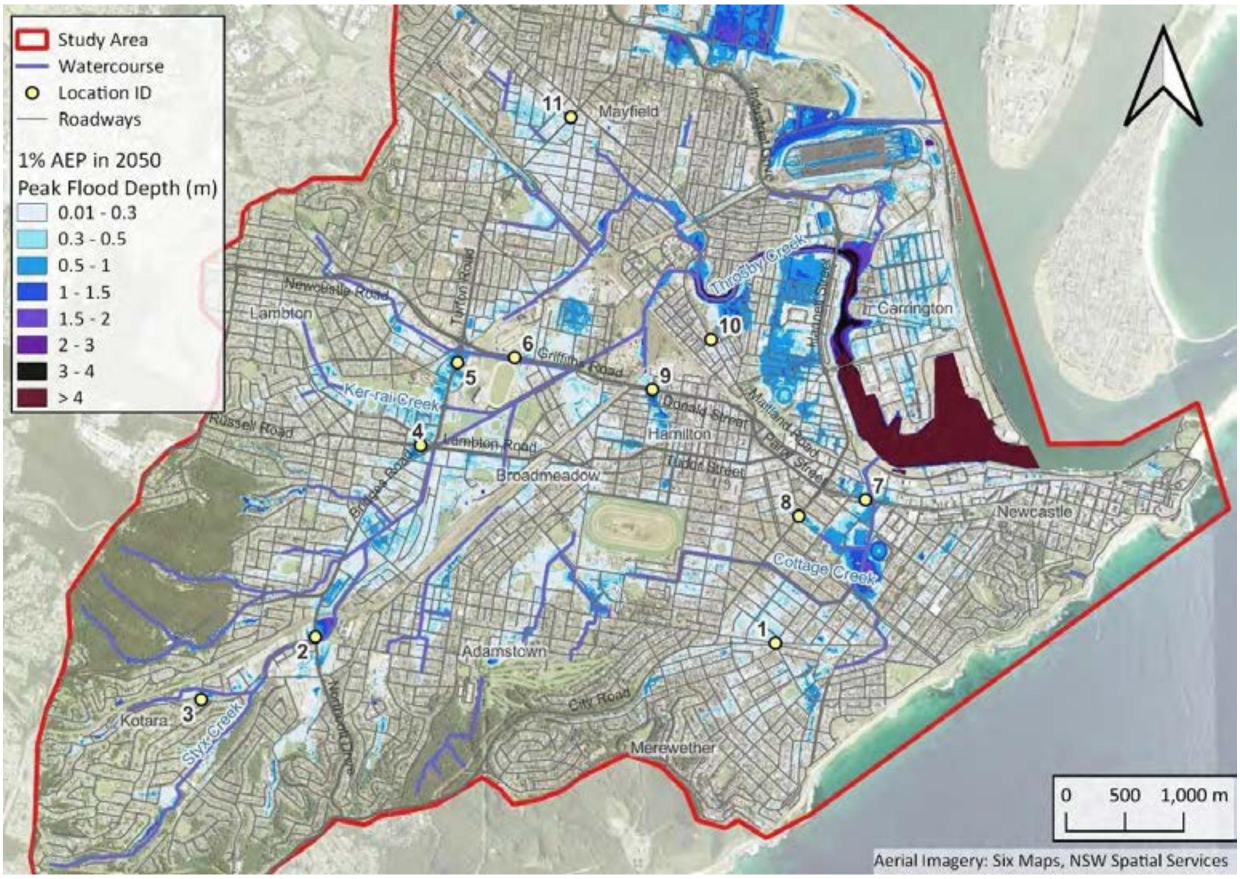

Figure 8-1. Key Roadway Overtopping Locations

Table 8-3. Peak Flood Depths Along Key Roadways

Location ID	Location Description	Peak Flood Depth (m)		
		10% AEP	1% AEP in 2050	PMF
1	Intersection of Glebe Road and Lingard Street, Merewether	0.09	0.11	0.41
2	Northcott Drive adjacent to Homemaker Centre, Kotara	0.14	0.38	2.79
3	Intersection of Park Avenue and Howell Street, Kotara	0.15	0.59	1.17
4	Lambton Road west of Bridges Road intersection, Broadmeadow	0.06	0.34	1.37
5	Turton Road south of Griffiths Road intersection, Broadmeadow	0.44	0.76	1.50
6	Griffiths Road west of Broadmeadow Road intersection, Broadmeadow	0.33	0.66	1.34
7	King Street west of Steel Street intersection, Newcastle West	0.12	0.70	2.34

Location ID	Location Description	Peak Flood Depth (m)		
		10% AEP	1% AEP in 2050	PMF
8	Stewart Avenue north of Corona Street intersection, Hamilton South	0.16	0.25	1.51
9	Intersection of Donald Street and Samdon Street, Hamilton	0.35	0.92	2.91
10	Intersection of Maitland Road and May Street, Islington	0.06	0.07	0.19
11	Hanbury Street south of Rawson Street intersection, Mayfield	0.05	0.23	1.00

Further assessment of evacuation routes and flood emergency management would be included in a future FRMS. The current FRMS, *Newcastle City-Wide Floodplain Risk Management Study and Plan* (BMT WBM, 2012) provides further details on flood emergency management for the Newcastle LGA.

9 References

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