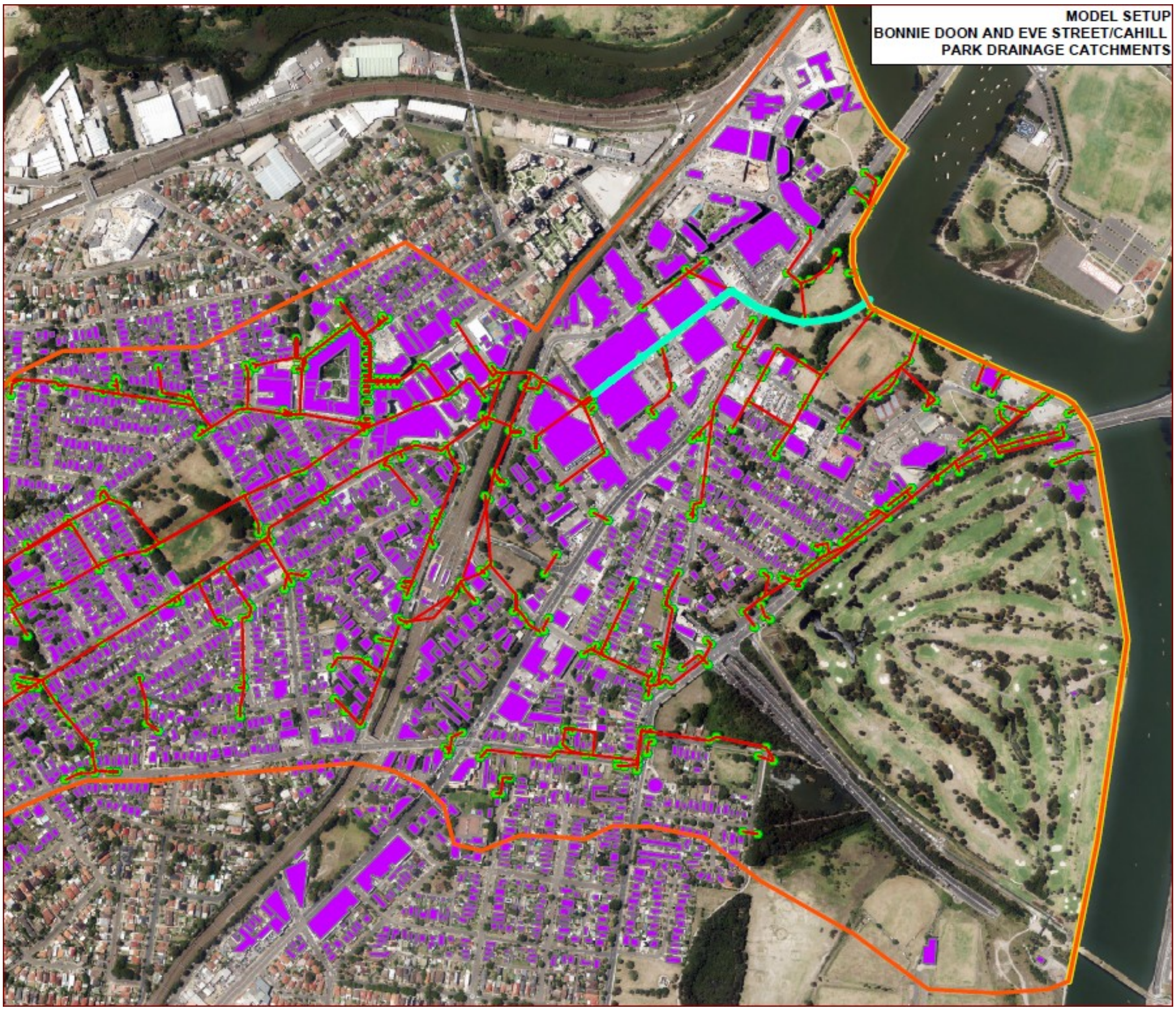
BAYSIDE COUNCIL

BONNIE DOON, EVE STREET / CAHILL PARK PIPE & OVERLAND 2D FLOOD STUDY



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BONNIE DOON, EVE STREET / CAHILL PARK PIPE & OVERLAND 2D FLOOD STUDY

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LIST OF ACRONYMS

AEP	Annual Exceedance Probability
AHD	Australian Height Datum
AR&R	Australian Rainfall and Runoff
ALS	Airborne Laser Scanning sometimes known as LiDAR
BoM	Bureau of Meteorology
DRAINS	Hydrologic computer model
DTM	Digital Terrain Model
EY	Exceedances per Year (updated term for events more frequent than a 10% AEP)
GIS	Geographic Information System
GSAM	General Southeast Australia Method
GSDM	Generalised Short Duration Method
HEC-RAS	1D hydraulic computer model
IFD	Intensity, Frequency and Duration of Rainfall
IPCC	Intergovernmental Panel on Climate Change
LEP	Local Environmental Plan
LGA	Local Government Area
m	metre
MIKE-11	1D hydraulic computer model
m^3/s	cubic metres per second (flow measurement)
m/s	metres per second (velocity measurement)
OEH	Office of Environment and Heritage
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
SWSOOS	Southern and Western Suburbs Ocean Outfall Sewer
TUFLOW	one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software program (hydraulic computer model)
1D	One dimensional hydraulic computer model
2D	Two dimensional hydraulic computer model

FOREWORD

The NSW State Government's Flood Policy provides a framework to ensure the sustainable use of floodplain environments. The Policy is specifically structured to provide solutions to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

Under the Policy, the management of flood liable land remains the responsibility of local government. The State Government subsidises flood mitigation works to alleviate existing problems and provides specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities.

The Policy provides for technical and financial support by the Government through four sequential stages:

1. Flood Study

- Determine the nature and extent of the flood problem.

2. Floodplain Risk Management

- Evaluates management options for the floodplain in respect of both existing and proposed development.

3. Floodplain Risk Management Plan

- Involves formal adoption by Council of a plan of management for the floodplain.

4. Implementation of the Plan

- Construction of flood mitigation works to protect existing development, use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

The Bonnie Doon, Eve Street / Cahill Park Pipe and Overland 2D Flood Study is the first stage of the management process for the these drainage catchments and adjacent areas. This study has been prepared for Bayside Council by WMAwater to define flood behaviour under current conditions. The study was initiated by Rockdale City Council but in September 2016 the City of Botany Bay and Rockdale City Council were amalgamated to form Bayside Council.

EXECUTIVE SUMMARY

The NSW Government's Flood Policy provides for:

- a framework to ensure the sustainable use of floodplain environments,
- solutions to flooding problems,
- a means of ensuring new development is compatible with the flood hazard.

Implementation of the Policy requires a four stage approach, the first of which is preparation of a Flood Study to determine the nature and extent of the flood problem.

A flood study of the Bonnie Doon catchment was undertaken to estimate drainage system performance and flood levels for a range of design rainfall events. These were the 20% (0.2 EY), 10%, 5%, and 1% AEP (Annual Exceedance Probability) events, and the PMF (Probable Maximum Flood) event.

The specific aims of the Flood Study are to:

- define flood behavior in the lower Bonnie Doon, Eve Street / Cahill Park catchments,
- prepare flood hazard and flood extent mapping,
- prepare suitable models of the catchment and floodplain for use in a subsequent Floodplain Risk Management Study.

This study follows on from the 2011 Bonnie Doon Pipe and Overland 2D Flood Study which undertook a similar Flood Study for the catchment upstream of the Illawarra railway line. The present study includes the remaining catchment downstream of the Illawarra railway line. However the resulting figures showing design flood information for the entire catchment have been included in this present report. Thus the figures in this report supersede those in the 2011 Bonnie Doon Pipe and Overland 2D Flood Study.

Description of Creek System: The Bonnie Doon catchment lies within the Bayside (formerly Rockdale City Council) LGA and is a minor tributary of the Cooks River, having a total catchment area of approximately 2.7km^2 to the Cooks River. The catchment is heavily urbanized with medium density residential developments in the upper catchment, and higher density residential, light industrial and commercial developments in the lower reaches downstream of Bonar Street.

There are few areas of open space upstream of the Illawarra railway line apart from Arncliffe Park. Downstream of the Illawarra railway line there are extensive commercial and light industrial developments bordering the Princes Highway with some low density residential developments in the Eve Street / Cahill Park areas. At the time of the study (2015/2016) significant re-development was occurring adjacent to the Illawarra railway line and nearby with the construction of high rise residential units replacing previous commercial and light industrial developments.

Flooding in the study area can occur as a result of rainfall over the catchment exceeding the capacity of the pit and pipe stormwater network and spreading across the floodplain or it can occur due to the Cooks River overtopping its banks. This study is principally concerned with the former mechanism and flood extent mapping for the Cooks River is included in the February 2009 Sydney Water Corporation Cooks River Flood Study.

Available Data: There are only limited records of past flooding in the catchment and no pluviometer (continuously records rainfall) within the catchment or nearby. Airborne Laser Scanning (ALS) survey was available for the entire study area and was used to determine catchment areas as well as to define the topography for the hydraulic model. Council provided details on the pit and pipe network. Previous reports (for the catchment upstream of the Illawarra railway line) were available to describe historical flooding and rainfall in the catchment.

Approach: The flood study was undertaken using numerical modelling techniques. The hydrologic and hydraulic modelling package DRAINS was utilised to determine catchment runoff and flows in the pit and pipe network. Flows at pits from DRAINS were then input to the hydraulic model TUFLOW for the determination of design flood levels and extents.

Calibration to Historical Flood Levels: The only recent historical event occurred in February 1993 and whilst there is some limited peak flood height data upstream of the Illawarra railway line there is insufficient information available downstream to undertake a model calibration. The available historical information overall is fairly limited and therefore following the next major flood both rainfall and flood level data should be collected (as soon as possible after the event) and used to further verify the results.

Determination of Design Flood Flows and Levels: Design rainfall data from Rockdale City Council's Stormwater Design Code (now superseded by Bayside Council) and design rainfall patterns from Australian Rainfall and Runoff (1987 edition) were obtained and input to DRAINS to determine design inflows.

The hydraulic model results indicate that in many locations the existing piped storm drainage system does not adequately cater for runoff generated from frequent design rainfall events. The lower reaches adjacent to the Cooks River are also inundated by Cooks River flooding which may or may not occur in conjunction with local catchment runoff flooding. Flooding is generally at shallow depths along roads and through private property.

Sensitivity analyses were undertaken of both the DRAINS and TUFLOW model results. Due to the limited quantity and quality of the calibration data available and in view of the sensitivity analyses, it is estimated that the order of accuracy of the design flood levels is up to ±0.5 m depending upon the location. These orders of accuracy are typical of such studies and can only be improved upon with additional observed flood data to refine the model calibration. A climate change induced increase in design rainfall intensities and impact of sea level rise were also undertaken.

Outcomes: The main outcomes of this study are:

- full documentation of the methodology and results,
- preparation of flood contour, depth, hazard and extent maps for the study area,
- a modeling platform that will form the basis for a subsequent Floodplain Risk

Management Study and Plan.

A key recommendation from this study is to highlight the importance of collecting and maintaining a database of historical rainfall and flood height data. It is vital that information from future flood events are collected within 24 hours and the magnitude and direction of flow paths through private property recorded. This flood study now provides a management tool in the form of the overall hydrologic and hydraulic models for assessing floodplain management options in the study area.

1. INTRODUCTION

1.1. General

The Bonnie Doon, Eve Street / Cahill Park drainage catchment is located within the Bayside (formerly Rockdale City) Council Local Government area (LGA) and drains the suburb of Arncliffe to the Cooks River. The total catchment area of the Cooks River is approximately 100 square kilometres (refer Figure 1). The catchment area of the Bonnie Doon channel upstream of the Illawarra railway line covers approximately 0.9 square kilometres, bounded generally by Forest Road to the south, Wollli Creek Road to the west, the Illawarra railway line to the east and Willington, Knoll and Lusty Streets to the north (refer Figure 1 and Photo 1). The total catchment to the Cooks River is approximately 2.7 square kilometres.

Photo 1: General locality of Bonnie Doon catchment (map courtesy of Google Maps)

Downstream of the Illawarra railway line and upstream of the Princes Highway the developments were principally large commercial usage (car yards) with some light industrial usage. However in the last 10 years the area has changed with significant redevelopment for high rise residential developments. Downstream of the Princes Highway there are smaller commercial developments combined with detached residential developments. There are extensive areas of open space at Cahill Park, Eve Street wetlands and at Kogarah Golf Course. However it is likely that significant re-development of this area will occur over the next 10 years.

In the past flooding in the Bonnie Doon catchment has caused considerable property damage. The cost of property damage and the inconvenience to residents by such flooding has prompted the former Rockdale City Council (now Bayside Council) to prepare a comprehensive and integrated Floodplain Management Plan for the Bonnie Doon catchment. This is part of the NSW State Government's program to manage major flood impacts and hazards in the floodplains, in accordance with the NSW Government's Floodplain Development Manual, 2005 (Reference 1).

The first step in the process of preparing a Floodplain Management Plan is the undertaking of a detailed Flood Study for the stormwater drainage system and associated floodplain of the Bonnie Doon, Eve Street / Cahill Park catchment. The former Rockdale City Council engaged WMAwater to undertake the flood study using current technology and data to determine the flood behaviour for the 1%, 5%, 10%, 20% annual exceedance probability (AEP) and PMF (Probable Maximum Flood) events. The 20% AEP is now termed the 0.2 EY (exceedances per year) event in line with terminology in the revised Australian rainfall and Runoff. In accordance with the study objectives, the study will determine the nature and extent of flooding through the estimation of design flows, levels, velocities and flood hazards.

The flood study was undertaken in two stages. Firstly, a full hydrologic investigation was carried out on the catchment. This included the collection of available historical rainfall and flood level data. Secondly, a detailed hydraulic model of the Bonnie Doon, Eve Street / Cahill Park stormwater system was established and calibrated using the available historical flood level data. The hydraulic model was then used with the design inflow conditions to simulate flood behaviour for various design rainfall events under existing catchment conditions.

1.2. Objectives

The study was developed in order to meet the primary objective of defining the flood behaviour under historical and existing conditions in the Bonnie Doon, Eve Street / Cahill Park catchment. The information and results obtained from the study will provide a firm basis for the development of targeted stormwater management studies and a subsequent Floodplain Risk Management Study and Plan.

This report details the results and findings of the Flood Study investigations. The key elements include:

- description of the study area,
- a summary of available historical flood related data,
- review of potential for calibration of the hydrologic and hydraulic models,
- definition of the design flood behaviour for existing conditions through the analysis and interpretation of model results.

A glossary of flood related terms is provided in Appendix A.

2. BACKGROUND

2.1. Study Area

There is a catchment area of approximately 0.9 km^2 to the Illawarra railway line, 1.2 km^2 to the SWSOOS (Southern and Western Suburbs Ocean Outfall Sewer) and a further 0.6km^2 to the Cooks River. The remainder of the 2.7 km^2 catchment is Kogarah Golf Course and open space areas. The study area included in the model is approximately 1.49 km^2.

The catchment upstream of the Illawarra railway line was previously investigated as part of the 2011 *Bonnie Doon Pipe & Overland 2D Flow Study* (Reference 2). The catchment study for that study area extended from upstream of Fripp Street to the Illawarra railway line. The railway line is raised above natural ground level and restricts surface flows from west to east apart from the road opening at Allen Street. The flows within the pipe network from the north-west part of the catchment drain in a northerly direction to the adjoining Bardwell Creek catchment. However, flows in excess of the pipe system capacity remain in the Bonnie Doon catchment.

Downstream of the Illawarra railway line (study area for the current Flood Study) there is an open concrete lined channel which exits into the Cooks River through Cahill Park. The SWSOOS provides a major obstacle to overland flow downstream of the Illawarra railway line, as does the Princes Highway where flows in excess of the culvert capacity must cross the highway.

The general relief of the study area is shown on Figure 2.

The land use upstream of the Illawarra railway line comprises a mix of residential, industrial and commercial developments together with areas of open space (Arncliffe Park). Upstream of Bonar Street the development is mainly residential while downstream includes light/medium industrial and commercial sites. Significant re-development for residential units has been occurring in the region from Bonar Street to the Illawarra railway line since the mid 2000s.

Three stormwater conduits drain water to the downstream side of the Illawarra railway line (Figure 3). They are located in Firth Street, Wollongong Road and the north-eastern extremity of Wollongong Road and comprise:

- a box culvert within the railway underpass between Wollongong Road and Allen Street,
- a 750 mm diameter pipe from Firth Street to the car park at Arncliffe railway station,
- a 1500 mm diameter pipe from the intersection of Wollongong Road and Martin Avenue draining to Arncliffe Street.

The existing storm drainage system (Figure 3) is typical of older areas of the Sydney metropolitan area and consists mainly of kerb and gutter drainage to pipes, with some box culverts in the lower reaches of the catchment. The main flow path is an open rectangular concrete lined channel extending from the SWSOOS to the Cooks River.

Appendix B provides a photographic description of some key drainage features of the catchment.

2.2. Historical Flooding Issues

In the catchment upstream of the Illawarra railway line historical flooding has been reported to occur on Hirst Street near the Dowling Street roundabout. Depending on the size of the flood, the surface flood flows then pass down Hirst Street and into the natural drainage line through residential properties in Kembla Street, Walters Street and Mitchell Street to Arncliffe Park and onwards across Broe Avenue. Floodwaters also affect properties on Kelsey Street, Bonar Street, Wollongong Road and the railway underpass at Allen Street. Flooding has also been reported on sections of Station Street. There are no accurate records of flood levels or depths apart from some descriptions of flooding for the February 1993 event.

The storm of February 1993 (Figure 4) caused significant flooding problems and disrupted morning peak traffic. Flood waters swept through four houses in Kelsey Street and ponding approximately 0.15 m above the kerb was experienced at Mitchell, Walters, Kembla and Dowling Streets, Arncliffe. Flood waters under the railway underpass at Allen Street at the intersection of Wollongong Road and Arncliffe Street were significant enough to move vehicles.

There have been other instances of floodwaters ponding under the Illawarra railway line but there is no detailed historical record.

In October 2015 a letter from Council, seeking flood information, was sent out to approximately 1500 residents. Less than 10 letters, email and telephone responses were received. Ponding of local runoff in low spots in the streets or private property has occurred several times in the past (refer Photo 2) but there were no records of extensive overland flow. Thus there is no historical data available suitable for calibration of the flood modelling system.

Photo 2: Flooding in Yard of Property in Flora Street (courtesy of resident)

2.3. Previous Studies

2.3.1. Bonnie Doon Pipe & Overland Flow Study, December 2011 (Reference 2)

This study included 2D modelling of the Bonnie Doon catchment upstream of the Illawarra railway line. The present flood study undertakes a similar type of study (using ALS, DRAINS hydrologic model and TUFLOW hydraulic model) but includes the catchment downstream of the Illawarra railway line to the Cooks River.

2.3.2. Bonnie Doon Drainage Catchment Flood Study, May 1997 (Reference 3)

The study was prepared by Lawson and Treloar Pty Ltd for Rockdale City Council and investigated the stormwater network drainage system and overland flow in the Bonnie Doon drainage catchment.

A hydrologic/pipe hydraulic model (MOUSE) and a hydraulic model (MIKE-11) were developed in order to assess the drainage system performance and to determine design flood flows and levels.

Cross-section data were obtained along the main overland flow drainage path from Forest Road to the Cooks River for input to the 1 dimensional (1D) MIKE-11 hydraulic model.

A limited calibration of the MIKE-11 hydraulic model to flood levels obtained for the February 1993 event was undertaken.

2.3.3. Wolli Creek, Bardwell Creek and Bonnie Doon Channel Flood Study, November 1996 (Reference 4)

This study was primarily undertaken to obtain design flood levels for Wolli Creek and Bardwell Creek and only considered the Bonnie Doon system to immediately upstream of the SWSOOS.

2.3.4. Additional Flood Related Studies Undertaken in the Catchment

Several drainage studies have been undertaken for private developers and Rockdale City Council since 1996. The majority of these have been undertaken by WMAwater (formerly Webb McKeown & Associates) or use the same flows or models as developed in Reference 2. Therefore these studies do not add significant additional information and have not been referenced for this study.

3. AVAILABLE DATA

The first stage in the investigation of flooding matters is to establish the nature, size and frequency of the problem. On large river systems such as the Cooks River there are generally stream height and historical records dating back to the early 1900's, or in some cases even further. However, in small urban catchments such as the Bonnie Doon catchment there are no stream gauges or official historical records available. A picture of flooding must therefore be obtained from an examination of rainfall records and local knowledge.

3.1. Peak Flood Heights

As part of the 1997 Bonnie Doon Flood Study (Reference 3), Rockdale City Council provided a brief report summarising observations from the February 1993 storm (documented in Appendix A of Reference 3). It is understood that February 1993 is the only flood event in the catchment for which there is any quantitative data available. A summary of the reported flooding is listed in the 2011 *Bonnie Doon Pipe and Overland Flow 2D Flood Study* (Reference 2) but only provided flood levels upstream of the Illawarra railway line.

3.2. Drainage Information

Details of the pit and pipe dimensions were provided by the then Rockdale City Council and included:

- Coordinates of each pit,
- Linkage between pits,
- Pipe dimensions,
- Pit details (type of pit, inlet type and dimensions, depth to invert).

The database was not verified as part of this study unless obvious errors were discovered. Where information was missing from the database it was obtained from either field inspection or interpolation. The surface levels of pits were obtained from the ALS (assumed accuracy of ±0.2 m on "hard" surfaces).

The pit and pipe network and sub catchments downstream of the Illawarra railway line used as part of this study are shown on Figure 3.

3.3. Topographic Survey

The then Rockdale City Council provided Aerial Laser Scanning (ALS) survey covering the then Rockdale City Council LGA (Figure 2). The ALS survey provides ground level spot heights at approximately 1m to 2m spacing and was used to derive a Digital Terrain Model (DTM). Technical data provided by the ALS supplier indicates that for well defined points mapped in clear areas, the expected nominal point accuracies (based on a 68% confidence interval) are between:

Vertical accuracy	±0.04m,
Horizontal accuracy	±0.55m.

However when interpreting the above, it should be noted that the accuracy of the ground definition can be adversely affected by the nature and density of vegetation and/or the presence of steeply varying terrain.

3.4. Rainfall Data

3.4.1. Historical Rainfall

Nearby pluviometer (measures rainfall continuously as opposed to daily read gauges) stations include Mortdale, Marrickville and Bexley. The only rainfall event recorded at these stations for which there is associated flood height data in the catchment is February 1993. Other significant rainfall events have been recorded but either the rainfall in the Bonnie Doon catchment has been insufficient to produce flooding or else flooding has occurred but no records of it are available. Recorded rainfall depths from these stations are provided on Table 1 and the hyetographs provided on Figure 4, together with a comparison with the design events. As there is considerable variation in the recorded rainfall depths the exact depth of rainfall in February 1993 over the Bonnie Doon catchment is unknown.

Table 1: February 1993 Rainfall Depths

Station Name	Depth (mm)	Approximate distance to catchment centroid
Mortdale	43	7 km
Marrickville Golf Club	97	2 km
Bexley Bowling Club	58	5 km

3.4.2. Design Rainfall

Design rainfalls were obtained from Rockdale City Council's Stormwater Design Code with temporal patters obtained from Australian Rainfall and Runoff (Reference 5). Probable Maximum Flood (PMF) design rainfall depths were obtained from Reference 6. A comparison between the design rainfalls obtained from Council's Stormwater Design Code and Australian Rainfall and Runoff (Reference 5) indicated there was very little difference in values obtained from the two sources.

4. APPROACH ADOPTED

4.1. General

The urbanised nature of the study area with its mix of pervious and impervious surfaces, and existing piped and overland flow drainage systems has created a complex hydrologic and hydraulic flow regime. A diagrammatic representation of the Flood Study process for the catchment is shown in Diagram 1.

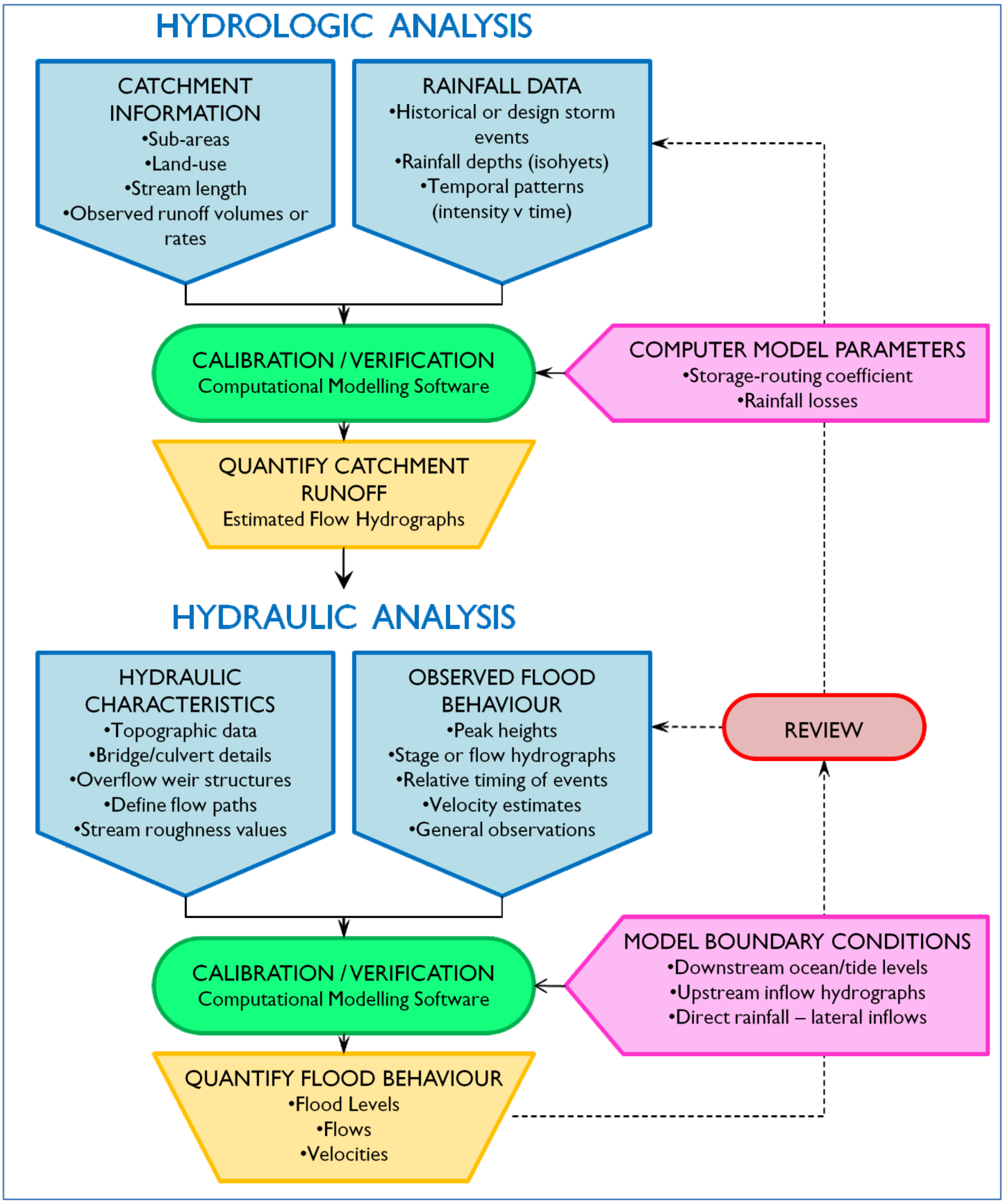


Diagram 1: Flood Study Process

4.2. Computer Models

4.2.1. Overview

A hydrologic/hydraulic model (DRAINS – Reference 7) was established for the entire catchment and used to create flow boundary conditions for input to a two-dimensional (2D) unsteady flow hydraulic model (TUFLOW – Reference 8). The TUFLOW hydraulic model assessed the runoff passing through the stormwater network and floodplain described by the ALS ground height data with inflows determined from the DRAINS model.

4.2.2. Model Calibration

To ensure confidence in the results, both models require calibration and verification against observed historical events. In an urban drainage situation, such as the Bonnie Doon catchment, there is rarely sufficient historical flood data available to permit either a flood frequency approach or a rigorous calibration of hydrologic and hydraulic models using a rainfall and runoff approach. In the study area there is no available historical data (Section 2.2). However a limited calibration of the modelling process was possible in the upper catchment (2011 *Bonnie Doon Pipe and Overland Flow 2D Flood Study* - Reference 2) using the available February 1993 rainfall and flood height data.

With the limited amount of flood height data available and given the lack of any stream gaugings, the parameters adopted in the model were largely based on modeller judgement and experience with sensitivity analysis undertaken to assess the impacts of different modelling assumptions. The adopted TUFLOW model was then used to quantify the design flood behaviour for a range of design storm events up to and including the PMF.

4.3. Design Flood Approach

There are two basic approaches to determining design flood levels, namely:

- *flood frequency analysis* – based upon a statistical analysis of the flood events, and
- *rainfall and runoff routing* – design rainfalls are processed by hydrologic and hydraulic computer models to produce estimates of design flood behaviour.

The *flood frequency* approach requires a reasonably complete homogeneous record of flood levels and flows over a number of decades to give satisfactory results. No such records were available within the catchment. For this reason a *rainfall and runoff routing* approach using the DRAINS model results was adopted for this study to derive inflow hydrographs for input to the TUFLOW hydraulic model, which determines design flood levels, flows and velocities. This approach reflects current engineering practice and is consistent with the quality and quantity of available data.

5. HYDROLOGIC MODEL

5.1. DRAINS Background

DRAINS is a hydrologic/hydraulic model that can simulate the full storm hydrograph and is capable of describing the flow behaviour of a catchment and pipe system for real storm events, as well as statistically based design storms. It is designed for analysing urban or partly urban catchments where artificial drainage elements have been installed.

The DRAINS model is broadly characterised by the following features:

- the hydrological component is based on the theory applied in the ILSAX model which has seen wide usage and acceptance in Australia;
- its application of the hydraulic grade line method for hydraulic analysis throughout the drainage system;
- the graphical display of network connections and results.

DRAINS generates a full hydrograph of surface flows arriving at each pit and routes these through the pipe network or overland, combining them where appropriate. Consequently, it avoids the "partial area" problems of the Rational Method and additionally it can model detention basins (unsteady flow rather than steady state).

Runoff hydrographs for each sub-catchment area are calculated using the time area method and the conveyance of flow through the drainage system is then modelled using the Hydraulic Grade Line method. Application of the Hydraulic Grade Line method is recommended for the design of pipe systems in AR&R (Reference 5). The method allows pipes to operate under pressure or to "surcharge", meaning that water rises within pits, but does not necessarily overflow out onto streets. This provides improved prediction of hydraulic behaviour, consistency in design, and greater freedom in selecting pipe slopes. It requires more complicated design procedures, since pipe capacity is influenced by upstream and downstream conditions.

However, DRAINS cannot adequately account for an elevated downstream tail-water level which would drown out the lower reaches of a drainage system (it can if the upstream pit is above the tail-water level but not if it is below). For this reason flooding within reaches affected by elevated water levels is more accurately assessed using the TUFLOW model.

It should be noted that DRAINS is not a true unsteady flow model and therefore does not account for the attenuation effects of routing through temporary floodplain storage (down streets or in yards).

The pit and pipe system was only included in DRAINS for isolated parts of the upper catchment drainage network. Typically, the sub-catchment runoff flows from DRAINS were directly input to TUFLOW and not routed through the pit and pipe network in DRAINS.

5.2. Input Data

An extensive amount of data was required to establish the DRAINS model including pipe size, length, slope, pit type, depth, inlet type, location, surface and invert levels, catchment characteristics (catchment area, % imperviousness, time of concentration, etc.), design rainfall and overland flow-paths.

The information was obtained from various sources and collated into a spreadsheet for input to DRAINS. The database was expanded to include relevant DRAINS input parameters such as reference names and pipe connectivity information. Sub-catchment areas were derived using the ground contours obtained from the ALS.

The following provides a summary of the source of the data and any qualifications regarding its accuracy.

Pit Location and Type: Co-ordinates were available in Rockdale City Council's drainage database. Figure 3 shows all the pits (inlet pits and junctions) located in the study area.

Junction pits do not have inlets to allow surface or bypass inflow and are typically where upstream branches combine or where two different sized pipes join or where there is a significant bend in the pipe. Junction pits were modelled as sealed pits without the ability to surcharge. A limitation of this method is that the pit is unable to represent surcharging, should a pit cover "blow off" under a highly pressurised pipe system.

Pit Surface Levels: Surface levels were obtained from the ALS.

Grate and Inlet Details: The grate and inlet type and size were taken from Rockdale City Council's database.

Pit Naming Convention: Details of this were provided by Rockdale City Council.

Pipe Size, Location and Depth to Invert: These were obtained from Rockdale City Council's database. Invert levels of pipes were adjusted where required to ensure that all pipes have a positive grade (a requirement of DRAINS). Pipe slopes were based on the assumed pipe inverts and the pipe distance (calculated using the pit coordinates).

Pit Connectivity: This information was obtained from Rockdale City Council's database.

Catchment areas: A sub-catchment area is specified within DRAINS for each inlet pit and labelled with the prefix "a" followed by the pit name. Sub-catchment areas were derived in GIS using the ALS contours (to define the flow paths and catchment divides) and are shown on Figure 3. For each sub-catchment area the proportion of pervious (grassed), impervious (paved), supplementary area (paved area not directly connected to pipe system - these were estimated in this study as 5% of the total catchment) were determined from field and aerial photographic inspections and summarised in Table 2. Figure 5 provides a map of the assumed percentage of imperviousness of the catchment.

Table 2: DRAINS Catchment Downstream of the Illawarra Railway Line

Area	Area (ha)	%
Paved Area	51.0	34
Grassed Area	90.5	61
Supplementary	7.5	5
TOTAL	**149.0**	**100**

Time of Concentration: The surface runoff from each sub-catchment contributing to a pit has a particular time of concentration. This is defined as the time it takes for runoff from the upper part of a sub-catchment to start contributing as inflow to the pit. It is mainly related to the flow path distance, slope and surface type over which the runoff has to travel.

The time of concentration was defined using a flow length based on the sub catchment slope and the size and shape of the contributing catchment. The delay lag of 2 minutes was applied to the pervious areas.

The catchment slopes were derived from inspection of the contours and it was found that the sub catchments had a mean slope of 4.6%.

Overland Flow Path: The precise route of the overland flow path is not given in DRAINS, only the link between the upstream and downstream inlet pits in a straight line.

Any runoff that was unable to enter a downstream pipe reach due to insufficient inlet or pipe capacity was modelled as overland flow. These overland flow paths were determined from field inspection and the ALS contour information. At each inlet pit where overland flow was possible, a downstream inlet pit was specified as the receiving destination, together with an estimated travel time.

Overland flow travel times can have a significant bearing upon the accumulated peak flows achieved further downstream. DRAINS does not route flows along overflow routes, but takes flows from one pit and places it at the downstream pit after a specified travel time.

Design Rainfall: Design rainfalls were obtained from Rockdale City Council's Stormwater Design Code with temporal patters obtained from Australian Rainfall and Runoff (Reference 5). Uniform depths of rainfall with zero areal-reduction factors were applied across the entire catchment.

5.3. Establishing DRAINS

The DRAINS model established for the study area downstream of the Illawarra railway line included 38 sub-catchments (Figure 3). The drainage system defined by the model is made up of:

- runoff entry points representing surface inlet pits;
- bends, junctions or inspections locations which are termed pits with no inlet (i.e. the lid is sealed);

- underground conduits (circular pipe or box) or open channel lengths between pits, called reaches.

A number of consecutive reaches is called a branch. The pipe system "tree" structure is defined by nominating the pits where two or more branches join. The length, slope, shape and dimension of each reach are specified, as well as representative inflow characteristics (surface inlet capacity) for each inlet pit.

5.4. Adopted Model Parameters

Losses from a paved or impervious area are considered to comprise only of an initial loss (an amount sufficient to wet the pavement and fill minor surface depressions). Losses from grassed areas are comprised of an initial loss and a continuing loss. The continuing loss was calculated from an infiltration equation curve incorporated into the model and is based on the estimated representative soil type and antecedent moisture condition. It was assumed that the soil in the catchment has a slow infiltration rate potential and the antecedent moisture condition was considered to be saturated. The latter was justified by the fact that the peak rainfall burst can typically occur within a longer event that has a duration lasting days.

The adopted parameters are summarised in Table 3.

Table 3: Adopted DRAINS Hydrologic Model Parameters

RAINFALL LOSSES	
Paved Area Depression Storage (Initial Loss)	1 mm
Grassed Area Depression Storage (Initial Loss)	5 mm
SOIL TYPE	3
Slow infiltration rates. This parameter, in conjunction with the AMC, determines the continuing loss	
ANTECEDENT MOISTURE CONDITIONS (AMC)	3
Total Rainfall in 5 Days Preceding the Storm	12.5 to 25 mm

6. HYDRAULIC MODEL

6.1. TUFLOW Background

The TUFLOW modelling package includes a finite difference numerical model for the solution of the depth averaged shallow water flow equations in two dimensions. The TUFLOW software is produced by BMT WBM (Reference 8) and has been widely used for a range of similar projects. The model is capable of dynamically simulating complex overland flow regimes. It is especially applicable to the hydraulic analysis of flooding in urban areas which is typically characterised by short duration events and a combination of supercritical and subcritical flow behaviour.

For the hydraulic analysis of overland flow paths, a two-dimensional (2D) model such as TUFLOW provides several key advantages when compared to a traditional one-dimensional (1D) model. For example, in comparison to a 1D approach, a 2D model can:

- provide localised detail of any topographic and/or structural feature that may influence flood behaviour;
- better facilitate the identification of the potential overland flow paths and flood problem areas;
- inherently represent the available floodplain storage within the 2D model geometry.

Importantly, a 2D hydraulic model can better define the spatial variations in flood behaviour across the study area. Information such as flow velocity, flood levels and hydraulic hazard can be readily mapped in detail across the model extent. This information can then be easily integrated into a GIS based environment enabling the outcomes to be incorporated into Council's planning activities.

6.2. Model Establishment

Given the objectives and requirements of the study and the availability of ALS data (Figure 2) a 2D overland flow hydraulic model is the most suitable model to effectively assess flood behaviour. The 2D TUFLOW model extends from upstream of Fripp Street to the Cooks River (Figure 6) and encompasses the TUFLOW model established as part of the 2011 *Bonnie Doon Pipe and Overland Flow 2D Flood Study* (Reference 2).

A 2m by 2m 2D grid was generated from the ALS data based on the aerial photography available at the time of the study. Whilst every attempt was made to include current buildings it should be noted that this was not always possible due to the changing nature of the study area. Pit and pipe information incorporated in the DRAINS model was used to create a 1D drainage network in TUFLOW.

6.3. Boundary Conditions

6.3.1. Design Inflows

The DRAINS model provides a comprehensive "picture" of the peak flows across the catchment (at pit inlets, in pipes and as overland flows). However, DRAINS does not provide water levels or flood extents along the overland flow paths (a key requirement of a flood study). TUFLOW does provide water levels, velocities and extents but requires inflow hydrographs (time v flow) from DRAINS as TUFLOW cannot generate inflow hydrographs. Thus design flow hydrographs from all the DRAINS sub-catchments are used as the hydrologic inflows into the TUFLOW model. These inflows were directly input to the respective inlet pit locations within the TUFLOW model (within the 1D TUFLOW model layout as the pipes are represented as 1D elements). In this way if the inflow at an inlet pit exceeds the capacity of the inlet pit (i.e the inlet grate and kerb lintel are too small or the pipe is too small or at capacity due to upstream inflows) then the inflows will surcharge at the pit and enter the 2D overland flow domain of TUFLOW. The 2D domain represents the streets and properties through which overland flow will travel and is defined by the ALS data.

6.3.2. Tailwater Level

A downstream or tailwater level is required at the Cooks River. This can be achieved in various ways (constant level or time varying hydrograph) and for the present study the approach taken was:

- Adopting a constant tailwater level in the Cooks River rather than a time varying level which introduces issues regarding the coincidence of the peaks of the local catchment runoff and Cooks River flooding;
- The tailwater level for all events was taken as the 5% AEP flood level in the Cooks River taken from the February 2009 Sydney Water Corporation Cooks River Flood Study. This varied from 1.93 mAHD at the railway crossing bridge at Wolli Creek to 1.63 mAHD at the SWSOOS crossing of the Cooks River at the southern limit of Kogarah Golf Course. It should be noted that in the lower reaches of the Bonnie Doon catchment the dominant flood mechanism is inundation from the Cooks River. Thus adopting the 5% AEP level rather than a lower level in the Cooks River will have little impact on flood levels adopted for development control purposes.

6.3.3. Roughness Co-efficient

The Manning's "n" values for each grid cell were largely estimated using engineering experience. These roughness values were applied to the 2D overland area based on the terrain shown in Table 4.

Table 4: Manning's "n" values adopted in TUFLOW

Manning's "n"	Description
0.04	Parks and grassed areas
0.022	Commercial areas
0.10	Residential areas
0.02	Road reserve
0.04	Dense Trees
0.07	Marshlands

For this study it has been considered that properties adjacent to the overland flow-path boundary would not be part of the effective flow path due to the presence of fences and buildings. However inundation of these properties has been allowed in the model. High Manning's "n" coefficients within adjacent properties as noted in Table 4 were adopted, in conjunction with extruding the building outlines in these areas.

6.3.4. Hydraulic Structures

Surcharging of pits in the Bonnie Doon catchment occurs at a number of locations, predominantly at sag points.

A key location for surcharging occurs adjacent to the intersections of Wollongong Road with Martin Avenue and Allen Street (Photo 3 and Photo 4). This low lying area located on the western side of the Illawarra railway line is at the confluence of several piped drainage systems and is drained by a single 1500 mm diameter pipe under the railway line north of the underpass and a box culvert beneath the railway underpass. The underpass itself acts as an overflow path after flood waters reach a depth of approximately 0.8 m at the intersection of Wollongong Road and Martin Avenue.

Photo 3: Intersection of Wollongong Rd and Martin Ave

Photo 4: Railway underpass upstream of Allen St

Buildings were excluded from the model grid as it is assumed that there is very little flow through the structures. The TUFLOW model was based on ALS data and photographic data available at the time of the study in 2015. However due to the continuing re-development of parts of the catchment it is likely that the TUFLOW grid does not exactly match the structures on the ground at a later date. Thus, if detailed information is required at a specific location it is essential that the grid is confirmed to ensure it represents the ground detail at the location. This is particularly relevant for the floodplain between Bonar Street and the railway line. It is noted that since 2015 a pedestrian underpass has been completed immediately north of the railway underpass on Photo 4.

In areas where there are large overland flows, significant obstructions by fences, and other flow restrictions, these features were modelled in more detail within TUFLOW. However it should be noted that only significant features were individually described in TUFLOW and again this aspect of the modelling should be reviewed if a specific location is under consideration.

6.4. Model Calibration - February 1993 Event

Ideally the TUFLOW model should be calibrated to one historical event and verified using another historical event. There should also be sufficient historical flood height data (preferably for both historical events) to define the flood gradient within the modelling extent. Unfortunately for the Bonnie Doon catchment this is not the case and approximate validation was only possible in the catchment upstream of the Illawarra railway line for the February 1993 event.

The magnitude of the February 1993 rainfall event cannot be accurately ascertained as there is no nearby pluviometer that would provide an indication of the magnitude of the rainfall. Figure 4 provides a comparison of the historical rainfalls with the design rainfall for the catchment. This suggests that the February 1993 event was probably less than a 5% AEP event at the station that recorded the greatest intensities (Marrickville).

7. DESIGN FLOOD RESULTS

7.1. Design Events

7.1.1. Critical Storm Duration

Initially the TUFLOW model was run for a series of design storm durations (15 minutes to 2 hours) for the 1% AEP event. A comparison of the peak water levels at the inlet pits indicated that the critical duration (event producing the highest flood level) was the 60 minute storm duration. This duration was then adopted as the critical storm duration for all other design events, including the PMF.

For the PMF design event, 60 minutes was found to be the critical duration in the majority of study area, with the 30 minute and 120 minute storms producing slightly higher flood levels in certain areas. 30 minutes was found to be critical in the southern part of the study area, but there were not significant differences in depth compared to the 60 minute storm and the depth was quite shallow. 120 minutes was critical in and near the downstream tidal area, where no properties are located. In view of the above the 60 minute storm was adopted for the PMF.

7.1.2. Results

Peak height profiles for the 0.2EY, 5%, 1% AEP events and the PMF are provided on Figure 7 with flood depths and contours provided on Figure 8 to Figure 12. Peak velocities are provided on Figure 13 to Figure 17. These figures cover the entire Bonnie Doon catchment and supersede the figures provided in the 2011 *Bonnie Doon Pipe and Overland Flow 2D Flood Study* (Reference 2). Flood depths at selected locations are provided on Table 5.

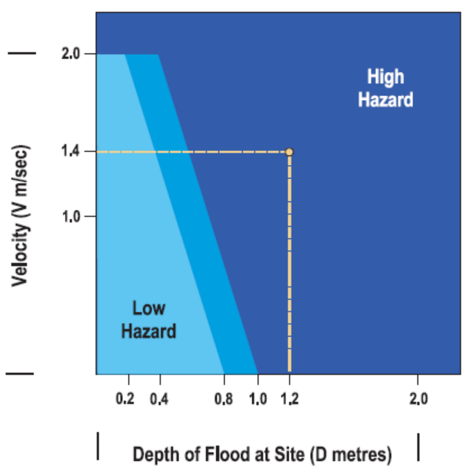
Table 5: Design Flood Depths

Location (refer Figure 6)	Flood Depth in m				
	0.2 EY	10% AEP	5% AEP	1% AEP	PMF
Marsh Street	0.20	0.21	0.22	0.23	0.43
Flora Street	0.31	0.33	0.36	0.40	0.61
Eve Street Cycleway	0.42	0.52	0.62	0.86	2.48
Eve Street	0.01	0.01	0.01	0.01	0.03
Wickham Street	0.03	0.03	0.03	0.04	0.06
Argyle Street	0.34	0.48	0.59	0.84	4.33
Arncliffe Street	0.70	0.83	0.94	1.13	3.56
SWSOOS	1.47	1.63	1.75	2.46	3.69
Open Channel	1.60	1.72	1.81	1.96	2.50
Guess Avenue	0.84	0.91	1.12	1.36	2.13
Princes Highway	0.09	0.10	0.11	0.21	1.14
Gertrude Street	0.42	0.43	0.44	0.51	1.29

7.1.3. Hazard and Hydraulic Categorisation

For the purposes of floodplain risk management in NSW the floodplain is divided into one of three Hydraulic categories (floodway, flood storage or flood fringe) and two Hazard categories (Low or High). These terms are defined in Appendix A and further details of this process are provided in the *NSW Government's Floodplain Development Manual* (Reference 1).

The Hazard categorisation was determined quantitatively based upon the available hydraulic and survey information in accordance with the provisional hydraulic hazard categorisation Figure L2 (opposite) provided in the *NSW Government's Floodplain Development Manual* (Reference 1). As indicated in the Manual this process of Hazard categorisation is **Provisional** and should be refined at a later date to reflect other factors that influence hazard (such as warning time, flood readiness, rate of rise, duration of flooding, evacuation problems, effective flood access and the type of development). The hazard categorization is provided on Figure 18 to Figure 22 for all design events.



Notes

The degree of hazard may be either -

- reduced by establishment of an effective flood evacuation procedure.
- increased if evacuation difficulties exist.

In the transition zone highlight by the median colour, the degree of hazard is dependant on site conditions and the nature of the proposed development.

Example:

If the depth of flood water is **1.2 m**
and the velocity of floodwater is **1.4 m/sec**
then the provisional hazard is **high**

FIGURE L2 - Provisional Hydraulic Hazard Categories

Definition of hydraulic categories is subjective and particularly in an urban catchment where the depths of inundation are relatively shallow and the peak flows small. However blocking a flowpath or a floodway can re direct flow onto adjoining properties and so adversely affect the adjoining property. This already occurs due to inappropriate fencing, landscaping or vegetation. Council endeavours to ensure that any new development that requires a Development Application takes this into account by requiring a flood study to be undertaken to assess the potential hydraulic impacts of the development.

Any filling on the floodplain or blocking of a flow path will affect flood levels elsewhere, however it is impractical for Council to monitor every development on the floodplain as many will have only a very minor impact. There is no absolute definition of Floodways. For the purposes of this study the following are defined as Floodways with the remainder of the floodplain defined as flood fringe (no flood storage):

- *All roads, drainage easements or parks inundated by floodwaters,*
- *All flood liable private property where runoff enters across one boundary and exits partially or fully across another.*

Floodways are not necessarily always defined as high hazard areas. Hazard reflects the potential harm to life and property due to flooding, whilst floodways reflect areas where if filled or modified will produce a significant adverse hydraulic impact on others.

High hazard areas also do not always represent a continuous unbroken area from upstream to downstream through the catchment. This is because in say a wide gently sloping area the depth and velocity are low, making the provisional hazard low but in the immediate upstream steeper and narrower floodplain the hazard is high.

7.2. Sensitivity Analysis

The design flood levels for existing conditions have been determined following consideration of design rainfall information, the available datasets, past flood behaviour and the nature of the catchment.

Within the constraints of the available data and the adopted modelling approach various assumptions have been made regarding a range of key factors including the adopted rainfall loss assumptions, roughness definitions, catchment characteristics and the performance of the drainage network.

Where possible, these parameters have been inferred based on the behaviour of the February 1993 event (upstream of the Illawarra railway line only) and our experience in similar catchments. To quantify the sensitivity of the model to these various assumptions, a number of additional model runs were undertaken for the 1% AEP design event to assess the impacts of the following and the results are provided in Table 6.

- Rainfall losses ± 20%,
- Change in Manning's “n” in TUFLOW by ± 20%,
- Blockage in pipes and bridges in TUFLOW of 50%,
- Blockage of all pipes in TUFLOW < 450 mm diameter.

Table 6: Results of Sensitivity Analyses – 1% AEP

Location (refer Figure 6)	Depth (m)	Change in Flood Depth (m)					
	Base	50% Blocked	< 450 mm Blocked	n - 20%	n + 20%	Losses Low	Losses High
Marsh Street	0.23	0.00	0.00	0.00	0.00	0.00	0.00
Flora Street	0.40	0.00	0.01	-0.01	0.01	0.00	0.00
Eve Street Cycleway	0.86	0.00	0.00	0.00	0.00	0.01	-0.01
Eve Street	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Wickham Street	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Argyle Street	0.84	0.96	0.01	0.04	-0.05	0.04	-0.04
Arncliffe Street	1.13	0.18	0.00	0.02	-0.03	0.04	-0.03
SWSOOS	2.46	0.01	0.00	0.04	-0.04	0.04	-0.04
Open Channel	1.96	-0.01	-0.01	0.00	0.00	0.02	-0.02
Guess Avenue	1.36	-0.02	-0.01	0.06	-0.01	0.03	-0.03
Princes Highway	0.21	-0.03	0.00	-0.03	0.01	0.02	-0.02
Gertrude Street A	0.51	-0.02	0.00	-0.03	0.01	0.02	-0.02
Gertrude Street B	0.54	-0.01	0.00	-0.01	0.00	0.01	-0.01

7.3. Climate Change

In accordance with the DECC Guideline 2007 (Reference 9), increases of 10%, 20% and 30% to design rainfall intensities were investigated. A possible sea level rise of 0.4 m and 0.9 m was also investigated (increase in tailwater level as described in Section 6.3.2).

The impact of the different rainfall and sea level assumptions at various locations in the catchments is shown in Table 7. As expected, peak flood depths increased with corresponding increases in rainfall. The increase in flood extents for the climate change scenarios are shown on Figure 23.

The results indicate that the average increase (based on a comparison of the peak level at the inlet pits) in the 1% AEP event is:

- 10% increase = 0.06 m,
- 20% increase = 0.11 m,
- 30% increase = 0.16 m.

Table 7: Results of Climate Change Analyses – 1% AEP Design Event

Location (refer Figure 6)	Depth (m)	Change in Flood Depth (m)				
	Base	rain + 10%	rain + 20%	rain + 30%	0.4m sea level rise	0.9m sea level rise
Marsh Street	0.23	0.00	0.01	0.01	0.39	0.69
Flora Street	0.40	0.02	0.04	0.05	0.12	0.41
Eve Street Cycleway	0.86	0.09	0.16	0.23	0.28	0.51
Eve Street	0.01	0.00	0.00	0.00	0.00	0.00
Wickham Street	0.04	0.00	0.00	0.01	0.00	0.00
Argyle Street	0.84	0.11	0.22	0.35	0.00	-0.02
Arncliffe Street	1.13	0.09	0.17	0.24	0.00	0.00
SWSOOS	2.46	0.11	0.21	0.28	0.02	0.04
Open Channel	1.96	0.05	0.10	0.13	0.09	0.15
Guess Avenue	1.36	0.12	0.23	0.29	0.12	0.15
Princes Highway	0.21	0.07	0.16	0.21	0.40	0.68
Gertrude Street A	0.51	0.06	0.13	0.16	0.43	0.71
Gertrude Street B	0.54	0.02	0.04	0.06	0.49	0.78

7.4. Review of Design Rainfall Intensities and Updated Design Methodology

In July 2013 the BoM published a new set of Intensity-Frequency-Duration (IFD) design rainfalls as part of the AR&R revision projects; Project One. The BoM and Engineers Australia advise that the 2013 IFD values should not be used in conjunction with flood modelling techniques based on AR&R87 IFD design rainfalls. Nonetheless, as flood methodologies using the 2013 curves have not yet been published (as at the time of the Draft report), this study compared the two IFD values. This indicates up to 30% decreases in intensities for some durations and AEPs over the catchment (refer Table 8). For the 60-minute duration, decreases are in the order of

20% to 30%.

Table 8: Percentage Change in IFD (increase from 1987 to 2013 datasets) at Arncliffe

	Frequency (AEP)						
Duration	**1EY**	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**
10 min	1%	-13%	-11%	-10%	-11%	-13%	-14%
30 min	-4%	-18%	-19%	-18%	-20%	-22%	-23%
1 hour	-8%	-22%	-23%	-23%	-25%	-27%	-29%
2 hour	-9%	-23%	-25%	-24%	-26%	-28%	-29%
3 hour	-9%	-23%	-24%	-22%	-24%	-25%	-26%
6 hour	-6%	-20%	-19%	-17%	-17%	-17%	-17%
12 hour	-3%	-16%	-13%	-9%	-8%	-8%	-6%
24 hour	-1%	-13%	-7%	-2%	-1%	1%	2%

A graph showing the 1987 and 2013 IFD datasets are provided on Diagram 2.

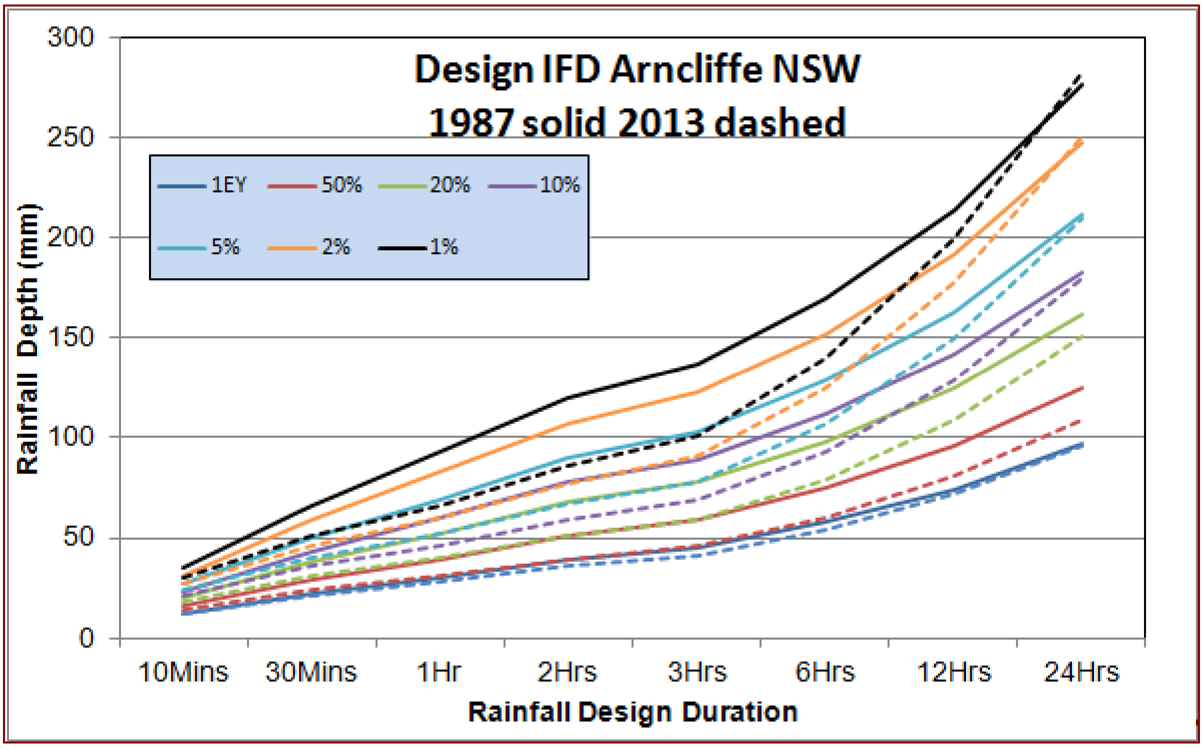


Diagram 2: Comparison of 1987 and 2013 IFD

A summary of Diagram 2 indicates:

- the 24 hour rainfalls have not changed much;
- the largest change is a significant reduction (up to 30%) for the 50% AEP and greater events for durations from 30 minutes to 6 hours;
- the 1987 5% AEP becomes the 2013 1% AEP;
- the 1987 10% AEP is becomes the 2013 2% AEP;
- the 1987 50% AEP (0.5EY) becomes the 2013 20% AEP (0.2EY);
- there is little change for the 1EY event.

The above changes may make a significant difference to the extent and depth of inundation, however the 2013 IFD curves cannot be used in isolation. The other outputs from the AR&R revision project will include revised temporal patterns, areal reduction factors, losses and base flow. As the IFD data aims to achieve AEP neutrality where the technique results in a design flood estimate with the same probability of exceedance as the IFD design rainfall estimate, so updates to the other design flood inputs are needed to ensure new design flood estimates are produced with the same AEP as the new 2013 IFD design rainfalls.

Current guidance says that the new 2013 IFD data should only be used with revised AR&R design parameters as they become available. It cannot be assumed that using the 2013 IFD design rainfalls with AR&R87 techniques and design parameters will deliver a more reliable estimate of the design flood. In addition, careful consideration should be given before using the 2013 IFD design rainfalls with the Average Variability Method temporal patterns and design losses from AR&R87.

7.5. Blockage

There are multiple factors to be considered in assessing the potential for blockage of culverts and bridges. These considerations include:

- the type and mobility of debris that can be washed into the waterway to block the structure or inlet;
- the dimensions of the debris in comparison to the structure;
- dimensions of the structure in relation to the upstream and downstream channels;
- the presence of piers, service crossings, or other obstructions to flow on which debris can accumulate; and
- catchment land-use.

For the Bonnie Doon catchment, consideration of these factors generally indicates a low risk of blockage. The structures in the lower channel are generally large, with openings greater than 3 m wide and the structures have similar widths as the open channel itself. Most of the bridges are clear spanning across the open channel, or the total width of the culverts is the same width as the channel, so there is very little contraction of flow at the structure entrances.

The presence of the railway line and SWSOOS upstream of the main open channel prevent significant debris from being mobilised into the channel. Inspection of the catchment indicated that there would be very low probability of debris large enough to block the structures (such as cars or large trees) being mobilised into the open channel, primarily due to the SWSOOS and railway line obstructions.

Based on this assessment, the assumed design blockage factors of 0% are in line with the recommendations of the guidelines for blockage developed as part of the ARR revision (Reference 10), based on low at-site debris potential and large structures relative to the debris type.

Blockage of up to 50% was investigated, which would represent an upper bound of severe blockage for the catchment, assuming a medium level of at-site debris potential, for debris larger than the open width of the structures. This scenario is considered unlikely. The sensitivity results indicate that for this relatively severe scenario, flood levels in the study area are insensitive to blockage, typically changing by less than 0.05 m. Only at Argyle Street and Arncliffe Street would blockage have more influence on flood levels. At these locations, the at-site debris potential is lowest because structures in this area are closest to the SWSOOS, with a very short length of open channel upstream, and little overbank floodplain from where debris can be mobilised.

8. ACKNOWLEDGEMENTS

This study was undertaken by WMAwater and funded by Rockdale City Council (now Bayside Council) and the NSW State Government. The assistance of the following in providing data and guidance to the study is gratefully acknowledged.

- Office of Environment and Heritage,
- Rockdale City Council (now Bayside Council),
- NSW State Government,
- Residents of the Bonnie Doon, Eve Street / Cahill Park catchment.

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Figures

FIGURE 1
STUDY AREA

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FIGURE 2
TOPOGRAPHY

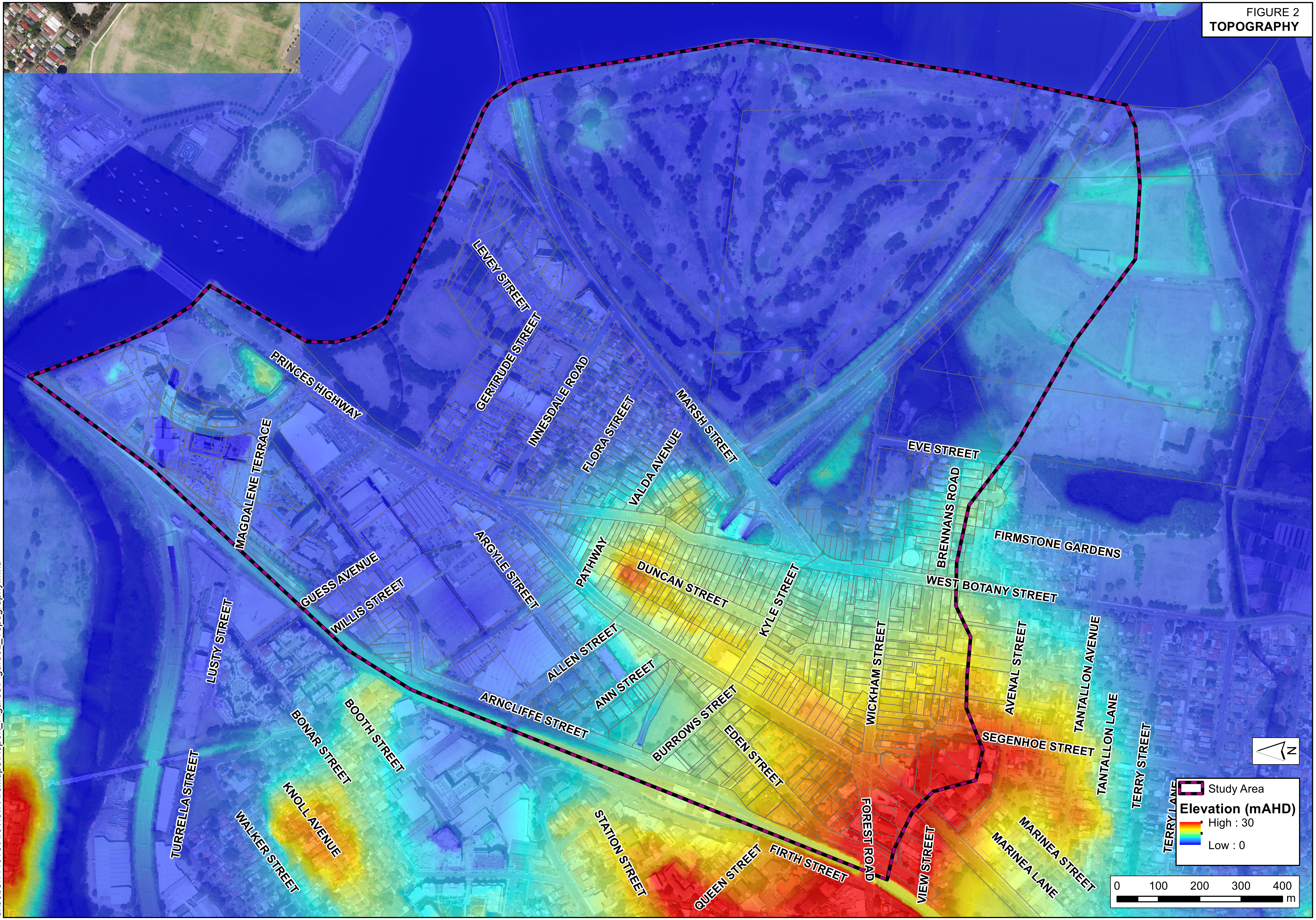

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FIGURE 3
DRAINAGE NETWORK AND SUBCATCHMENTS

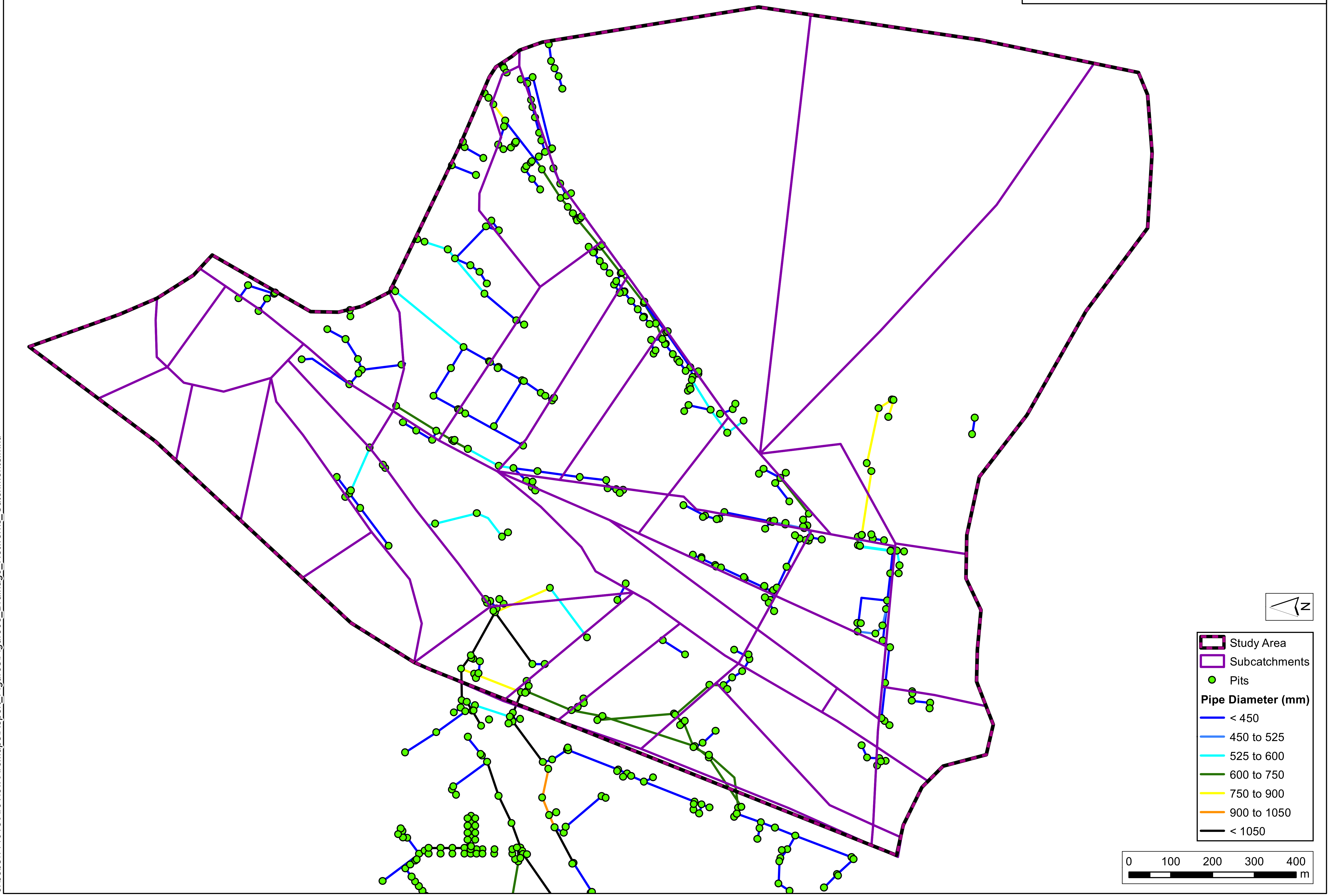

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FIGURE 4
COMPARISON OF HISTORICAL AND DESIGN RAINFALL DEPTHS

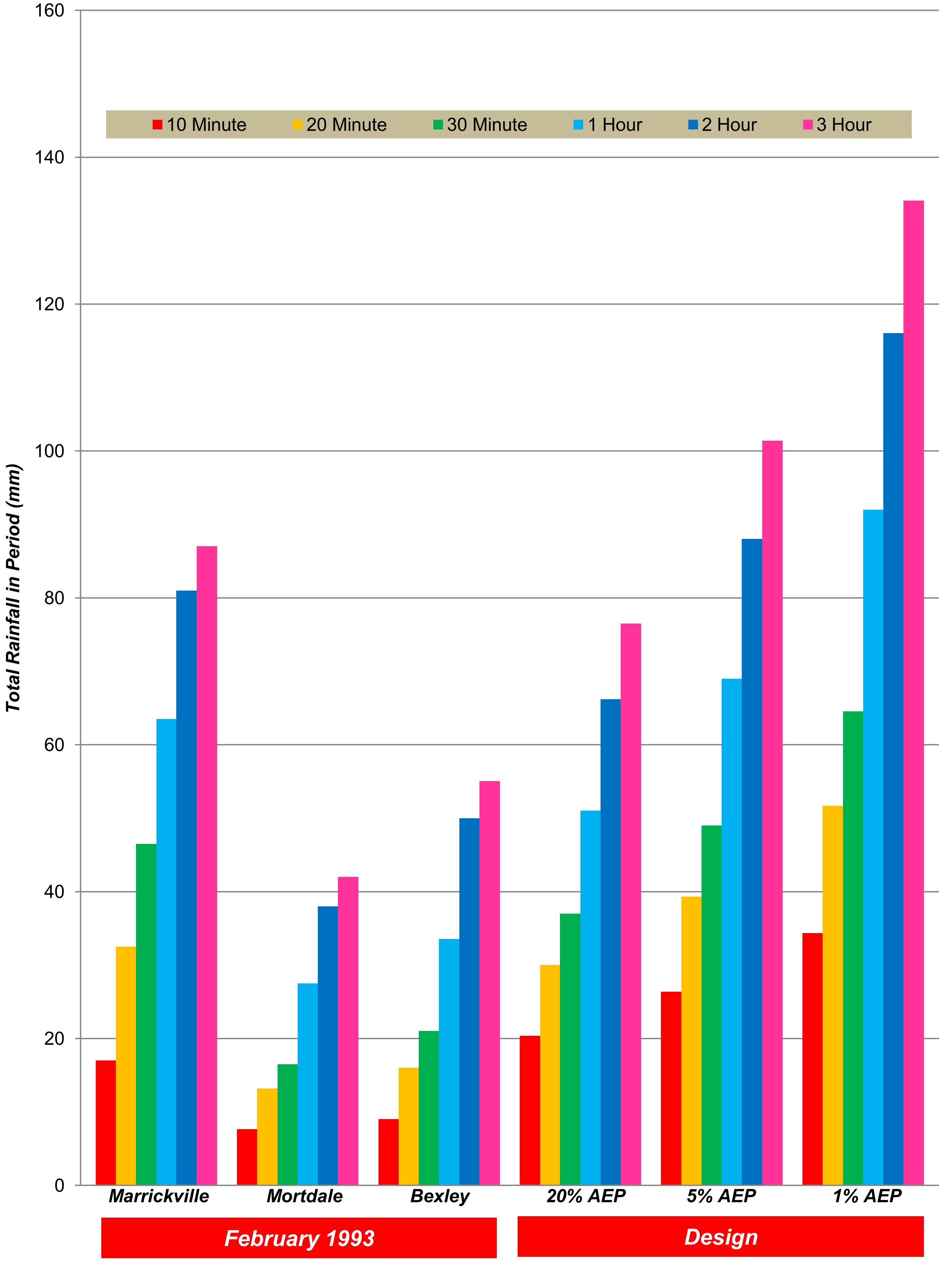
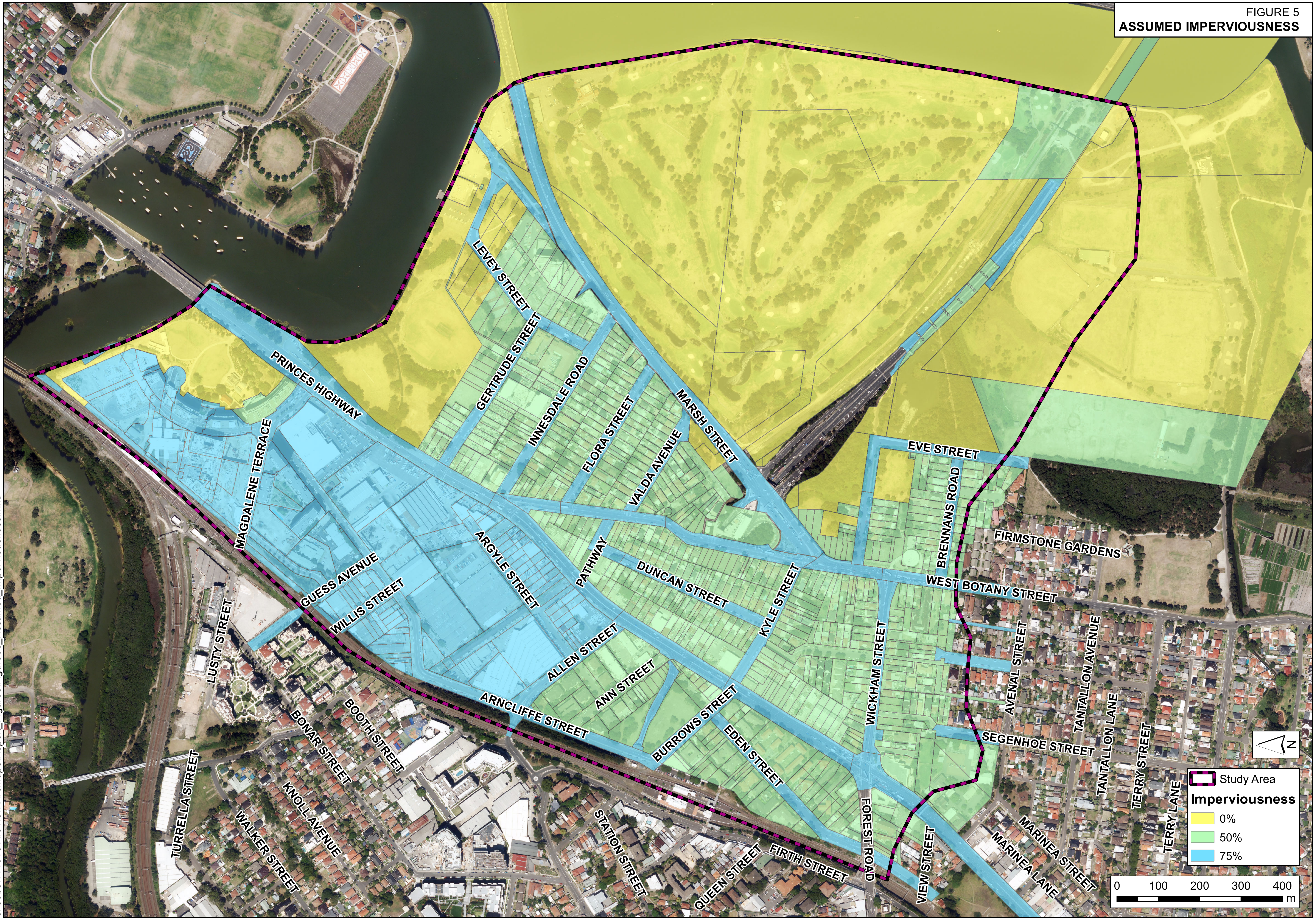


FIGURE 5
ASSUMED IMPERVIOUSNESS



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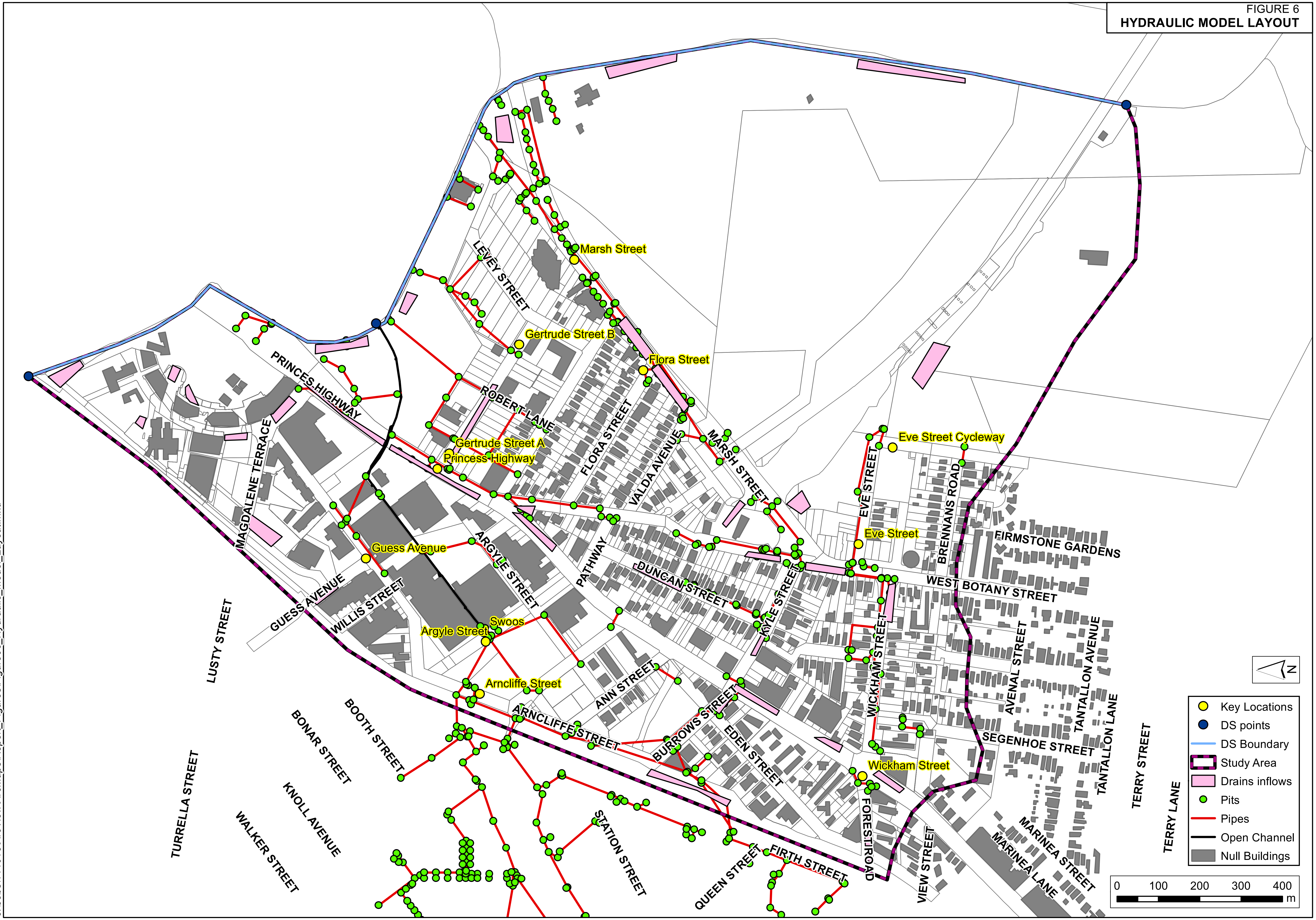

FIGURE 6
HYDRAULIC MODEL LAYOUT

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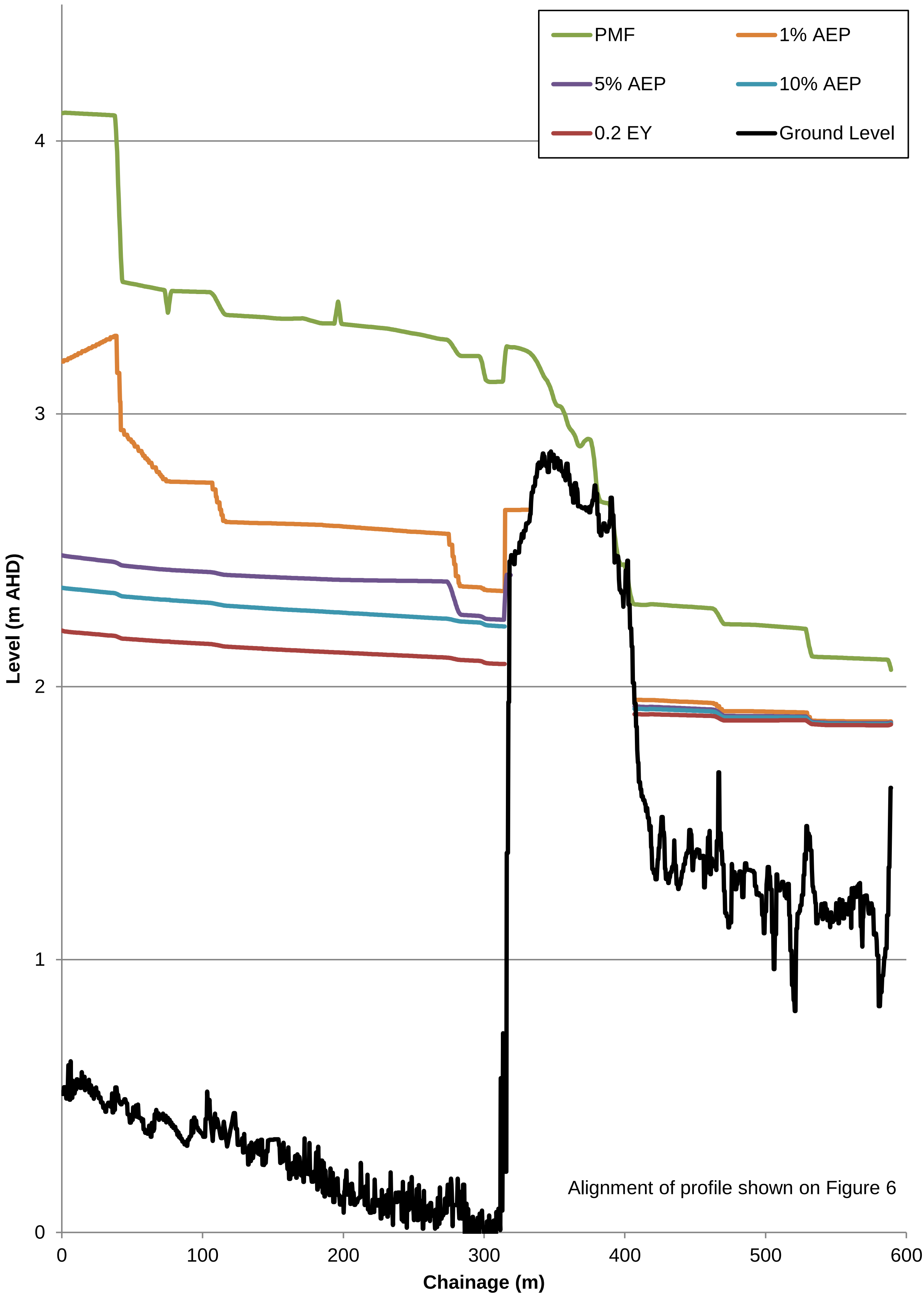
FIGURE 7
PEAK WATER LEVEL PROFILES
DESIGN FLOOD EVENTS



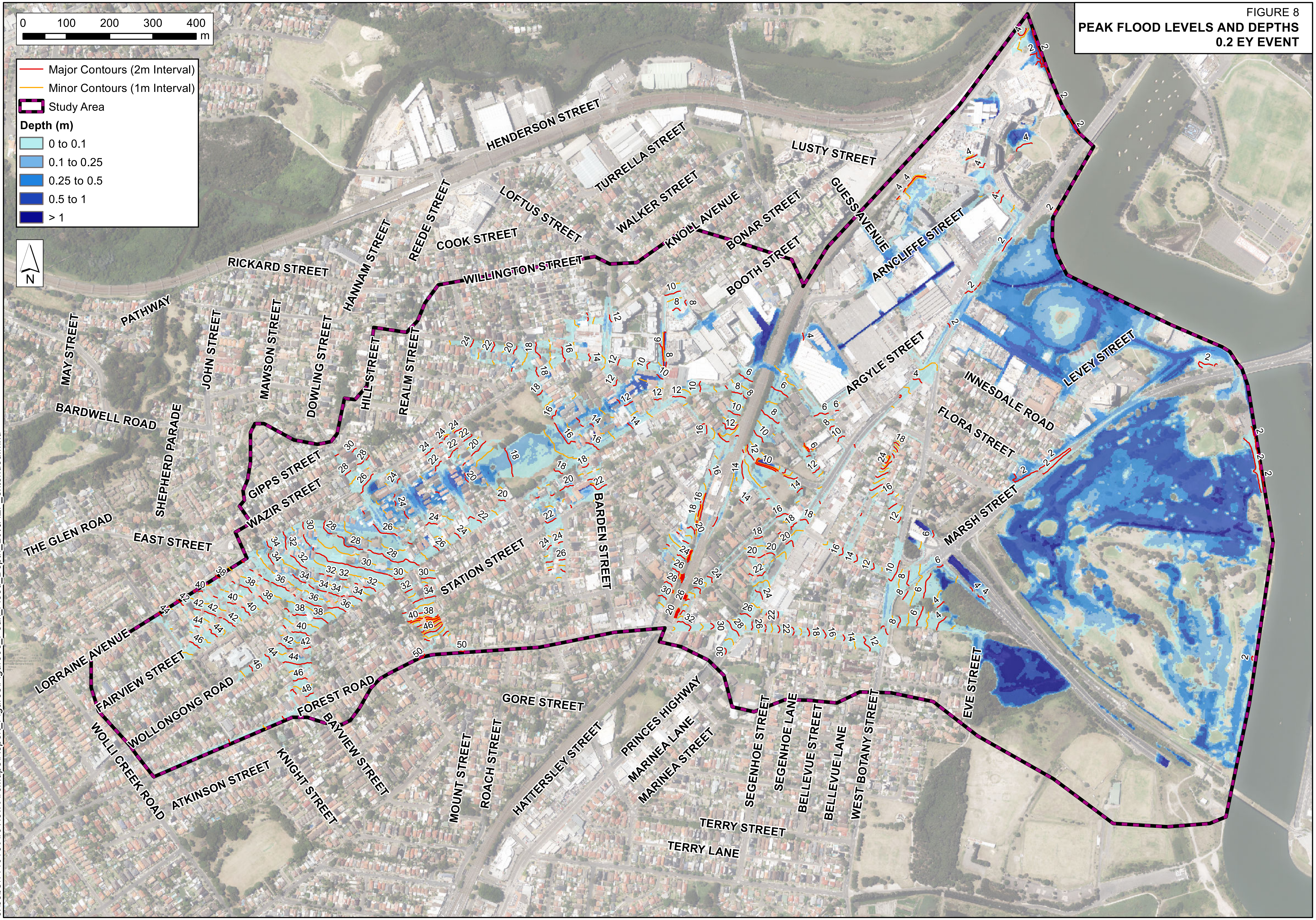


FIGURE 8
PEAK FLOOD LEVELS AND DEPTHS
0.2 EY EVENT

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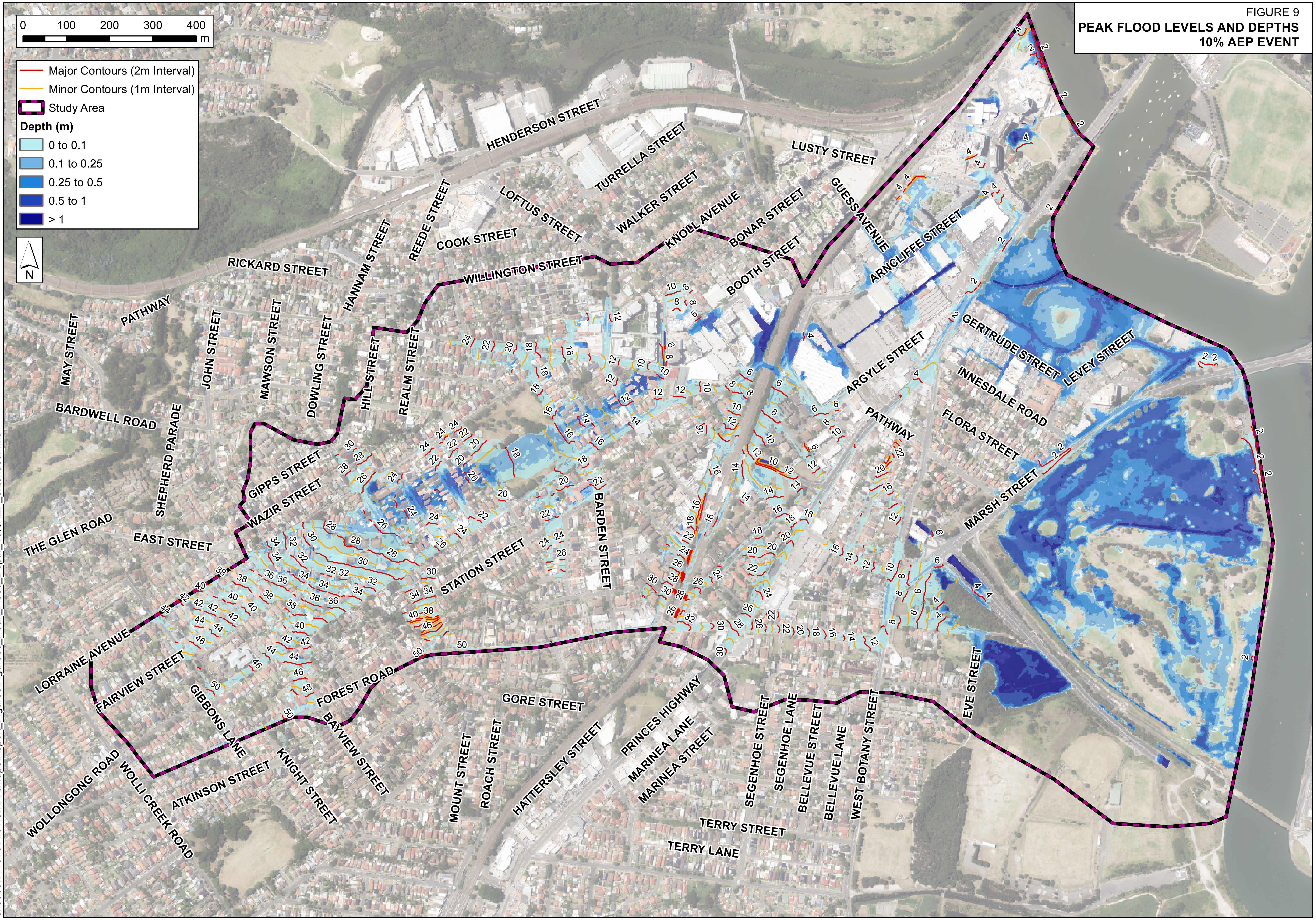

FIGURE 9
PEAK FLOOD LEVELS AND DEPTHS
10% AEP EVENT
0 100 200 300 400 m
Major Contours (2m Interval)
Minor Contours (1m Interval)
Study Area
Depth (m)
0 to 0.1
0.1 to 0.25
0.25 to 0.5
0.5 to 1
> 1
N
HENDERSON STREET
TURRELLA STREET
LUSTY STREET
LOFTUS STREET
WALKER STREET
KNOLL AVENUE
BONAR STREET
GUESS AVENUE
ARNCLIFFE STREET
BOOTH STREET
COOK STREET
REEDE STREET
HANNAM STREET
RICKARD STREET
WILLINGTON STREET
PATHWAY
MAY STREET
JOHN STREET
MAWSON STREET
DOWLING STREET
HILL STREET
REALM STREET
BARDWELL ROAD
SHEPHERD PARADE
GIPPS STREET
WAZIR STREET
THE GLEN ROAD
EAST STREET
GERTRUDE STREET
LEVEY STREET
INNESDALE ROAD
ARGYLE STREET
FLORA STREET
MARSH STREET
STATION STREET
BARDEN STREET
LORRAINE AVENUE
FAIRVIEW STREET
GIBBONS LANE
FOREST ROAD
BAYVIEW STREET
GORE STREET
PRINCES HIGHWAY
MARINEA LANE
MARINEA STREET
SEGENHOE STREET
SEGENHOE LANE
BELLEVUE STREET
BELLEVUE LANE
WEST BOTANY STREET
EVE STREET
WOLLONGONG ROAD
WOLLI CREEK ROAD
ATKINSON STREET
KNIGHT STREET
MOUNT STREET
ROACH STREET
HATTERSLEY STREET
TERRY STREET
TERRY LANE
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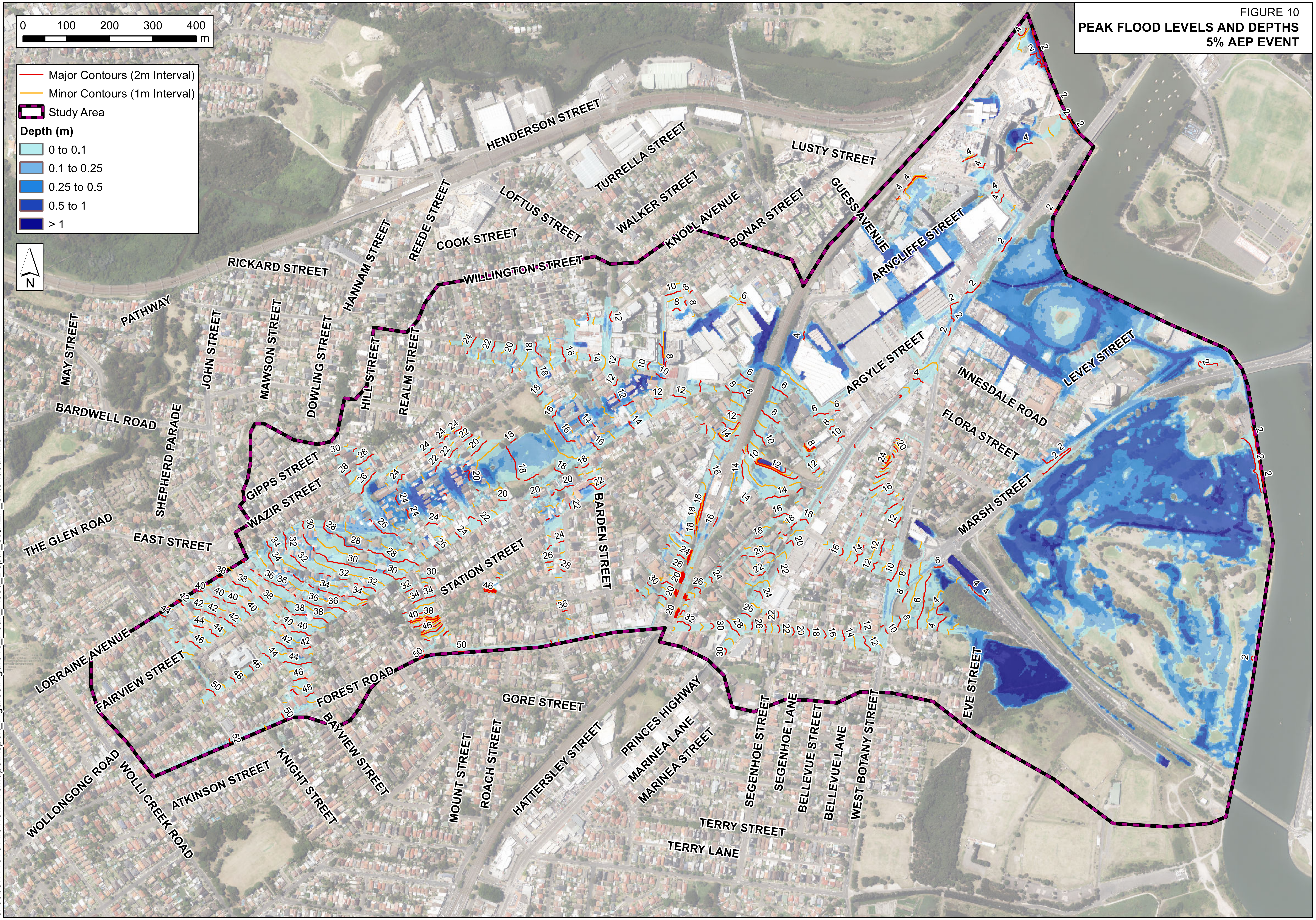
FIGURE 10
PEAK FLOOD LEVELS AND DEPTHS
5% AEP EVENT



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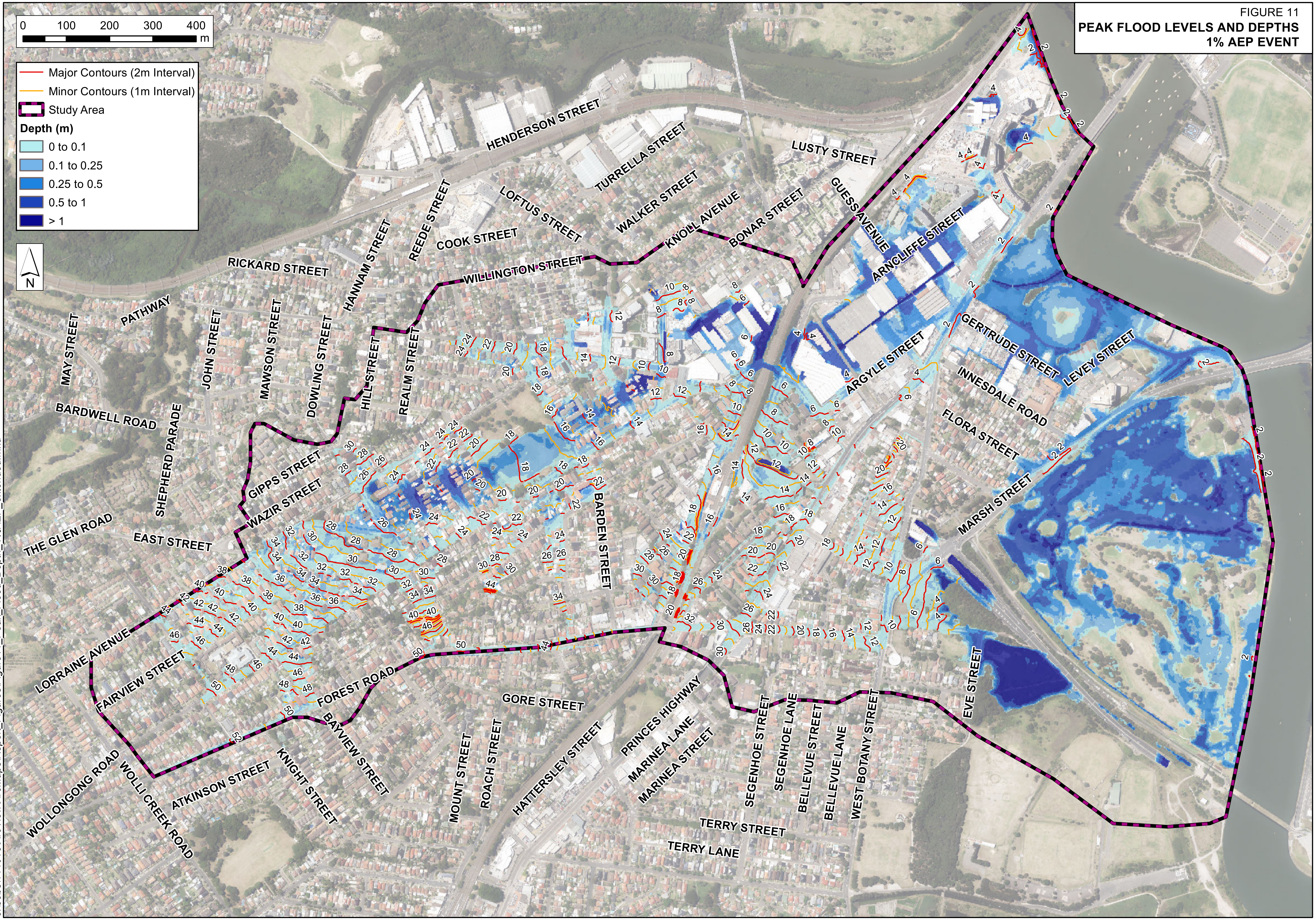

FIGURE 11
PEAK FLOOD LEVELS AND DEPTHS
1% AEP EVENT

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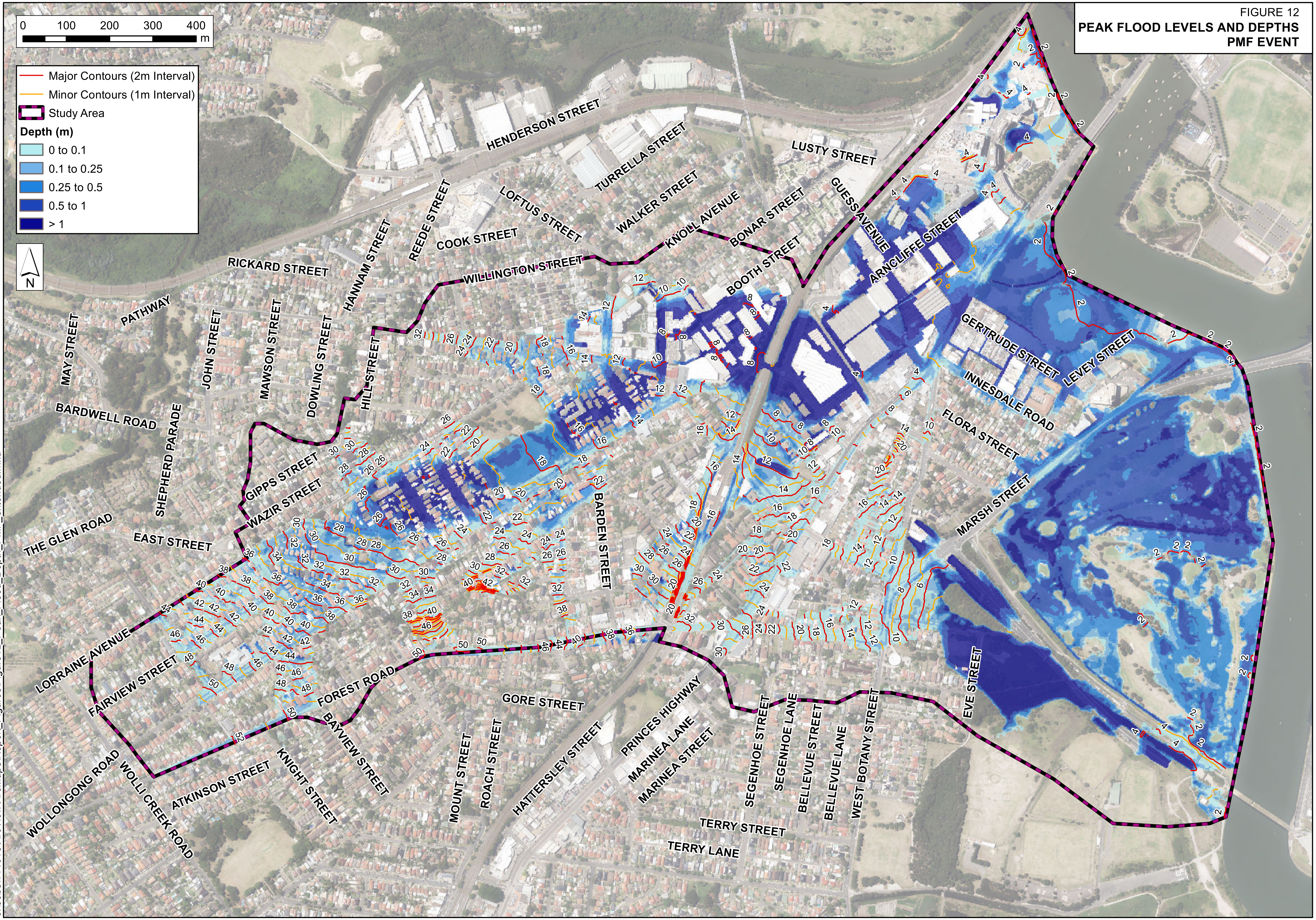

FIGURE 12
PEAK FLOOD LEVELS AND DEPTHS
PMF EVENT

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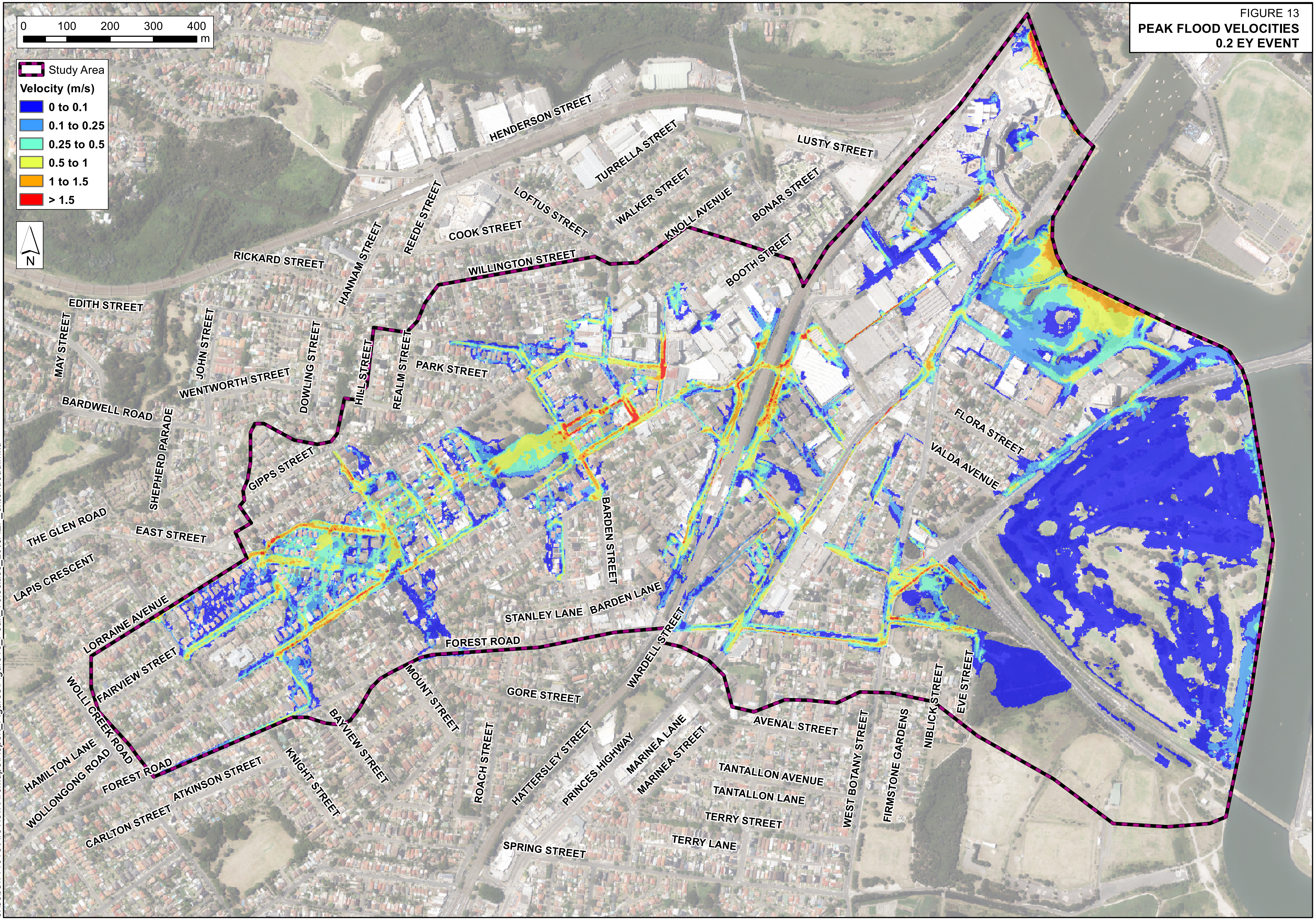

FIGURE 13
PEAK FLOOD VELOCITIES
0.2 EY EVENT

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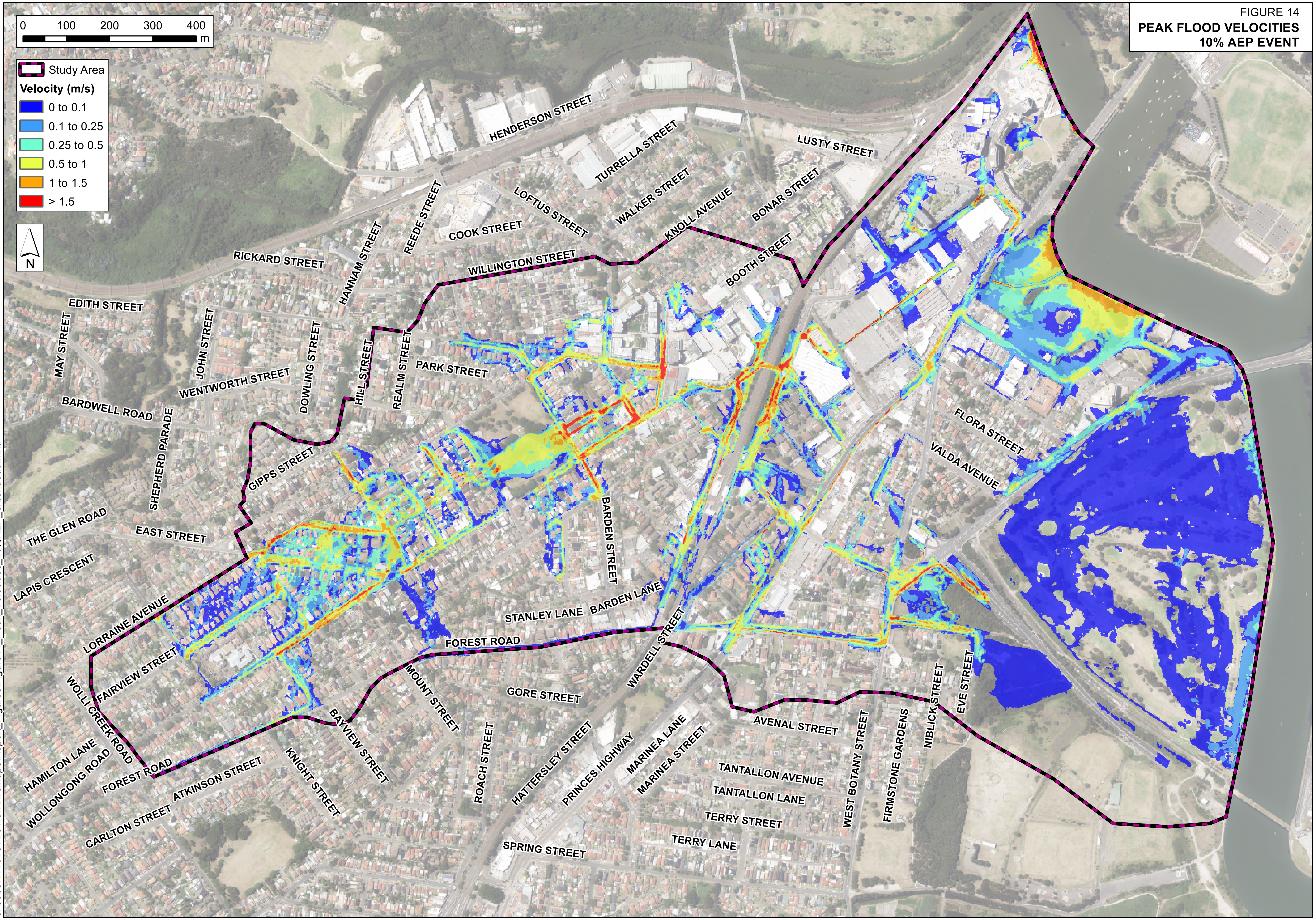
FIGURE 14
PEAK FLOOD VELOCITIES
10% AEP EVENT



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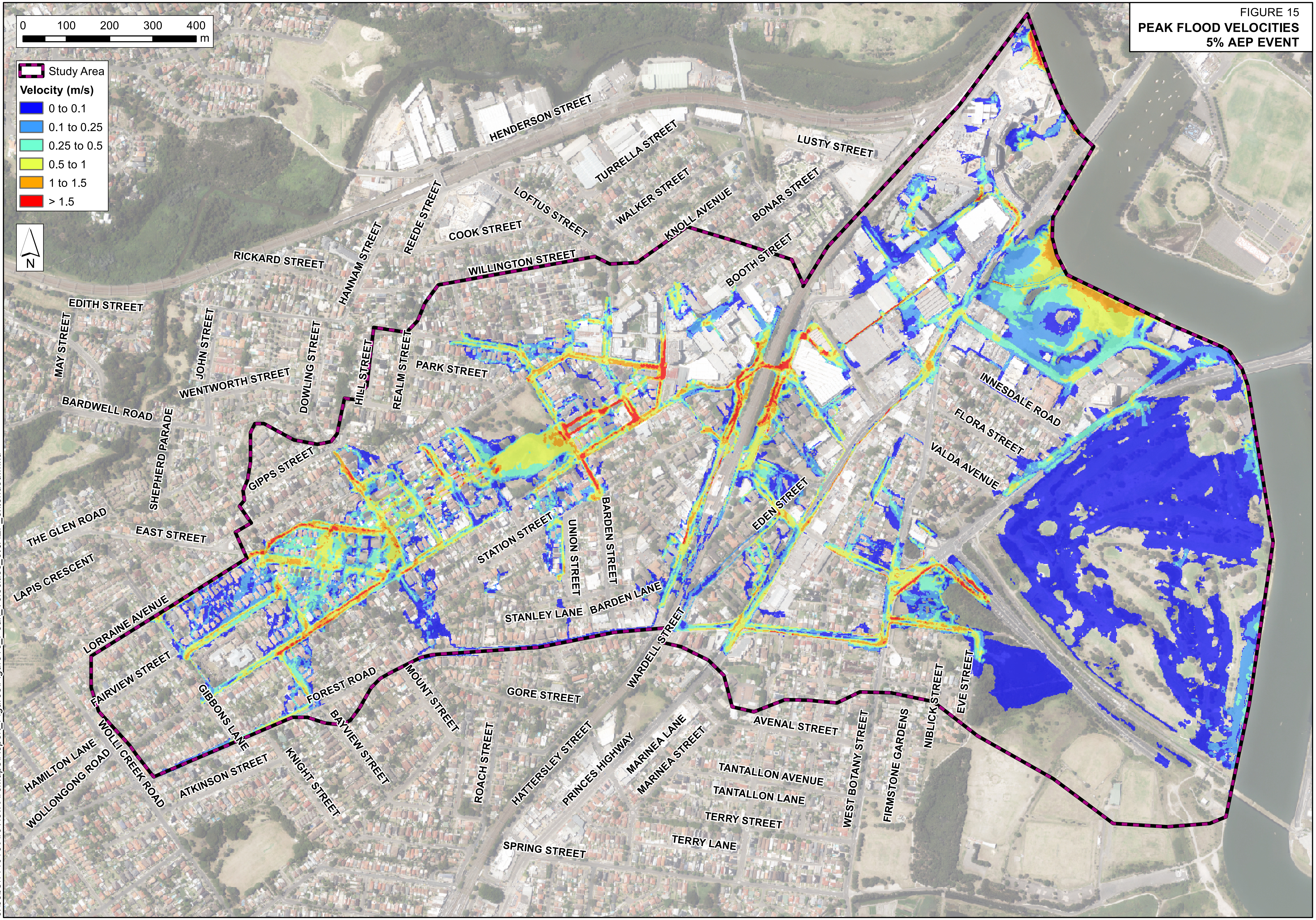

FIGURE 15
PEAK FLOOD VELOCITIES
5% AEP EVENT

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FIGURE 16
PEAK FLOOD VELOCITIES
1% AEP EVENT

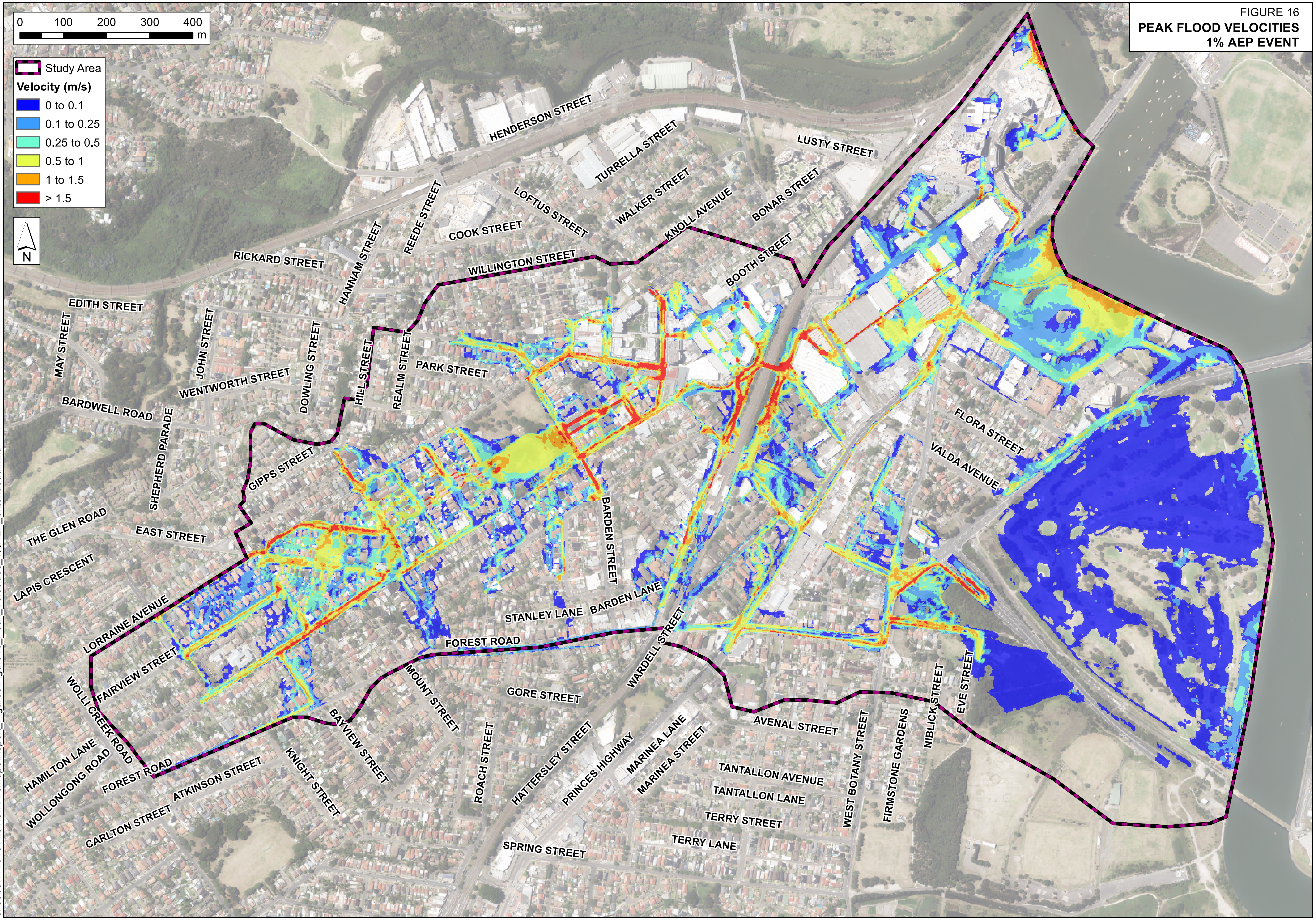

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FIGURE 17
PEAK FLOOD VELOCITIES
PMF EVENT

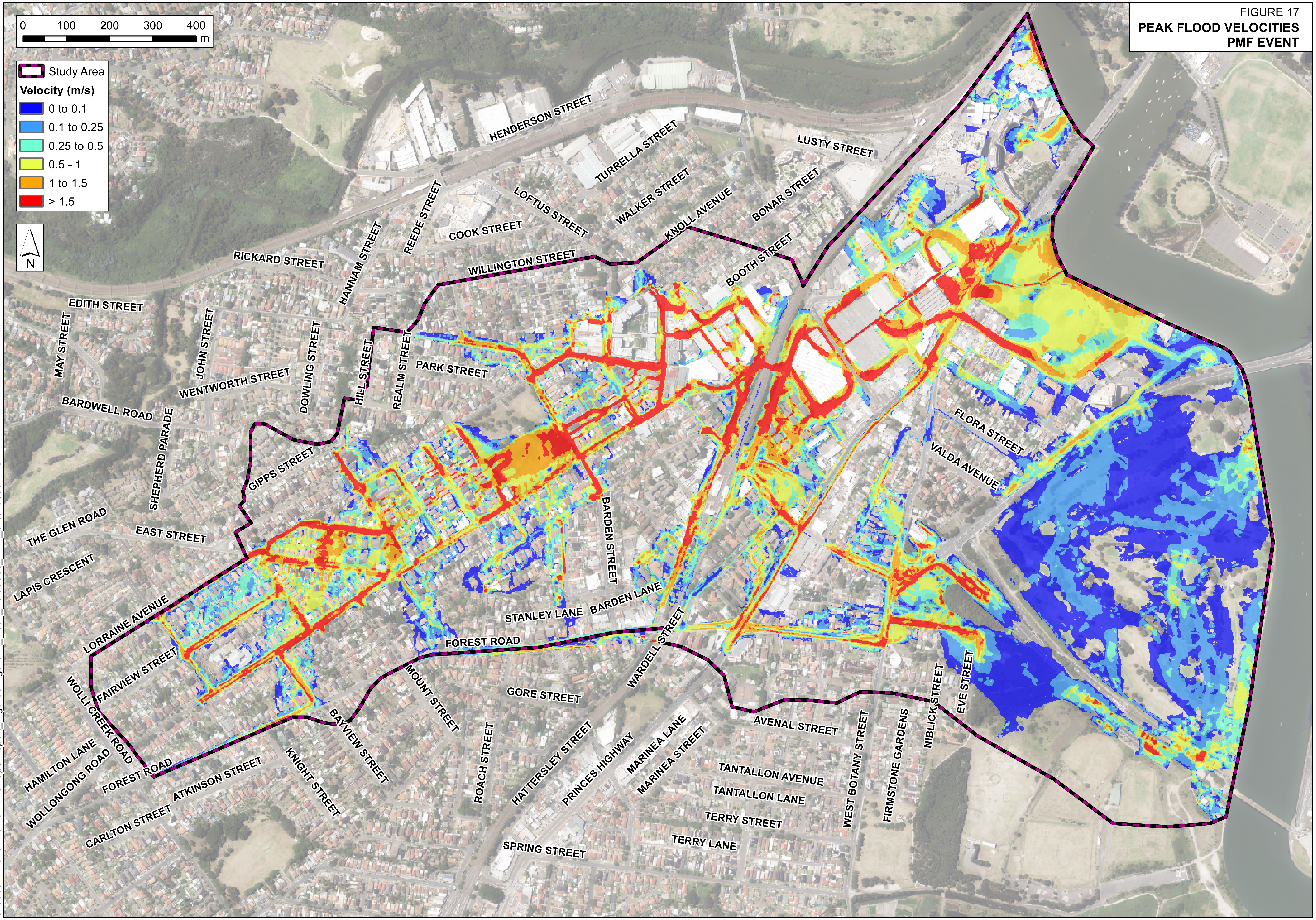

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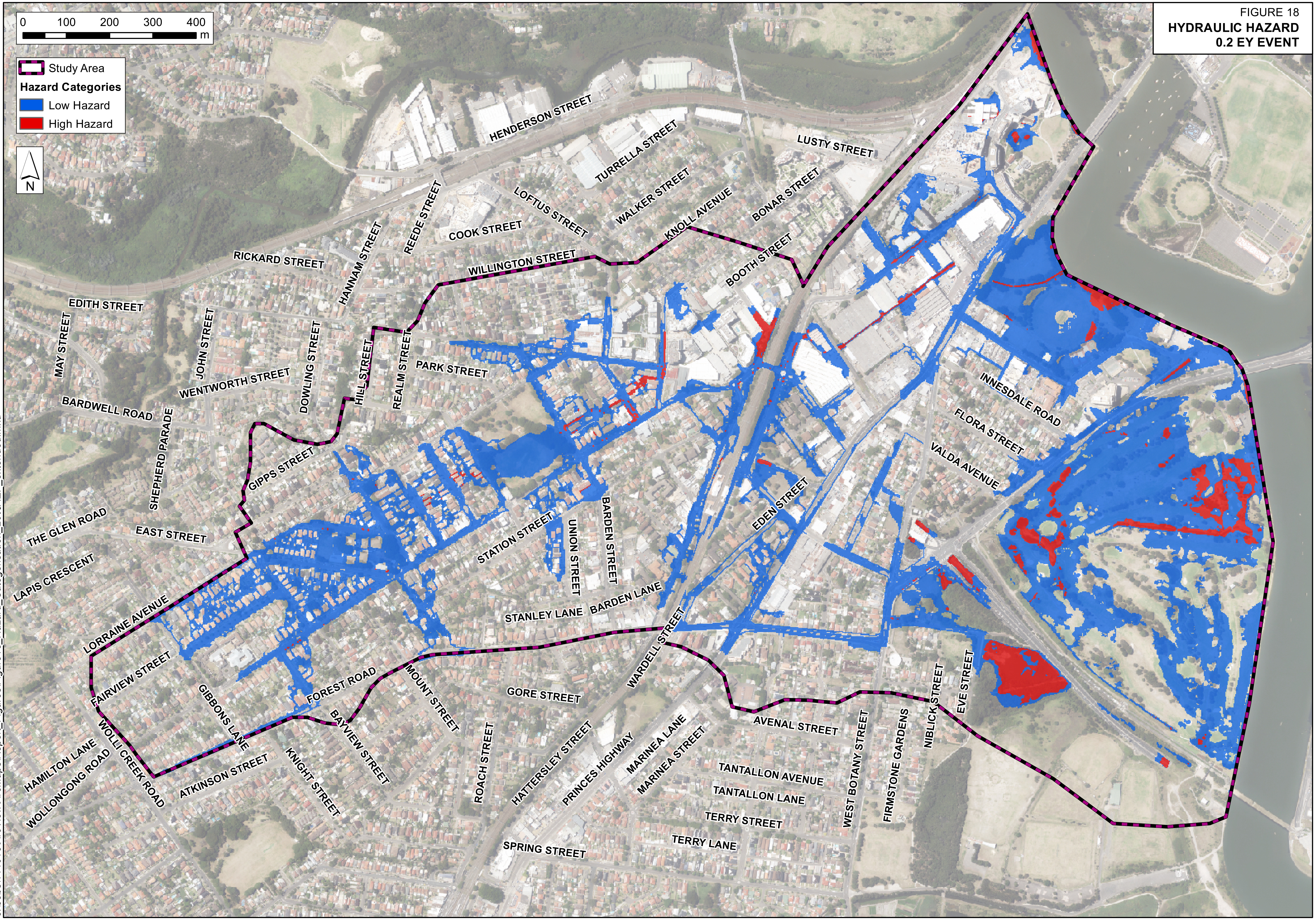
FIGURE 18
HYDRAULIC HAZARD
0.2 EY EVENT



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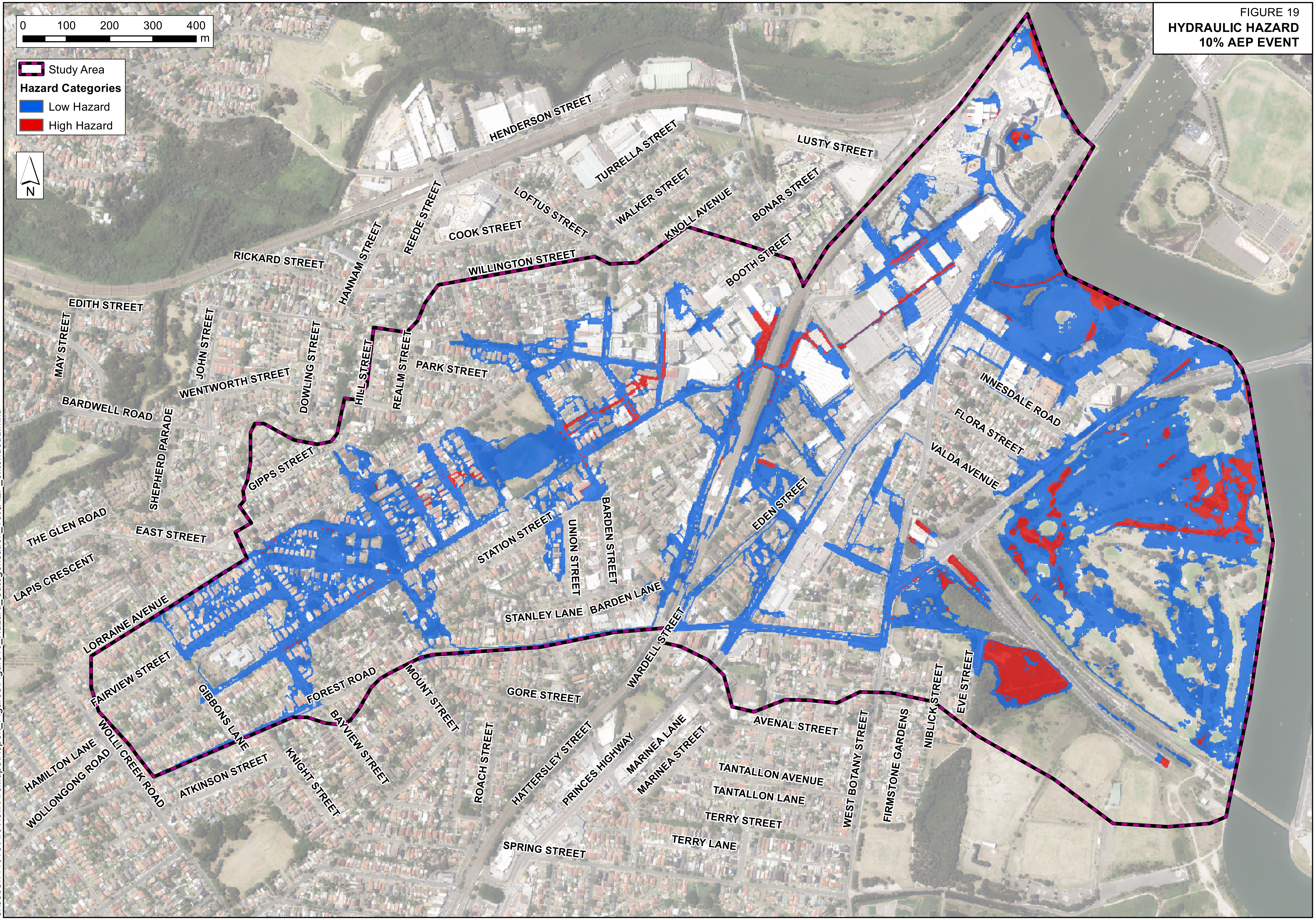
FIGURE 19
HYDRAULIC HAZARD
10% AEP EVENT
0 100 200 300 400 m
Study Area
Hazard Categories
Low Hazard
High Hazard
N
J:\Jobs\114018\ArcView\ArcMaps\Report_Figures\Figure19_Hazard_Categorisation_10%AEP_extendedd.mxd

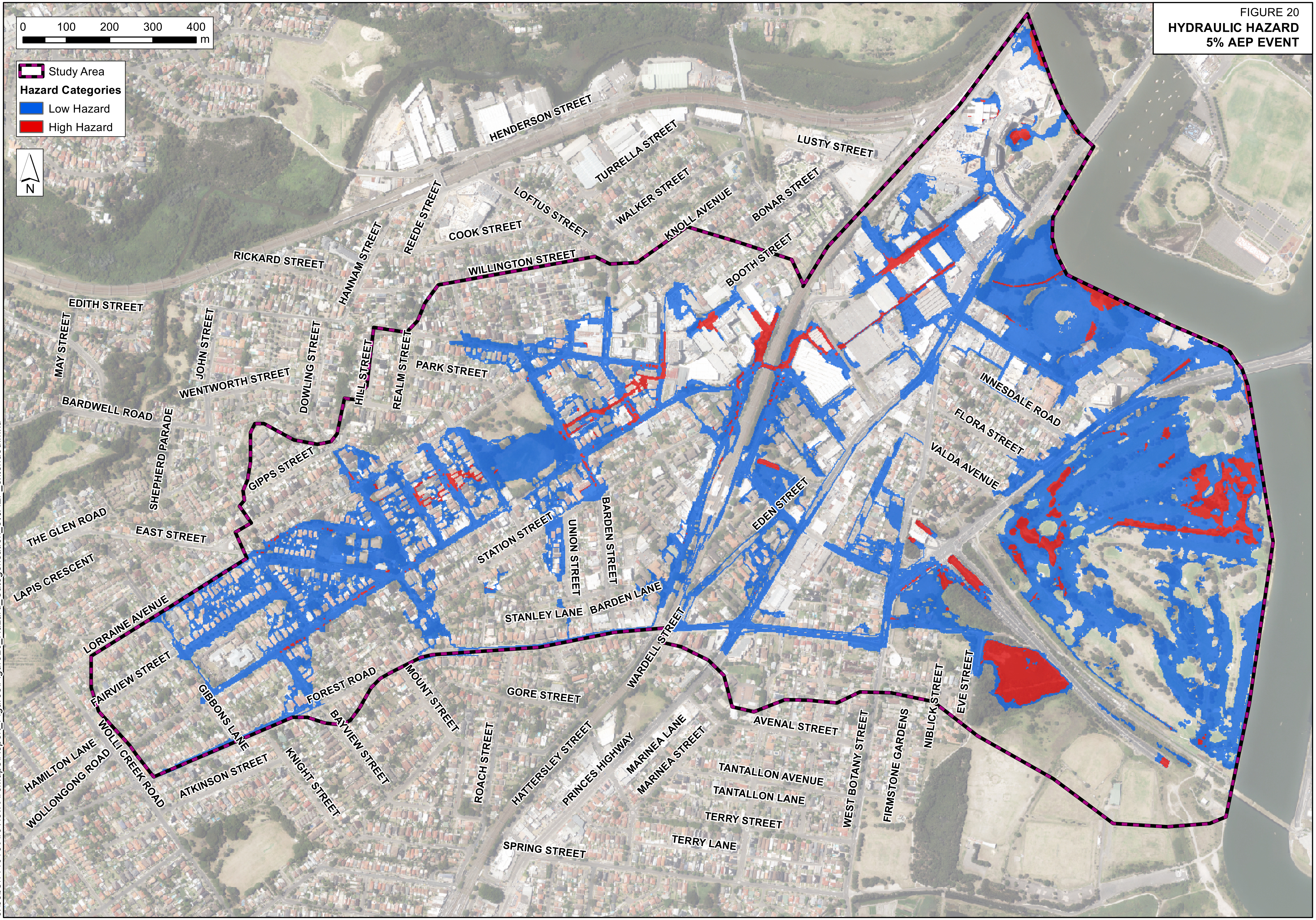

FIGURE 20
HYDRAULIC HAZARD
5% AEP EVENT

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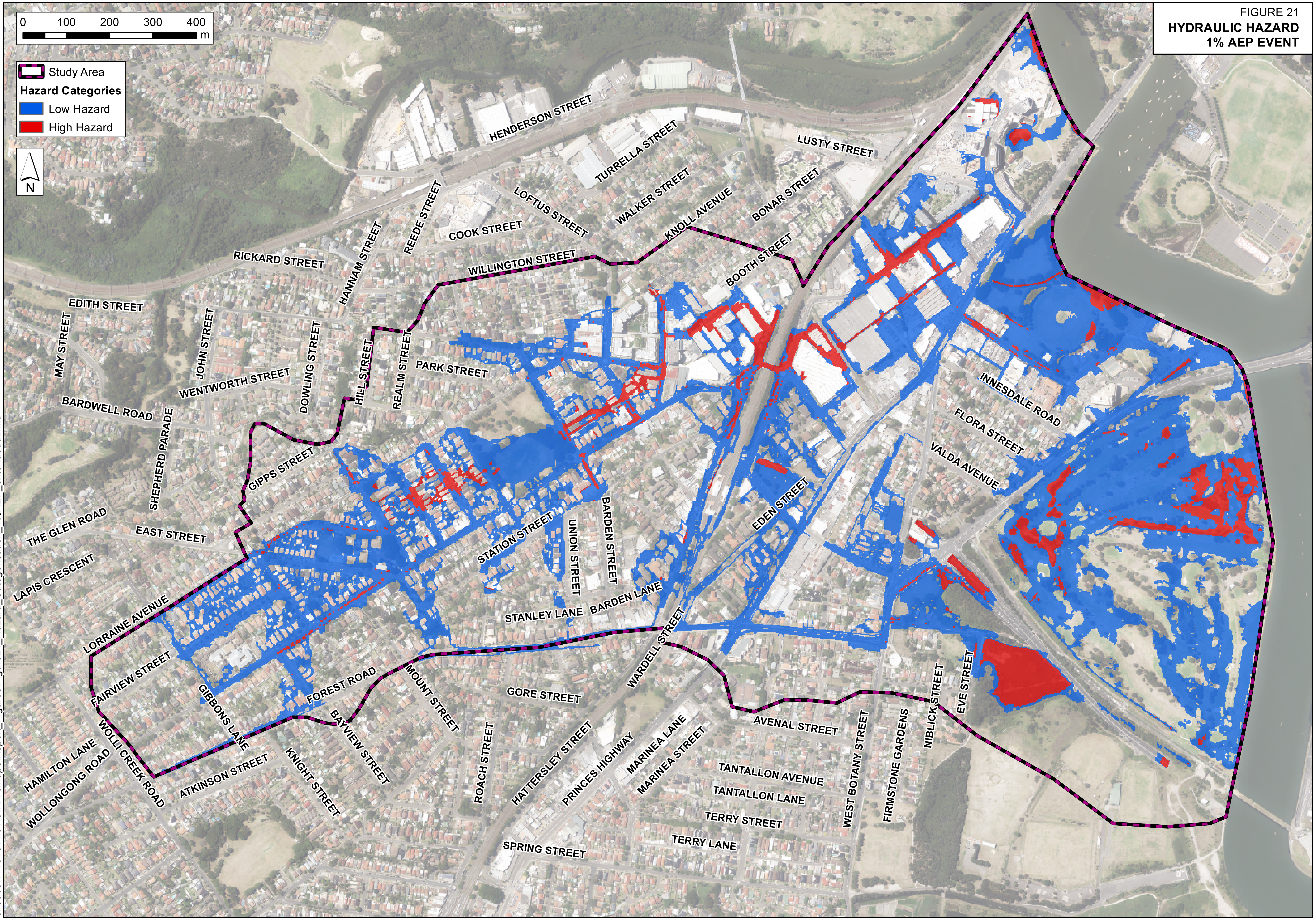

FIGURE 21
HYDRAULIC HAZARD
1% AEP EVENT
0 100 200 300 400 m
Study Area
Hazard Categories
Low Hazard
High Hazard
N
HENDERSON STREET
TURRELLA STREET
LUSTY STREET
REEDE STREET
LOFTUS STREET
WALKER STREET
KNOLL AVENUE
BONAR STREET
COOK STREET
HANNAM STREET
RICKARD STREET
WILLINGTON STREET
BOOTH STREET
EDITH STREET
MAY STREET
JOHN STREET
DOWLING STREET
HILL STREET
REALM STREET
PARK STREET
WENTWORTH STREET
BARDWELL ROAD
SHEPHERD PARADE
GIPPS STREET
INNESDALE ROAD
FLORA STREET
VALDA AVENUE
THE GLEN ROAD
EAST STREET
LAPIS CRESCENT
STATION STREET
UNION STREET
BARDEN STREET
EDEN STREET
LORRAINE AVENUE
STANLEY LANE
BARDEN LANE
WARDELL STREET
FAIRVIEW STREET
GIBBONS LANE
FOREST ROAD
MOUNT STREET
GORE STREET
EVE STREET
NIBLICK STREET
AVENAL STREET
HAMILTON LANE
WOLLONGONG ROAD
WOLLI CREEK ROAD
ATKINSON STREET
KNIGHT STREET
BAYVIEW STREET
ROACH STREET
HATTERSLEY STREET
PRINCES HIGHWAY
MARINEA LANE
MARINEA STREET
TANTALLON AVENUE
TANTALLON LANE
TERRY STREET
TERRY LANE
WEST BOTANY STREET
FIRMSTONE GARDENS
SPRING STREET
J:\Jobs\114018\ArcView\ArcMaps\Report_Figures\Figure21_Hazard_Categorisation_1%AEP_extendedd.mxd

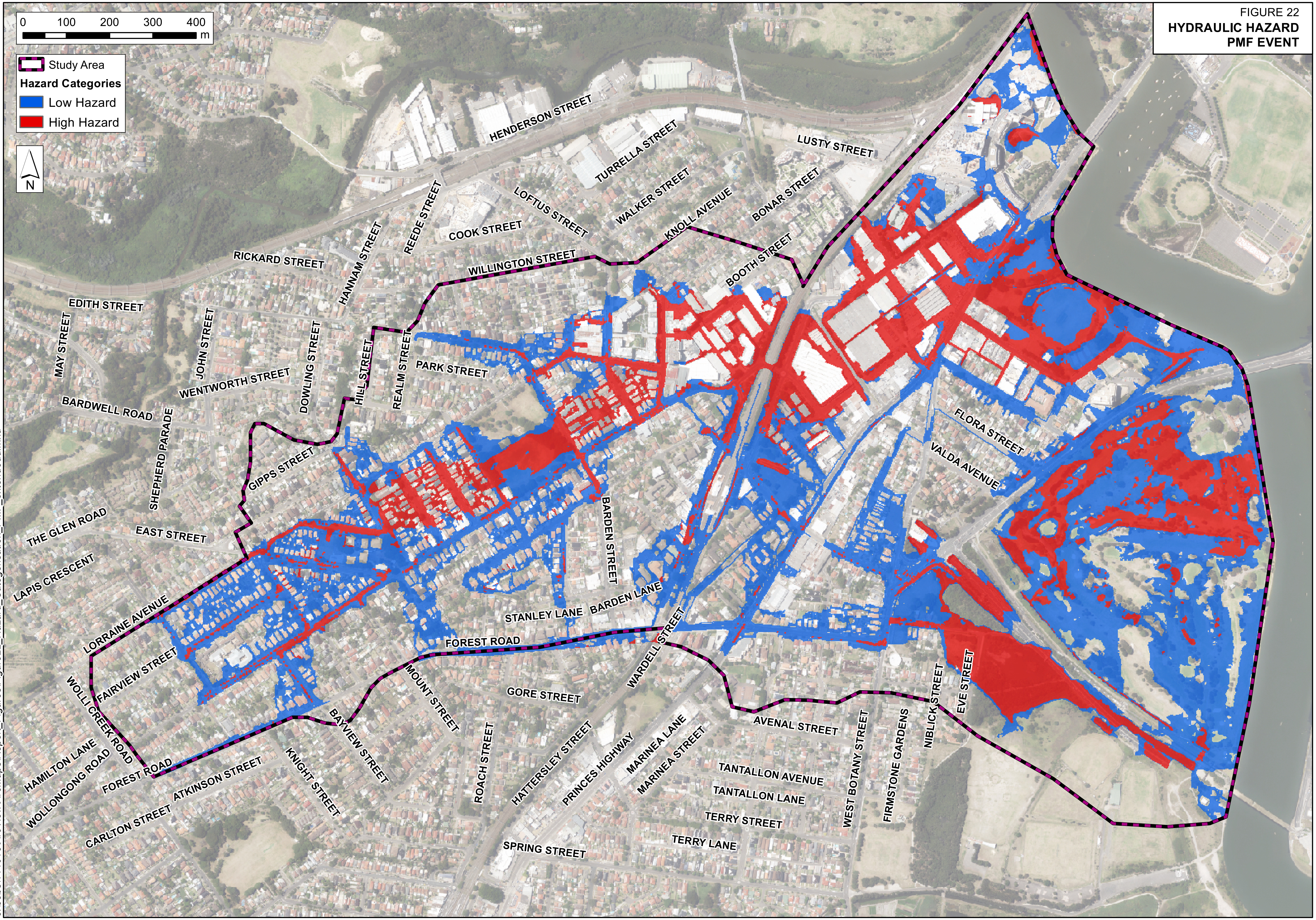

FIGURE 22
HYDRAULIC HAZARD
PMF EVENT
0 100 200 300 400 m
Study Area
Hazard Categories
Low Hazard
High Hazard
N
HENDERSON STREET
TURRELLA STREET
LUSTY STREET
LOFTUS STREET
WALKER STREET
KNOLL AVENUE
BONAR STREET
COOK STREET
REEDE STREET
HANNAM STREET
RICKARD STREET
WILLINGTON STREET
BOOTH STREET
EDITH STREET
MAY STREET
JOHN STREET
DOWLING STREET
HILL STREET
REALM STREET
PARK STREET
WENTWORTH STREET
BARDWELL ROAD
SHEPHERD PARADE
GIPPS STREET
FLORA STREET
VALDA AVENUE
THE GLEN ROAD
EAST STREET
BARDEN STREET
LAPIS CRESCENT
LORRAINE AVENUE
STANLEY LANE
BARDEN LANE
FOREST ROAD
WARDELL STREET
FAIRVIEW STREET
WOLLI CREEK ROAD
MOUNT STREET
GORE STREET
EVE STREET
NIBLICK STREET
AVENAL STREET
BAYVIEW STREET
HAMILTON LANE
WOLLONGONG ROAD
FOREST ROAD
ATKINSON STREET
KNIGHT STREET
ROACH STREET
HATTERSLEY STREET
PRINCES HIGHWAY
MARINEA LANE
MARINEA STREET
TANTALLON AVENUE
TANTALLON LANE
WEST BOTANY STREET
FIRMSTONE GARDENS
TERRY STREET
TERRY LANE
CARLTON STREET
SPRING STREET
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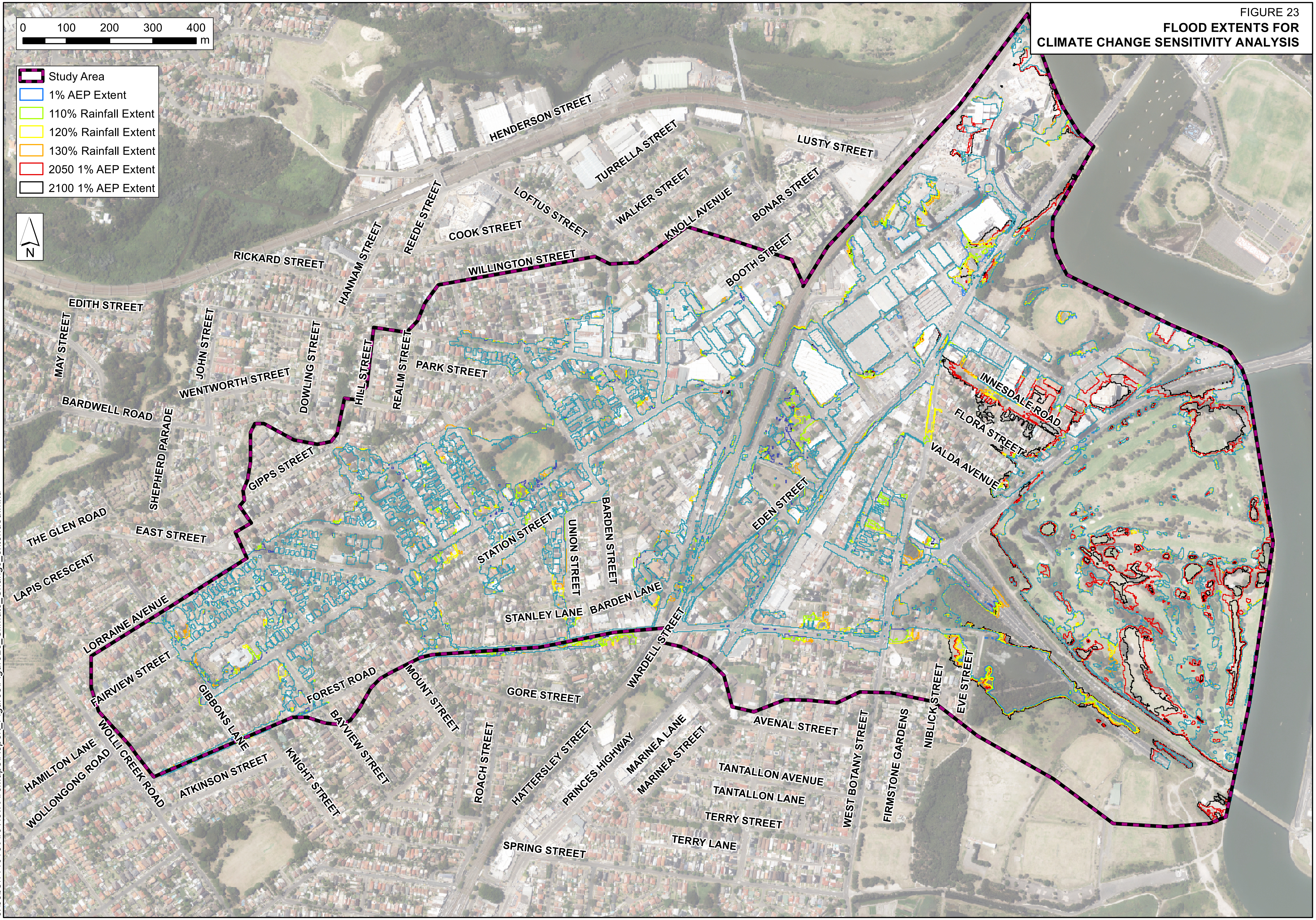
FIGURE 23
FLOOD EXTENTS FOR CLIMATE CHANGE SENSITIVITY ANALYSIS



Appendix A

APPENDIX A: GLOSSARY OF TERMS

Taken from the Floodplain Development Manual (April 2005 edition)

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

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

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

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

	land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well being of the States rivers and floodplains. The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into Council plans, policy and EPIs. At a site specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local floodplain risk management policy and EPIs.
minor, moderate and major flooding	Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood: minor flooding: causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded. moderate flooding: low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered. major flooding: appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.
modification measures	Measures that modify either the flood, the property or the response to flooding. Examples are indicated in Table 2.1 with further discussion in the Manual.
peak discharge	The maximum discharge occurring during a flood event.
Probable Maximum Flood (PMF)	The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.
Probable Maximum Precipitation (PMP)	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
probability	A statistical measure of the expected chance of flooding (see AEP).
risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	Equivalent to water level. Both are measured with reference to a specified datum.

stage hydrograph	A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
survey plan	A plan prepared by a registered surveyor.
water surface profile	A graph showing the flood stage at any given location along a watercourse at a particular time.
wind fetch	The horizontal distance in the direction of wind over which wind waves are generated.

Appendix B

Photo 1: Corner of Wollongong and Firth Street (just before the round-a-bout)

Photo 2: Railway underpass at Allen Street

Photo 3: Downstream of Princes Highway culvert

Photo 4: Sealed culvert under SWSOOS

Photo 5: Open channel downstream of SWSOOS