EXILE BAY, ST LUKES AND WILLIAM STREET FLOOD STUDY

DRAFT REPORT 3

MARCH 2017

Level 2, 160 Clarence Street
Sydney, NSW, 2000

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

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Client Burwood Council		**Client's Representative** Kundan Pokharel	
Authors Erika Taylor Stephen Gray		**Prepared by** TO BE SIGNED FOR FINAL REPORT	
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EXILE BAY, ST LUKES AND WILLIAM STREET FLOOD STUDY

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LIST OF ABBREVIATIONS

AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ARI	Average Recurrence Interval
AR&R	Australian Rainfall and Runoff
ALS	Airborne Laser Scanning sometimes known as LiDAR
BCC	Burwood City Council
BoM	Bureau of Meteorology
CBD	Central Business District
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CFERP	Community Flood Emergency Response Plan
DEM	Digital Elevation Model
DRAINS	Hydrologic computer model developed from ILSAX
EPR	Entire Period of Record (of gauge data at Elva Street gauge)
EY	Exceedances per Year
FFA	Flood Frequency Analysis
GEV	Generalised Extreme Value probability distribution
GIS	Geographic Information System
GSDM	Generalised Short Duration Method
HEC-RAS	1D hydraulic computer model
HGL	Hydraulic Grade Line
ILSAX	Hydrologic model - a precursor to DRAINS
IFD	Intensity, Frequency and Duration of Rainfall
IPCC	Intergovernmental Panel on Climate Change
LEP	Local Environmental Plan
LGA	Local Government Area
LiDAR	Light Detection and Radar
LPI	Land and Property Information
LP3	Log Pearson III probability distribution
m	metre
MHL	Manly Hydraulics Laboratory
m^3/s	cubic metres per second (flow measurement)
m/s	metres per second (velocity measurement)
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
SEPP	State Environmental Planning Policy
SMC	Strathfield Municipal Council
SWC	Sydney Water Corporation
TIN	Triangular Irregular Network
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 Exile Bay, St Lukes and William Street Flood Study constitutes the first stage of the management process.

EXECUTIVE SUMMARY

BACKGROUND

The Exile Bay, St Lukes and William Street Catchments are adjacent catchments (listed west to east) that drain north into Iron Cove on the Parramatta River, shown in Figure 1. The upstream catchment area is within Burwood Council LGA and the downstream catchment area is within the Canada Bay LGA; with Parramatta Road as the boundary between the two LGA's. The study area comprises of the three aforementioned catchments up to Parramatta Road, with the area downstream of Parramatta Road outside the area of interest of this study.

OBJECTIVES

The primary objective of this Flood Study is to develop computational hydrologic and hydraulic models that define design flood behaviour for the 0.2 EY, 10% AEP, 5% AEP, 2% AEP and 1% AEP design storms and the Probable Maximum Flood (PMF) in the Exile Bay, St Lukes and William Street catchments and to:

- prepare suitable models of the catchment and floodplain for use in a subsequent Floodplain Risk Management Study;
- provide results for flood behaviour in terms of design flood levels, depths, velocities, flows and flood extents within the study area;
- prepare maps of provisional hydraulic categories and provisional hazard categories;
- prepare preliminary emergency response classifications for communities;
- determine provisional residential flood planning levels and flood planning area;
- assess the sensitivity of flood behaviour to potential climate change effects such as increases in rainfall intensities and sea level rise

FLOODING HISTORY

In examining the flooding history, it must be noted that the drainage characteristics of this catchment have been significantly altered as a result of urbanisation in the area and as such older flood extents and depths for a given storm may not apply to present day conditions. There have been a number of instances of flooding in the past including the 19 May 1946, 24 November 1961 and the 2 January 1996.

HYDROLOGIC AND HYDRAULIC MODELLING PROCESS

The hydrologic modelling was undertaken using DRAINS and the hydraulic model was established using TUFLOW.

These models were verified by comparison to specific yield rates for similar areas in the Sydney Metropolitan region and comparison to previous studies undertaken in the Exile Bay, St Lukes and William Street catchments.

The design rainfall events that were modelled were the 0.2 EY, 10% AEP, 5% AEP, 2% AEP and 1% AEP design storms and the Probable Maximum Precipitation (PMP). The temporal patterns for the design events were sourced from Australian Rainfall and Runoff (AR&R) (Pilgrim, 1987) and the Intensity-Frequency-Duration (IFD) data was obtained from the Bureau of Meteorology's (BoM) internet-based tool. The PMP estimates were derived according to the BoM guidelines, the *Generalised Short Duration Method* (BoM, 2003).

OUTCOMES

The design flood modelling indicates that notable flooding may occur in a number of locations including the intersection of Short Street and Parramatta Road; Parramatta Road and Shaftesbury Road; the intersection of Philip Street and Parramatta Road; Milton Street; New Street; and Railway Parade.

A preliminary investigation into properties subject to flood related development controls shows that approximately 278 lots (of the approximately 1,951 lots within the study area and accounting for around 14%) are liable to be identified under the criteria adopted for the study.

1. INTRODUCTION

1.1. Background

The study was commissioned by Burwood City Council (BCC), with the assistance of the NSW Government (Office of Environment and Heritage). Additional information has been provided by Sydney Water Corporation (SWC).

1.2. Description of the Catchments

The Exile Bay, St Lukes and William Street Catchments are adjacent catchments (listed west to east) that drain north into Iron Cove on the Parramatta River, shown in Figure 1. The upstream catchment area is within Burwood Council LGA and the downstream catchment area is within the Canada Bay LGA; with Parramatta Road as the boundary between the two LGA's. The study area comprises of the three aforementioned catchments up to Parramatta Road, with the area downstream of Parramatta Road outside the area of interest of this study.

The study area includes the suburbs of Strathfield, Burwood and Croydon. The area is fully urbanised, with 64% of the catchment zoned residential, 16% mixed use, 10% enterprise corridor (adjacent to Parramatta Road) and 10% for public recreation.

Elevations in the upper part of the catchment reach approximately 35 m AHD near Livingston Street and moderate grades of 3%. In the lower parts of the catchment, slopes are relatively shallow, in the order of 0.5%. The St Lukes and William Street catchments are tidal up to Queens Road.

1.3. Objectives

The primary objective of this Flood Study is to develop computational hydrologic and hydraulic models that define design flood behaviour for the 0.2 EY, 10% AEP, 5% AEP, 2% AEP and 1% AEP design storms and the Probable Maximum Flood (PMF) in the Exile Bay, St Lukes and William Street catchments and to:

- prepare suitable models of the catchment and floodplain for use in a subsequent Floodplain Risk Management Study;
- provide results for flood behaviour in terms of design flood levels, depths, velocities, flows and flood extents within the study area;
- prepare maps of provisional hydraulic categories and provisional hazard categories;
- prepare preliminary emergency response classifications for communities;
- determine provisional residential flood planning levels and flood planning area;
- assess the sensitivity of flood behaviour to potential climate change effects such as increases in rainfall intensities and sea level rise.

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

2. AVAILABLE DATA

2.1. Overview

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 Hawkesbury 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 that of Exile Bay, St Lukes and William Street Catchments there are no stream gauges or official historical records available. A picture of flooding must therefore be obtained from an examination of Council records, previous reports, rainfall records and local knowledge.

2.2. Topographic Data

Airborne Light Detection and Ranging (LiDAR) survey of the catchment and its immediate surroundings was obtained from Land and Property Information (LPI), which is a division of the Department of Finance, Services and Innovation (NSW Government). It was indicated that the data were collected in 2013. These data typically have accuracy in the order of:

- +/- 0.15m (for 70% of points) in the vertical direction on clear, hard ground; and
- +/- 0.75m in the horizontal direction.

The accuracy of the LiDAR data can be influenced by the presence of open water or vegetation (tree or shrub canopy) at the time of the survey.

The 1 m by 1 m Digital Elevation Model (DEM) generated from the LiDAR, which formed the basis of the two-dimensional hydraulic modelling for the study, is shown in Figure 2.

2.3. Pit and Pipe Data

The SWC capacity assessment reports provided dimensions for SWC owned underground pipes, in addition to the open channel cross-sections within the catchment area downstream of the Burwood LGA boundary. Appended to this SWC drainage network are underground pipes owned by BCC. BCC provided pipe dimensions, as well as pit inverts and dimensions.

2.4. Historical Flood Level Data

2.4.1. SWC Historic Flood Database

An historic flood database was supplied by SWC and provided information on flooding within the two catchments that SWC maintains assets within (the St Lukes and William Street Catchment) from 1946 to 1996. A summary of available historic flood levels is provided in Table 1.

Table 1: Summary of Historical Flood Data – SWC Database

Flood Events	Total Records	Number of Observed Flood Levels
19 May 1946	1	0
24 November 1961	1	0
2 January 1996	3	1

2.4.2. BCC Historic Flood Database

An historic flood database was supplied by BCC and provided information on flooding within the catchments from 2003 to 2015. Many of these reports were concerned with stormwater and drainage issues.

A summary of available historic flood locations is provided in Table 2.

Table 2: Summary of Historical Flood Data – BCC Database

Location	Catchment	Total Records
Cooper Lane	Exile Bay	1
Cooper Street	Exile Bay	5
Corner of Cooper Street and Wentworth Road	Exile Bay	3
Wentworth Road	Exile Bay	2
Mt Pleasant Avenue	Exile Bay	3
Roberts Street	Exile Bay	1
White Street	Exile Bay	1
Belmore Street	St Lukes	4
Belmore Street (Corner Wynne Ave)	St Lukes	2
Burwood Road	St Lukes	13
Burwood Road (Nr Station)	St Lukes	1
Cheltenham Road	St Lukes	7
Clarendon Place	St Lukes	3
Comer Street	St Lukes	2
Conder Street	St Lukes	1
Conder Street (Corner Hornsey St)	St Lukes	2
Elsie Street	St Lukes	1
Gladstone Street	St Lukes	1
Ilfracombe Avenue	St Lukes	1
John Street	St Lukes	1
King Edward Street	St Lukes	1
Lucas Road	St Lukes	13
Luke Avenue	St Lukes	11
Luke Street (Corner Bennett St)	St Lukes	1
Marmaduke Street	St Lukes	1
Meryla Street	St Lukes	9
Neich Parade	St Lukes	4
Park Road	St Lukes	3
Parramatta Road	St Lukes	1
Railway Crescent	St Lukes	1
Railway Parade	St Lukes	3
Rostherne Avenue	St Lukes	1
Royce Avenue	St Lukes	3

Royce Avenue (Corner Monash Pde)	St Lukes	2
Shaftesbury Road	St Lukes	4
Shaftesbury Road (Corner Wilga Street)	St Lukes	1
Simpson Avenue	St Lukes	2
Sym Avenue	St Lukes	4
Victoria Street	St Lukes	5
Wilga Street	St Lukes	2
Wynne Avenue	St Lukes	7
Youth Lane	St Lukes	1
Acton Street	William Street	11
Bay Street	William Street	3
Dawson Street	William Street	1
Grogan Street	William Street	1
Monash Parade	William Street	1
Short Street	William Street	2
Wychbury Avenue	William Street	8
Wychbury Lane	William Street	1
Corner of King Edward Street and Parramatta Road	William Street	1

2.4.3. Community Consultation

A community consultation process was undertaken in collaboration with BCC. This included distribution of an information sheet and a questionnaire to gather information pertaining to the community's experience of flooding within the catchments. BCC undertook this distribution to properties affected by a preliminary 1% AEP extent.

The response rate was on average 4% across the study area. This is similar to the response rate from community consultation carried out for Flood Studies in adjacent catchment areas and/or adjacent Council areas. This is considered to be influenced by the proportion of rental dwellings within the area (the Australian Bureau of Statistics recorded 37% of the Burwood population as residing in rental dwellings).

Two reports of flooding within the house were reported; with indications that at these locations the floor level is elevated and flood waters enter the cavity beneath the floor. The flood water reported beneath the houses were said to drain slowly and result in rising damp within the walls of the house. In both instances, no date was given and the flooding experienced was described as occurring any time there is heavy rainfall.

2.5. Historical Rainfall Data

Rainfall data is recorded either daily (24hr rainfall totals to 9:00 am) or continuously (pluviometers measuring rainfall in small increments – less than 1 mm). Daily rainfall data have been recorded for over 100 years at many locations within the Sydney basin. In general, pluviometers have only been installed since the 1970's. Together these records provide a picture of when and how often large rainfall events have occurred in the past.

However, care must be taken when interpreting historical rainfall measurements. Rainfall records may not provide an accurate representation of past events due to a combination of factors including local site conditions, human error or limitations inherent to the type of recording instrument used. Examples of limitations that may impact the quality of data used for the present study are highlighted in the following:

- Rainfall gauges frequently fail to accurately record the total amount of rainfall. This can occur for a range of reasons including operator error, instrument failure, overtopping and vandalism. In particular, many gauges fail during periods of heavy rainfall and records of large events are often lost or misrepresented.
- Daily read information is usually obtained at 9:00 am in the morning. Thus if a single storm is experienced both before and after 9:00 am, then the rainfall is "split" between two days of record and a large single day total cannot be identified.
- In the past, rainfall over weekends was often erroneously accumulated and recorded as a combined Monday 9:00 am reading.
- The duration of intense rainfall required to produce overland flooding in the study area is typically less than 6 hours (though this rainfall may be contained within a longer period of rainfall). This is termed the "critical storm duration". For a larger catchment (such as the Parramatta River) the critical storm duration may be greater (say 9 hours). For the study area a short intense period of rainfall can produce flooding but if the rain stops quickly, the daily rainfall total may not necessarily reflect the magnitude of the intensity and subsequent flooding. Alternatively the rainfall may be relatively consistent throughout the day, producing a large total but only minor flooding.
- Rainfall records can frequently have "gaps" ranging from a few days to several weeks or even years.
- Pluviometer (continuous) records provide a much greater insight into the intensity (depth vs. time) of rainfall events and have the advantage that the data can generally be analysed electronically. This data has much fewer limitations than daily read data. Pluviometers can also fail during storm events due to the extreme weather conditions.

Rainfall events which cause overland flooding (as opposed to mainstream flooding) in the study area are usually localised and as such are only accurately represented by a nearby gauge. Gauges sited even only a kilometre away can show very different intensities and total rainfall depths.

2.5.1. Rainfall Stations

Table 3 presents a summary of the official rainfall gauges (sourced from the Bureau of Meteorology) located close to or within the catchment and Figure 5 shows the location of these rainfall gauges. This includes daily read stations, continuous pluviometer stations, operational stations and synoptic stations. These gauges are operated either by Sydney Water Corporation (SWC) or the Bureau of Meteorology (BOM).

Table 3: Rainfall stations within 7km of the centroid of the study areas

Station Number	Station Name	Operating Authority	Distance from centre of the catchment (km)	Elevation (m AHD)	Date Opened	Date Closed	Type
66017	Barnwell Park Golf Course	BOM	1.11	4	29/11/1929	28/11/2003	Daily
66150	Canterbury Heights	BOM	1.29	61	30/08/1906	29/12/1916	Daily
566064	Concord Greenlees BC (formerly Wests Rugby Club)	SWB	2.05		1/06/1988		Continuous
66091	Burwood 2 Public School	BOM	2.49		29/09/1911	29/12/1923	Daily
66165	Ashfield Prospect Rd	BOM	2.49	43	01/01/1894	1/01/1904	Daily
66013	Concord Golf Club	BOM	2.56	15	1/01/1930		Daily
66113	Burwood 1	BOM	2.61		01/01/1884	1/01/1922	Daily
66026	Homebush	BOM	2.61		30/10/1924	29/12/1952	Daily
66000	Ashfield Bowling Club	BOM	2.67	25	30/03/1896		Daily
566112	Ashfield (Ashfield Park Bowling Club)	SWB	2.70		2/12/1993		Continuous
66111	Craydon	BOM	2.72		30/01/1879	29/12/1921	Daily
566022	Homebush SPS041 (formerly Homebush BC)	SWB	3.16		9/05/1969		Continuous
66034	Abbotsford (Blackwall Point Rd)	BOM	3.17	15	1/01/2004		Daily
566020	Enfield (composite site)	SWB	3.57		18/06/1983		Continuous
66194	Canterbury Racecourse AWS	BOM	3.58	3	2/10/1995		Synop
566113	Canterbury Racecourse	SWB	3.78		9/12/1993		Continuous
566066	Five Dock SPS065	SWB	3.80		19/10/1989		Continuous
66071	Gladesville Champion Rd	BOM	3.99	10	27/02/1997	29/09/2000	Daily
66070	Strathfield Golf Club	BOM	4.31	21	1/01/1952		Daily
66070	Strathfield Golf Club	BOMNS	4.31	21	11/06/1997		Operational
66164	Rookwood (Hawthorne Ave)	BOM	4.73	41	1/01/1945		Daily
66164	Rookwood (Hawthorne Ave)	BOM	4.73	41	29/11/1973	29/01/1985	Continuous
566065	Lilyfield Bowling Club	SWB	4.88		12/01/1989		Continuous
66108	Hunters Hill St Josephs Colleg	BOM	5.01		1/01/1916	1/01/1923	Daily
66064	Concord Walker Hospital	BOM	5.06	7.6	30/10/1894	29/12/1972	Daily
66082	Concord West Plaster Mills	BOM	5.06	5	1/01/1961	1/01/1982	Daily
66135	Ranad Newington	BOM	5.94	8	1/01/1967	1/01/1973	Daily
66135	Ranad Newington	BOM	5.94	8	27/05/1967	29/12/1973	Continuous

66175	Schnapper Island	BOM	5.95	5	28/02/1932	29/12/1939	Daily
66036	Marrickville Golf Club	BOM	6.05	6	29/04/1904	29/12/1970	Daily
66036	Marrickville Golf Club	BOMNS	6.05	6	6/04/2001		Operational
66102	Meadow Bank	BOM	6.35		1/01/1903	1/01/1916	Daily
566026	Marrickville Bowling Club	SWB	6.50		31/12/1979		Continuous
566064	Lidcombe (Carnarvon Golf Club)	BOMNS	6.53		5/08/1999		Operational
66018	Earlwood Bowling Club	BOM	6.66	31.1	30/07/1914	29/12/1975	Daily
66057	Ryde Pumping Stn	BOM	6.74	24.4	01/01/1894	1/01/1978	Daily
66131	Riverview Observatory	BOM	6.84	40	1/01/1905		Daily
66131	Riverview Observatory	BOM	6.84	40	1/01/1905		Synop
566036	Potts Hill Reservoir	SWB	6.91		29/12/1981		Continuous
66149	Glebe Point Syd. Water Supply	BOM	6.92	15.2	30/05/1907	29/12/1914	Daily
66015	Crown St. Reservoir	BOM	6.96		30/01/1882	29/12/1960	Daily
66097	Ranwick Bunnerong Rd	BOM	6.96		1/01/1904	1/01/1924	Daily

2.5.2. Analysis of Daily Read Data

An analysis of the records for the nearest daily rainfall stations, namely Barnwell Park Golf Course (66017) and Concord Golf Club (66013) was undertaken. The Barnwell Park and Concord Golf Club gauges are located within the Canada Bay Council LGA; with the former located in the William Street Catchment and the latter located on the north-western border of the Exile Bay Catchment.

Table 4: Daily rainfalls greater than 150mm at Barnwell Park Golf Club and Concord Golf Club

Barnwell Park Golf Course (66017)		
Nov 1929 – Nov 2003		
Rank	**Date**	**Rainfall (mm)**
1	30/03/1942	315
2	11/06/1991	253 (5 day total)
3	6/08/1986	250
4	5/02/1990	245 (3 day total)
5	11/02/1992	238 (3 day total)
6	30/04/1988	228
7	10/02/1956	201
8	9/04/1973	197
9	16/02/1988	164 (4 day total)
10	19/11/1961	163
11	10/01/1949	156
12	1/05/1955	156
13	27/11/1955	155
14	8/08/1998	152
15	15/06/1952	151

Concord Golf Club (66013)		
Jan 1930 – to date		
Rank	**Date**	**Rainfall (mm)**
1	28/03/1942	295
2	6/08/1986	249
3	3/02/1990	234
4	20/03/1978	222 (2 day total)
5	10/02/1956	221
6	11/06/1991	220 (2 day total)
7	10/01/1949	208
8	16/06/1952	208 (2 day total)
9	27/11/1955	206
10	22/02/1954	198
11	16/04/1946	187
12	26/07/1952	176
13	19/11/1961	154
14	11/03/1958	153
15	16/06/1950	151

The results indicate that the 1942, 1986 and 1990 events were the largest daily rainfall events since records began in 1930. The 1986 event was reported (via the community consultation) as resulting in flooding within the William Street Catchment and SWC records reported flooding to have occurred in the adjacent Dobroyd Canal Catchment during this period.

However, high daily rainfall totals will not necessarily result in widespread flooding of the catchments, particularly if the rainfall was fairly evenly distributed throughout the day. This can be attributed to flooding within the catchments typically resulting from intense rainfall over sub-daily durations.

2.5.3. Analysis of Pluviometer Data

Continuous pluviometer records provide a more detailed description of temporal variations in rainfall. As such, the Concord Greenlees BC, Ashfield Park Bowling Club, Homebush SPS041, Enfield and Canterbury Racecourse pluviometer stations were analysed.

These pluviometer stations are all operated by SWC. The Ashfield Park Bowling Club gauge had the shortest period of record; having been established in December 1993 and decommissioned in February 2001. The other gauges remain in operation. The Enfield gauge was established in 1959, with sub-daily records beginning in June 1983. The Concord gauge was established in June 1988; the Homebush gauge was established in May 1969; and the Canterbury gauge was established in December 1993.

Table 5: Approximate ARI Recorded at Pluviometer Stations

Station Name	Years of Record	Highest Approximate ARI (AR&R 1987)	
		30 minute storm burst	1 hour storm burst
Concord Greenlees BC (formerly Wests Rugby Club)	27	2 – 5 year ARI	2 – 5 year ARI
Ashfield Park Bowling Club (566112)	7	2 – 5 year ARI	1 – 2 year ARI
Homebush SPS041 (formerly Homebush BC)	46	20 – 50 year ARI	50 – 100 year ARI
Enfield (composite site)	32	20 – 50 year ARI	10 – 20 year ARI
Canterbury Racecourse	22	5 – 10 year ARI	2 – 5 year ARI

The period of record and highest approximate ARI's for short storm bursts at the closest pluviometer stations to the study area are shown in Table 5. From this, the Homebush pluviometer recorded the highest approximate ARI for the 30 minute and 1 hour storm burst. This occurred on the 20th June 1978 (for the 30 minute storm burst) and the 31st March 2015 (for the 1 hour storm burst).

From Table 6, the 1996 event was found to be a high intensity, short duration storm event; with relatively high approximate ARI's for the 30 minute duration at the Enfield gauge. The 1996 event also appears to have been highly localised as the other proximate gauges recorded low approximate ARI's across the 30 minute, 1 hour and 2 hour storm durations. Furthermore, the 1996 event resulted in 3 reports of flooding (1 of which was above floor flooding) within the

William Street Catchment according to SWC records, discussed in Section 2.4.1.

Table 6: Rainfall Intensities for the 2nd January 1996

	Duration (minutes)		
	30	60	120
Concord Greenlees BC (566064)			
Max Rainfall (mm)	30	34	50
Intensity (mm/hr)	59	34	25
Approximate ARI	2 – 5 year ARI	1 – 2 year ARI	2 – 5 year ARI
Rank comparative to gauge records for relevant duration	3	5	2
Ashfield Park Bowling Club (566112)			
Max Rainfall (mm)	25	28	32
Intensity (mm/hr)	50	28	16
Approximate ARI	1 – 2 year ARI	~ 1 year ARI	< 1 year ARI
Rank comparative to gauge records for relevant duration	4	6	9
Homebush SPS041 (566022)			
Max Rainfall (mm)	31	33	40
Intensity (mm/hr)	61	33	20
Approximate ARI	2 – 5 year ARI	1 – 2 year ARI	1 – 2 year ARI
Rank comparative to gauge records for relevant duration	6	9	13
Enfield (566020)			
Max Rainfall (mm)	49	49	50
Intensity (mm/hr)	97	49	25
Approximate ARI	20 – 50 year ARI	5 – 10 year ARI	2 – 5 year ARI
Rank comparative to gauge records for relevant duration	2	3	6
Canterbury Racecourse (566113)			
Max Rainfall (mm)	36	38	45
Intensity (mm/hr)	71	38	22
Approximate ARI	5 – 10 year ARI	2 – 5 year ARI	1 – 2 year ARI
Rank comparative to gauge records for relevant duration	2	4	7

2.6. Design Rainfall Data

The design rainfall intensity-frequency-duration (IFD) data (shown in Table 7) was obtained from the Bureau of Meteorology's online design rainfall tool. The input parameters for these calculations are sourced from AR&R (1987).

Table 7: Rainfall IFD data (mm/hr)

DURATION	Design Rainfall Intensity (mm/hr)						
	1 yr ARI	2 yr ARI	5 yr ARI	10 yr ARI	20 yr ARI	50 yr ARI	100 yr ARI
5 minutes	92.2	118	150	168	192	224	248
6 minutes	86.4	111	141	158	181	210	233
10 minutes	70.7	90.7	116	130	149	174	193
20 minutes	51.7	66.5	85.6	96.7	111	130	145
30 minutes	42.1	54.2	70.1	79.3	91.4	107	119
1 hour	28.5	36.8	47.9	54.4	62.9	74.1	82.6
2 hours	18.6	24.1	31.5	35.8	41.5	49	54.7
3 hours	14.4	18.6	24.4	27.7	32.2	38	42.4
6 hours	9.18	11.9	15.6	17.8	20.7	24.5	27.4
12 hours	5.92	7.69	10.1	11.5	13.4	15.9	17.7
24 hours	3.88	5.04	6.61	7.55	8.77	10.4	11.6
48 hours	2.51	3.26	4.27	4.87	5.66	6.69	7.47
72 hours	1.88	2.44	3.2	3.65	4.23	5	5.59

The Probable Maximum Precipitation (PMP) estimates were derived according to Bureau of Meteorology guidelines, namely the *Generalised Short Duration Method* (BoM, 2003). The estimates obtained are summarised in Table 8.

Table 8: PMP Design Rainfall Intensity (mm/hr)

Duration	Design Rainfall Intensity (mm/hr)
15 minutes	649.6
30 minutes	470.4
1 hour	345.1
2 hours	219.8
3 hours	164.5
6 hours	102.55

2.7. Previous Studies

2.7.1. Hydraulic Study and On-Site Detention Modelling for Burwood Council Catchments (Robinson GRC Consulting, 2002)

Robinson GRC Consulting prepared this report on behalf of Burwood City Council from 2000 to 2002. The catchments were within the bounds of Burwood City Council's jurisdiction, and included the Dobroyd Canal, Cooks River, Powells Creek, Exile Bay, St Lukes and William Street catchments. The primary objective of this study was to develop a computer model to assess the 1% AEP event and from this determine insufficiencies in the drainage system, as well as identify overland flow paths that occurred to an unfavourable frequency. Once these "hotspots" were identified, possible mitigation measures were proposed with further modelling undertaken to assess these. Additional to this, the report modelled the 50%, 5% and 1% AEP event with the purpose to propose Permissible Site Discharge (PSD) and storage volumes for potential On-Site Detention (OSD) systems.

The data collected for the purpose of this study included:

- survey of pit levels;
- survey of levels of the kerb, gutter, road centrelines and driveways in locations that were deemed important;
- survey of property levels that may be subject to flooding;
- three laser-doppler flow gauges recorded over the period of the 8th May 2000 to the 31st August 2000. One was located in the Cooks River catchment and two were located in the Dobroyd Canal catchment; and
- two tipping-bucket rain gauges recorded over the period of the 3rd May 2000 to the 15th September 2000. These were located at the Woodstock Park Community Centre (on Church Street, Burwood) and in Council's Depot (near Tangarra Road, Croydon Park).

However, during the period in which the flow gauges and rain gauges were in operation, the rainfall experienced was not of a significant magnitude. The largest rainfall recorded over the period of record was 13 mm over a 24 hour period.

The hydraulic model established for this report was DRAINS. This model was calibrated to the flow gauge and rain gauge records that were collected for the purpose of this study. However, as these events were not of a significant magnitude, the calibration was determined to be inconclusive.

2.7.1.1. Exile Bay Catchment

The critical duration for the Exile Bay Catchment was found to be 25 minutes in the 1% AEP event and 15 minute in the PMF event.

The hotspots identified in this report for the Exile Bay Catchment were:

- Wentworth Road;
- Philip Street; and
- Parramatta Road.

The general assessment concerning hotspots in the Exile Bay Catchment was that the pipes were at full capacity in the 1 year ARI event. However pipe dimensions were limited by the 1050 mm diameter pipe (owned by the City of Canada Bay Council) at the downstream end of the Burwood portion of the Exile Bay Catchment.

2.7.1.2. St Lukes Catchment

The critical duration for the St Lukes Catchment was found to be 25 minutes in the 1% AEP event.

The hotspots identified in this report for the St Lukes Catchment were:

- Railway Parade;
- Elsie Street;
- John Street and Dunns Lane;

- New Street;
- Park Road;
- Britannia Avenue;
- Neich Parade;
- Milton Street;
- Royce Avenue;
- Cheltenham Road; and
- Parramatta Road and Lucas Road.

2.7.1.3. William Street Catchment

The critical duration for the William Street Catchment was found to be 25 minutes in the 1% AEP event.

The hotspots identified in this report for the William Street Catchment were:

- Bay Street;
- Wychbury Avenue and Wychbury Lane;
- Parramatta Road; and
- Acton Street.

2.7.2. Sydney Water Stormwater Capacity Assessment Reports

SWC have prepared various reports that investigated the capacity performance of the SWC owned infrastructure. The reports were:

- St Lukes Park (SWC 90) Capacity Assessment – June 1997; and
- William Street (SWC97) Capacity Assessment – June 1997.

The Exile Bay Catchment did not have a SWC report available as this catchment does not have SWC owned infrastructure within the catchment area.

The drainage data used for the SWC studies included the SWC trunk drainage system only and the analysis was undertaken using a spread sheet analysis based on:

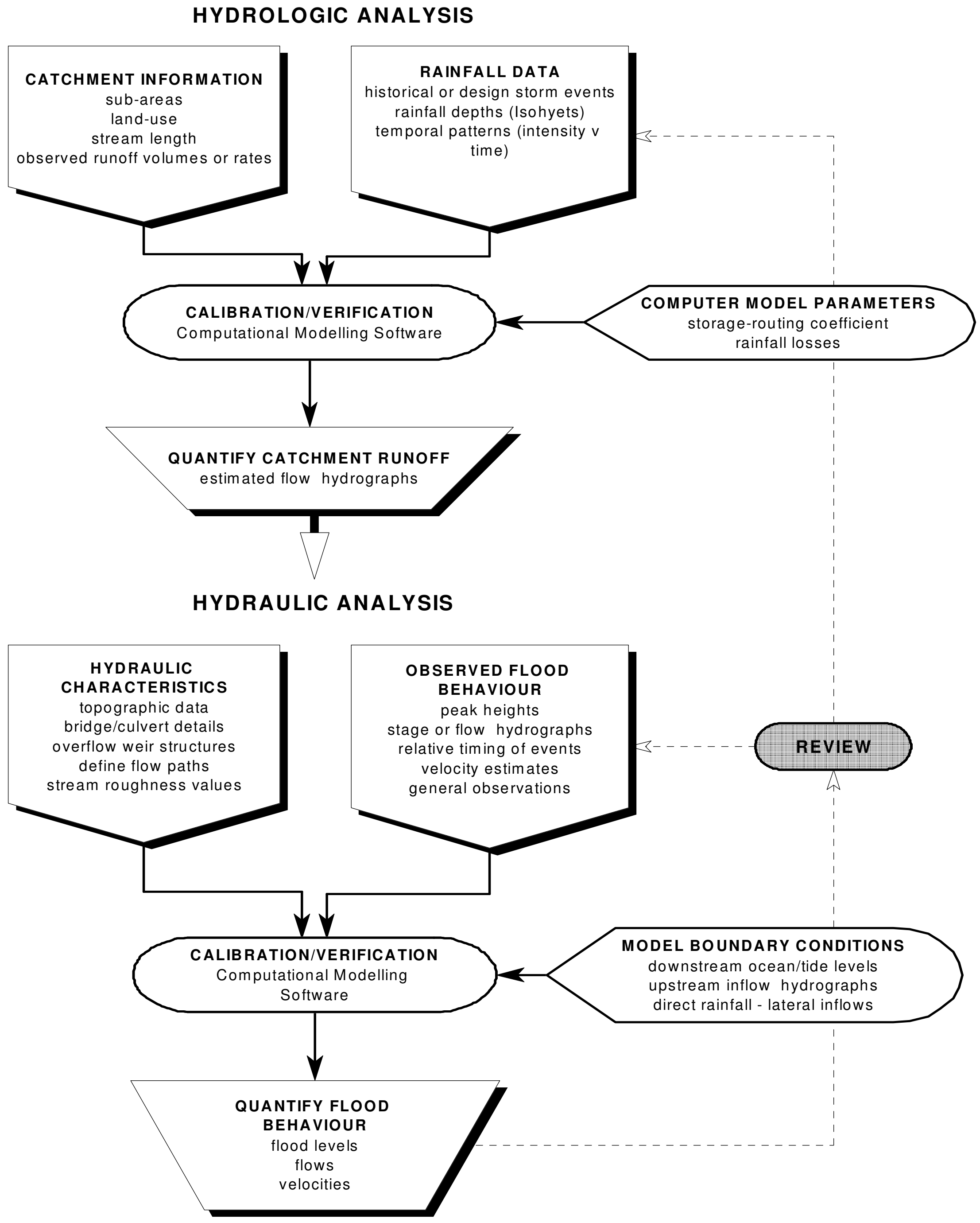
- Rational Method for inflows;
- Approximate capacities of pipes based on grade and area;
- Approximation of channel capacities using Manning's "n" formula; and the
- Hydraulic Grade Line method.

The SWC Capacity Assessment reports have been used in the present study for informing the SWC owned pit and pipe details (discussed in Section 2.3), as well as for model verification (to be completed).

3. STUDY METHODOLGOGY

A diagrammatic representation of the Flood Study process is shown in Diagram 1. 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.

Diagram 1: Flood Study Process



The estimation of flood behaviour in a catchment is undertaken as a two-stage process, consisting of:

1. hydrologic modelling to convert rainfall estimates to overland flow and stream runoff; and
2. hydraulic modelling to estimate overland flow distributions, flood levels and velocities.

As such, the hydrologic model, DRAINS, was built and used to create flow boundary conditions for input into a two-dimensional unsteady flow hydraulic model, i.e. TUFLOW.

Good historical flood data facilitates calibration of the models and increases confidence in the estimates. The calibration process involves modifying the initial model parameter values to produce modelled results that concur with observed data. Validation is undertaken to ensure that the calibration model parameter values are acceptable in other storm events with no additional alteration of values. Recorded rainfall and stream-flow data are required for calibration of the hydrologic model, while historic records of flood levels, velocities and inundation extents can be used for the calibration of hydraulic model parameters. In the absence of such data, model verification is the only option and a detailed sensitivity analysis of the different model input parameters constitutes current best practice.

There are no stream-flow records in the catchment, so the use of a flood frequency approach for the estimation of design floods or independent calibration of the hydrologic model was not possible.

Flood estimation in urban catchments generally presents challenges for the integration of the hydrologic and hydraulic modelling approaches, which have been treated as two distinct tasks as part of traditional flood modelling methodologies. As the main output of a hydrologic model is the flow at the outlet of a catchment or sub-catchment, it is generally used to estimate inflows from catchment areas upstream of an area of interest, and the approach does not lend itself well to estimating flood inundation in mid- to upper-catchment areas, as required for this study. The aim of identifying the full extent of flood inundation can therefore be complicated by the separation of hydrologic and hydraulic processes into separate models, and these processes are increasingly being combined in a single modelling approach.

In view of the above, the broad approach adopted for this study was to use a widely utilised and well-regarded hydrologic model to conceptually model the rainfall concentration phase (including runoff from roof drainage systems, gutters, etc.). The hydrologic model used design rainfall patterns specified in AR&R (1987) and the runoff hydrographs were then used in a hydraulic model to estimate flood depths, velocities and hazard in the study area.

The sub-catchments in the hydrologic model were kept small (on average approximately 1.5 ha) such that the overland flow behaviour for the study was generally defined by the hydraulic model. This joint modelling approach was verified against previous studies and alternative methods.

3.1. Hydrologic Model

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; and
- 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 (1987). 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.

DRAINS cannot however adequately account for an elevated downstream tailwater level which would drown out the lower reaches of a drainage system (it can if the upstream pit is above the tailwater 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). As such the use of DRAINS within the study is limited to some minor upstream routing and development of hydrological inputs into the downstream TUFLOW model.

3.2. Hydraulic Model

The availability of high quality LIDAR/ALS data means that the study area is suitable for two-dimensional (2D) hydraulic modelling. Various 2D software packages are available and the TUFLOW package was adopted as it is widely used in Australia and WMAwater have extensive experience with the model.

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 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.

The study area consists of a wide range of developments, with residential, commercial and open space areas. For this catchment, the study objectives require accurate representation of the overland flow system including kerbs and gutters and defined drainage controls.

For the hydraulic analysis of complex overland flow paths (such as the present study area where overland flow occurs between and around buildings), an integrated 1D/2D model such as TUFLOW provides several key advantages when compared to a 1D only model. For example, a 2D approach can:

- provide localised detail of any topographic and/or structural features that may influence flood behaviour,
- better facilitate the identification of the potential overland flow paths and flood problem areas,
- dynamically model the interaction between hydraulic structures such as culverts and complex overland flowpaths; and
- 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 across the model extent. This information can then be easily integrated into a GIS based environment enabling the outcomes to be readily incorporated into Council's planning activities. The model developed for the present study provides a flexible modelling platform to properly assess the impacts of any overland flow management strategies within the floodplain (as part of the ongoing floodplain management process.

In TUFLOW the ground topography is represented as a uniformly-spaced grid with a ground elevation and a Manning's "n" roughness value assigned to each grid cell. The grid cell size is determined as a balance between the model result definition required and the computer run time (which is largely determined by the total number of grid cells.

4. HYDROLOGIC MODEL

4.1. Sub-catchment Definition

The study area represented by the current DRAINS model is 1.8 km^2. This area has been represented by a total of 142 sub-catchments giving an average sub-catchment size of approximately 0.013 km^2. The sub-catchment delineation ensures that where hydraulic controls exist that these are accounted for and able to be appropriately incorporated into hydraulic routing. The sub-catchment layout is shown in Figure 6.

4.2. Impervious Surface Area

Runoff from connected impervious surfaces such as roads, gutters, roofs or concrete surfaces occur significantly faster than from vegetated surfaces. This results in a faster concentration of flow within the downstream area of the catchment, and increased peak flow in some situations. It is therefore necessary to estimate the proportion of the catchment area that is covered by such surfaces.

DRAINS categorises these surface areas as either:

- paved areas (impervious areas directly connected to the drainage system),
- supplementary areas (impervious areas not directly connected to the drainage system, instead connected to the drainage system via the pervious areas), and
- grassed areas (pervious areas).

Within the study area, a uniform 5% was adopted as a supplementary area across the catchment. The remaining 95% was attributed to impervious (or paved areas) and pervious surface areas, as estimated for each individual sub-catchment. This was undertaken by determining the proportion of the sub-catchment area allocated to a land-use category and the estimated impervious percentage of each land-use category, summarised in Table 9.

Table 9: Impervious Percentage per Land-use

Land-use Category	Impervious Percentage
Property	50% Impervious
Vegetation (such as public parks)	0% Impervious
Roadway	100% Impervious

The proportion of each land-use category within a sub-catchment was determined based upon the hydraulic model roughness schematisation, shown in Figure 8. The impervious percentages attributed to each land-use category were estimated based on aerial observation of a representative area.

4.3. Rainfall Losses

Methods for modelling the proportion of rainfall that is "lost" to infiltration are outlined in AR&R (1987). The methods are of varying degrees of complexity, with the more complex options only suitable if sufficient data are available. The method most typically used for design flood estimation is to apply an initial and continuing loss to the rainfall. The initial loss represents the wetting of the catchment prior to runoff starting to occur and the continuing loss represents the ongoing infiltration of water into the saturated soils while rainfall continues.

Rainfall losses from a paved or impervious area are considered to consist of only an initial loss (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 is calculated from an infiltration equation curve incorporated into the model and is based on the selected representative soil type and antecedent moisture condition. The catchment soil was assumed to have a slow infiltration rate and the antecedent moisture condition was considered to be rather wet.

The adopted parameters are summarised in Table 10. These are consistent with the parameters adopted in the adjacent catchments of Dobroyd Canal (WMAwater, 2013) and Powells Creek (WMAwater, 2015).

Table 10: Adopted DRAINS hydrologic model parameters

RAINFALL LOSSES	
Paved Area Depression Storage (Initial Loss)	1.0 mm
Grassed Area Depression Storage (Initial Loss)	5.0 mm
SOIL TYPE	**3**
Slow infiltration rates. This parameter, in conjunction with the AMC, determines the continuing loss	
ANTECEDENT MOISTURE CONDITONS (AMC)	**3**
Description	Rather wet
Total Rainfall in 5 Days Preceding the Storm	12.5 to 25 mm

5. HYDRAULIC MODEL

5.1. Digital Elevation Model

Given the objectives and requirements of the study and the availability of ALS data, a 2D overland flow hydraulic model is the most suitable model to effectively assess flood behaviour.

The model uses a regularly spaced computational grid, with a cell size of 3 m by 3 m. This resolution was adopted as it provides an appropriate balance between providing sufficient detail for roads and overland flow paths, while still resulting in workable computational run-times. The model grid was established by sampling from a 1 m by 1 m DEM. This DEM was generated from a triangulation of filtered ground points from the LiDAR dataset, discussed in Section 2.2. This DEM is shown in Figure 2.

5.2. Boundary Locations

The hydraulic model boundary was Queens Road / Gipps Street, which is located downstream of Parramatta Road and the Burwood LGA boundary (which is the subject of this Flood Study). The St Lukes and William Street hydraulic boundaries are within tidally affected areas and have design tidal conditions applied to the 1D and 2D domains. The Exile Bay hydraulic boundary is not affected by tide levels and as such, the invert level of the stormwater pipe in the 1D domain and the ground level of the roadway in the 2D domain were applied to the boundary.

5.3. Roughness Co-efficient

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

The spatial variation in Manning's "n" values is shown on Figure 8. The Manning's "n" values adopted for these areas, including flowpaths (overland, pipe and in-channel), are shown in Table 11. These values have been adopted based on site inspection and past experience in similar floodplain environments. The values are consistent with typical values in the literature (Chow, 1959 and Henderson, 1966).

Table 11: Manning's "n" values adopted in TUFLOW

Surface	Manning's "n" Adopted
Pipes	0.015
Roads and Footpaths	0.02
Light Vegetation	0.03
Properties	0.05

5.4. Hydraulic Structures

5.4.1. Buildings

Buildings and other significant features likely to act as flow obstructions were incorporated into the model network based on building footprints, defined using aerial photography. These types of features were modelled as impermeable obstructions to the floodwaters.

5.4.2. Fencing and Obstructions

Smaller localised obstructions within or bordering private property, such as fences, were not explicitly represented within the hydraulic model, due to the relative impermanence of these features. The cumulative effects of these features on flow behaviour were assumed to be addressed partially by the adopted roughness parameters.

5.4.3. Sub-surface Drainage Network

Figure 7 shows the location and extent of drainage lines within the study catchment that have been included in the TUFLOW model. The drainage system defined in the model comprises:

- 2514 pipes;
- 19 open channel segments; and
- 2556 pits and nodes.

5.5. Blockage Assumptions

Blockage of hydraulic structures can occur with the transportation of a number of materials by flood waters. This includes vegetation, garbage bins, building materials and cars, the latter of which has been seen post-flood in Newcastle. However, the disparity in materials that may be mobilised within a catchment can vary greatly.

Debris availability and mobility can be influenced by factors such as channel shear stress, height of floodwaters, severity of winds, storm duration and seasonal factors relating to vegetation. The channel shear stress and height of floodwaters that influence the initial dislodgment of blockage materials are also related to the average exceedance probability (AEP) of the event. Storm duration is another influencing factor, with the mobilisation of blockage materials generally increasing with increasing storm duration (Barthelmess and Rigby 2009, cited in Engineers Australia 2013).

The potential effects of blockage include:

- decreased conveyance of flood waters through the blocked hydraulic structure or drainage system;
- variation in peak flood levels;
- variation in flood extent due to flows diverting into adjoining flow paths; and
- overtopping of hydraulic structures.

Existing practices and guidance on the application of blockage can be found in:

- the Queensland Urban Drainage Manual (Department of Natural Resources and Water, 2008);
- AR&R Revision Project 11 Blockage of Hydraulic Structures (Engineers Australia, 2013); and
- the policies of various local authorities and infrastructure agencies.

The guidelines proposed by the AR&R Revision Project 11 utilise generic blockage factors presented in Table 12.

Table 12: Suggested 'Design' and 'Severe' Blockage Conditions for Various Structures (Engineers Australia, 2013)

Type of structure		**Blockage conditions**	
		Design blockage	**Severe blockage**
Sag Kerb Inlet	Kerb slot inlet only Grated inlet only Combined inlets	0/20% 0/50% [1]	100% (all cases)
On-grade kerb inlets	Kerb slot inlet only Grated inlet only (longitudinal bars) Grated inlet only (transverse bars) Combined inlets	0/20% 0/40% 0/50% [2]	100% (all cases)
Field (drop) inlets	Flush mounted Elevated (pill box) horizontal grate Dome screen	0/80% 0/50% 0/50%	100% (all cases)
Pipe inlets and waterway culverts	*Inlet height < 3m and width < 5m* Inlet Chamber	0/20% [3]	100% [4]
	Inlet height > 3m and width > 5m Inlet Chamber	0/10% [3]	25% [3]
	Culverts and pipe inlets with effective debris control features	As above	As above
	Screened pipe and culvert inlets	0/50%	100%
Bridges	Clear opening height < 3 m Clear opening height > 3 m Central piers	[5] 0% [7]	100% [6] [7]
Solid handrails and traffic barriers associated with bridges and culverts		100%	100%
Fencing across overland flow paths		[8]	100%
Screened stormwater outlets		100%	100%

Current modelling has been undertaken assuming no blockage of pipes, culverts and bridges greater than 300 mm in diameter. Pipes less than or equal to 300 mm in diameter were conservatively assumed to be completely blocked.

6. VERIFICATION MODELLING

6.1. Introduction

Prior to use for defining design flood behaviour it is important that the performance of the overall modelling system be substantiated. Calibration involves modifying the initial model parameter values to produce modelled results that concur with observed data. Validation is undertaken to ensure that the calibration model parameter values are acceptable in other storm events with no additional alteration of values. Best practice is that the modelling system should be calibrated to one historical event and validated using multiple historical events. To facilitate this there needs to be adequate historical flood observations and sufficient pluviometer rainfall data.

Typically in urban areas such information is lacking. Issues which may prevent a thorough calibration of hydrologic and hydraulic models are:

- there is only a limited amount of historical flood information available for the study area. For example, in Sydney (east of Parramatta) there are only two water level recorders in urban catchments similar to that of the study area; and
- rainfall records for past floods are limited and there is a lack of temporal information describing historical rainfall patterns within the catchment.

In the event that a calibration and validation of the models is not possible or limited in scope, it is best practice to undertake a verification of the models and a detailed sensitivity analysis.

6.2. Correlating Data

The correlation between the historic flood level data (discussed in Section 2.4) and available pluviometer data (discussed in Section 2.5.3) is summarised in Table 13.

The approximate ARI for these storm events have been estimated based on the pluviometer rainfall gauge at Concord Greenlees BC (566064) for the 30 minute storm duration and the IFD data for the centre of the study area (discussed in Section 2.6).

For the storm events in which a pluviometer station was present, the ARI estimated was typically of a small magnitude (shown in Table 13). Engineers Australia (2012) advises that calibration events “span the magnitude range of the intended design events with a preference for the more important design floods (eg. 1% AEP event)”. For this reason, a verification of the models was undertaken instead of calibrating or validating the models.

Table 13: Data available for various storm events

Storm Events	Total Records	Indicative Depths Available	Approximate ARI	Pluviometer Stations in Operation
19 May 1946	1	0	N/A	
Nov 1961	1	0	N/A	
1986	1	0	N/A	Ashfield Park Bowling Club (566112) Homebush SPS041 (566022) Enfield (566020)
2 Jan 1996	3	1	2 – 5 year ARI	Concord Greenlees BC (566064) Homebush SPS041 (566022) Enfield (566020) Canterbury Racecourse (566113)
2009	1	1	< 1 year ARI *	Concord Greenlees BC (566064) Ashfield Park Bowling Club (566112) Homebush SPS041 (566022) Enfield (566020) Canterbury Racecourse (566113)
2013	1	1	< 1 year ARI *	Concord Greenlees BC (566064) Ashfield Park Bowling Club (566112) Homebush SPS041 (566022) Enfield (566020) Canterbury Racecourse (566113)
Mar 2014	1	1	1 – 2 year ARI *	Concord Greenlees BC (566064) Ashfield Park Bowling Club (566112) Homebush SPS041 (566022) Enfield (566020) Canterbury Racecourse (566113)
8 Nov 2014	1	1	< 1 year ARI	Concord Greenlees BC (566064) Ashfield Park Bowling Club (566112) Homebush SPS041 (566022) Enfield (566020) Canterbury Racecourse (566113)
Aug 2015	1	0	< 1 year ARI *	Concord Greenlees BC (566064) Ashfield Park Bowling Club (566112) Homebush SPS041 (566022) Enfield (566020) Canterbury Racecourse (566113)

* Note: Where the precise date was not specified, the largest approximate ARI event to occur within the date range provided is shown.

6.3. Hydrologic Model Verification

A comparison against previous studies of nearby catchments can be undertaken to verify the model. For this study, the hydrologic model from the Rose Bay catchment was compared to study area. DRAINS was the hydrologic model used in Rose Bay and the catchment is located approximately 12 km from the study area.

Comparison of specific yield was used for the model verification and is calculated by dividing the peak discharge by the area of the upstream catchment. This calculation removes the effects that variations in sub-catchment size have on peak discharge. Also, to remove the effects that differences in catchment delineation can have on peak discharge, the specific yield was calculated for multiple, randomly-selected, sub-catchments. The results are shown in Table 14 and the specific yields from the two different DRAINS models were found to be comparable.

Table 14: Comparable sub-catchment hydrologic model verification

Sub-catchment	Exile Bay, St Lukes and William Street			Rose Bay		
	Area (ha)	Peak Discharge (m^3/s)	Specific Yield ($m^3/s/ha$)	Area (ha)	Peak Discharge (m^3/s)	Specific Yield ($m^3/s/ha$)
1	0.4	0.3	0.6	1	0.6	0.7
2	2.8	1.5	0.5	0.4	0.2	0.6
3	13.8	6.4	0.5	0.6	0.4	0.6

6.4. Hydrologic and Hydraulic Model Verification

Verification of the hydraulic model was undertaken by:

- comparing the modelled design results against the results in the 1997 report by SWC;
- comparing the modelled design results against the hotspots identified in the 2002 report by Robinson GRC Consulting.

6.4.1. Comparison with the SWC (1997) report

Comparison was undertaken on the 20% AEP peak flows produced in the TUFLOW hydraulic model and those in the SWC report, summarised in Table 15.

Table 15: SWC (1997) results compared to the current study results – for the 20% AEP event

Pipe/Channel ID	Catchment	SWC Report (1998) (m^3/s)	Current Study (m^3/s)
C-D	St Lukes	24.3	17.2
D-E	St Lukes	15.2	8.8
E-K	St Lukes	10.2	4.8
K-F	St Lukes	5.5	3.1
G-H	St Lukes	4.8	3.2
H-HA	St Lukes	3.5	2.9
HA-HB	St Lukes	3.2	2.7
HB-J	St Lukes	2.6	2.7
D-D1	St Lukes	7.9	4.4
B-C	William Street	8.1	4.0
C-D	William Street	7.4	4.0
D-E	William Street	6.9	3.9
E-F	William Street	6.9	3.7
F-G	William Street	5.8	3.4
B-BA	William Street	3.1	0.6
BA-BB	William Street	2.1	0.1
BB-BC	William Street	2.1	0.1
BC-BD	William Street	1.5	0.0
BA-BAA	William Street	1.1	0.6
BAA-BAB	William Street	0.8	0.6

Peak flows in the current study were significantly less than those in the previous study. The peak flows produced in the previous study were obtained using the Manning's "n" formula and did not explicitly account for storage within the catchment. Within the study area, this has a significant influence due to parks that act as detention basins and obstructions such as buildings and the railway embankment impeding flow.

6.4.2. Comparison with the Robinson GRC Consulting (2002) report

Comparison was made between the 1% AEP flood extent obtained in the current study with the hotspots identified in the Robinson GRC Consulting (2002) report. It was found that the hotspots identified in the previous report coincided with the flow paths identified in the current study. This is summarised in Table 16.

Table 16: Robinson GRC Consulting (2002) hotspots compared to the 1% AEP peak flood depth

Location	Catchment	Flood Depth (m)
Wentworth Road	Exile Bay	0.31
Philip Street	Exile Bay	0.22
Parramatta Road	Exile Bay	0.49
Railway Parade	St Lukes	0.49
Elsie Street	St Lukes	0.52
John Street and Dunns Lane	St Lukes	0.54
New Street	St Lukes	0.56
Park Road	St Lukes	0.02
Britannia Avenue	St Lukes	0.15
Neich Parade	St Lukes	0.30
Milton Street	St Lukes	0.69
Royce Avenue	St Lukes	0.12
Cheltenham Road	St Lukes	0.27
Parramatta Road and Lucas Road	St Lukes	0.63
Bay Street	William Street	0.22
Wychbury Avenue and Wychbury Lane	William Street	0.59
Parramatta Road	William Street	0.55
Acton Street	William Street	0.03

7. DESIGN EVENT MODELLING

7.1. Overview

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 homogenous record of flood levels and flows over a number of decades to give satisfactory results. No such records were available within this catchment. For this reason a *rainfall and runoff routing* approach using 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 outlined in the recent revisions to Australian Rainfall and Runoff (Engineers Australia, 2016) and is consistent with the quality and quantity of available data.

7.2. Critical Duration

To determine the critical duration for various parts of the catchments, modelling of the 1% AEP event was undertaken for a range of design storm durations from 15 minutes to 9 hours, using temporal patterns from AR&R (1987). An envelope of the model results was created, and the storm duration producing the maximum flood depth was determined for each grid point within the study area.

It was found that a combination of the 25 minute and 1 hour design storm durations were critical across all the catchments for the 1% AEP event. The 1 hour storm duration was critical in the downstream areas; up to and including Parramatta Road within the Exile Bay and William Street Catchments; and up to Burwood Road (to the west), New Street (to the south) and Lucas Road (to the east) within the St Lukes Catchment. The 1 hour storm duration was also critical between George Street and Park Avenue to the west of the buildings on Burwood Road. The critical duration that was predominant across the remainder of the study area was the 25 minute storm burst. The difference between the peak flood levels for the 25 minute and 1 hour storm durations was within ± 0.15 m. Therefore it was determined appropriate to adopt an embedded design storm for the entire catchment, using the 25 minute design storm burst within the 1 hour design storm, adjusted to maintain the correct 1 hour total rainfall depth. This method is described in References 10, 11 and 12.

Additionally, the critical storm duration was determined for the PMF event for a range of storm durations, ranging from 15 minutes to 6 hours. Similarly, an envelope of the model results was created, and the storm duration producing the maximum flood depth was determined for each grid point within the study area.

It was found that a combination of the 15 minute, 30 minute and 1 hour design storm durations were critical in the PMF event. The 1 hour storm duration was critical upstream of the railway embankment (along Railway Parade). The 30 minute storm duration was critical from Wangal Park to Cheltenham Road and in the downstream areas up to and including Parramatta Road within the St Lukes and William Street Catchments. The critical duration that was predominant across the remainder of the study area was the 15 minute storm burst. The difference between the peak flood levels for the 15 minute and 30 minute storm durations was within ± 0.10 m. Therefore, a peak envelope of the 15 minute and 30 minute storm durations was adopted.

7.3. Downstream Boundary Conditions

In addition to runoff from the catchment, downstream areas can also be influenced by high water levels within Iron Cove and the trunk drainage system. Consideration must therefore be given to accounting for the joint probability to coincident flooding from both catchment runoff and backwater effects.

The combined impact of these two sources on overall flood risk varies significantly with distance from the ocean and the degree of ocean influence, which is in turn affected by the entrance conditions. The *Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways* guide (2015) presents a multivariate approach for hydraulic modelling purposes and was applied in this study.

Given the short duration of the critical storm burst, the simplistic approach using a steady state ocean boundary was considered sufficient. The catchment was defined as Entrance Type A (open oceanic embayment) and was located south of Crowdy Head; resulting in the 1% AEP and 5% AEP ocean levels as those shown in Table 17.

Table 17: Combinations of Catchment Flooding and Oceanic Inundation Scenarios

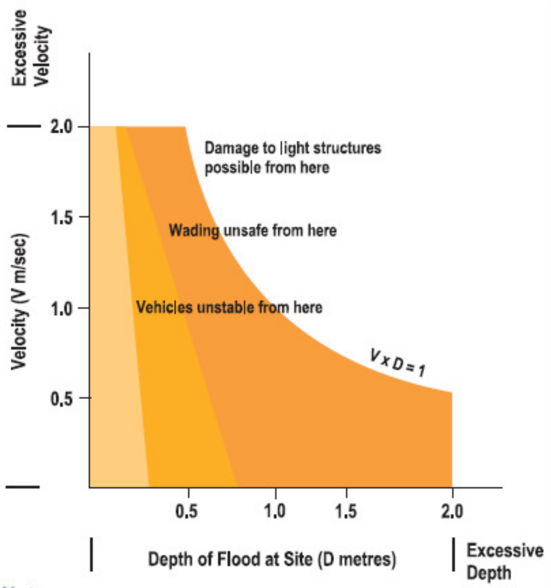
Design AEP for peak flood levels	Catchment Flood Scenario	Ocean Water Level Boundary
0.2 EY	0.2 EY Rainfall	HHWS Ocean Level 1.25 m AHD
10% AEP	10% AEP Rainfall	HHWS Ocean Level 1.25 m AHD
5% AEP	5% AEP Rainfall	HHWS Ocean Level 1.25 m AHD
2% AEP	2% AEP Rainfall	5% AEP Ocean Level 1.40 m AHD
1% AEP (Enveloped)	5% AEP Rainfall	1% AEP Ocean Level 1.45 m AHD
	1% AEP Rainfall	5% AEP Ocean Level 1.40 m AHD
PMF	PMF Rainfall	1% AEP Ocean Level 1.45 m AHD

7.4. Analysis

7.4.1. Provisional Hydraulic Hazard

Hazard categories were determined in accordance with Appendix L of the NSW Floodplain Development Manual, the relevant section of which is shown in Diagram 2. For the purposes of this report, the transition zone presented in Diagram 2 (L2) was considered to be high hazard.

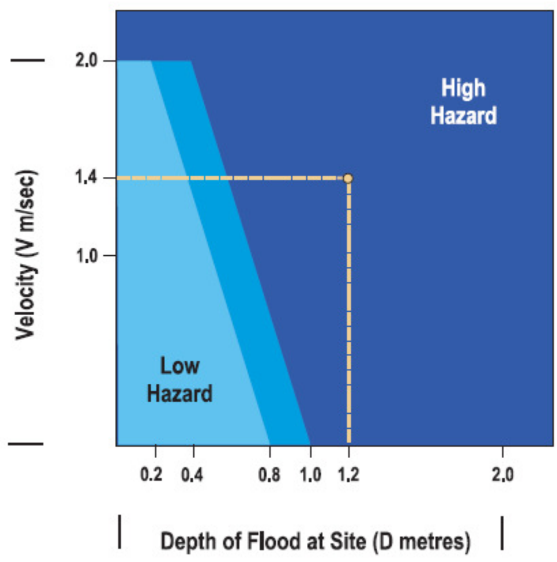
Diagram 2: (L1) Velocity and Depth Relationship; (L2) Provisional Hydraulic Hazard Categories (NSW State Government, 2005)



Notes

1. At velocities in excess of 2.0 m/s, the stability of foundations and poles can be affected by scour. Also, grass and earth surfaces begin to scour and can become rough and unstable
2. The velocity of floodwaters passing between buildings can produce a hazard, which may not be apparent if only the average velocity is considered. For instance, the velocity of floodwaters in a model test has risen from an average of 1 m/sec to 3 m/sec between houses.
3. Vehicle instability is initially by buoyancy.
4. At floodwater depths in excess of 2.0 meters and even at low velocities, there can be damage to light-framed buildings from water pressure, flotation and debris impact.

Derived from laboratory testing and flood conditions which caused damage.



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**

7.4.2. Provisional Hydraulic Categorisation

The hydraulic categories, namely floodway, flood storage and flood fringe, are described in the Floodplain Development Manual (NSW State Government, 2005). However, there is no technical definition of hydraulic categorisation that would be suitable for all catchments, and different approaches are used by different consultants and authorities, based on the specific features of the study area.

For this study, hydraulic categories were defined by the following criteria, which correspond in part with the criteria proposed by Howells et. al. (2003):

- Floodway is defined as areas where:
    - the peak value of velocity multiplied by depth (V x D) > 0.25 m^2/s **AND** peak velocity > 0.25 m/s, **OR**
    - peak velocity > 1.0 m/s **AND** peak depth > 0.15 m

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

- Flood Storage comprises areas outside the floodway where peak depth > 0.5 m; and
- Flood Fringe comprises areas outside the Floodway where peak depth < 0.5 m

7.4.3. Preliminary Flood Emergency Response Classification of Communities

The Floodplain Development Manual, 2005 requires flood studies to address the management of continuing flood risk to both existing and future development areas. As continuing flood risk varies across the floodplain so does the type and scale of emergency response problem and therefore the information necessary for effective Emergency Response Planning (ERP). Classification provides an indication of the vulnerability of the community in flood emergency response and identifies the type and scale of information needed by the SES to assist in emergency response planning (ERP).

Criteria for determining flood ERP classifications and an indication of the emergency response required for these classifications are provided in the Floodplain Risk Management Guideline, 2007 (Flood Emergency Response Planning: Classification of Communities). Table 18 summarises the response required for areas of different classification. However, these may vary depending on local flood characteristics and resultant flood behaviour, i.e. in flash flooding or overland flood areas.

Table 18: Response Required for Different Flood ERP Classifications

Classification	Response Required		
	Resupply	Rescue/Medivac	Evacuation
High Flood Island	Yes	Possibly	Possibly
Low Flood Island	No	Yes	Yes
Area with Rising Road Access	No	Possibly	Yes
Area with Overland Escape Routes	No	Possibly	Yes
Low Trapped Perimeter	No	Yes	Yes
High Trapped Perimeter	Yes	Possibly	Possibly
Indirectly Affected Areas	Possibly	Possibly	Possibly

7.5. Results

The results from this study are presented as:

- Peak flood level profiles in Figure 10;
- Flow and level hydrographs in Figure 11;
- Peak flood depths and level contours in Figure 12 to Figure 17;
- Peak flood velocities in Figure 18 to Figure 20;
- Provisional hydraulic hazard in Figure 21 to Figure 23;
- Provisional hydraulic categorisation in Figure 24 to Figure 26;
- Preliminary flood emergency response classification of communities in Figure 27; and
- Preliminary flood planning areas in Figure 28.

7.5.1. Peak Flood Depths and Levels

The tabulated summary of peak flood depths is presented in Table 19.

Table 19: Peak Flood Depths (m) at Key Locations

ID	Location	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	PMF
H01	Parramatta Rd – Between Philip St and Wentworth Rd	0.32	0.37	0.42	0.45	0.49	0.93
H02	Cnr Wentworth Rd and White St	0.13	0.15	0.17	0.18	0.19	0.42
H03	Parramatta Rd – Between Shaftesbury Rd and Luke Ave	0.40	0.45	0.51	0.58	0.63	1.31
H04	Cnr Milton St and Archer St	0.44	0.50	0.57	0.64	0.69	1.62
H05	Meryla St	0.33	0.36	0.39	0.42	0.45	0.93
H06	Cnr Burwood Rd and Park Ave	0.29	0.32	0.36	0.39	0.43	1.18
H07	Elsie St	0.22	0.33	0.42	0.47	0.52	0.93
H08	Railway Parade near Wynne Ave	0.36	0.39	0.43	0.46	0.49	2.14
H09	Lucas Rd – Between Parramatta Rd and Stuart St	0.24	0.28	0.37	0.44	0.49	1.01
H10	Wangal Park	0.89	1.06	1.17	1.36	1.50	2.58
H11	Cnr Parramatta Rd and Short St	0.44	0.47	0.50	0.52	0.55	1.21
H12	Grogan St	0.38	0.40	0.44	0.46	0.48	0.92
H13	Wychbury La	0.40	0.45	0.50	0.54	0.59	1.26

The tabulated summary of peak flood levels is presented in Table 20.

Table 20: Peak Flood Levels (m AHD) at Key Locations

ID	Location	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	PMF
H01	Parramatta Rd – Between Philip St and Wentworth Rd	15.26	15.30	15.35	15.39	15.43	15.86
H02	Cnr Wentworth Rd and White St	18.55	18.57	18.59	18.60	18.61	18.84
H03	Parramatta Rd – Between Shaftesbury Rd and Luke Ave	4.17	4.22	4.29	4.35	4.40	5.08
H04	Cnr Milton St and Archer St	5.67	5.73	5.80	5.87	5.92	6.85
H05	Meryla St	9.25	9.27	9.31	9.33	9.36	9.85
H06	Cnr Burwood Rd and Park Ave	11.66	11.69	11.73	11.76	11.80	12.55
H07	Elsie St	14.36	14.47	14.56	14.61	14.65	15.07
H08	Railway Parade near Wynne Ave	19.20	19.24	19.27	19.30	19.33	20.99
H09	Lucas Rd – Between Parramatta Rd and Stuart St	5.89	5.94	6.03	6.10	6.14	6.66
H10	Wangal Park	13.89	14.06	14.17	14.36	14.50	15.58
H11	Cnr Parramatta Rd and Short St	3.91	3.94	3.97	3.99	4.02	4.68
H12	Grogan St	4.90	4.93	4.96	4.98	5.00	5.45
H13	Wychbury La	9.58	9.63	9.69	9.73	9.77	10.45

7.5.2. Peak Flow

The tabulated summary of peak flows within the stormwater pipes and overland is presented in Table 21.

Table 21: Peak Flow (m^3/s) at Key Locations

ID	Location	Type	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Q01	Parramatta Rd – From Mosely St and Melbourne St	Overland	2.3	3.6	5.3	6.6	8.1	45.4
		Pipe	2.1	2.2	2.2	2.2	2.3	2.7
Q02	Cnr Wentworth Rd and Nixon La	Overland	0.5	0.7	1.0	1.2	1.5	9.6
		Pipe	0.8	0.9	1.0	1.1	1.1	1.6
Q03	Parramatta Rd – From Loftus St to Taylor St	Overland	4.6	6.8	10.4	15.1	19.2	141.6
		Pipe	13.1	13.9	15.0	15.5	16.3	17.8
Q04	Shaftesbury Rd – Between Milton St and Parramatta Rd	Overland	4.5	6.2	8.9	12.0	15.0	95.8
		Pipe	8.8	9.0	9.9	9.7	9.9	10.2
Q05	New Street	Overland	6.0	7.6	9.9	12.1	14.4	79.7
		Pipe	5.3	5.2	5.6	5.7	5.8	7.0
Q06	Cnr Burwood Rd and Wilga St	Overland	3.7	4.6	5.8	6.5	7.9	46.5
		Pipe	2.9	3.0	3.1	3.1	3.1	4.1
Q07	Elsie St	Overland	0.2	0.6	1.1	1.5	1.9	9.8
		Pipe	2.5	2.5	2.6	2.6	2.6	3.0
Q08	Railway Embankment (Railway Parade)	Overland	0.0	0.0	0.0	0.0	0.0	0.0
		Pipe	1.8	2.0	2.1	2.2	2.4	4.2
Q09	Lucas Rd – Between Parramatta Rd and Stuart St	Overland	1.8	2.3	3.2	4.4	5.6	29.5
		Pipe	1.9	1.9	2.0	2.1	2.1	2.3
Q10	Wangal Park	Overland	0.0	0.0	0.0	0.0	0.0	5.1
		Pipe	0.2	0.2	0.2	0.2	0.2	0.3
Q11	Parramatta Rd – Between Royce Ave and Lang St	Overland	3.5	5.3	7.5	9.3	11.1	60.8
		Pipe	3.4	3.4	3.5	3.5	3.5	3.6
Q12	Grogan St	Overland	4.6	5.6	7.0	8.1	9.4	47.1
		Pipe	0.8	0.8	0.8	0.9	0.9	0.9
Q13	Wychbury La	Overland	0.5	0.6	0.8	0.9	1.1	4.3
		Pipe	0.3	0.3	0.3	0.3	0.3	0.4

7.5.3. Provisional Hydraulic Hazard

The high hazard areas were predominantly located in the roadways in the 1% AEP event. The areas of high hazard were located at:

- Esher Street, south of New Street;
- Milton Street;
- Shaftesbury Road, north of Milton Street;
- Parramatta Road, between Shaftesbury Road and the open channel;
- St Lukes open channel and Concord Oval; and
- William Street, north of Parramatta Road.

7.5.4. Provisional Hydraulic Categorisation

In the 1% AEP event, the floodway areas were predominantly located in the roadways, located at:

- Wentworth Road, north of White Street;
- Burwood Road, between Victoria Street East and Meryla Street;
- Meryla Street, west of Esher Street;
- Esher Street, south of New Street;
- New Street;
- Archer Street, north of New Street;
- Milton Street, between Esher Street and Archer Street;
- Shaftesbury Road, north of Milton Street;
- Parramatta Road, between Shaftesbury Road and Lucas Road;
- Lucas Road, north of Stuart Street;
- St Lukes open channel;
- Short Street; and
- William Street.

The flood storage areas were predominantly located in parks, such as Wangal Park and Concord Oval.

7.5.5. Preliminary Flood Emergency Response Classification of Communities

ERP classifications for the study area are shown in Figure 27. Due to the railway embankment between Burwood Road and Park Road, the area immediately upstream of the embankment was classified as a Low Trapped Perimeter Area and the area immediately downstream was classified as a High Trapped Perimeter Area. Areas along Wentworth Road, Burwood Road, Milton Street and Parramatta Road were classified as Low Flood Island areas. The areas classified as Rising Road Access are likely to be inundated but have roads rising uphill and away from the rising floodwaters.

The criteria for classification of floodplain communities are generally more applicable to riverine flooding where significant flood warning time is available and emergency response action can be taken prior to the flood. In urban areas like Burwood, flash flooding from local catchment and overland flow will generally occur as a direct response to intense rainfall without significant warning. For most (if not all) flood affected properties in the catchment, remaining inside the building is likely to present less risk to life than attempting to drive or wade through floodwaters, as flow velocities and depths are likely to be greater in the roadway.

8. SENSITIVITY ANALYSIS

8.1. Overview

The following sensitivity analyses were undertaken to establish the variation in design flood levels and flow that may occur if different parameter assumptions were made:

- Routing Lag: The hydrologic routing length values were increased and decreased by 20% for all sub-catchments;
- Manning's "n": The hydraulic roughness values were increased and decreased by 20%;
- Blockage (pipes): Sensitivity to blockage of all pipes was assessed for 20% and 50% blockage;
- Climate Change (Rainfall Increase): Sensitivity to rainfall/runoff estimates were assessed by increasing the rainfall intensities by 10%, 20% and 30% as recommended under current guidelines;
- Climate Change (Sea Level Rise): Sea level rise scenarios of 0.4 m and 0.9 m were assessed.

These sensitivity scenarios were undertaken for the 1% AEP rainfall event with the 5% AEP ocean level.

8.2. Climate Change Background

Intensive scientific investigation is ongoing to estimate the effects that increasing amounts of greenhouse gases (water vapour, carbon dioxide, methane, nitrous oxide, ozone) are having on the average earth surface temperature. Changes to surface and atmospheric temperatures may affect climate and sea levels. The extent of any permanent climatic or sea level change can only be established with certainty through scientific observations over several decades. Nevertheless, it is prudent to consider the possible range of impacts with regard to flooding and the level of flood protection provided by any mitigation works.

Based on the latest research by the United Nations Intergovernmental Panel on Climate Change, evidence is emerging on the likelihood of climate change and sea level rise as a result of increasing greenhouse gasses. In this regard, the following points can be made:

- greenhouse gas concentrations continue to increase;
- global sea level has risen about 0.1 m to 0.25 m in the past century;
- many uncertainties limit the accuracy to which future climate change and sea level rises can be projected and predicted.

8.2.1. Rainfall Increase

The Bureau of Meteorology has indicated that there is no intention at present to revise design rainfalls to take account of the potential climate change, as the implications of temperature changes on extreme rainfall intensities are presently unclear, and there is no certainty that the changes would in fact increase design rainfalls for major flood producing storms. There is some recent literature by CSIRO that suggests extreme rainfalls may increase by up to 30% in parts of NSW (in other places the projected increases are much less or even decrease); however this information is not of sufficient accuracy for use as yet (NSW State Government, 2007).

Any increase in design flood rainfall intensities will increase the frequency, depth and extent of inundation across the catchment. It has also been suggested that the cyclone belt may move further southwards. The possible impacts of this on design rainfalls cannot be ascertained at this time as little is known about the mechanisms that determine the movement of cyclones under existing conditions.

Projected increases to evaporation are also an important consideration because increased evaporation would lead to generally dryer catchment conditions, resulting in lower runoff from rainfall. Mean annual rainfall is projected to decrease, which will also result in generally dryer catchment conditions. The influence of dry catchment conditions on river runoff is observable in climate variability using the Indian Pacific Oscillation (IPO) index (Westra et al, 2009). Although mean daily rainfall intensity is not observed to differ significantly between IPO phases, runoff is significantly reduced during periods with fewer rain days.

The combination of uncertainty about projected changes in rainfall and evaporation makes it extremely difficult to predict with confidence the likely changes to peak flows for large flood events within the Dobroyd Canal catchment under warmer climate scenarios.

In light of this uncertainty, the NSW State Government (2007) advice recommends sensitivity analysis on flood modelling should be undertaken to develop an understanding of the effect of various levels of change in the hydrologic regime on the project at hand. Specifically, it is suggested that increases of 10%, 20% and 30% to rainfall intensity be considered.

8.2.2. Sea Level Rise

The *NSW Sea Level Rise Policy Statement* was released by the NSW Government in October 2009. This Policy Statement was accompanied by the *Derivation of the NSW Government's sea level rise planning benchmarks* (NSW State Government, 2009) which provided technical details on how the sea level rise assessment was undertaken. Additional guidelines were issued by OEH, including the *Flood Risk Management Guide: Incorporating sea level rise benchmarks in flood risk assessments 2010.*

The Policy Statement says:

> *"Over the period 1870-2001, global sea levels rose by 20 cm, with a current global average rate of increase approximately twice the historical average. Sea levels are expected to continue rising throughout the twenty-first century and there is no scientific evidence to suggest that sea levels will stop rising beyond 2100 or that current trends will be reversed… However, the 4th Intergovernmental Panel on Climate Change in 2007 also acknowledged that higher rates of sea level rise are possible"* (NSW State Government, 2009)

In light of this uncertainty, the NSW State Government's advice is subject to periodical review. As of 2012, the NSW State Government withdrew endorsement of sea level rise predictions but still require sea level rise to be considered. The current Flood Study assessed the sensitivity to a projected sea level rise of 0.4 m by 2050 and 0.9 m by 2100, corresponding to the sea level rise sensitivity analysis in the adjacent Dobroyd Canal Flood Study.

8.3. Results

The sensitivity scenario results were compared to the 1% AEP rainfall event with the 5% AEP ocean level. A summary of peak flood level and peak flow differences at various locations are provided in:

- Table 22 for variations in routing;
- Table 24 for variations in roughness;
- Table 26 for variations in blockage; and
- Table 28 for variations in climate conditions.

Comparison of peak flood levels have been highlighted such that yellow highlighting indicates that the magnitude of the change is greater than 0.1 m, while red highlighting indicates changes greater than 0.3 m in magnitude.

8.3.1. Roughness Variations

Overall peak flood level results were shown to be relatively insensitivity to variations in the roughness parameter. Generally, these results were found to be within ± 0.05 m.

Table 22: Results of Roughness Analysis – Change in Level

ID	Location	Peak Flood Depth 1% AEP	Difference with 1% AEP (m)	
			Roughness Decreased by 20%	Roughness Increased by 20%
H01	Parramatta Rd – Between Philip St and Wentworth Rd	0.49	-0.01	0.00
H02	Cnr Wentworth Rd and White St	0.19	-0.01	0.01
H03	Parramatta Rd – Between Shaftesbury Rd and Luke Ave	0.63	0.00	0.00
H04	Cnr Milton St and Archer St	0.69	-0.01	0.01
H05	Meryla St	0.45	0.00	0.01
H06	Cnr Burwood Rd and Park Ave	0.43	-0.01	0.01
H07	Elsie St	0.52	-0.01	0.01
H08	Railway Parade near Wynne Ave	0.49	0.00	0.01
H09	Lucas Rd – Between Parramatta Rd and Stuart St	0.49	-0.02	0.01
H10	Wangal Park	1.50	-0.01	0.01
H11	Cnr Parramatta Rd and Short St	0.55	0.00	0.00
H12	Grogan St	0.48	-0.01	0.01
H13	Wychbury La	0.59	-0.01	0.02

Table 23: Results of Roughness Analysis – Change in Flow

ID	Location	Type	Peak Flow 1% AEP	Difference with 1% AEP (m^3/s)	
				Roughness Decreased by 20%	Roughness Increased by 20%
Q01	Parramatta Rd – From Mosely St and Melbourne St	Overland	8.1	0.3	-0.3
		Pipe	2.3	0.0	0.0
Q02	Cnr Wentworth Rd and Nixon La	Overland	1.5	0.0	-0.1
		Pipe	1.1	0.0	0.0
Q03	Parramatta Rd – From Loftus St to Taylor St	Overland	19.2	1.7	-1.3
		Pipe	16.3	-0.9	0.3
Q04	Shaftesbury Rd – Between Milton St and Parramatta Rd	Overland	15.0	1.0	-1.0
		Pipe	9.9	-0.2	0.0
Q05	New Street	Overland	14.4	0.7	-0.6
		Pipe	5.8	-0.5	-0.1
Q06	Cnr Burwood Rd and Wilga St	Overland	7.9	0.2	-0.2
		Pipe	3.1	0.1	0.0
Q07	Elsie St	Overland	1.9	0.0	0.0
		Pipe	2.6	0.0	0.0
Q08	Railway Embankment (Railway Parade)	Overland	0.0	0.0	0.0
		Pipe	2.4	-0.1	0.1
Q09	Lucas Rd – Between Parramatta Rd and Stuart St	Overland	5.6	0.3	-0.3
		Pipe	2.1	0.0	0.0
Q10	Wangal Park	Overland	0.0	0.0	0.0
		Pipe	0.2	0.0	0.0
Q11	Parramatta Rd – Between Royce Ave and Lang St	Overland	11.1	0.6	-0.5
		Pipe	3.5	0.0	0.0
Q12	Grogan St	Overland	9.4	0.2	-0.2
		Pipe	0.9	0.0	0.0
Q13	Wychbury La	Overland	1.1	0.0	0.0
		Pipe	0.3	0.0	0.0

8.3.2. Routing Variations

Overall peak flood level results were shown to be relatively insensitivity to variations in the routing parameter. Generally, these results were found to be within ± 0.05 m.

Table 24: Results of Routing Analysis – Change in Levels

ID	Location	Peak Flood Depth 1% AEP	Difference with 1% AEP (m)	
			Routing Decreased by 20%	Routing Increased by 20%
H01	Parramatta Rd – Between Philip St and Wentworth Rd	0.49	0.00	0.00
H02	Cnr Wentworth Rd and White St	0.19	0.00	0.00
H03	Parramatta Rd – Between Shaftesbury Rd and Luke Ave	0.63	0.00	0.00
H04	Cnr Milton St and Archer St	0.69	0.00	0.00
H05	Meryla St	0.45	0.00	0.00
H06	Cnr Burwood Rd and Park Ave	0.43	0.00	0.00
H07	Elsie St	0.52	0.00	0.00
H08	Railway Parade near Wynne Ave	0.49	0.00	0.00
H09	Lucas Rd – Between Parramatta Rd and Stuart St	0.49	0.00	0.00
H10	Wangal Park	1.50	0.00	0.00
H11	Cnr Parramatta Rd and Short St	0.55	0.00	-0.01
H12	Grogan St	0.48	0.00	0.00
H13	Wychbury La	0.59	0.01	-0.01

Table 25: Results of Routing Analysis – Change in Flow

ID	Location	Type	Peak Flow 1% AEP	Difference with 1% AEP (m^3/s)	
				Routing Decreased by 20%	Routing Increased by 20%
Q01	Parramatta Rd – From Mosely St and Melbourne St	Overland	8.1	-0.3	0.2
		Pipe	2.3	0.0	0.0
Q02	Cnr Wentworth Rd and Nixon La	Overland	1.5	-0.1	0.1
		Pipe	1.1	0.0	0.0
Q03	Parramatta Rd – From Loftus St to Taylor St	Overland	19.2	-1.3	0.1
		Pipe	16.3	0.3	-0.4
Q04	Shaftesbury Rd – Between Milton St and Parramatta Rd	Overland	15.0	-1.0	0.1
		Pipe	9.9	0.0	0.1
Q05	New Street	Overland	14.4	-0.6	0.2
		Pipe	5.8	-0.1	-0.1
Q06	Cnr Burwood Rd and Wilga St	Overland	7.9	-0.2	0.2
		Pipe	3.1	0.0	0.0
Q07	Elsie St	Overland	1.9	0.0	0.0
		Pipe	2.6	0.0	0.0
Q08	Railway Embankment (Railway Parade)	Overland	0.0	0.0	0.0
		Pipe	2.4	0.1	0.1
Q09	Lucas Rd – Between Parramatta Rd and Stuart St	Overland	5.6	-0.3	0.1
		Pipe	2.1	0.0	0.0
Q10	Wangal Park	Overland	0.0	0.0	0.0
		Pipe	0.2	0.0	0.0
Q11	Parramatta Rd – Between Royce Ave and Lang St	Overland	11.1	-0.5	0.3
		Pipe	3.5	0.0	0.0
Q12	Grogan St	Overland	9.4	-0.2	0.2
		Pipe	0.9	0.0	0.0
Q13	Wychbury La	Overland	1.1	0.0	0.0
		Pipe	0.3	0.0	0.0

8.3.3. Blockage Variations

Peak flood level results were found to be relatively insensitive to blockage of pipes, with the exclusion of Railway Parade and Wangal Park.

Railway Parade is a trapped low point and the pits and pipes are the sole means of discharge from this area (as discussed in Section 10.5), therefore blockage of pipes resulted in increased peak flood levels.

In the case of Wangal Park, the area was designed to function as a detention basin; with inflows from pits and pipes diverting flow into this location as well as local runoff. Outflows from Wangal Park occur predominantly via pipes, with the exclusion of the PMF event in which the detention basin is overtopped and overland flow occurs (as shown in Table 21). Therefore, in the pipe blockage scenario the decrease in outflows exceeds the decrease in inflows and resulted in increased peak flood levels.

Table 26: Results of Blockage Analysis – Change in Level

ID	Location	Peak Flood Depth 1% AEP	Difference with 1% AEP (m)	
			Blockage (Pipes) by 20%	Blockage (Pipes) by 50%
H01	Parramatta Rd – Between Philip St and Wentworth Rd	0.49	0.01	0.03
H02	Cnr Wentworth Rd and White St	0.19	0.00	0.01
H03	Parramatta Rd – Between Shaftesbury Rd and Luke Ave	0.63	0.02	0.06
H04	Cnr Milton St and Archer St	0.69	0.02	0.05
H05	Meryla St	0.45	0.01	0.02
H06	Cnr Burwood Rd and Park Ave	0.43	0.02	0.06
H07	Elsie St	0.52	0.03	0.06
H08	Railway Parade near Wynne Ave	0.49	0.03	0.12
H09	Lucas Rd – Between Parramatta Rd and Stuart St	0.49	0.02	0.04
H10	Wangal Park	1.50	0.08	0.20
H11	Cnr Parramatta Rd and Short St	0.55	0.01	0.03
H12	Grogan St	0.48	0.00	0.01
H13	Wychbury La	0.59	0.02	0.04

Table 27: Results of Blockage Analysis – Change in Flow

ID	Location	Type	Peak Flow 1% AEP	Difference with 1% AEP (m^3/s)	
				Blockage (Pipes) by 20%	Blockage (Pipes) by 50%
Q01	Parramatta Rd – From Mosely St and Melbourne St	Overland	8.1	0.5	1.4
		Pipe	2.3	-0.4	-1.2
Q02	Cnr Wentworth Rd and Nixon La	Overland	1.5	0.2	0.5
		Pipe	1.1	-0.2	-0.5
Q03	Parramatta Rd – From Loftus St to Taylor St	Overland	19.2	1.9	5.6
		Pipe	16.3	-3.5	-8.1
Q04	Shaftesbury Rd – Between Milton St and Parramatta Rd	Overland	15.0	1.3	3.7
		Pipe	9.9	-2.0	-5.0
Q05	New Street	Overland	14.4	0.4	1.3
		Pipe	5.8	-1.3	-2.8
Q06	Cnr Burwood Rd and Wilga St	Overland	7.9	0.5	1.7
		Pipe	3.1	-0.6	-1.5
Q07	Elsie St	Overland	1.9	0.3	0.6
		Pipe	2.6	-0.5	-1.3
Q08	Railway Embankment (Railway Parade)	Overland	0.0	0.0	0.0
		Pipe	2.4	-0.2	-0.6
Q09	Lucas Rd – Between Parramatta Rd and Stuart St	Overland	5.6	0.4	1.2
		Pipe	2.1	-0.4	-1.1
Q10	Wangal Park	Overland	0.0	0.0	0.0
		Pipe	0.2	-0.1	-0.1
Q11	Parramatta Rd – Between Royce Ave and Lang St	Overland	11.1	0.6	1.7
		Pipe	3.5	-0.7	-1.8
Q12	Grogan St	Overland	9.4	0.1	0.4
		Pipe	0.9	-0.2	-0.5
Q13	Wychbury La	Overland	1.1	0.1	0.2
		Pipe	0.3	-0.1	-0.2

8.3.4. Climate Variations

The effect of increasing the design rainfalls by 10%, 20% and 30% has been evaluated for the 1% AEP rainfall event with impacts on peak flood levels observed throughout the study area; with the greatest increases occurring in flood storage areas such as Wangal Park, Concord Oval and Spencer Avenue Five Dock. Generally speaking, each incremental 10% increase in rainfall results in an approximately 0.1 m increase in peak flood levels at the more sensitive locations analysed. The 1% AEP event with a rainfall increase of 30% is approximately equivalent to a 0.2% AEP event in present day conditions and an impact on flood levels is not unexpected.

The sea level rise scenarios were found not to have a significant effect on peak flood levels upstream of Parramatta Road. Downstream of Parramatta Road, areas found to be sensitive to sea level rise were the St Lukes open channel, William Street, Spencer Street and Queens Road Five Dock.

Table 28: Results of Climate Change Analysis – Change in Level

ID	Location	Peak Flood Depth 1% AEP	Difference with 1% AEP (m)				
			Rainfall Increase 10%	Rainfall Increase 20%	Rainfall Increase 30%	2050 Sea Level Rise + 0.4 m	2100 Sea Level Rise + 0.9 m
H01	Parramatta Rd – Between Philip St and Wentworth Rd	0.49	0.03	0.05	0.08	0.00	0.00
H02	Cnr Wentworth Rd and White St	0.19	0.01	0.03	0.03	0.00	0.00
H03	Parramatta Rd – Between Shaftesbury Rd and Luke Ave	0.63	0.05	0.09	0.13	0.00	0.00
H04	Cnr Milton St and Archer St	0.69	0.05	0.10	0.14	0.00	0.00
H05	Meryla St	0.45	0.03	0.06	0.08	0.00	0.00
H06	Cnr Burwood Rd and Park Ave	0.43	0.04	0.08	0.12	0.00	0.00
H07	Elsie St	0.52	0.03	0.06	0.08	0.00	0.00
H08	Railway Parade near Wynne Ave	0.49	0.07	0.14	0.21	0.00	0.00
H09	Lucas Rd – Between Parramatta Rd and Stuart St	0.49	0.04	0.07	0.10	0.00	0.00
H10	Wangal Park	1.50	0.13	0.26	0.37	0.00	0.00
H11	Cnr Parramatta Rd and Short St	0.55	0.03	0.06	0.09	0.00	0.01
H12	Grogan St	0.48	0.02	0.04	0.06	0.00	0.00
H13	Wychbury La	0.59	0.04	0.08	0.12	0.00	0.00

Table 29: Results of Climate Change Analysis (Rainfall Increase) – Change in Flow

ID	Location	Type	Peak Flow 1% AEP	Difference with 1% AEP (m^3/s)		
				Rainfall Increase 10%	Rainfall Increase 20%	Rainfall Increase 30%
Q01	Parramatta Rd – From Mosely St and Melbourne St	Overland	8.1	1.4	2.8	4.1
		Pipe	2.3	0.0	0.0	0.1
Q02	Cnr Wentworth Rd and Nixon La	Overland	1.5	0.3	0.5	0.8
		Pipe	1.1	0.0	0.1	0.1
Q03	Parramatta Rd – From Loftus St to Taylor St	Overland	19.2	4.3	8.3	12.5
		Pipe	16.3	-0.7	-0.4	-0.2
Q04	Shaftesbury Rd – Between Milton St and Parramatta Rd	Overland	15.0	3.0	6.2	9.5
		Pipe	9.9	0.0	0.0	0.1
Q05	New Street	Overland	14.4	2.4	5.0	7.4
		Pipe	5.8	-0.1	-0.1	0.0
Q06	Cnr Burwood Rd and Wilga St	Overland	7.9	1.4	2.8	4.3
		Pipe	3.1	0.1	0.1	0.2
Q07	Elsie St	Overland	1.9	0.3	0.7	1.0
		Pipe	2.6	0.0	0.0	0.0
Q08	Railway Embankment (Railway Parade)	Overland	0.0	0.0	0.0	0.0
		Pipe	2.4	0.2	0.3	0.4
Q09	Lucas Rd – Between Parramatta Rd and Stuart St	Overland	5.6	1.1	2.1	3.1
		Pipe	2.1	0.0	0.0	0.1
Q10	Wangal Park	Overland	0.0	0.0	0.0	0.0
		Pipe	0.2	0.0	0.0	0.0
Q11	Parramatta Rd – Between Royce Ave and Lang St	Overland	11.1	1.8	3.6	5.4
		Pipe	3.5	0.0	0.0	0.0
Q12	Grogan St	Overland	9.4	1.1	2.3	3.6
		Pipe	0.9	0.0	0.0	0.0
Q13	Wychbury La	Overland	1.1	0.2	0.3	0.5
		Pipe	0.3	0.0	0.0	0.0

Table 30: Results of Climate Change Analysis (Sea Level Rise) – Change in Flow

ID	Location	Type	Peak Flow 1% AEP	Difference with 1% AEP (m^3/s)	
				2050 Sea Level Rise + 0.4 m	2100 Sea Level Rise + 0.9 m
Q01	Parramatta Rd – From Mosely St and Melbourne St	Overland	8.1	0.0	0.0
		Pipe	2.3	0.0	0.0
Q02	Cnr Wentworth Rd and Nixon La	Overland	1.5	0.0	0.0
		Pipe	1.1	0.0	0.0
Q03	Parramatta Rd – From Loftus St to Taylor St	Overland	19.2	-0.1	0.0
		Pipe	16.3	-1.2	-1.1
Q04	Shaftesbury Rd – Between Milton St and Parramatta Rd	Overland	15.0	-0.1	-0.1
		Pipe	9.9	0.0	-0.1
Q05	New Street	Overland	14.4	0.0	0.0
		Pipe	5.8	-0.1	-0.4
Q06	Cnr Burwood Rd and Wilga St	Overland	7.9	0.0	0.0
		Pipe	3.1	0.0	0.0
Q07	Elsie St	Overland	1.9	0.0	0.0
		Pipe	2.6	0.0	0.0
Q08	Railway Embankment (Railway Parade)	Overland	0.0	0.0	0.0
		Pipe	2.4	0.0	0.0
Q09	Lucas Rd – Between Parramatta Rd and Stuart St	Overland	5.6	0.0	0.0
		Pipe	2.1	0.0	0.0
Q10	Wangal Park	Overland	0.0	0.0	0.0
		Pipe	0.2	0.0	0.0
Q11	Parramatta Rd – Between Royce Ave and Lang St	Overland	11.1	0.2	0.5
		Pipe	3.5	-0.1	-0.5
Q12	Grogan St	Overland	9.4	0.0	0.0
		Pipe	0.9	0.0	-0.1
Q13	Wychbury La	Overland	1.1	0.0	0.0
		Pipe	0.3	0.0	0.0

9. PRELIMINARY FLOOD PLANNING AREAS

9.1. Background

Land use planning is considered to be one of the most effective means of minimising flood risk and damages from flooding. The Flood Planning Area (FPA) identifies land that is subject to flood related development controls via Section 149(2) notifications under the 1979 EP&A Act. The Flood Planning Level (FPL) is the minimum floor level applied to new developments within the FPA.

The process of defining FPA's and FPL's is somewhat complicated by the variability of flow conditions between mainstream and local overland flow, particularly in urban areas. The more traditional approaches typically having been developed for riverine environments and mainstream flow.

Defining the area of flood affectation due to overland flow (which by its nature includes shallow flow) often involves determining at which point it becomes significant enough to classify as "flooding". The difference in peak flood level between events of varying magnitude may be minor in areas of overland flow, such that applying the typical freeboard can result in a FPL greater than the Probable Maximum Flood (PMF) level.

The FPA should include properties where future development would result in impacts on flood behaviour in the surrounding area and areas of high hazard that pose a risk to safety or life. Further to this, the FPL is determined with the purpose to decrease the likelihood of over-floor flooding of buildings and the associated damages.

The Floodplain Development Manual suggests that the FPL generally be based on the 1% AEP event plus an appropriate freeboard. The typical freeboard cited in the manual is that of 0.5 m; however it also recognises that different freeboards may be deemed more appropriate due to local conditions. In these circumstances, some justification is called for where a lower value is adopted.

The FPA is classified as 'provisional' as it is based on results from the current study, and may be re-assessed as part of a floodplain risk management study for the catchment. Such a study would review the area's existing planning policies with respect to floodplain management, and then make recommendations (including adoption of a Flood Planning Area and Flood Planning Level) via a floodplain risk management plan. It may also be that the same assessment for the LGA's other catchments be undertaken so that a single LGA-wide FPA/FPL can be adopted.

9.2. Methodology and Criteria

The methodology used in this report is consistent with that adopted in a number of previous studies. It divides flooding between Mainstream flooding and Overland flooding using the following criteria:

- Mainstream flooding: Any percentage of the cadastral area is affected by mainstream flooding in the 1% AEP event. This has been defined as the peak flood level within the open channel section of Dobroyd Canal plus a 0.5 m freeboard, with the level extended perpendicular to the flow direction.
- Overland flooding: Greater than or equal to 10% of the "active" cadastral area is affected by the 1% AEP peak flood depth of greater than 0.15 m. The "active" cadastral area was considered to be the cadastral area excluding the building area that was modelled as impermeable

In situations where a cadastral lot is subject to both mainstream flooding and overland flooding, the mechanism that produces the highest Flood Planning Level is given precedence, although both levels have been provided.

Furthermore, a "ground truthing" exercise was undertaken to ensure that the properties identified as subject to flood related development controls were located within a continuous flow path area.

9.3. Results

The provisional FPA is shown on Figure 28. The mainstream flood affectation was limited to the Canada Bay LGA (not reported herein); with only overland flood affectation within the Burwood LGA portion of the study area.

A total of 278 properties were tagged for flood related development controls in the study area. This results in total averages of 1.7 properties per hectare for the study area. This value was consistent with those obtained in adjacent urban catchments.

Properties that are not tagged as part of this process may not be excluded from development controls. It is advisable that new developments (regardless of whether they are tagged as flood liable or not) have habitable floor levels a minimum of 300 mm above the surrounding ground level to minimise affectation due to local overland flow

10. DISCUSSION

Various locations were identified as "hotspots" or "areas of interest" with the study area. These locations were identified based upon flood behaviour occurring at ground level. The above floor liability of these locations has not yet been determined due to a lack of surveyed floor levels at this stage. However, some over floor liability is likely at some of these locations.

10.1. Parramatta Road / Short Street, Croydon

The intersection of Parramatta Road and Short Street is located on the boundary between the Burwood LGA and the City of Canada Bay LGA. The area is a topographical low point exacerbated with buildings obstructing flow and tidally affected areas in close proximity, immediately downstream. The contributing catchment area is approximately 30 ha.

Two trapezoidal pipes, each with a cross-sectional area of approximately 1.1 m^2, convey flow across Parramatta Road. The capacity of these pipes and the surrounding pipes in this location was found to be less than a 5 year ARI event. The peak flows within the pipe and the overland flow path across Parramatta Road are provided in Table 31.

Table 31: Parramatta Road/Short Street – Peak Flow (m^3/s)

ID	Location	Type	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Q11	Parramatta Rd – Between Royce Ave and Lang St	Overland	3.5	5.3	7.5	9.3	11.1	60.8
		Pipe	3.4	3.4	3.5	3.5	3.5	3.6

The peak flood depths and levels at this location are shown in Table 32.

Table 32: Parramatta Road/Short Street – Peak Flood Depths (m) and Levels (m AHD)

ID	Location	Type	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	PMF
H11	Cnr Parramatta Rd and Short St	Depth	0.44	0.47	0.50	0.52	0.55	1.21
		Level	3.91	3.94	3.97	3.99	4.02	4.68

10.2. Parramatta Road / Concord Oval

Parramatta Road, between Shaftesbury Road and Bennett Street, is a topographic low point at the confluence of two flow paths. The upstream flow paths originate from the south-east and south-west; with a contributing catchment area of approximately 31 ha and 88 ha respectively. Downstream of Parramatta Road, the flow is conveyed north primarily via the open channel.

The Hockey Complex to the east of the open channel has a ridge parallel to Parramatta Road; in some locations 2.4 m higher than the road elevation. Concord Oval to the west of the open channel has a similar ridge; in some locations 1.5 m higher than the road elevation. The combined effect of these ridges is to constrict flow exiting Parramatta Road to the open channel and to a small gully into Concord Oval (located at the south-east corner of the Oval). Flow that enters Concord Oval is retained there, as the Oval acts as a detention basin. In extreme events, such as the PMF event, alternative flow paths form along the eastern boundary of the Hockey Complex and along the western boundary of Concord Oval.

The peak flood depths and levels at this location are shown in Table 33.

Table 33: Parramatta Road / Concord Oval – Peak Flood Depths (m) and Levels (m AHD)

ID	Location	Type	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	PMF
H03	Parramatta Rd – Between Shaftesbury Rd and Luke Ave	Depth	0.40	0.45	0.51	0.58	0.63	1.31
		Level	4.17	4.22	4.29	4.35	4.40	5.08

Two Sydney Water stormwater pipes convey flow across Parramatta Road. The pipe adjacent to Luke Avenue was U-shaped with a height of 1.37 m and a maximum width of 2.67 m. The pipe located between Shaftesbury Road and Loftus was mostly rectangular shaped with a maximum height of 1.37 m and a maximum width of 3.35 m. The peak flows within the pipes and the overland flow path across Parramatta Road are provided in Table 34.

Table 34: Parramatta Road / Concord Oval – Peak Flows (m^3/s)

ID	Location	Type	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Q03	Parramatta Rd – From Loftus St to Taylor St	Overland	4.6	6.8	10.4	15.1	19.2	141.6
		Pipe	13.1	13.9	15.0	15.5	16.3	17.8

10.3. Parramatta Road / Wentworth Road

Parramatta Road between Wentworth Road and Philip Street is located in a topographic low point. The contributing catchment area is approximately 24 ha.

One 1.05 m diameter pipe conveys flow across Parramatta Road. The capacity of this pipe and the surrounding pipes in this location was found to be less than a 5 year ARI event. The peak flows within the pipe and the overland flow path across Parramatta Road are provided in Table 35.

Table 35: Parramatta Road / Wentworth Road – Peak Flows (m^3/s)

ID	Location	Type	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Q01	Parramatta Rd – From Mosely St and Melbourne St	Overland	2.3	3.6	5.3	6.6	8.1	45.4
		Pipe	2.1	2.2	2.2	2.2	2.3	2.7

The peak flood depths and levels at this location are shown in Table 36.

Table 36: Parramatta Road/Wentworth Road – Peak Flood Depths (m) and Levels (m AHD)

ID	Location	Type	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	PMF
H01	Parramatta Rd – Between Philip St and Wentworth Rd	Depth	0.32	0.37	0.42	0.45	0.49	0.93
		Level	15.26	15.30	15.35	15.39	15.43	15.86

10.4. Shaftesbury Road / Burwood Road

From the Burwood Road – Meryla Street intersection to the Shaftesbury Road – Parramatta Road intersection, flow occurs in a north-east direction and often through private property. Where buildings intersect the flow path, flood water accumulates on the upstream side.

The pipe sizes vary across this area and include divergent amplification within the roadway area. Some sections of this drainage network are operating at capacity in events up to and including the 5 year ARI event. During the PMF event, all pipes within this area were operating at capacity. The peak flows within select pipes and overland flow paths in this area are provided in Table 37.

Table 37: Shaftesbury Road / Burwood Road – Peak Flows (m^3/s)

ID	Location	Type	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Q04	Shaftesbury Rd – Between Milton St and Parramatta Rd	Overland	4.5	6.2	8.9	12.0	15.0	95.8
		Pipe	8.8	9.0	9.9	9.7	9.9	10.2
Q05	New Street	Overland	6.0	7.6	9.9	12.1	14.4	79.7
		Pipe	5.3	5.2	5.6	5.7	5.8	7.0
Q06	Cnr Burwood Rd and Wilga St	Overland	3.7	4.6	5.8	6.5	7.9	46.5
		Pipe	2.9	3.0	3.1	3.1	3.1	4.1

The peak flood depths at select locations are shown in Table 38.

Table 38: Shaftesbury Road / Burwood Road – Peak Flood Depths (m)

ID	Location	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	PMF
H04	Cnr Milton St and Archer St	0.44	0.50	0.57	0.64	0.69	1.62
H05	Meryla St	0.33	0.36	0.39	0.42	0.45	0.93
H06	Cnr Burwood Rd and Park Ave	0.29	0.32	0.36	0.39	0.43	1.18

10.5. Railway Parade

Railway Parade (near the junction with Wynne Avenue) is a trapped low point. The railway embankment located to the north and downstream of Railway Parade prevents flow from discharging overland from this location. The BCC-owned stormwater pipes through the railway embankment are the primary means of drainage.

The railway embankment is approximately 5.5 m higher than the roadway at the lowest point. Alternate overland flow paths to the east (where Burwood Road cuts into the embankment) and to the west (where the road becomes level with the railway tracks), are 3.8 m and 2.3 m higher than the lowest point on Railway Parade.

The contributing catchment area is approximately 8 ha. A stormwater pipe with a diameter of 1.35 m conveys flow through the railway embankment, as shown in Table 39. This pipe is not directly connected to an inlet pit, but accepts flow from four pipes with inlet pits along Railway Parade. These feeder pipes include a 1.35 m diameter pipe, a 600 mm diameter pipe and two 450 mm diameter pipes.

Table 39: Railway Parade – Peak Flows (m^3/s)

ID	Location	Type	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Q08	Railway Embankment (Railway Parade)	Overland	0.0	0.0	0.0	0.0	0.0	0.0
		Pipe	1.8	2.0	2.1	2.2	2.4	4.2

The peak flood depths and levels at this location are shown in Table 40. In the PMF event, the peak flood depth is less than the elevation difference that would allow alternative overland flow paths to be activated.

Table 40: Railway Parade – Peak Flood Depths (m) and Levels (m AHD)

ID	Location	Type	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	PMF
H08	Railway Parade near Wynne Ave	Depth	0.36	0.39	0.43	0.46	0.49	2.14
		Level	19.20	19.24	19.27	19.30	19.33	20.99

11. ACKNOWLEDGEMENTS

WMAwater wish to acknowledge the assistance of Burwood City Council staff in carrying out this study, the NSW Government (Office of Environment and Heritage) and the residents of the Exile Bay, St Lukes and William Street Catchments. This study was jointly funded by Burwood Council and the NSW Government.

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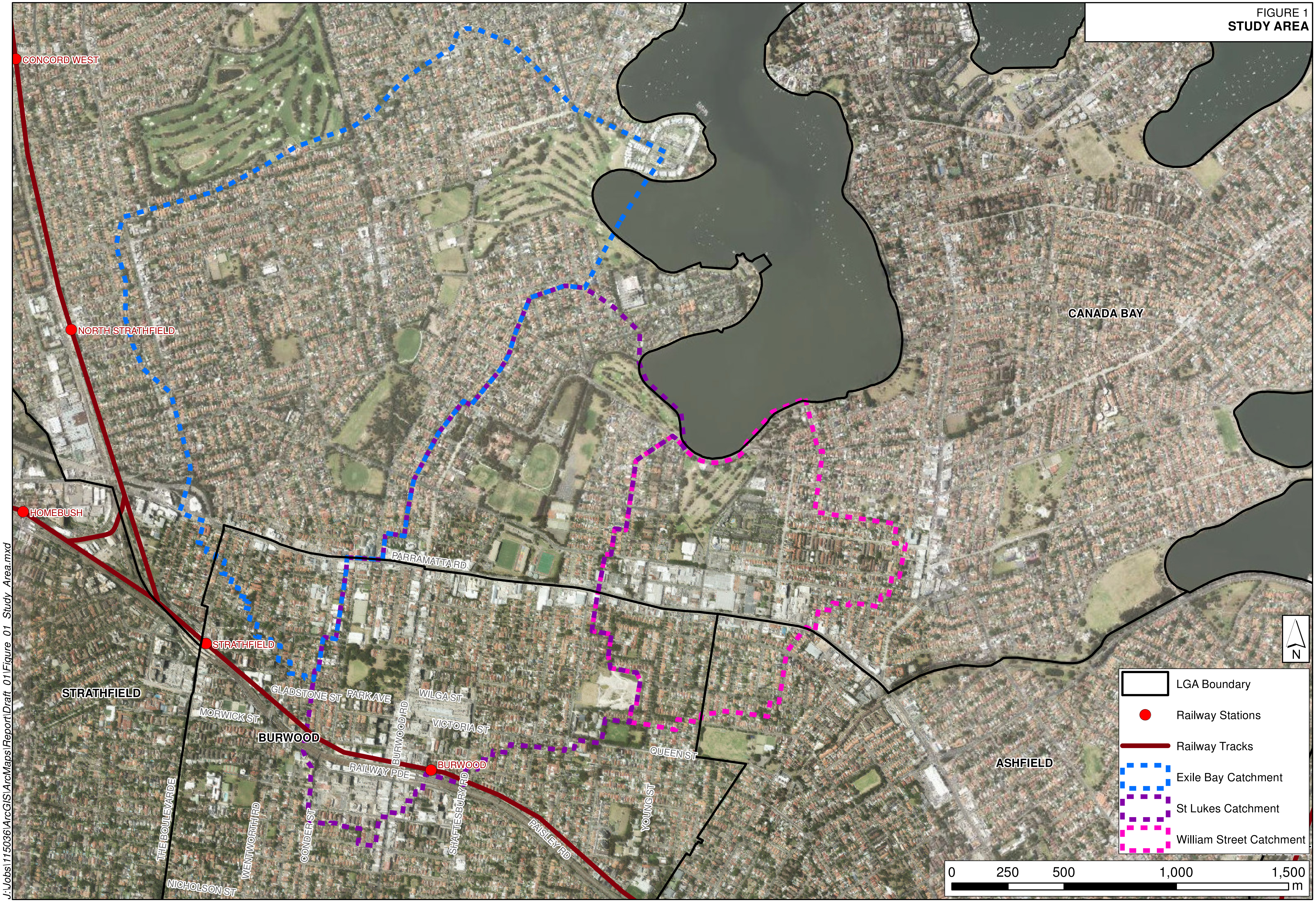
Figures

FIGURE 1
STUDY AREA



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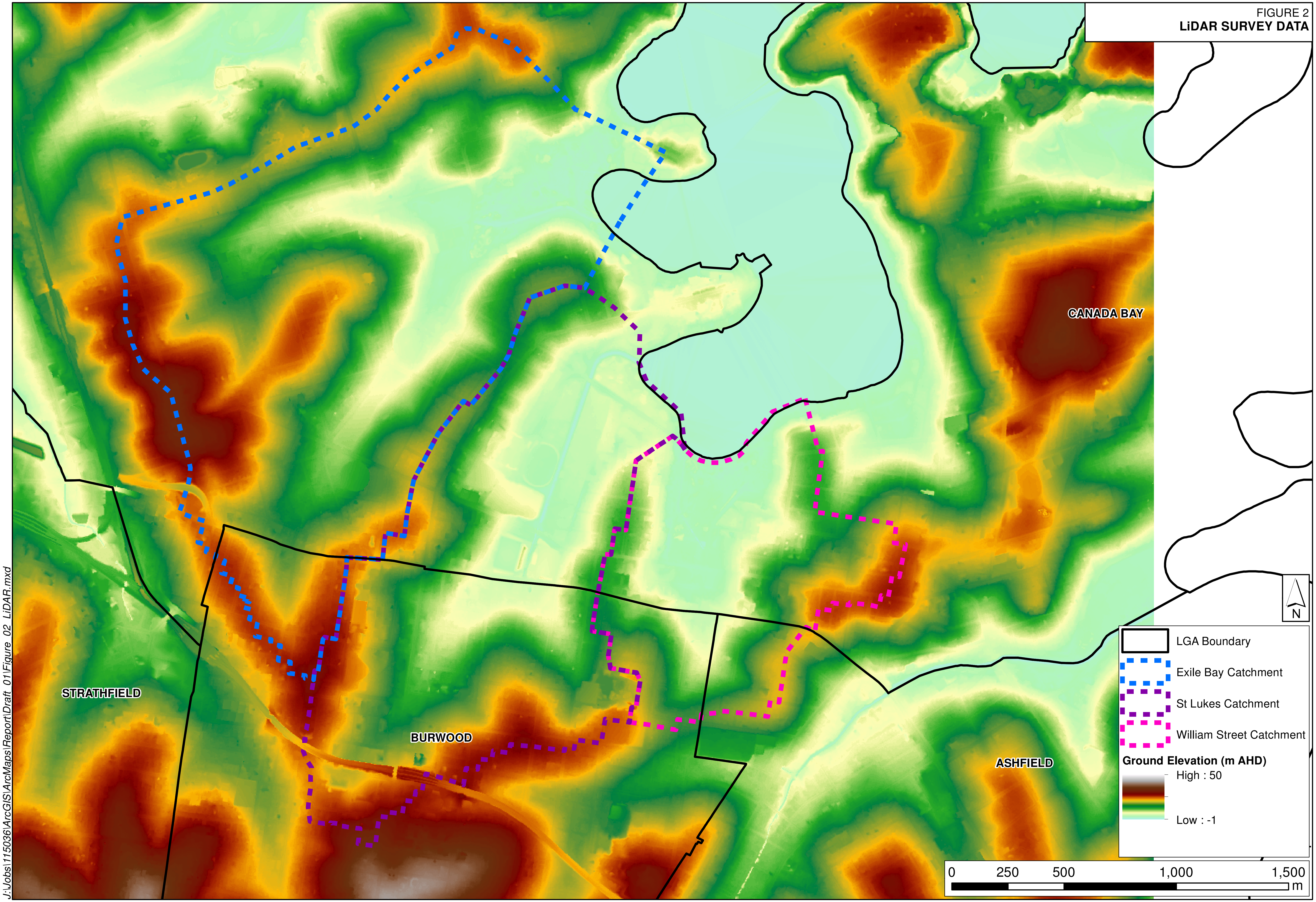

FIGURE 2
LiDAR SURVEY DATA
CANADA BAY
STRATHFIELD
BURWOOD
ASHFIELD
N
LGA Boundary
Exile Bay Catchment
St Lukes Catchment
William Street Catchment
Ground Elevation (m AHD)
High : 50
Low : -1
0
250
500
1,000
1,500
m
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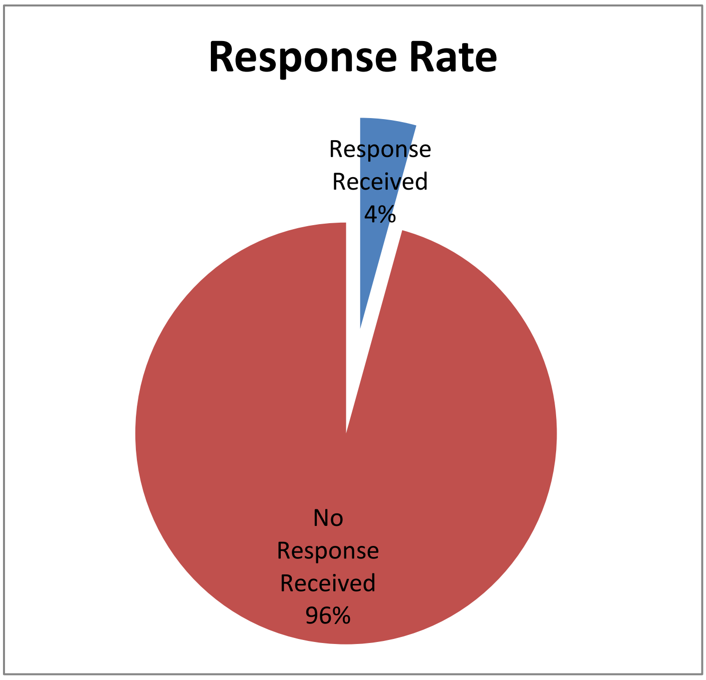
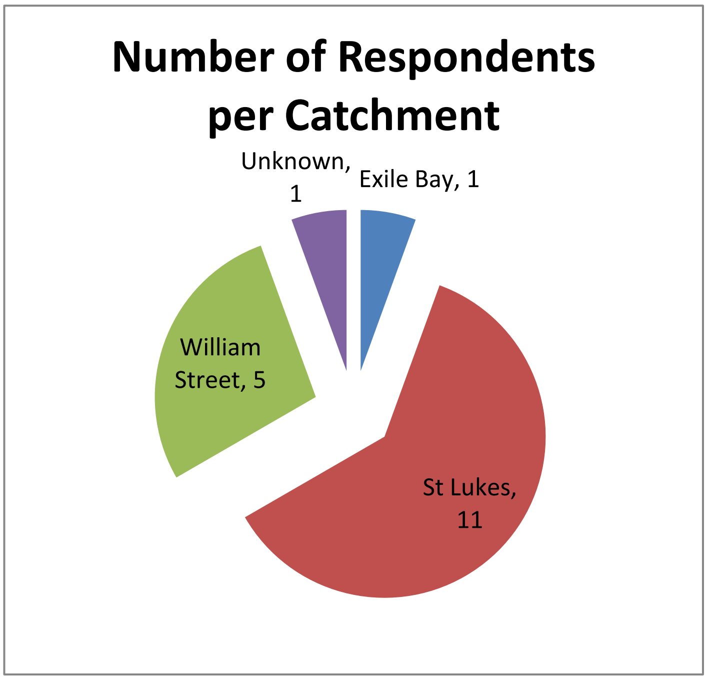
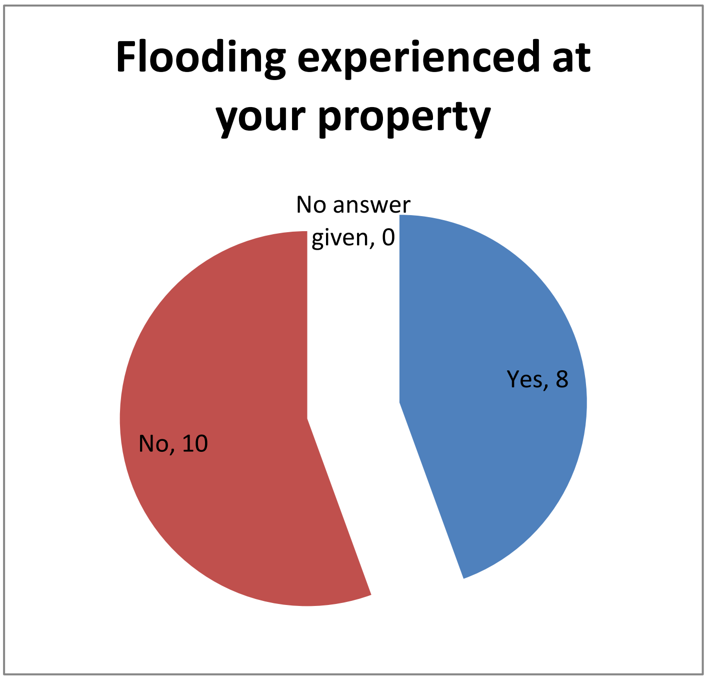
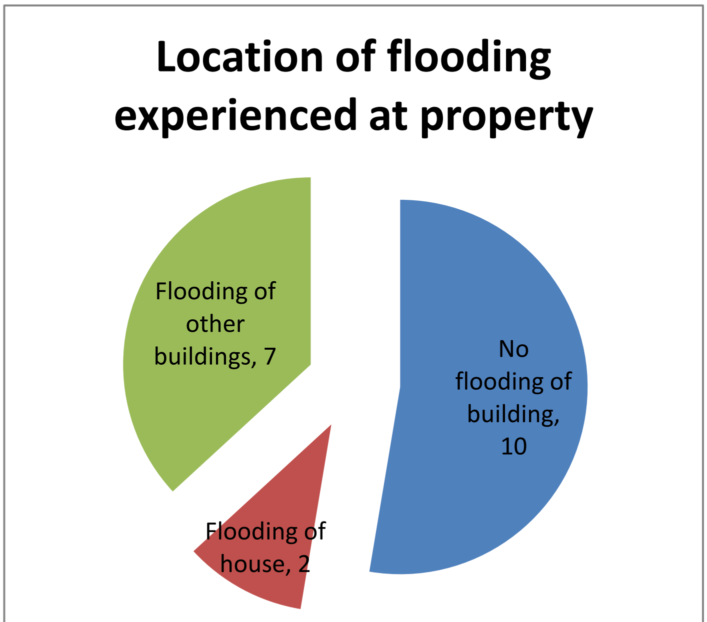
FIGURE 3
SUMMARY OF COMMUNITY CONSULTATION STATISTICAL ANAYLSIS









Note: Responses may have experienced both flooding of other buildings and flooding of house

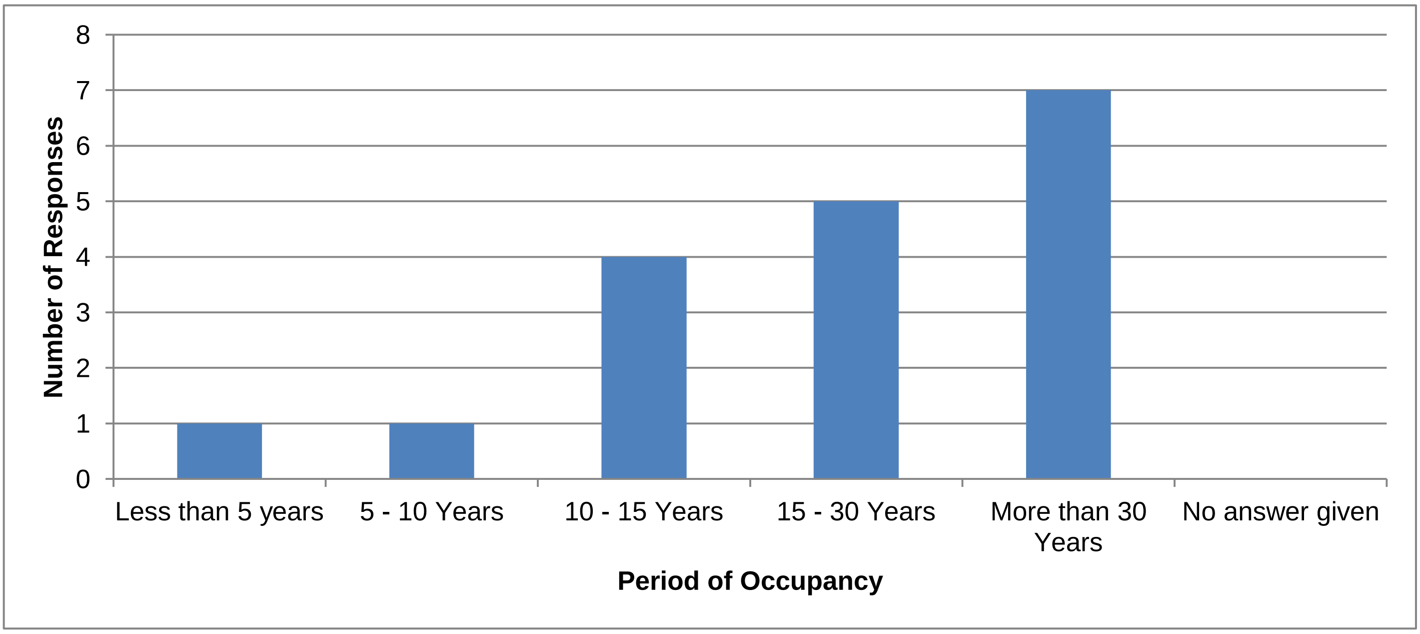


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FIGURE 5
RAINFALL GAUGE LOCATIONS

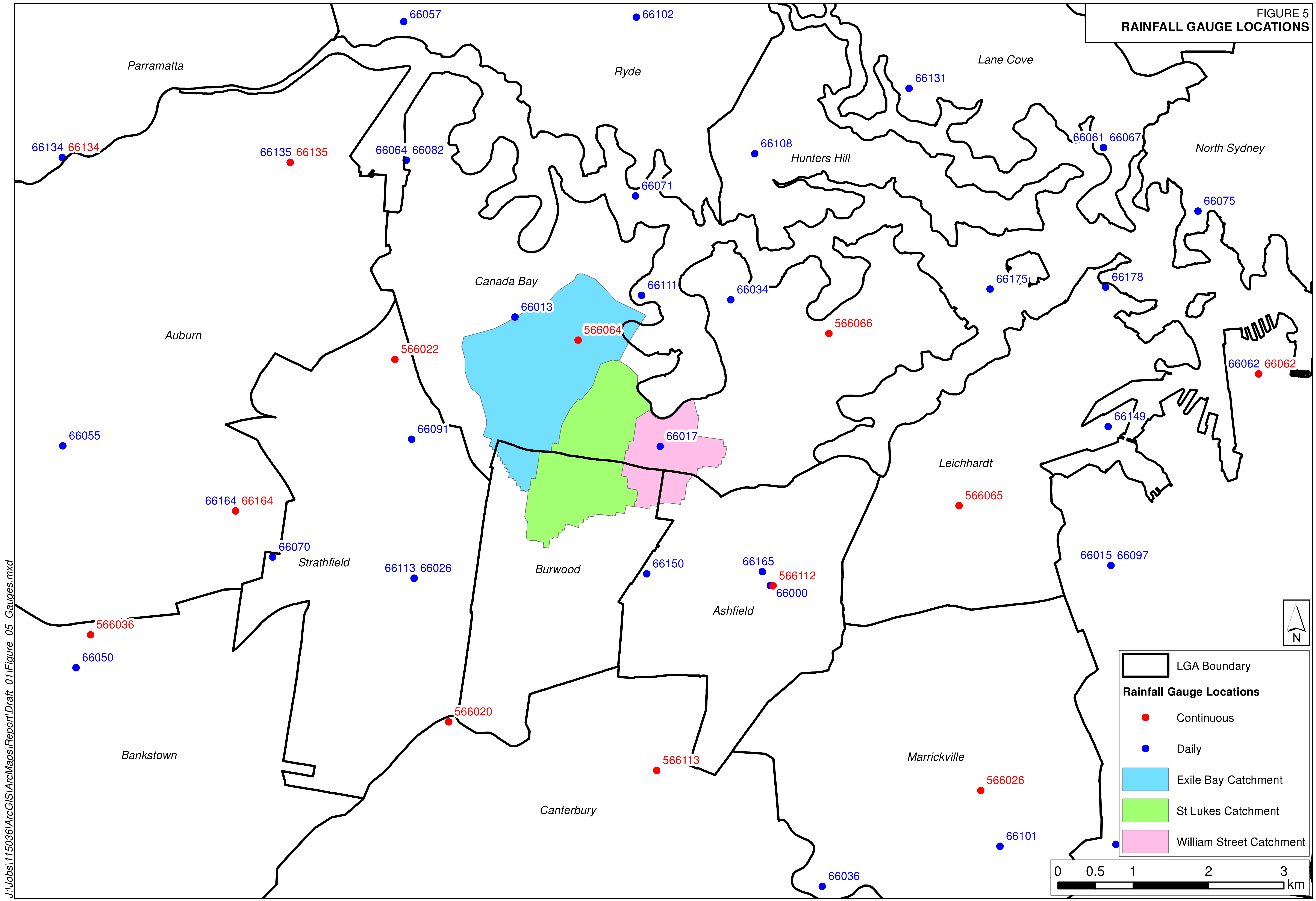

FIGURE 6
HYDROLOGIC MODEL SCHEMATISATION

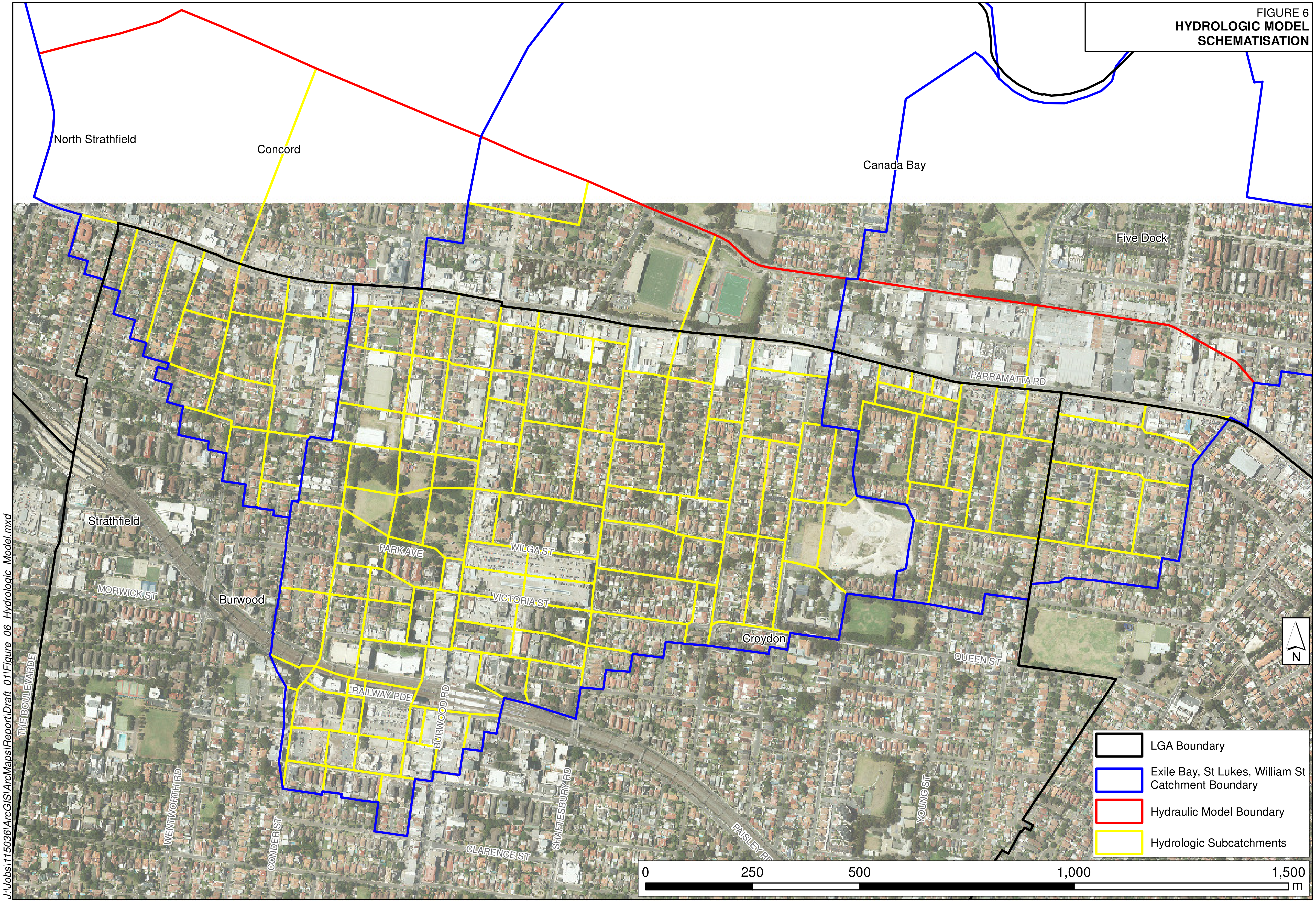

FIGURE 7
HYDRAULIC MODEL SCHEMATISATION

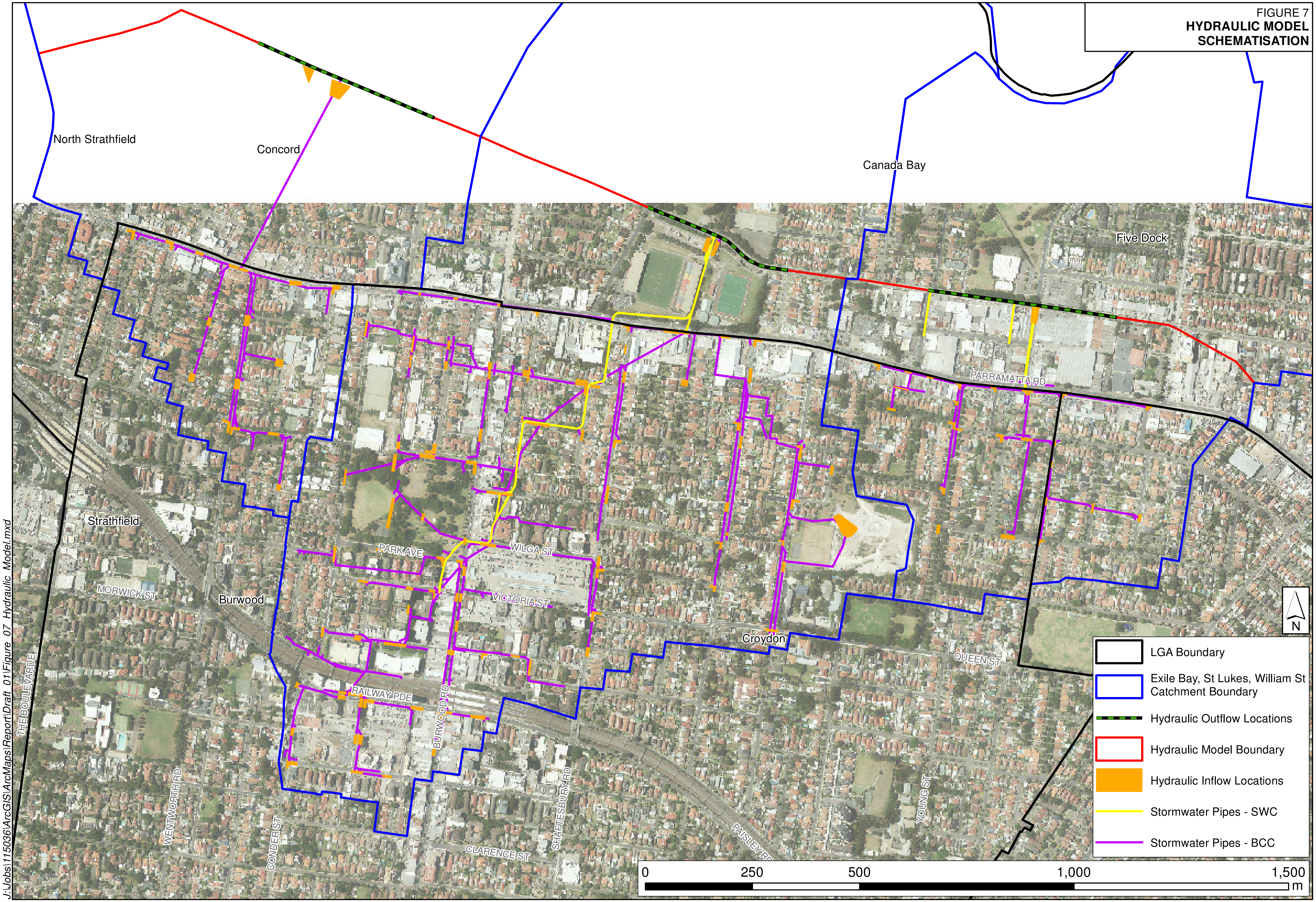

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FIGURE 8
HYDRAULIC MODEL ROUGHNESS VALUES

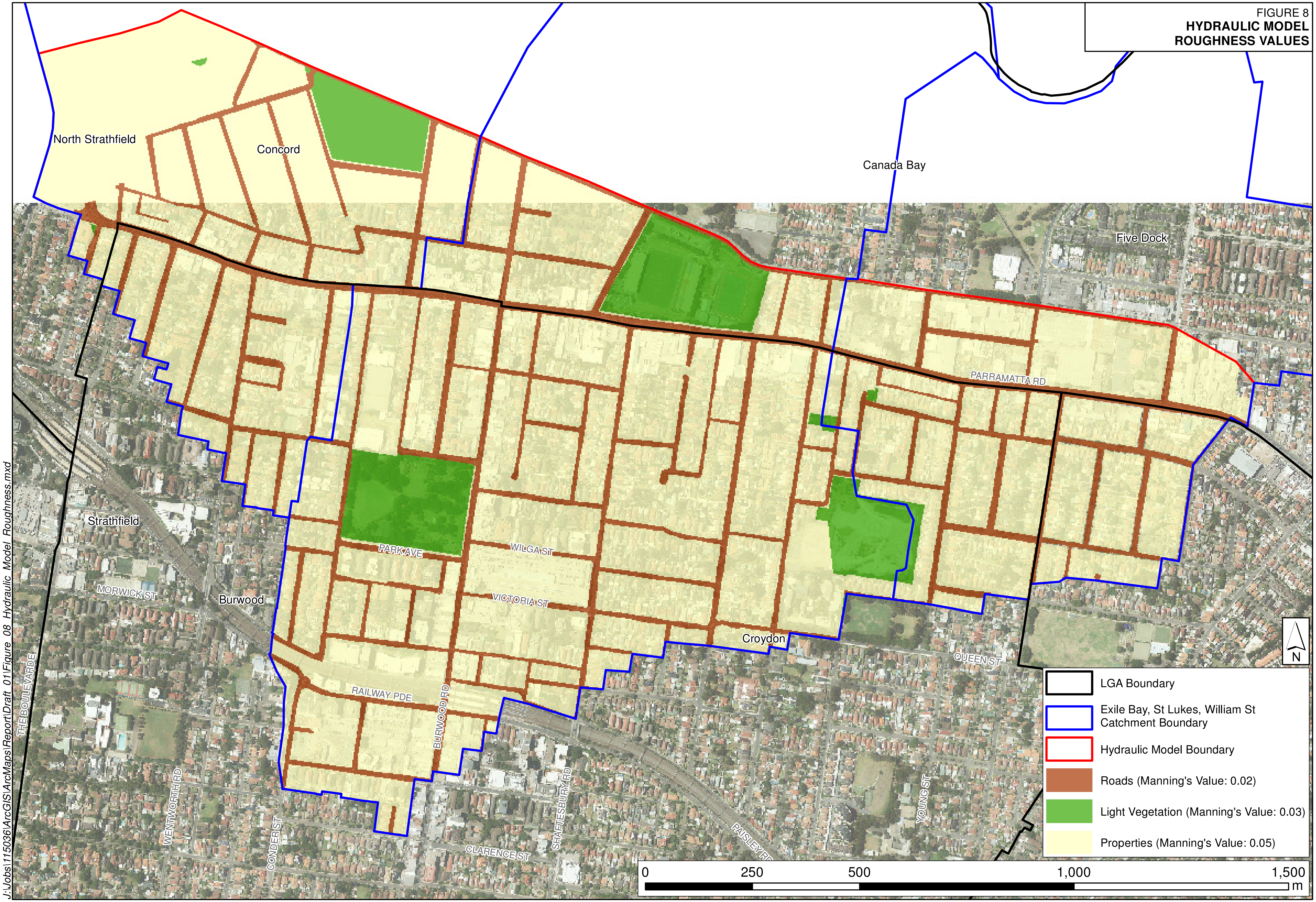


FIGURE 9
RESULTS LAYOUT

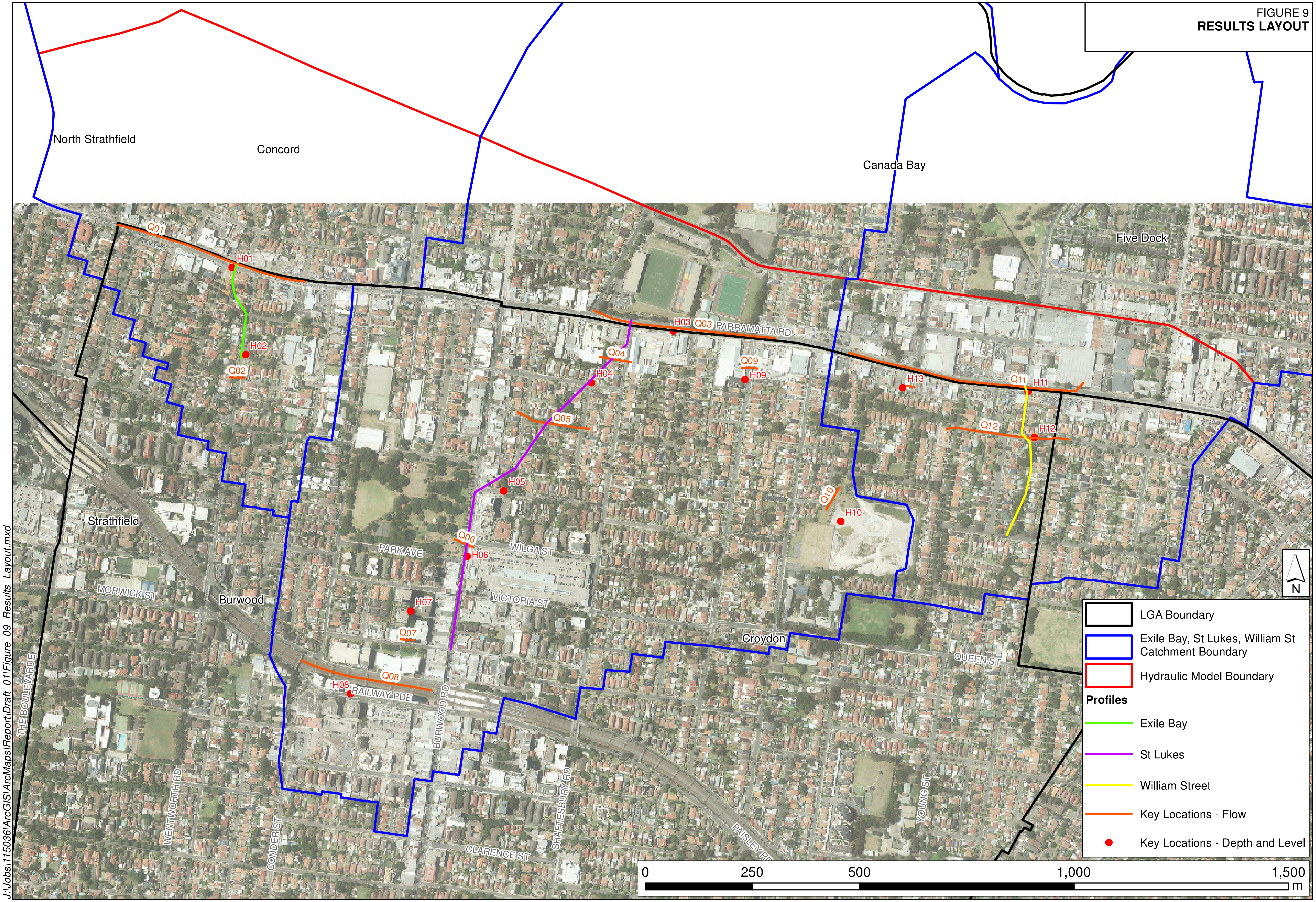
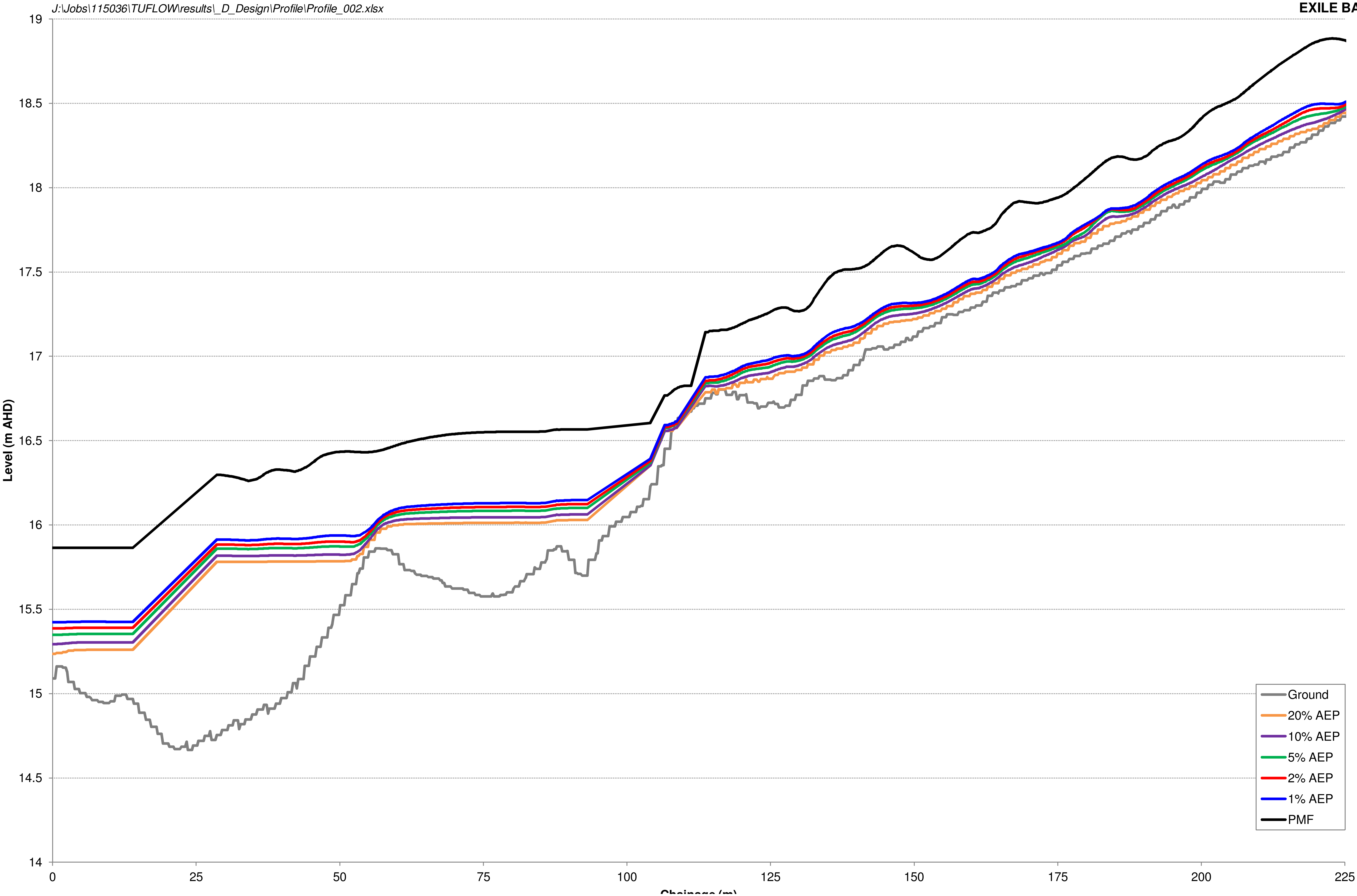


FIGURE 10A
PEAK FLOOD LEVEL PROFILE
EXILE BAY



PEAK FLOOD LEVEL PROFILE
ST LUKES

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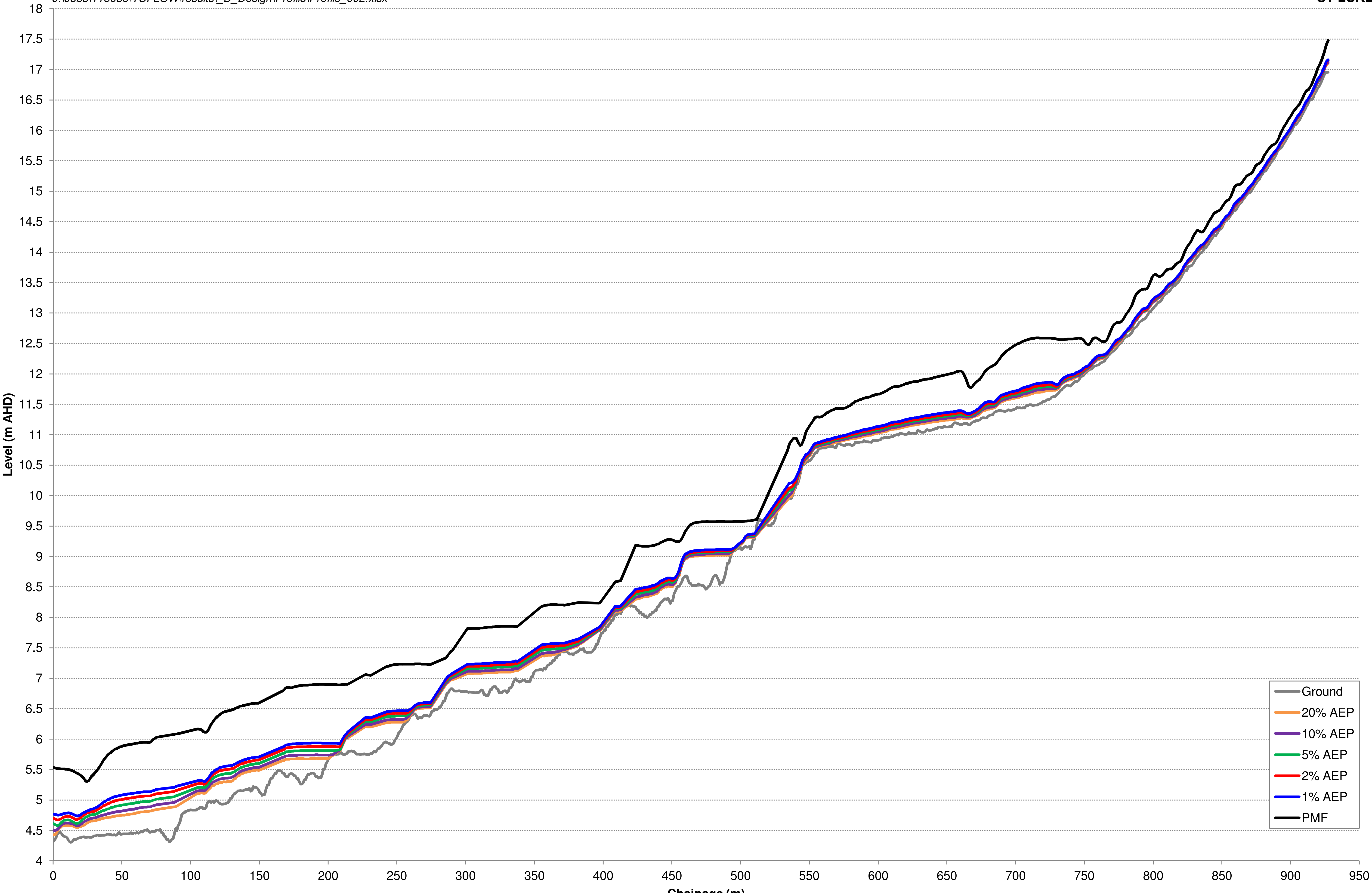

FIGURE 10C
PEAK FLOOD LEVEL PROFILE
WILLIAM STREET

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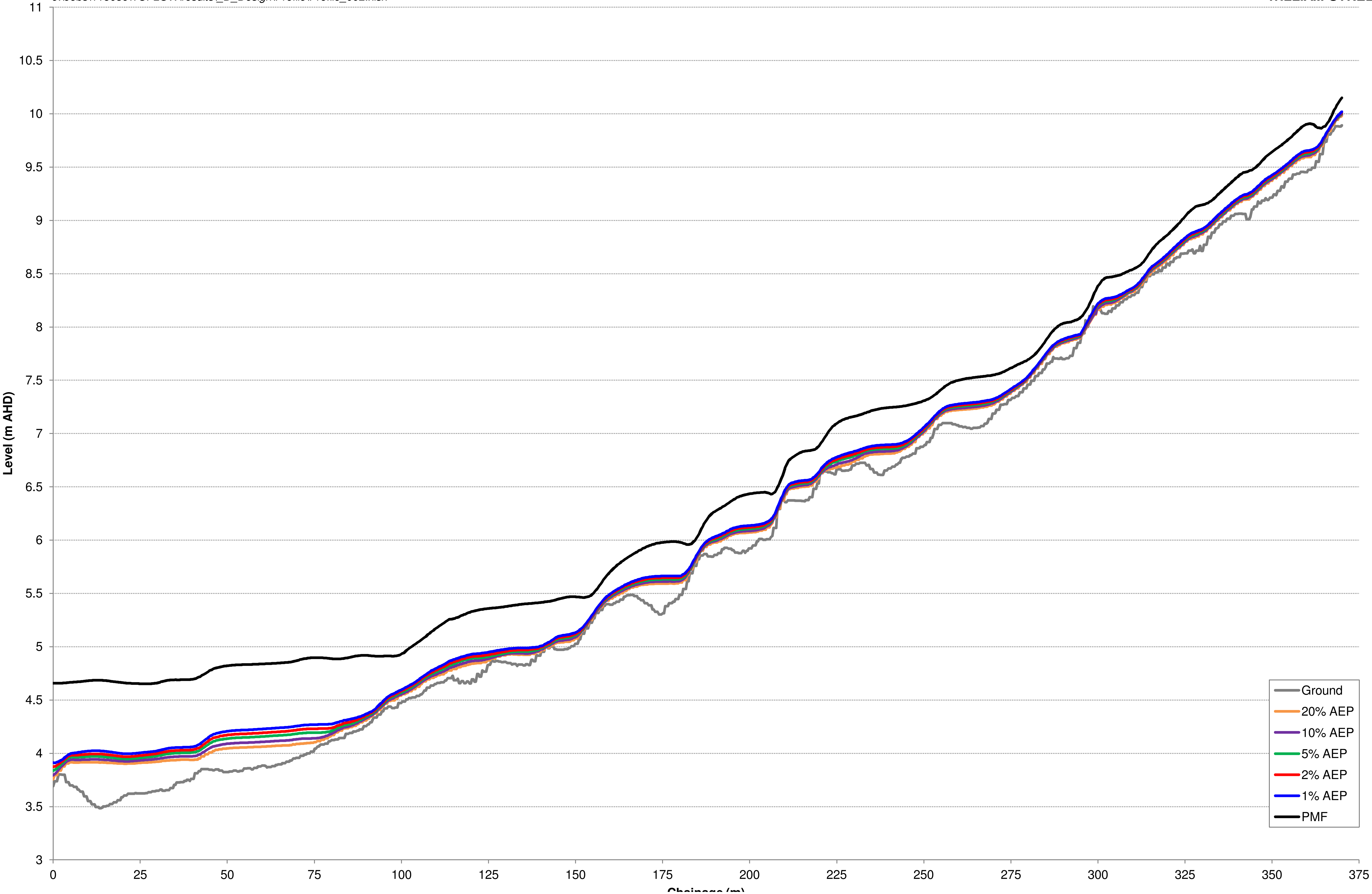

FIGURE 11A
DESIGN HYDROGRAPHS
Q01 - PARRAMATTA ROAD

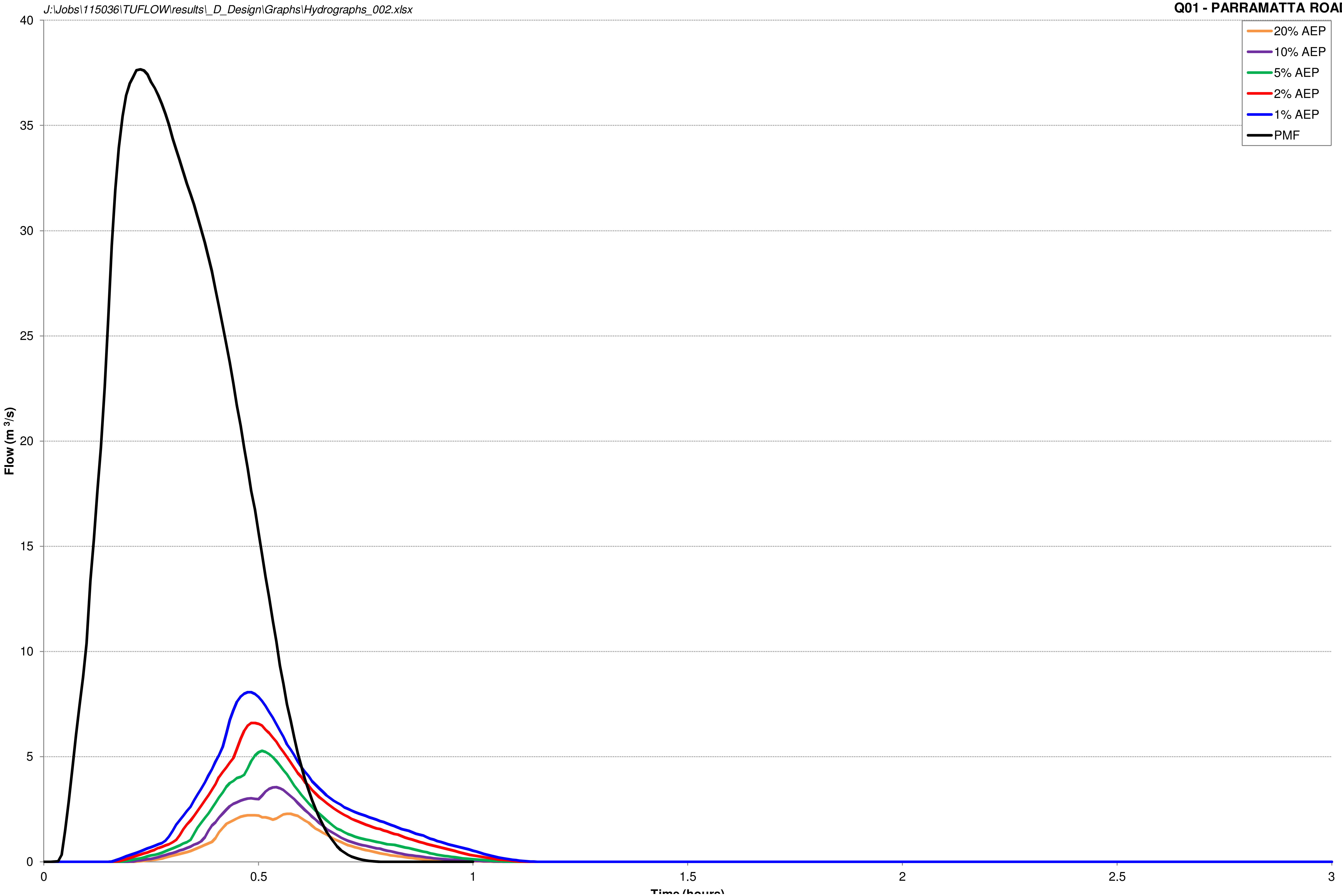

FIGURE 11B
DESIGN HYDROGRAPHS
Q03 - PARRAMATTA ROAD

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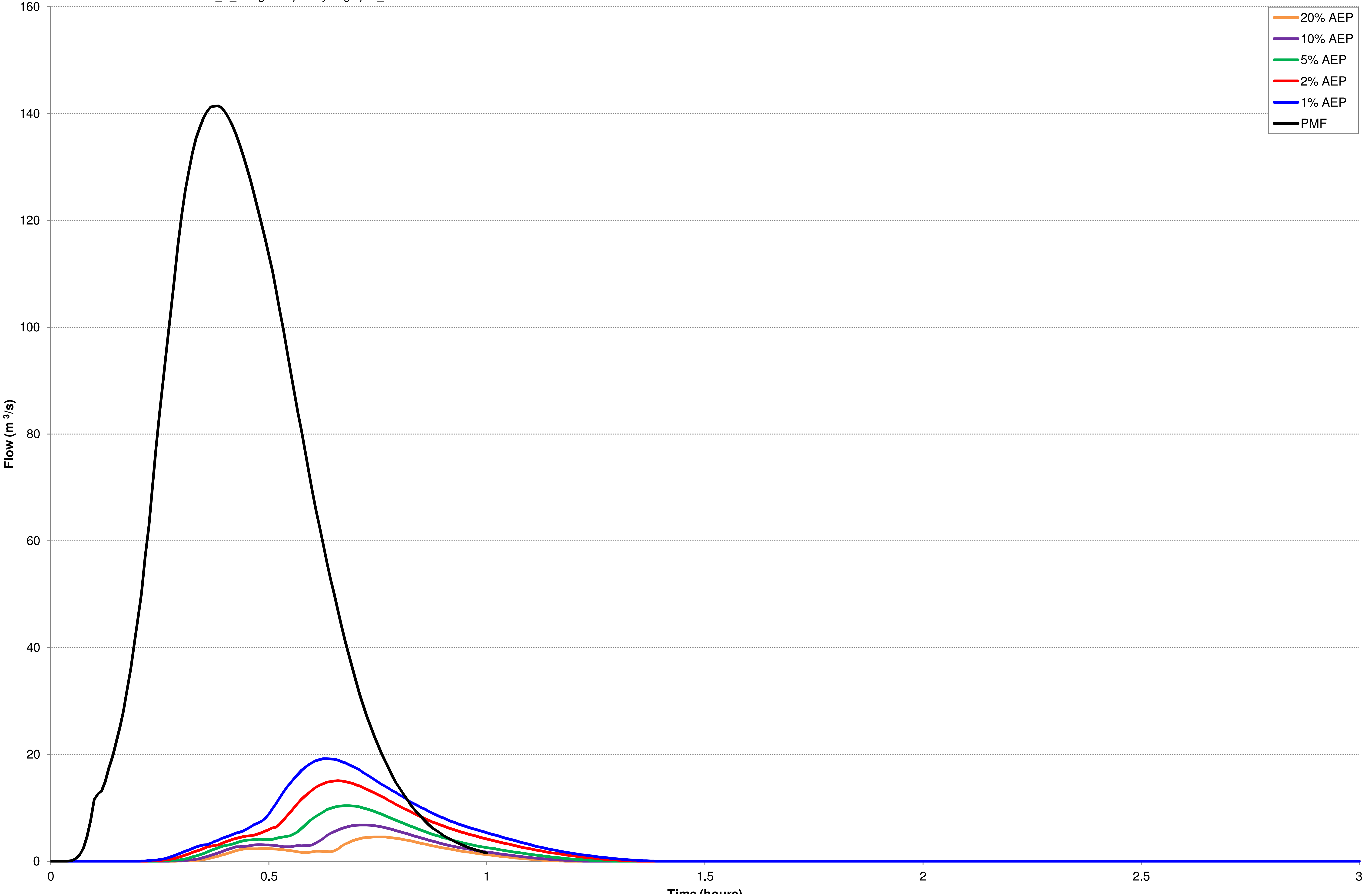

DESIGN HYDROGRAPHS
Q11 - PARRAMATTA ROAD

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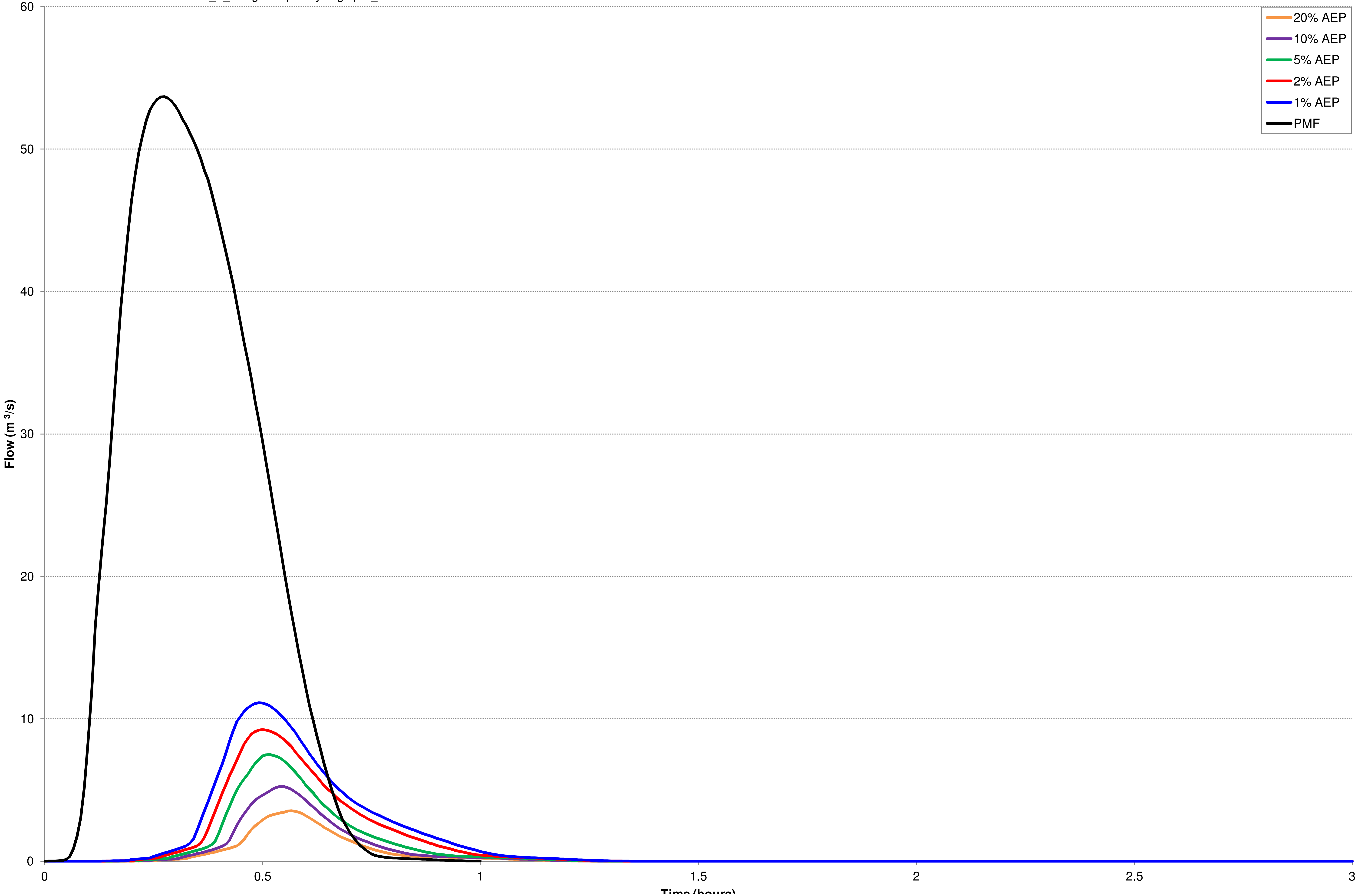

FIGURE 12
PEAK FLOOD DEPTHS AND
FLOOD LEVEL CONTOURS
20% AEP

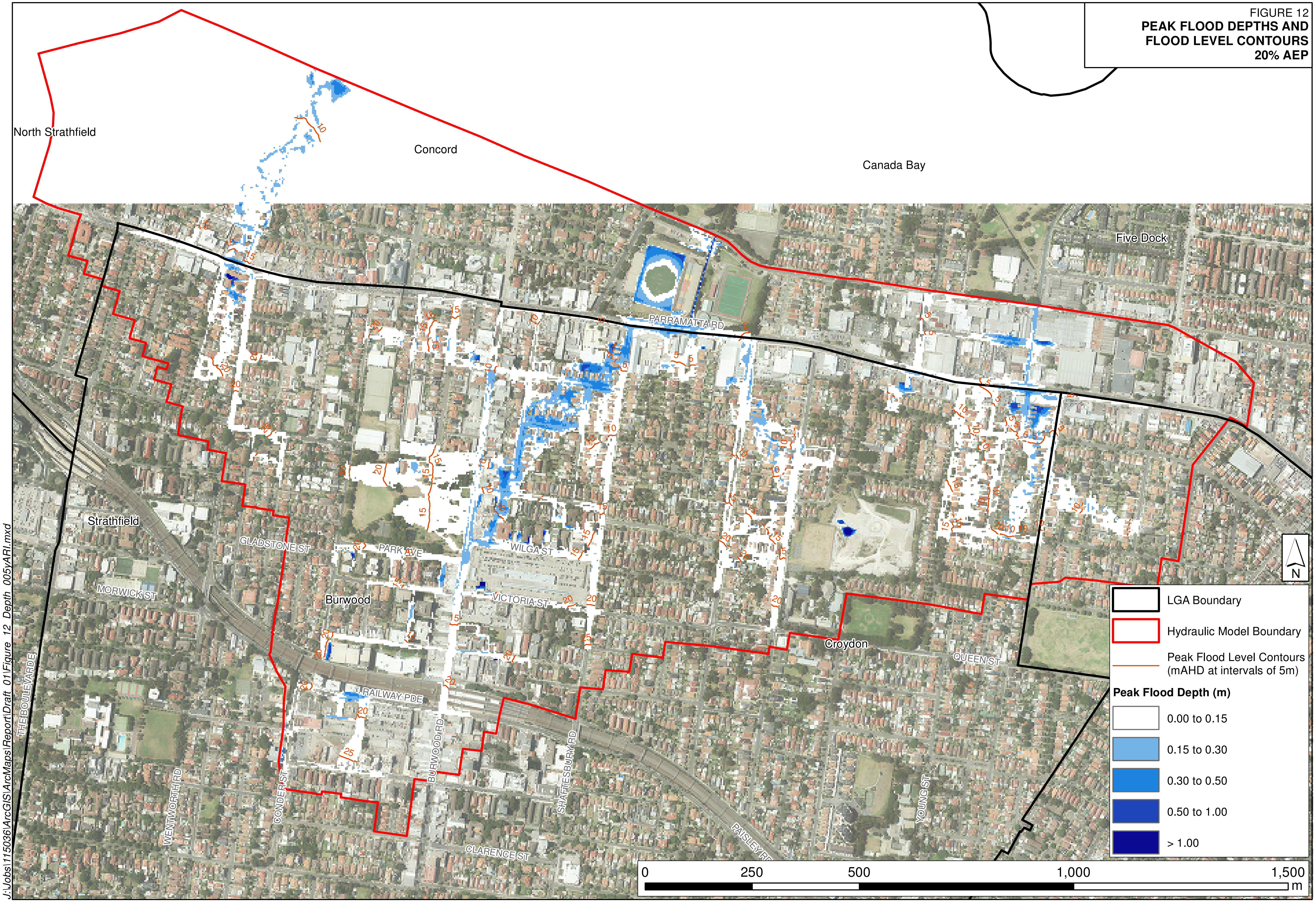
North Strathfield
Concord
Canada Bay
Five Dock
Strathfield
Burwood
Croydon
PARRAMATTA RD
GLADSTONE ST
PARK AVE
WILGA ST
VICTORIA ST
MORWICK ST
RAILWAY PDE
QUEEN ST
THE BOULEVARDE
WENTWORTH RD
CONDER ST
BURWOOD RD
SHAFTESBURY RD
PAISLEY RD
YOUNG ST
CLARENCE ST
N
LGA Boundary
Hydraulic Model Boundary
Peak Flood Level Contours (mAHD at intervals of 5m)
Peak Flood Depth (m)
0.00 to 0.15
0.15 to 0.30
0.30 to 0.50
0.50 to 1.00
> 1.00
0
250
500
1,000
1,500
m
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FIGURE 13
PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS 10% AEP

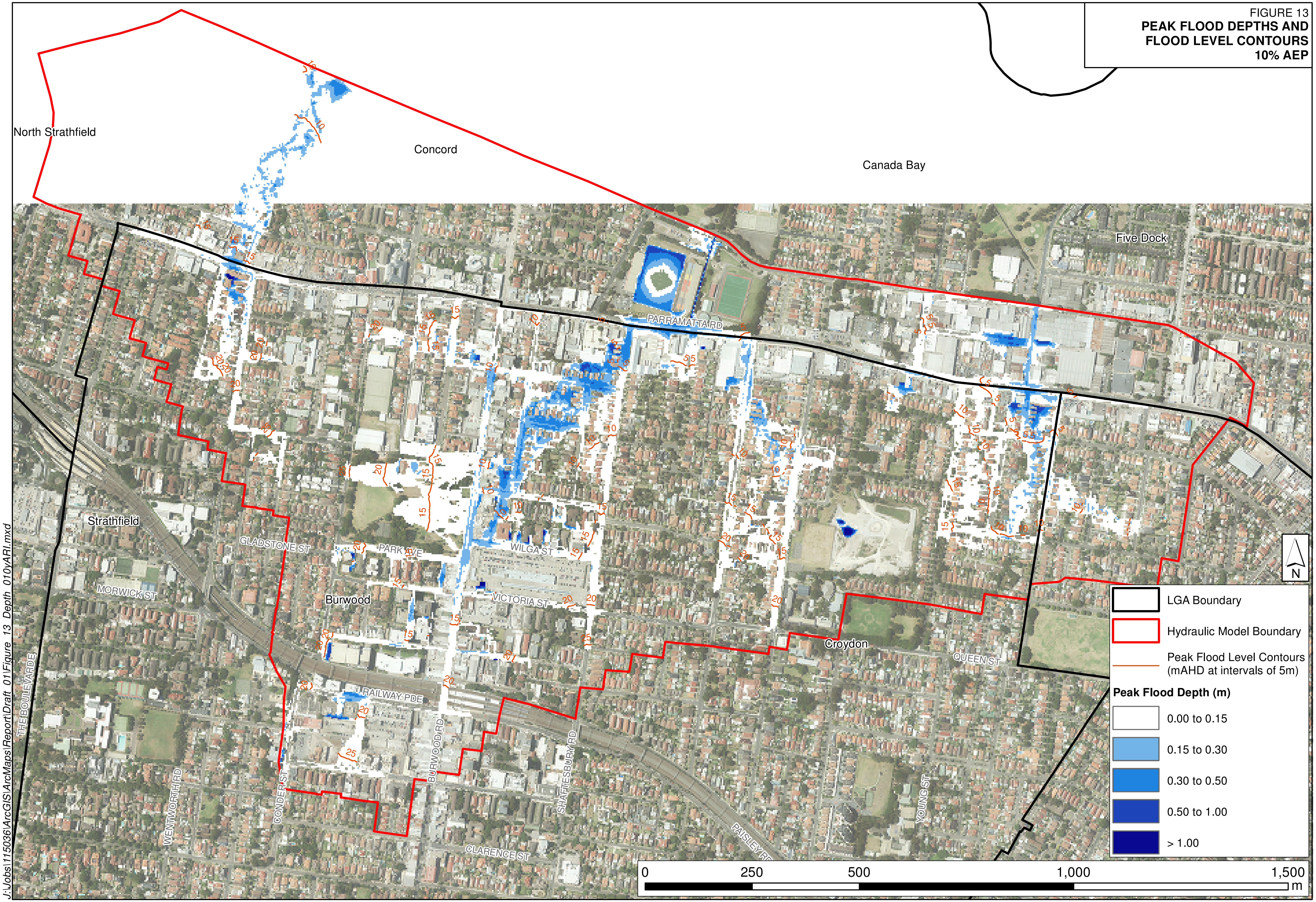


FIGURE 14
PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS 5% AEP

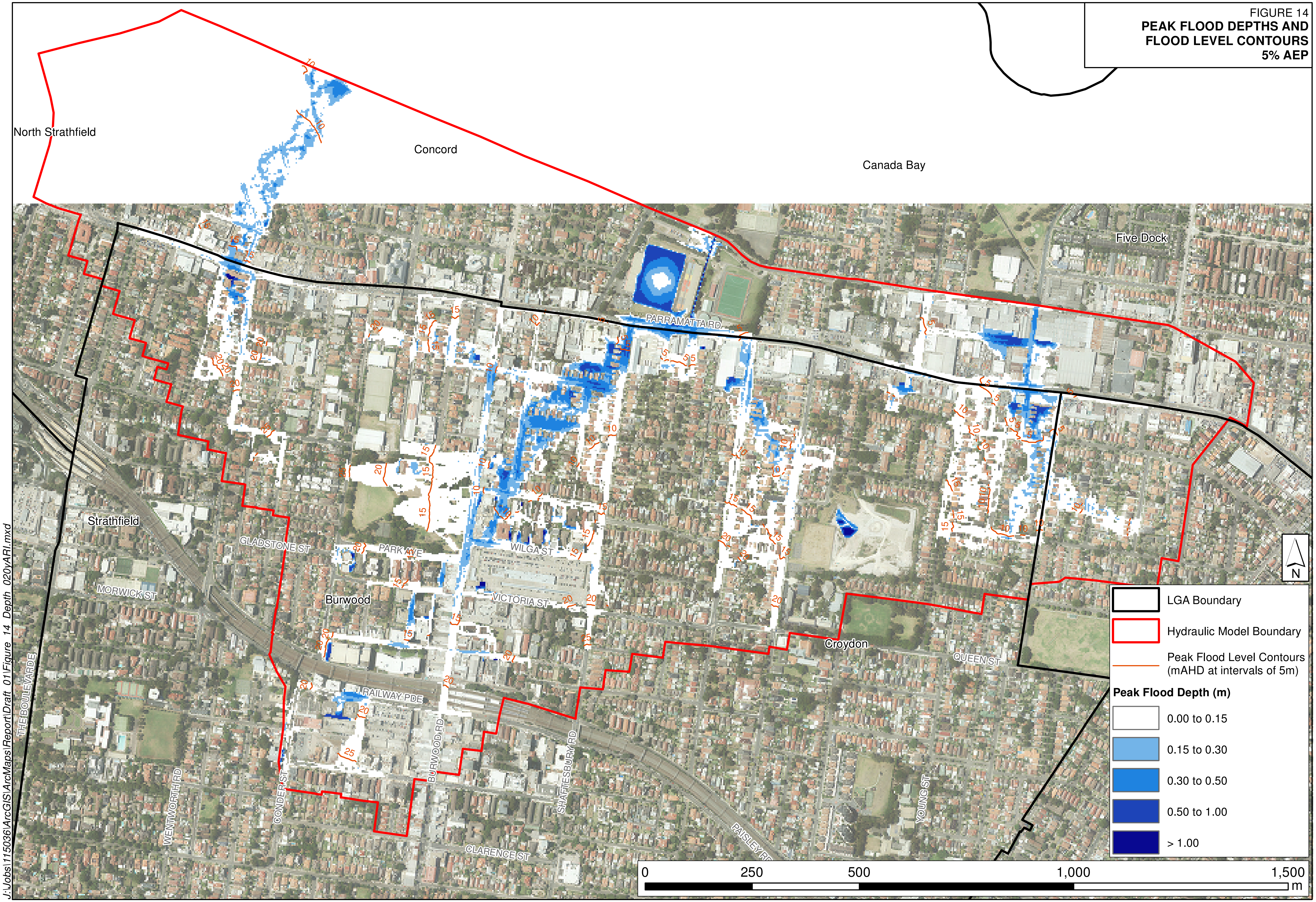
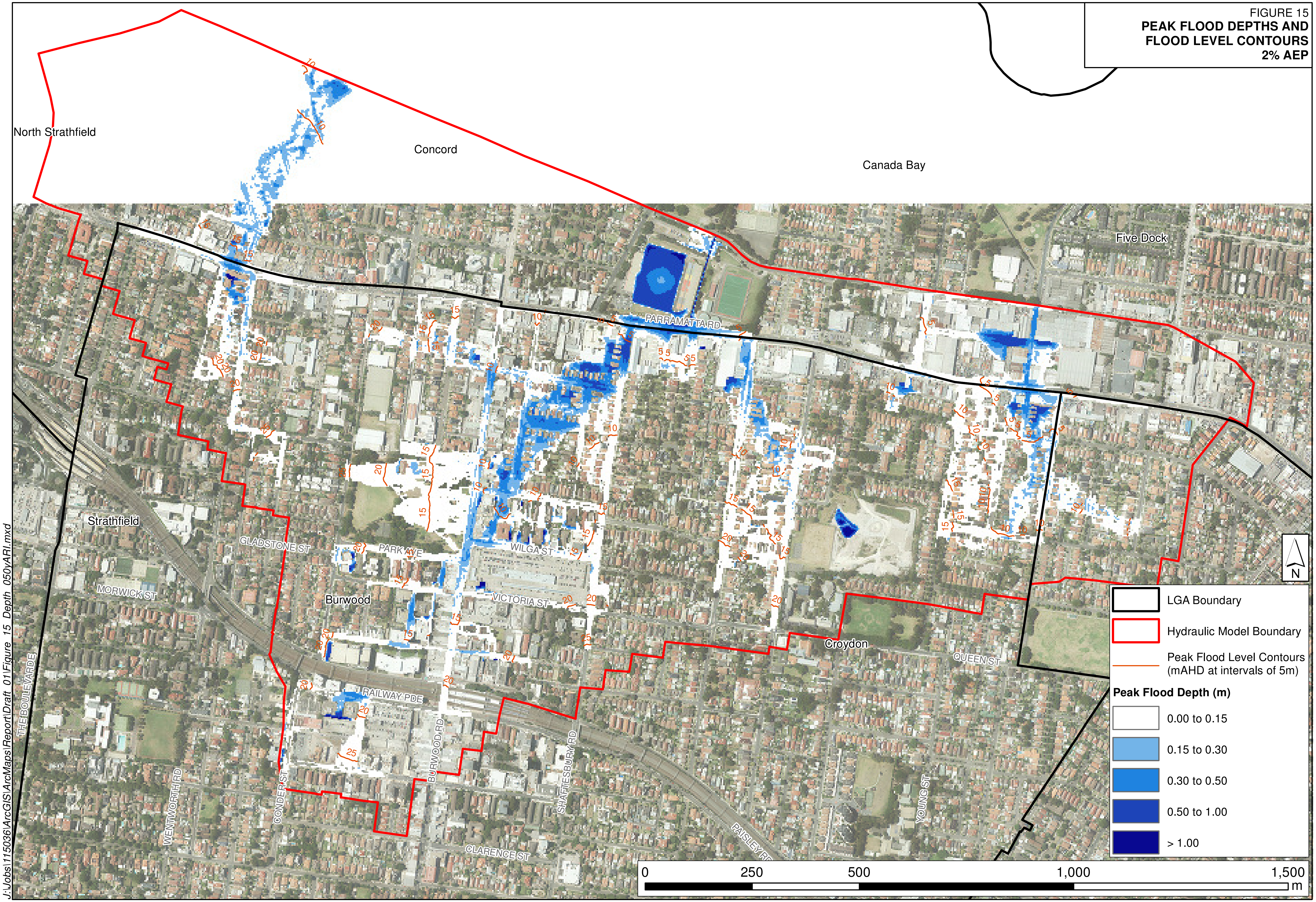


FIGURE 15
PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS 2% AEP



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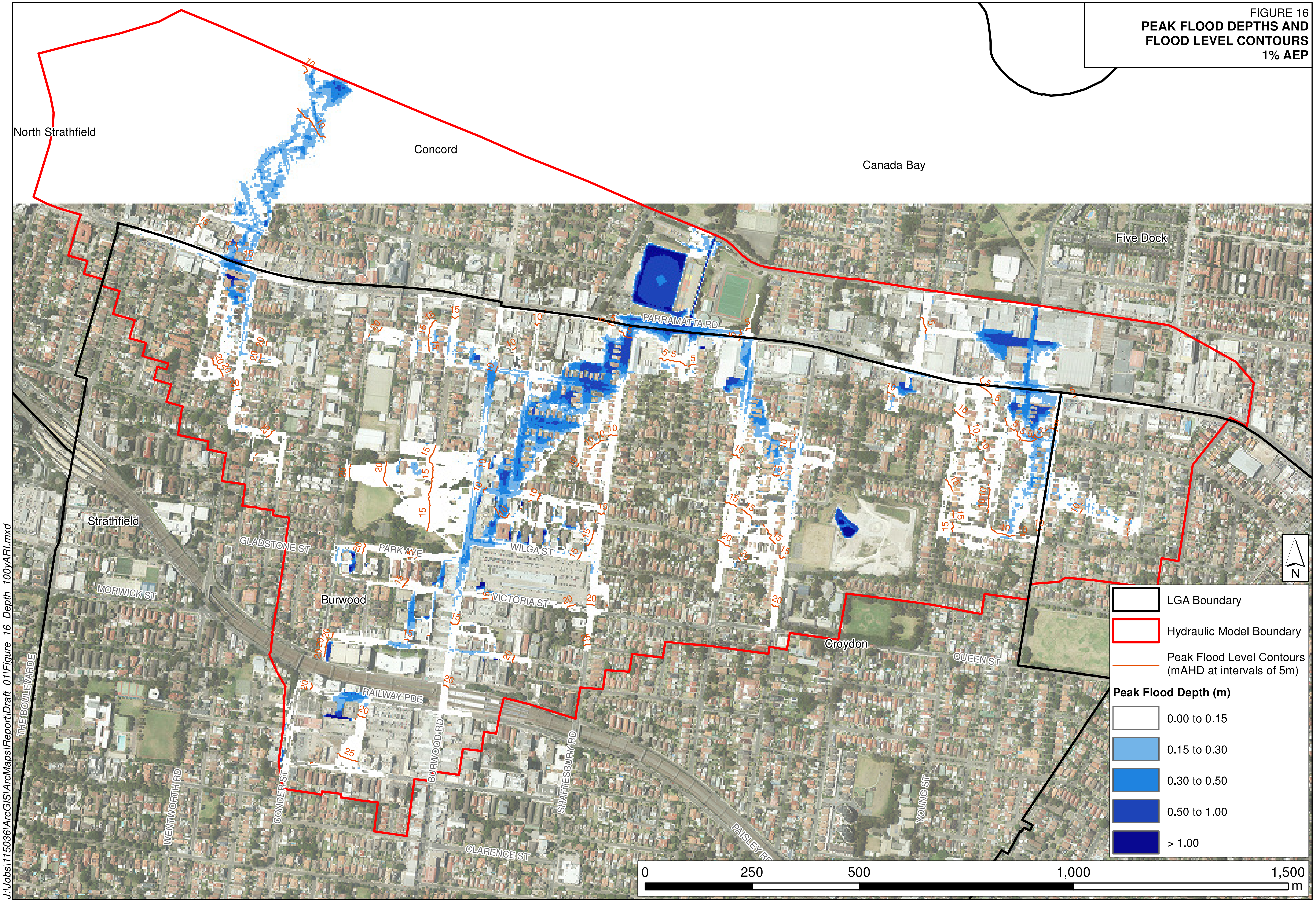

FIGURE 16
PEAK FLOOD DEPTHS AND
FLOOD LEVEL CONTOURS
1% AEP
North Strathfield
Concord
Canada Bay
Five Dock
Strathfield
Burwood
Croydon
PARRAMATTA RD
GLADSTONE ST
PARK AVE
WILGA ST
MORWICK ST
VICTORIA ST
RAILWAY PDE
QUEEN ST
THE BOULEVARDE
WENTWORTH RD
CONDER ST
BURWOOD RD
SHAFTESBURY RD
CLARENCE ST
PAISLEY RD
YOUNG ST
LGA Boundary
Hydraulic Model Boundary
Peak Flood Level Contours
(mAHD at intervals of 5m)
Peak Flood Depth (m)
0.00 to 0.15
0.15 to 0.30
0.30 to 0.50
0.50 to 1.00
> 1.00
N
0
250
500
1,000
1,500
m
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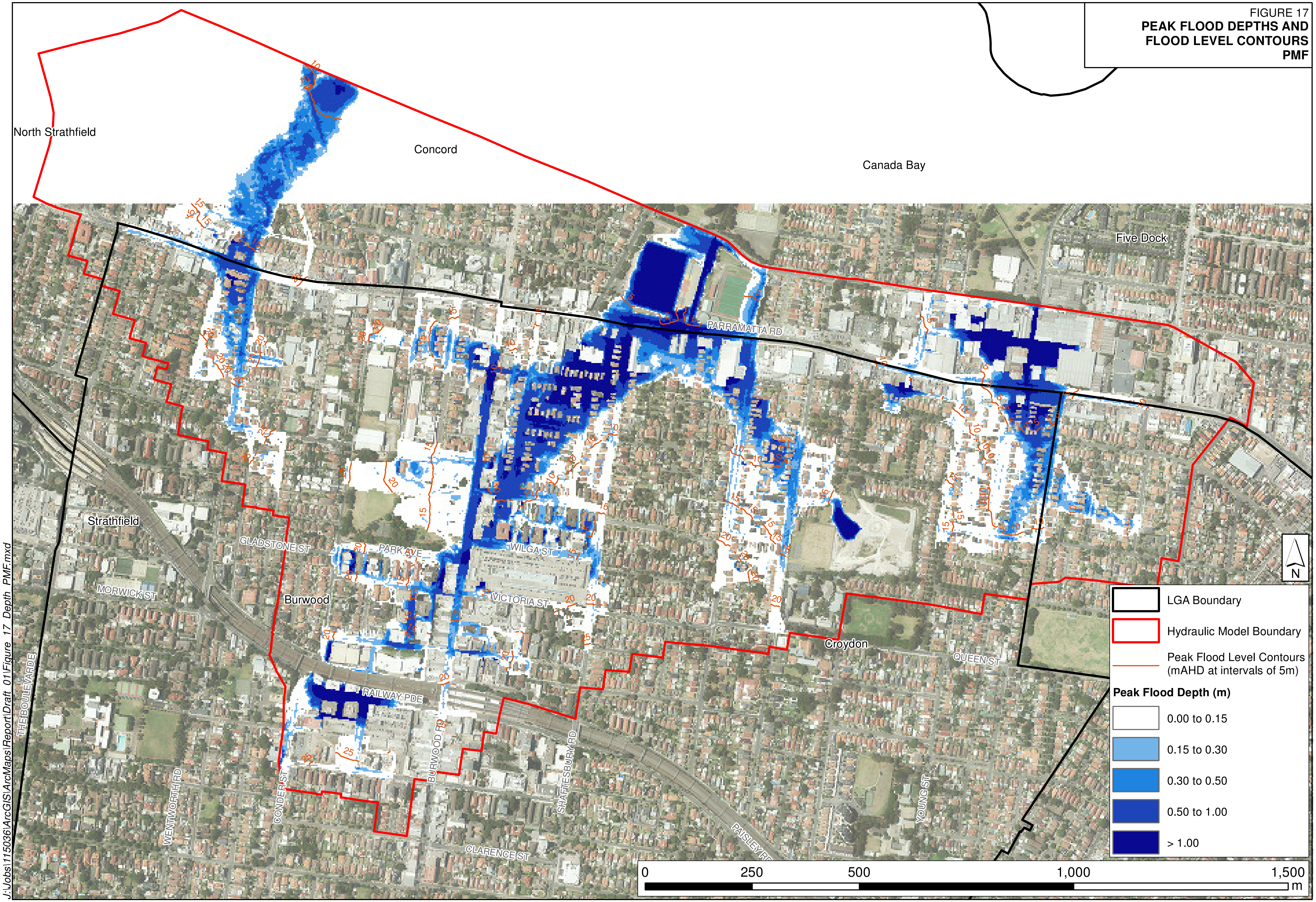
FIGURE 17
PEAK FLOOD DEPTHS AND
FLOOD LEVEL CONTOURS
PMF
North Strathfield
Concord
Canada Bay
Five Dock
Strathfield
Burwood
Croydon
PARRAMATTA RD
GLADSTONE ST
PARK AVE
WILGA ST
VICTORIA ST
MORWICK ST
RAILWAY PDE
QUEEN ST
BURWOOD RD
SHAFTESBURY RD
CONDER ST
WENTWORTH RD
THE BOULEVARDE
CLARENCE ST
PAISLEY RD
YOUNG ST
N
LGA Boundary
Hydraulic Model Boundary
Peak Flood Level Contours
(mAHD at intervals of 5m)
Peak Flood Depth (m)
0.00 to 0.15
0.15 to 0.30
0.30 to 0.50
0.50 to 1.00
> 1.00
0
250
500
1,000
1,500
m
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FIGURE 18
PEAK FLOOD VELOCITY
5% AEP

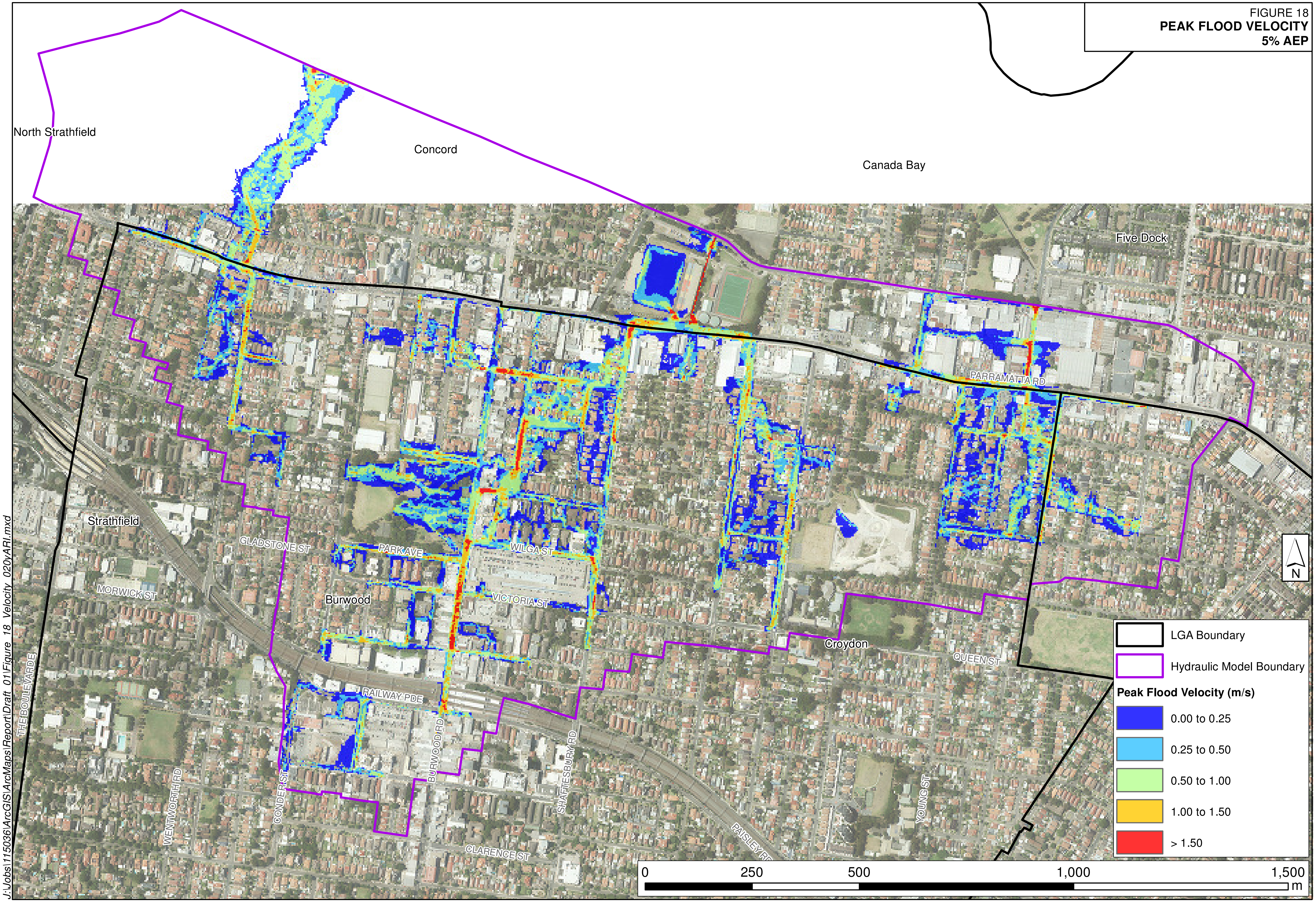

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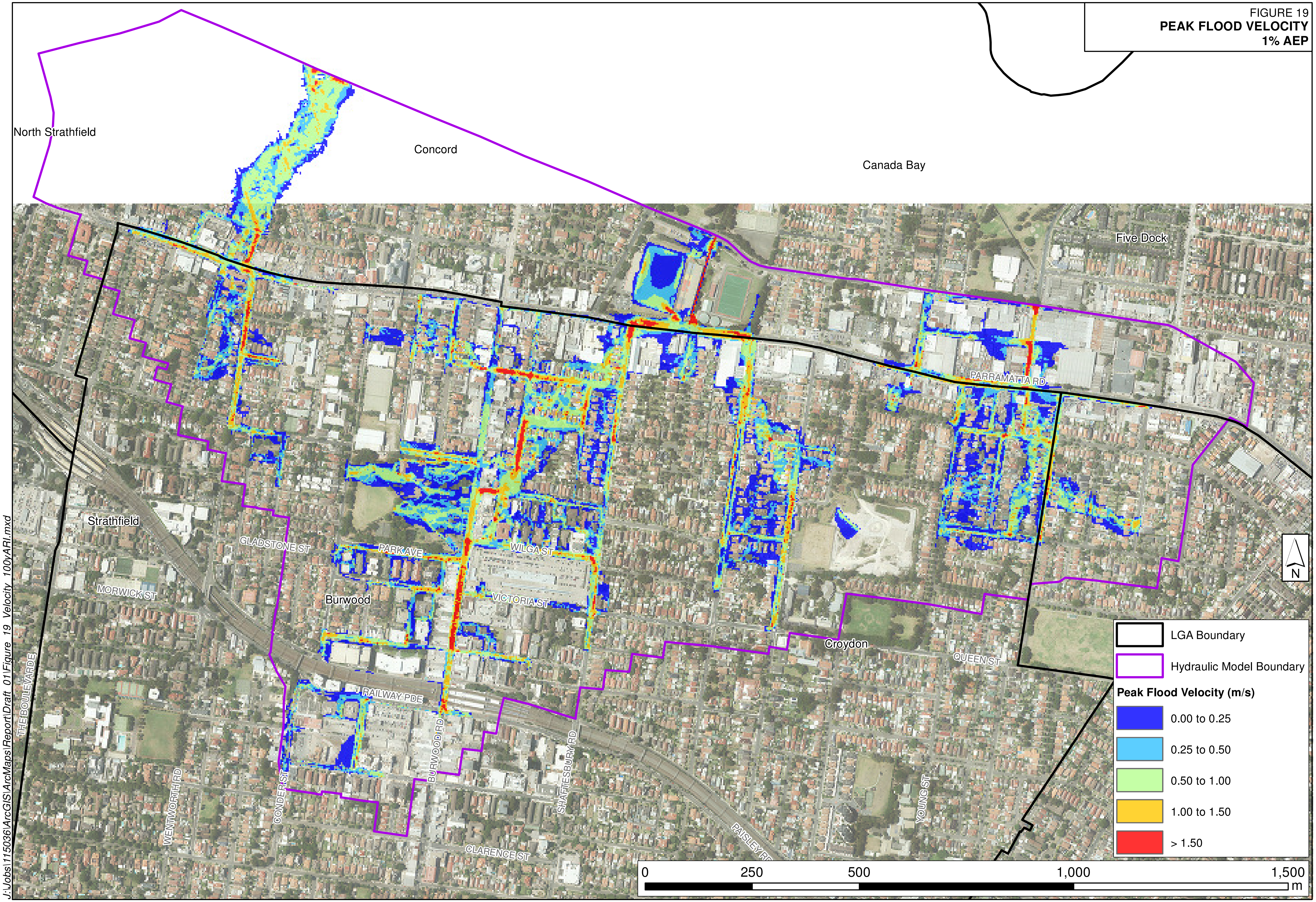
FIGURE 19
PEAK FLOOD VELOCITY
1% AEP



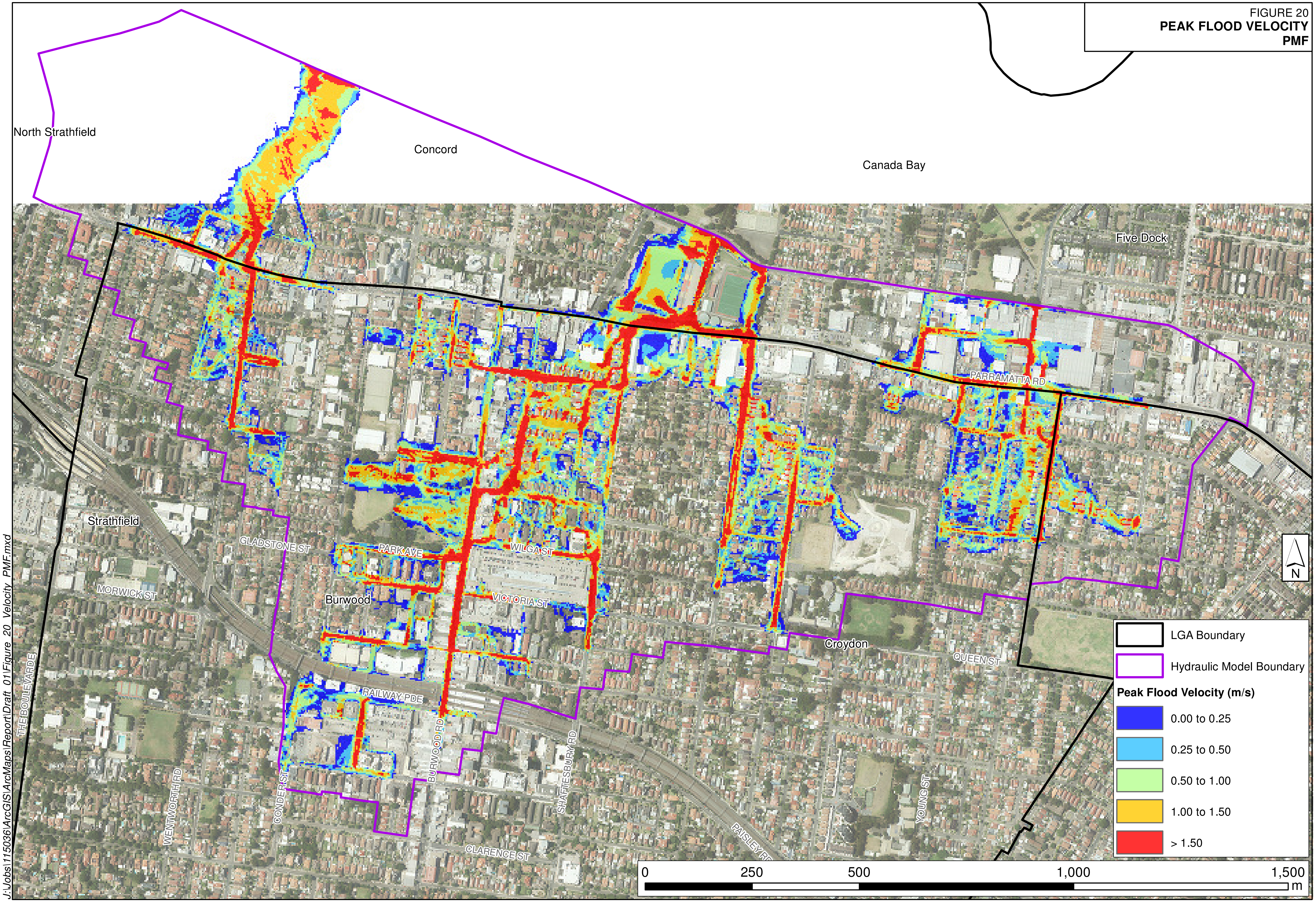
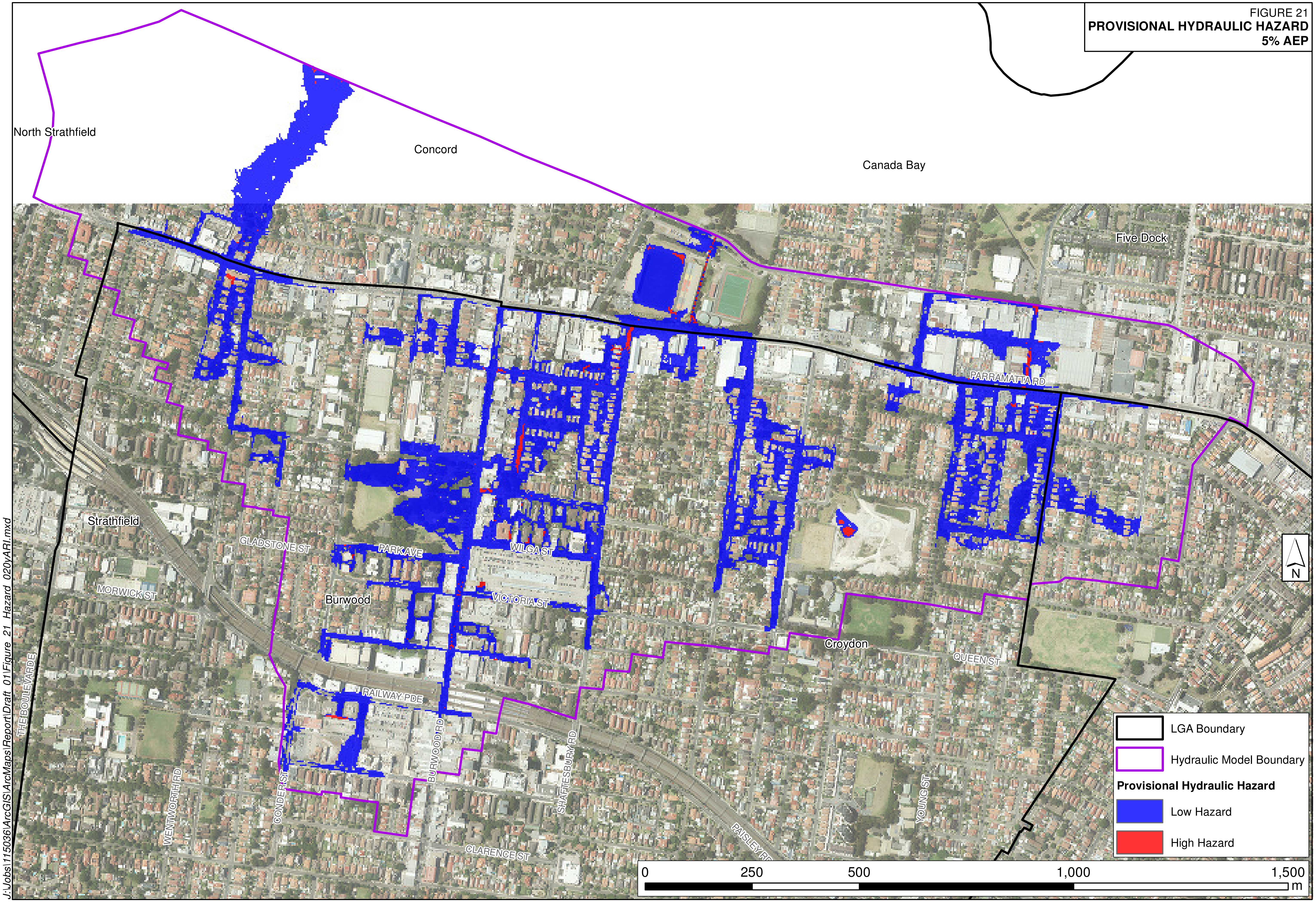


FIGURE 20
PEAK FLOOD VELOCITY
PMF
North Strathfield
Concord
Canada Bay
Five Dock
PARRAMATTA RD
Strathfield
GLADSTONE ST
PARK AVE
WILGA ST
MORWICK ST
Burwood
VICTORIA ST
Croydon
QUEEN ST
RAILWAY PDE
THE BOULEVARDE
WENTWORTH RD
CONDER ST
BURWOOD RD
SHAFTESBURY RD
PAISLEY RD
YOUNG ST
CLARENCE ST
N
LGA Boundary
Hydraulic Model Boundary
Peak Flood Velocity (m/s)
0.00 to 0.25
0.25 to 0.50
0.50 to 1.00
1.00 to 1.50
> 1.50
0
250
500
1,000
1,500
m
J:\Jobs\115036\ArcGIS\ArcMaps\Report\Draft_01\Figure_20_Velocity_PMF.mxd

FIGURE 21
PROVISIONAL HYDRAULIC HAZARD
5% AEP



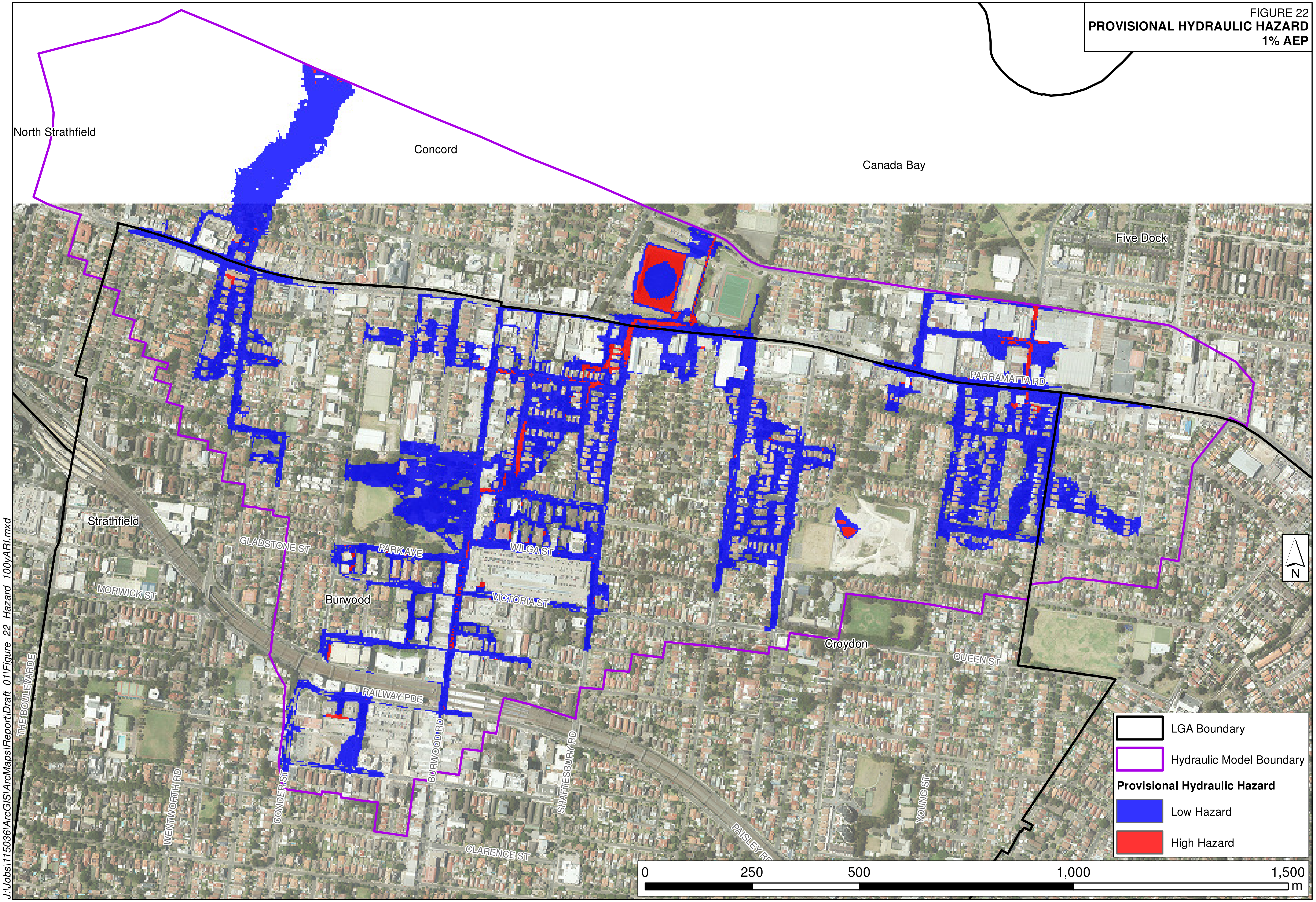


FIGURE 22
PROVISIONAL HYDRAULIC HAZARD
1% AEP

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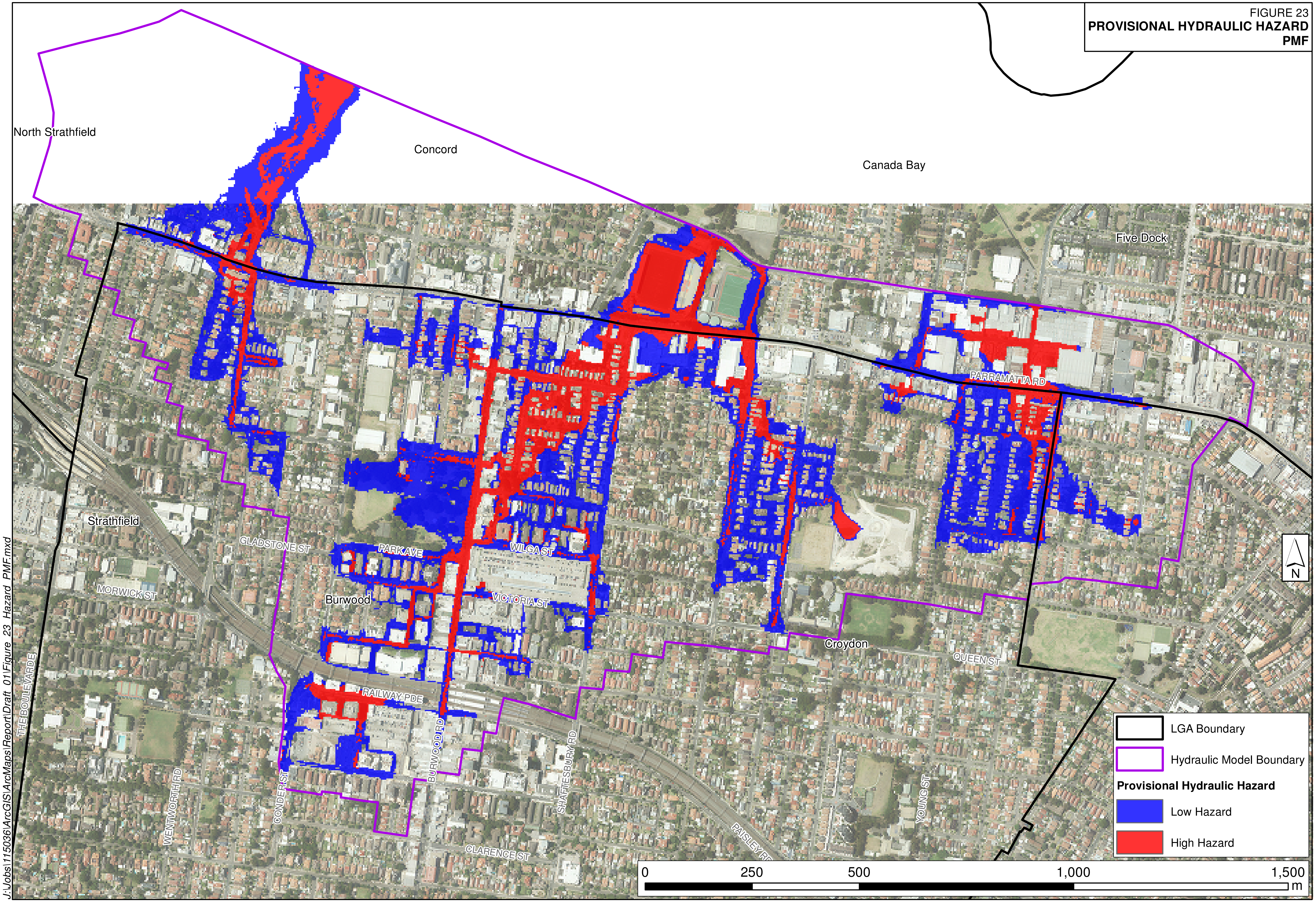
FIGURE 23

PROVISIONAL HYDRAULIC HAZARD PMF



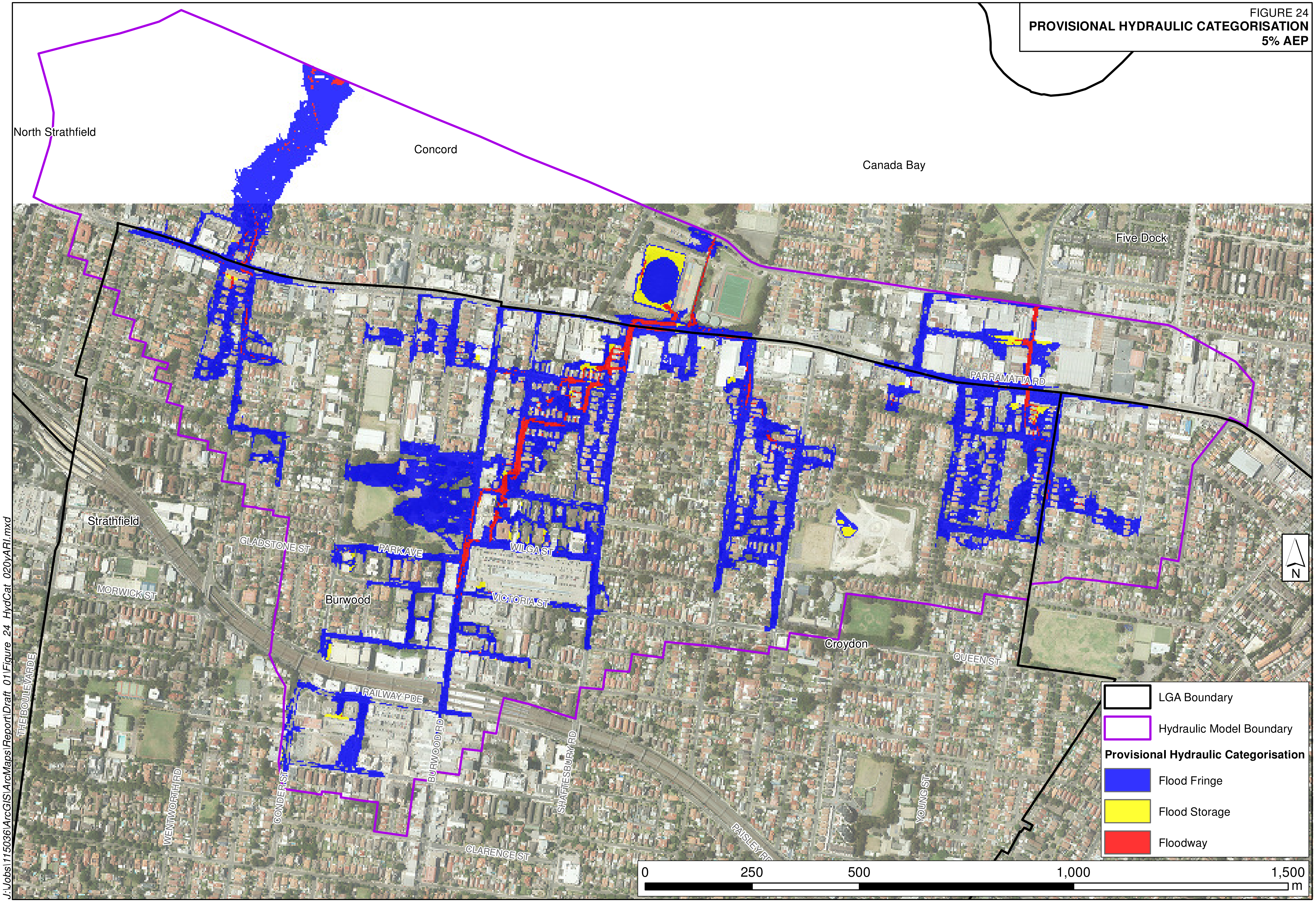


FIGURE 24
PROVISIONAL HYDRAULIC CATEGORISATION
5% AEP
North Strathfield
Concord
Canada Bay
Five Dock
PARRAMATTA RD
Strathfield
GLADSTONE ST
PARK AVE
WILGA ST
MORWICK ST
Burwood
VICTORIA ST
Croydon
QUEEN ST
RAILWAY PDE
THE BOULEVARDE
WENTWORTH RD
CONDER ST
BURWOOD RD
SHAFTESBURY RD
CLARENCE ST
YOUNG ST
PAISLEY RD
N
LGA Boundary
Hydraulic Model Boundary
Provisional Hydraulic Categorisation
Flood Fringe
Flood Storage
Floodway
0
250
500
1,000
1,500
m
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FIGURE 25
PROVISIONAL HYDRAULIC CATEGORISATION
1% AEP

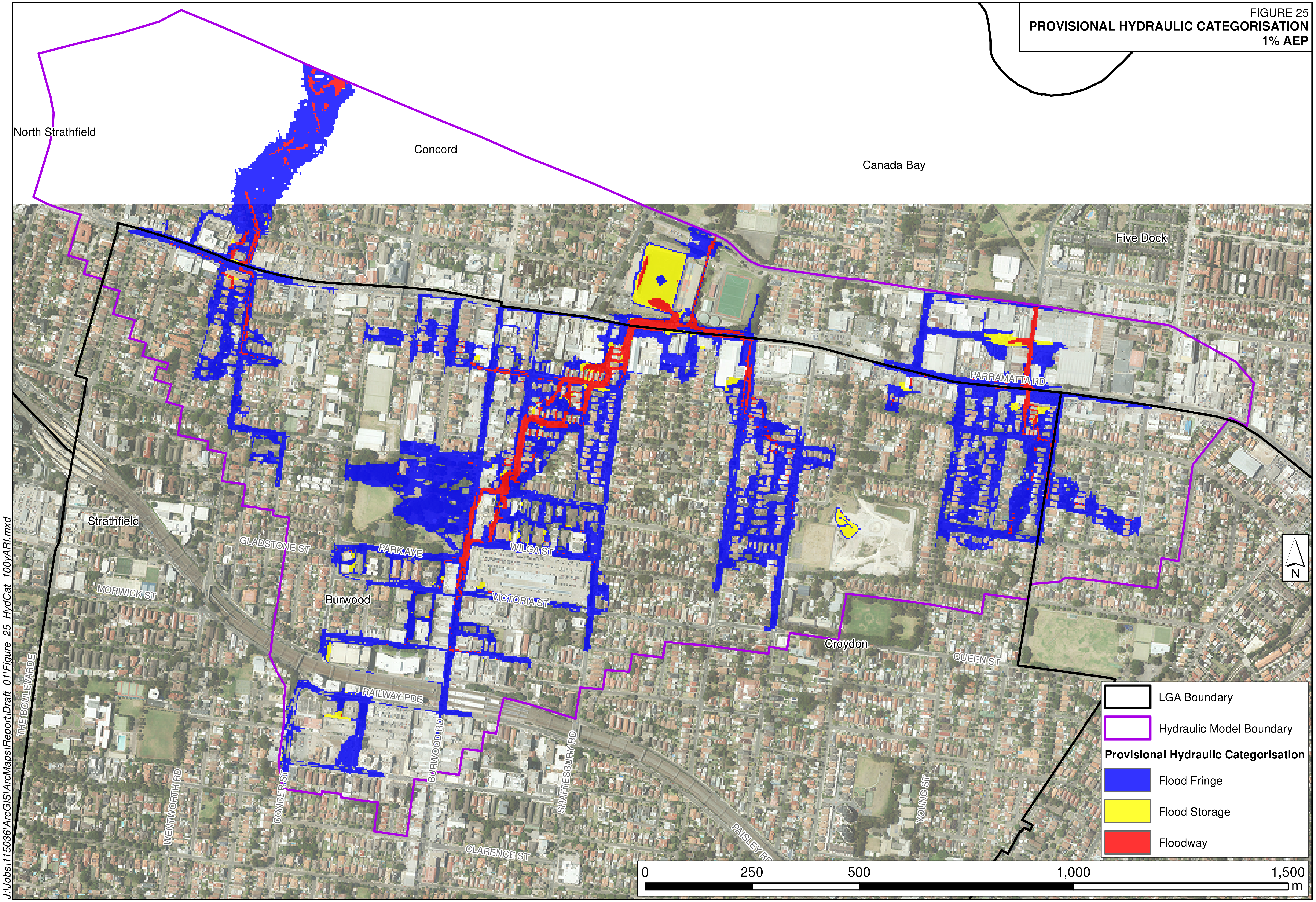

FIGURE 26
PROVISIONAL HYDRAULIC CATEGORISATION PMF

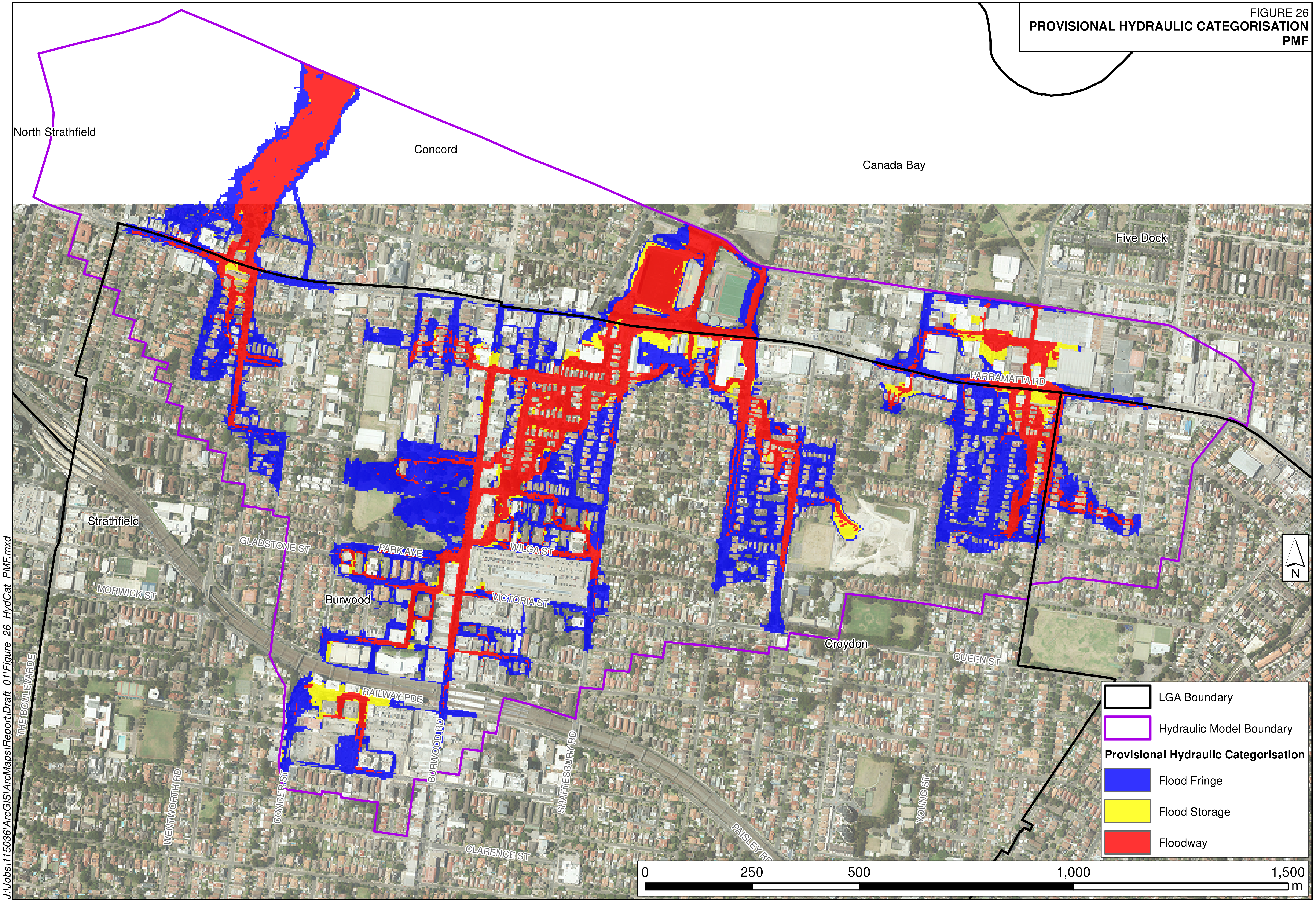

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FIGURE 27
PRELIMINARY FLOOD EMERGENCY RESPONSE CLASSIFICATION OF COMMUNITIES

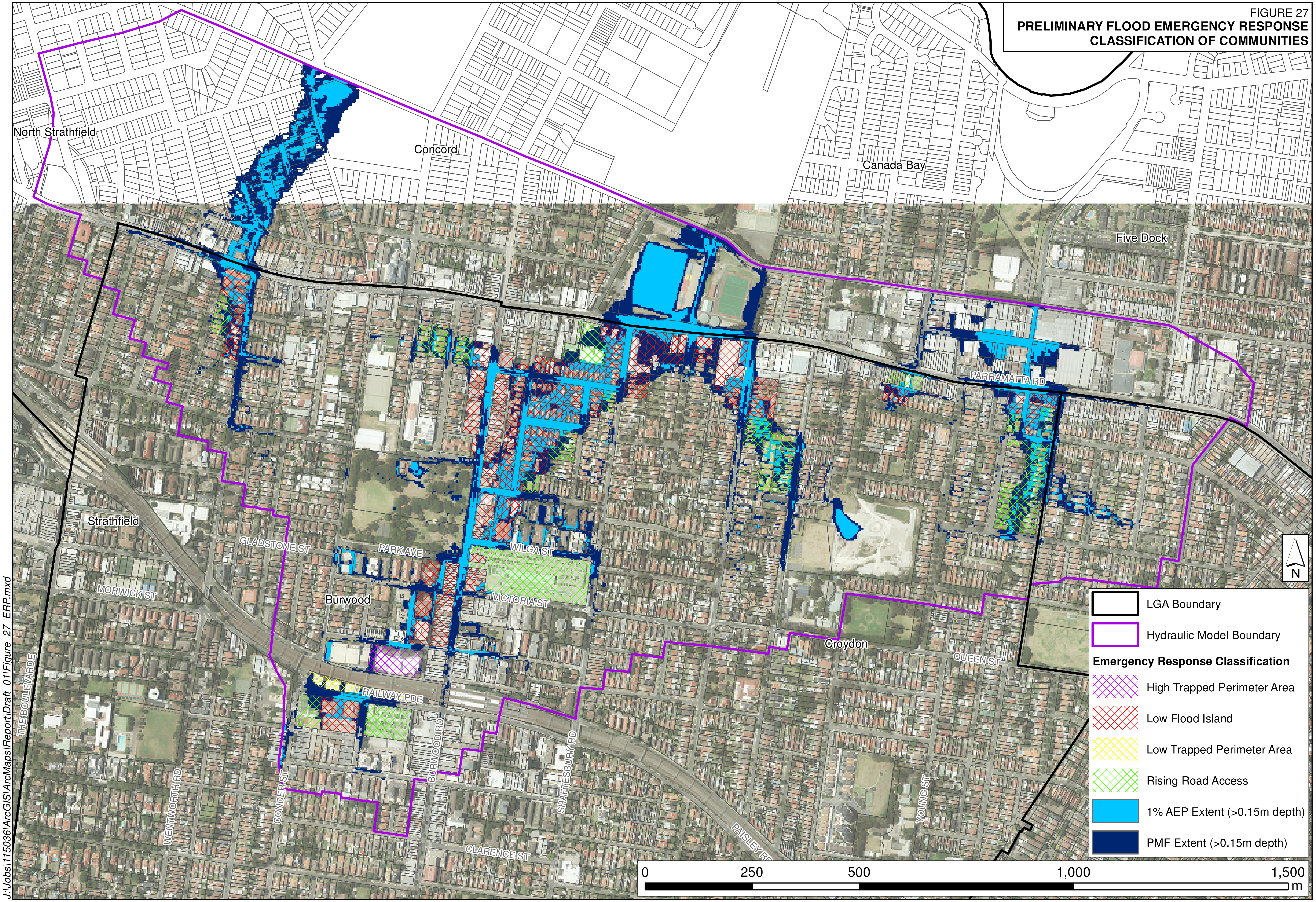

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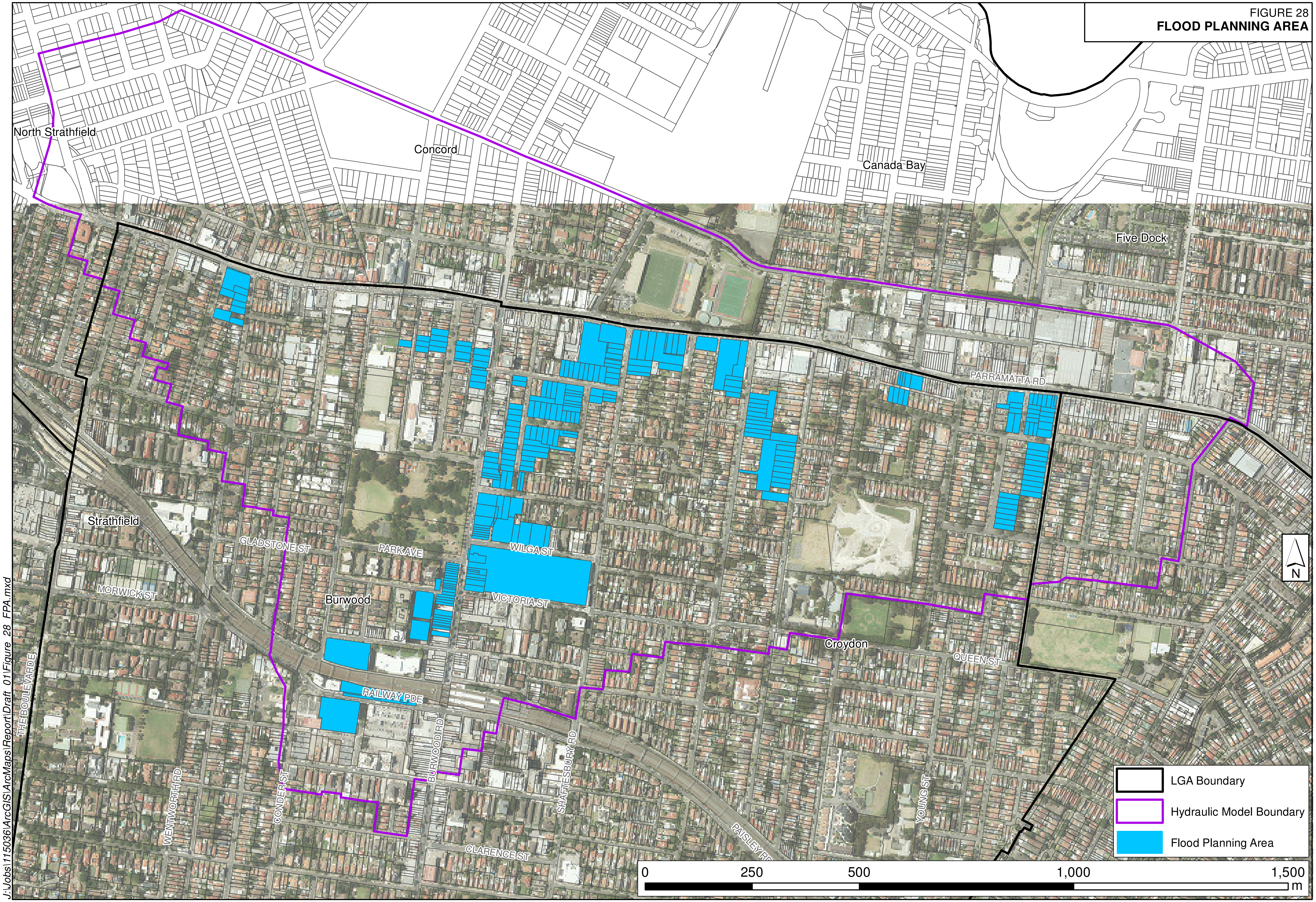
FIGURE 28
FLOOD PLANNING AREA



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Appendix A

APPENDIX A. GLOSSARY

Taken from the Floodplain Development Manual (April 2005 edition)

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

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

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

floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.

floodway areas Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.

freeboard Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.

habitable room **in a residential situation:** a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom.

in an industrial or commercial situation: an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.

hazard A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Manual.

hydraulics Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.

hydrograph A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.

hydrology Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.

local overland flooding Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.

local drainage Are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.

mainstream flooding Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.

major drainage Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purpose of this manual major drainage involves:

$ the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or

$ water depths generally in excess of 0.3 m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or

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

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

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

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

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

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

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

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

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

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

peak discharge — The maximum discharge occurring during a flood event.

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

Probable Maximum Precipitation (PMP)	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
probability	A statistical measure of the expected chance of flooding (see AEP).
risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	Equivalent to Awater level@. Both are measured with reference to a specified datum.
stage hydrograph	A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
survey plan	A plan prepared by a registered surveyor.
water surface profile	A graph showing the flood stage at any given location along a watercourse at a particular time.
wind fetch	The horizontal distance in the direction of wind over which wind waves are generated.

Appendix B

HOTSPOT LOCATIONS

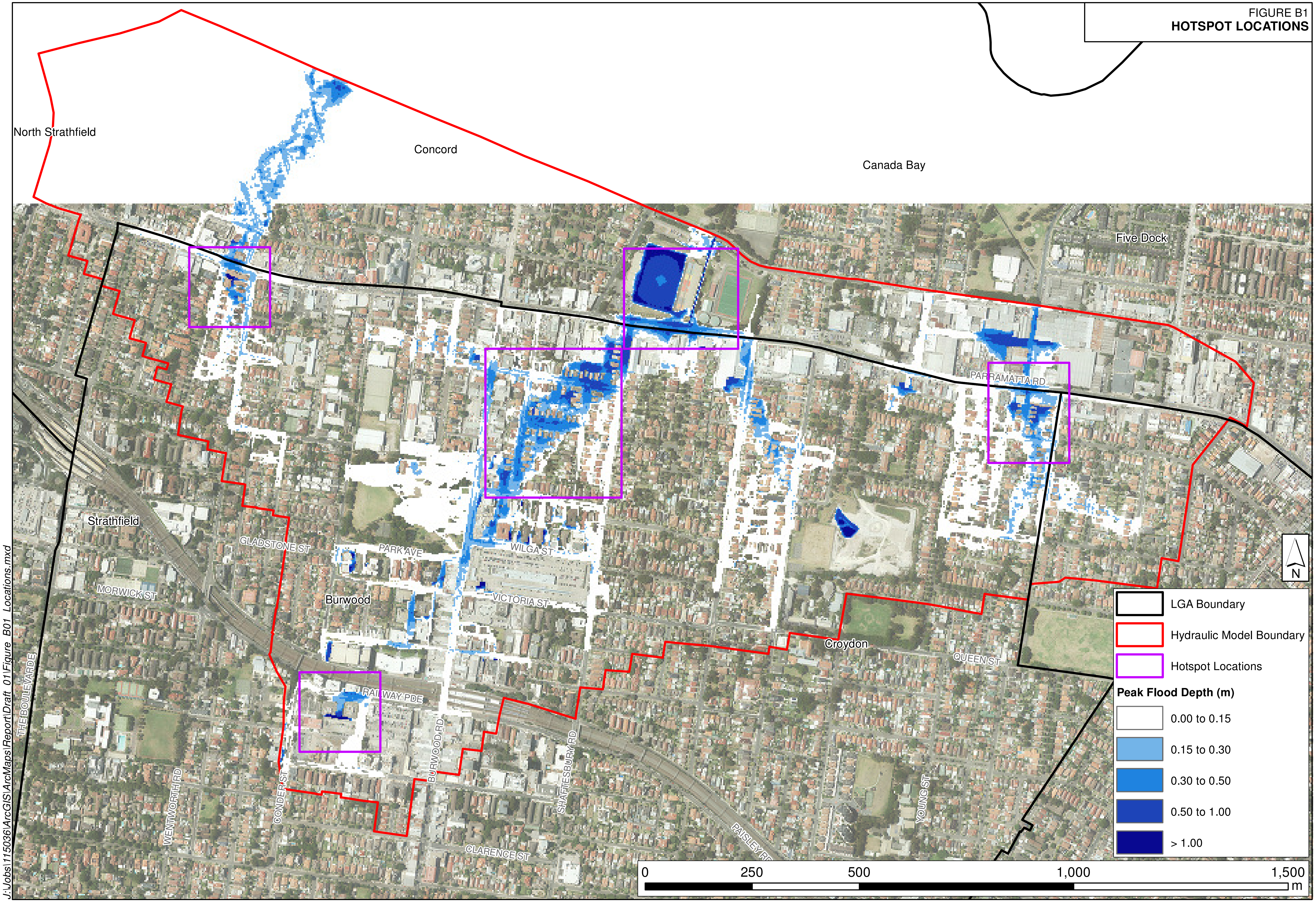
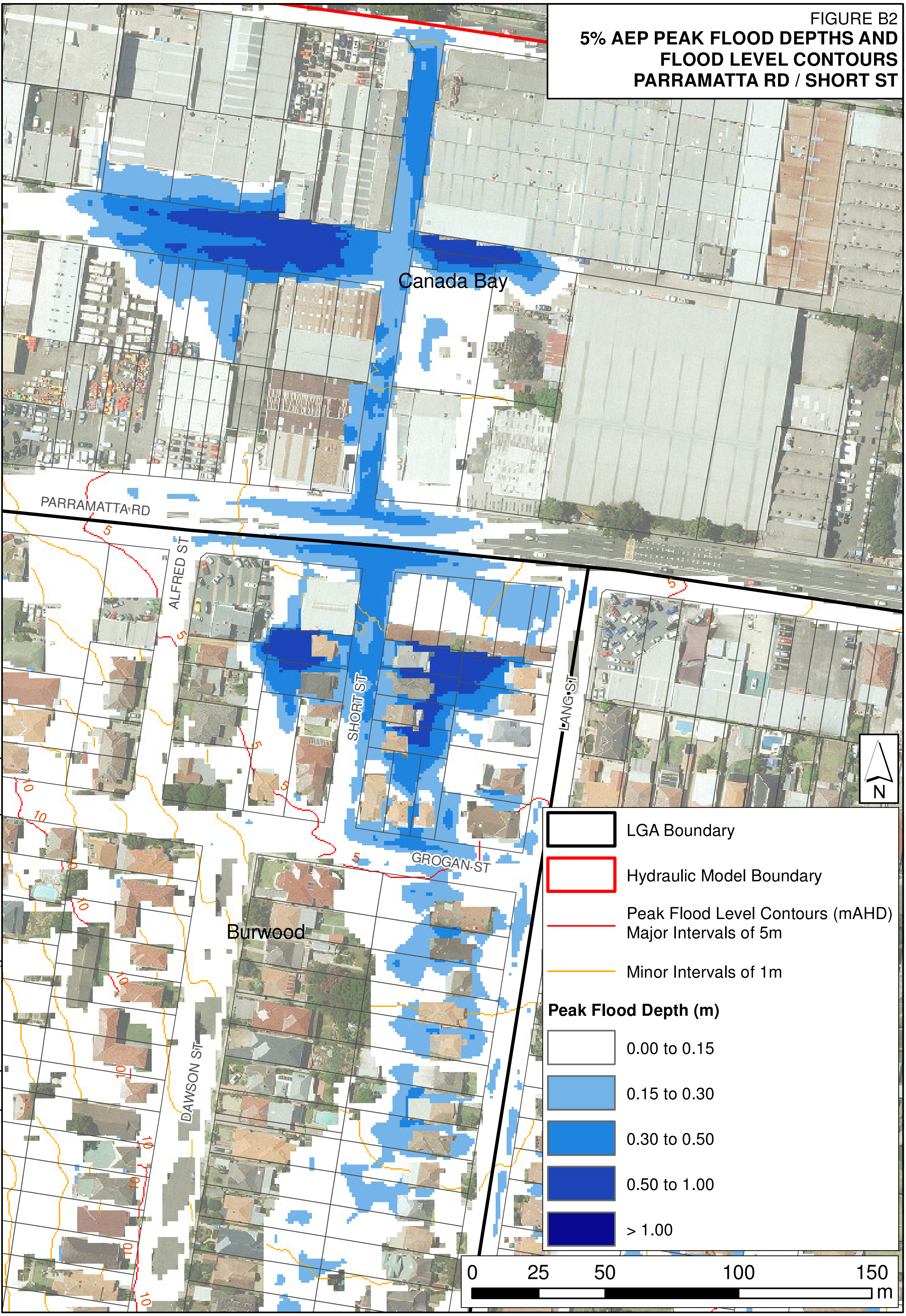


FIGURE B2

5% AEP PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS PARRAMATTA RD / SHORT ST



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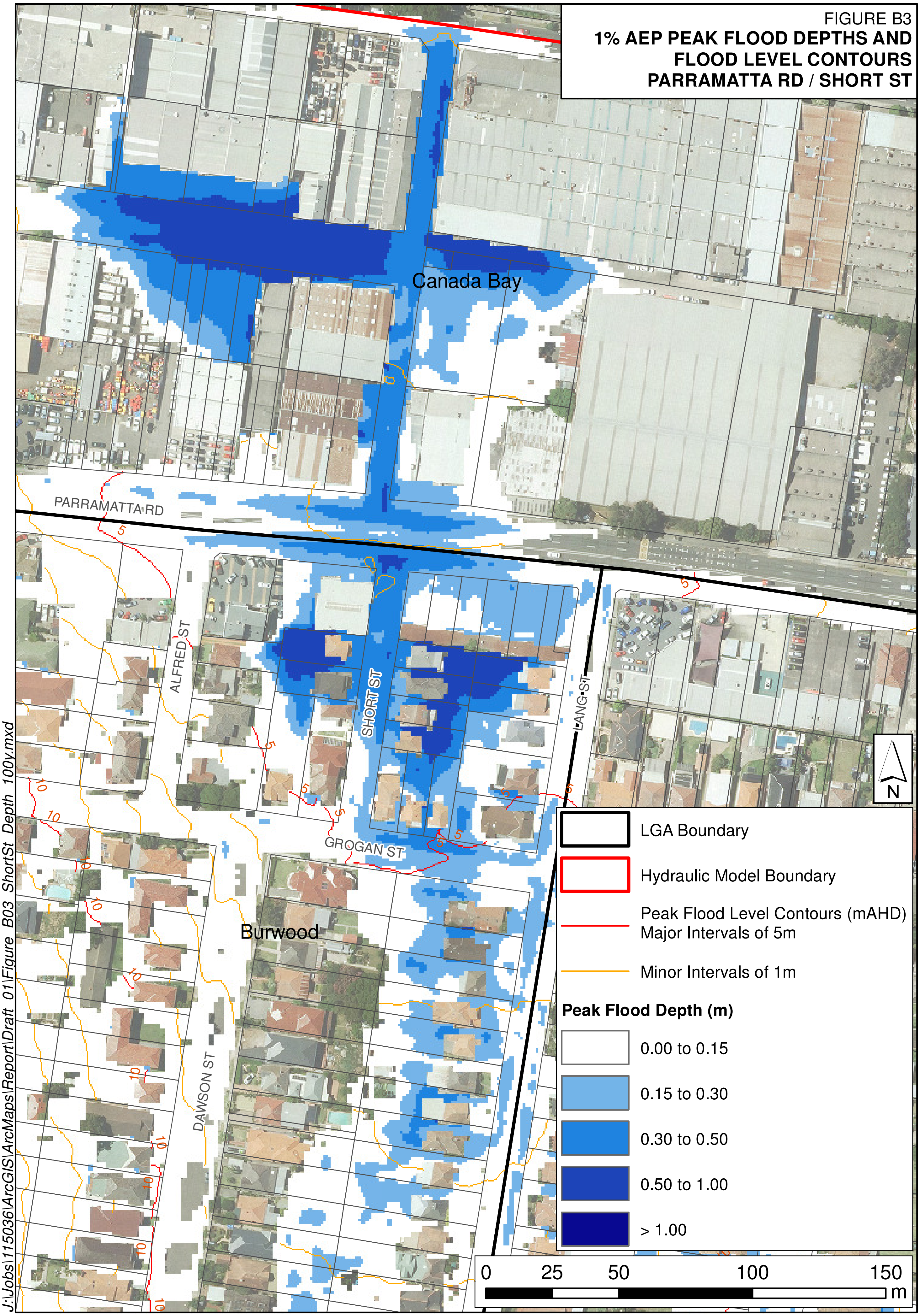
FIGURE B3
1% AEP PEAK FLOOD DEPTHS AND
FLOOD LEVEL CONTOURS
PARRAMATTA RD / SHORT ST
Canada Bay
PARRAMATTA RD
ALFRED ST
SHORT ST
LANG ST
GROGAN ST
DAWSON ST
Burwood
N
LGA Boundary
Hydraulic Model Boundary
Peak Flood Level Contours (mAHD)
Major Intervals of 5m
Minor Intervals of 1m
Peak Flood Depth (m)
0.00 to 0.15
0.15 to 0.30
0.30 to 0.50
0.50 to 1.00
> 1.00
0
25
50
100
150
m
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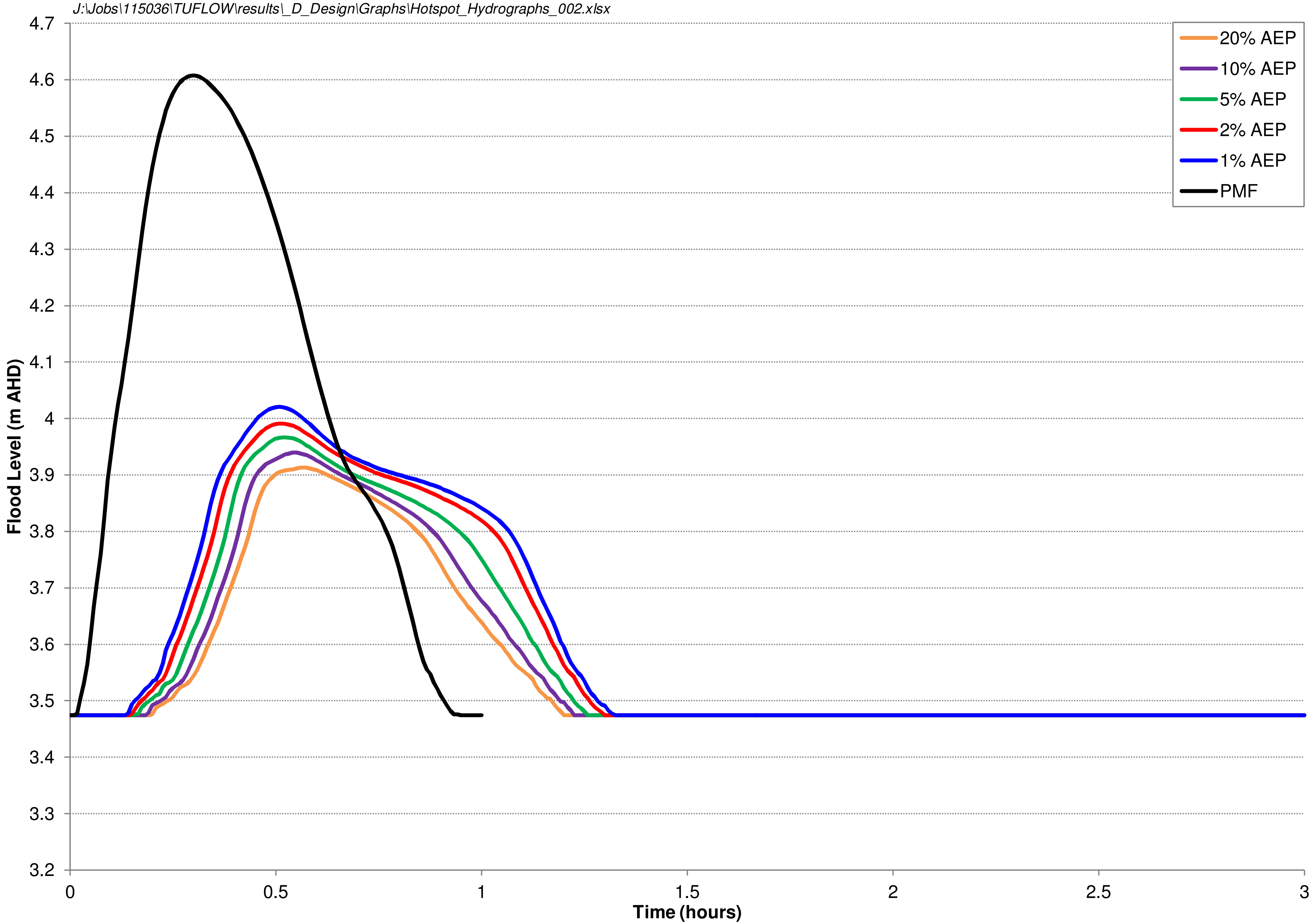

FIGURE B4
DESIGN HYDROGRAPHS
H11 - PARRAMATTA ROAD - SHORT STREET

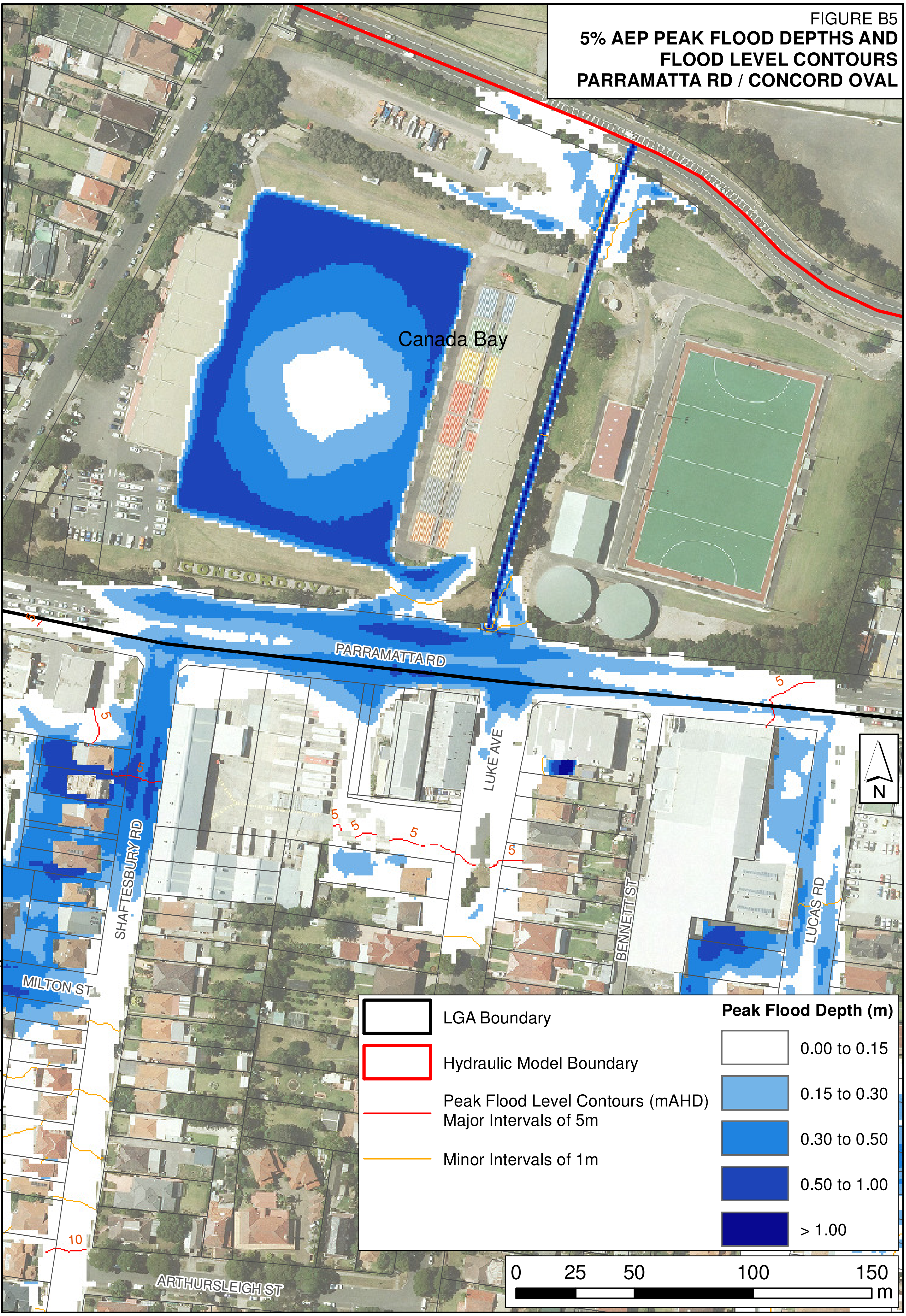

FIGURE B5
5% AEP PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS PARRAMATTA RD / CONCORD OVAL
Canada Bay
PARRAMATTA RD
LUKE AVE
SHAFTESBURY RD
BENNETT ST
LUCAS RD
MILTON ST
ARTHURSLEIGH ST
N
LGA Boundary
Hydraulic Model Boundary
Peak Flood Level Contours (mAHD)
Major Intervals of 5m
Minor Intervals of 1m
Peak Flood Depth (m)
0.00 to 0.15
0.15 to 0.30
0.30 to 0.50
0.50 to 1.00
> 1.00
0 25 50 100 150
m
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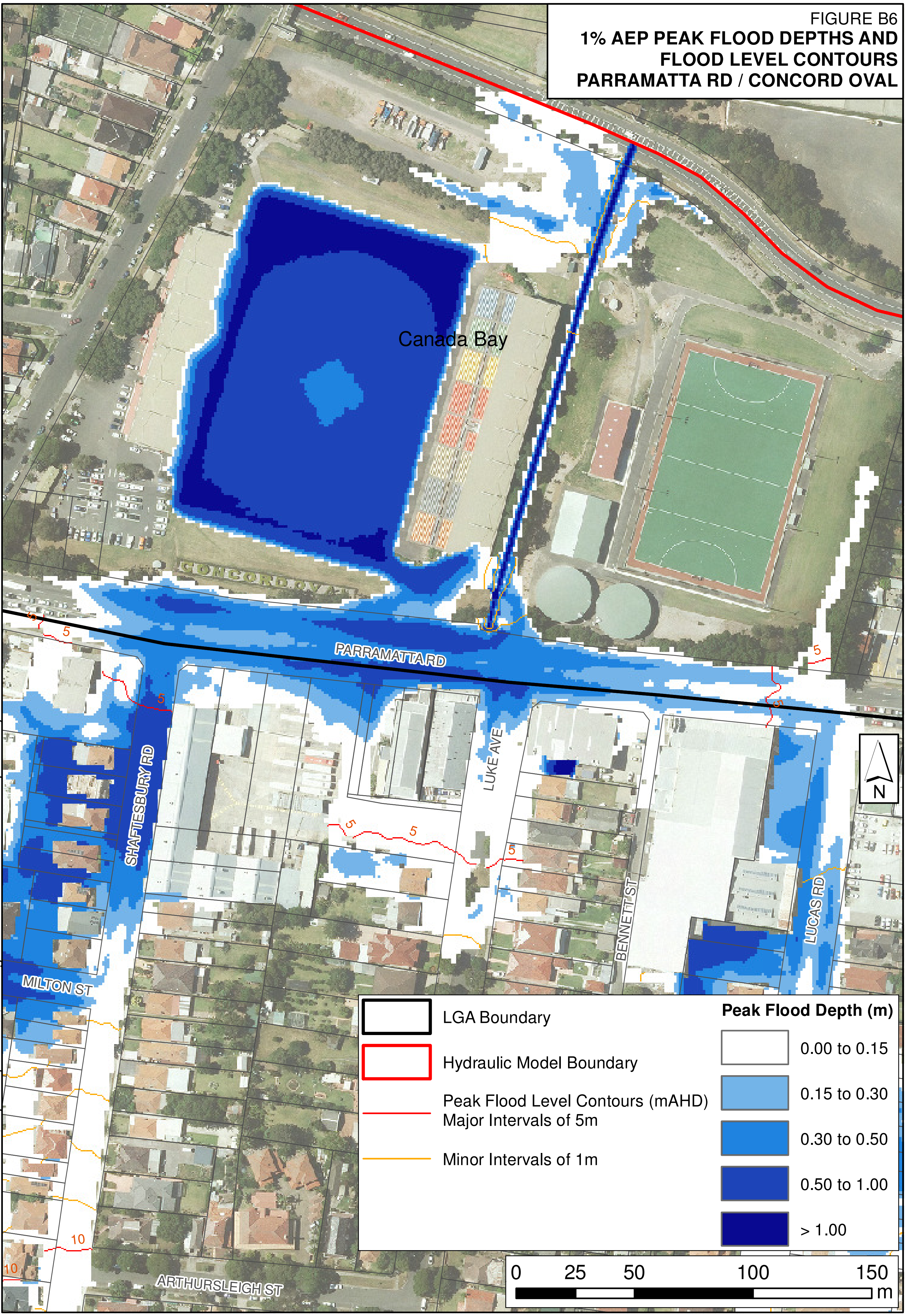
FIGURE B6
1% AEP PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS PARRAMATTA RD / CONCORD OVAL



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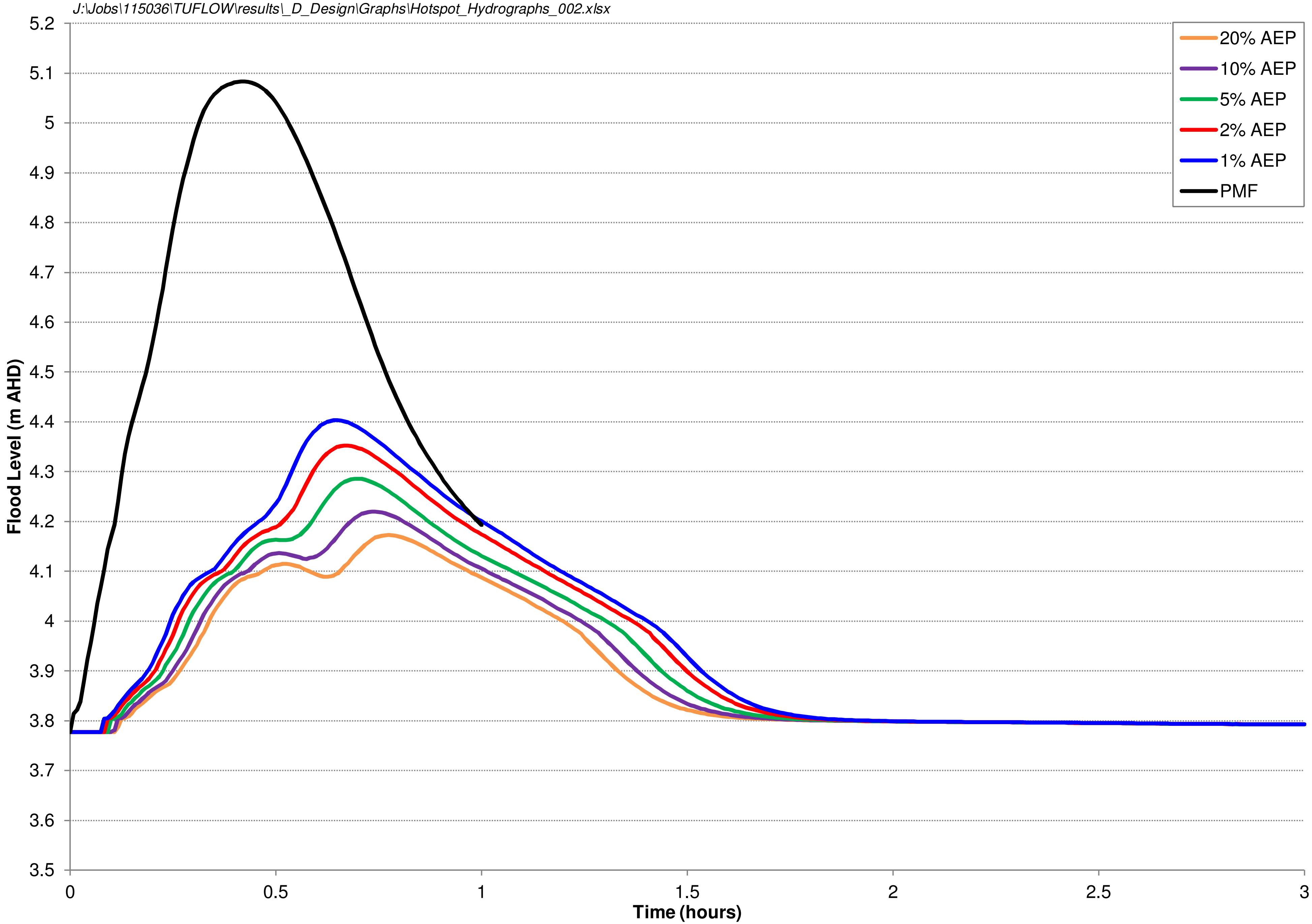


FIGURE B7
DESIGN HYDROGRAPHS
H03 - PARRAMATTA ROAD - CONCORD OVAL

FIGURE B8
5% AEP PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS PARRAMATTA RD / WENTWORTH RD

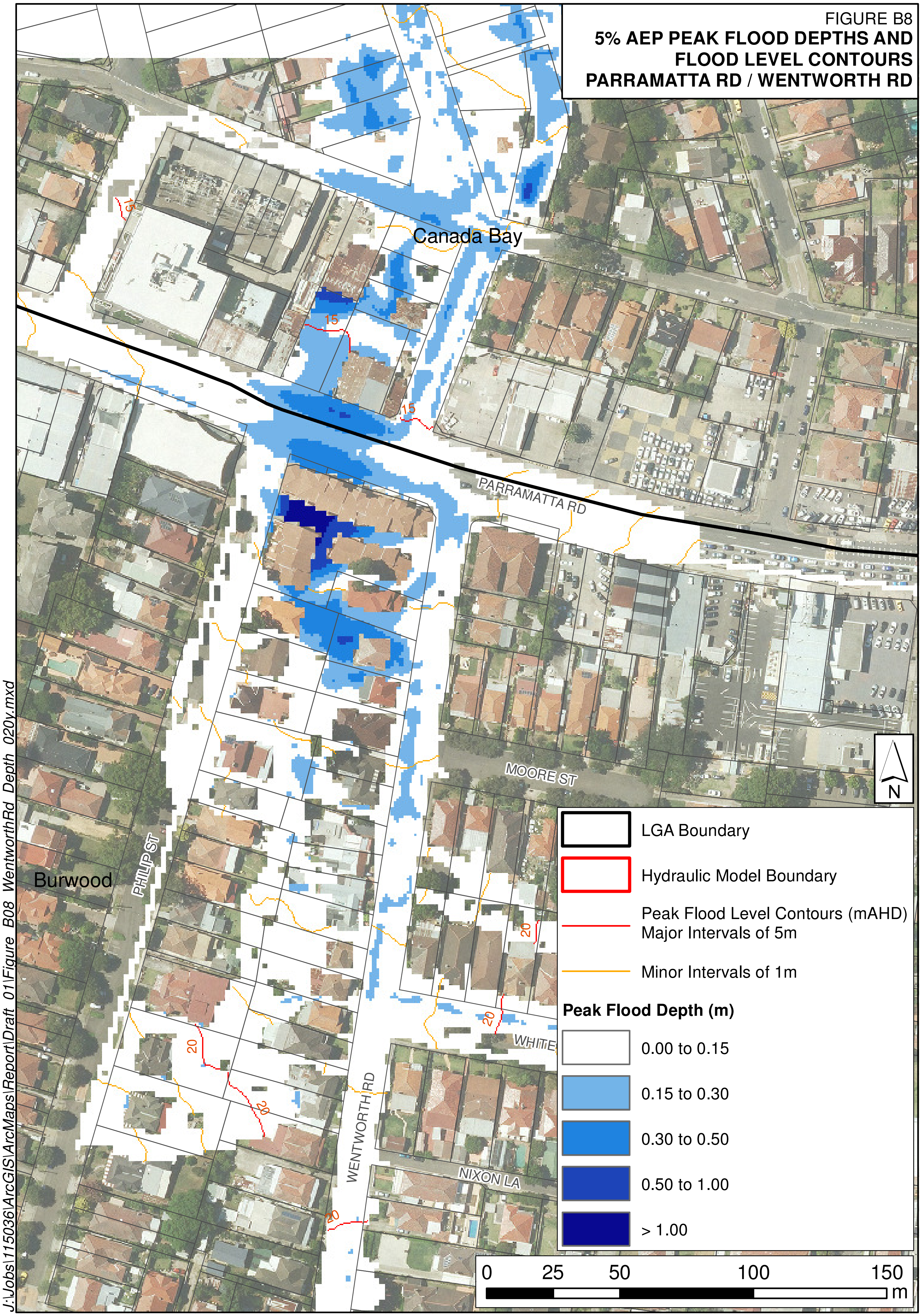
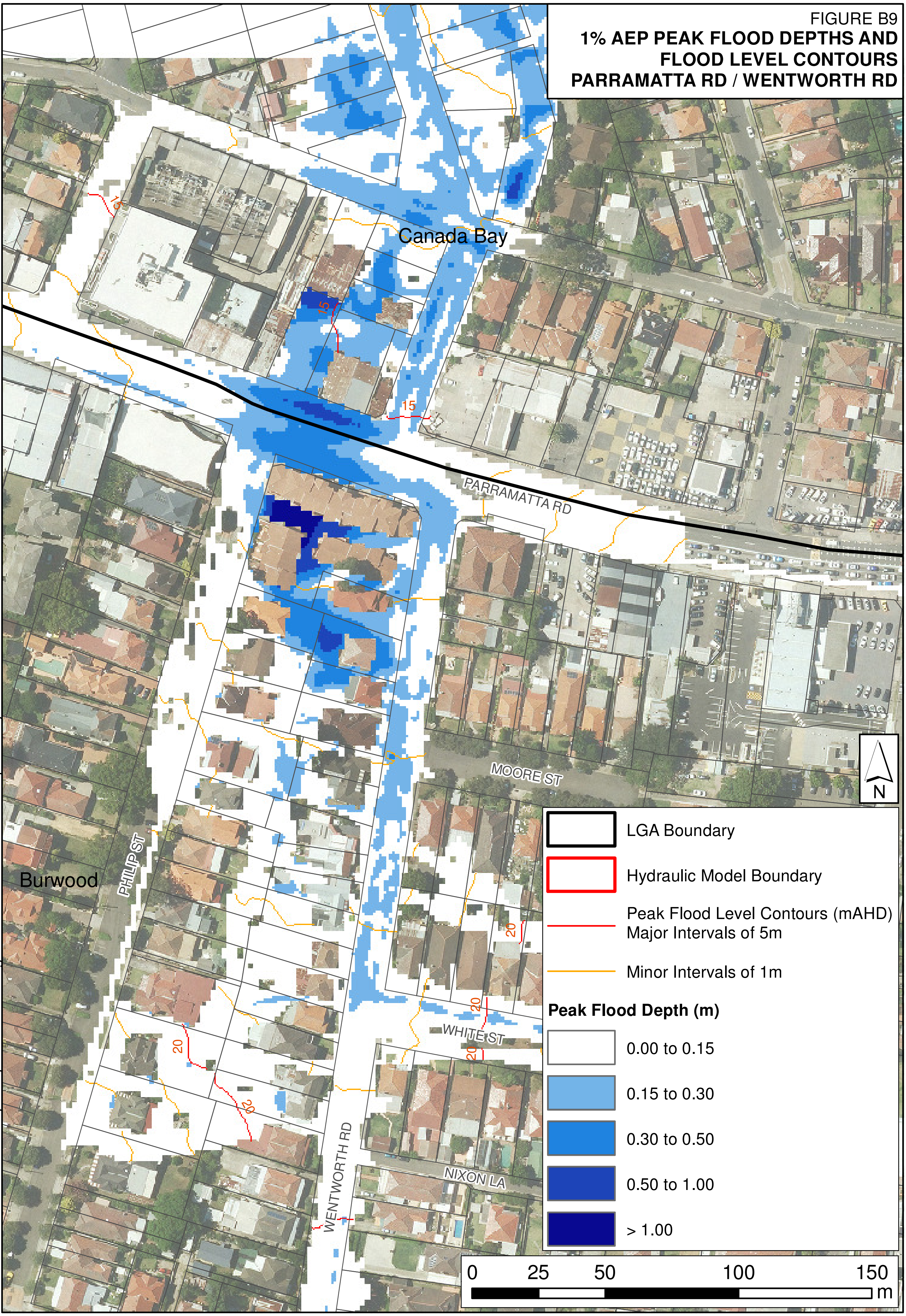


FIGURE B9

1% AEP PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS PARRAMATTA RD / WENTWORTH RD



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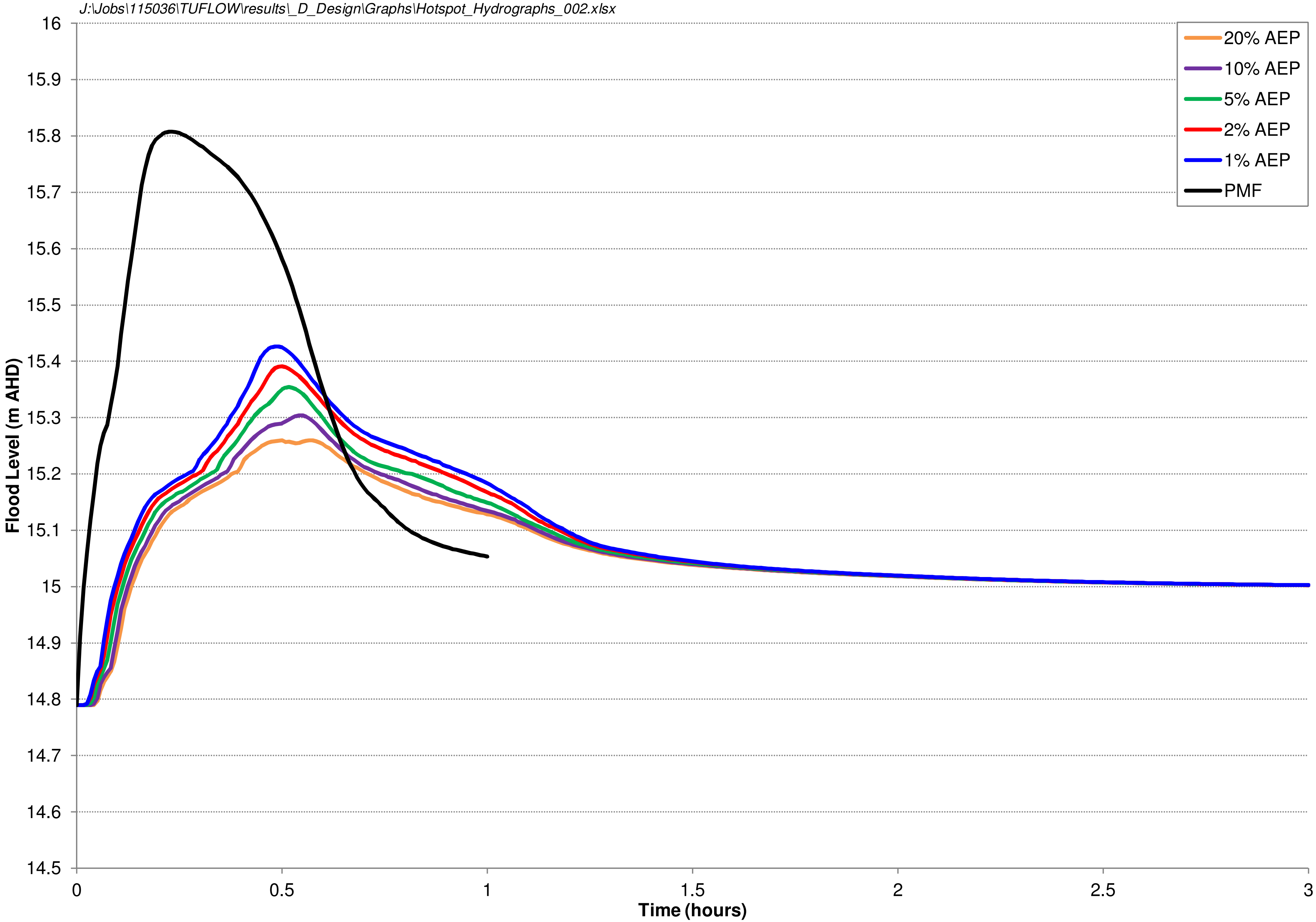

FIGURE B10
DESIGN HYDROGRAPHS
H01 - PARRAMATTA ROAD - WENTWORTH ROAD

FIGURE B11

5% AEP PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS SHAFTESBURY RD / BURWOOD RD

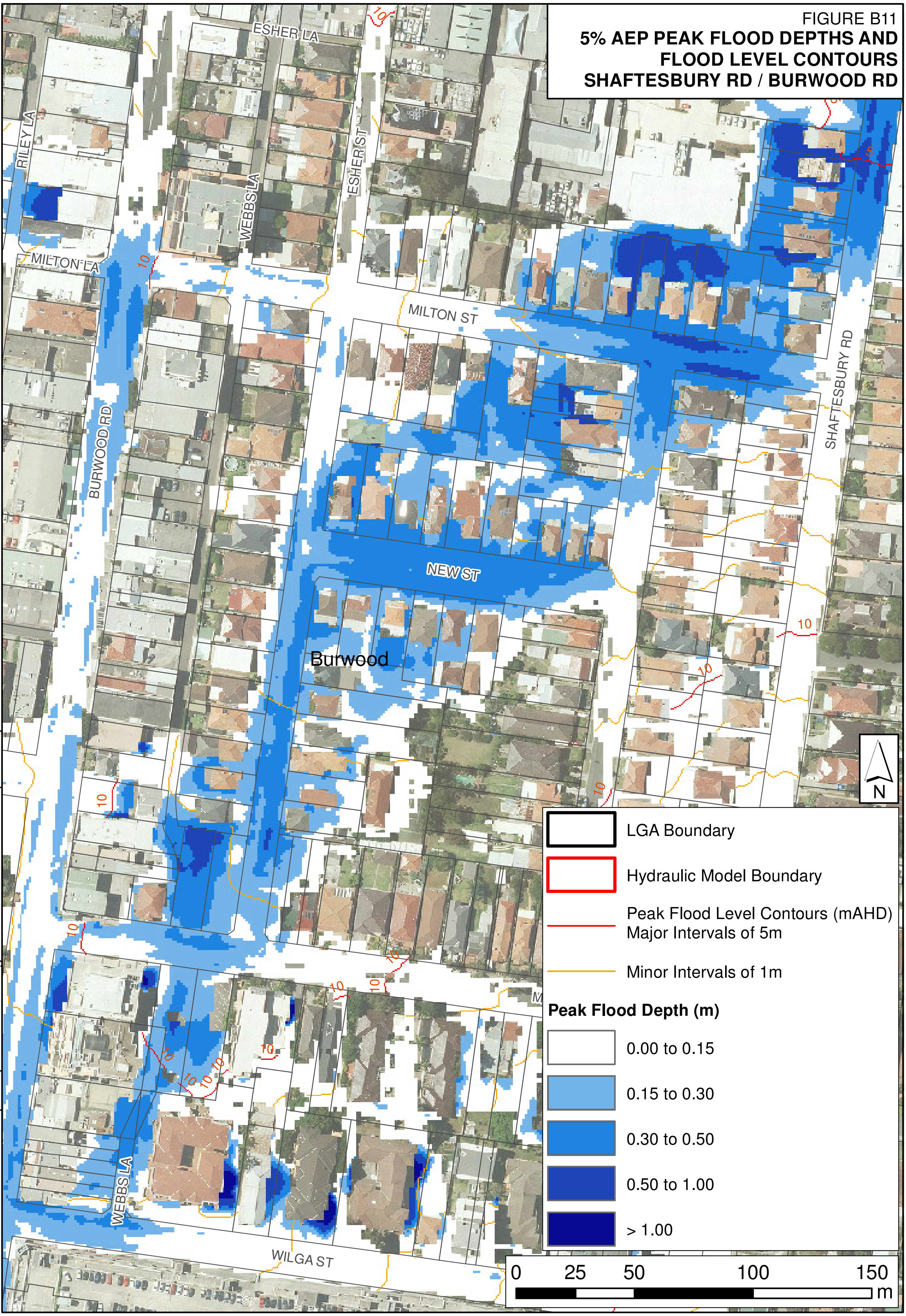

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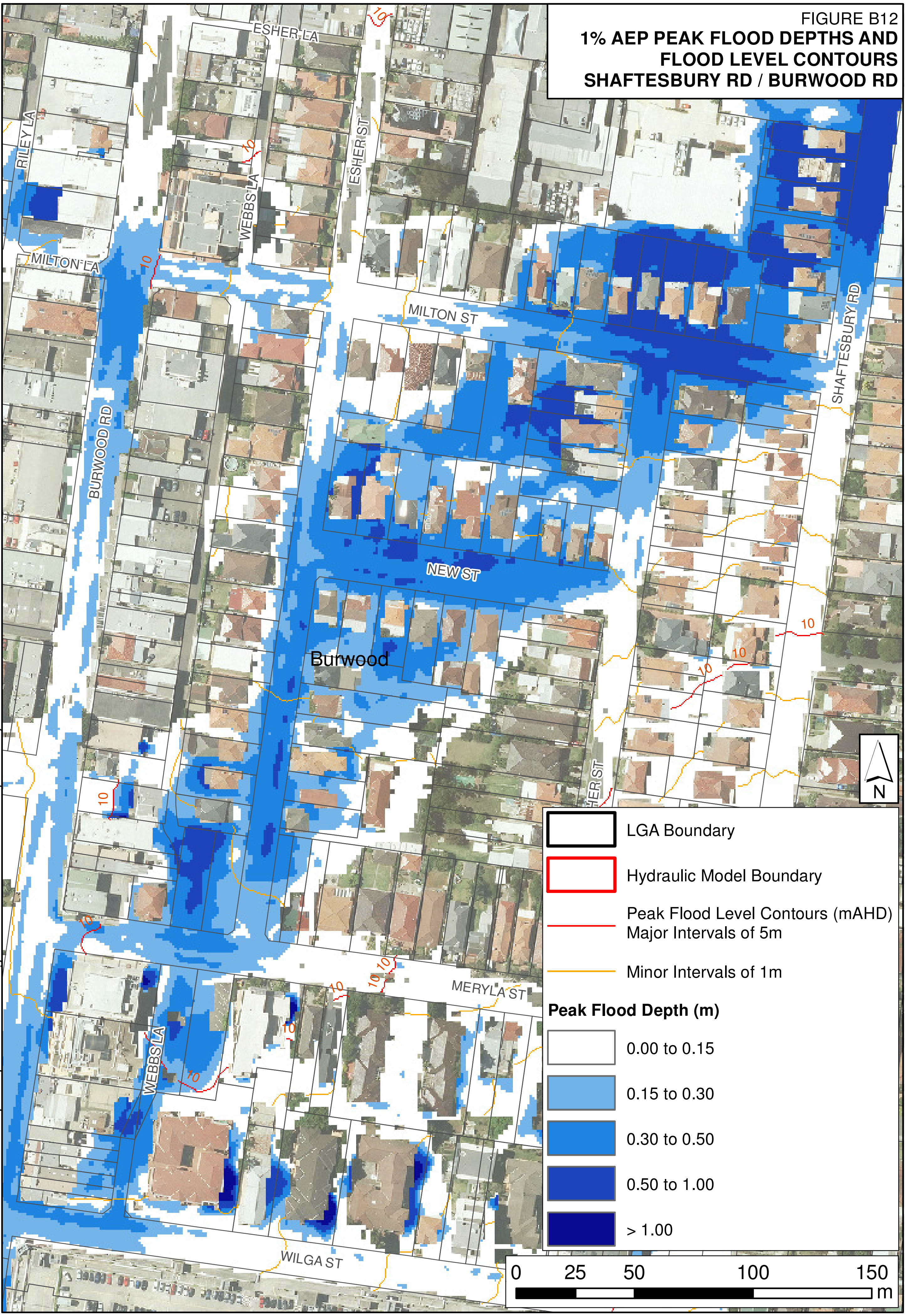
FIGURE B12

1% AEP PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS SHAFTESBURY RD / BURWOOD RD



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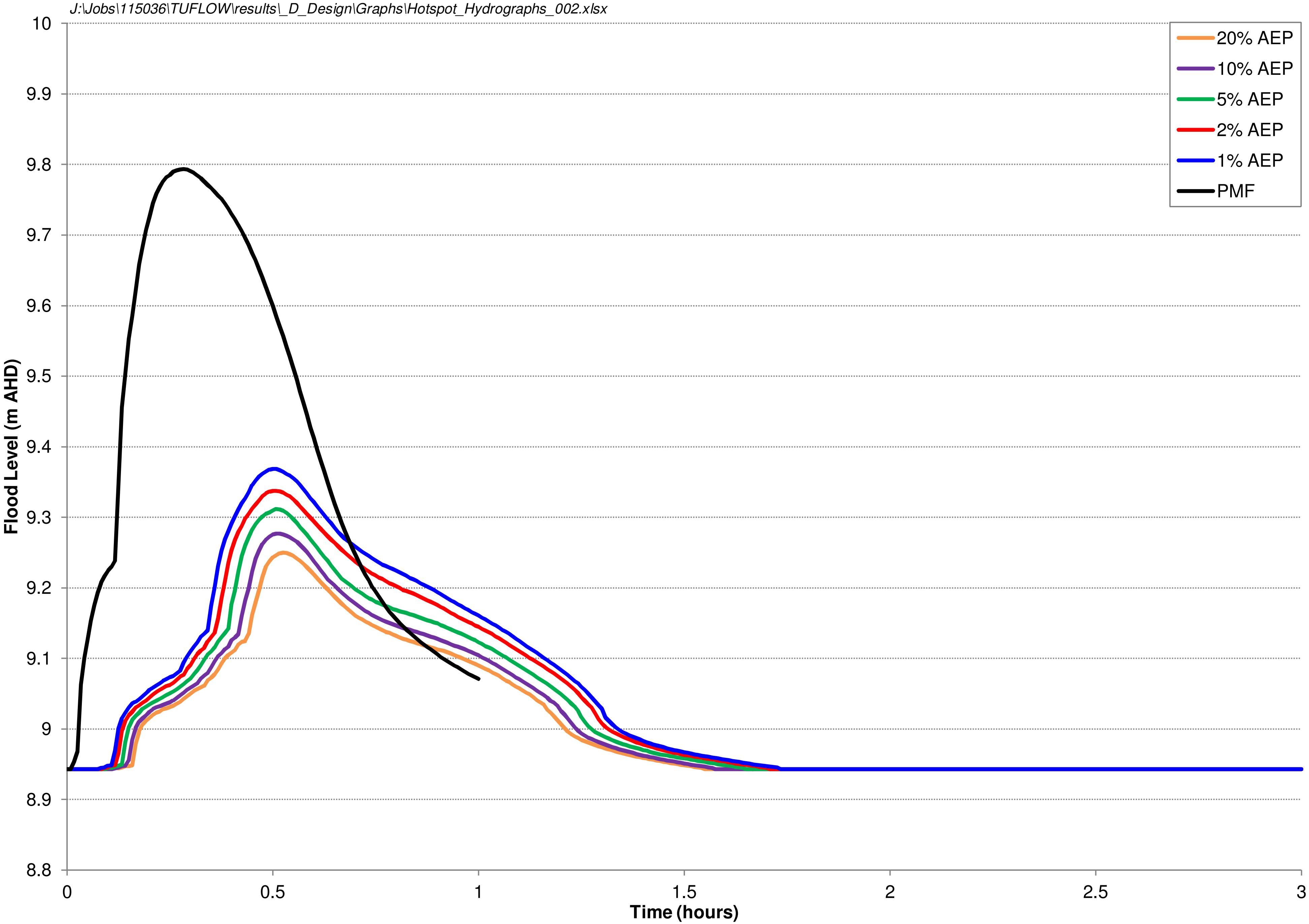

FIGURE B13
DESIGN HYDROGRAPHS
H05 - MERYLA STREET

FIGURE B14
5% AEP PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS RAILWAY PARADE

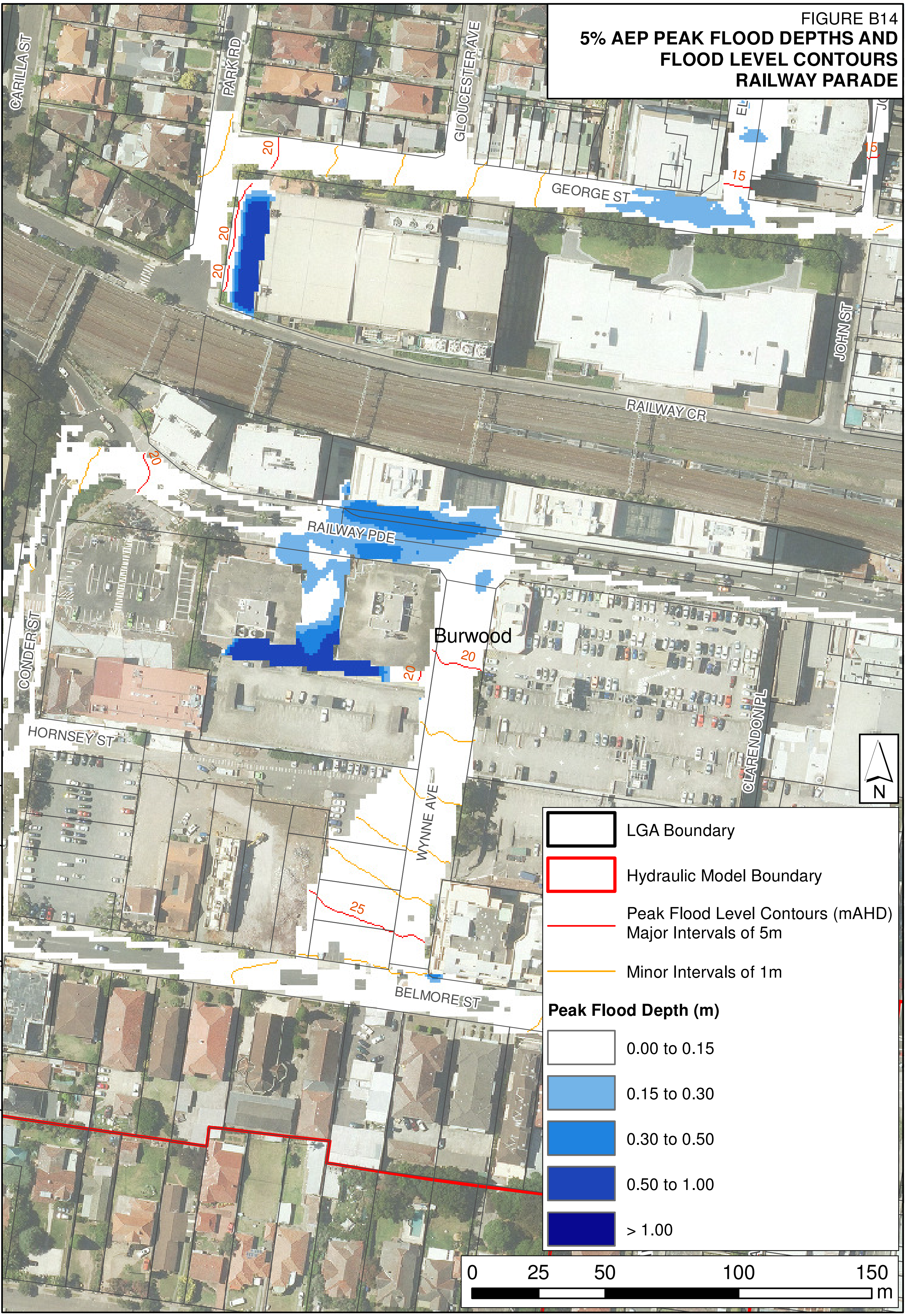

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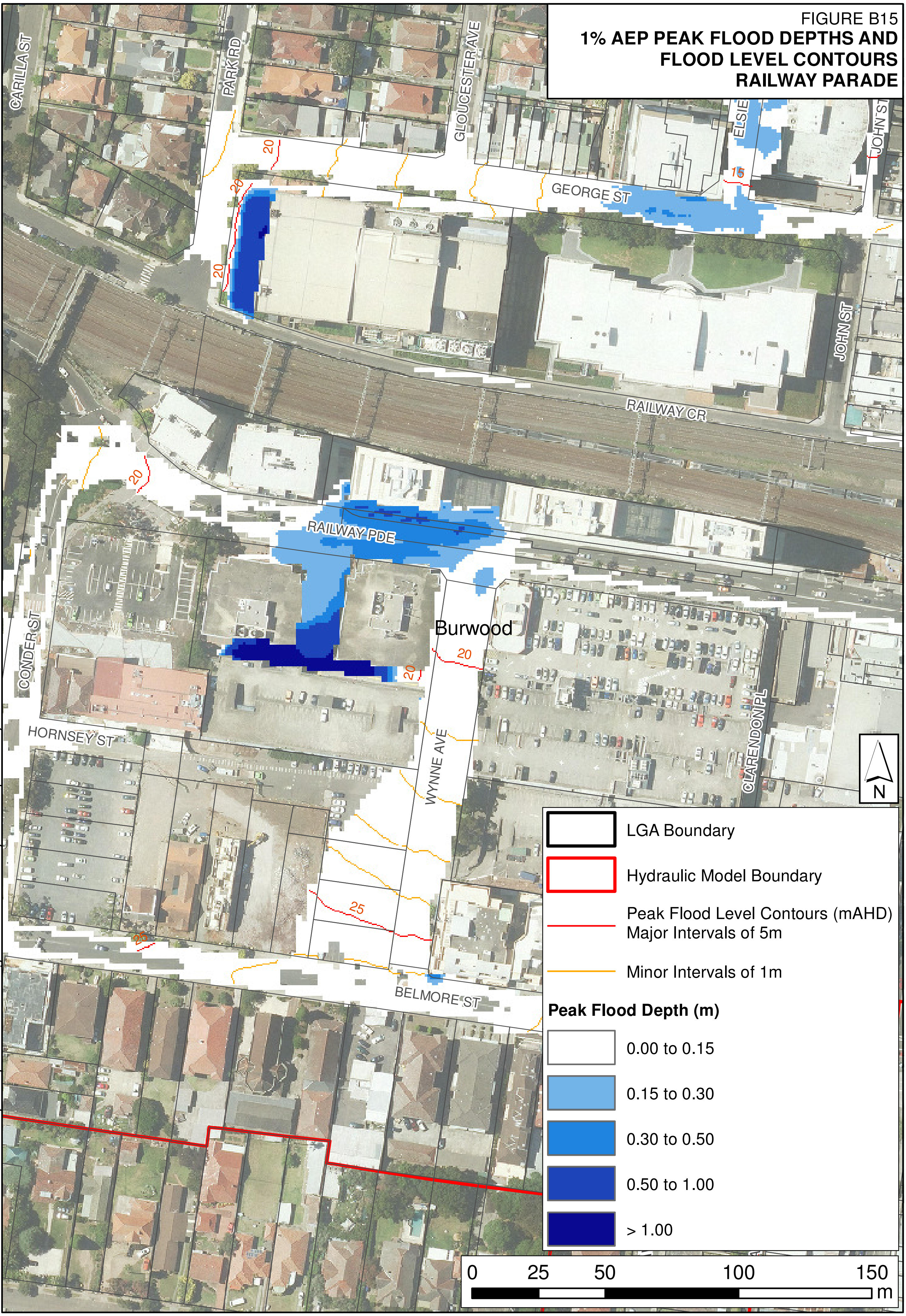
FIGURE B15
1% AEP PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS RAILWAY PARADE



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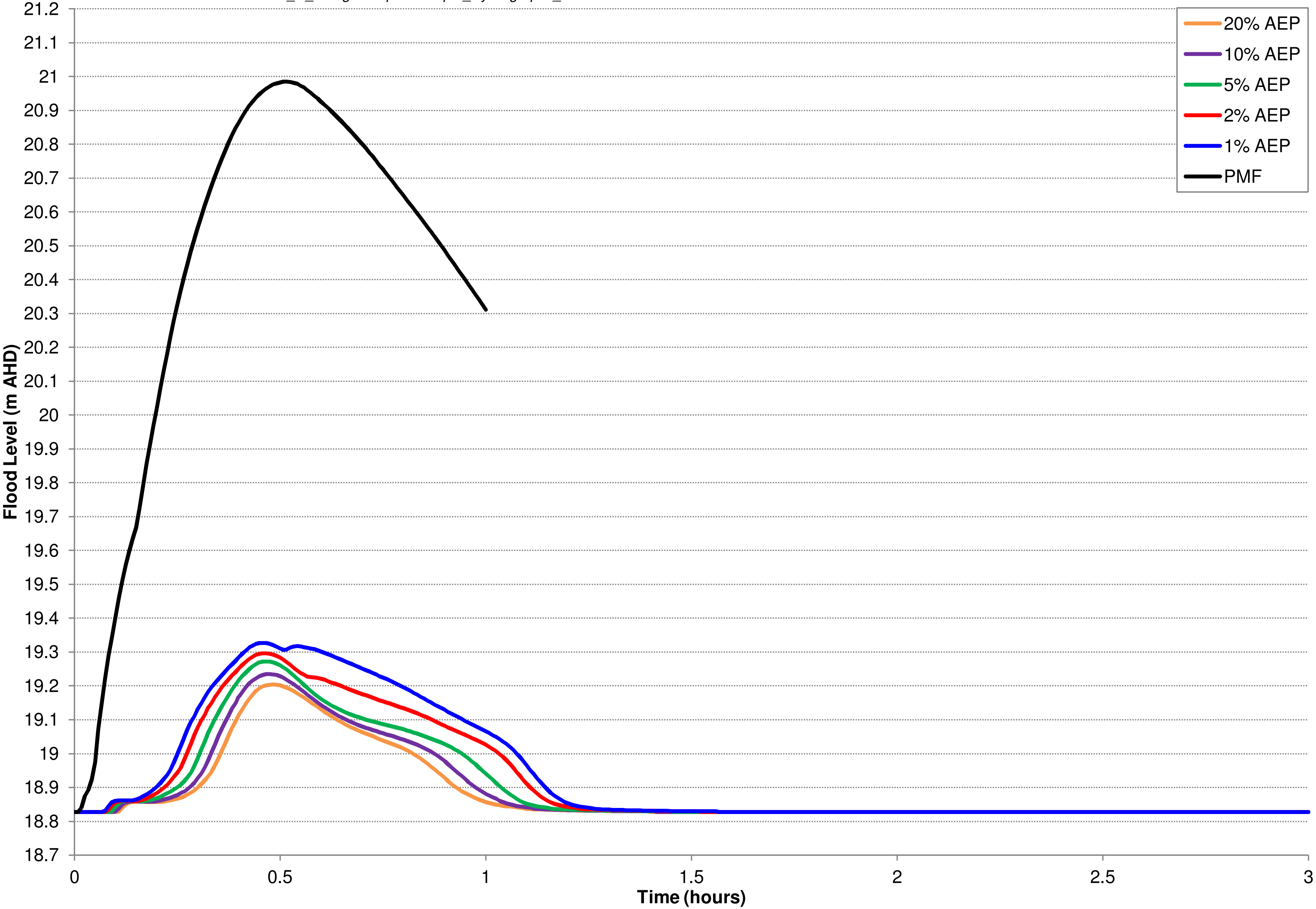

FIGURE B16
DESIGN HYDROGRAPHS
H08 - RAILWAY PARADE