INNER WEST COUNCIL

ALEXANDRA CANAL

FLOOD STUDY

FINAL REPORT

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MAY 2017

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LIST OF ABBREVIATIONS

1D	One dimensional hydraulic computer model
2D	Two dimensional hydraulic computer model
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ALS	Airborne Laser Scanning, sometimes known as LiDAR
AR&R	Australian Rainfall and Runoff
ARI	Average Recurrence Interval
BoM	Bureau of Meteorology
CBD	Central Business District
CFERP	Community Flood Emergency Response Plan
CSIRO	Commonwealth Scientific and Industrial Research Organisation
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
IFD	Intensity, Frequency and Duration of Rainfall
ILSAX	Hydrologic model - a precursor to DRAINS
IPCC	Intergovernmental Panel on Climate Change
IWC	Inner West Council
LEP	Local Environmental Plan
LGA	Local Government Area
LiDAR	Light Detection and Radar, sometimes known as ALS
LP3	Log Pearson III probability distribution
LPI	Land and Property Information
m	metre
m/s	metres per second (velocity measurement)
m^3/s	cubic metres per second (flow measurement)
MHL	Manly Hydraulics Laboratory
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
SEPP	State Environmental Planning Policy
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)

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.

EXECUTIVE SUMMARY

Background

The Alexandra Canal catchment is located in Sydney's Inner West region, approximately 7.5km from the CBD. The catchment includes the suburbs of Tempe, St Peters, Alexandria and Mascot. The Local Government Areas (LGAs) that are within the Alexandra Canal catchment are City of Sydney, former Marrickville Council, Botany Bay Council and Randwick Council. The study area contains the portion of the Alexandra Canal catchment that lies within the former Marrickville Council Area.

Objectives

The purpose of this Flood Study is to identify local overland flow as well as mainstream flow and define existing flood liability. This objective is achieved through the development of a suitable model that can also be used as the basis for a future Floodplain Risk Management Study and Plan for the study area, and to assist the Inner West Council (IWC) when undertaking flood-related planning decisions for existing and future developments.

The primary objectives of the study are 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;
- determine provisional residential flood planning levels and flood planning area;
- prepare preliminary emergency response classifications for communities; and
- assess the sensitivity of flood behaviour to potential climate change effects such as increases in rainfall intensities and sea level rise.

Flooding Behaviour

There are three main overland flow paths that exist in the study area, all originating along the Princes Highway: Smith St to Cooks River draining into Tempe Wetlands and Cooks River, from Sutherland Street to the Smith Street draining into the railway corridor and the container yard, and from Silver Street to Sutherland Street training into Canal Road.

The Smith Street overland flow path drains south-south-west along the Princes Highway and diverts along the streets to the south-east towards South Street. Some of this flow enters Tempe Wetlands and the remaining flow is conveyed along South Street towards Station Street and ultimately into the Cooks River. This area is also significantly affected by mainstream flooding of the Cooks River up to Station Street; the drainage again is into Cooks River.

The Sutherland Street flow path drains towards the railway corridor on either side. This flows from the south-west side over the Ikea carpark and part of the shipping container yard at Swamp Road and into the railway corridor/northern lands carpark. From the north-east flows across the maritime services container yard, into the freight loading railway line and eventually into the

railway corridor.

The Silver Street flow path drains to Canal Road and into Alexandra Canal. Overland flow reaches the low point on the Princes Highway at the Canal Road intersection and is forced south-east along Canal Road towards Alexandra Canal, pooling at the low point at the intersection between Canal Road and Burrows Road.

Additionally, local low points exist that pool flood waters outside of the major overland flow paths; namely Barwon Park Road, Short Street and Edith Street.

1. INTRODUCTION

1.1. Background

The study was commissioned by the former Marrickville Council (now the Inner West Council), with the assistance of the NSW Government Office of Environment and Heritage (OEH). Additional information has been provided by Sydney Water Corporation (SWC).

1.2. Description of the Study Area

Alexandra Canal has a total catchment area of approximately 1565 ha, which drains into the Alexandra Canal and Cooks River. Of this area, 1140 ha is within the City of Sydney LGA, 230 ha is within the former Marrickville Council LGA, 51 ha is within Botany Bay LGA, and 51 ha is within Randwick Council LGA. The study area contains the portion of the Alexandra Canal catchment that lies within the former Marrickville Council Area and is shown in Figure 1.

The study area is a fully developed urban area, with predominantly industrial areas and semi-detached and terrace housing. There exist some areas of large open space such as Tempe Recreational Reserve, Kendrick Park, Tempe Golf Driving Range, Tempe Park as well as other open industrial use areas such as Boral Concrete.

A number of locations within the catchment are flood liable. The flood liability relates to the nature of the topography within the study area as well as the capacity of service provided by drainage assets. The topography of the region is fairly steep, with ridges existing along the north-west edge of the catchment which turns to flat, low floodplain near the canal to the east of Tempe Golf Driving Range at the south-east edge of the catchment. A freight railway line (Australian Rail Track Corporation Network) runs through the centre of the catchment adjacent to Bellevue St and under the Princes Highway, collecting flow from the Princes Highway and open areas adjacent to the line like Boral Concrete. This flow collects on the low-lying track and carries it east-south-east towards Alexandra Canal.

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 50% AEP, 20% AEP, 10% AEP, 5% AEP, 2% AEP and 1% AEP design storms and the Probable Maximum Flood (PMF) in the Alexandra Canal catchment 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;
- determine provisional residential flood planning levels and flood planning area;
- prepare preliminary emergency response classifications for communities; and

- 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 the Alexandra Canal Catchment 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

2.2.1. LiDAR

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.

2.2.2. Ground and Floor Level Survey

Detailed survey of ground levels and floor levels at selected locations were obtained for the Alexandra Canal Catchment Drainage Study (report discussed in Section 2.9.4) carried out in 1997.

The current study utilised the ground level survey from the previous study to verify the LiDAR data employed in the current study (refer to Section 2.2). From this the average difference between the ground level survey and the LiDAR was found to be 0.04 m. The ground level survey locations are shown on Figure 2.

2.2.3. Tempe Wetlands Construction Drawings

Council provided the construction drawings for the Tempe Wetlands remediation and earthworks that was undertaken by Cardno Willing (NSW) Pty Ltd in 2004. This included the construction of three successive stormwater basins / ponds connected via 450mm diameter pipes, such that flow travels north to south through each of the basins. The Tempe Wetlands are located to the south-east of South Street and to the north-west of the Tempe Golf Driving Range.

The Tempe Wetlands had a fair amount of vegetation and still water within each basin / pond during the site visit discussed in Section 2.4. As the presence of heavy vegetation and water adversely affects the collection of LiDAR data (discussed in Section 2.2.1), the detailed construction drawings were considered to be more accurate and hence were appended to the digital elevation model used in the hydraulic modelling (discussed in Section 5.1).

2.2.4. Westconnex Stage 2: New M5

At the commencement of this flood study, the Australian and NSW State Government were in the process of undertaking design and approval for the WestConnex project. As part of the WestConnex project, a St Peters Interchange was proposed for the Alexandria Landfill site located between Canal Road, Campbell Street, the Princes Highway and Burrows Road, as well as a number of other roads nearby. Due to the proposal being in the preliminary concept design stage, the St Peters Interchange and associated construction works have not been included in this flood study.

2.3. Pit and Pipe Data

The pit data provided was not complete with missing pit invert levels across the pit network. Hydrographic & Cadastral Survey Pty. Ltd. were engaged to carry out a GPS survey on accessible pits in the Alexandra Canal area where pit invert levels were not available. Pit blockages due to vegetation and pits that are now sealed due to redevelopment at a site also resulted in pits not being surveyed. A summary of the number of pits surveyed is presented in Table 1.

Table 1: Pit Survey Summary

Requested	97
Surveyed	51
Unreachable	28
Not surveyed (other reason)	18

2.4. Site Visit

Site visits to the study area are often carried out through the course of the flood study to gain an understanding of catchment details and to inform the model flood behaviour.

WMAwater conducted a site visit on Thursday 14th July 2016. A selection of photographs taken during the site visit is shown on Figure 4. Hydraulic structures (such as bridges), the Tempe Wetlands and preliminary hotspot locations were the primary focus of the site visit.

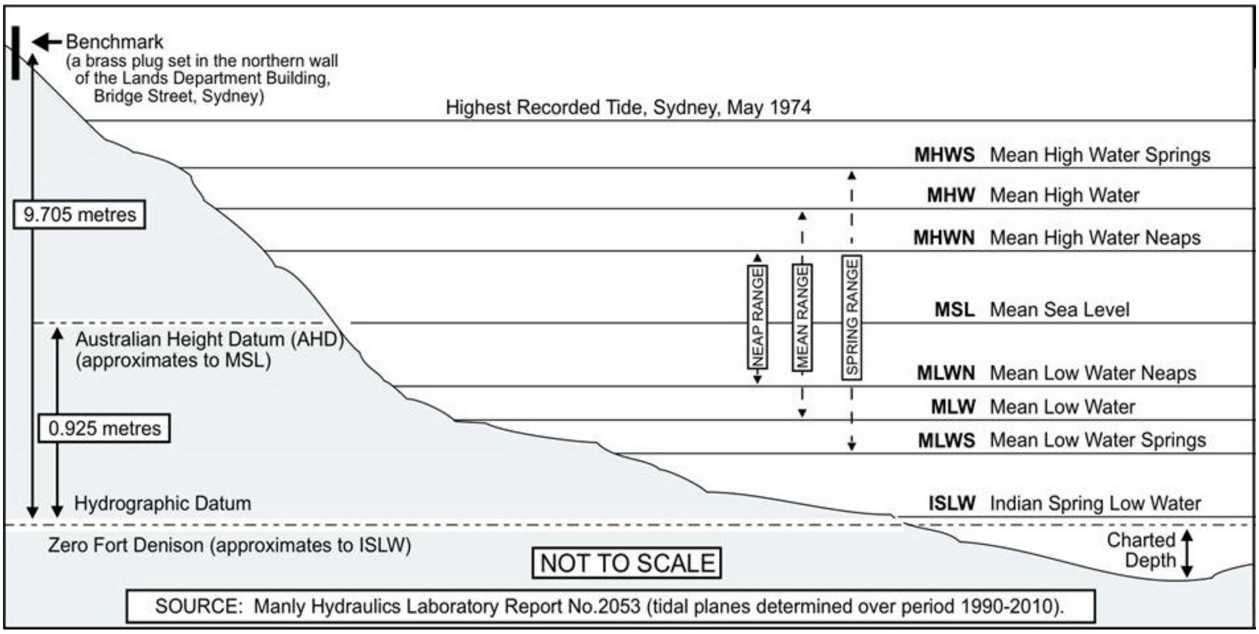
2.5. NSW Tidal Planes Analysis

Manly Hydraulics Laboratory prepared the *NSW Tidal Planes Analysis: 1990-2010 Harmonic Analysis* report on behalf of the NSW Office of Environment and Heritage. It was released in October 2012 and was based on data from 188 tidal monitoring stations from the 1st July 1990 to the 30th June 2010. Data from the relevant stations are shown in Table 2.

Table 2: Tidal Planes Analysis Results (MHL, 2012)

Tidal Planes	Annual Average Amplitude (m AHD)		
	Ocean Tide Gauge – Sydney's Port Jackson (213470)	Ocean Tide Gauge – Port Hacking (213473)	Station Locations – Cooks River at Tempe Bridge (213415)
High High Water Solstices Springs (HHWSS)	0.995	1.039	1.055
Mean High Water Springs (MHWS)	0.647	0.68	0.696
Mean High Water (MHW)	0.524	0.561	0.572
Mean High Water Neaps (MHWN)	0.401	0.441	0.447
Mean Sea Level (MSL)	0.02	0.066	0.057
Mean Low Water Neaps (MLWN)	-0.361	-0.309	-0.334
Mean Low Water (MLW)	-0.484	-0.429	-0.458
Mean Low Water Springs (MLWS)	-0.607	-0.549	-0.582
Indian Spring Low Water (ISLW)	-0.856	-0.805	-0.839

Diagram 1: Tidal Planes Diagram



2.6. Historical Flood Level Data

2.6.1. SWC Historic Flood Database

A historic flood database was supplied by SWC and provided information on flooding within the two parallel Flood Studies (the current Alexandra Canal Flood Study; and the Johnstons Creek and Whites Creek Flood Study). However, there is no available data for the Alexandra Canal catchment contained within the database.

2.6.2. Council's Complaints Database

A historic flood database was supplied by Council and provided information on flooding within the study area. This included a complaint regarding drainage on the Princes Highway and another regarding tidal inundation on Holbeach Avenue, Bay Street, Old Street, Tempe Reserve, Illawarra Road, Wharf Road, Riverside Crescent and Mackey Park (the latter four were outside of the study area, in the upstream Cooks River Catchment).

The tidal inundation issues occurred in January 2014 and were investigated by the SES (and subsequently provided to Council). The SES found that the January 2014 period of inundation occurred during a period of high tide levels and no recorded rainfall within the preceding 24 hour period. The maximum river height recorded during the period investigated was 1.41 m AHD at Tempe Bridge. The photographs taken by the SES on the 2 January 2014 are shown below.

Photo 1: Holbeach Avenue

Photo 2: Holbeach Avenue

Photo 3: Bay Street

Photo 4: Old Street

2.6.3. Community Consultation

A community consultation process was undertaken in collaboration with Council at the commencement of this study; with the community consultation process ending on the 29 April 2016. This included distribution of an information sheet and a questionnaire to gather information pertaining to the community's experience of flooding within the catchments. Council undertook this distribution to all properties within the study area, a total of 953.

The response rate for the questionnaire was 0.8%. Major points raised during the consultation were:

- All of the flooding responses received were contained in the area to the south-east of the Princes Highway near the Cooks River. These were either along the main overland flow path or within localised topographical depressions.
- One response included above floor level flooding in South Street between Barden and Fanning Streets which is located in the same flood-affected area described above. The resident did not say what event caused this flooding. Flood damage was estimated at $5,000.
- Most of the responses did not list the event that caused flooding; whereas two responses selected flooding in every event on the questionnaire (April 2015, October 2014, March 2014, and March 2012).

A summary of community consultation flood respondent locations is shown in Figure 5, and a summary of all responses received is shown in Figure 6.

2.7. 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.

2.7.1. Rainfall Stations

Table 3 presents a summary of the official rainfall gauges (sourced from the Bureau of Meteorology) located within 7 km of the catchment and Figure 7 shows the location of these rainfall gauges. This includes daily read stations, continuous pluviometer stations, operational stations and synoptic stations. Sydney Water Corporation (SWC) or the Bureau of Meteorology (BOM) operate these gauges.

Table 3: Available Rainfall Stations

Station Number	Station Name	Operating Authority	Distance from centre of study area (km)	Elevation (mAHD)	Date Opened	Date Closed	Type
66101	Fernbank	BOM (AUS)	0.54		01/01/1889	1/01/1913	Daily
566026	Marrickville Sps	SWC (NSW)	1.33	5	1/05/1904		Continuous
566026	Marrickville Sps	SWC (NSW)	1.33	5	1/05/1904		Daily
66021	Erskineville	BOM (AUS)	1.50	6	29/04/1904	29/12/1973	Daily
66037	Sydney Airport Amo	BOM (AUS)	2.22	6	1/01/1960		Continuous
66037	Sydney Airport Amo	BOM (AUS)	2.22	6	29/06/1994		Synop
66192	Sydney Airport Tbrg	BOM (AUS)	2.22	3	1/01/1993	1/01/1997	Continuous
66036	Marrickville Golf Club	BOMNS (NSW)	2.50	6	6/04/2001		Operational
66036	Marrickville Golf Club	BOM (AUS)	2.50	6	29/04/1904	29/12/1970	Daily
566091	Kyeemagh Bowling Club	SWC (NSW)	2.89	5	19/09/1991		Continuous
566110	Erskineville Bowling Club	SWC (NSW)	3.02	10	2/06/1993	8/02/2001	Continuous
66033	Alexandria (Henderson Rd)	BOM (AUS)	3.39	15	29/04/1962	29/12/1963	Daily
66033	Alexandria (Henderson Rd)	BOM (AUS)	3.39	15	30/03/1999	12/03/2002	Daily
66097	Ranwick Bunnerong Rd	BOM (AUS)	4.45		1/01/1904	1/01/1924	Daily
66015	Crown St. Reservoir	BOM (AUS)	4.46		30/01/1882	29/12/1960	Daily
66074	Rockdale Bowling Club	BOM (AUS)	4.52	22.9	1/01/1949	1/01/1974	Daily
66007	Botany No.1 Dam	BOM (AUS)	4.68	6.1	01/01/1870	1/01/1978	Daily
566028	Mascot Bowling Club	SWC (NSW)	4.83	5	28/08/1973		Continuous
566028	Mascot Bowling Club	SWC (NSW)	4.83	5	28/08/1973		Daily
66018	Earlwood Bowling Club	BOM (AUS)	4.94	31.1	30/07/1914	29/12/1975	Daily
566113	Canterbury Racecourse	SWC (NSW)	4.95	3	9/12/1993	1/02/2001	Continuous
566112	Ashfield (Ashfield Park Bowling Club)	SWC (NSW)	5.08	20	2/12/1993	1/02/2001	Continuous
566065	Annandale	SWC (NSW)	5.09	20	21/12/1988		Continuous
66000	Ashfield Bowling Club	BOM (AUS)	5.11	25	30/03/1896		Daily
66165	Ashfield Prospect Rd	BOM (AUS)	5.32	43	01/01/1894	1/01/1904	Daily
66194	Canterbury Racecourse AWS	BOM (AUS)	5.36	3	2/10/1995		Synop

Station Number	Station Name	Operating Authority	Distance from centre of study area (km)	Elevation (mAHD)	Date Opened	Date Closed	Type
566099	Randwick Racecourse	SWC (NSW)	5.57	30	29/11/1991		Continuous
66073	Randwick Racecourse	BOM (AUS)	5.63	25	1/01/1937		Daily
566062	Bexley Bowling Club	SWC (NSW)	5.85	25	24/05/1988	8/02/2001	Continuous
66004	Bexley Bowling Club	BOM (AUS)	5.90	30	27/02/1931	1/07/2008	Daily
66132	Carlton	BOM (AUS)	5.97	30.5	30/01/1907	29/12/1924	Daily
66139	Paddington	BOM (AUS)	6.17	4.6	1/01/1968	1/01/1976	Daily
66149	Glebe Point Syd. Water Supply	BOM (AUS)	6.23	15.2	30/05/1907	29/12/1914	Daily
66150	Canterbury Heights	BOM (AUS)	6.37	61	30/08/1906	29/12/1916	Daily
566032	Paddington (Composite Site)	SWC (NSW)	6.52	45	10/04/1961		Continuous
566032	Paddington (Composite Site)	SWC (NSW)	6.52	45	10/04/1961		Daily
213008	Duck Pond	DNR (NSW)	6.65				
66160	Centennial Park	BOM (AUS)	6.72	38	30/05/1900		Daily
213007	Busby Bore Pond	DNR (NSW)	6.87				
66052	Randwick Bowling Club	BOM (AUS)	6.94	75	01/01/1888		Daily

2.7.2. Analysis of Daily Read Data

An analysis of the records for the nearest complete data daily rainfall stations, namely Sydney Airport Amo (66037), Randwick Racecourse (66073) and Marrickville Golf Club (66036). The Sydney Airport (66037) gauge and the Randwick (66073) gauge are proximate to the study area and have a relatively long period of record; having been established in 1929 and 1937, respectively. The Marrickville (66036) gauge despite being proximate to the study area and established in 1904; appeared to have gaps in the data covering the periods from:

- January 1926 to November 1948;
- January 1949 to January 1966; and
- November 1970 to July 2001.

Table 4: The 15 highest daily rainfall totals at Sydney Airport Amo, Randwick Racecourse and Marrickville Golf Club

Sydney Airport Amo (66037)		
September 1929 –to date		
Rank	Date	Rainfall (mm)
1	3/02/1990	216.2
2	10/02/1956	207.8
3	6/08/1986	207
4	11/03/1975	202
5	13/12/1963	182.1
6	4/02/1990	177.8
7	30/04/1988	174
8	1/05/1955	165.9

Marrickville Golf Club (66036)		
April 1904 – to date		
Rank	Date	Rainfall (mm)
1	9/03/1913	215.9
2	14/11/1969	143.5
3	13/01/1911	139.7
4	10/07/1904	127
5	15/10/2014	124
6	21/04/2015	123
7	5/02/2002	118
8	27/04/1966	116.3

9	8/01/1973	157
10	11/06/1991	151.2
11	14/11/1969	143.3
12	28/03/1942	139.4
13	27/11/1955	138.4
14	23/01/1933	135.1
15	11/03/1958	134.4

9	5/05/1919	111.8
10	16/04/1969	108.2
11	22/07/2011	105
12	28/07/1908	104.1
13	22/04/2015	104
14	5/06/2016	104
15	2/04/1905	101.6

Randwick Racecourse (66037)		
January 1937 – to date		
Rank	**Date**	**Rainfall (mm)**
1	10/02/1992 (2 days)	294
2	20/11/1961 (4 days)	270.3
3	30/10/1959	266.7
4	6/08/1986	263
5	11/03/1975	261
6	14/05/1962 (3 days)	258.1
7	10/02/1958 (2 days)	255.8
8	5/02/1990 (2 days)	248
9	3/02/1990	244
10	9/11/1984	240
11	20/03/1978	236.8
12	6/11/1984	223
13	28/03/1942	213.1
14	31/01/1938	211.3
15	10/02/1956	195.1

The results indicate that the 1992, 1986 and 1959 events were the largest daily rainfall events since records began on these gauges.

However, high daily rainfall totals will not necessarily result in widespread flooding of the catchment, 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. This is evident in that the April 2015 event that caused flooding in neighbouring catchments does not show up on the highest daily totals for Sydney Airport or Randwick, and is ranked thirteenth for Marrickville.

2.7.3. Analysis of Pluviometer Data

Continuous pluviometer records provide a more detailed description of temporal variations in rainfall. As such, the Marrickville SPS (566026), Erskineville Bowling Club (566110), Randwick Racecourse (566099) and Kyeemagh Bowling Club (566091) stations were analysed.

These pluviometer stations are all operated by SWC. The four gauges remain in operation. The Marrickville gauge was established in 1979, with sub-daily records beginning in Jan 1980. The

Kyeemagh gauge was established in 1990, with sub-daily records beginning in September 1991. The Erskineville gauge was establish in 1993. The Randwick gauge was established in 1991.

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
Marrickville SPS (566026)	36	10 – 20 year ARI	10 – 20 year ARI
Erskineville Bowling Club (566110)	23	10 – 20 year ARI	20 – 50 year ARI
Randwick Racecourse (566099)	25	5 – 10 year ARI	2 – 5 year ARI
Kyeemagh Bowling Club (566091)	25	2 – 5 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 Erskineville pluviometer recorded the highest approximate ARI for the 30 minute and 1 hour storm burst. This occurred on the 10 April 1998 and corresponded to three reports of flooding in the nearby Whites Creek catchment (as provided by SWC).

The rainfall distribution and IFD analysis of the pluviometer data is shown on Figure 8, Figure 9 and Figure 10.

2.7.3.1. 30 January 2016

From Figure 9A, the 30 January 2016 event was found to be highly localised to the Strathfield South / Croydon Park / Belfield area (within the Strathfield, Burwood and Canterbury Council LGA's). Across the Alexandra Canal total catchment area this event was found to be less than a 1 year ARI event (or 1 E/Y event). This event was not used for calibration or validation of the models due to the small estimated ARI within the study area.

2.7.3.2. 25 April 2015

From Table 6, the April 2015 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 Erskineville Bowling Club gauge. The 2015 event also appears to have been highly localised as the other gauges recorded low approximate ARI's across the 30 minute, 1 hour and 2 hour storm durations.

Table 6: Rainfall Intensities for the 25 April 2015 Event

	Duration (minutes)		
	30	**60**	**120**
Marrickville SPS (566026)			
Max Rainfall (mm)	27	29.5	30.5
Intensity (mm/hr)	54	29.5	15.25
Approximate ARI	2 – 5y	1y	<1y
Rank comparative to gauge records for relevant duration	12	30	52
Kyeemagh Bowling Club (566091)			
Max Rainfall (mm)	5	6.5	7.5
Intensity (mm/hr)	10	6.5	3.75

Approximate ARI	<1y	<1y	<1y
Rank comparative to gauge records for relevant duration	673	606	680
Randwick Racecourse (566099)			
Max Rainfall (mm)	24	24	35
Intensity (mm/hr)	48	24	17.5
Approximate ARI	2 – 5y	<1y	<1y
Rank comparative to gauge records for relevant duration	15	29	15
Erskineville Bowling Club (566110)			
Max Rainfall (mm)	43.5	44.5	50
Intensity (mm/hr)	87	44.5	25
Approximate ARI	10y	2 – 5y	1 – 2y
Rank comparative to gauge records for relevant duration	3	4	6

2.7.3.3. 14 October 2014

From Figure 8C, the October 2014 event was found to be centred around the Bexley North area (within the Rockdale Council LGA). Within the study area this event was found to be less than a 10 year ARI event in the south-western area and less than a 5 year ARI in the north-eastern area. For this reason, the October 2014 event was not used for calibration or validation of the models.

2.7.3.4. 5 March 2014

The March 2014 event was centred around the Marrickville and Newtown area (shown on Figure 8D), however the estimated ARI of the event was less than a 1 year ARI event (or 1 EY event) across the Alexandra Canal catchment area and the surrounding areas (shown on Figure 9D and Figure 10D). For this reason, the March 2014 event was not used for calibration or validation of the models.

2.7.3.5. 7 March 2012

From Figure 10E, the March 2012 event was found to have rainfall distributed across the course of 24 hours; with no particular burst. The approximate ARI hovered within the 1 – 2 year ARI range for the majority of the event at the Erskineville (566110) gauge. Additionally, the March 2012 event was found to be distributed across a large area, shown in Figure 8E and Figure 9E. This event was not used for calibration or validation of the models due to the small estimated ARI within the study area.

2.7.3.6. 13 May 2003

The May 2003 event was a 1 hour storm that recorded the highest approximate ARI for the 30 minute and 1 hour burst at the Marrickville (566026) gauge, which the storm appeared to be centred around (shown in Figure 9F). Within the study area, the approximate ARI was within the 2 – 5 year ARI range. For this reason, the May 2003 event was not used for calibration or validation of the models.

2.7.3.7. 10 April 1998

The April 1998 event was a 3 hour storm that recorded the highest approximate ARI for the 30 minute and 1 hour burst at the Erskineville (566110) gauge, which the storm appeared to be centred around (shown in Figure 9G). The mainstream Alexandra Canal would have been affected by this 20 – 50 year ARI storm centre; however the overland flow within the study area would have been affected by the lower ARI of around the 5 – 10 year ARI.

Given the large period of time since this event occurred (almost 20 years), it is likely that the catchment conditions have changed and records of observed levels are likely to be scare or unreliable with residents moving etc. Due to this, the April 1998 event was not used for calibration or validation purposes.

2.7.3.8. 17 February 1993

The February 1993 event was a six hour storm with a 30 minute burst embedded within it (shown on Figure 10H). This event recorded the highest approximate ARI for the 30 minute and 1 hour burst at the Annandale (566065) gauge; with the storm centred around this area (shown on Figure 8H and Figure 9H).Within the study area this event was found to be less than a 5 year ARI event.

For similar reasons as those detailed for the April 1998 event, the February 1993 event was not used for calibration or validation purposes.

2.8. 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	100	128	163	182	208	242	267
6 minutes	93.9	120	152	171	195	227	251
10 minutes	76.9	98.7	126	142	163	190	210
20 minutes	56.4	72.8	94.3	107	123	145	162
30 minutes	45.9	59.5	77.7	88.4	102	121	135
1 hour	31.1	40.4	53.1	60.7	70.6	83.6	93.6
2 hours	20.1	26.2	34.5	39.4	45.8	54.3	60.8
3 hours	15.4	20	26.3	30.1	34.9	41.4	46.3
6 hours	9.75	12.6	16.5	18.8	21.8	25.7	28.7
12 hours	6.23	8.05	10.5	11.9	13.7	16.2	18
24 hours	4.05	5.22	6.79	7.71	8.91	10.5	11.7
48 hours	2.6	3.35	4.37	4.96	5.73	6.76	7.54
72 hours	1.93	2.5	3.24	3.68	4.25	5.01	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)
30 minutes	480
1 hour	350
2 hours	265
3 hours	213
6 hours	142

2.9. Previous Studies

2.9.1. Alexandra Canal Flood Study (Cardno, 2010)

Cardno prepared a flood study report for City of Sydney Council, preliminary draft submitted 23/12/2010 that examined the flood behaviour in the upstream regions of Alexandra Canal. The model comprised of the sub-catchments Sheas Creek, Roseberry, Munni Street-Erskineville and Alexandra Canal.

A dedicated hydrologic model was not used in the study, instead a Direct Rainfall method was employed in the hydraulic model, but the hydrology was verified with XP-RAFTS. The results were verified by comparing the results for a 100 year ARI event between the Direct Rainfall hydraulic model and the RAFTS hydrologic model, resulting in a reasonable representation of each other.

The hydraulic model that was to be used with the Direct Rainfall method was SOBEK, with the design rainfall intensity for the 30minute duration 100 year storm being 135 mm/h. The hydraulic model was calibrated to three events: November 1984, January 1991 and February 2001.

2.9.2. Alexandra Canal Catchment Model Conversion (BMT, 2016)

The model described in section 2.10.1 had its hydraulic model converted to TUFLOW the results from the converted model were used as the inflows into this model.

2.9.3. Cooks River Flood Study and Floodplain Risk Management Study and Plan (Parsons Brinckerhoff, 2009&WMAwater, 2012)

Two previous flooding studies exist for the Cooks River system. The first was a flood study that defined the flooding behaviour of the watercourse was commissioned by SWC and completed by Parsons Brinckerhoff in 2009. The study developed a hydrologic model for the Cooks River catchment and a hydraulic model for the Cooks River and all significant tributaries. The second was a Floodplain Risk Management Study and Plan that details mitigation options and effects in the Cooks River catchment, concentrating of flood prone land lying adjacent to the Cooks River within the former Marrickville Council area. This report was commissioned by the former Marrickville Council.

The hydrologic model used to model the Cooks River catchment was WBNM with 44 sub-catchments defined upstream of Botany Bay. The WBNM model was calibrated by adjusting parameters to match the flows obtained in the previous flood study (WMAwater, 1994), which in turn was joint-calibrated in its respective study with the hydraulic model.

The hydraulic model employed was a 2D TUFLOW model. The TUFLOW model extents included Cooks River, Alexandra Canal, Wolli Creek and Coxs Creek. The hydraulic model was calibrated to two events, November 1961 and March 1983 comparing the model to flood heights recorded during the events.

-

Values for flows in Cooks River and Alexandra Canal were taken from the hydraulic model as inflows to the present study, as well as cross section data for Cooks River and Alexandra Canal.

2.9.4. Alexandra Canal Catchment Drainage Study (Lucas Consulting Engineers, 1998)

A catchment drainage study for Alexandra Canal was completed in March 1998. It was commissioned by the former Marrickville Council and the study completed by Lucas Consulting Engineers. The study aimed to establish an overview of the stormwater runoff within the portion of Alexandra Canal that exists in the former Marrickville Council LGA.

The 17/2/1993, 19/11/1988 and the 23/1/1991 were identified as the three most significant events to occur across the 10 year period preceding 1996-1997 (when the study had commenced). Using the Marrickville pluviometer (566026) and design rainfall data, these three events were estimated to be between a 2 year and a 5 year ARI event.

Interviews with residents were conducted and found:

- a property on Crown Street (with a floor level of 13.32 m AHD) had experienced above floor flooding twice in the 7 years preceding the 1998 study;
- a property on the Princes Highway (near Short Street) that experienced 300 mm of flow through the building in the 1988 event;
- a property on the Princes Highway (near Short Street) that experienced flooding and built a flood wall to prevent future inundation;
- a property on Bay Street that reported a flood level 5 bricks high (measured to be 1.65 m) in the 1988 event.

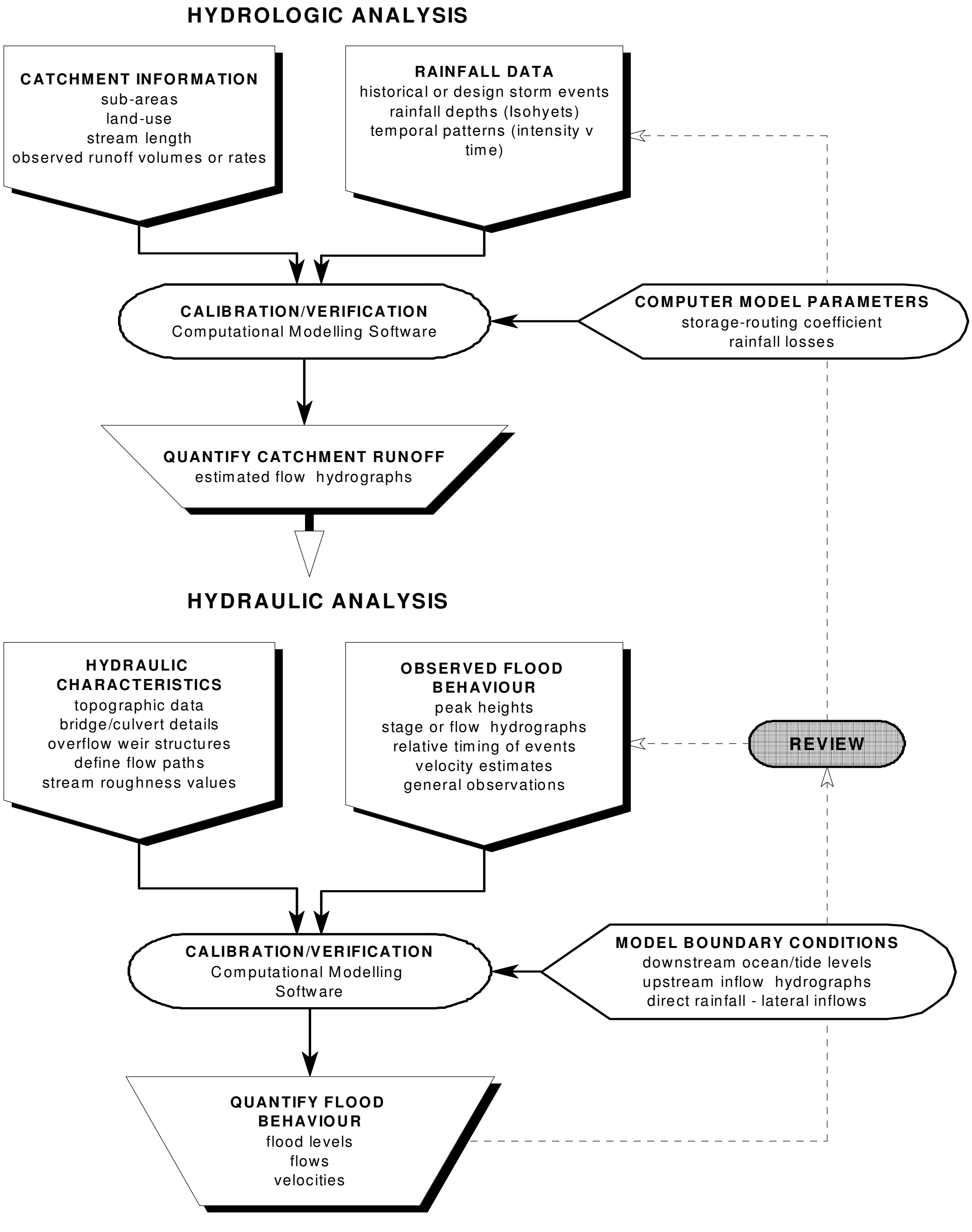
The drainage study used an ILSAX hydrologic model. The model was used to identify low points with flat gradients that act as basins in flood events. Calibration was undertaken on the three aforementioned events and compared to the observations obtained through interviews with residents.

Design flood event modelling identified hotspots in the study area including the Princes Highway near Railway Road, low lying areas around Bay Street, and trapped low points in Crown Street and Barwon Park Road.

3. STUDY METHODOLOGY

A diagrammatic representation of the Flood Study process is shown in Diagram 2. 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 2: 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 parameters 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 study area, 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 adoption of the TUFLOW modelling package also ensured consistency between other flood studies (Marrickville Valley Flood Study and Hawthorne Canal Flood Study) completed within the Marrickville Council LGA.

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 sub-catchment delineation ensures that where hydraulic controls exist that these are accounted for and able to be appropriately incorporated into hydraulic routing. The study area, number of sub-catchments and average sub-catchment size for Alexandra Canal is presented in Table 9. The sub-catchment delineation is shown on Figure 11.

Table 9: Sub-catchment parameters

	Alexandra Canal
Study Area (km^2)	2.20
Number of Catchments	143
Average catchment size (ha)	1.5

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:

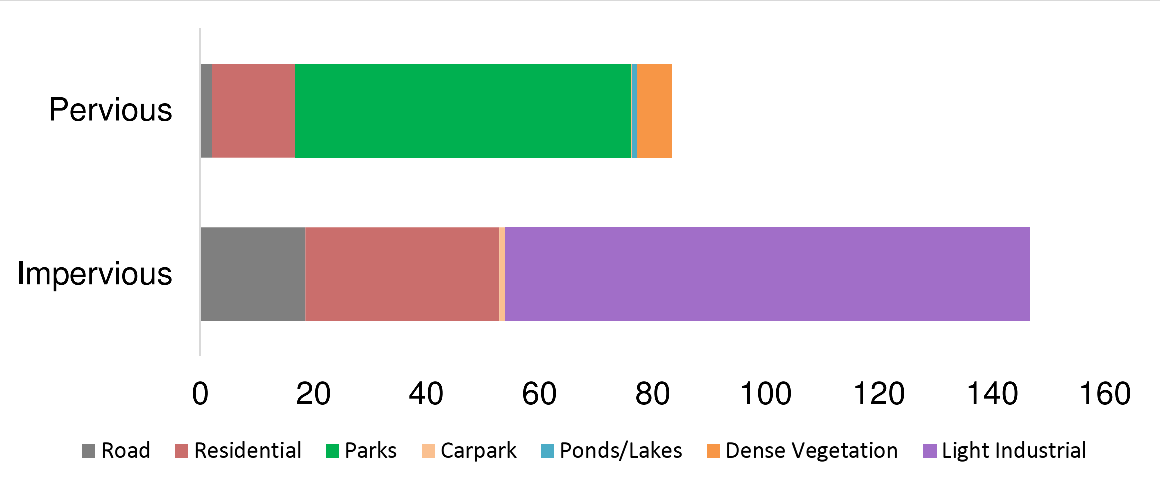
- paved areas (impervious areas directly connected to the drainage system),
- supplementary areas (impervious areas not directly connected to the drainage system, instead connected to the drainage system via the pervious areas), and
- grassed areas (pervious areas).

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 10.

Table 10: Impervious Percentage per Land-use

Land-use Category	Impervious Percentage	Area (ha) within Alexandra Canal
Vegetation (such as public parks and dense vegetation)	0% Impervious	66
Residential	70% Impervious	49
Infrastructure (roads, train tracks etc)	90% Impervious	21
Carparks	90% Impervious	1
Industrial	100% Impervious	93

Chart 1: Alexandra Canal Impervious / Pervious Land-use Categories



The proportion of each land-use category within a sub-catchment was determined based upon the hydraulic model roughness schematisation, shown in Figure 13. 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 11. These are consistent with the parameters adopted in the nearby catchments of Dobroyd Canal (WMAwater, 2015) and Hawthorne Canal (WMAwater, 2015).

Table 11: 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 2 m by 2 m. This resolution was adopted as it provides sufficient detail for roads and overland flow paths. The model grid was established by sampling from a 1 m by 1 m DEM (generated from a triangulation of filtered ground points from the LiDAR dataset, discussed in Section 2.2.1) and finer detail ground data was appended to the hydraulic model grid (such as lowering of the kerb elevations to facilitate flow through the gutter system, and including the Tempe Wetlands data, discussed in Section 2.2.3).

The TUFLOW hydraulic model includes the downstream portion of the Alexandra Canal catchment within the former Marrickville Council LGA. The 2D model is bounded by the Illawarra Railway Bridge over the Cooks River (to the west); from 270 m upstream of the Canal Road – Ricketty Street Bridge over the Alexandra Canal (to the north); and the Marsh Street – Airport Drive Bridge over the Alexandra Canal (to the south). The total area included in the 2D model is 3.2 km^2. The extents of the TUFLOW model are shown in Figure 12.

5.2. Boundary Locations

5.2.1. Inflows

For local sub-catchments within the TUFLOW model domain, local runoff hydrographs were extracted from the DRAINS model (see Section4). These were applied to the 2D domain of the TUFLOW model; at the downstream end of the sub-catchments. The inflow locations typically corresponded with inlet pits on the roadway as this is where most rainfall is directed.

5.2.2. Downstream Boundary

The study area is influenced by the water level conditions in the open channel along the south-east and south-west boundary of the study area. These two open channels are in turn influenced by the:

- ocean levels (where the channels converge at the Marsh Street – Airport Drive Bridge);
- inflows from the Cooks River catchment area (entering the hydraulic model at the Princes Highway Bridge);
- inflows from the Alexandra Canal catchment area (entering the hydraulic model upstream of the Canal Road Bridge); and
- inflows from the Mascot catchment area (entering the hydraulic model at Coward Street in the vicinity of where the Mascot open channel converges with Alexandra Canal).

These boundaries are shown in Figure 12.

The inflows from the Cooks River catchment areas have been extracted from the Cooks River Floodplain Risk Management Study and Plan (WMAwater and Storm Consulting, 2015), the inflows from the Alexandra Canal catchment have been extracted from the Alexandra Canal Catchment Model Conversion (BMT WBM, 2016), and the inflows from the Mascot catchment area have been extracted from the Mascot, Roseberry and Eastlakes Flood Study (WMAwater, 2015). The hydrographs of these inflows have been applied so that the inflow hydrograph peak corresponds to the rainfall peak in both the historical event and design event modelling.

The ocean levels have been applied as a constant level, given the relatively short duration of the storm events (both historical and design). The historic ocean levels have been extracted from the tidal gauge located at Port Kembla; obtained from the Bureau of Meteorology's National Tidal Centre. The design ocean levels have been determined by the *Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways* guide (2015).

The coincidence of the inflows and ocean levels with the rainfall events for the historic events and design events are discussed in Section 6.3 and Section 7.3, respectively.

5.2.3. Outflows into Adjacent Catchments

In some locations within the study area, flow paths split such that the primary flow continues to be conveyed through the Alexandra Canal catchment area (either overland and/or through the stormwater drainage network) and a divergent flow enters the adjacent Marrickville Valley catchment.

The hydraulic model was schematised so as not to restrict flow from crossing the catchment boundary. As such, the hydraulic model extent was expanded to include small portions of the adjoining catchment. Where the catchment boundary was crossed, the flow was removed from the hydraulic model with localised hydraulic boundaries, shown on Figure 12.

Outflows into the Marrickville Valley catchment were located outside the study area, and results from the Marrickville Valley Flood Study and Floodplain Risk Management Study take precedence over results from this study where they occur within the Marrickville Valley catchment area.

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 13. The Manning's "n" values adopted for these areas, including flowpaths (overland, pipe and in-channel), are shown in Table

12. These values have been adopted based on site inspection and correspondence to similar floodplain environments. The values are consistent with those provided in the recent revisions to Australian Rainfall and Runoff (Engineers Australia, 2016).

Table 12: Manning's "n" values adopted in TUFLOW

Surface	Manning's "n" Adopted
Pipes	0.013
Roads and Footpaths	0.02
Lakes / Wetlands	0.03
Industrial Areas	0.04
Residential Areas	0.05
Parks with Moderate Vegetation	0.06
Dense Vegetation	0.08

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

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 are in part addressed by the adopted roughness parameters.

5.4.3. Bridges

Key hydraulic structures were included in the hydraulic model. Bridges were modelled as 1D features within the 1D open channels, with the purpose of maintaining continuity within the model. The modelling parameter values for the culverts and bridges were based on the geometrical properties of the structures, which were obtained from the *Cooks River Flood Study* and *Floodplain Risk Management Study and Plan* (Parsons Brinckerhoff, 2009 &WMAwater, 2012).

5.4.4. Sub-surface Drainage Network

Figure 3 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:

- 225 pipes;
- 259 pits and nodes; and
- 288 open channel segments.

Where pit data was not available, 2.4 x 0.15 m pits were assumed to exist. This has little impact on the results in many of the design events as the capacity of the pipe is the determining factor of the effectiveness of the pit-pipe network.

Where pipe data was not available, 0.5 m diameter circular pipes were assumed to exist. This may have some significant impacts on the results, however the amount of pipes missing data was minimal and many were not in locations of large flows.

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.

Current modelling has been undertaken assuming no blockage of pipes, culverts and bridges greater than 300 mm in diameter. Pipes less than 300 mm in diameter were conservatively assumed to be completely blocked. The study area's sensitivity to blockage of pipes is discussed in Section 8.3.3.

Furthermore, the event in which the pipe network's capacity is exceeded is shown on Figure 17. From this, it was found that the majority of the pipes within the study area have a capacity in the range of the 50% AEP or 20% AEP event.

6. CALIBRATION AND VERIFICATION

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. Verification is undertaken to ensure that the calibration model parameter values are acceptable in other storm events with no additional alteration of values. Industry practice is that the modelling system should be calibrated to one historical event and verified using multiple historical events. To facilitate this there needs to be adequate historical flood observations and sufficient pluviometer rainfall data.

However, there are several limitations which prevent a thorough calibration of the hydrologic and hydraulic models:

- There is only a limited amount of historical flood level 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.

These limitations are typical of the majority of urban catchments and the validation exercise undertaken here constitutes current best practice.

6.2. 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 Alexandra Canal catchment. DRAINS was the hydrologic model used in Rose Bay and the catchment is located approximately 15 km from the Alexandra Canal Catchment.

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 13.

Table 13: Specific Yield

Sub-catchment	Alexandra Canal			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	1.2	0.6	0.5	1	0.6	0.7
2	0.5	0.2	0.5	0.4	0.2	0.6
3	0.3	0.1	0.5	0.6	0.4	0.6

The specific yields from the two different DRAINS models were found to be comparable.

6.3. Hydrologic/Hydraulic Model Calibration

The 25th April 2015 event was modelled for the purpose of hydrologic and hydraulic model calibration, as discussed below.

6.3.1. Rainfall Distribution

The rainfall distribution shown in Figure 8B was applied to the individual localised inflows across the study area.

6.3.2. Downstream Boundary Conditions

The Alexandra Canal inflows, Cooks River inflows, Mascot inflows and ocean levels applied to the model in the simulation of the April 2015 event is shown in Table 14.

Table 14: Downstream Boundary Conditions – Historic Events

	Alexandra Canal Inflow	**Cooks River Inflow**	**Mascot Inflow**	**Ocean Level**
April 2015	Max 106.3 m^3/s	Max 355.4 m^3/s	Max 0.9 m^3/s	Constant 0.245 m AHD
	Corresponding to the 50% AEP event	Corresponding to the 50% AEP event	Corresponding to the 50% AEP event	Corresponding to the levels at the time the rainfall event started

6.3.3. Results

From Council's database of flooding complaints, five locations were reported to experience flooding either during heavy rainfall or during large tidal events. The flood affectation at these locations was compared to the model results for the April 2015 event, shown in Table 15.

Table 15: Comparison of Historic Events – Council's Complaints Database

Location	**April 2015 – Modelled Results**
Holbeach Avenue, Tempe	0.1 m
Bay Street, Tempe (east)	0.4 m
Old Street, Tempe (mid-way)	0.4 m
Tempe Reserve, Tempe	0.4 m
Princes Highway, Sydenham	0.1 m

Furthermore, from the community consultation responses that were collected, four road locations were reported to experience flooding during heavy rainfall. The flood affectation at these locations was compared to the model results for the April 2015 event, shown in Table 16. These results demonstrate that where the community reported flood affectation, the models are effectively replicating some degree of flood affectation.

Table 16: Comparison of Historic Events – Community Consultation

Location	April 2015 – Modelled Results
Bay Street, Tempe (east)	0.4 m
Old Street, Tempe (north)	0.2 m
Young Street, Tempe	0.1 m
South Street, Tempe	0.1 m

6.4. Hydrologic/Hydraulic Model Verification

The results from previous studies have been compared to modelled results for the purpose of verification.

6.4.1. Comparison with the Dalland & Lucas Report

The ILSAX results (Dalland& Lucas, 1998) were compared to the TUFLOW results from the current study for the 1% AEP event, shown in Table 17.

The majority of the locations verified were within ± 0.10 m; with the exception of the Princes Highway (near Short Street), Crown Street and Station Street. The former two are interdependent, with Crown Street immediately downstream of the Princes Highway location. Given the period of time that has passed since the 1998 report, it is possible that catchment conditions have changed at this location causing flow to be impeded on the Princes Highway.

The Station Street estimate in the previous study appears to be considering the local catchment along Station Street as being unaffected by catchments that are conveyed along South Street (as evidenced by 0.8 m^3/s conveyed along South Street downstream of Hart Street and 0.45 m^3/s conveyed through downstream properties on Station Street). The previous 1D modelling technique required different flow paths to be independent; whereas the current 2D modelling technique allows interaction between differing flow paths based upon the topography. As such, the Station Street measurement is incomparable.

Table 17: Verification Comparison of the 1% AEP event – Dalland and Lucas Report

Location	Dalland& Lucas Report	Current Study	Difference (m)
Princes Hwy (near Short St)	15.24	15.36	0.12
Crown St (between Campbell St and Barwon Park Rd)	13.47	13.31	-0.15
Barwon Park Rd (between Campbell St and Crown St)	11.93	11.99	0.06
Edith St	14.78	14.70	-0.08
Princes Hwy (between Park Rd and Railway Rd)	8.11	8.04	-0.07
Station St (between Old St and South St)	2.27	2.53	0.25
Bay St and Old St	1.90	1.92	0.02

7. DESIGN EVENT MODELLING

7.1. Introduction

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 study area. 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 storm duration for various parts of the catchment, modelling of the 1% AEP event was undertaken for a range of design storm durations from 15 minutes to 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, 1 hour, 2 hour and 6 hour design storm durations were critical across the study area for the 1% AEP event. The 25 minute design storm duration was mostly critical in areas of shallow overland flow, with 98% of the area considered critical in this storm duration having a peak flood depth no greater than 0.3 m. As such, the 25 minute storm burst was disregarded as a critical storm burst. The 6 hour design storm burst was predominantly critical within flood storage areas such as the Tempe Golf Driving Range and the industrial area bordered by Alexandra Canal, the freight railway line and Canal Road. The 1 hour design storm duration was found to be critical along the primary overland flow path through Tempe and along Canal Road; whereas the 2 hour design storm duration was critical along the mainstream flow path of Alexandra Canal. The peak flood level difference between the 1 hour results and the enveloped results was less than 0.25 m; and between the 2 hour results and the enveloped results was less than 0.15 m. Therefore, it was determined appropriate to adopt the 1 hour design storm duration as the critical duration.

7.3. Downstream Boundary Conditions

In addition to runoff from the catchment, downstream areas can also be influenced by high water levels within the Cooks River / Botany Bay 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. Additionally, consideration must also be given to influencing factors that fluctuate, such as wind stress and wave setup. 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 18.

Table 18: Combinations of Catchment Flooding and Oceanic Inundation Scenarios

Design AEP for peak flood levels	Catchment Flood Scenario	Ocean Water Level Boundary
50% AEP	50% AEP Rainfall	HHWS Ocean Level 1.25 m AHD
20% AEP	20% AEP 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

The Alexandra Canal inflows, Cooks River inflows and Mascot inflows applied to the model in the design events are shown in Table 19. Generally, the inflow events corresponded to the rainfall event (as the inflows were driven by rainfall runoff). However, in the 2% AEP event the Cooks River inflows did not have corresponding results, and as such the 5% AEP results were used as the inflows in this case.

In the PMF event, the Cooks River inflow was taken from the 2h PMP event that was run as the critical duration for the Cooks River model. For Alexandra Canal only the 30, 45 and 90 minute PMF durations were run, of which the 30 minute event was critical at the location where the canal flows into the study area. Due to this we applied a constant boundary equal to the peak of the 30 minute PMF flow for the duration of the PMF event at the boundary.

Table 19: Downstream Boundary Conditions – Design Events

Design AEP	Alexandra Canal Peak Inflow	Cooks River Peak Inflow	Mascot Peak Inflow
50% AEP	Max 106.3 m^3/s	Max 355.4 m^3/s	Max 3.4 m^3/s
	Corresponding to the 50% AEP event	Corresponding to the 50% AEP event	Corresponding to the 50% AEP event
20% AEP	Max 131.7 m^3/s	Max 445.9 m^3/s	Max 5.4 m^3/s
	Corresponding to the 20% AEP event	Corresponding to the 20% AEP event	Corresponding to the 20% AEP event
10% AEP	Max 144.6 m^3/s	Max 496.7 m^3/s	Max 7.5 m^3/s
	Corresponding to the 10% AEP event	Corresponding to the 10% AEP event	Corresponding to the 10% AEP event
5% AEP	Max 159.4 m^3/s	Max 567.1 m^3/s	Max 8.0 m^3/s
	Corresponding to the 5% AEP event	Corresponding to the 5% AEP event	Corresponding to the 5% AEP event
2% AEP	Max 171.6 m^3/s	Max 567.1 m^3/s	Max 9.6 m^3/s
	Corresponding to the 5% AEP event	Corresponding to the 5% AEP event	Corresponding to the 2% AEP event
1% AEP	Max 188.9 m^3/s	Max 702.3 m^3/s	Max 11.3 m^3/s
	Corresponding to the 1% AEP event	Corresponding to the 1% AEP event	Corresponding to the 1% AEP event

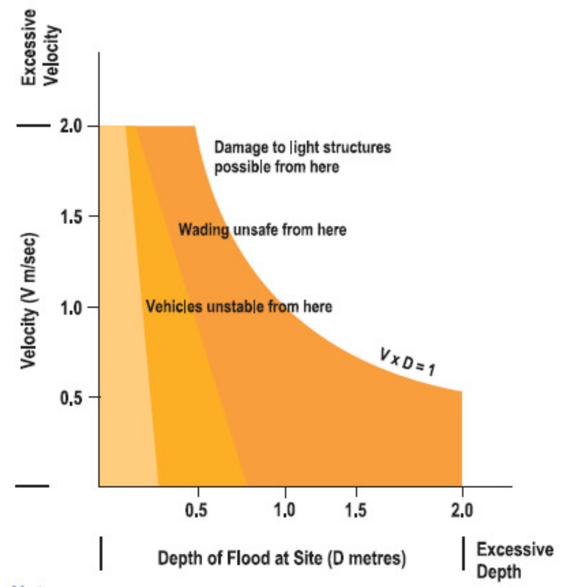
7.4. Analysis

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 3. For the purposes of this report, the transition zone presented in Diagram 3 (L2) was considered to be high hazard.

Maps of provisional hydraulic hazard in the Alexandra Canal catchment are presented in.Figure 33 to Figure 36.

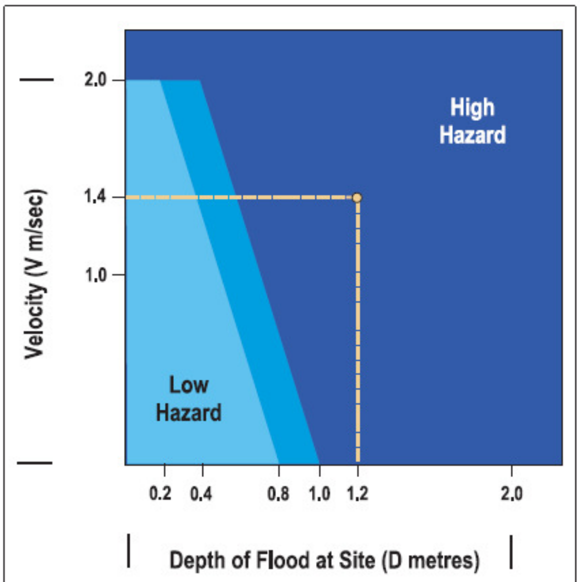
Diagram 3: (L1) Velocity and Depth Relationship; (L2) Provisional Hydraulic Hazard Categories (NSW State Government, 2005)



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

Figure 37 to Figure 40 show the provisional hydraulic categorisations for the Alexandra Canal catchment for the 20% AEP, 5% AEP, 1% AEP and PMF events.

7.4.3. Flood Emergency Response Classifications

The *Technical Flood Risk Management Guideline – Flood Emergency Response Classification of the Floodplain (AEMI, 2014)* provides national guidance on flood emergency response. This Guideline builds upon the earlier NSW guidelines (DECC, 2007) and presents six classifications that are described in the following Table 20.

The PMF results determined in this study were used to define the flood emergency response classifications as per the Guideline. The preliminary flood emergency response classification of communities is shown in Figure 41.

Table 20: Flood Emergency Response Classifictions (Extract from Table 1 *Technical Flood Risk Management Guideline – Flood emergency response classification of the floodplain AEMI 2014*)

Primary Classification	**Description**	**Secondary Classification**	**Description**	**Tertiary Classification**	**Description**
Flooded (F)	The area is flooded in the PMF	Isolated (I)	Areas that are isolated from community evacuation facilities (located on flood-free land) by floodwater and/or impassable terrain as waters rise during a flood event up to and including the PMF. These areas are likely to lose electricity, gas, water, sewerage and telecommunications during a flood.	Submerged (FIS)	Where all the land in the isolated area will be fully submerged in a PMF after becoming isolated.
				Elevated (FIE)	Where there is a substantial amount of land in isolated areas elevated above the PMF.
		Exit Route (E)	Areas that are not isolated in the PMF and have an exit route to community evacuation facilities (located on flood-free land).	Overland Escape (FEO)	Evacuation from the area relies upon overland escape routes that rise out of the floodplain.
				Rising Road Access (FER)	Evacuation routes from the area follow roads that rise out of the floodplain.
Not Flooded (N)	The area is not flooded in the PMF			Indirect Consequences (NIC)	Areas that are not flooded but may lose electricity, gas, water, sewerage, telecommunications and transport links due to flooding.
				Flood Free	Areas that are not flood affected and are not affected by indirect consequences of flooding.

Notes:

1. Classifications are based upon the Probable Maximum Flood (PMF) or similar extreme flood, if the PMF is not available. Where classifications are being retrofitted to areas covered by existing studies and the PMF or a similar extreme flood is not available, and a decision is made to not estimate or approximate an extreme event, classifications should be clearly indicted as ‘Preliminary based upon the largest flood available’.
2. Isolated areas may also be known as:
   - Flood islands, where areas are isolated solely by flood waters. Where flood islands are completely submerged in the PMF, these may be called low-flood islands. Where flood islands have elevated areas above the PMF, they may be called high-flood islands.
   - Trapped perimeter areas, where areas are isolated by a combination of floodwaters and impassable terrain. Where trapped perimeter areas are completely submerged in the PMF, these may be called low-trapped perimeter areas. Where trapped perimeter areas have elevated areas above the PMF, they may be called high-trapped perimeter areas.

7.5. Results

The results are presented as:

- Peak flood level profiles on Figure 16;
- Peak flood depths and level contours on Figure 21 to Figure 27;
- Peak flood velocities on Figure 28 to Figure 32;
- Provisional hydraulic hazard on Figure 33 to Figure 36;
- Provisional hydraulic categorisation on Figure 37 to Figure 40; and
- Preliminary flood emergency response classification of communities on Figure 41.

7.5.1. Peak Flood Depths and Levels

The tabulated summary of peak flood depths and peak flood levels are presented in Table 21 and Table 22. The below locations are shown on Figure 15.

Table 21: Peak Flood Depths (m) at Key Locations

ID	Location	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
H01	Holbeach Avenue	0.15	0.19	0.23	0.26	0.33	0.38	1.47
H02	Cnr Bay Street and Old Street	0.69	0.73	0.75	0.78	0.81	0.85	1.79
H03	Cnr Princes Highway and Railway Avenue	0.00	0.01	0.12	0.29	0.40	0.46	0.82
H04	Cnr Canal Road and Burrows Road South	0.32	0.38	0.41	0.44	0.47	0.49	1.51
H05	Barwon Park Road (north of Campbell Street)	0.00	0.10	0.11	0.12	0.13	0.14	0.81
H06	Princes Highway (north of Campbell Street)	0.01	0.02	0.08	0.19	0.24	0.27	0.46
H07	Edith Street	0.16	0.19	0.20	0.22	0.23	0.24	0.35

Table 22: Peak Flood Levels (m AHD) at Key Locations

ID	Location	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
H01	Holbeach Avenue	1.48	1.52	1.55	1.58	1.66	1.70	2.80
H02	Cnr Bay Street and Old Street	1.75	1.78	1.81	1.84	1.87	1.91	2.85
H03	Cnr Princes Highway and Railway Avenue	7.62	7.63	7.73	7.91	8.01	8.08	8.44
H04	Cnr Canal Road and Burrows Road South	2.61	2.67	2.69	2.72	2.75	2.77	3.79
H05	Barwon Park Road (north of Campbell Street)	N/A	11.39	11.39	11.40	11.41	11.43	12.10
H06	Princes Highway (north of Campbell Street)	15.07	15.09	15.14	15.26	15.30	15.34	15.52
H07	Edith Street	14.61	14.64	14.65	14.67	14.69	14.70	14.81

7.5.2. Peak Flows

A tabulated summary of peak flows is presented in Table 23.

Table 23: Peak Flood Flows (m^3/s) at Key Locations

ID	Location	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Q01	Holbeach Avenue	0.94	1.78	2.67	3.75	4.88	5.81	36.95
Q02	Bay Street and Old Street	1.15	1.98	2.61	3.53	4.51	5.37	39.80
Q03	Princes Highway and Railway Avenue	0.07	0.09	0.10	0.11	0.29	0.66	6.95
Q04	Canal Road and Burrows Road South	1.32	2.04	2.48	3.05	3.65	4.25	20.17
Q05	Barwon Park Road (north of Campbell Street)	0.00	0.00	0.00	0.00	0.00	0.00	0.90
Q06	Princes Highway (north of Campbell Street)	0.06	0.08	0.09	0.12	0.25	0.42	2.87
Q07	Edith Street	0.12	0.26	0.36	0.49	0.59	0.69	2.21

7.5.3. Provisional Hydraulic Hazard

In events up to and including the 1% AEP event, high hydraulic hazard was found to occur within Alexandra Canal, Cooks River and the Tempe Wetlands. In the PMF event, these high hazard areas extend across Holbeach Avenue, Bay Street and Old Street (between Tempe Wetlands and Cooks River); along Canal Road and Burrows Road; and along the freight railway line and the industrial area between the railway line and Canal Road.

7.5.4. Provisional Hydraulic Categorisation

During events ranging from the 20% AEP event and the PMF event, the Alexandra Canal and Cooks River were classified as Floodway areas. Flood Storage areas were found within Tempe Wetlands, along Bay Street, Old Street, Canal Road and Burrows Road in events up to and including the 1% AEP event. In the PMF event, Floodway areas extended from Tempe Wetlands to the Cooks River (via Holbeach Avenue); along Canal Road and Burrows Road; and along the freight railway line. Flood Storage also extended across the industrial area between the freight railway line and Canal Road in the PMF event.

7.5.5. Flood Emergency Response Classifications

There are some areas of ‘Land Submerged in the PMF (FIS)’, such as the industrial area between the freight railway line and Canal Road, and some locations along Holbeach Avenue, Bay Street and Old Street. Other areas were classified as ‘Roads Rise out of the Floodplain (FER)’, with the largest located between the freight railway line and Smith Street. Areas not denoted with a Flood Emergency Response Classification were classified as not flooded in the PMF event.

8. SENSITIVITY ANALYSIS

8.1. Introduction

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. Prior to 2012, the benchmarks required Council to plan for projected sea level rise of 0.4 m by 2050 and 0.9 m by 2100 (NSW State Government, 2010), relative to 1990 levels.

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 24 for variations in roughness;
- Table 25 for variation in routing;
- Table 26 for variation in pipe blockage; and
- Table 27 for variation 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 insensitive to variations in the roughness parameter. Generally, these results were found to be within ± 0.05 m.

Table 24: 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	Holbeach Avenue	0.38	-0.03	0.00
H02	Cnr Bay Street and Old Street	0.85	-0.02	0.02
H03	Cnr Princes Highway and Railway Avenue	0.46	0.00	0.00
H04	Cnr Canal Road and Burrows Road South	0.49	-0.01	0.01
H05	Barwon Park Road (north of Campbell Street)	0.14	-0.01	0.01
H06	Princes Highway (north of Campbell Street)	0.27	0.00	0.00
H07	Edith Street	0.24	-0.01	0.01

8.3.2. Routing Variations

Overall peak flood level results from TUFLOW were shown to be relatively insensitive to variations in the routing parameter. Generally, these results were found to be within ± 0.05 m. Routing is parametrised in DRAINS by the subcatchment flow length.

Table 25: Results of Routing Analysis – Change in Level

ID	Location	Peak Flood Depth 1% AEP	Difference with 1% AEP (m)	
			Routing Decreased by 20%	Routing Increased by 20%
H01	Holbeach Avenue	0.38	-0.01	-0.01
H02	Cnr Bay Street and Old Street	0.85	0.00	0.00
H03	Cnr Princes Highway and Railway Avenue	0.46	0.00	0.00
H04	Cnr Canal Road and Burrows Road South	0.49	0.00	0.00
H05	Barwon Park Road (north of Campbell Street)	0.14	0.00	0.00
H06	Princes Highway (north of Campbell Street)	0.27	0.00	0.00
H07	Edith Street	0.24	0.00	0.00

8.3.3. Blockage Variations

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

Table 26: Results of Blockage Analysis – Change in Level

ID	Location	Peak Flood Depth 1% AEP	Difference with 1% AEP (m)	
			Blockage of Pipes by 20%	Blockage of Pipes by 50%
H01	Holbeach Avenue	0.38	-0.01	0.00
H02	Cnr Bay Street and Old Street	0.85	0.01	0.02
H03	Cnr Princes Highway and Railway Avenue	0.46	0.05	0.12
H04	Cnr Canal Road and Burrows Road South	0.49	0.00	-0.01
H05	Barwon Park Road (north of Campbell Street)	0.14	0.00	0.01
H06	Princes Highway (north of Campbell Street)	0.27	0.02	0.05
H07	Edith Street	0.24	0.01	0.01

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. Generally speaking, the study area was relatively insensitive to increases in design rainfalls due to the relatively small local catchment area.

The sea level rise scenarios were found not to have a significant effect on peak flood levels upstream of Old Street, Tempe. The sea level rise impacts decreased with increasing distance from the waterway; with increases on the corner of Bay Street and Old Street lower than the increases on Holbeach Avenue (located downstream of the former).

Table 27: 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	Holbeach Avenue	0.38	0.02	0.06	0.10	0.25	0.69
H02	Cnr Bay Street and Old Street	0.85	0.04	0.07	0.10	0.06	0.49
H03	Cnr Princes Highway and Railway Avenue	0.46	0.06	0.10	0.13	0.00	0.00
H04	Cnr Canal Road and Burrows Road South	0.49	0.02	0.04	0.06	0.02	0.26
H05	Barwon Park Road (north of Campbell Street)	0.14	0.01	0.05	0.10	0.00	0.00
H06	Princes Highway (north of Campbell Street)	0.27	0.03	0.05	0.07	0.00	0.00
H07	Edith Street	0.24	0.01	0.02	0.03	0.00	0.00

9. PLANNING CONTROLS

9.1. State Environment Planning Policy – Exempt and Complying Development

9.1.1. Background

The State Environmental Planning Policy (Exempt and Complying Development Codes) 2008 aims to "*provide streamlined assessment processes for development that complies with specific development standards*".

"Exempt" development includes minor renovations or alterations with low impact which don't require planning or building approval. "Complying" development is straightforward development that can be approved by Council or a private certifier if it meets the SEPP codes. The requirements are identical for new and existing dwellings.

Subdivision 9 Clause 3.36C of this Policy applies to development on "flood control lots" (the specification of which is determined by Council) and must satisfy the following criteria:

1) *This clause applies:*
    a. *to all development specified for this code that is to be carried out on a flood control lot, and*
    b. *in addition to all other development standards specified for this code.*
2) *The development must not be on any part of a flood control lot unless that part of the lot has been certified, for the purposes of the issue of the relevant complying development certificate, by the council or a professional engineer who specialises in hydraulic engineering as not being any of the following:*
    a. *a flood storage area,*
    b. *a floodway area,*
    c. *a flow path,*
    d. *a high hazard area,*
    e. *a high risk area.*
3) *The development must, to the extent it is within a flood planning area:*
    a. *have all habitable rooms no lower than the floor levels set by the council for that lot, and*
    b. *have the part of the development at or below the flood planning level constructed of flood compatible material, and*
    c. *be able to withstand the forces of floodwater, debris and buoyancy up to the flood planning level (or if on-site refuge is proposed, the probable maximum flood level), and*
    d. *not increase flood affectation elsewhere in the floodplain, and*
    e. *have reliable access for pedestrians and vehicles from the development, at a minimum level equal to the lowest habitable floor level of the development, to a safe refuge, and*
    f. *have open car parking spaces or carports that are no lower than the 20-year*

flood level, and

g. *have driveways between car parking spaces and the connecting public roadway that will not be inundated by a depth of water greater than 0.3m during a 1:100 ARI (average recurrent interval) flood event.*

4) *A standard specified in subclause (3) (c) or (d) is satisfied if a joint report by a professional engineer who specialises in hydraulic engineering and a professional engineer who specialises in civil engineering confirms that the development:*
   a. *can withstand the forces of floodwater, debris and buoyancy up to the flood planning level (or if on-site refuge is proposed, the probable maximum flood level), or*
   b. *will not increase flood affectation elsewhere in the floodplain.*

Development occurring under the SEPP codes would bypass Council's full Development Application (DA) requirements, including some of the flood-related requirements of the Council Development Control Plan (DCP). While the SEPP requirements echo the broader requirements outlined in the DCP, they are less nuanced in some regards.

9.1.2. Results

Figure 42 shows the areas defined as flood storage, floodway, flow path (estimated to be where depths exceed 0.3 m) and high hazard areas within which exempt and complying development cannot be undertaken.

9.2. Flood Control Lot

9.2.1. Background

Land use planning is considered to be one of the most effective means of minimising flood risk and damages from flooding. The Flood Control Lot, also known as the Flood Planning Area (FPA) identifies land that is subject to flood related development controls via Section 149(2) notifications under the Environmental Planning and Assessment (EP&A) Act 1979. 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.

9.2.2. Methodology and Criteria

The methodology used in this report is consistent with that adopted in a number of previous studies. Overland flooding affectation was defined as greater than or equal to 10% of the cadastral area is affected by the 1% AEP peak flood depth of greater than 0.15 m.

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. Following on from the information sessions held during Public Exhibition, council staff visited properties from which submissions were received and this supplemented the "ground truthing" exercise.

9.2.3. Results

Figure 43 shows the FPA extent subsequent to "ground truthing".

10. DISCUSSION

Various locations were identified as “hotspots” within 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.

Figure B 1 shows the location of the hotspots that include:

- Hotspot 1 – Holbeach Avenue, Bay Street and Old Street, Tempe
- Hotspot 2 – Canal Road and Burrows Road, Tempe
- Hotspot 3 – Princes Highway, Barwon Park Road and Crown Street, St Peters
- Hotspot 4 – Princes Highway, Talbot Street and Bellevue Street, Sydenham

10.1. Hotspot 1 – Holbeach Ave, Bay St and Old St

Hotspot 1 covers the Holbeach Avenue, Bay Street and Old Street area within Tempe. Figure B 2 shows the 1% AEP peak flood depths and levels and Table 28 shows the results summary at this location.

Rainfall runoff arrives at this location from the north-east, via Old Street and Young Street, and converges on Bay Street. The properties on the downstream side (southern side) of Bay Street have ground level elevations greater than the roadway, thereby restricting the ability of overland flow to exit Bay Street.

Additionally, the ground elevations are around 1.1 m AHD along Bay Street and 1.3 m AHD along Holbeach Avenue at the lowest points. This places the ground levels proximate to or below the MHL Tidal Planes Analysis ocean / river levels (discussed in Section 0 and Table 2) and the Floodplain Risk Management Guide design ocean levels (discussed in Section 7.3 and Table 18). This impedes the flow of rainfall runoff exiting the catchment during a storm event, as well as causes the area to be tidally inundated outside of a storm event. This was demonstrated in January 2014, whereby river levels of 1.41 m AHD at Tempe Bridge resulted in inundation within this area (discussed in Section 2.6.2).

Table 28: Hotspot 1 – Result Summary

ID	Location	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Peak Flood Depths (m)								
H01	Holbeach Avenue	0.15	0.19	0.23	0.26	0.33	0.38	1.47
H02	Cnr Bay Street and Old Street	0.69	0.73	0.75	0.78	0.81	0.85	1.79
Peak Flood Levels (m AHD)								
H01	Holbeach Avenue	1.48	1.52	1.55	1.58	1.66	1.70	2.80
H02	Cnr Bay Street and Old Street	1.75	1.78	1.81	1.84	1.87	1.91	2.85
Peak Flood Flows (m^3/s)								
Q01	Holbeach Avenue	0.94	1.78	2.67	3.75	4.88	5.81	36.95
Q02	Bay Street and Old Street	1.15	1.98	2.61	3.53	4.51	5.37	39.80

10.2. Hotspot 2 – Canal Rd and Burrows Rd

The area surrounding the junction of Canal Road and Burrows Road in Tempe is Hotspot 2. Figure B 3 shows the 1% AEP peak flood depths and levels and Table 29 shows the results summary at this location.

Flow arrives at this location from the north-west, having been conveyed along Canal Road. There is a low point on Canal Road approximately 270 m upstream of the junction with Burrows Road that captures a portion of this flow. However, the more significant topographically low point occurs at the intersection; as well as along Burrows Road to the north of the junction with Canal Road. To the south-east of the Canal Road – Burrows Road intersection, Canal Road increases in elevation to the crest of the bridge where it crosses Alexandra Canal. Parallel and to the north of the roadway is a pedestrian path that provides access to the open channel and underside of the roadway bridge (though it is relatively narrow comparative to the roadway width).

Table 29: Hotspot 2 – Result Summary

ID	Location	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Peak Flood Depths (m)								
H04	Cnr Canal Road and Burrows Road South	0.32	0.38	0.41	0.44	0.47	0.49	1.51
Peak Flood Levels (m AHD)								
H04	Cnr Canal Road and Burrows Road South	2.61	2.67	2.69	2.72	2.75	2.77	3.79
Peak Flood Flows (m^3/s)								
Q04	Canal Road and Burrows Road South	1.32	2.04	2.48	3.05	3.65	4.25	20.17

Canal Road is a state-owned road and a relatively important traffic thoroughfare. As such, it is important to note that flood depths exceed 0.3 m in at least the 50% AEP event and greater. Flood depths greater than 0.3 m are currently considered to be the threshold for road accessibility.

10.3. Hotspot 3 – Princes Hwy, Barwon Park Rd and Crown St

Hotspot 3 covers the area around Barwon Park Road, Crown Street and the Princes Highway in St Peters. Figure B 4 shows the 1% AEP peak flood depths and levels and Table 30 shows the results summary at this location.

The Princes Highway, Crown Street and Barwon Park Road contain topographical depressions in this area that is exacerbated by large building extents obstructing overland flow from exiting the area.

Flow from Crown Street is conveyed east to Barwon Park Road. From Barwon Park Road, flow continues east via the stormwater pipe network and when the capacity of the stormwater network is exceeded, overland flow occurs through Sydney Park (which is part of the City of Sydney Local Government Area (LGA), with Barwon Park Road the LGA boundary).

Flow from the Princes Highway is conveyed overland in a westerly direction. The obstruction to overland flow (via topography and buildings) and the consequent accumulation of flood water on the Princes Highway is mainly a concern in extreme events such as the PMF, whereby depths exceed 0.3 m. Flood depths greater than 0.3 m are currently considered to be the threshold for road accessibility.

Table 30: Hotspot 3 – Results Summary

ID	Location	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Peak Flood Depths (m)								
H05	Barwon Park Road (north of Campbell Street)	0.00	0.10	0.11	0.12	0.13	0.14	0.81
H06	Princes Highway (north of Campbell Street)	0.01	0.02	0.08	0.19	0.24	0.27	0.46
Peak Flood Levels (m AHD)								
H05	Barwon Park Road (north of Campbell Street)	N/A	11.39	11.39	11.40	11.41	11.43	12.10
H06	Princes Highway (north of Campbell Street)	15.07	15.09	15.14	15.26	15.30	15.34	15.52
Peak Flood Flows (m^3/s)								
Q05	Barwon Park Road (north of Campbell Street)	0.00	0.00	0.00	0.00	0.00	0.00	0.90
Q06	Princes Highway (north of Campbell Street)	0.06	0.08	0.09	0.12	0.25	0.42	2.87

10.4. Hotspot 4 – Princes Hwy, Talbot St and Bellevue St

The area surrounding the Princes Highway, Talbot Street and Bellevue Street in Sydenham is Hotspot 4. Figure B 5 shows the 1% AEP peak flood depths and levels and Table 31 shows the results summary at this location.

There is a topographical depression at the intersection of the Princes Highway and Railway Avenue, which in addition to the large building extents along the Princes Highway, impede overland flow from exiting the area. Once this accumulated flood water reaches a high enough level, overland flow paths occur along Talbot Street and through private property to the south of the Princes Highway. Significant accumulation of flood water also occurs along and within private property on Bellevue Street, which is located downstream of the Princes Highway depression.

Table 31: Hotspot 4 – Results Summary

ID	Location	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Peak Flood Depths (m)								
H03	Cnr Princes Highway and Railway Avenue	0.00	0.01	0.12	0.29	0.40	0.46	0.82
Peak Flood Levels (m AHD)								
H03	Cnr Princes Highway and Railway Avenue	7.62	7.63	7.73	7.91	8.01	8.08	8.44
Peak Flood Flows (m^3/s)								
Q03	Princes Highway and Railway Avenue	0.07	0.09	0.10	0.11	0.29	0.66	6.95

The Princes Highway is a state-owned road and as such, it is important to note that flood depths exceed 0.3 m around a 5% AEP event. Flood depths greater than 0.3 m are currently considered to be the threshold for road accessibility.

11. PUBLIC EXHIBITION

Inner West Council resolved to place the Draft Alexandra Canal Flood Study on public exhibition at their February 2017 meeting.

The Flood Study was put on public exhibition during March and April 2017. A website was established to enable feedback online and to provide a copy of the flood study. All flood affected property owners were notified of the exhibition by letter. In addition three information sessions were organised to enable flood affected property owners to discuss impacts on their specific property one-on-one with Council's consultants and staff.

No submissions were received on the Alexandra Canal Flood Study. This is likely due to the low numbers of residential properties in the area and the fact many properties in the area had already been identified as flood affected in 2015, based on the Cooks River Flood Study.

The final Alexandra Canal Flood Study was subsequently adopted by the Inner West Council in June 2017.

12. ACKNOWLEDGEMENTS

WMAwater wish to acknowledge the assistance of the former Marrickville Council staff in carrying out this study, the NSW Government Office of Environment and Heritage and the residents of the Alexandra Catchment. This study was jointly funded by the former Marrickville Council and the NSW Government.

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Open Channel Flow
MacMillian, 1966

Figures

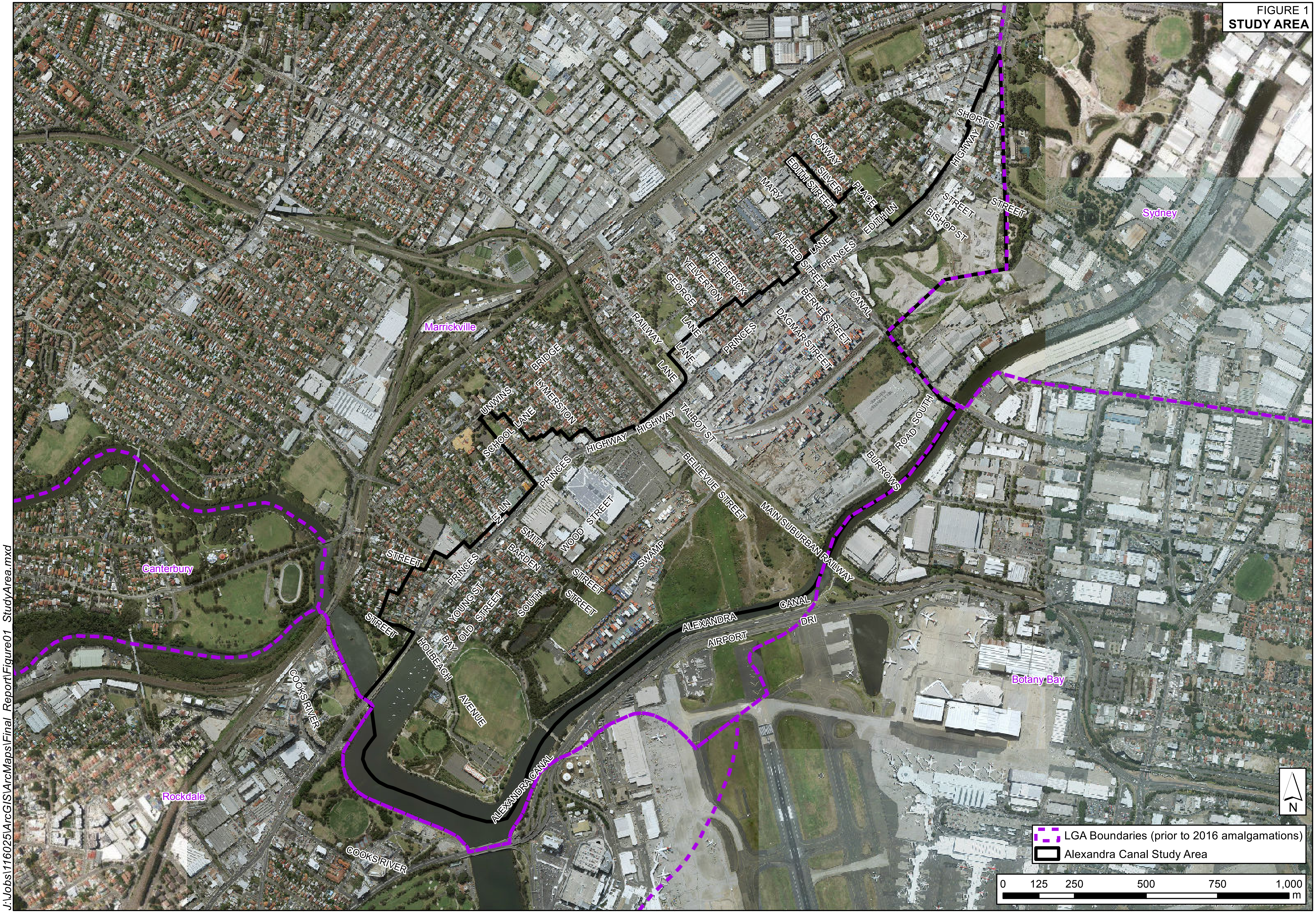

FIGURE 1
STUDY AREA

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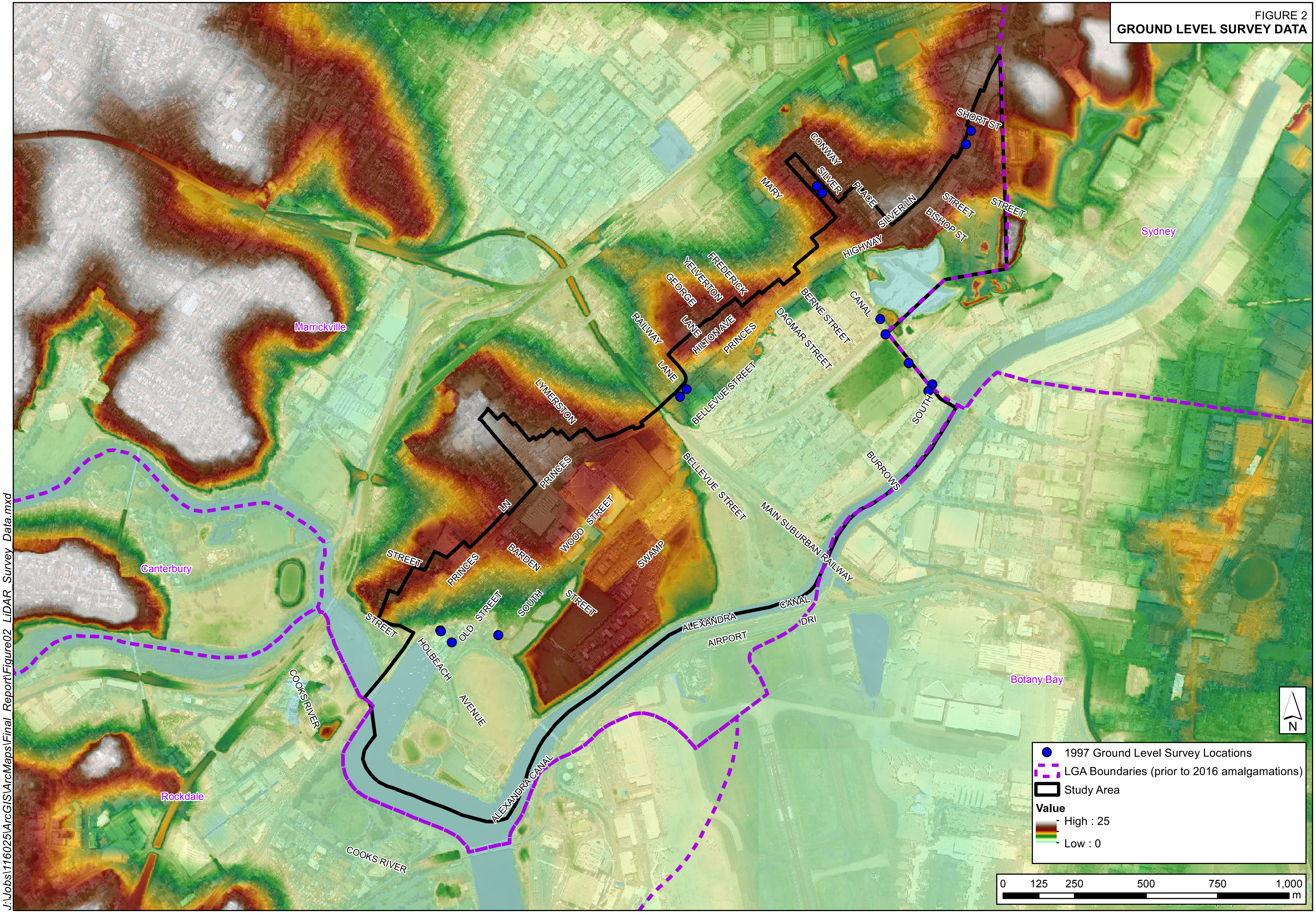

FIGURE 2
GROUND LEVEL SURVEY DATA

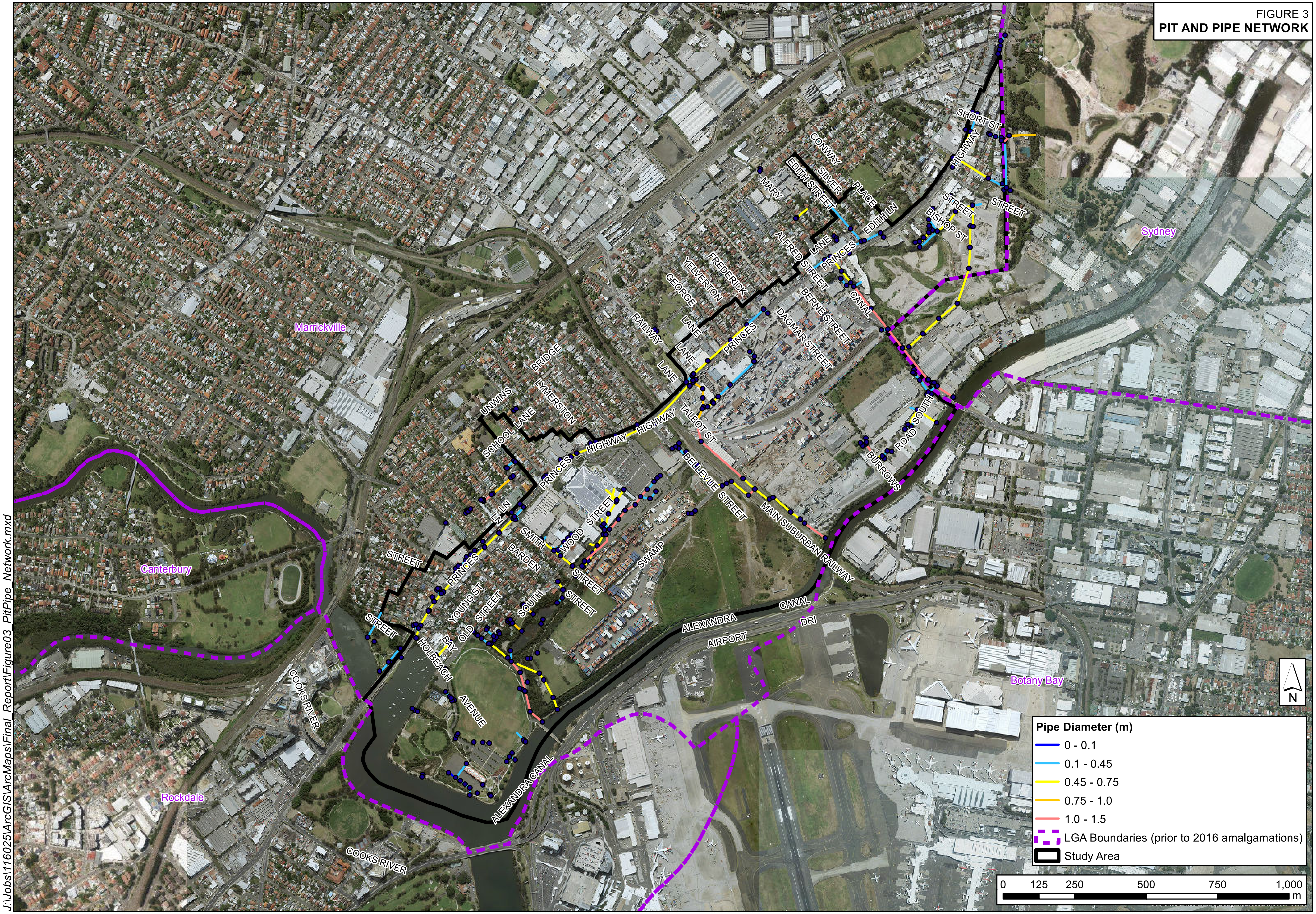

FIGURE 3
PIT AND PIPE NETWORK

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SITE VISIT PHOTOGRAPHS

Above: Alexandra Canal upstream of the Pedestrian Bridge between Tempe Recreation Reserve and Airport Drive

Above: Princes Highway bridge over the Freight Railway Line

Above: Tempe Wetlands pond through the trees

Above: Tempe Wetlands walking track separating the ponds

FIGURE 5
COMMUNITY CONSULTATION

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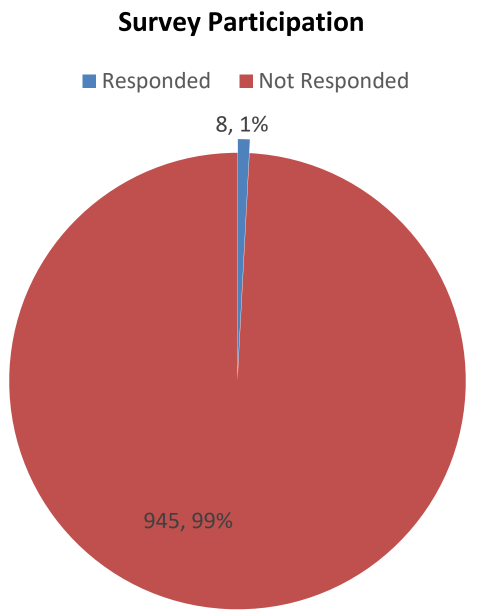
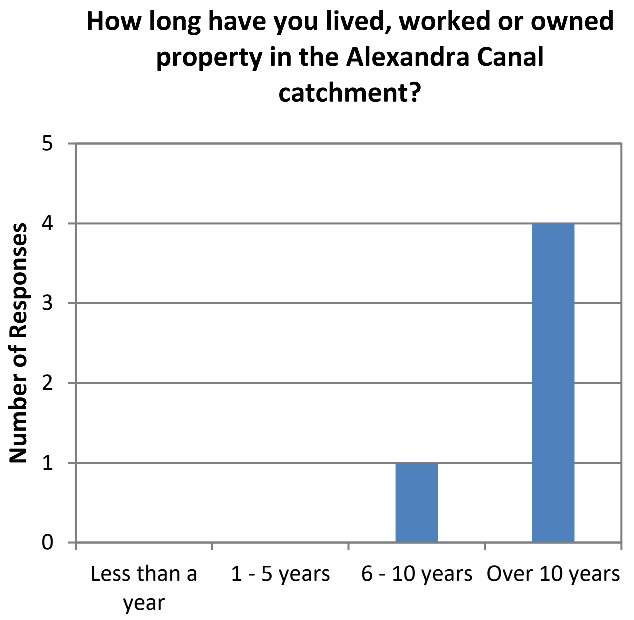
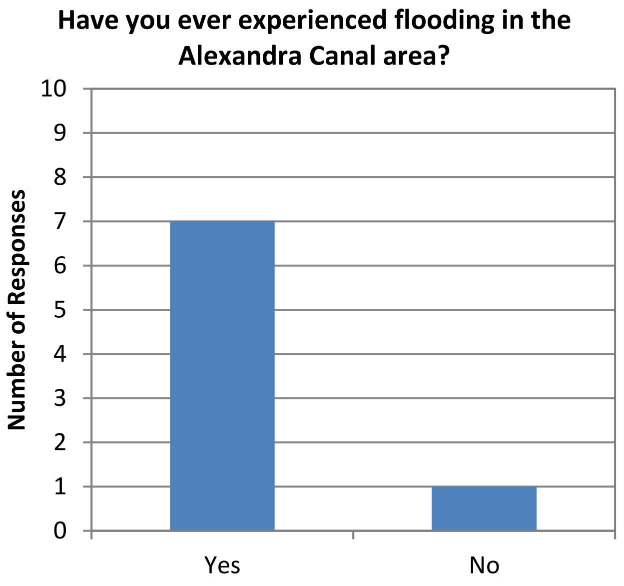
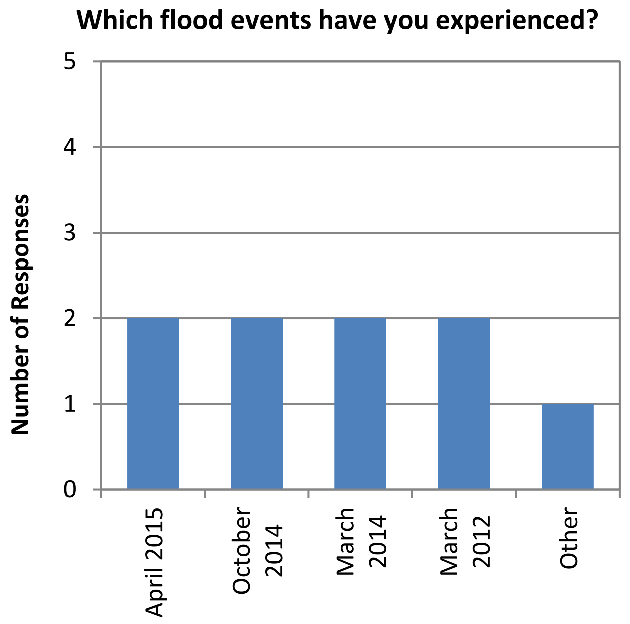
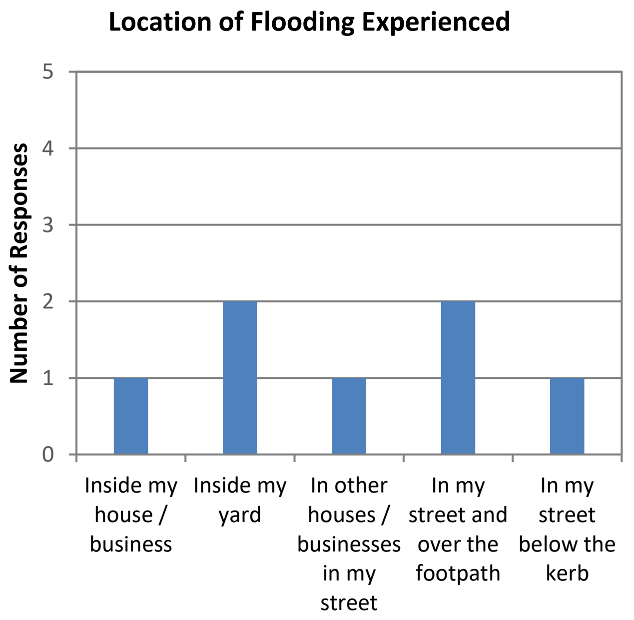
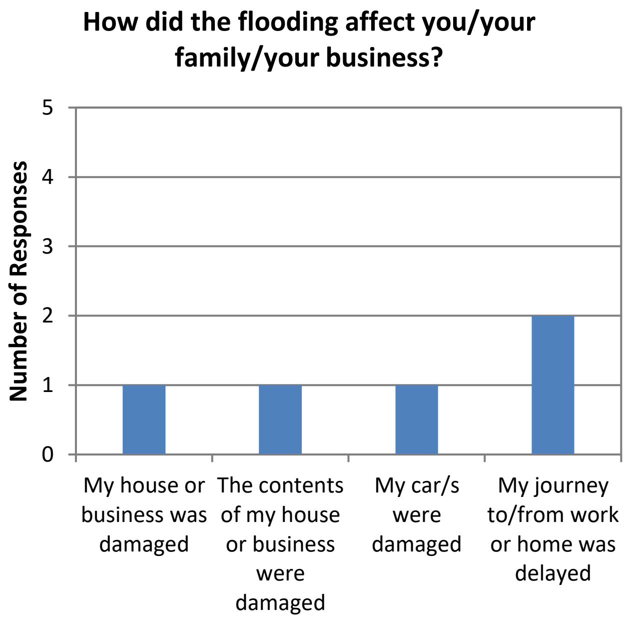

Survey Participation
Responded
Not Responded
8, 1%
945, 99%


How long have you lived, worked or owned property in the Alexandra Canal catchment?
Number of Responses
0
1
2
3
4
5
Less than a year
1 - 5 years
6 - 10 years
Over 10 years


Have you ever experienced flooding in the Alexandra Canal area?
Number of Responses
0
1
2
3
4
5
6
7
8
9
10
Yes
No


Which flood events have you experienced?
Number of Responses
0
1
2
3
4
5
April 2015
October 2014
March 2014
March 2012
Other


Location of Flooding Experienced
Number of Responses
0
1
2
3
4
5
Inside my house / business
Inside my yard
In other houses / businesses in my street
In my street and over the footpath
In my street below the kerb


How did the flooding affect you/your family/your business?
Number of Responses
0
1
2
3
4
5
My house or business was damaged
The contents of my house or business were damaged
My car/s were damaged
My journey to/from work or home was delayed

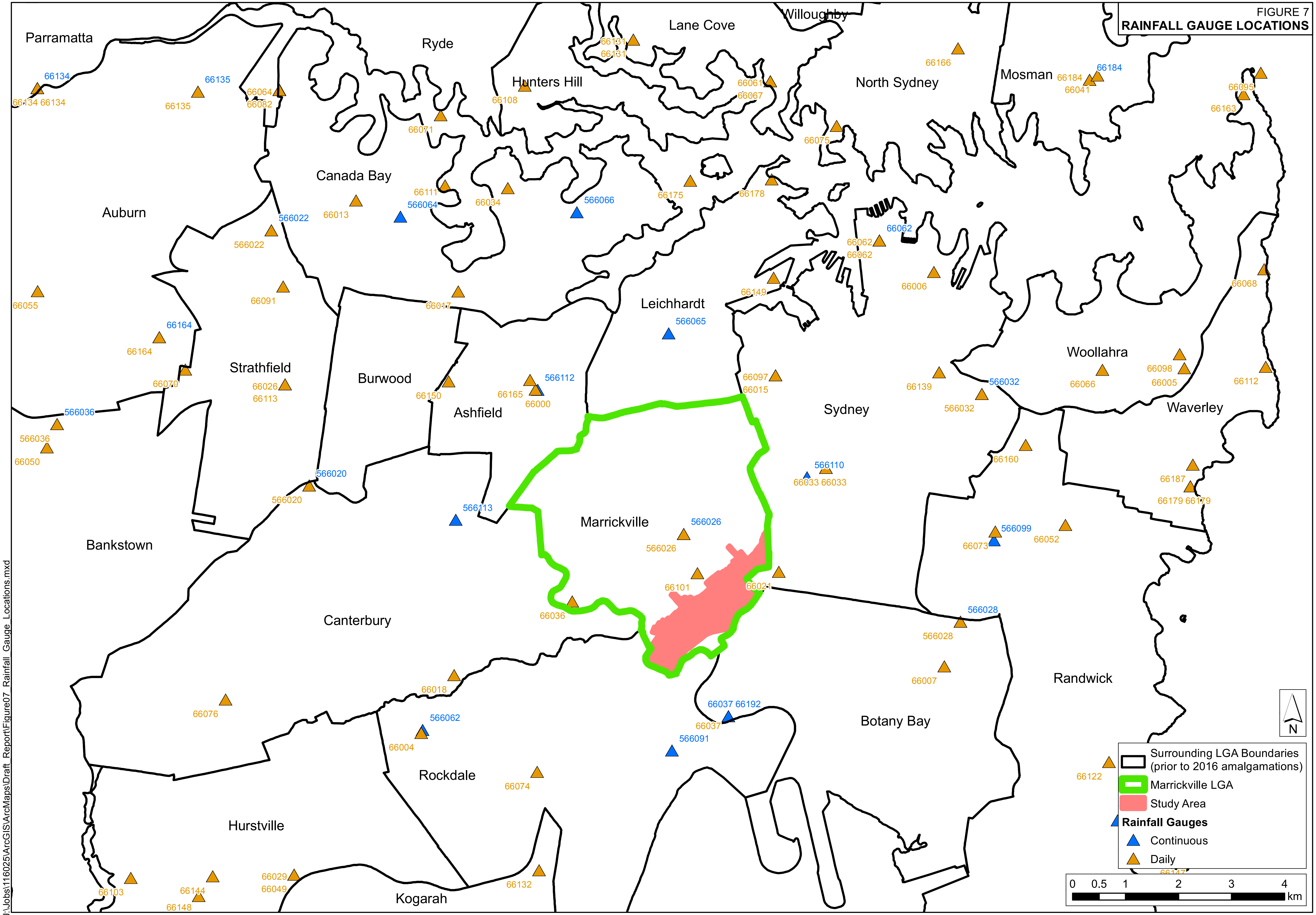


FIGURE 7
RAINFALL GAUGE LOCATIONS

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FIGURE 8A
RAINFALL DISTRIBUTION - DEPTH
30 JAN 2016 4:00PM - 30 MIN DURATION

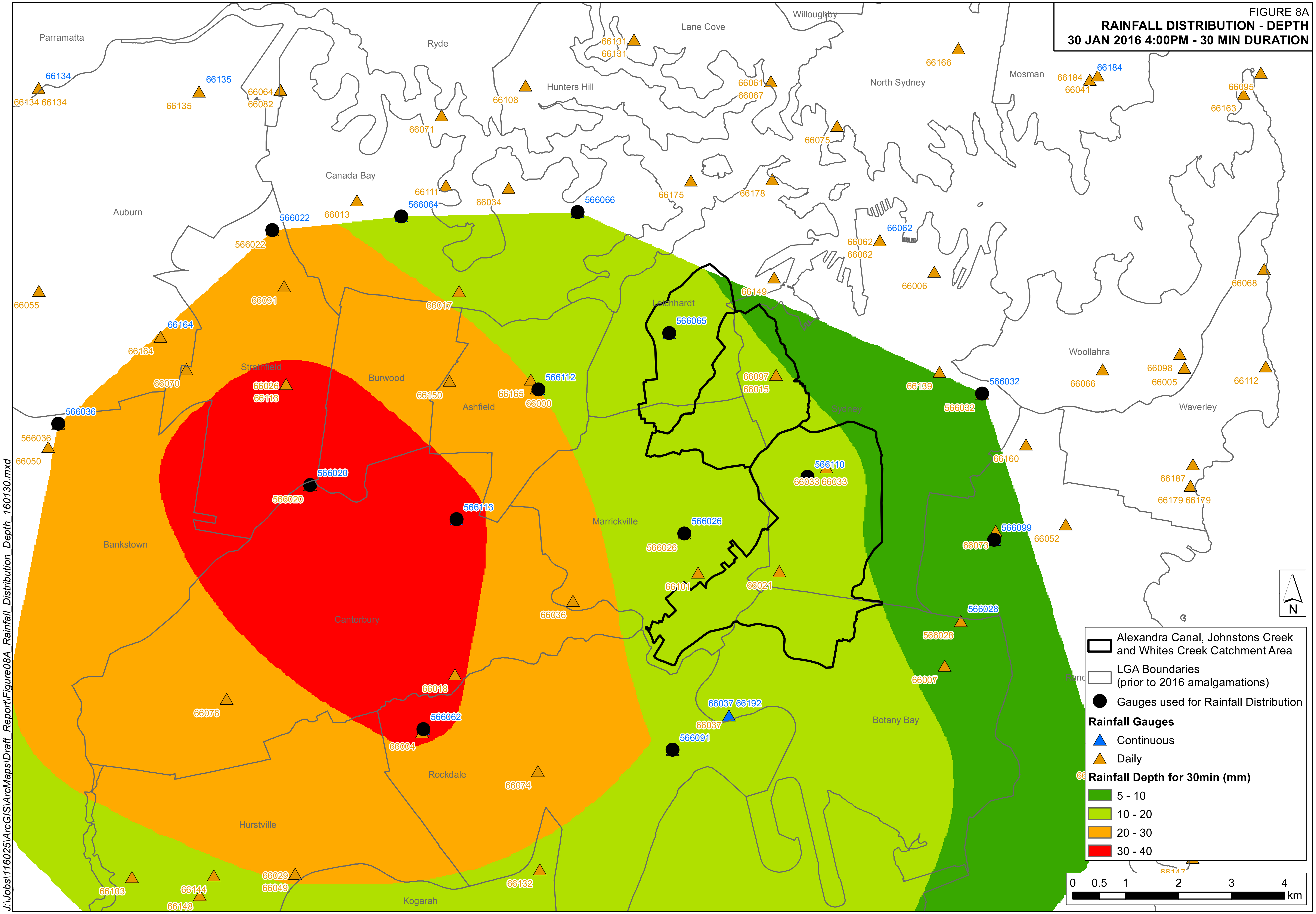

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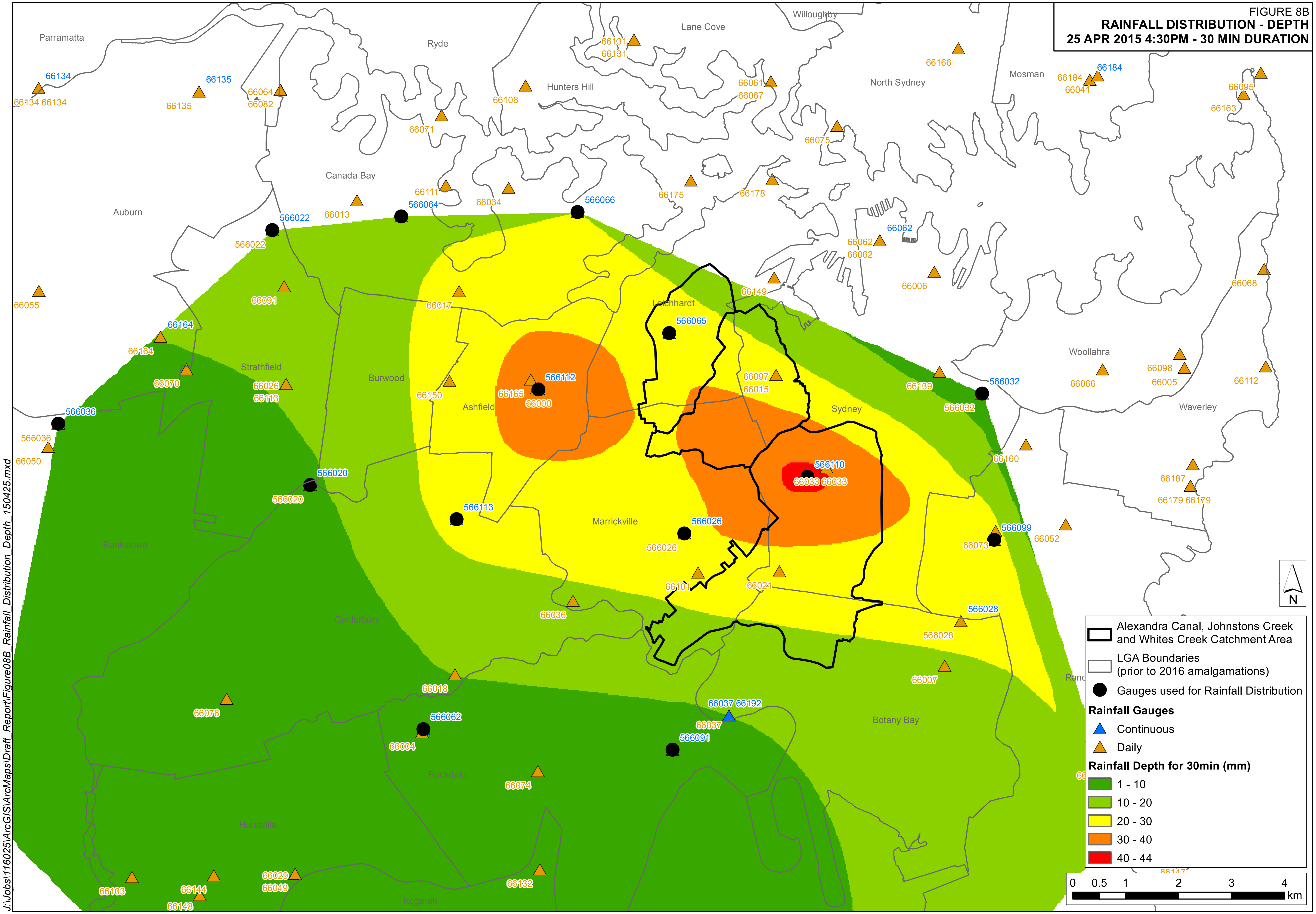
FIGURE 8B
RAINFALL DISTRIBUTION - DEPTH
25 APR 2015 4:30PM - 30 MIN DURATION



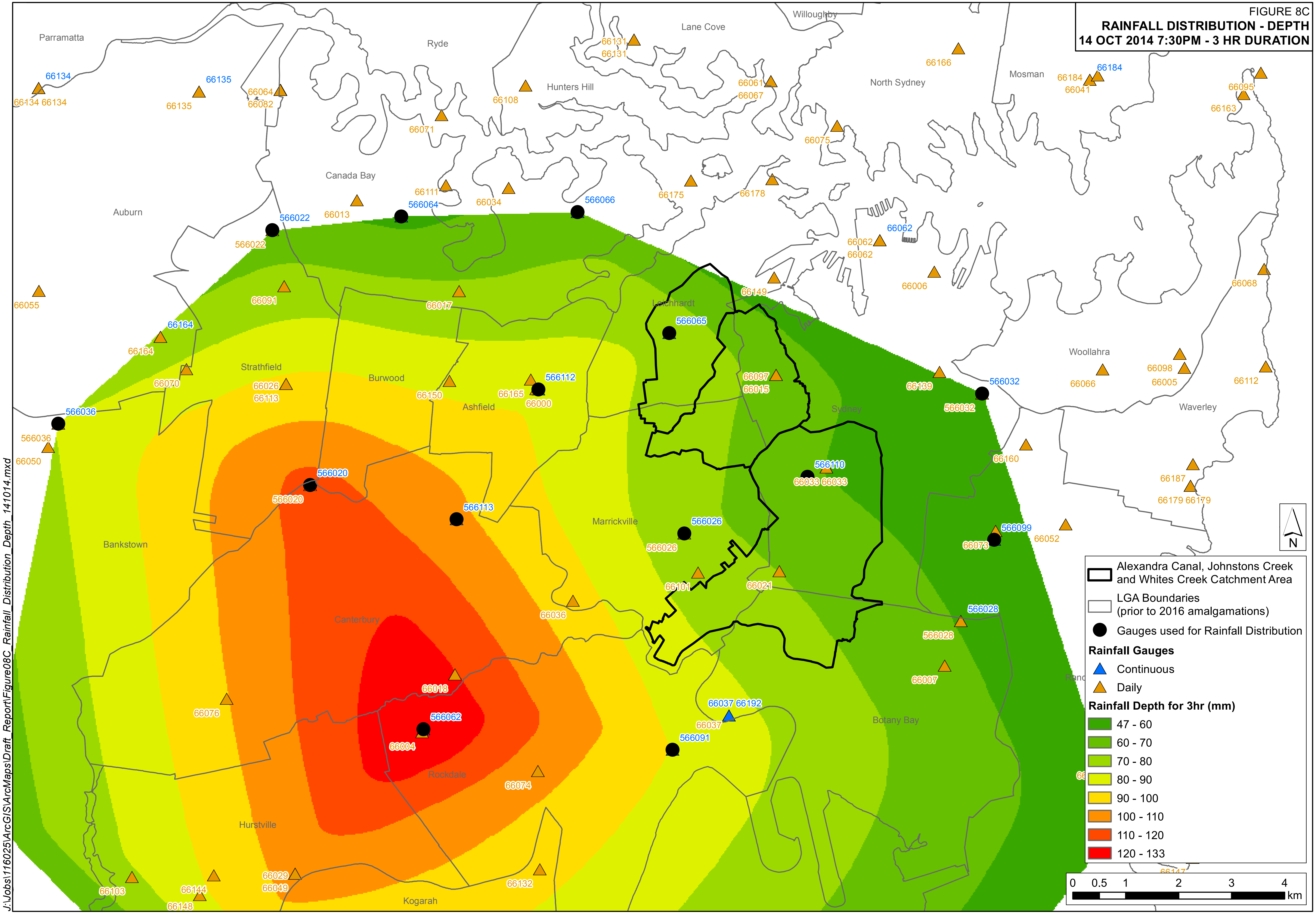


FIGURE 8C
RAINFALL DISTRIBUTION - DEPTH
14 OCT 2014 7:30PM - 3 HR DURATION
Alexandra Canal, Johnstons Creek and Whites Creek Catchment Area
LGA Boundaries (prior to 2016 amalgamations)
Gauges used for Rainfall Distribution
Rainfall Gauges
Continuous
Daily
Rainfall Depth for 3hr (mm)
47 - 60
60 - 70
70 - 80
80 - 90
90 - 100
100 - 110
110 - 120
120 - 133
0 0.5 1 2 3 4
km
N
J:\Jobs\116025\ArcGIS\ArcMaps\Draft_Report\Figure08C_Rainfall_Distribution_Depth_141014.mxd

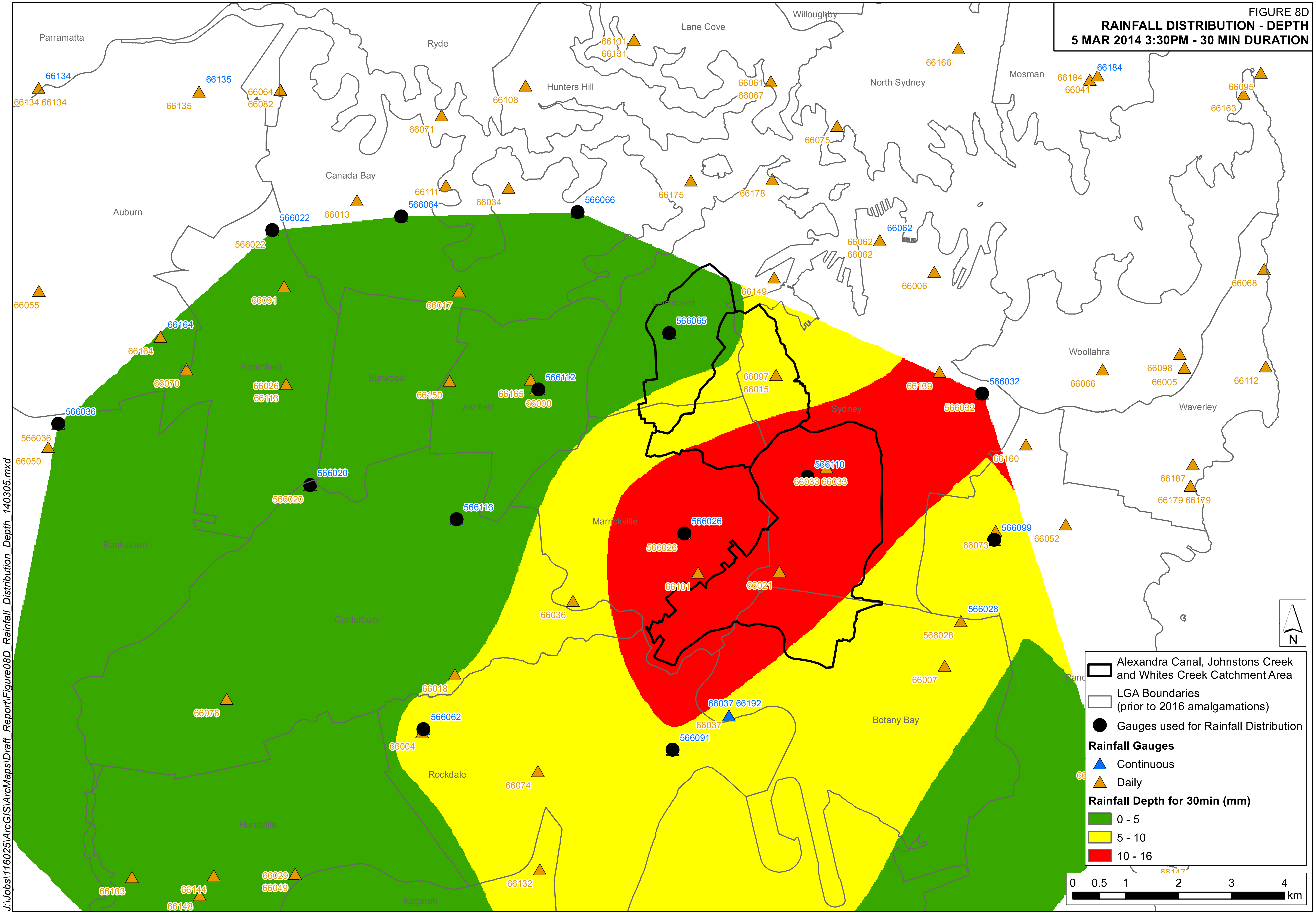


FIGURE 8D
RAINFALL DISTRIBUTION - DEPTH
5 MAR 2014 3:30PM - 30 MIN DURATION

J:\Jobs\116025\ArcGIS\ArcMaps\Draft_Report\Figure08D_Rainfall_Distribution_Depth_140305.mxd

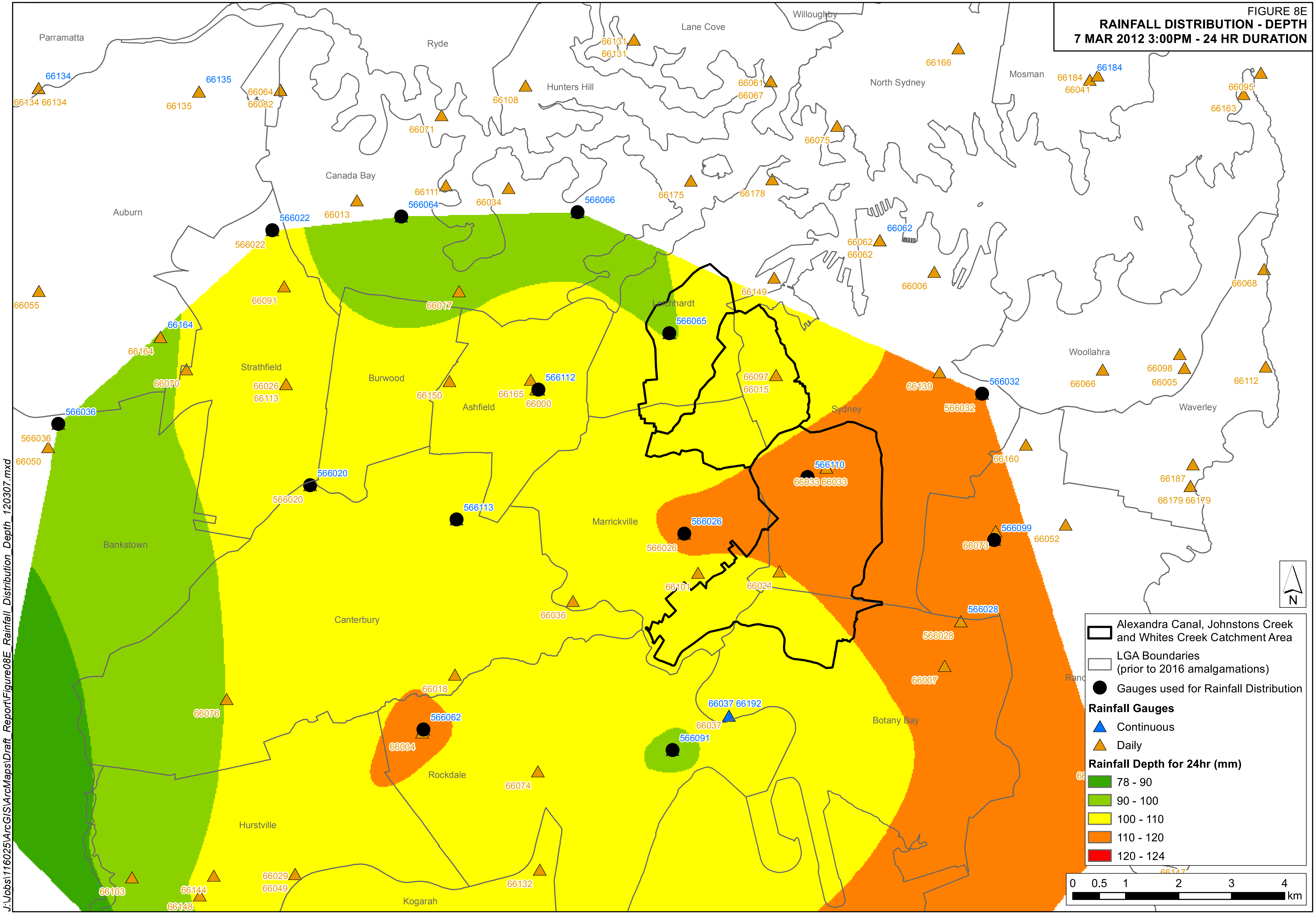


FIGURE 8E
RAINFALL DISTRIBUTION - DEPTH
7 MAR 2012 3:00PM - 24 HR DURATION
Alexandra Canal, Johnstons Creek and Whites Creek Catchment Area
LGA Boundaries (prior to 2016 amalgamations)
Gauges used for Rainfall Distribution
Rainfall Gauges
Continuous
Daily
Rainfall Depth for 24hr (mm)
78 - 90
90 - 100
100 - 110
110 - 120
120 - 124
0 0.5 1 2 3 4 km
N
Parramatta
Ryde
Lane Cove
Willoughby
Hunters Hill
North Sydney
Mosman
Canada Bay
Auburn
Strathfield
Burwood
Ashfield
Leichhardt
Sydney
Woollahra
Waverley
Marrickville
Bankstown
Canterbury
Rockdale
Hurstville
Kogarah
Botany Bay
J:\Jobs\116025\ArcGIS\ArcMaps\Draft_Report\Figure08E_Rainfall_Distribution_Depth_120307.mxd

FIGURE 8F
RAINFALL DISTRIBUTION - DEPTH
13 MAY 2003 9:00AM - 1 HR DURATION

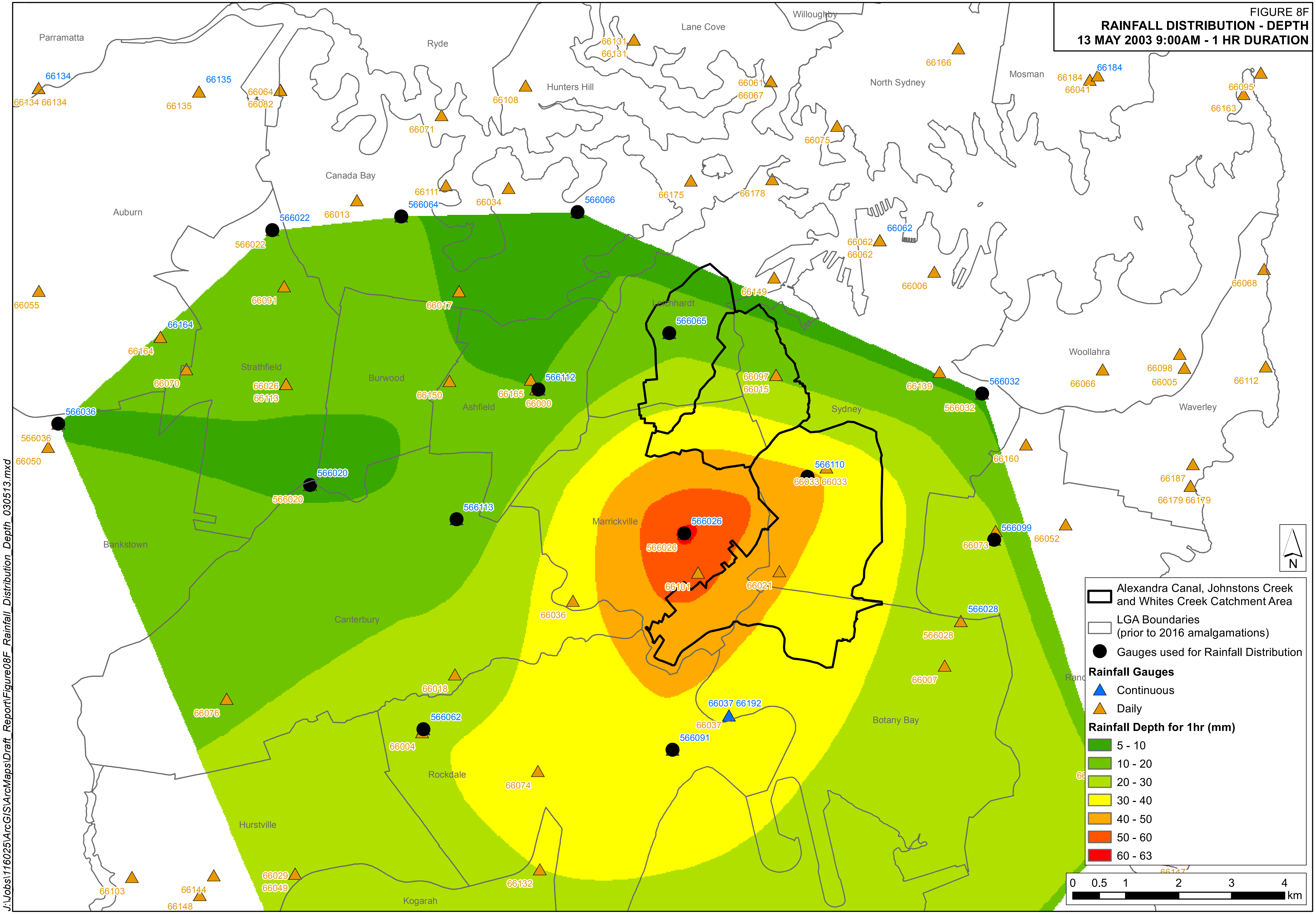
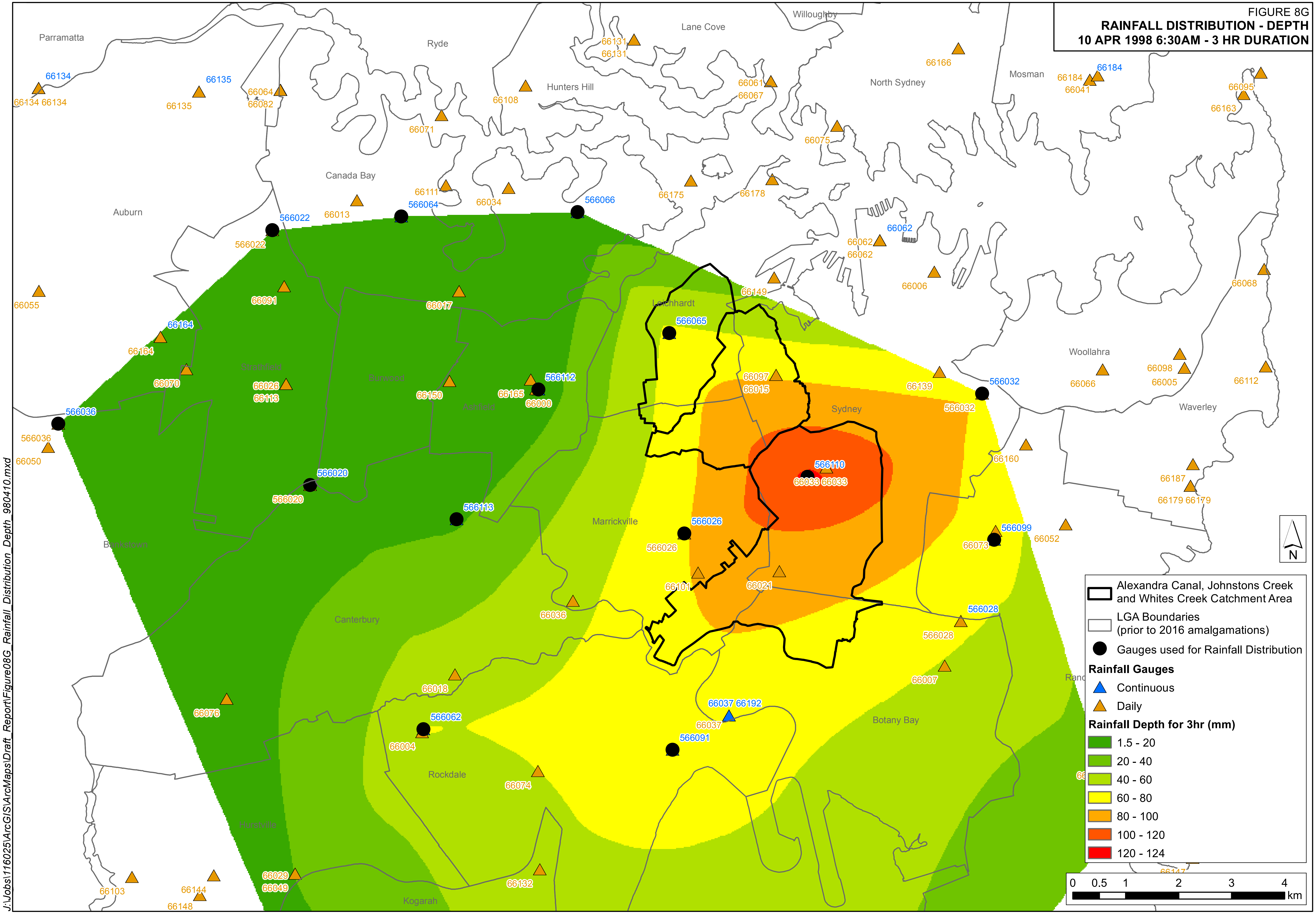


FIGURE 8G
RAINFALL DISTRIBUTION - DEPTH
10 APR 1998 6:30AM - 3 HR DURATION



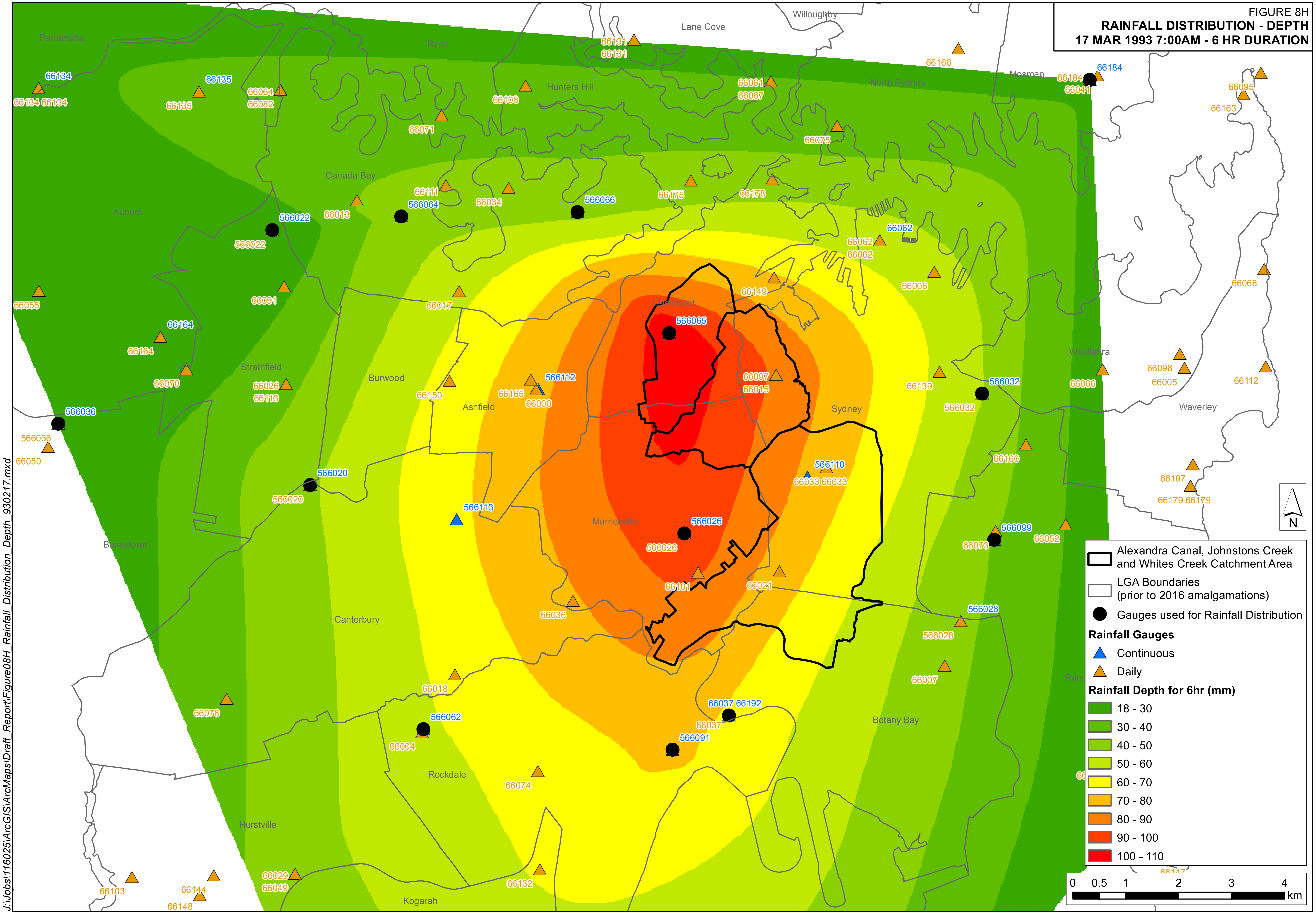
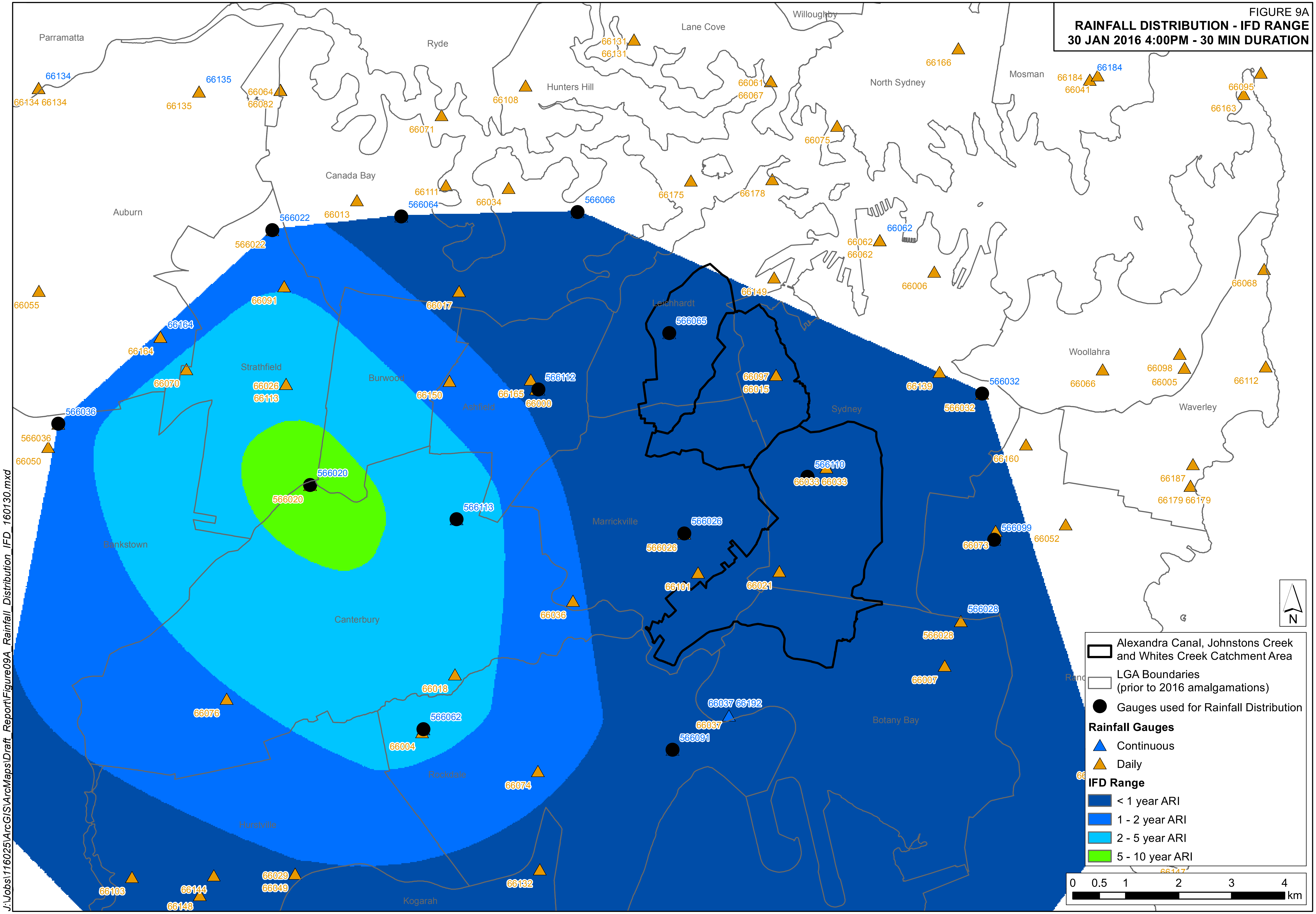


FIGURE 8H
RAINFALL DISTRIBUTION - DEPTH
17 MAR 1993 7:00AM - 6 HR DURATION
Alexandra Canal, Johnstons Creek and Whites Creek Catchment Area
LGA Boundaries (prior to 2016 amalgamations)
Gauges used for Rainfall Distribution
Rainfall Gauges
Continuous
Daily
Rainfall Depth for 6hr (mm)
18 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100
100 - 110
0 0.5 1 2 3 4 km
N
Parramatta
Ryde
Lane Cove
Willoughby
Hunters Hill
North Sydney
Mosman
Canada Bay
Auburn
Strathfield
Burwood
Ashfield
Leichhardt
Sydney
Woollahra
Waverley
Marrickville
Bankstown
Canterbury
Rockdale
Botany Bay
Hurstville
Kogarah
J:\Jobs\116025\ArcGIS\ArcMaps\Draft_Report\Figure08H_Rainfall_Distribution_Depth_930217.mxd

FIGURE 9A
RAINFALL DISTRIBUTION - IFD RANGE
30 JAN 2016 4:00PM - 30 MIN DURATION



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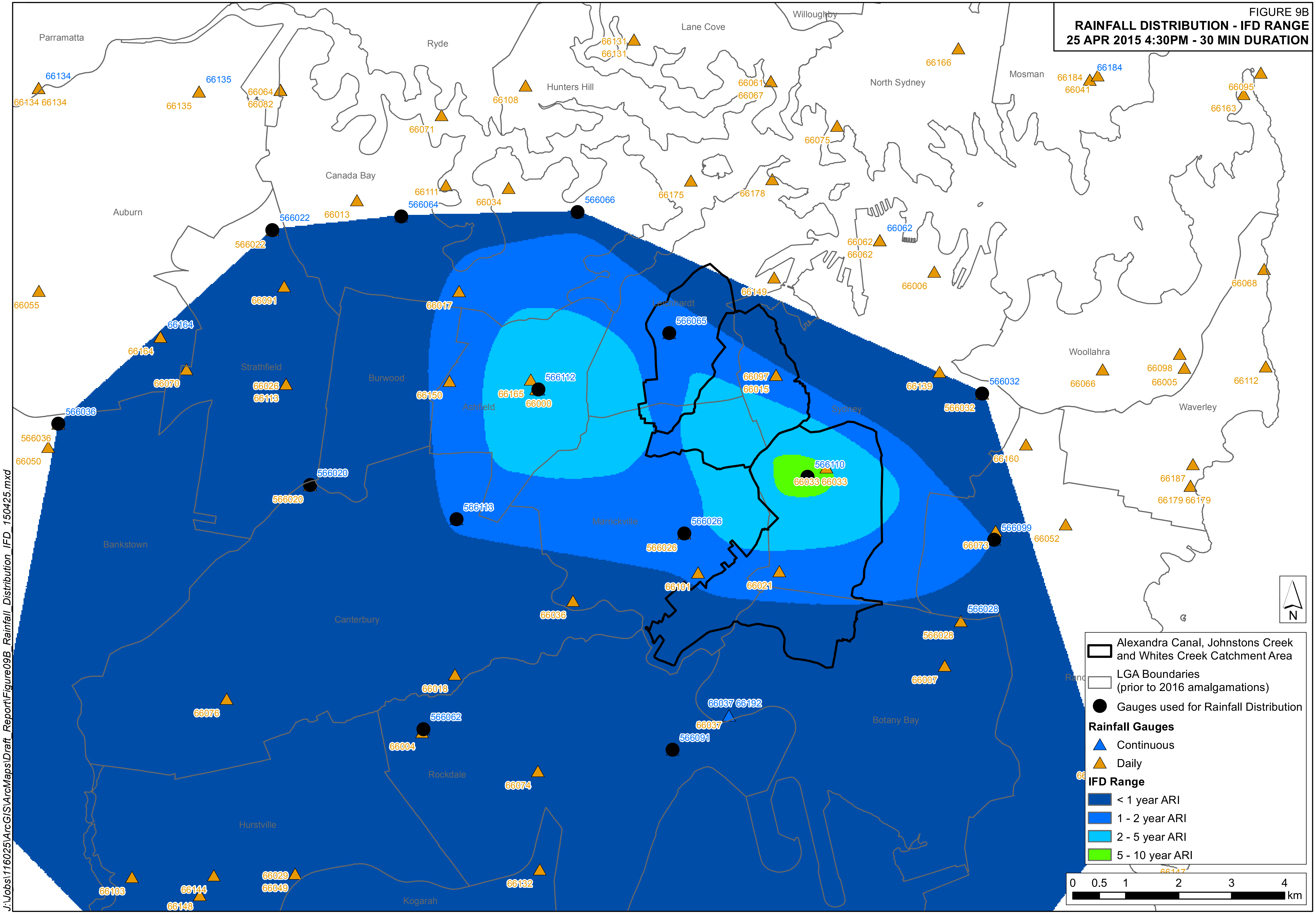

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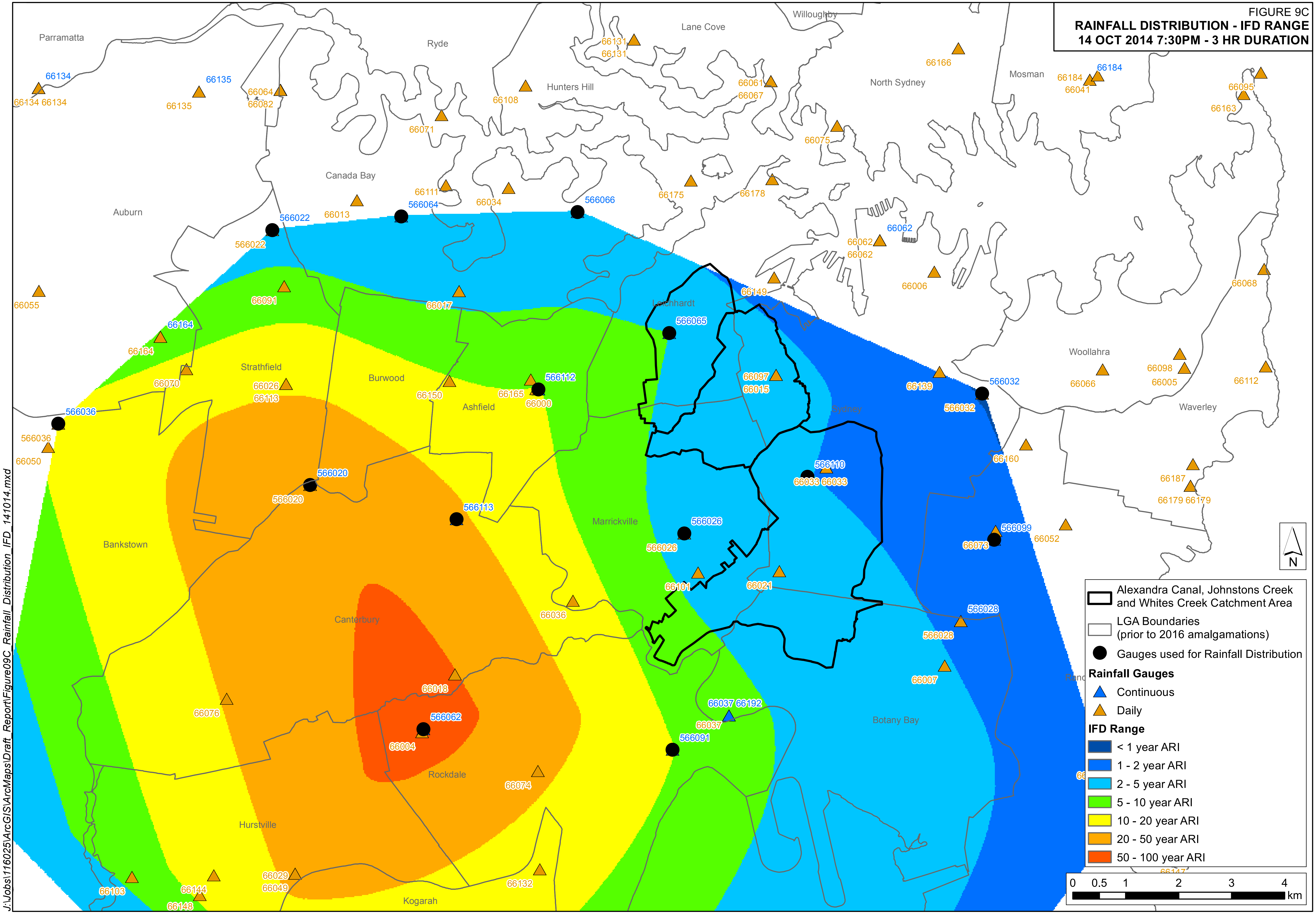

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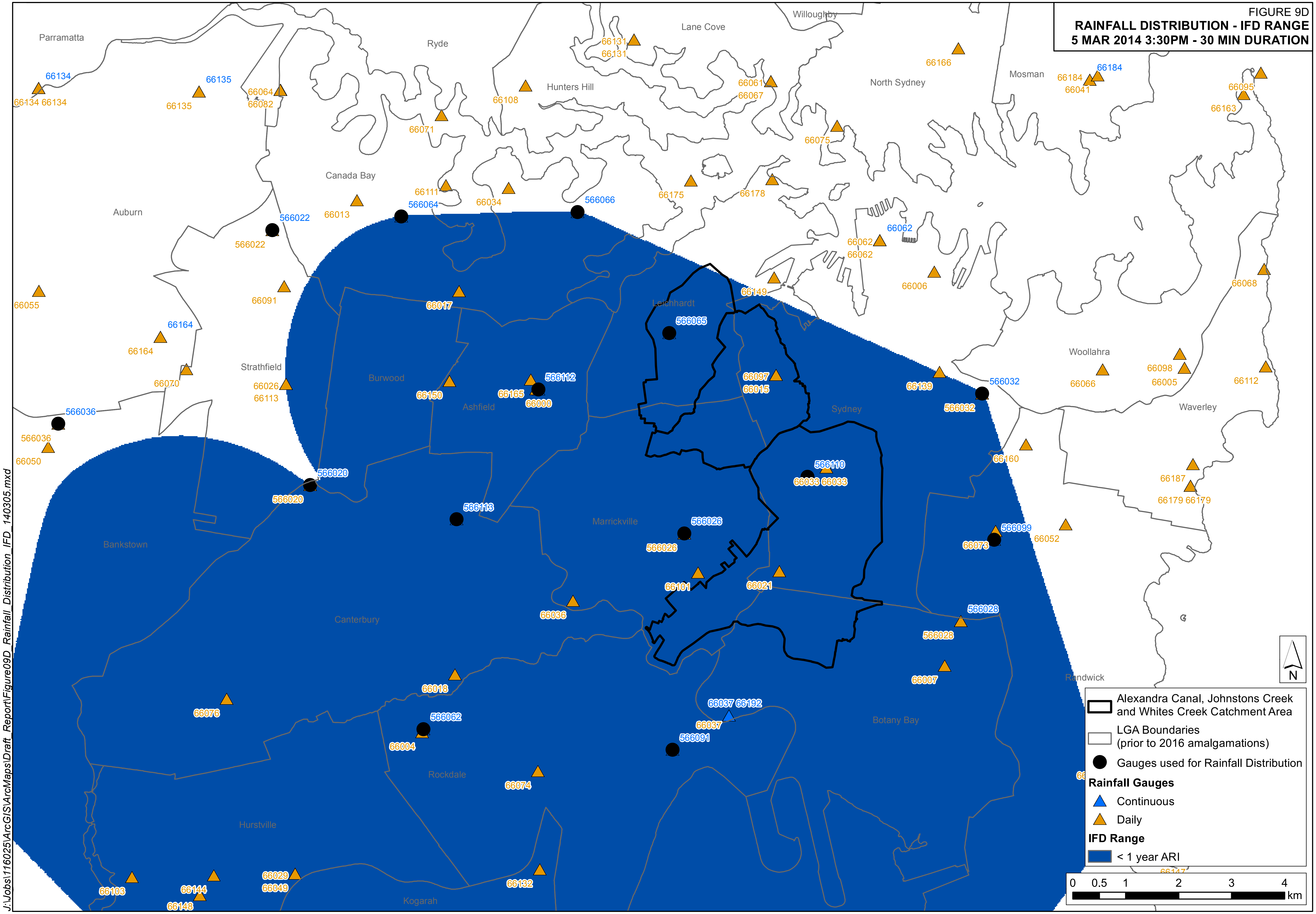
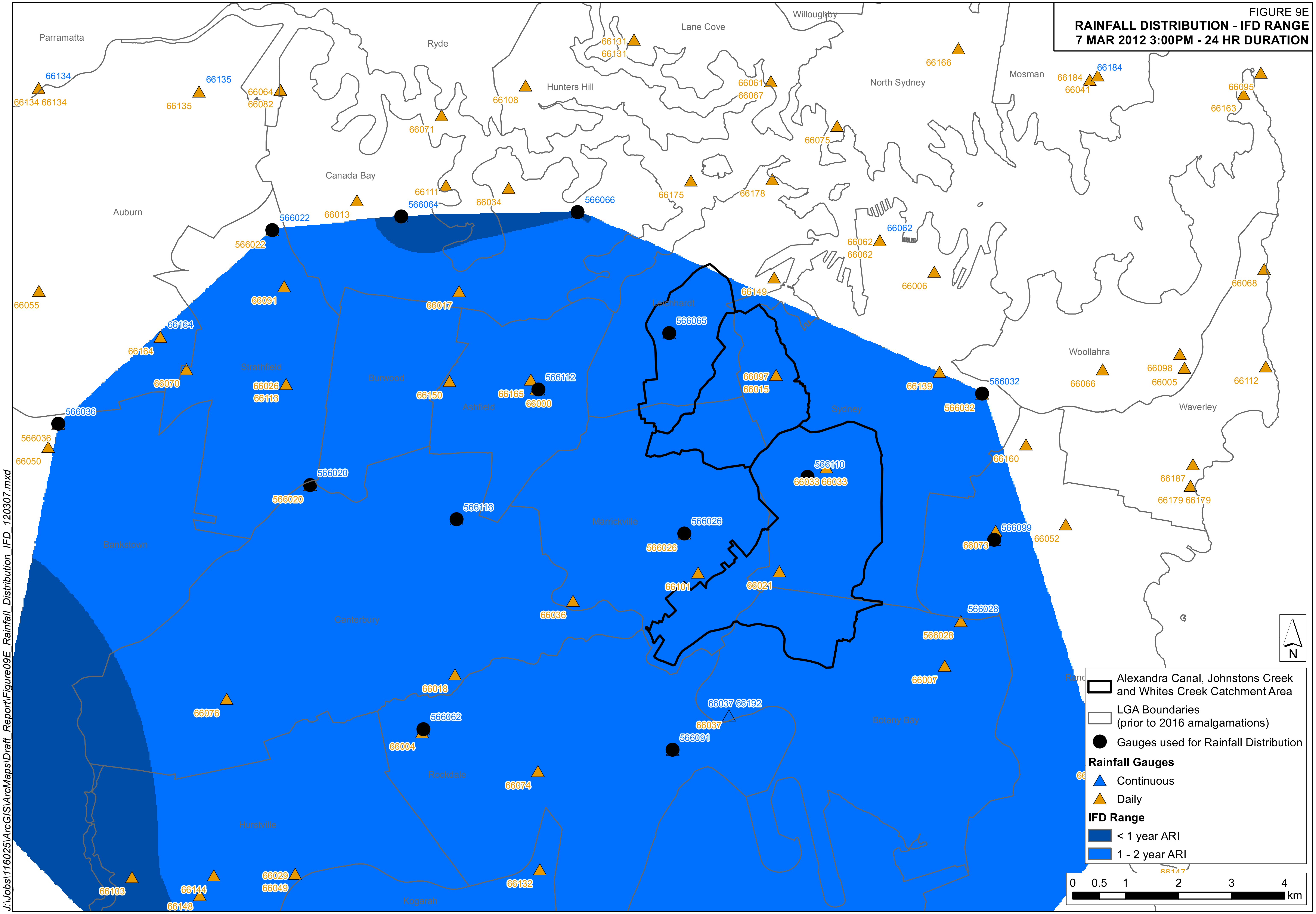


FIGURE 9D
RAINFALL DISTRIBUTION - IFD RANGE
5 MAR 2014 3:30PM - 30 MIN DURATION

J:\Jobs\116025\ArcGIS\ArcMaps\Draft_Report\Figure09D_Rainfall_Distribution_IFD_140305.mxd

FIGURE 9E
RAINFALL DISTRIBUTION - IFD RANGE
7 MAR 2012 3:00PM - 24 HR DURATION



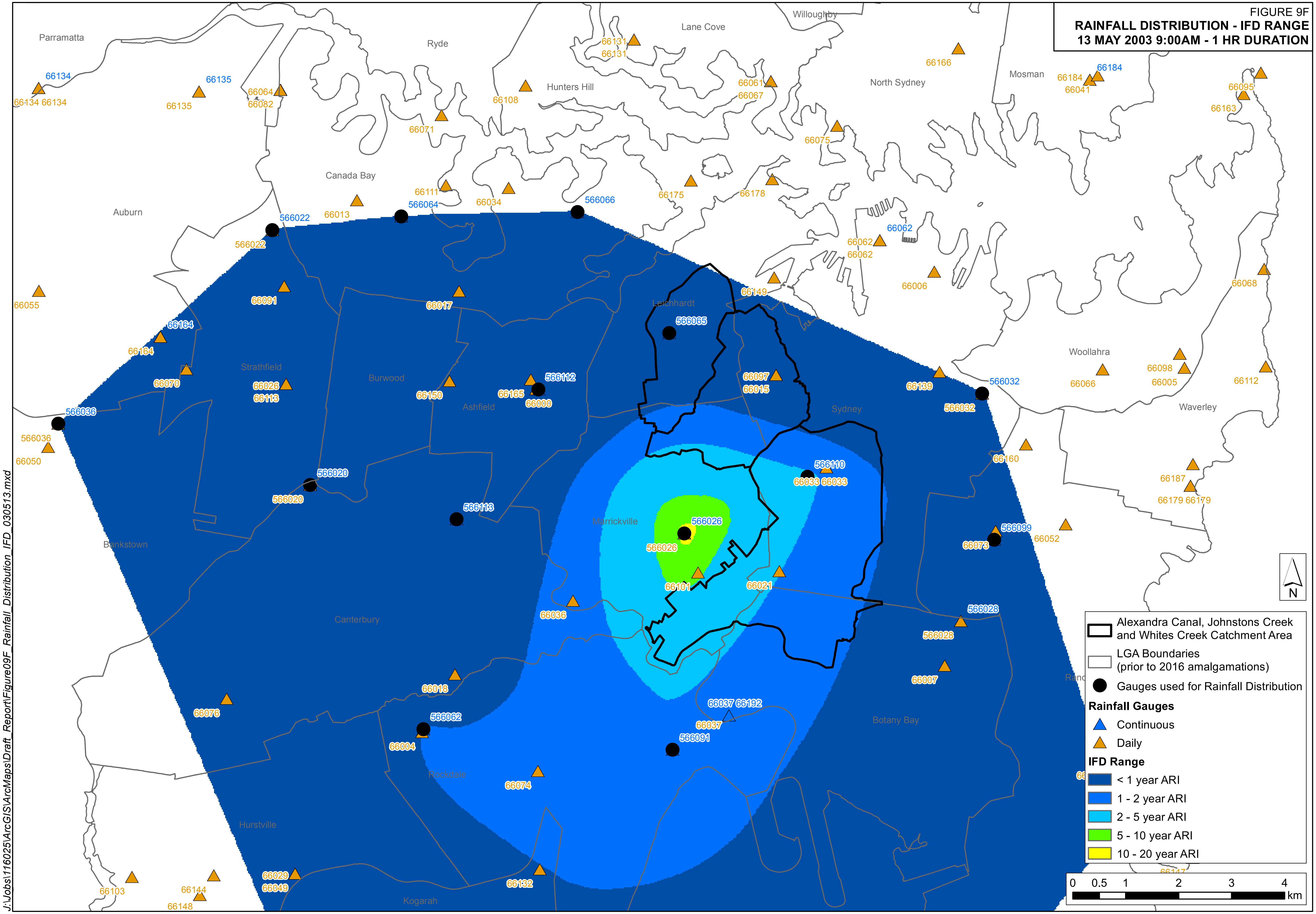
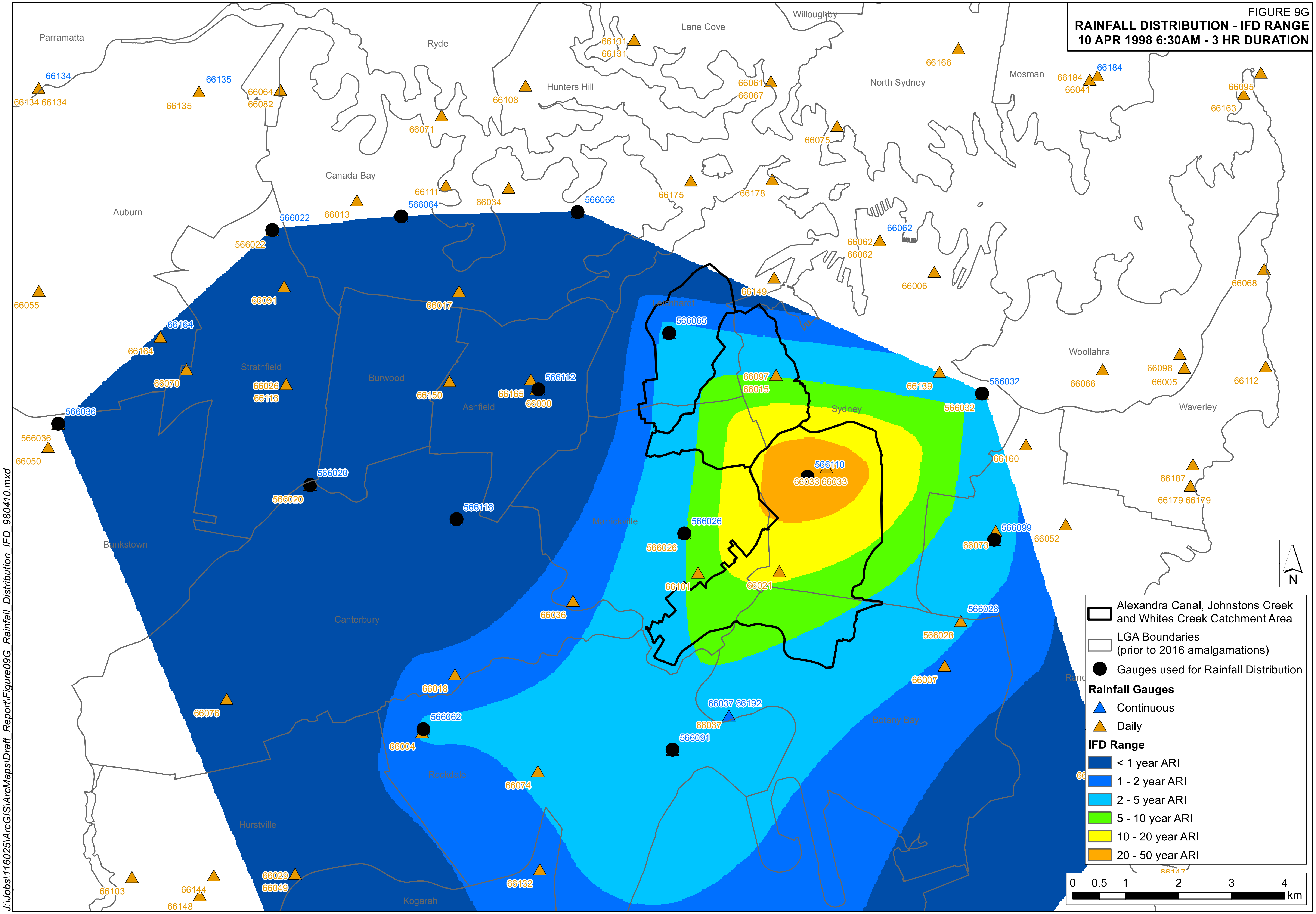


FIGURE 9F
RAINFALL DISTRIBUTION - IFD RANGE
13 MAY 2003 9:00AM - 1 HR DURATION

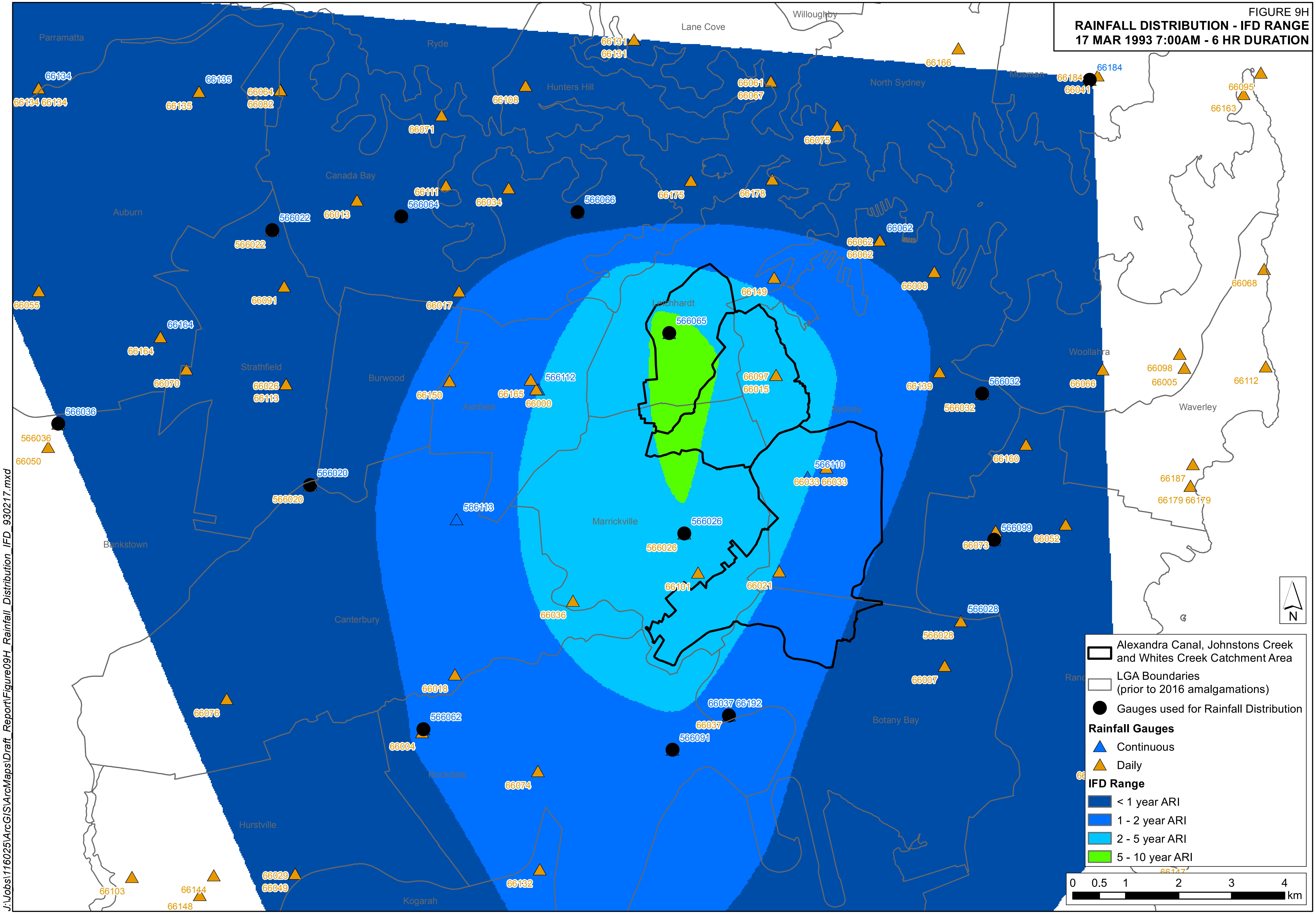
J:\Jobs\116025\ArcGIS\ArcMaps\Draft_Report\Figure09F_Rainfall_Distribution_IFD_030513.mxd

FIGURE 9G
RAINFALL DISTRIBUTION - IFD RANGE
10 APR 1998 6:30AM - 3 HR DURATION



J:\Jobs\116025\ArcGIS\ArcMaps\Draft_Report\Figure09G_Rainfall_Distribution_IFD_980410.mxd

FIGURE 9H
RAINFALL DISTRIBUTION - IFD RANGE
17 MAR 1993 7:00AM - 6 HR DURATION



J:\Jobs\116025\ArcGIS\ArcMaps\Draft_Report\Figure09H_Rainfall_Distribution_IFD_930217.mxd

FIGURE 10A

BURST INTENSITIES AND FREQUENCIES 30 JAN 2016

J:\Jobs\116011\Calibration\IFD_Graphs\IFD_Bursts_MACRO_20160130.xlsm

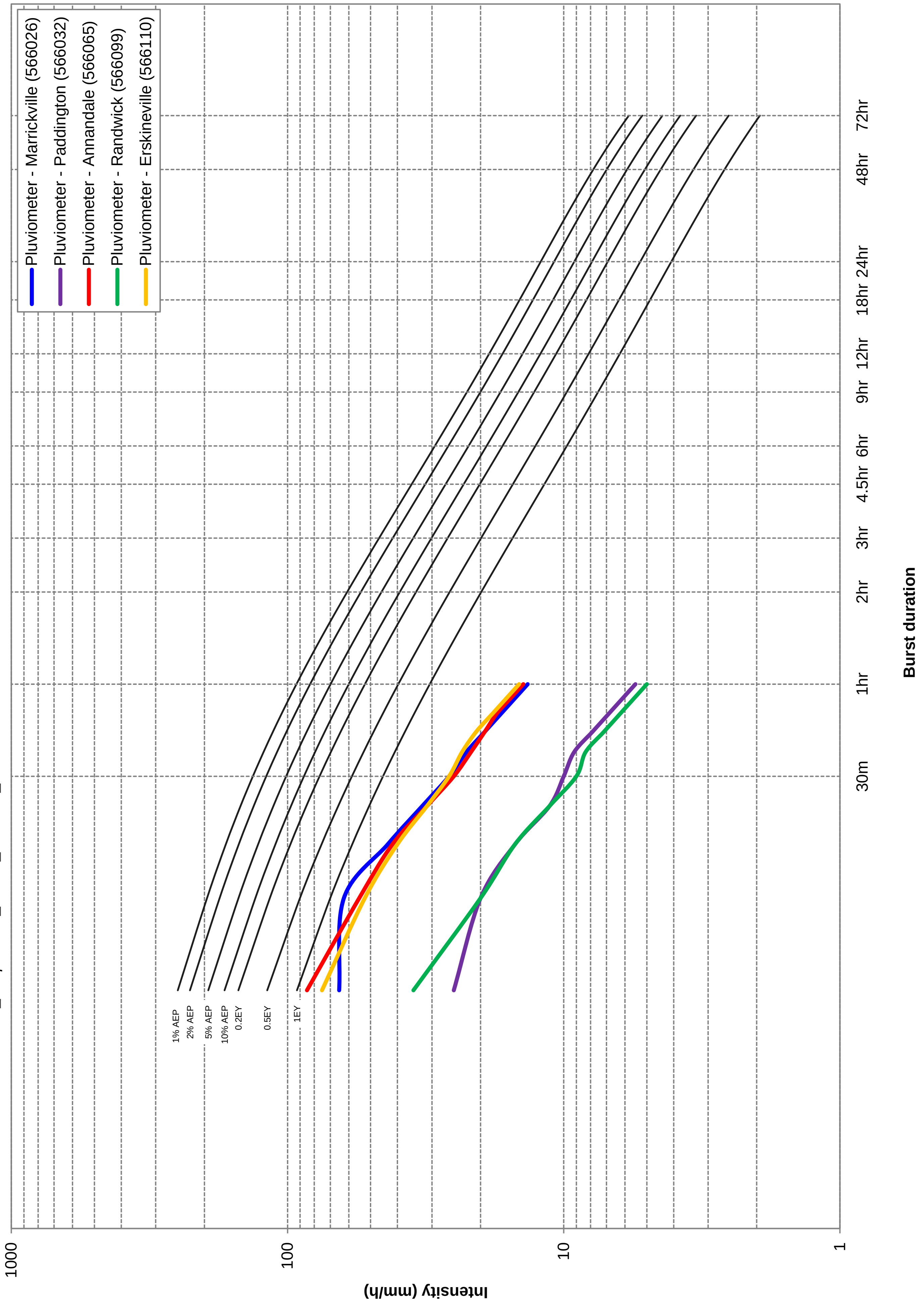


FIGURE 10B
BURST INTENSITIES
AND FREQUENCIES
25 APR 2015

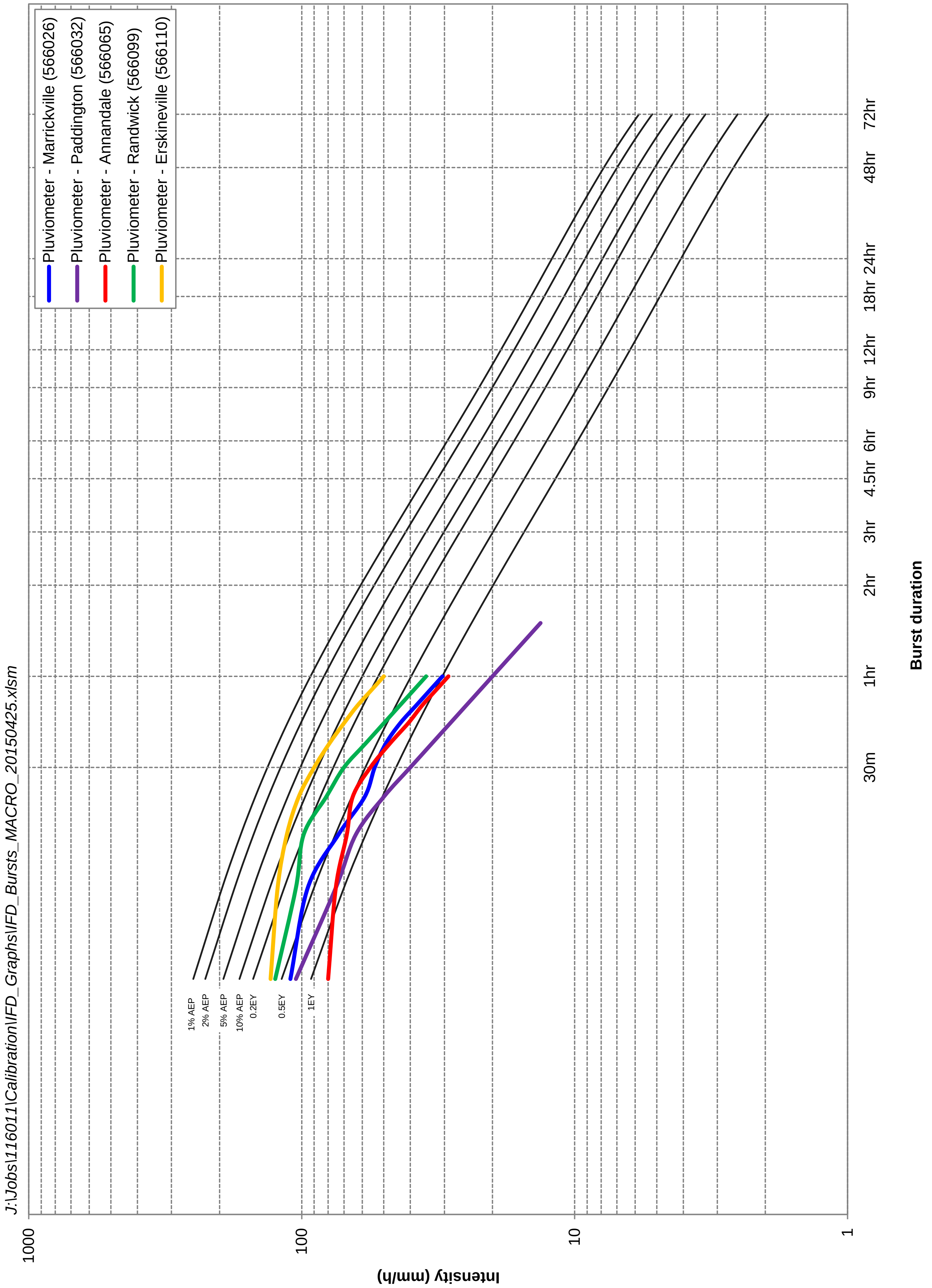


FIGURE 10C
BURST INTENSITIES AND FREQUENCIES 14 OCT 2014

J:\Jobs\116011\Calibration\IFD_Graphs\IFD_Bursts_MACRO_20141014.xlsm

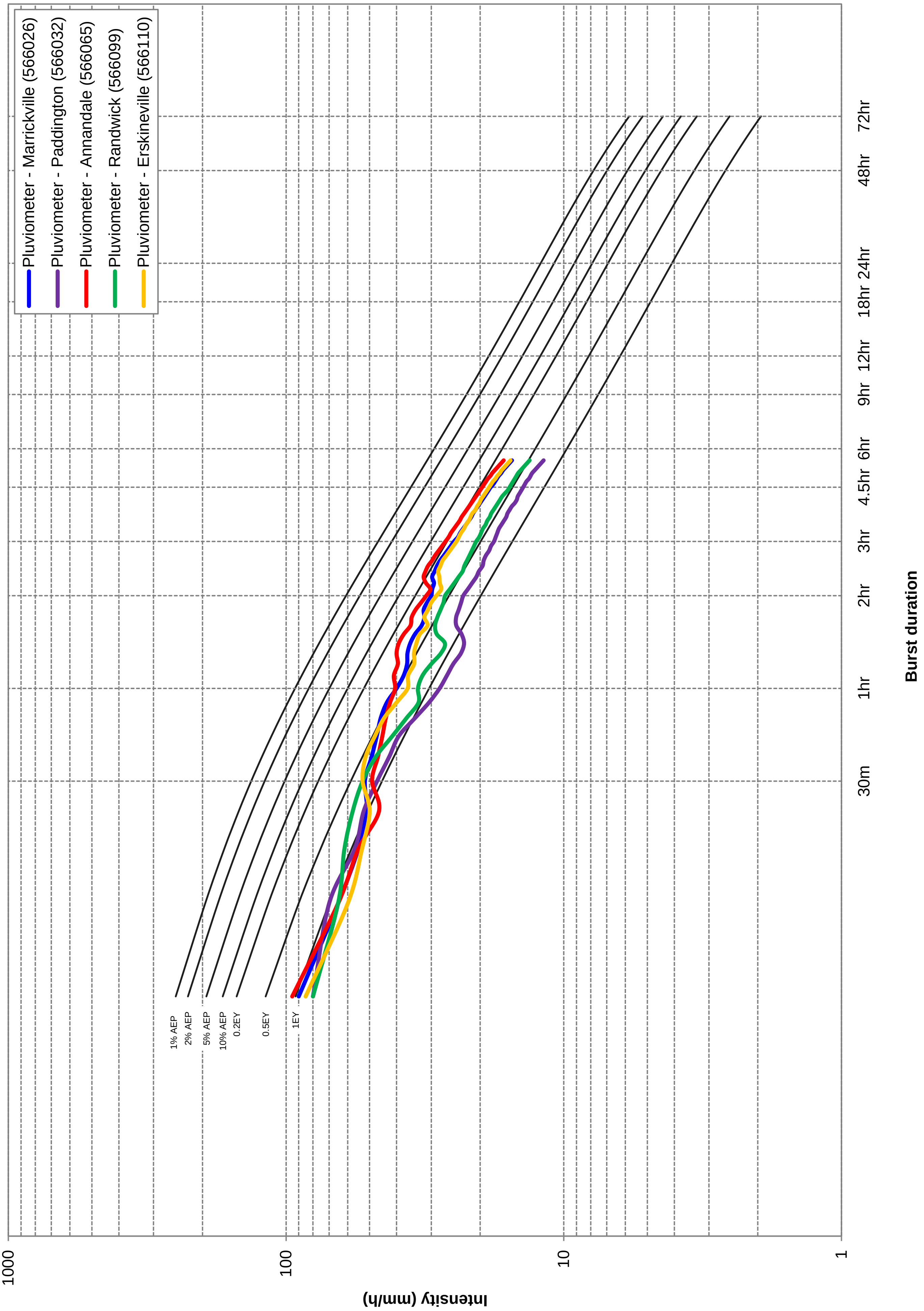


FIGURE 10D
BURST INTENSITIES
AND FREQUENCIES
5 MAR 2014

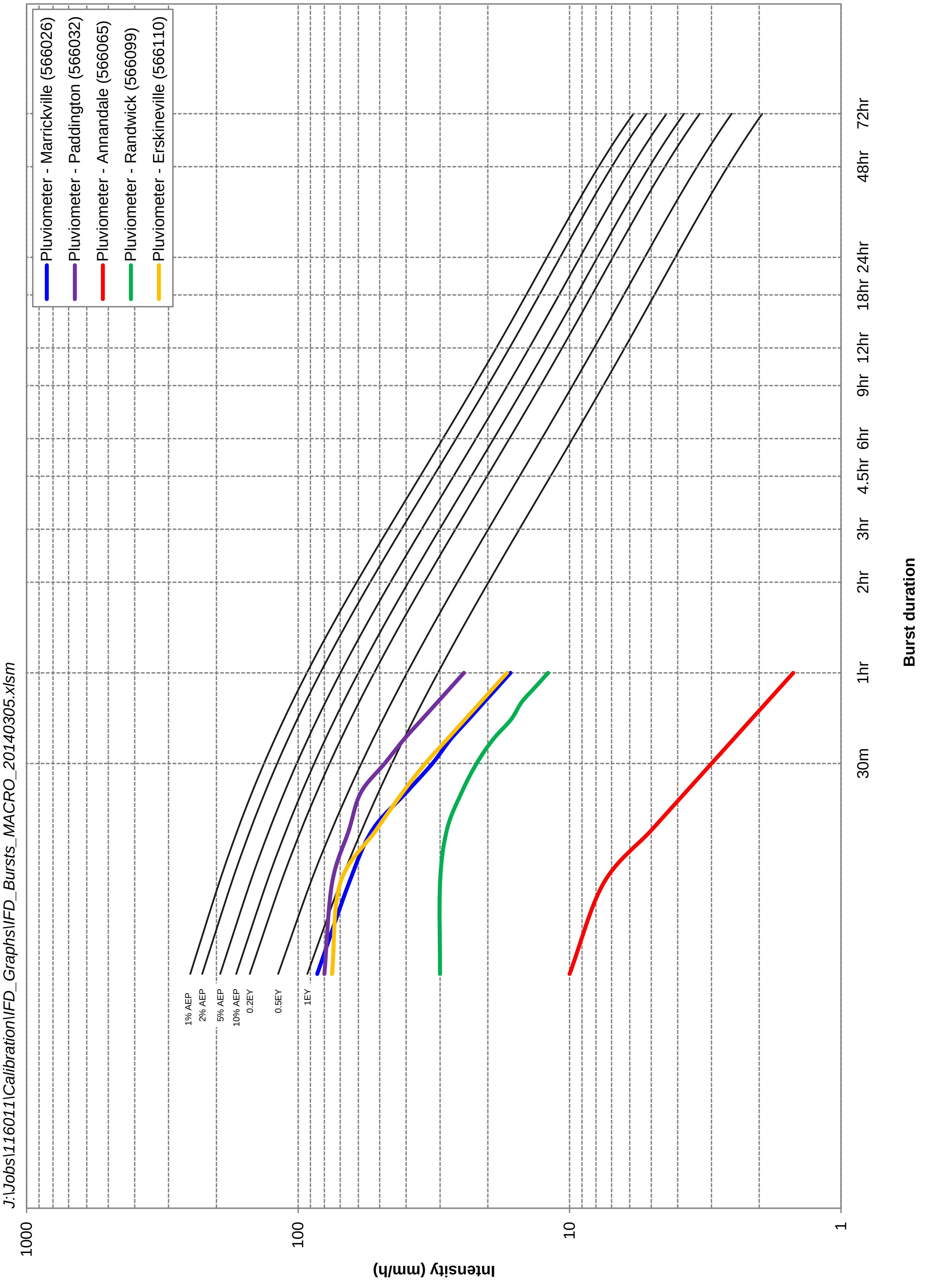


FIGURE 10E

BURST INTENSITIES AND FREQUENCIES

7 MAR 2012

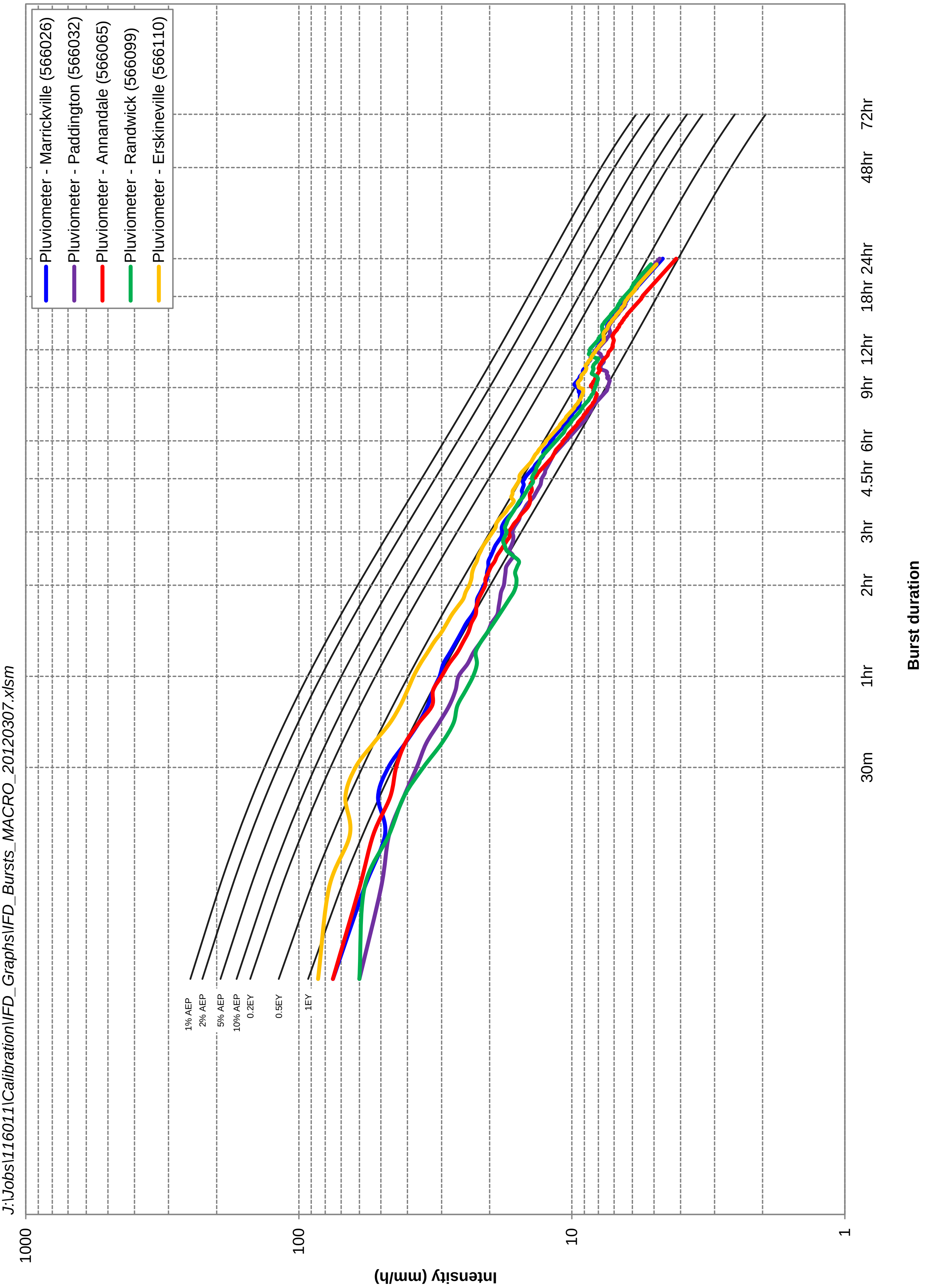
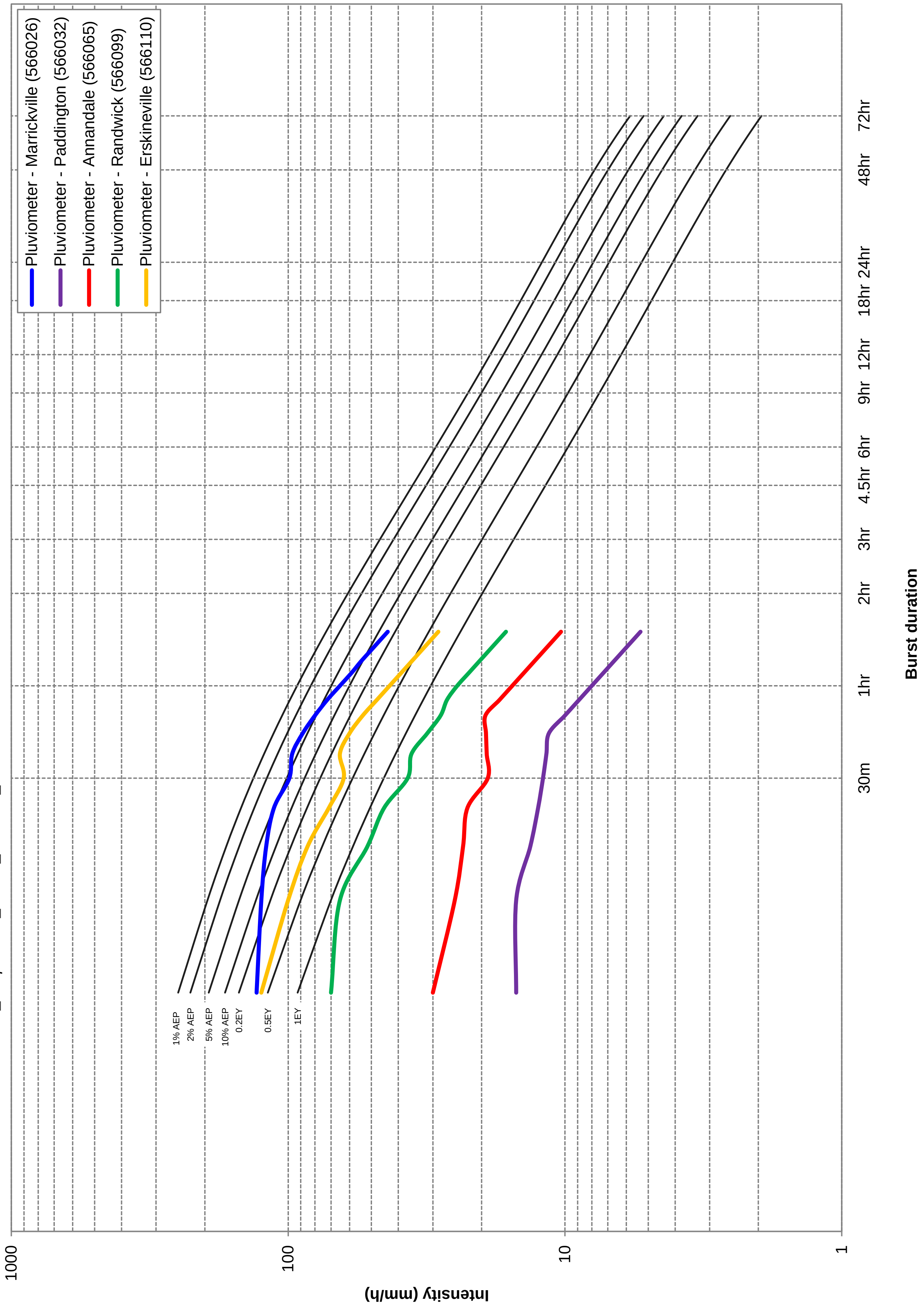


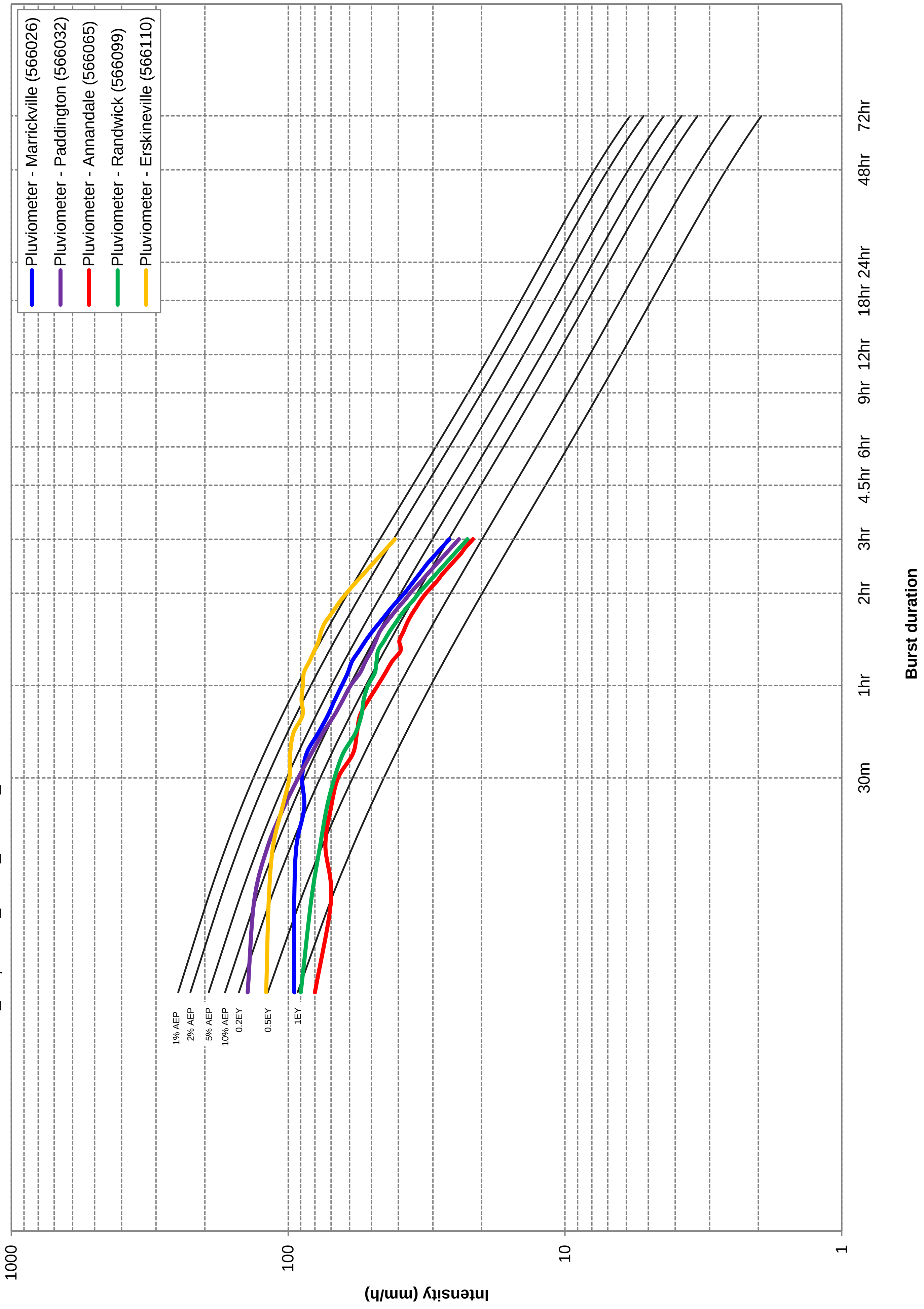
FIGURE 10F
BURST INTENSITIES
AND FREQUENCIES
13 MAY 2003



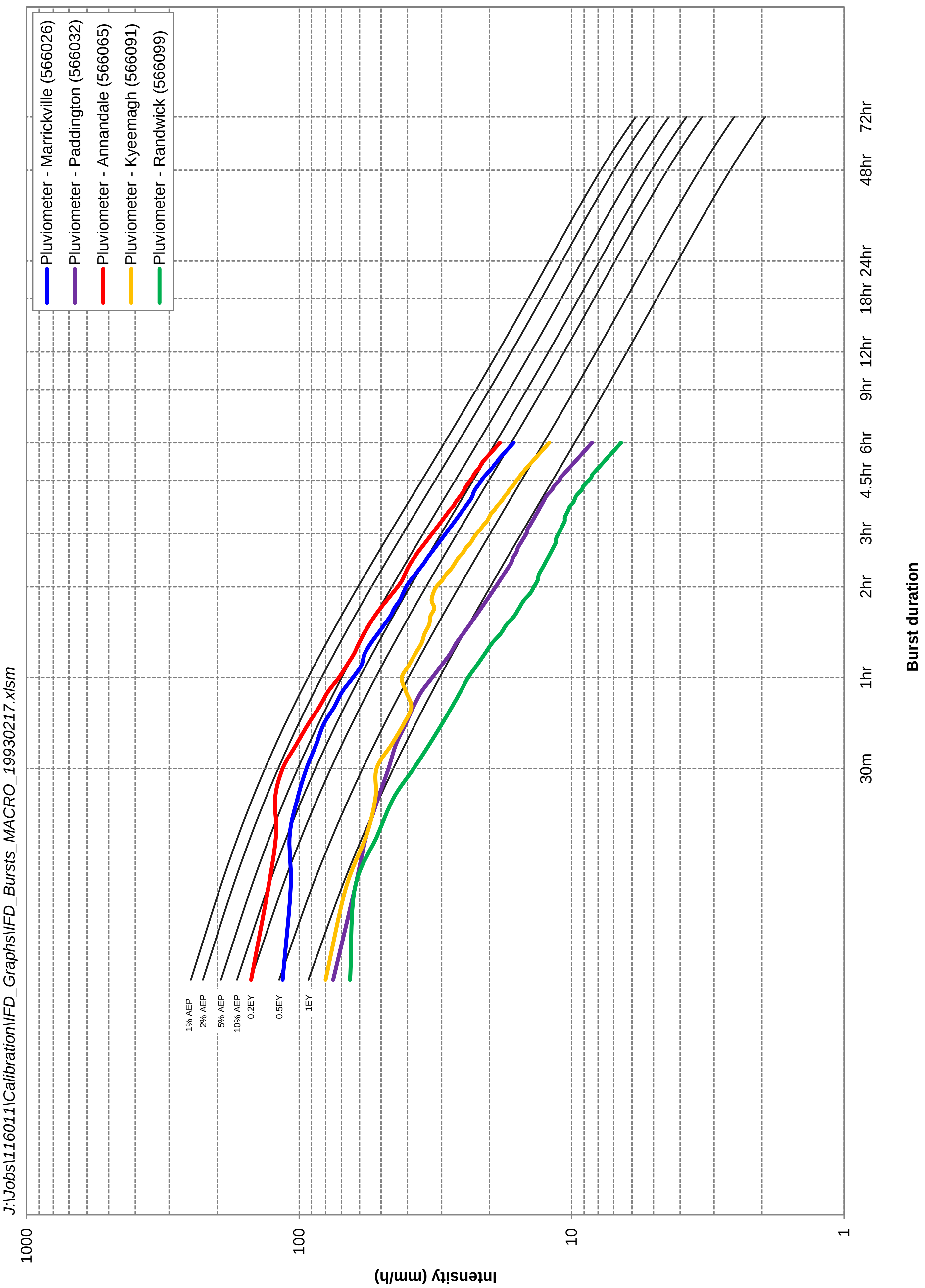
J:\Jobs\116011\Calibration\IFD_Graphs\IFD_Bursts_MACRO_20030513.xlsm

FIGURE 10G
**BURST INTENSITIES
AND FREQUENCIES
10 APR 1998**

J:\Jobs\116011\Calibration\IFD_Graphs\IFD_Bursts_MACRO_19980410.xlsm



BURST INTENSITIES AND FREQUENCIES 17 FEB 1993



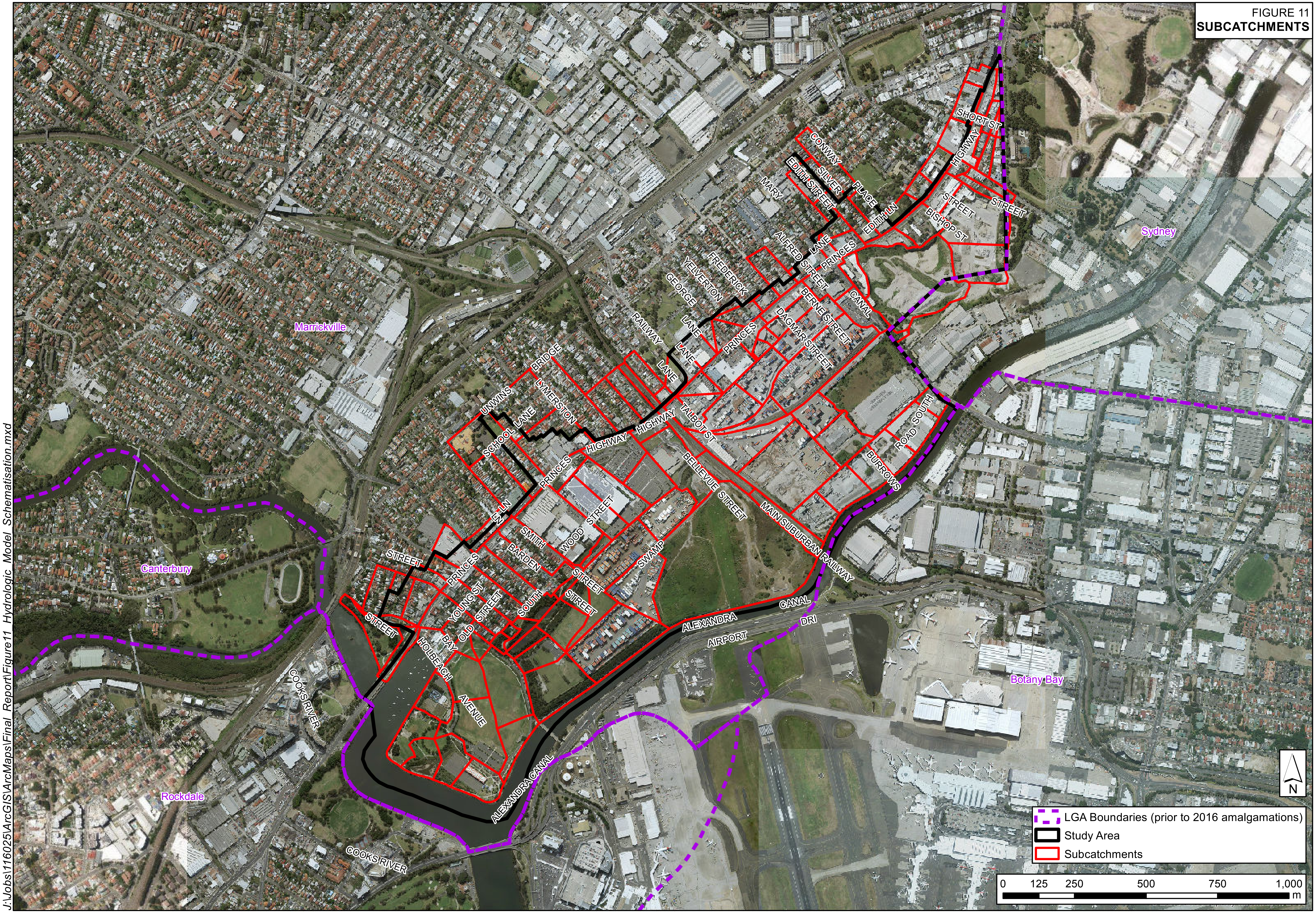
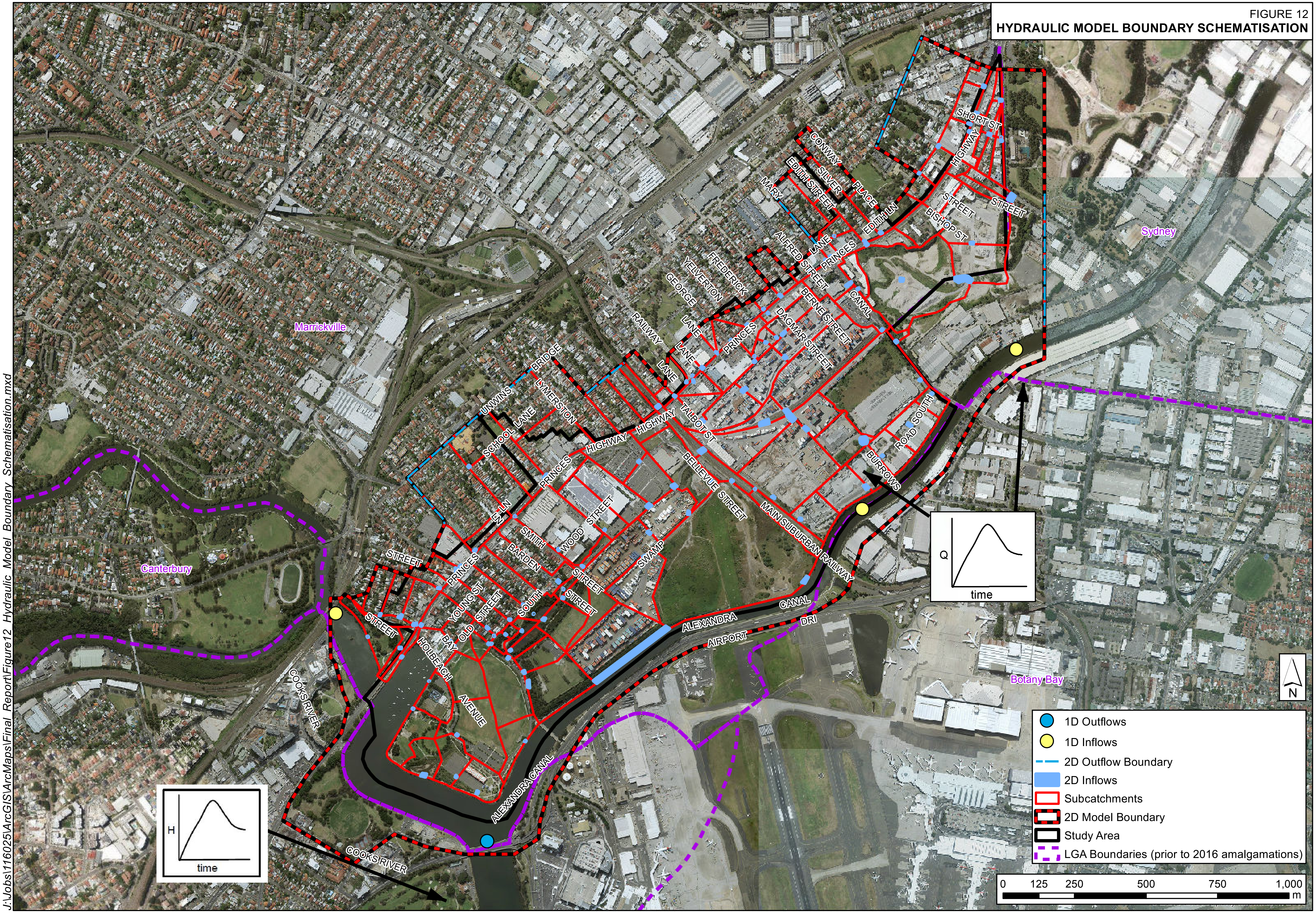


FIGURE 11
SUBCATCHMENTS

J:Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure11 Hydrologic Model Schematisation.mxd

FIGURE 12
HYDRAULIC MODEL BOUNDARY SCHEMATISATION



J:\Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure12 Hydraulic Model Boundary Schematisation.mxd

FIGURE 13
HYDRAULIC ROUGHNESS SCHEMATISATION

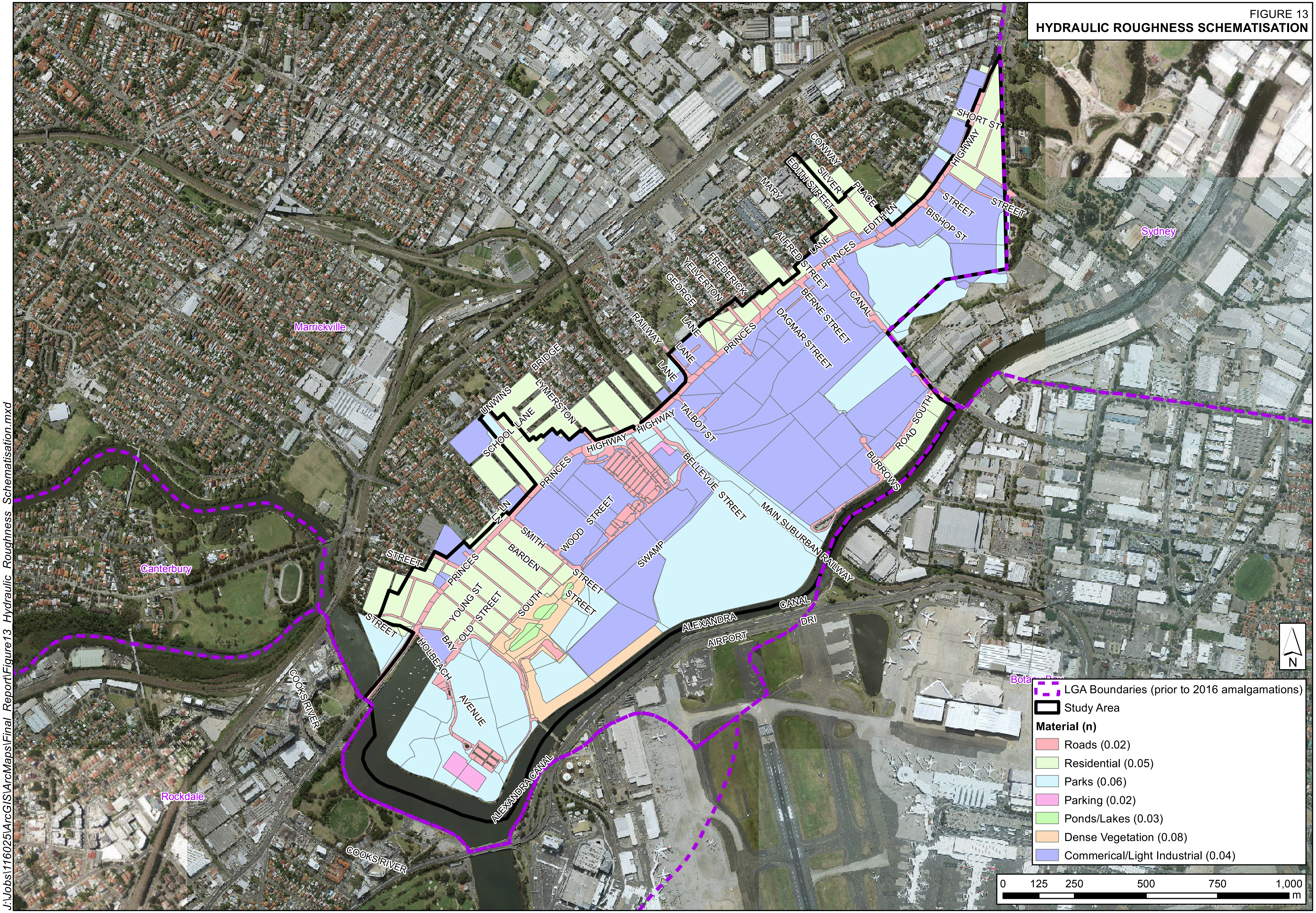
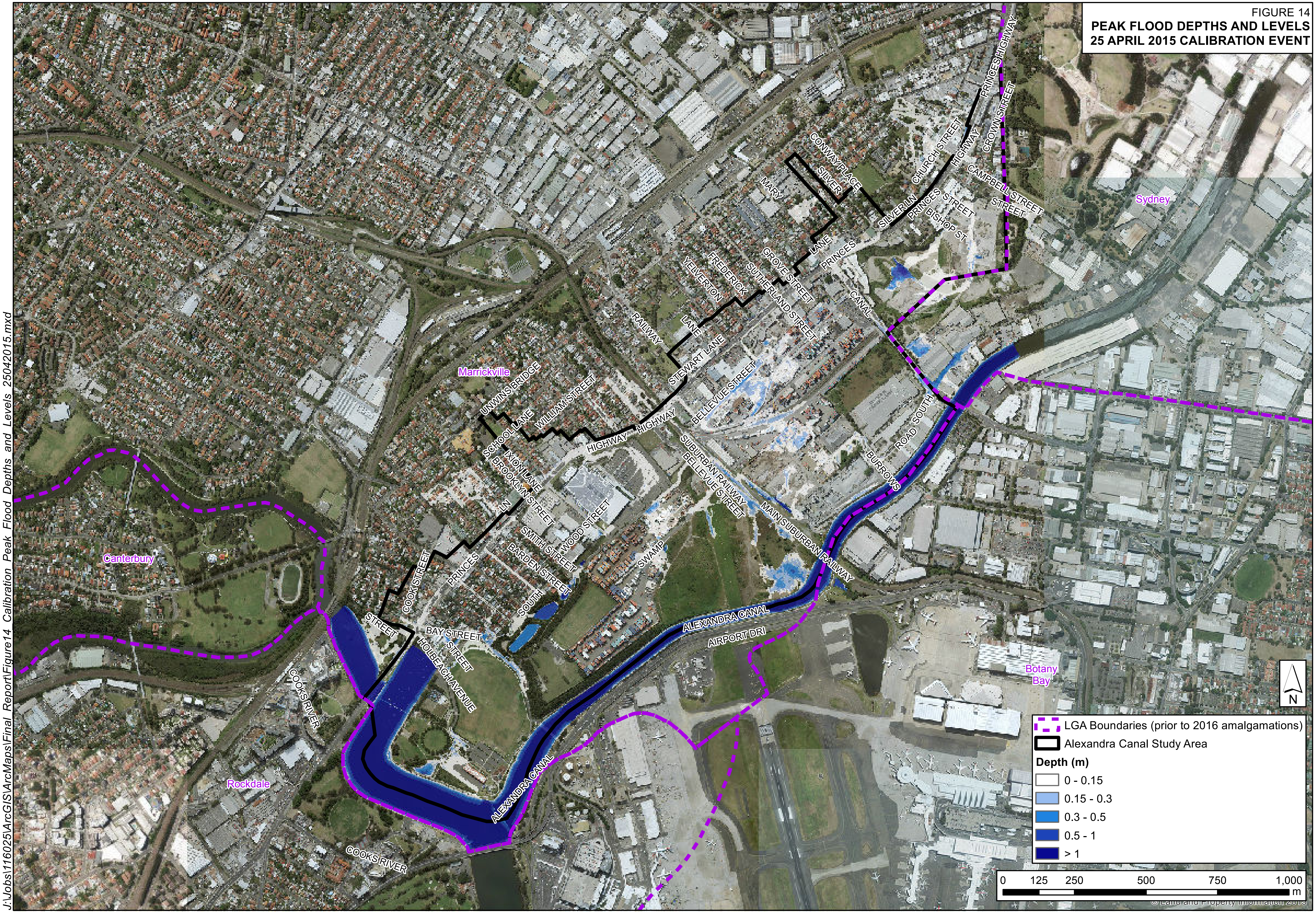


FIGURE 14
PEAK FLOOD DEPTHS AND LEVELS
25 APRIL 2015 CALIBRATION EVENT



J:\Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure14 Calibration Peak Flood Depths and Levels 25042015.mxd


FIGURE 15
RESULTS LAYOUT
Marrickville
Canterbury
Rockdale
Sydney
Botany Bay
H01
H02
H03
H04
H05
H06
H07
Q01
Q02
Q03
Q04
Q05
Q06
Q07
ALEXANDRA CANAL
COOKS RIVER
PRINCES HIGHWAY
MAIN SUBURBAN RAILWAY
BURROWS ROAD SOUTH
AIRPORT DRI
Key Locations - Depth and Level
Peak Flood Profile
Key Locations - Flow
LGA Boundaries (prior to 2016 amalgamations)
Alexandra Canal Study Area
0 125 250 500 750 1,000 m
N
J:\Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure15_Results.mxd

FIGURE 16

PEAK FLOOD PROFILES

J:\Jobs\116025\TUFLOW\MAC\results_D_Design\Profile\Profile.xlsx

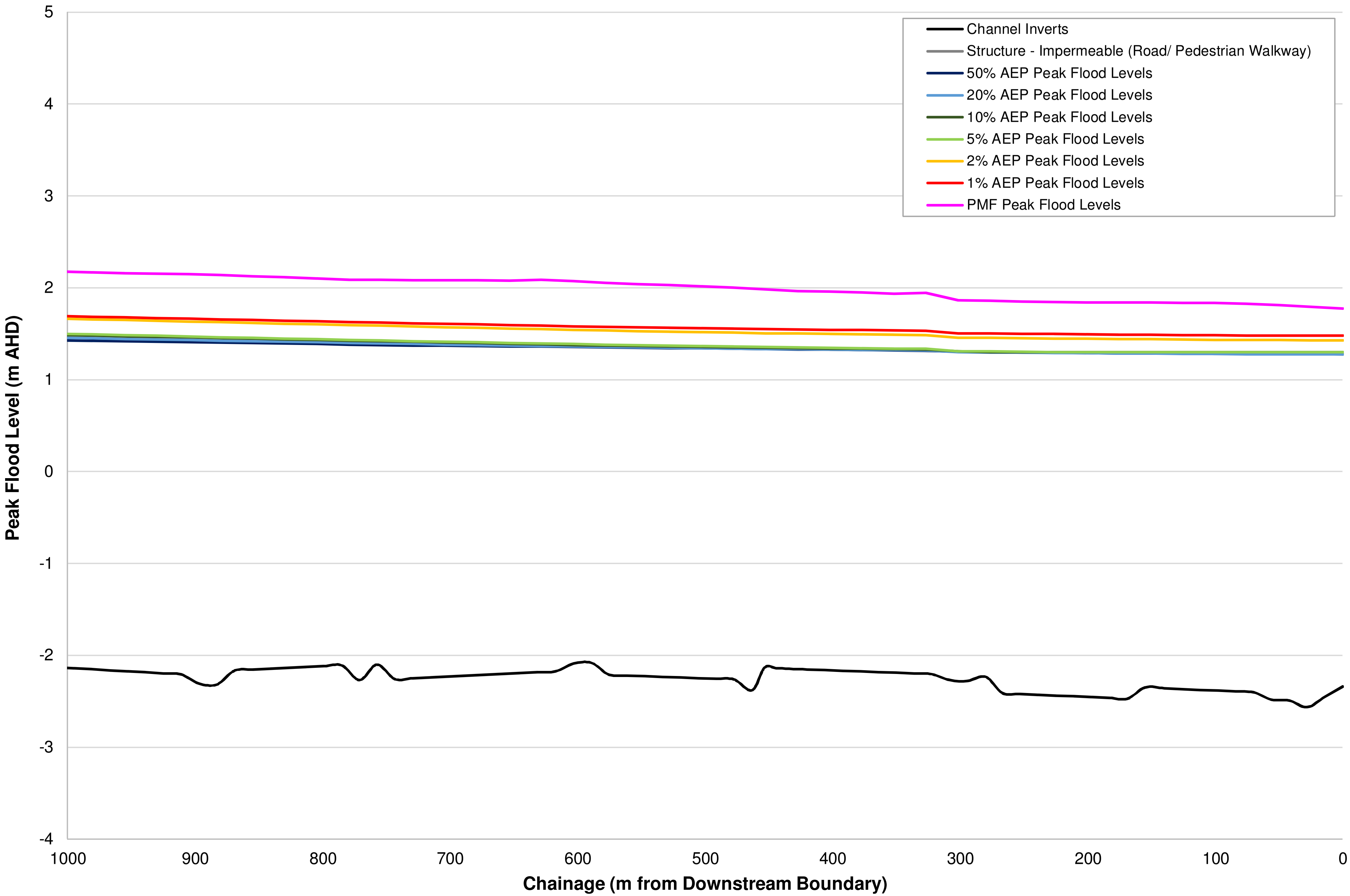
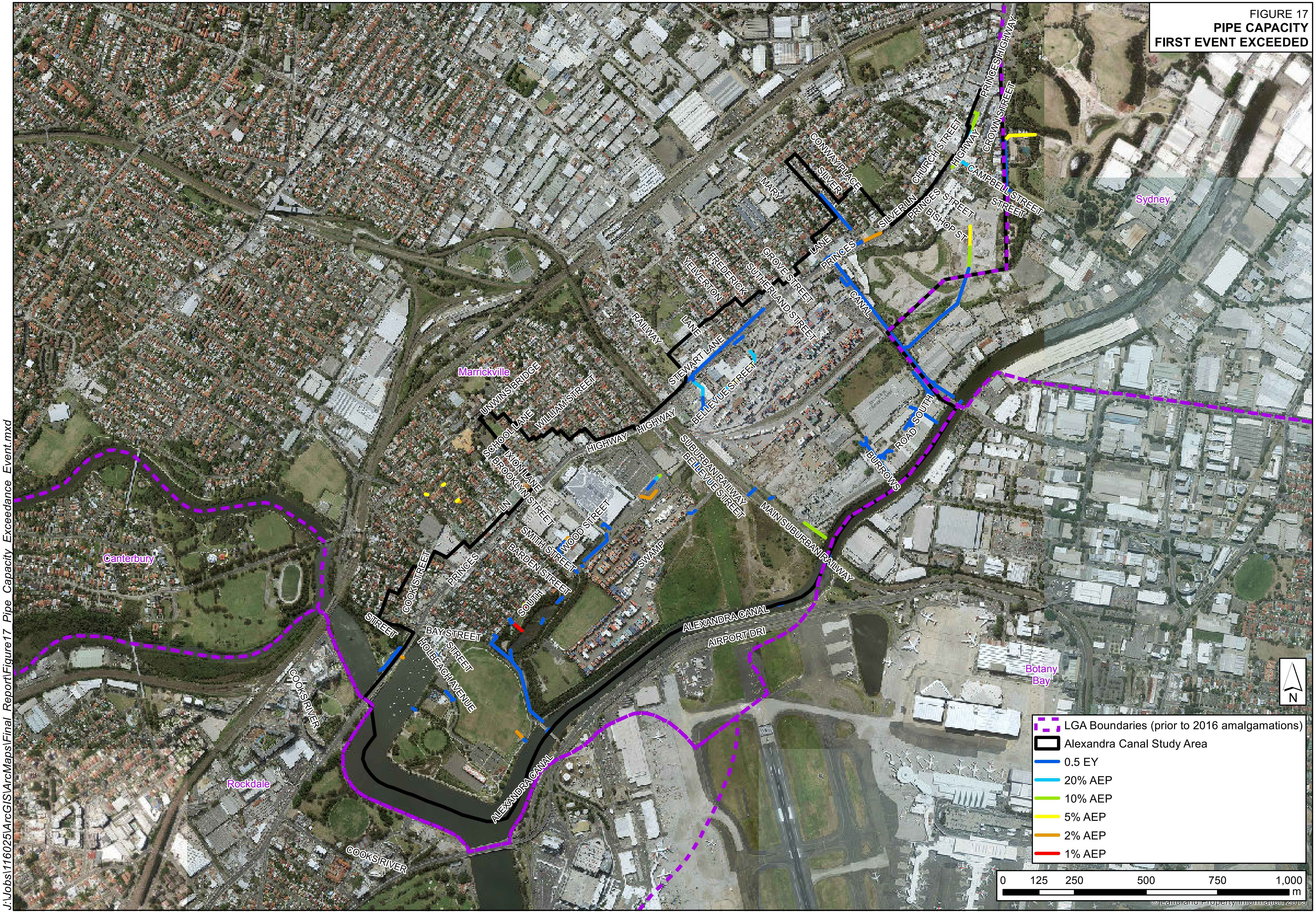
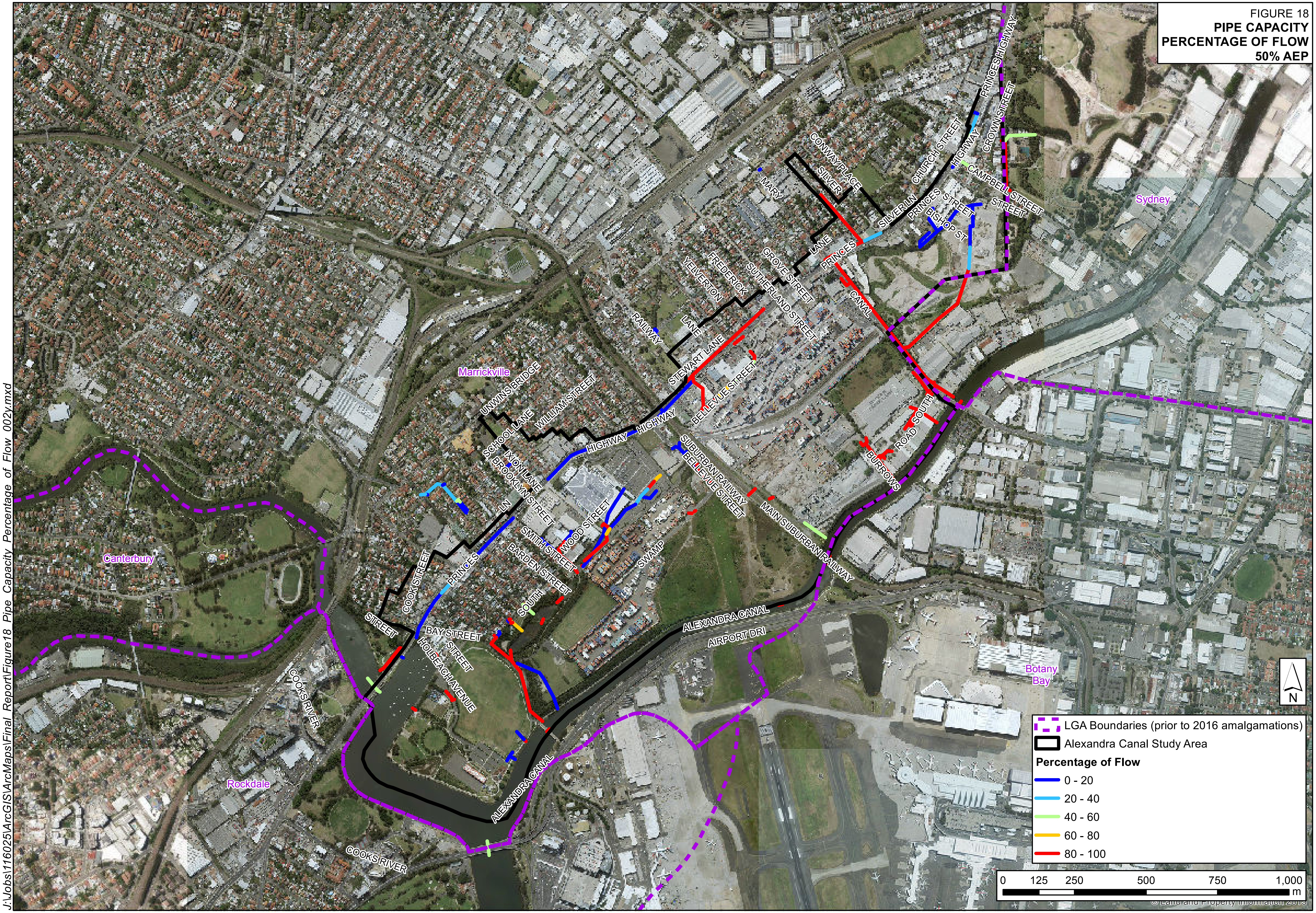


FIGURE 17
PIPE CAPACITY
FIRST EVENT EXCEEDED



J:\Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure17 Pipe Capacity Exceedance Event.mxd



J:\Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure18 Pipe Capacity Percentage of Flow 002y.mxd

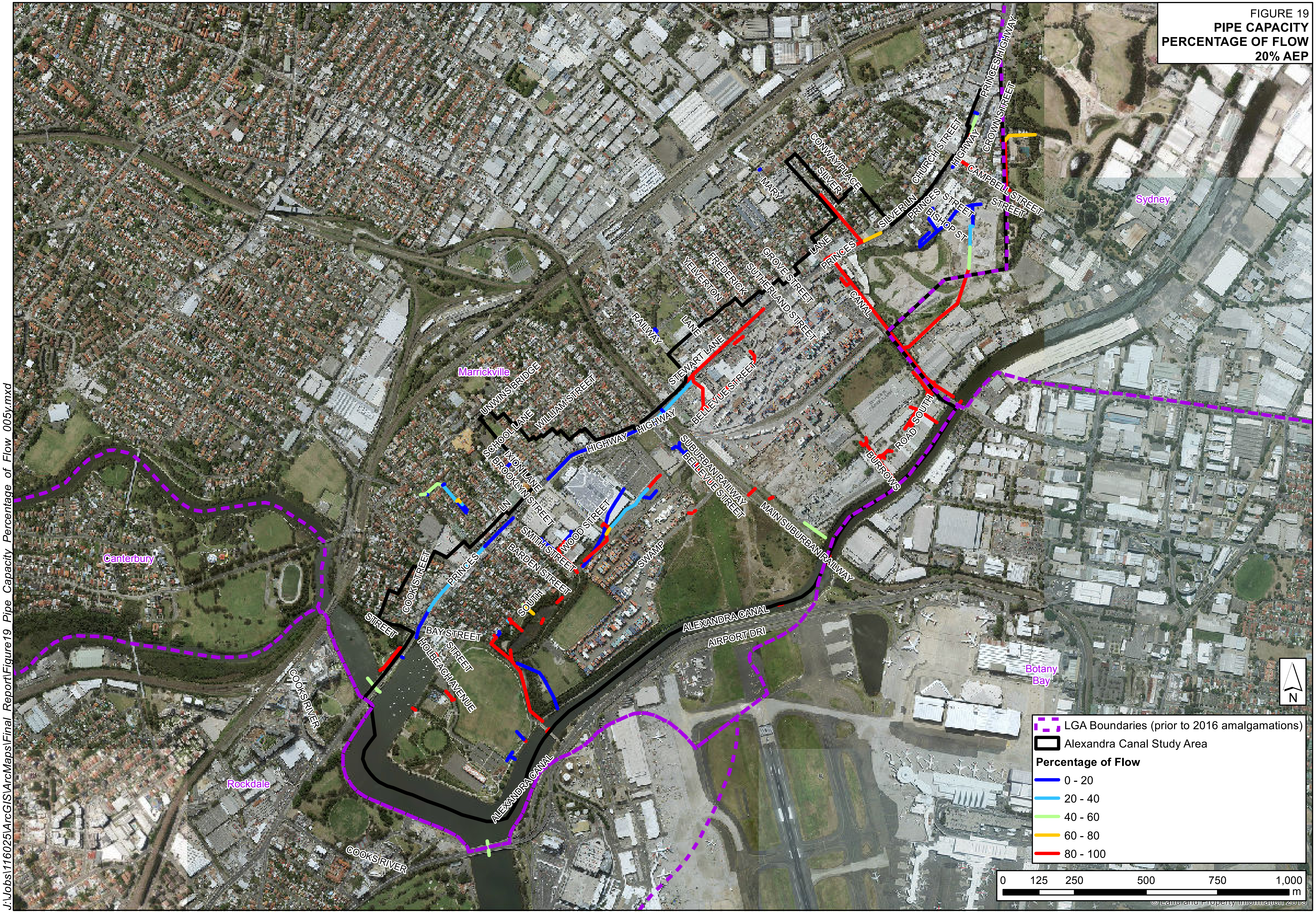
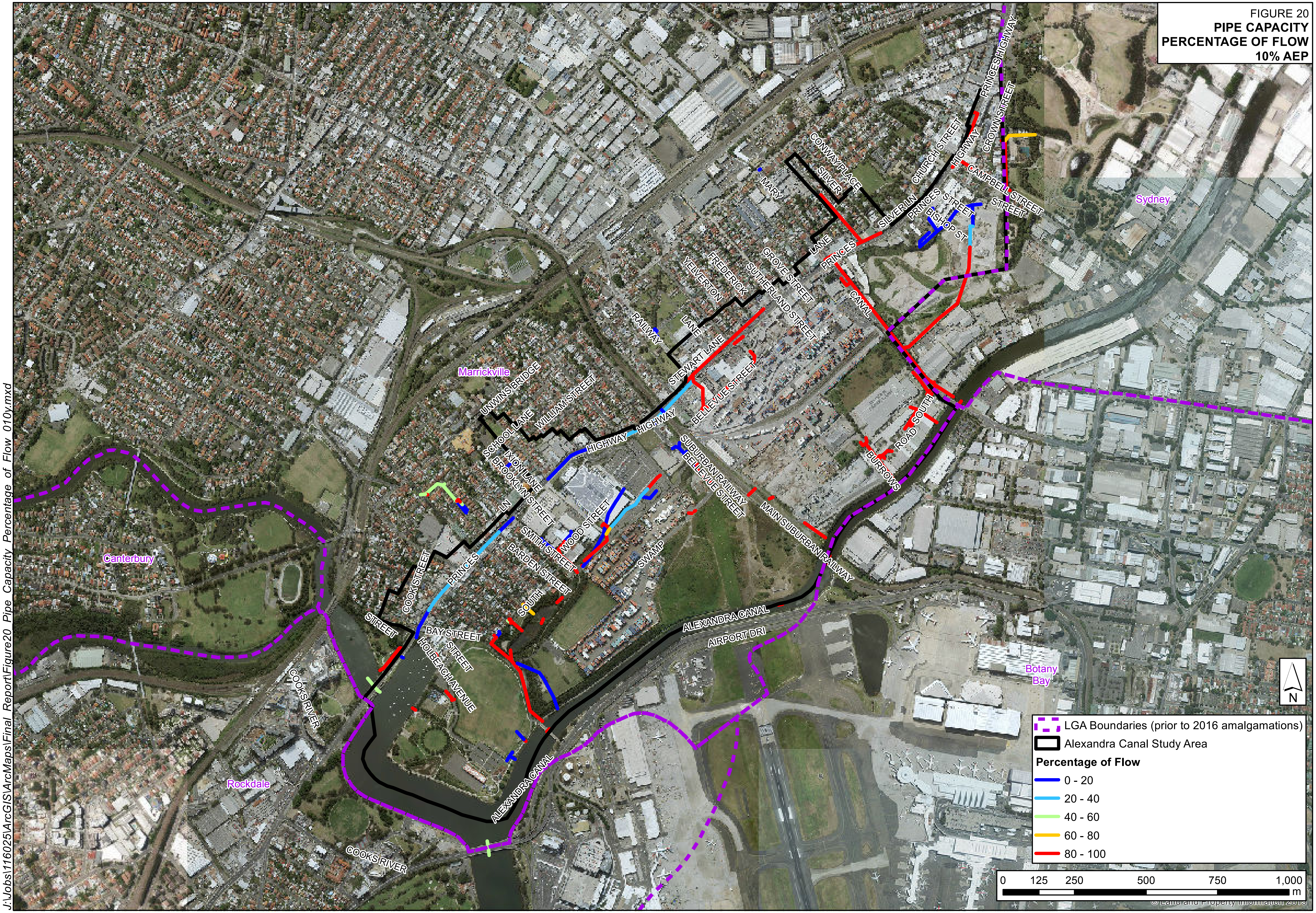


FIGURE 19
PIPE CAPACITY
PERCENTAGE OF FLOW
20% AEP

J:\Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure19 Pipe Capacity Percentage of Flow 005y.mxd



J:\Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure20 Pipe Capacity Percentage of Flow 010y.mxd

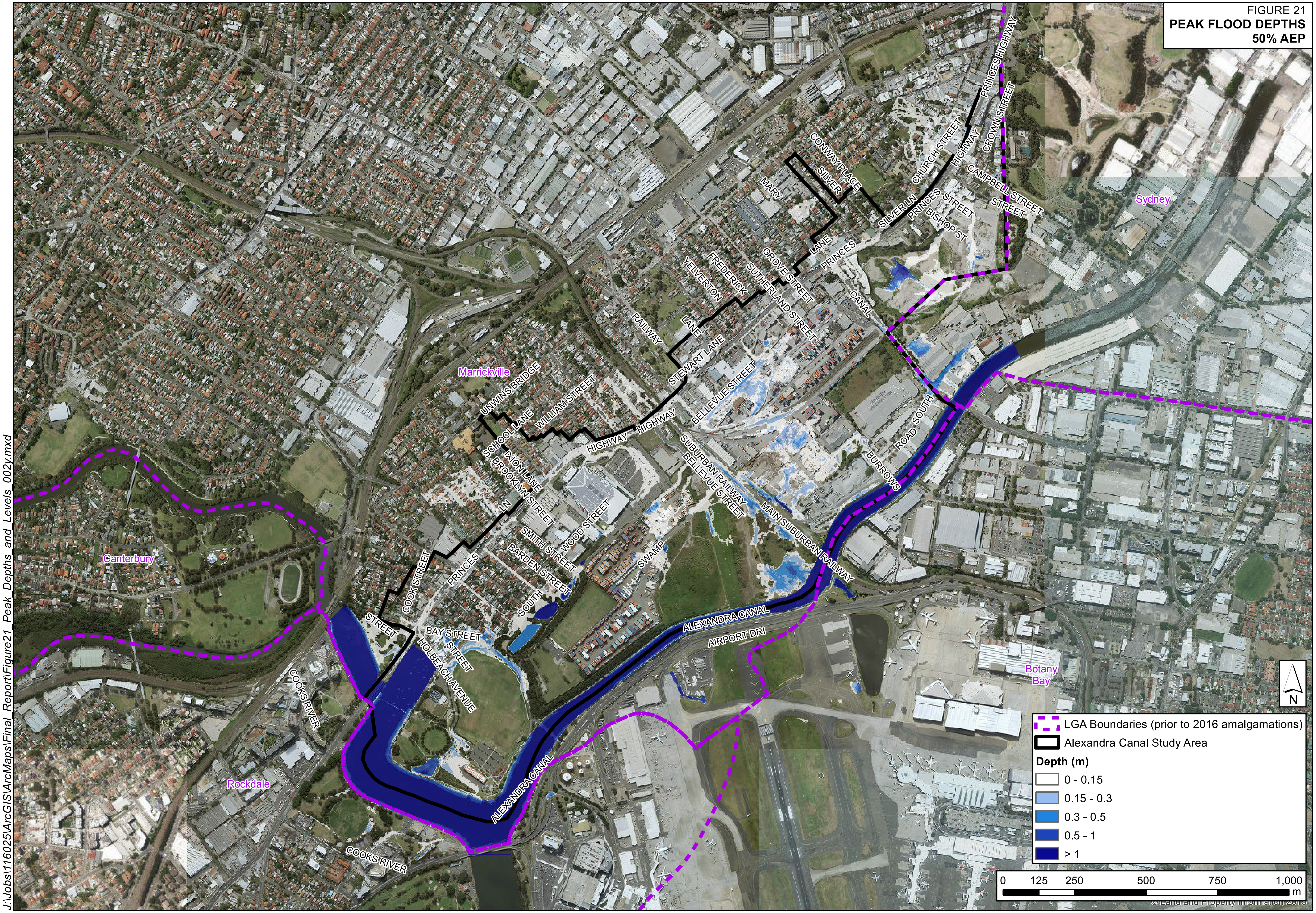


FIGURE 21
PEAK FLOOD DEPTHS
50% AEP
Marrickville
Canterbury
Rockdale
Sydney
Botany Bay
ALEXANDRA CANAL
AIRPORT DRI
COOKS RIVER
PRINCES HIGHWAY
BURROWS ROAD SOUTH
MAIN SUBURBAN RAILWAY
LGA Boundaries (prior to 2016 amalgamations)
Alexandra Canal Study Area
Depth (m)
0 - 0.15
0.15 - 0.3
0.3 - 0.5
0.5 - 1
> 1
0 125 250 500 750 1,000
m
N
© Land and Property Information 2015
J:\Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure21 Peak Depths and Levels 002y.mxd

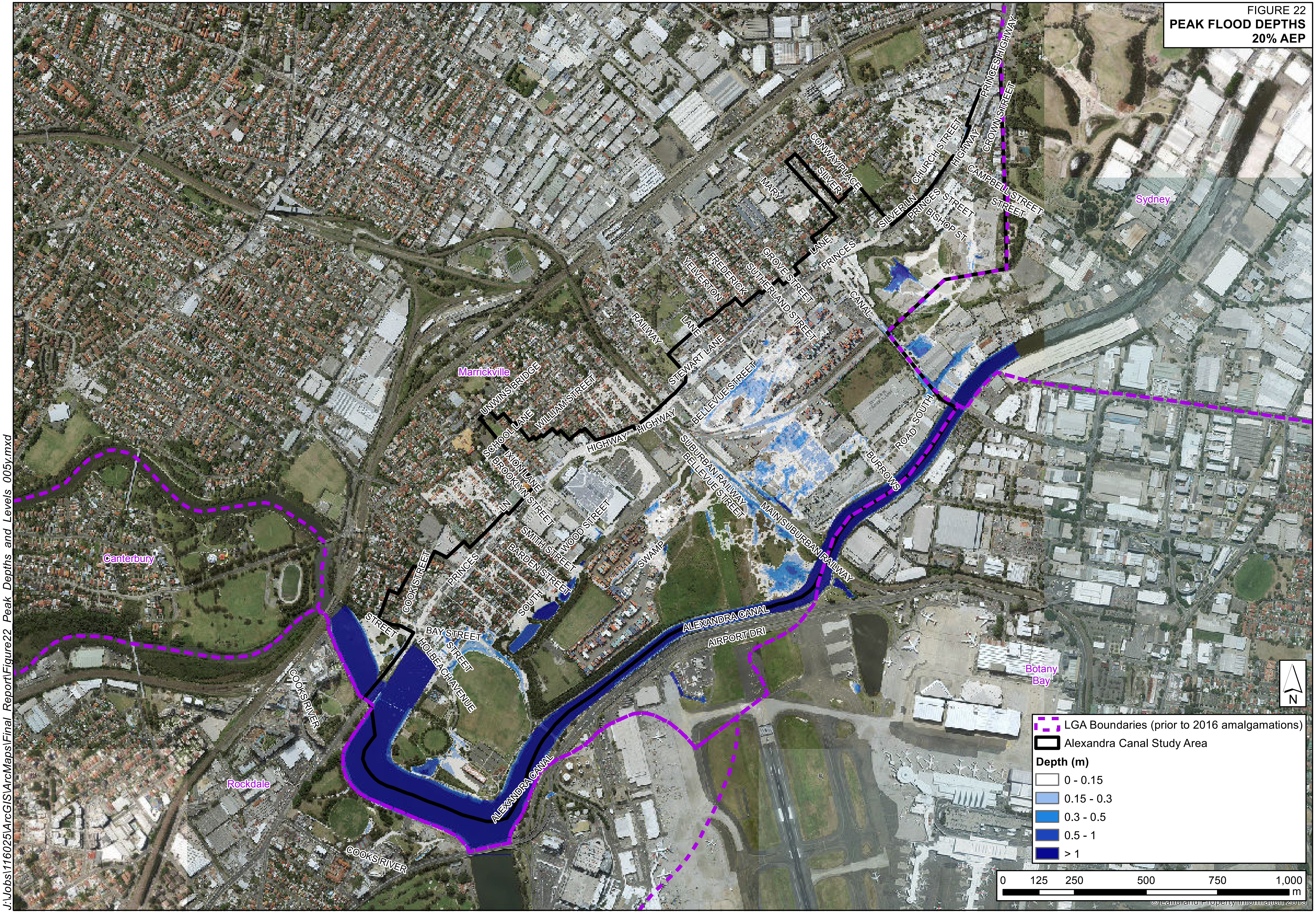


FIGURE 22
PEAK FLOOD DEPTHS
20% AEP

J:\Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure22 Peak Depths and Levels 005y.mxd

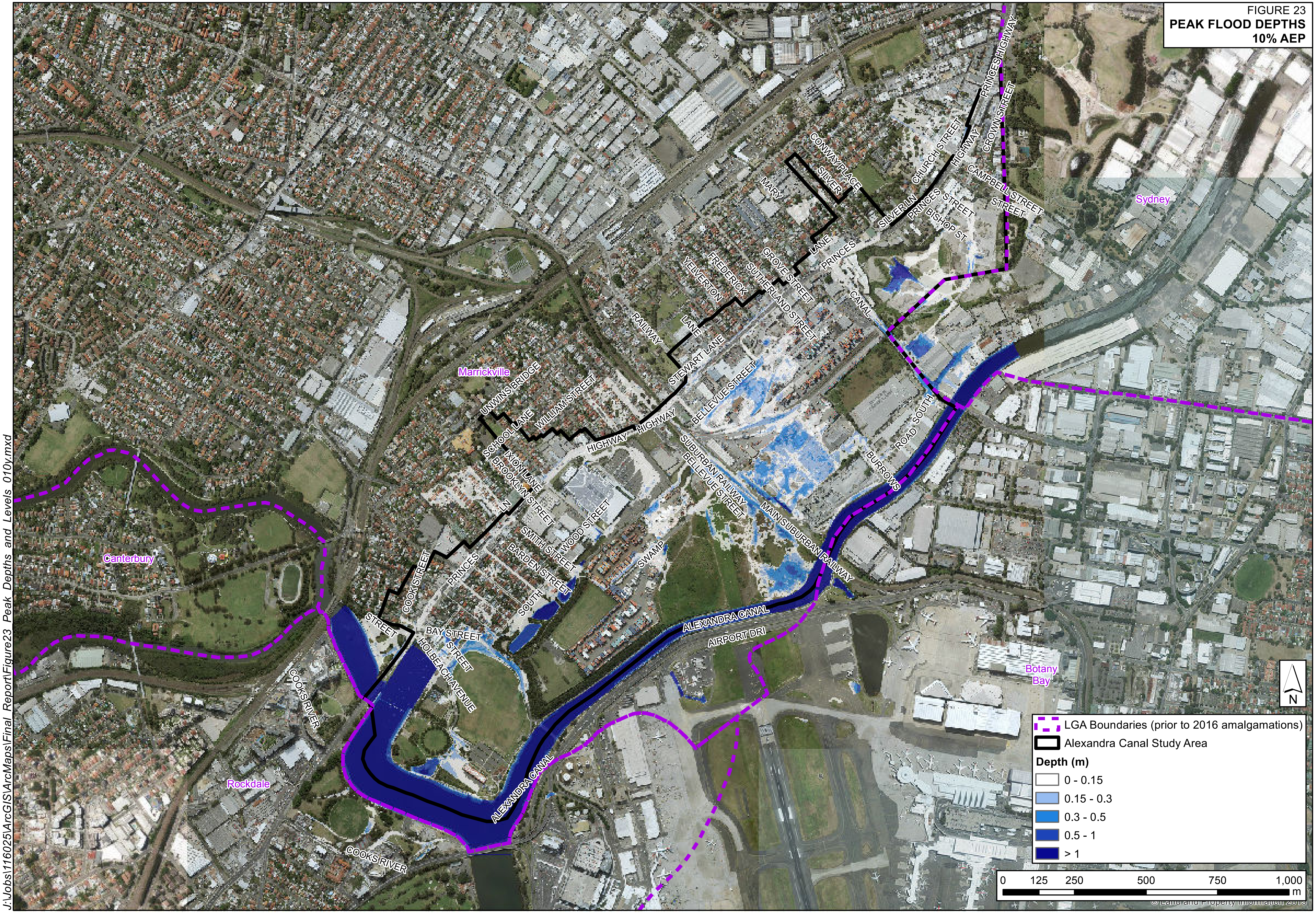
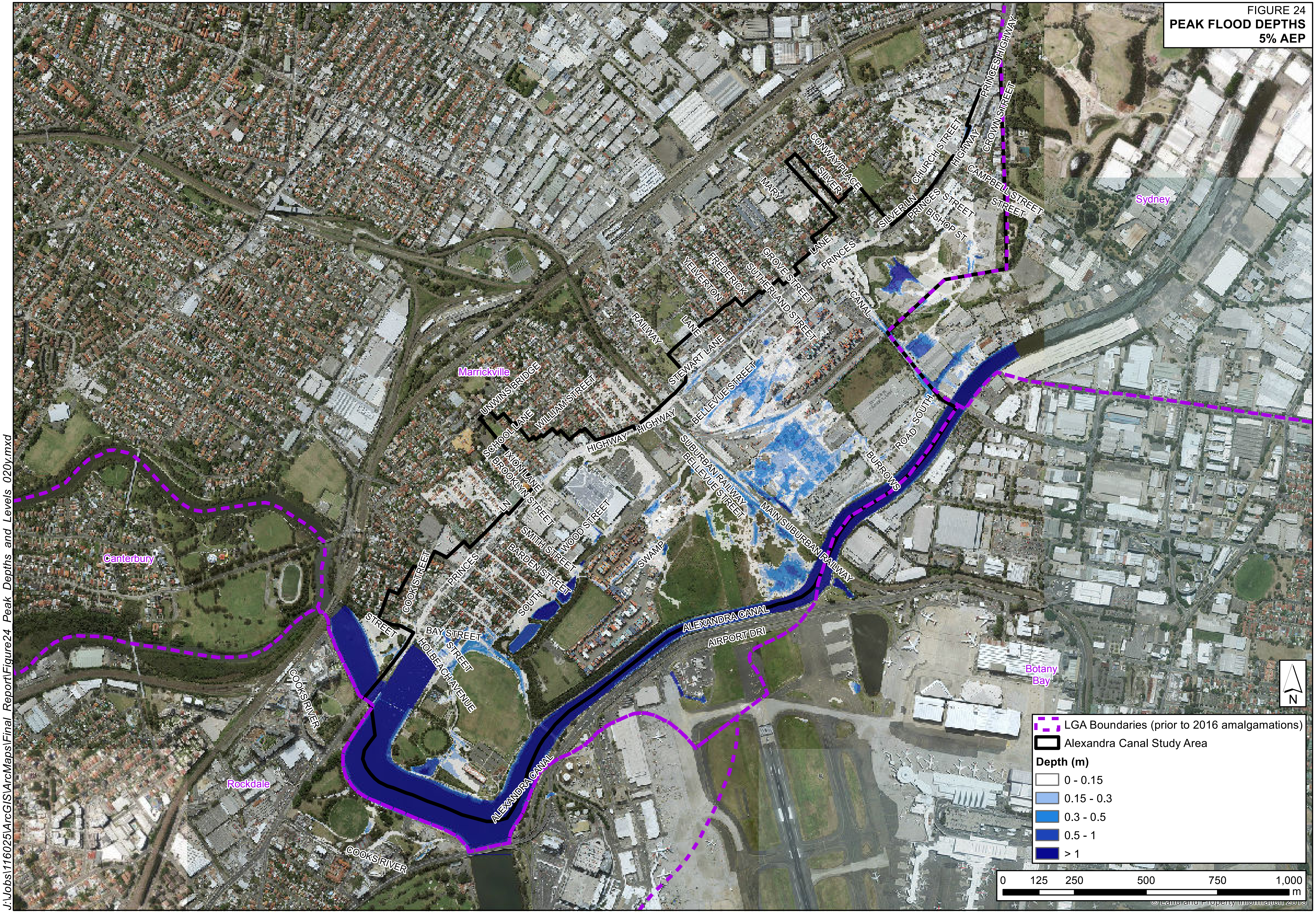


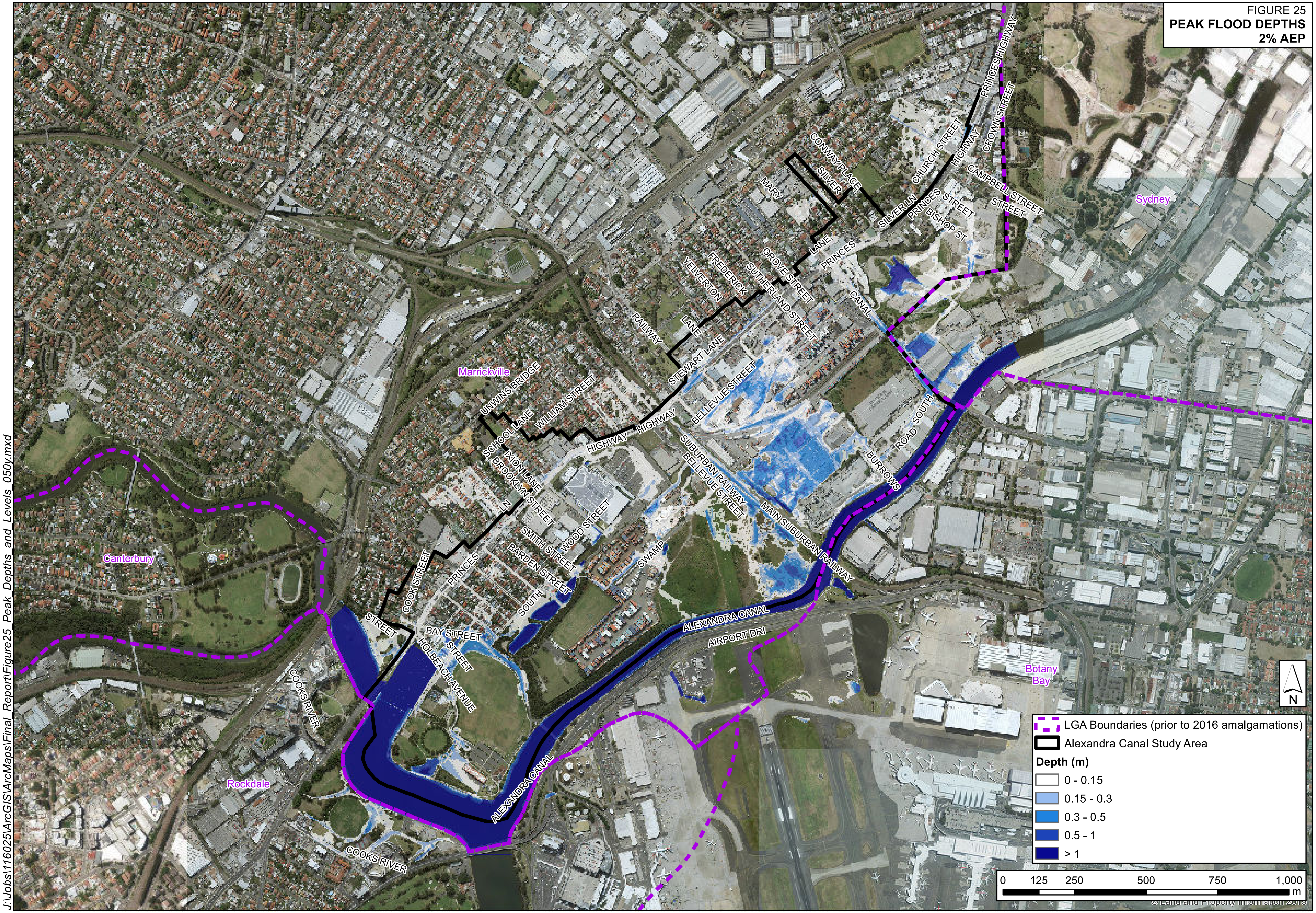
FIGURE 23
PEAK FLOOD DEPTHS
10% AEP

J:\Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure23 Peak Depths and Levels 010y.mxd



J:\Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure24 Peak Depths and Levels 020y.mxd

FIGURE 25
PEAK FLOOD DEPTHS
2% AEP



J:\Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure25 Peak Depths and Levels 050y.mxd

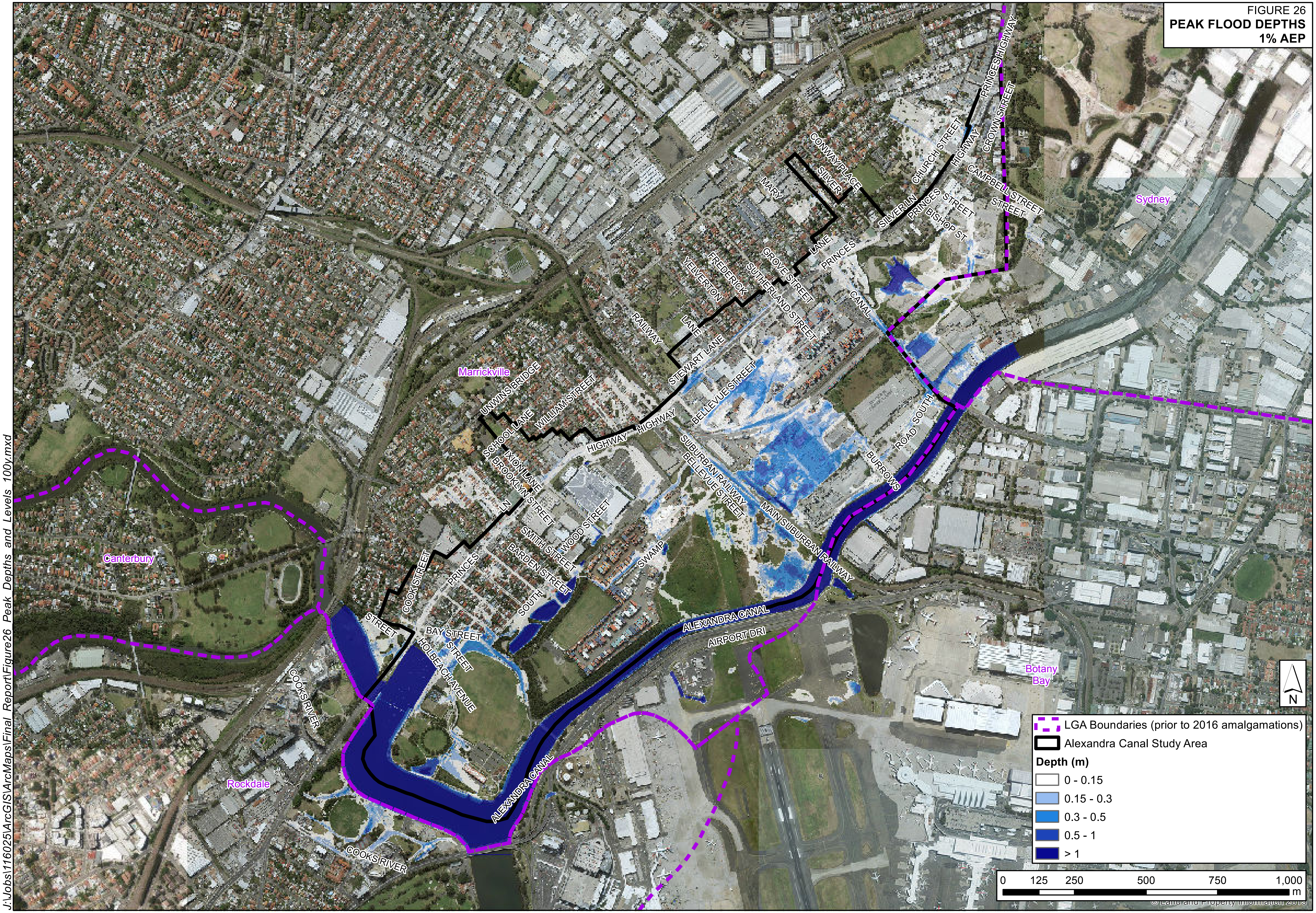
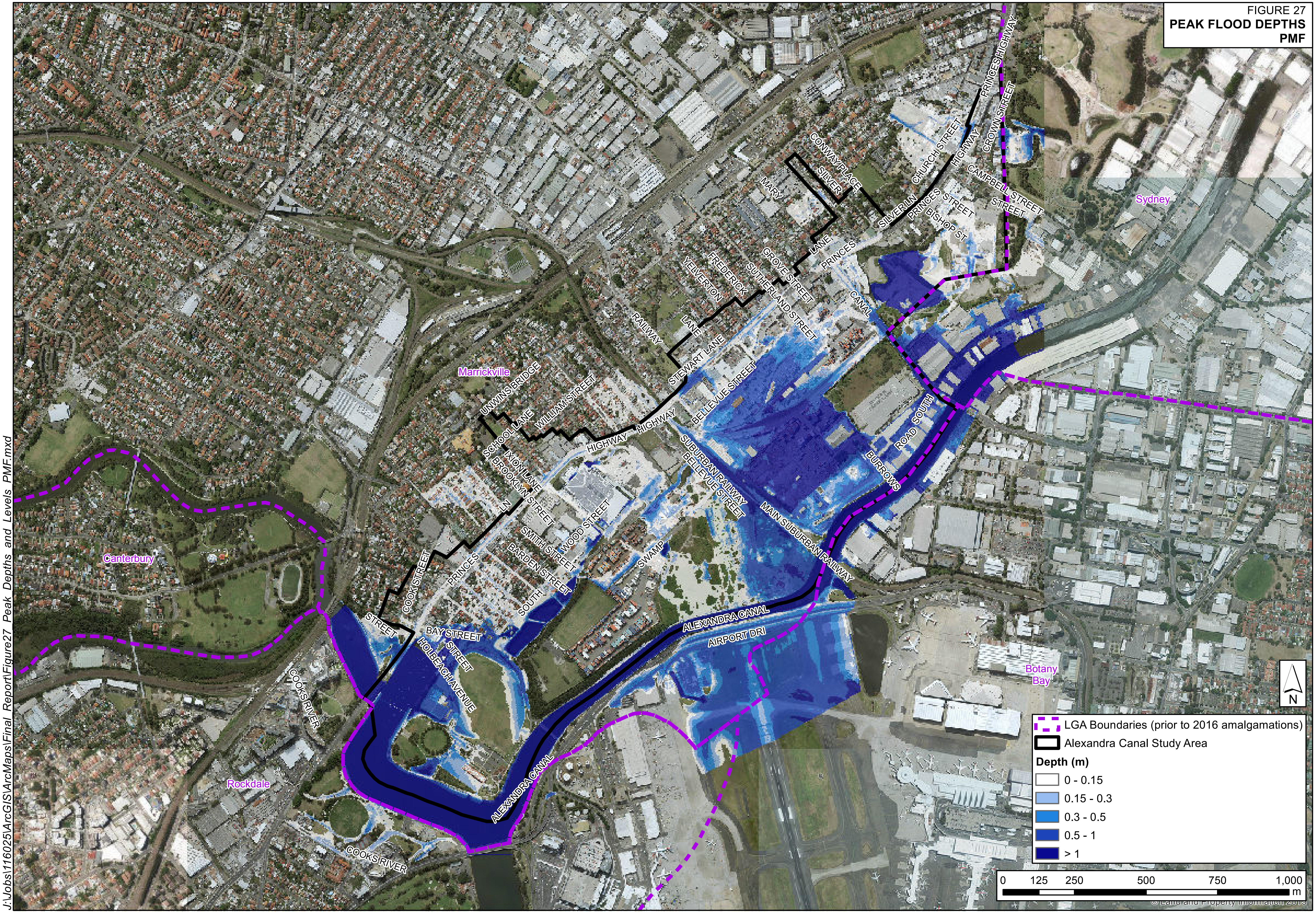


FIGURE 26
PEAK FLOOD DEPTHS
1% AEP
Sydney
Marrickville
Canterbury
Rockdale
Botany Bay
ALEXANDRA CANAL
COOKS RIVER
AIRPORT DRI
PRINCES HIGHWAY
MAIN SUBURBAN RAILWAY
BURROWS ROAD SOUTH
LGA Boundaries (prior to 2016 amalgamations)
Alexandra Canal Study Area
Depth (m)
0 - 0.15
0.15 - 0.3
0.3 - 0.5
0.5 - 1
> 1
0 125 250 500 750 1,000 m
N
J:\Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure26 Peak Depths and Levels 100y.mxd



J:\Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure27 Peak Depths and Levels PMF.mxd

J:\Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure28 Peak Velocity 002y.mxd

FIGURE 29
PEAK FLOOD VELOCITY
20% AEP

J:\Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure29 Peak Velocity 005y.mxd

FIGURE 30
PEAK FLOOD VELOCITY
10% AEP

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FIGURE 31
PEAK FLOOD VELOCITY
1% AEP

J:\Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure31 Peak Velocity 100y.mxd

FIGURE 32
PEAK FLOOD VELOCITY PMF

J:\Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure32 Peak Velocity PMF.mxd

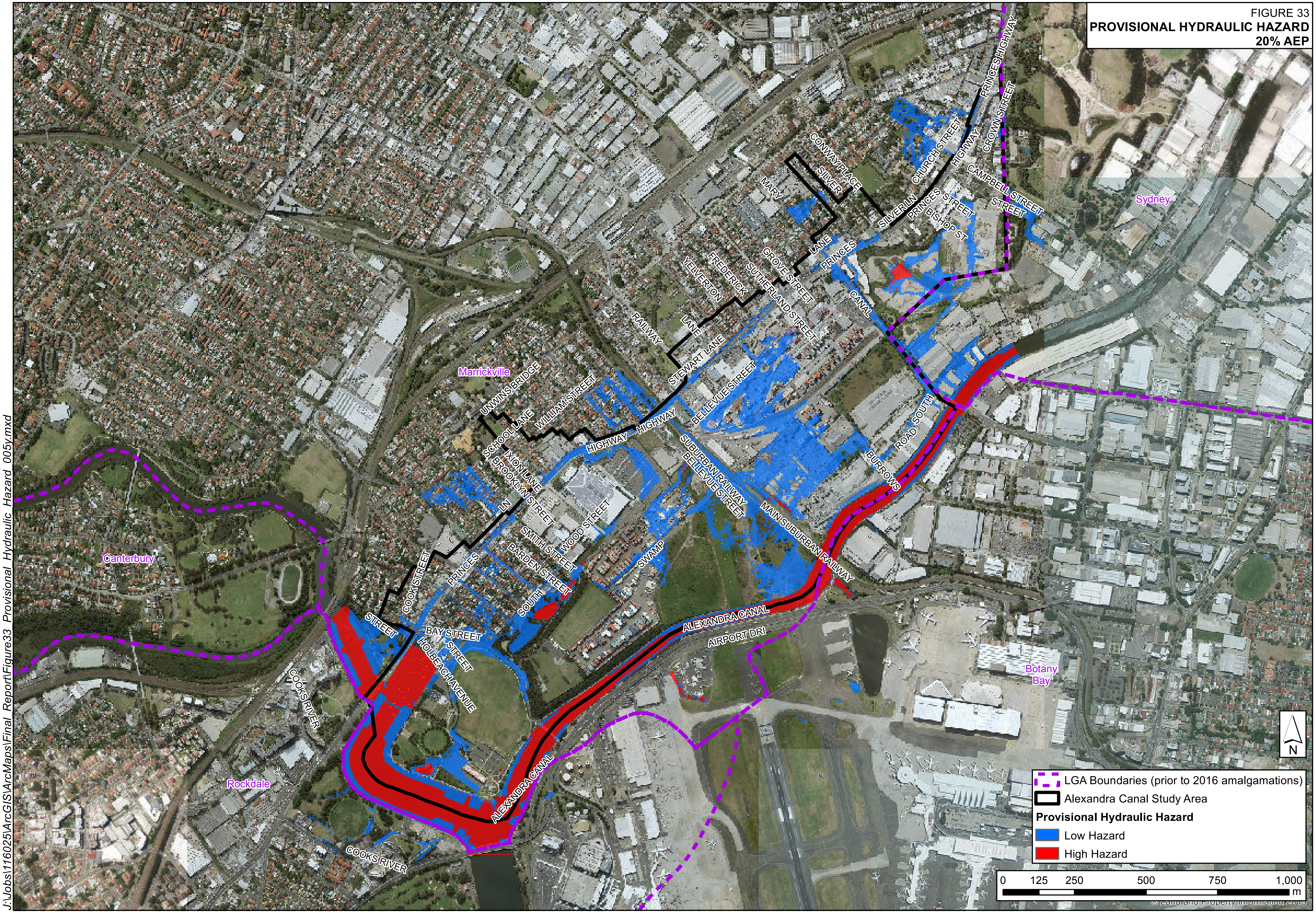


FIGURE 33
PROVISIONAL HYDRAULIC HAZARD
20% AEP

J:\Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure33 Provisional Hydraulic Hazard 005y.mxd

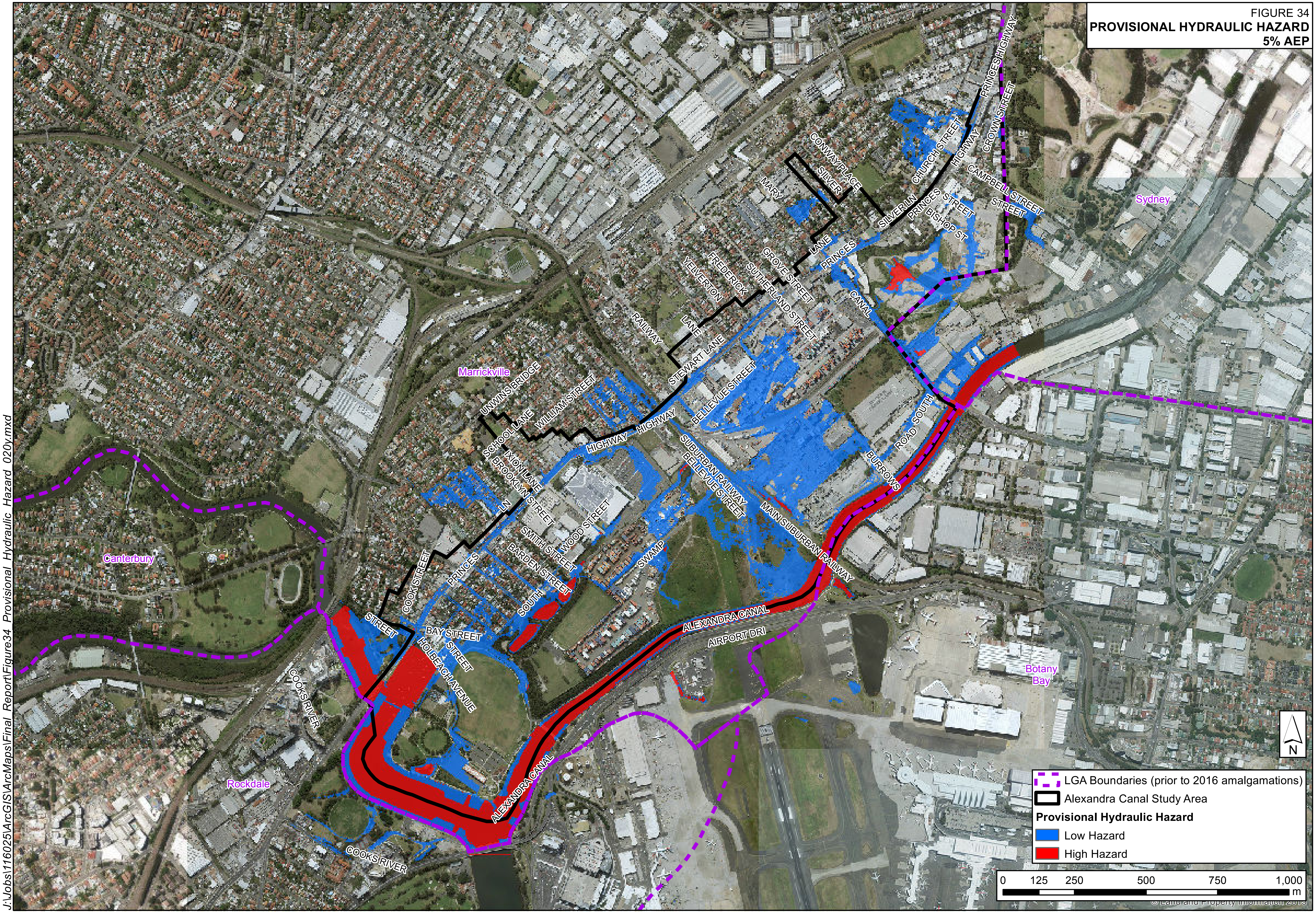
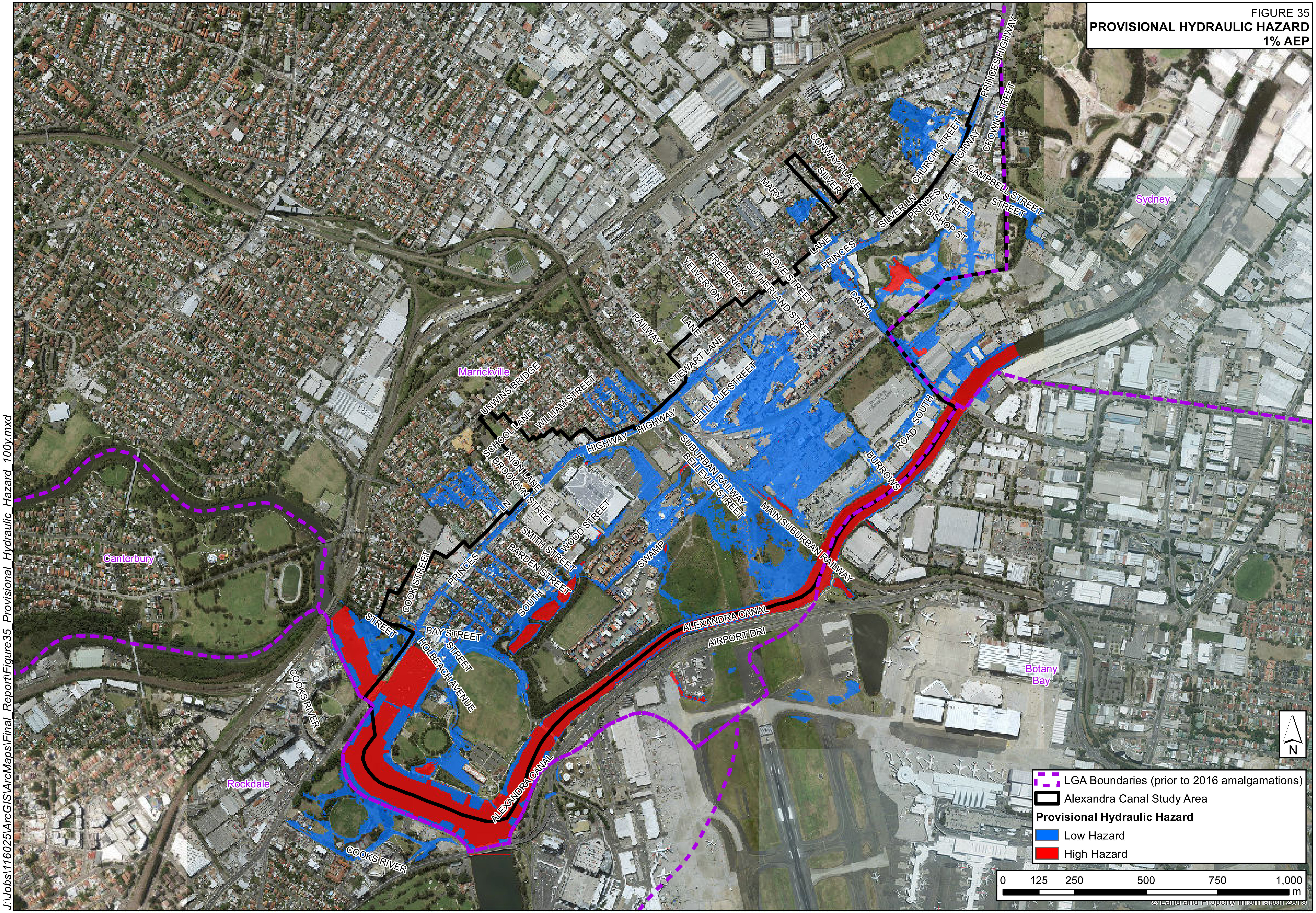


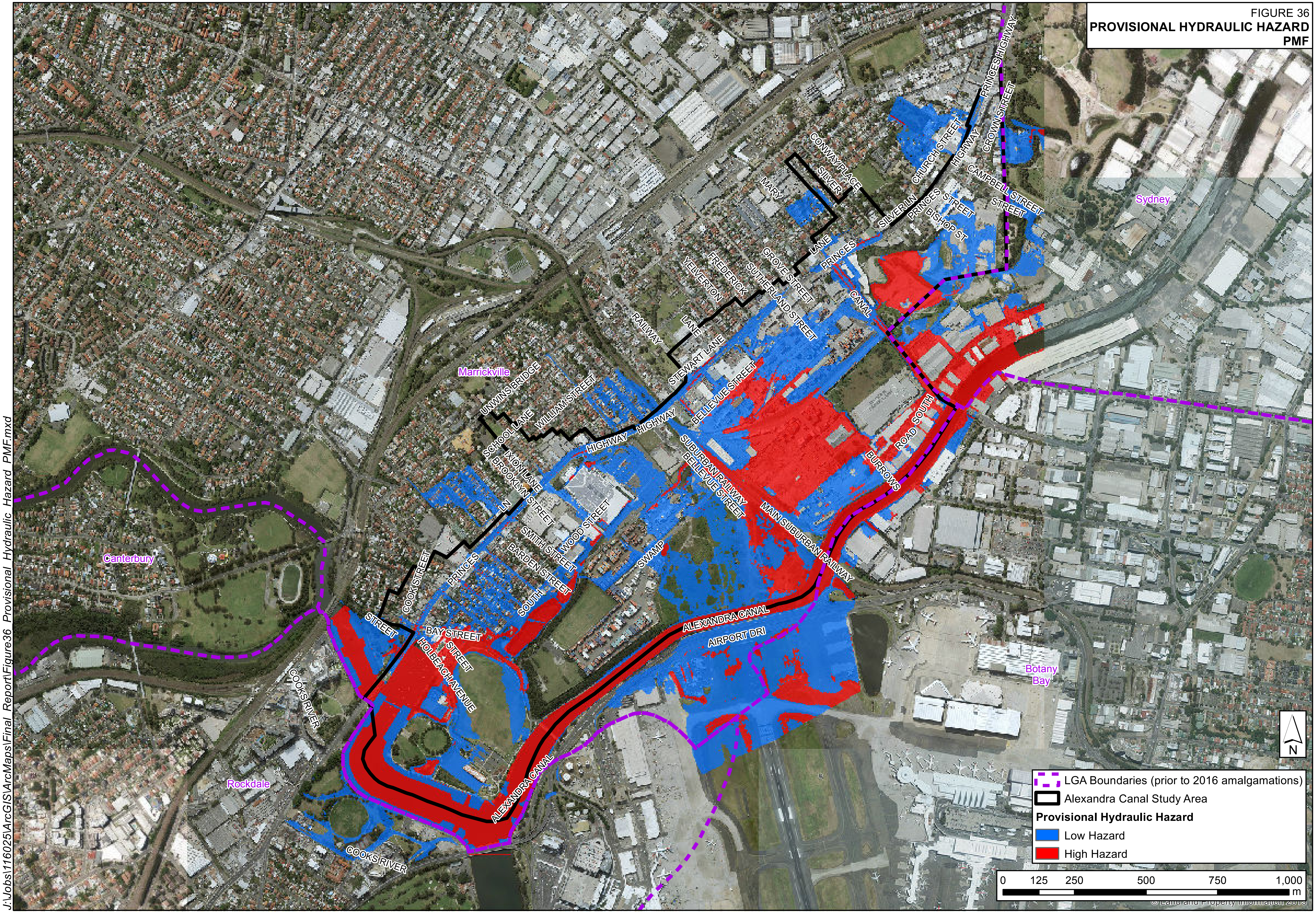
FIGURE 34
PROVISIONAL HYDRAULIC HAZARD
5% AEP

J:\Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure34 Provisional Hydraulic Hazard 020y.mxd



J:\Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure35 Provisional Hydraulic Hazard 100y.mxd

FIGURE 36
PROVISIONAL HYDRAULIC HAZARD PMF



J:\Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure36 Provisional Hydraulic Hazard PMF.mxd

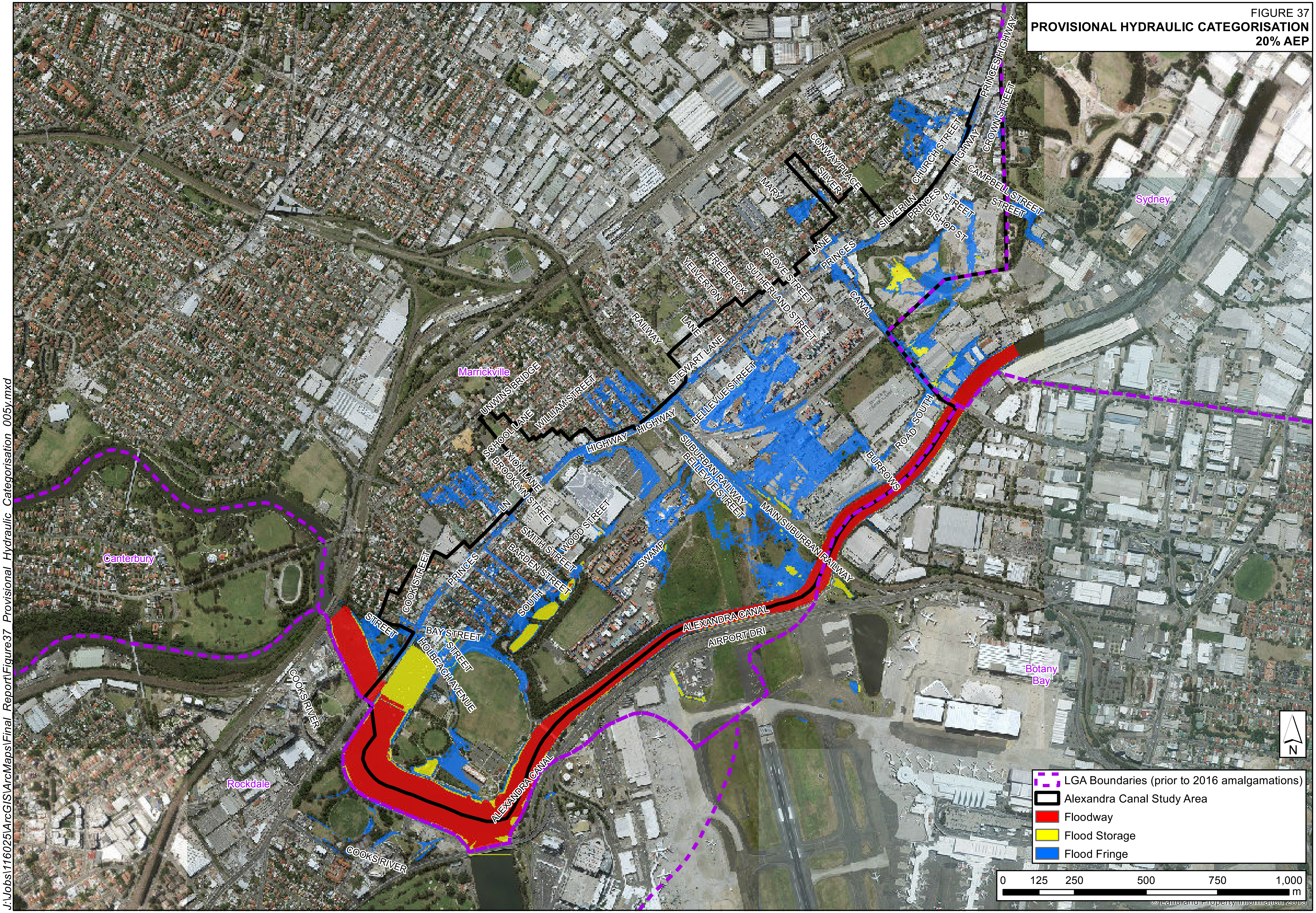
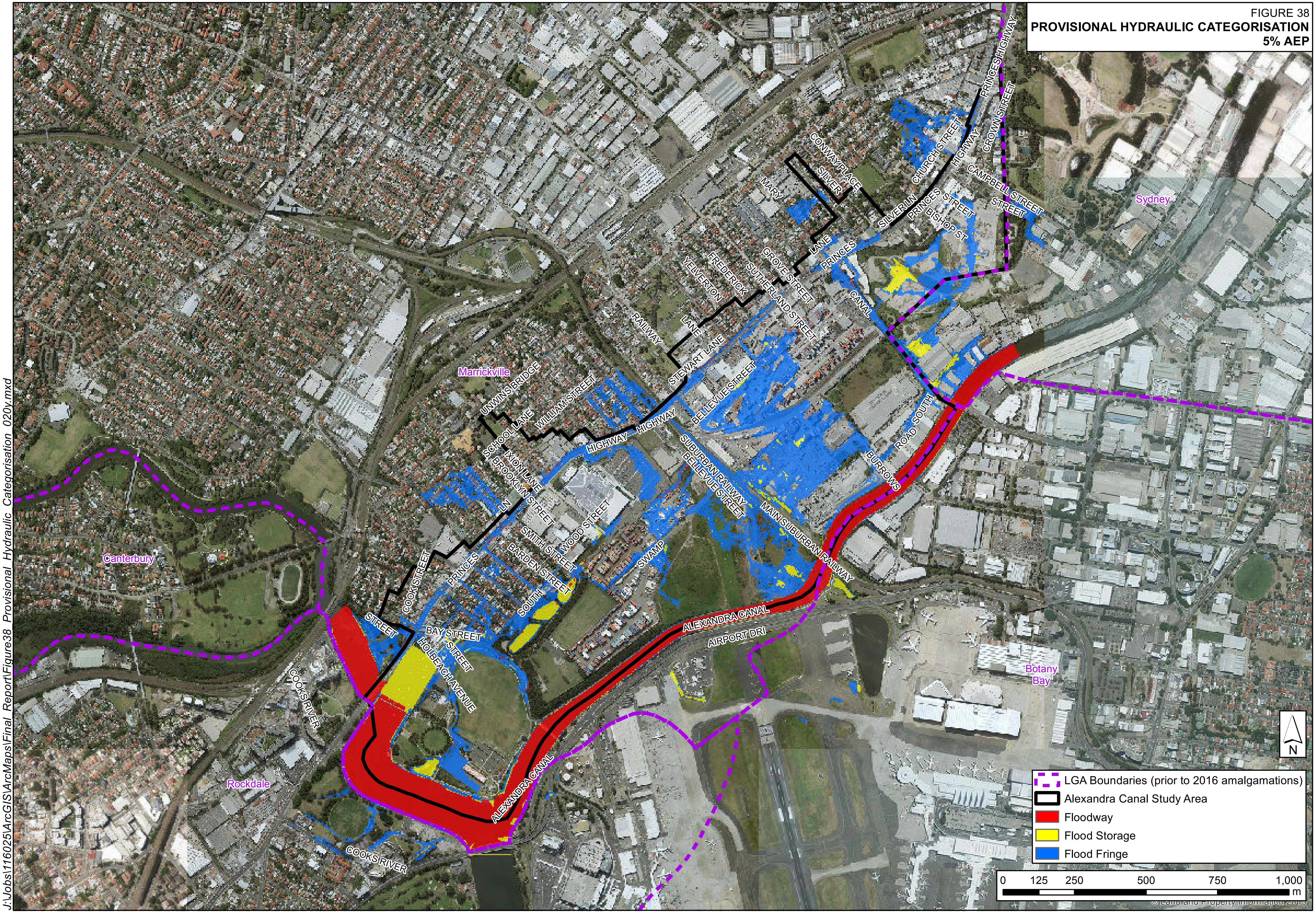


FIGURE 37
PROVISIONAL HYDRAULIC CATEGORISATION
20% AEP

J:\Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure37 Provisional Hydraulic Categorisation 005y.mxd

FIGURE 38
PROVISIONAL HYDRAULIC CATEGORISATION
5% AEP



J:\Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure38 Provisional Hydraulic Categorisation 020v.mxd

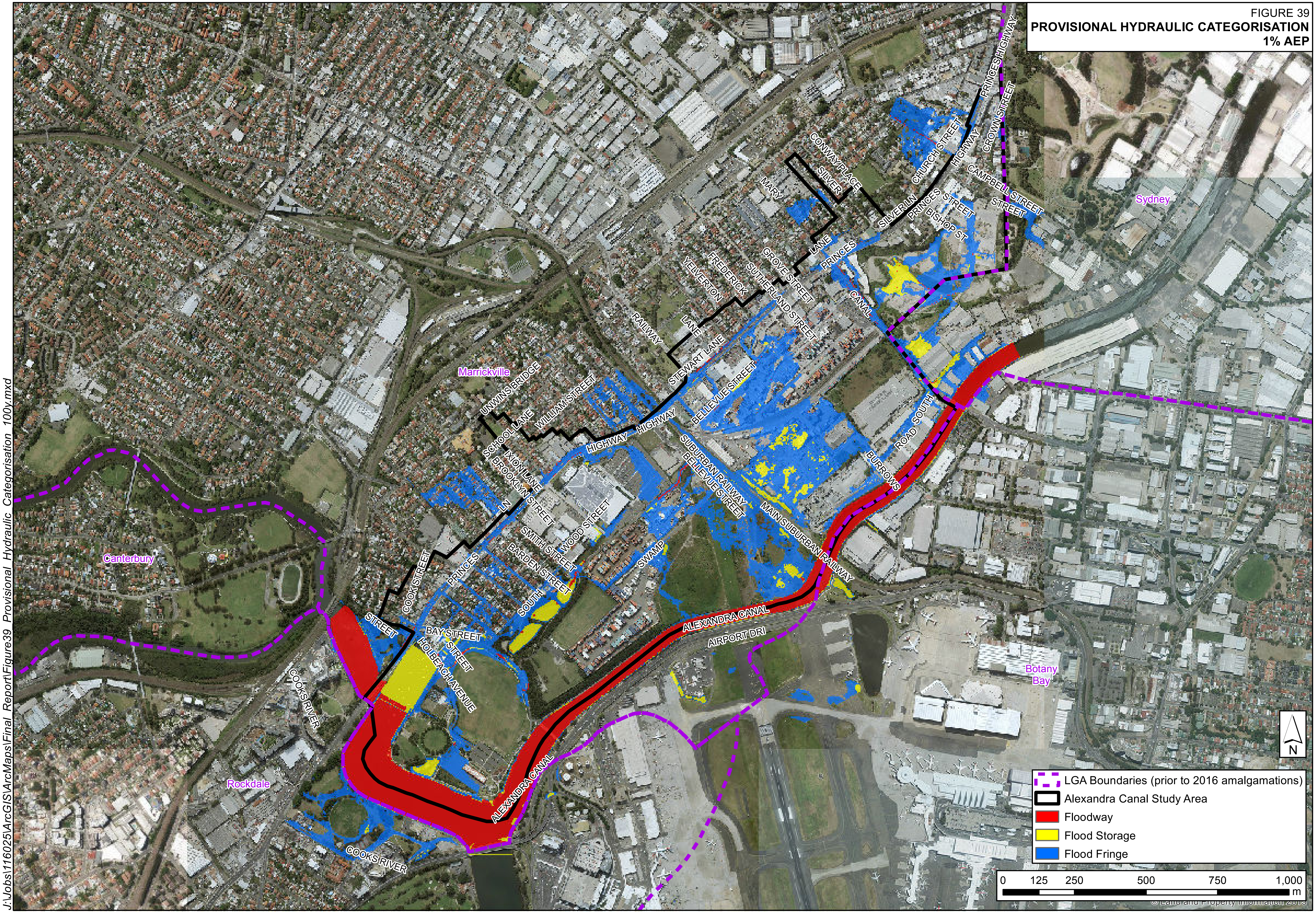


FIGURE 39
PROVISIONAL HYDRAULIC CATEGORISATION
1% AEP

J:\Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure39 Provisional Hydraulic Categorisation 100y.mxd

FIGURE 40
PROVISIONAL HYDRAULIC CATEGORISATION PMF

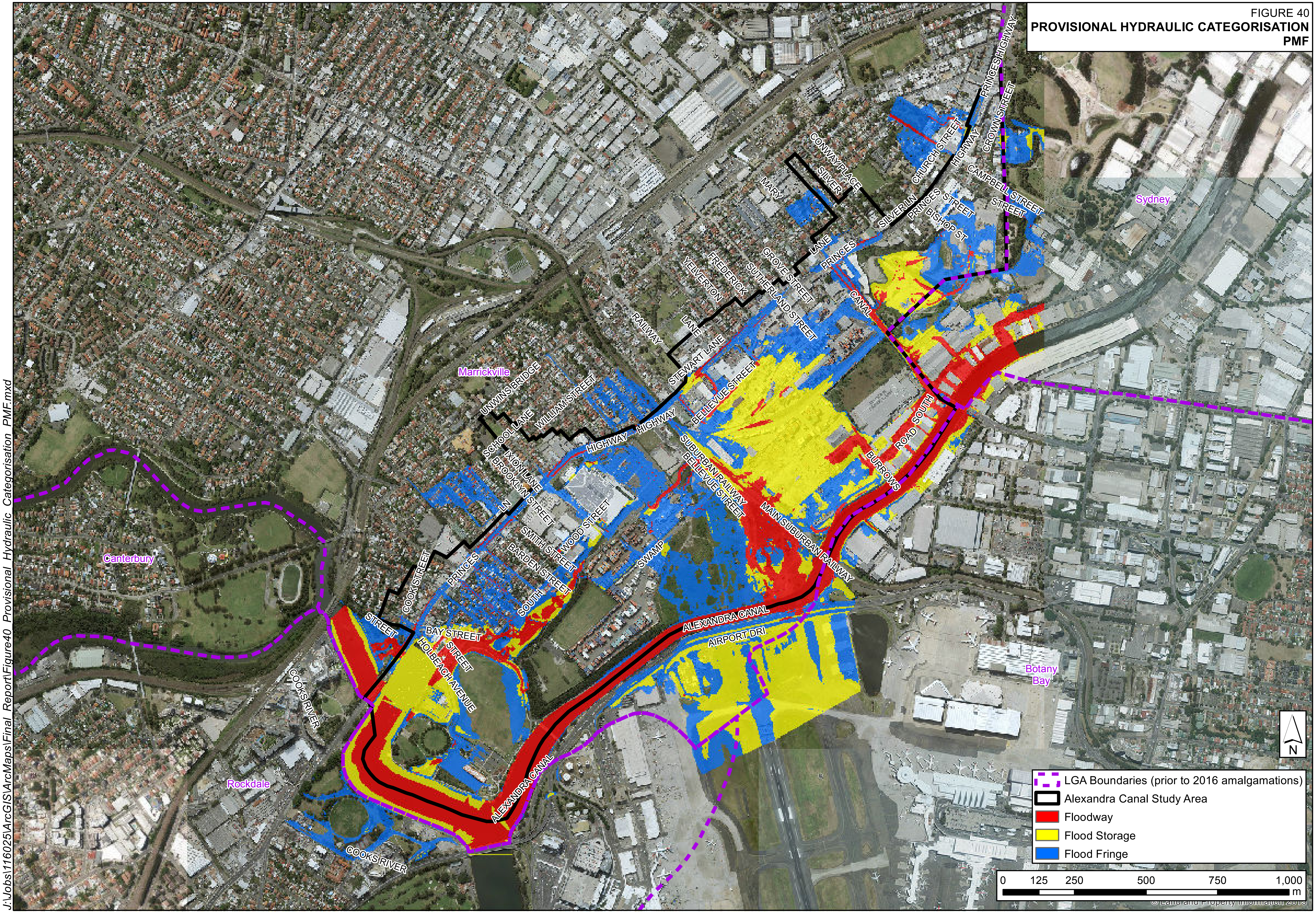


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FIGURE 41
PRELIMINARY FLOOD EMERGENCY RESPONSE CLASSIFICATION

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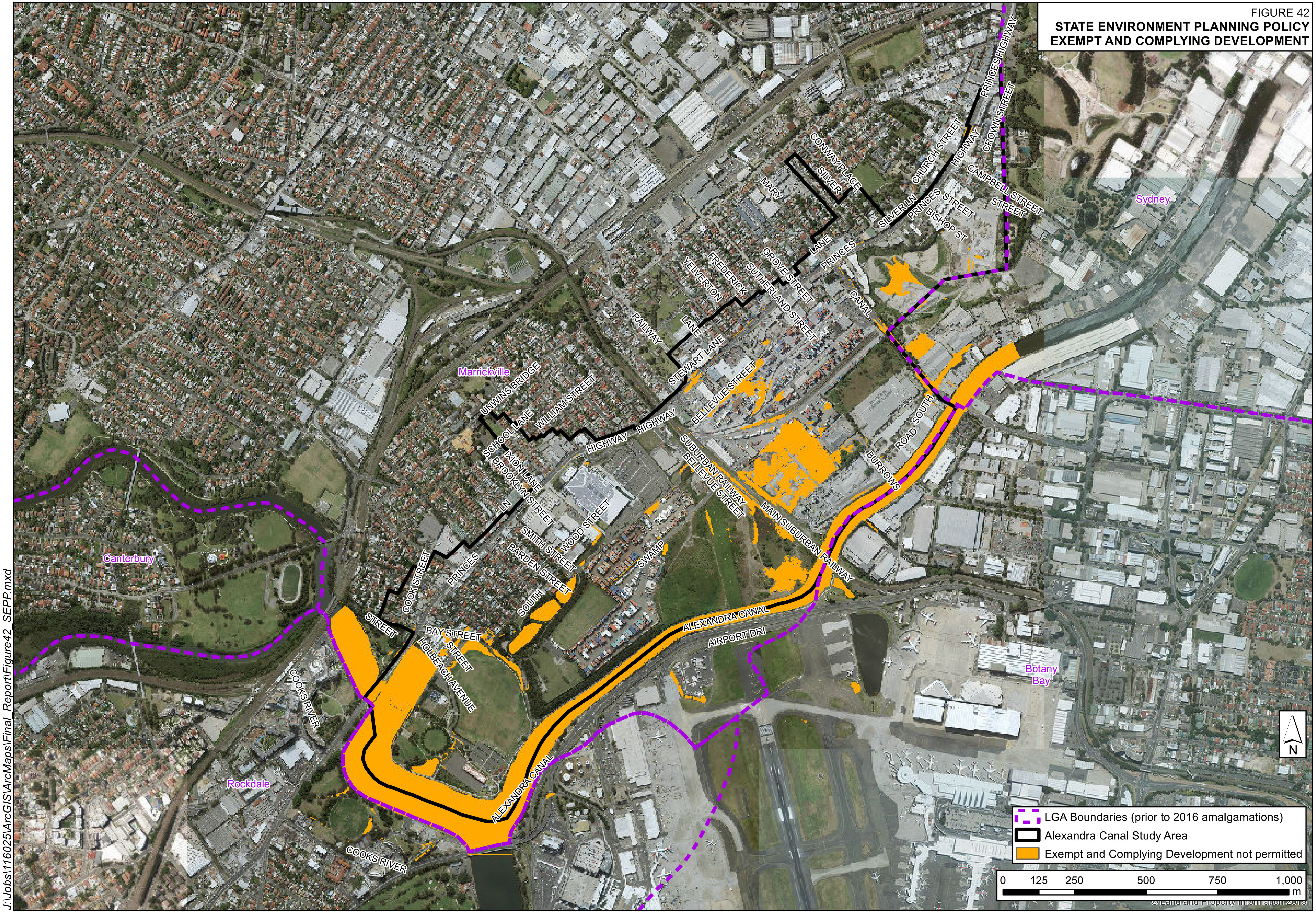

FIGURE 42
STATE ENVIRONMENT PLANNING POLICY EXEMPT AND COMPLYING DEVELOPMENT

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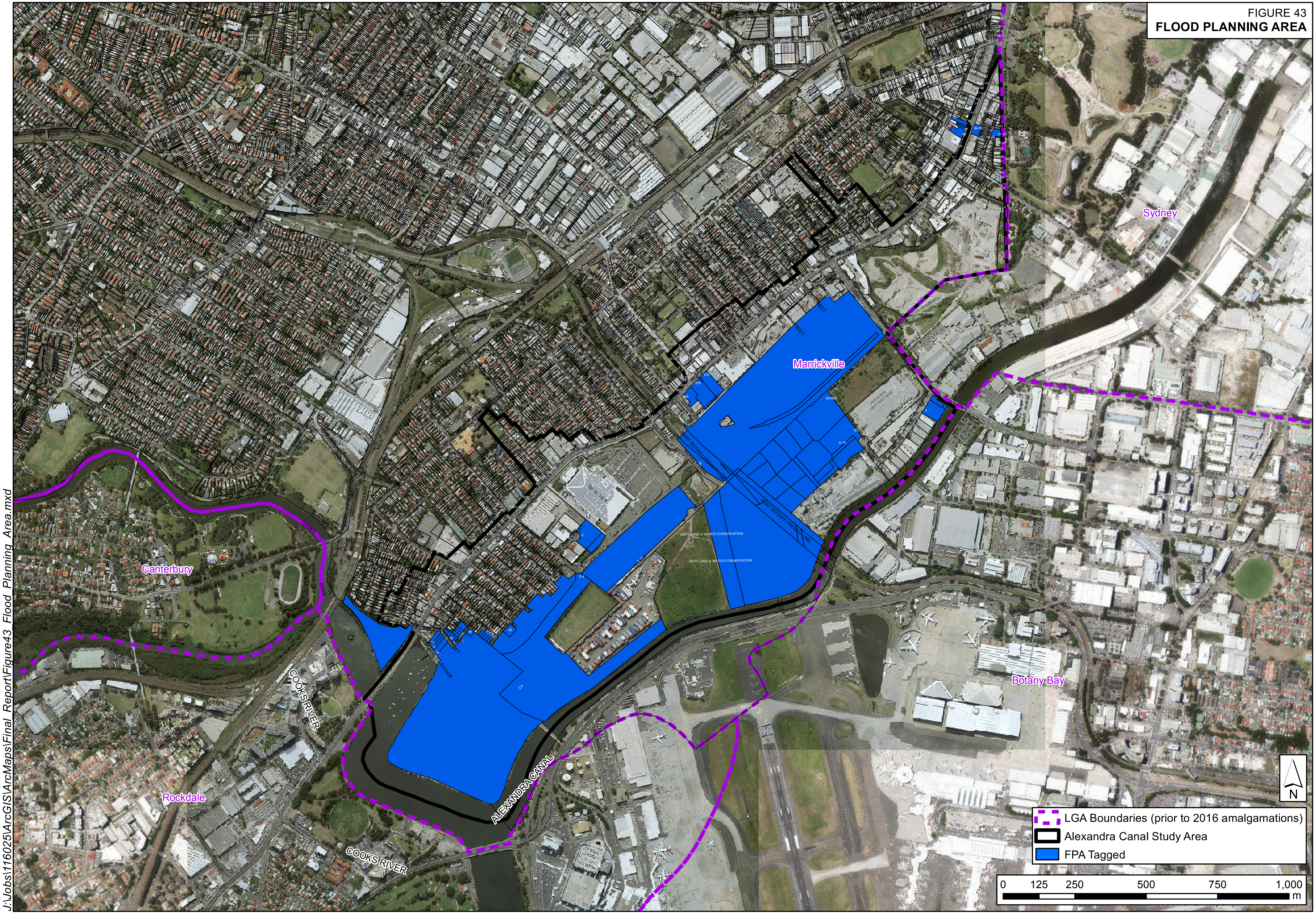
FIGURE 43
FLOOD PLANNING AREA



J:\Jobs\116025\ArcGIS\ArcMaps\Final Report\Figure43 Flood Planning Area.mxd

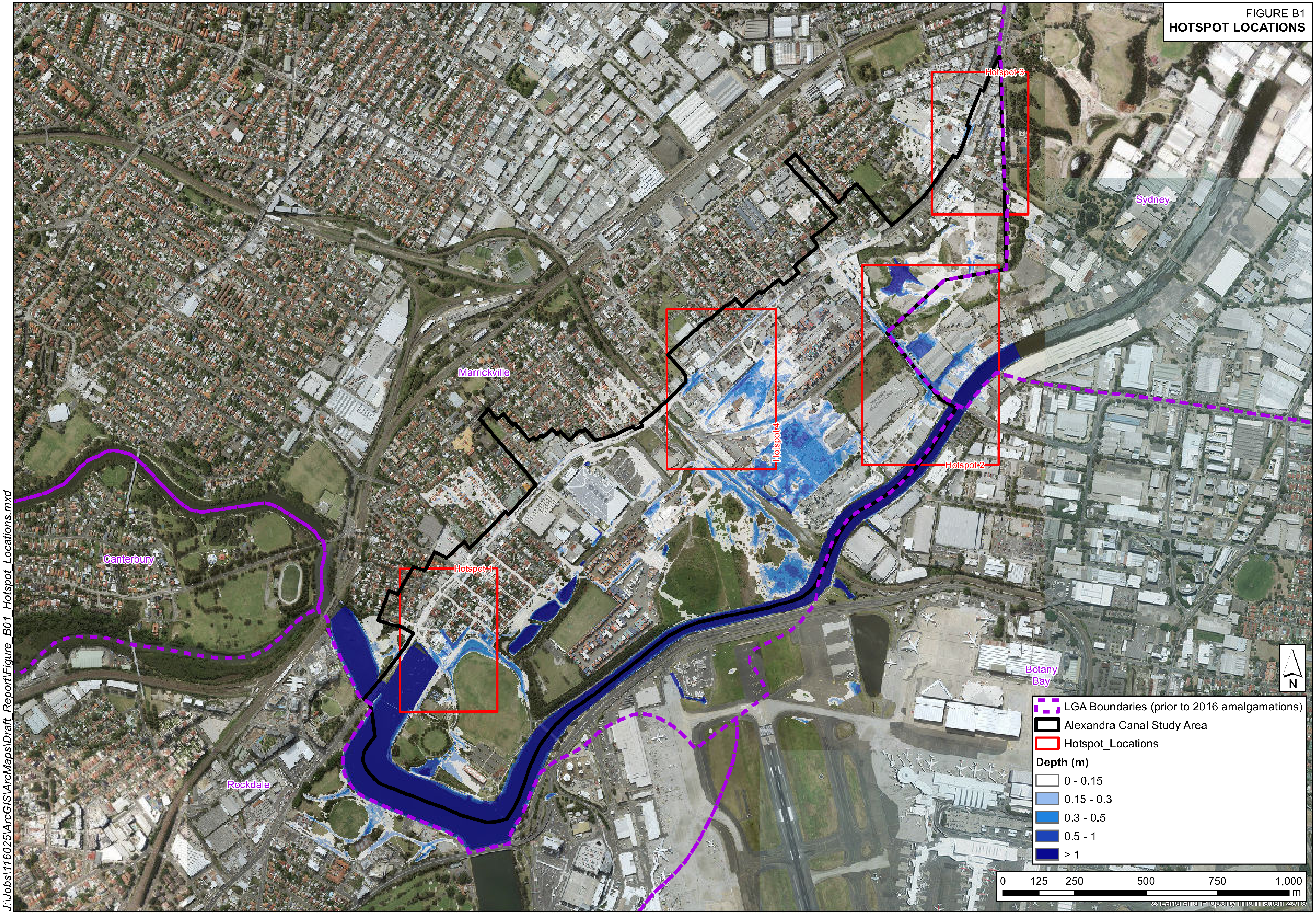


FIGURE B1
HOTSPOT LOCATIONS

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FIGURE B2
HOTSPOT 1 - HOLBEACH AVE, BAY ST AND OLD ST PEAK FLOOD DEPTHS AND LEVELS 1% AEP

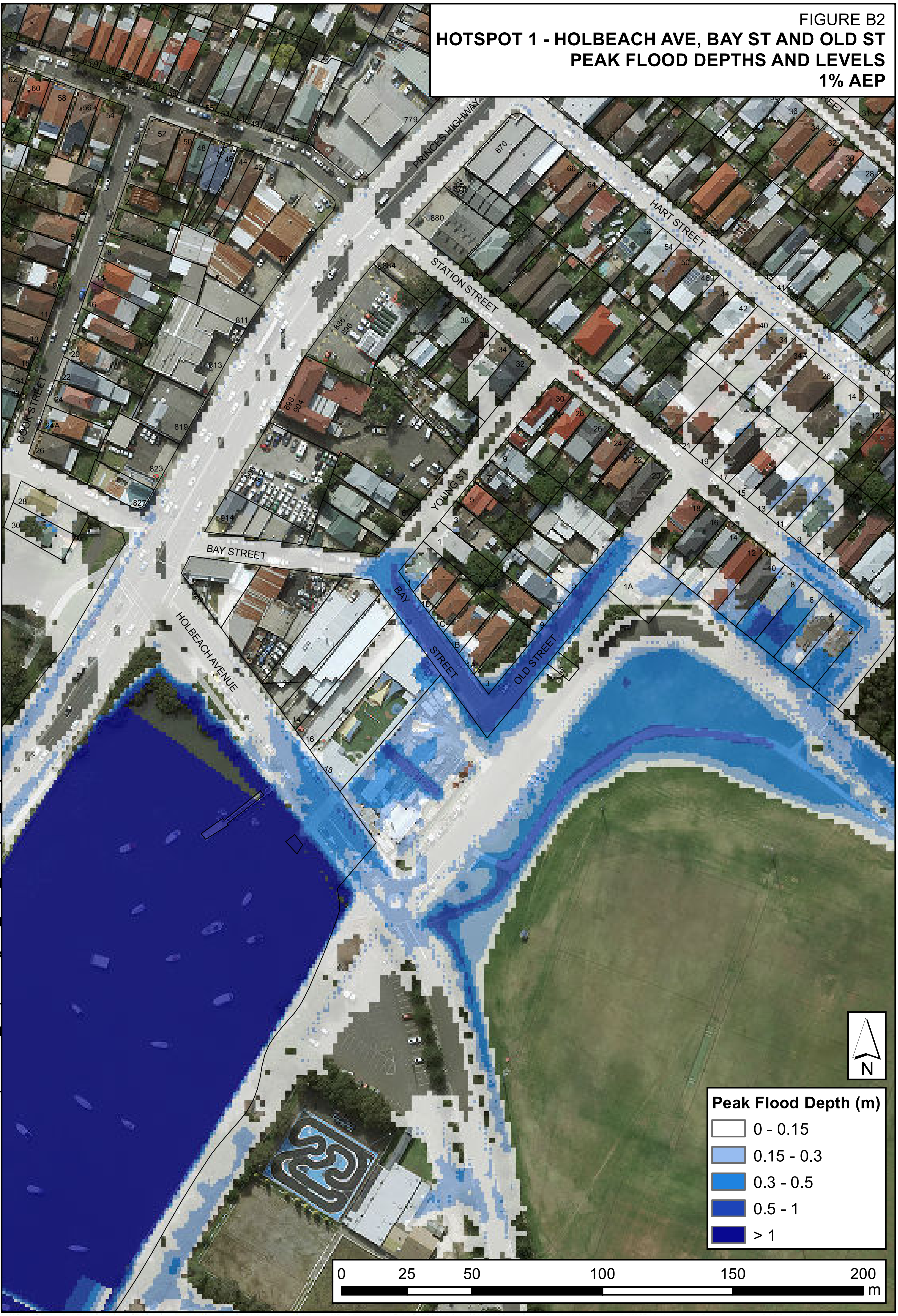

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FIGURE B3

HOTSPOT 2 - CANAL RD AND BURROWS RD PEAK FLOOD DEPTHS AND LEVELS 1% AEP

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FIGURE B4

HOTSPOT 3 - PRINCES HWY, BARWON PARK RD AND CROWN ST PEAK FLOOD DEPTHS AND LEVELS 1% AEP

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FIGURE B5

HOTSPOT 4 - PRINCES HWY, TALBOT ST AND BELLEVUE ST

PEAK FLOOD DEPTHS AND LEVELS

1% AEP

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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 and their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.
flood fringe areas	The remaining area of flood prone land after floodway and flood storage areas have been defined.
flood liable land	Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).
flood mitigation standard	The average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.

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

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

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

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

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

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

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

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

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

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

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

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

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

- the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or
- water depths generally in excess of 0.3 m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or
- major overland flow paths through developed areas outside of defined drainage reserves; and/or
- the potential to affect a number of buildings along the major flow path.

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

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

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

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

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

survey plan A plan prepared by a registered surveyor.

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

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