INNER WEST COUNCIL

JOHNSTONS CREEK AND WHITES CREEK

FINAL REPORT

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JOHNSTONS CREEK FLOOD STUDY

FINAL REPORT

APRIL 2017

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JOHNSTONS CREEK FLOOD STUDY

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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
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 Johnstons Creek and Whites Creek catchments are located in Sydney's Inner West region, approximately 7.5km from the CBD. The catchments include the suburbs of Enmore, Newtown, Stanmore, Camperdown, Petersham, Lewisham and Annandale. The Local Government Areas (LGAs) that are within the Johnstons Creek and Whites Creek catchments are City of Sydney, the former Marrickville Council and the former Leichhardt Council. The study area contains the portion of the Johnstons Creek and Whites Creek catchments that lie 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

Within the Johnstons Creek study area, the former Marrickville Council LGA receives flow from the City of Sydney LGA located to the east. From the former Marrickville Council LGA, water is routed through the former Leichhardt Council LGA and into Rozelle Bay via Council and Sydney Water Corporations (SWC) drainage systems.

Within the Whites Creek study area, the flows from the former Marrickville Council LGA enter the former Leichhardt Council LGA; with no LGA upstream of the former Marrickville Council LGA inside the Whites Creek catchment.

As urbanisation occurred, many natural drainage lines were built over and piped. However, with limited consideration given to formal overland flow paths, the study area contains many unrelieved sag locations. Due to these drainage restrictions, topographic depressions can cause localised flooding, as excess flows have no opportunity to escape via overland flow paths. This creates a significant drainage/flooding problem in many areas throughout both catchments.

As urbanisation occurred, many natural drainage lines were built over and piped. However, with limited consideration given to formal overland flow paths, the study area contains many unrelieved sag locations. Due to these drainage restrictions, topographic depressions can cause localised flooding, as excess flows have no opportunity to escape via overland flow paths. This creates a significant drainage/flooding problem in many areas throughout both catchments.

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

Johnstons Creek has a total catchment area of approximately 460 ha, which drains into Rozelle Bay. Of the total catchment area, 183 ha are within the former Marrickville Council LGA, 168 ha are within the former Leichhardt Council LGA and 108 ha are within the City of Sydney LGA. The Marrickville portion of the Johnstons Creek catchment is located in the upper catchment where it receives some flow from the City of Sydney and then drains into Leichhardt.

Whites Creek has a total catchment area of approximately 262 ha, which drains into Rozelle Bay. Of the total catchment area, 35 ha are within the former Marrickville Council LGA and 226 ha are within the former Leichhardt Council LGA. The Marrickville portion of the Whites Creek catchment is located upstream and drains into the Leichhardt portion of the catchment.

The study area contains the portion of Johnstons Creek and Whites Creek catchments that are within the former Marrickville Council area and is shown in Figure 1.

The Johnstons Creek and Whites Creek catchments are fully developed urban areas, with predominantly semi-detached and terrace housing. There exist some areas of large open space such as Camperdown Park, O'Dea Reserve, Camperdown Memorial Rest Park, Maundrell Park and Weekley Park.

Water is removed from the study areas via council drainage systems (consisting of covered channels, in-ground pipes, culverts and kerb inlet pits) and Sydney Water's major trunk drainage systems; known as SWC55 and SWC95 which serve Johnstons Creek and Whites Creek catchment respectively. Both of the trunk drainage systems discharge into Rozelle bay from a combination of open and covered channels.

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, 1% AEP design storms, and the Probable Maximum Flood (PMF) in the Johnstons Creek and Whites Creek catchments and to:

- prepare suitable models of the catchment and floodplain for use in a subsequent Floodplain Risk Management Study;

- provide results for flood behaviour in terms of design flood levels, depths, velocities, flows and flood extents within the study area;
- prepare maps of provisional hydraulic categories and provisional hazard categories;
- 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 Johnstons Creek and Whites Creek Catchments there are no stream gauges or official historical records available. A picture of flooding must therefore be obtained from an examination of Council records, previous reports, rainfall records and local knowledge.

2.2. Topographic Data

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 at selected locations were obtained for the Whites Creek, Johnstons Creek North, Johnstons Creek South and Johnstons Creek West (report discussed in Section 2.9.2 and Section 2.9.3).

The current study utilised the ground level survey from the previous studies 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 less than 0.01 m in the Johnstons Creek Catchment and -0.02 m in the Whites Creek Catchment. The ground level survey locations are shown on Figure 2.

2.2.3. Channel Cross-Section Data

The cross sections for the open channel system for both Johnstons Creek and Whites Creek were obtained from a combination of previous studies and data collected during fieldtrips.

The SWC Capacity Assessment report (Reference 9) has been used to inform cross-section dimensions, pipe type (closed/ open) and channel slope. Data collected during fieldtrips were used to supplement this, particularly at crossings along Johnstons Creek Channel (e.g. Pedestrian Walkways and Parramatta Road). Cross section details for Booth Street Bridge (the downstream boundary of the Johnstons Creek TUFLOW model) was available from Cardno, which were surveyed a part of the 2010 Leichhardt Flood Study (Reference 11).

2.3. Pit and Pipe Data

The SWC capacity assessment documents (SWC, 1998) provided dimensions for SWC owned underground pipes and open channel cross-sections. Further, Work As Executed (WAE) drawings from Sydney Water were supplied by council at the inception of the study. These drawings were used to supplement or improve the pipe data available across the Johnstons Creek catchment.

Further details for these reports are discussed in Section 2.9.4. Appended to this SWC drainage network are underground pipes owned by the various Council jurisdictions within the catchment areas.Council provided data for pit and pipe dimensions and locations, which are shown in Figure 3.

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 Johnstons Creek and Whites Creek area where pit invert levels were not available. It was found that some of the pits requested for survey were identified as surface level inlets (collect overland from kerb and exits culvert/pit at kerb) and therefore no pit invert was surveyed. 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	654
Surveyed	371
Unreachable	4
Not surveyed (other reason)	167
Ongoing	112

Further revisions were made to the pit and pipe network to include recent developments. These include:

- Bedford Street Drainage Upgrade
- Under floor flowpath under 11-17 Australia Street and 10-16 Denison Street
- Under floor flowpath under 370 Parramatta Road (AMR Motors)

The City of Sydney drainage network that connects into the former Marrickville Council drainage network was obtained from the Johnstons Creek TUFLOW model that was built for City of

Sydney. The City of Sydney provided this data to Marrickville Council to facilitate this work. The location of the City of Sydney drainage network (within the Johnstons Creek study area but outside of the Marrickville council LGA) is shown on Figure 3.

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 over the open channel, and preliminary hotspot locations were the primary focus of the site visit.

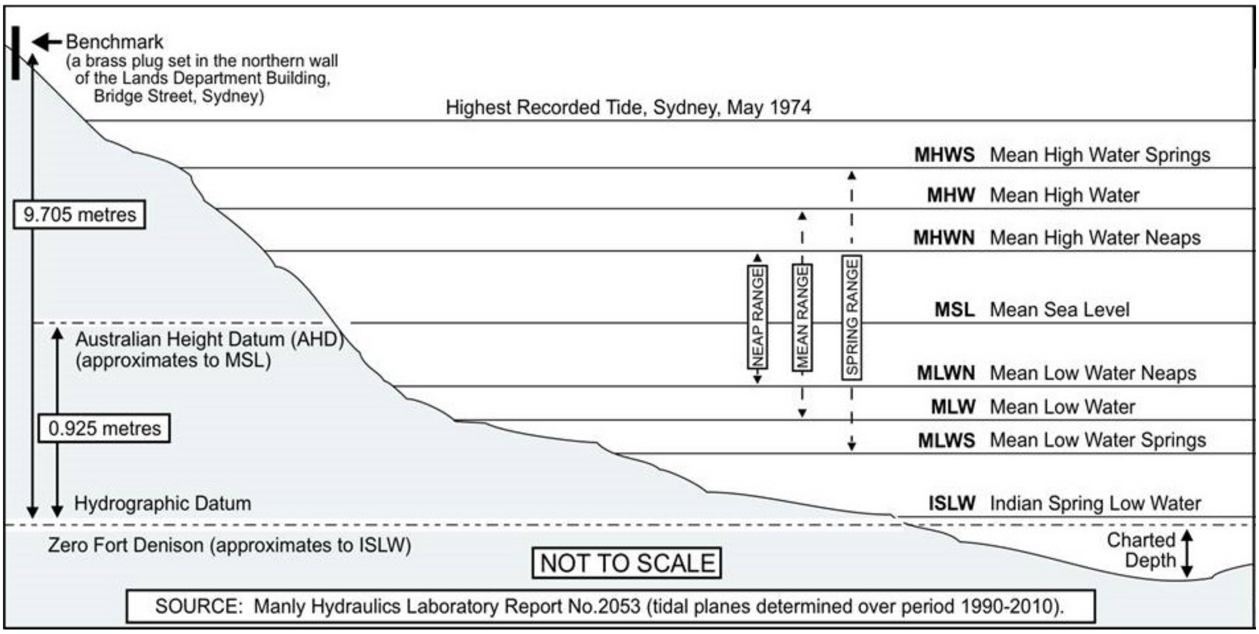
2.5. NSW Tidal Planes Analysis

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 Observations

A historic flood database was supplied by SWC that provided information on flooding within Whites Creek and Johnstons Creek. A summary of the records available for each catchment are presented below.

2.6.1.1. Johnstons Creek

There are 87 records available for Johnstons Creek catchment for the period between 1938 and 1994. It was found that 30 records were located within or in close proximity to the study area, 36 records were outside the study area and the remaining 21 do not have an exact location or the location no longer exists. The location of the 30 records are shown in Figure 5A. Of the 30 records, 5 properties experienced flooding above floor level as shown in Figure 5B. Further, it was found that 5 properties reported being affected by flooding on at least 2 occasions with one property reporting 5 cases of flooding above floor level since records began. The areas of most affection include:

- Cahill Street, Camperdown (6 records);
- Salisbury Road, Stanmore (4 records);
- Booth Street, Camperdown (2 records);
- Gibbens Street, Camperdown (2 records);
- Susan Street, Annandale (2 records); and
- Australia Street, Newtown and Camperdown (2 records).

2.6.1.2. Whites Creek

There are 29 records available for Whites Creek catchment for the period between 1972 and 1998. It was found that 11 records were located just outside the study area, north of Parramatta Road, as shown in Figure 5A. Records indicate that ponding and overland flow were the main causes of flooding with 5 records reporting property inundation and 1 property experiencing flooding above floor level as shown in Figure 5B. The areas of affection include:

- Hearne Street, Leichhardt (4 records);
- Albion Street, Annandale (2 records);
- Clarke Street, Annandale (3 records);
- Balmain Road, Leichhardt (1 record); and
- Ferris Street, Annandale (1 record).

2.6.2. Council's Complaints Database

A historic flood database was supplied by Council and provided information on flooding within the study area. From the database of flooding complaints, 27 locations were reported to experience flooding during heavy rainfall. The location of these complaints is shown on Figure 5A.

2.6.3. Community Consultation

A community consultation process was undertaken in collaboration with Council. 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 4971.

The response rate was on average 2% across the study areas, a total of 94 responses. From this, it was found that 74% of respondents had experienced flooding. The April 2015 event was identified as the most well-known event, with 32% of respondents saying they had experienced the event. The October 2014, March 2014 and March 2012 events were also identified as being significant events.

Further, 50% of the respondents reported flooding on roads and footpaths, which serve as formalised overland flow paths in this catchment as the sub-surface drainage system is overwhelmed by the runoff volume associated with more extreme events. Low-lying areas, drainage deficiencies and pit blockage due to leaves and hail were identified most commonly as the cause of flooding by respondents.

The locations of the community consultation respondents are shown in Figure 5A. Areas identified as experiencing flooding above floor level or problem flood areas are shown in Figure 5B. The full set of results from the community consultation questionnaire are summarised in Figure 6.

The following photos were provided as part of the community consultation process.

Photo 1: Extracted from video – Railway Ave near Liberty St (2015)

Photo 2: Extracted from video – Railway Ave near Liberty St (2015)

Photo 3: Extracted from video – Liberty St near Bedford St (2015)

Photo 4: Bedford St near Liberty St (8 November 2011)

Photo 5: Corner of Albany Rd and Percival Rd

Photo 6: Trafalgar St near Liberty St

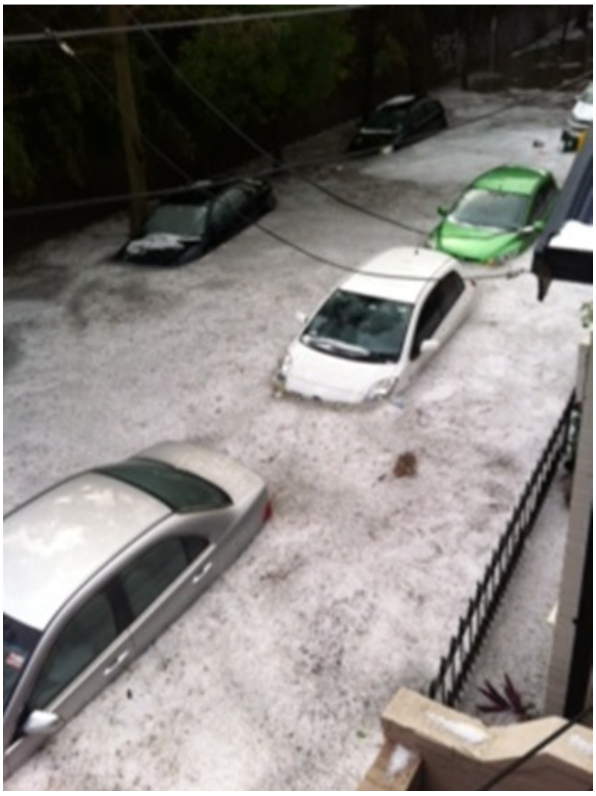


Photo 7: Probert St near Bishopgate Ln

Photo 8: Bridge Rd near Cruikshank St

Photo 9: Salisbury Rd near Bridge Rd

Photo 10: Lennox St near Mary St (25 April 2015)

Photo 11: Lennox St near Mary St (25 April 2015)

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 affect 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 that 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
66097	Ranwick Bunnerong Rd	BOM (AUS)	1.50		1/01/1904	1/01/1924	Daily
66015	Crown St. Reservoir	BOM (AUS)	1.50		30/01/1882	29/12/1960	Daily
566065	Annandale	SWC (NSW)	1.87	20	21/12/1988		Continuous
566110	Erskineville Bowling Club	SWC (NSW)	2.08	10	2/06/1993	8/02/2001	Continuous
566026	Marrickville Sps	SWC (NSW)	2.16	5	1/05/1904		Continuous
566026	Marrickville Sps	SWC (NSW)	2.16	5	1/05/1904		Daily
66033	Alexandria (Henderson Rd)	BOM (AUS)	2.32	15	29/04/1962	29/12/1963	Daily
66033	Alexandria (Henderson Rd)	BOM (AUS)	2.32	15	30/03/1999	12/03/2002	Daily
66101	Fernbank	BOM (AUS)	2.85		01/01/1889	1/01/1913	Daily
66149	Glebe Point Syd. Water Supply	BOM (AUS)	2.98	15.2	30/05/1907	29/12/1914	Daily
66021	Erskineville	BOM (AUS)	3.08	6	29/04/1904	29/12/1973	Daily
566112	Ashfield (Ashfield Park Bowling Club)	SWC (NSW)	3.34	20	2/12/1993	1/02/2001	Continuous
66000	Ashfield Bowling Club	BOM (AUS)	3.37	25	30/03/1896		Daily
66165	Ashfield Prospect Rd	BOM (AUS)	3.51	43	01/01/1894	1/01/1904	Daily
66036	Marrickville Golf Club	BOMNS (NSW)	4.27	6	6/04/2001		Operational
66036	Marrickville Golf Club	BOM (AUS)	4.27	6	29/04/1904	29/12/1970	Daily
66139	Paddington	BOM (AUS)	4.40	4.6	1/01/1968	1/01/1976	Daily
66175	Schnapper Island	BOM (AUS)	4.58	5	28/02/1932	29/12/1939	Daily
66062	Sydney (Observatory Hill)	BOMNS (NSW)	4.68	39	17/06/1996		Operational
66062	Sydney (Observatory Hill)	BOM (AUS)	4.68	39	1/01/1913		Continuous
66062	Sydney (Observatory Hill)	BOM (AUS)	4.68	39	29/06/1858	6/08/1990	Daily
66062	Sydney (Observatory Hill)	BOM (AUS)	4.68	39	29/06/1858		Synop
566066	Fivedock Sps65	SWC (NSW)	4.71	10	19/09/1989	7/02/2001	Continuous
66178	Birchgrove School	BOM (AUS)	4.73	10	29/04/1904	29/12/1910	Daily
66150	Canterbury Heights	BOM (AUS)	5.01	61	30/08/1906	29/12/1916	Daily
66006	Sydney Botanic	BOM (AUS)	5.07	15	01/01/1885		Daily

Station Number	Station Name	Operating Authority	Distance from centre of study area (km)	Elevation (mAHD)	Date Opened	Date Closed	Type
	Gardens						
566032	Paddington (Composite Site)	SWC (NSW)	5.13	45	10/04/1961		Continuous
566032	Paddington (Composite Site)	SWC (NSW)	5.13	45	10/04/1961		Daily
566113	Canterbury Racecourse	SWC (NSW)	5.16	3	9/12/1993	1/02/2001	Continuous
66017	Barnwell Park Golf Course	BOM (AUS)	5.37	4	29/11/1929	28/11/2003	Daily
66194	Canterbury Racecourse AWS	BOM (AUS)	5.49	3	2/10/1995		Synop
66037	Sydney Airport Amo	BOM (AUS)	5.54	6	1/01/1960		Continuous
66037	Sydney Airport Amo	BOM (AUS)	5.54	6	29/06/1994		Synop
66192	Sydney Airport Tbrg	BOM (AUS)	5.54	3	1/01/1993	1/01/1997	Continuous
66073	Randwick Racecourse	BOM (AUS)	5.73	25	1/01/1937		Daily
566099	Randwick Racecourse	SWC (NSW)	5.77	30	29/11/1991		Continuous
213007	Busby Bore Pond	DNR (NSW)	5.85				
66034	Abbotsford (Blackwall Point Rd)	BOM (AUS)	5.85	15	1/01/2004		Daily
66160	Centennial Park	BOM (AUS)	5.94	38	30/05/1900		Daily
566028	Mascot Bowling Club	SWC (NSW)	6.01	5	28/08/1973		Continuous
566028	Mascot Bowling Club	SWC (NSW)	6.01	5	28/08/1973		Daily
66075	Waverton Bowling Club	BOM (AUS)	6.08	21	29/11/1955	3/01/2001	Daily
566091	Kyeemagh Bowling Club	SWC (NSW)	6.23	5	19/09/1991		Continuous
213008	Duck Pond	DNR (NSW)	6.31				
66007	Botany No.1 Dam	BOM (AUS)	6.36	6.1	01/01/1870	1/01/1978	Daily
66061	Sydney North Bowling Club	BOM (AUS)	6.54	75	30/03/1950	29/12/1974	Daily
66067	Wollstonecraft	BOM (AUS)	6.54	52.7	1/01/1915	1/01/1975	Daily
66111	Craydon	BOM (AUS)	6.73		30/01/1879	29/12/1921	Daily
66018	Earlwood Bowling Club	BOM (AUS)	6.80	31.1	30/07/1914	29/12/1975	Daily
66052	Randwick Bowling Club	BOM (AUS)	6.95	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 Marrickville Golf Club (66036), Ashfield Bowling Club (66000), Randwick Racecourse (66073) and Sydney Observatory Hill (66062).

The Ashfield (66000) gauge, the Sydney Observatory Hill (66062) gauge and the Randwick (66073) gauge are proximate to the study area and have a relatively long period of record; having been established in 1894, 1858 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 Marrickville Golf Club, Ashfield Bowling Club, Randwick Racecourse and Sydney Observatory Hill

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	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

Ashfield Bowling Club (66000) March 1894 – March 2012		
Rank	Date	Rainfall (mm)
1	6/08/1986	245
2	9/03/1913	210.3
3	28/03/1942	206.2
4	3/02/1990	206
5	10/02/1956	194.3
6	17/06/1950 (2 days)	182.4
7	13/01/1911	175.3
8	27/11/1955	166.6
9	22/02/1954 (2 days)	159.5
10	26/03/1984 (3 days)	158
11	24/01/1955 (2 days)	156.5
12	11/03/1958	153.7
13	19/02/1959	151.9
14	10/01/1949	151.4
15	10/03/1958 (2 days)	149.9

Randwick Racecourse (66073) 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

Sydney (Observatory Hill) (66062) June 1858 – to date		
Rank	Date	Rainfall (mm)
1	6/08/1986	327.6
2	28/03/1942	280.7
3	3/02/1990	243.6
4	9/11/1984	234.6
5	25/02/1873	226.1
6	28/05/1889	212.3
7	11/03/1975	198.2
8	7/07/1931	198.1
9	10/02/1956	192
10	6/02/1878	191.3
11	29/04/1860	191
12	17/01/1988	191
13	9/02/1992	190
14	1/05/1955	188.2

15	10/02/1956	195.1	15	13/01/1911	179.8

The results indicate that the 1990, 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 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 the Johnstons Creek catchment does not show up on the highest daily totals for Ashfield, Sydney Observatory Hill or Randwick, and is ranked sixth and 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), Annandale (566065), and Paddington (566032) 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 Paddington gauge was established in 1961, with sub-daily records beginning in December 1979. The Erskineville gauge was establish in 1993. The Annandale gauge was established in 1989.

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
Annandale (566065)	27	20 – 50 year ARI	10 – 20 year ARI
Paddington (566032)	37	20 – 50 year ARI	50 – 100 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 Paddington pluviometer recorded the highest approximate ARI for the 30 minute and 1 hour storm burst. This occurred in 1989 and 1984.

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). Within the Johnstons Creek and Whites Creek 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 short, intense burst 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 two highly localised storm cells (shown on Figure 9B) 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) [change to 566099]			
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
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
Lilyfield Bowling Club (566065)			
Max Rainfall (mm)	26.5	28.5	29
Intensity (mm/hr)	53	28.5	15.25
Approximate ARI	1 – 2y	<1y	<1y
Rank comparative to gauge records for relevant duration	11	1322	40

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 Johnstons Creek and Whites Creek catchment area, this event was found to be mostly within the range of a 2 – 5 year ARI event. 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 catchments in this study 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 Johnstons Creek Catchment, the estimated ARI of the event was below a 5 year ARI event and within the Whites Creek Catchment the estimated ARI was below a 2 year ARI event. 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). Within the Johnstons Creek Catchment, the estimated ARI of the event was below a 20 year ARI event and within the Whites Creek Catchment the estimated ARI was below a 5 year ARI event.

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 6 hour storm with a 30 minute burst embedded within it (shown in 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 in Figure 8H and Figure 9H). Within the Johnstons Creek and Whites Creek Catchments, the estimated ARI of the event was below a 10 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. Johnstons Creek Catchment Flood Study (WMAwater, 2014)

The report was prepared by WMAwater (formerly Webb, McKeown & Associates) on behalf of City of Sydney (Council) and the Office of Environment and Heritage (OEH) under the guidance of Council's floodplain management committee. The aim of the report was to define flood behaviour in the Johnstons Creek catchment.

TUFLOW was used to model both the hydrologic and hydraulic calculations in the catchment, using a rainfall on grid approach. The integrity of this method was verified against a traditional approach. The specific yield (m^3/s/ha) was calculated for several catchments and compared against catchments from the Rose Bay hydrological model (DRAINS). Similarity in the results identified the rainfall on grid method to be suitable.

No specific historical flood level marks were available for the study although the community consultation phase identified areas generally prone to flooding. These locations were compared to the flood extent resulting from the 5 year ARI design event and were used to determine whether the model was producing reasonable results. The models parameters, including losses, imperviousness and Manning's 'n' value were taken from the Blackwattle Bay Flood Study that was undertaken at the same time by WMAwater. The Blackwattle Bay model was verified against historical events.

Relevant information taken from the report were:

- Rainfall intensities as low as 2 year ARI can cause flooding within the catchment;
- The most historically significant flooding events include: June 1949, November 1961, March 1975, November 1984, January 1991 and April 1998.

2.9.2. Johnstons Creek West Drainage Study (Cardno, 2008)

Cardno was commissioned by the former Marrickville Council to undertake a Drainage Study for the Johnstons Creek West catchment. The study aimed to complete an analysis of the existing drainage system and propose a management plan to alleviate flooding within the catchment. The study identified that the main sources of flooding were overland flow paths, mainstream flooding and local drainage deficiencies because of an old drainage system.

The study adopted DRAINS as the hydrological model using parameters obtained from previous studies. The adopted parameters are presented in the table below.

Table 9 - Adopted hydrological model parameters for Johnstons Creek West Drainage Study

Parameter		Value
Soil		3
AMS		3
Infiltration, Initial	Paved Area	1 (mm)
	Supplementary Area	1 (mm)
	Grassed Area	5 (mm)
Time of Entry		Kinematic wave formula

The model was calibrated and verified using the pluviometer station 566026 for three historical events: 20 November 1988, 26 January 1991 and 16 April 1993. The design runs found the critical duration to vary between the 25 minute (upper catchment) and the 60 minute (at Bridge Road) storm burst.

Trapped low points were identified as problem areas during the study and corresponded to locations where sag pits removed water from these areas. Ponding would occur if either the hydraulic or the inlet capacity was exceeded. The identified areas include:

- Merton Lane;
- Trafalgar Street (near Crammond Park);
- Intersection of Trafalgar Street and Harrow Road;
- Railway Avenue at Surrey Street;
- Stanmore Lane at Warwick Road;
- Clarendon Lane (near Weekley Park);
- Crescent Lane (at 20 Gordon Crescent); and
- Bridge Road at the intersection of Corunna Road).

2.9.3. Whites Creek, Johnstons Creek South and Johnstons Creek North Drainage Study (Dalland and Lucas, 1996, 1998 and 1999)

The three drainage studies were commissioned by the former Marrickville Council and prepared by Dalland and Lucas. The studies investigated existing drainage systems and flooding within the study areas and proposed mitigation options.

The studies adopted an ILSAX model for hydrologic and hydraulic analysis. The ILSAX model uses a time-area method and Horton infiltration to produce flow hydrographs, which are used to route water through the stormwater drainage systems.

The three largest events for the study areas occurred on the 14 February 1993, the 17 November 1988, and the 23 January 1991; and these were found to vary between a 2 year ARI event and a 5 year ARI event. These events were used for calibration in the Johnstons Creek North and Johnstons Creek South catchments, where flood level data was available (obtained from interviews with residents). No flood level data was observed within the Whites Creek catchment and therefore calibration was unable to be undertaken.

Relevant information taken from each study are below.

<u>Johnstons Creek North</u>

- In the 100year ARI event, 65 properties incurred above ground flooding with 25 experiencing above floor level flooding;
- The critical duration ranged between 20 minutes to 120 minutes (depending on ARI); and
- At the catchment outlet (Cardigan Street), peak flows of 8.9 m^3/s, 14.5 m^3/s and 19.4 m^3/s were determined for the 5 year, the 20 year and the 100 year ARI events, respectively.

<u>Johnstons Creek South</u>

- In the 100 year ARI event, 156 properties incurred above ground flooding with 31 experiencing above floor level flooding;
- The critical duration ranged between 25 minutes to 90 minutes (depending on ARI); and
- At the catchment outlet (Salisbury Road), peak flows of 15.3 m^3/s, 18.5 m^3/s and 22.1 m^3/s were determined for the 5 year, the 20 year and the 100 year ARI events, respectively.

<u>Whites Creek</u>

- In the 100 year ARI event, 41 properties incurred above ground flooding with 5 experiencing above floor level flooding;
- There was no reliable flood level data available for calibration;
- Critical duration was found to be 25 minutes; and
- At the catchment outlet (Parramatta Road), peak flows of 7.6 m^3/s, 9.4 m^3/s and 12.5 m^3/s were determined for the 5 year, the 20 year and the 100 year ARI events, respectively.

2.9.4. Sydney Water Stormwater Capacity Assessment Report

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

- Johnstons Creek (SWC 55) Capacity Assessment – December 1995; and
- Whites Creek (SWC 95) Capacity Assessment – July 1996.

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

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

The SWC Capacity Assessment reports have been used in the present study for informing the SWC owned pit and pipe details.

2.9.5. Leichhardt Flood Study (Cardno Lawson Treloar, 2010)

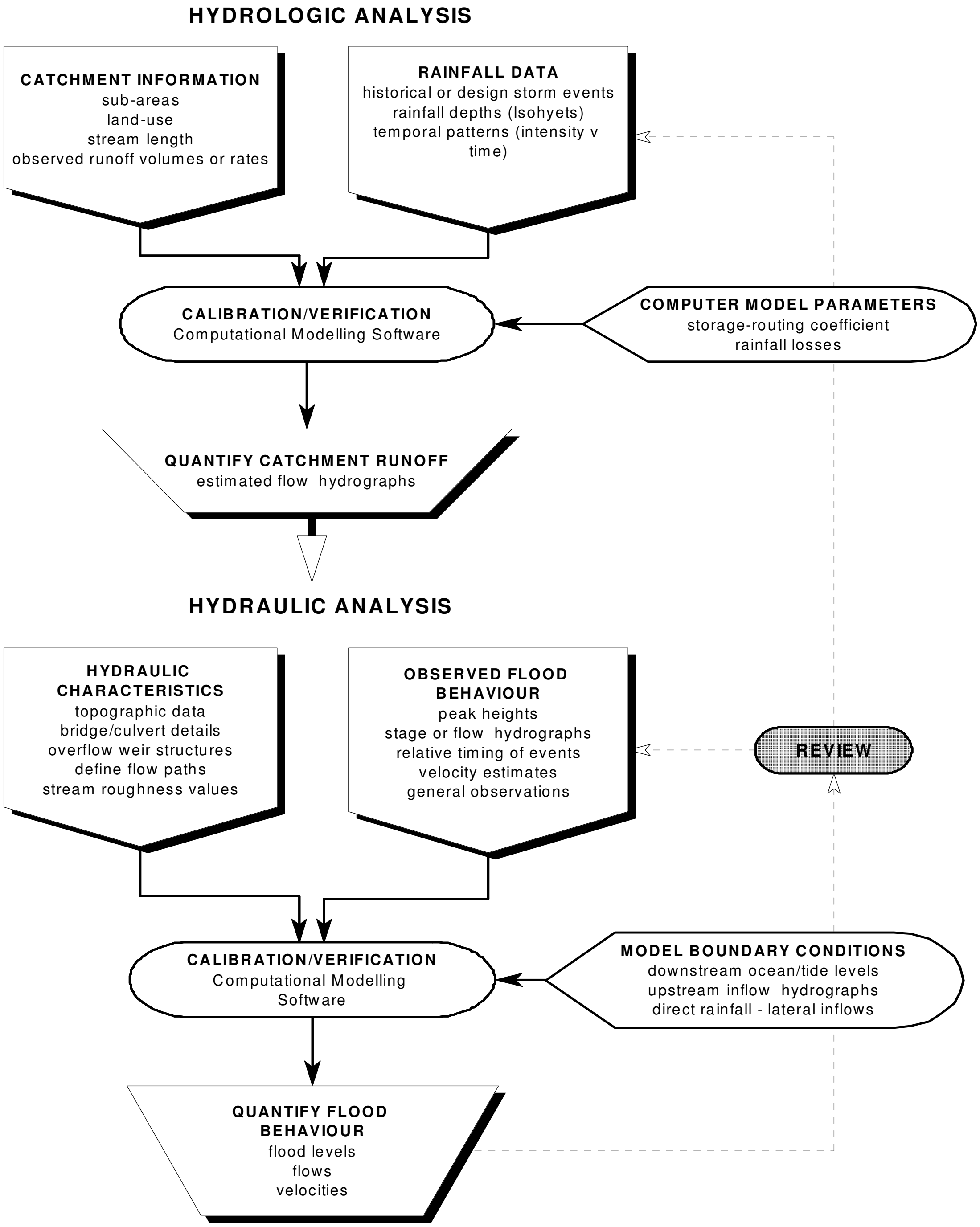
Cardno Lawson Treloar was commissioned by the former Leichhardt Council to complete a Flood Study covering the former Leichhardt LGA. The study aimed to identify existing flood behaviour in the study area.

As part of the study, an extensive survey was completed of bridges and major crossings along the Johnstons Creek open channel. The survey extended upstream towards the intersection of Parramatta Road and Bridge Road Stanmore, located to the south-east boundary of the current study area. These surveyed sections were incorporated into the current study.

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 Johnstons Creek and Whites Creek is presented in Table 10. The sub-catchment delineation is shown on Figure 11.

Table 10: Sub-catchment parameters

	Johnstons Creek	Whites Creek
Study Area (km^2)	2.5	0.7
Number of Catchments	240	48
Average catchment size (ha)	1.1	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 11.

Table 11: Impervious Percentage per Land-use

Land-use Category	Impervious Percentage	Area (ha) within Johnstons Creek	Area (ha) within Whites Creek
Open Space (parks, rail corridor etc)	0% Impervious	21	0
Residential	70% Impervious	151	58
Infrastructure (roads, footpath, verge etc.)	90% Impervious	50	7
Carparks	100% Impervious	2	0
Commercial / Industrial	100% Impervious	30	5

Chart 1: Johnstons Creek Impervious / Pervious Land-use Categories

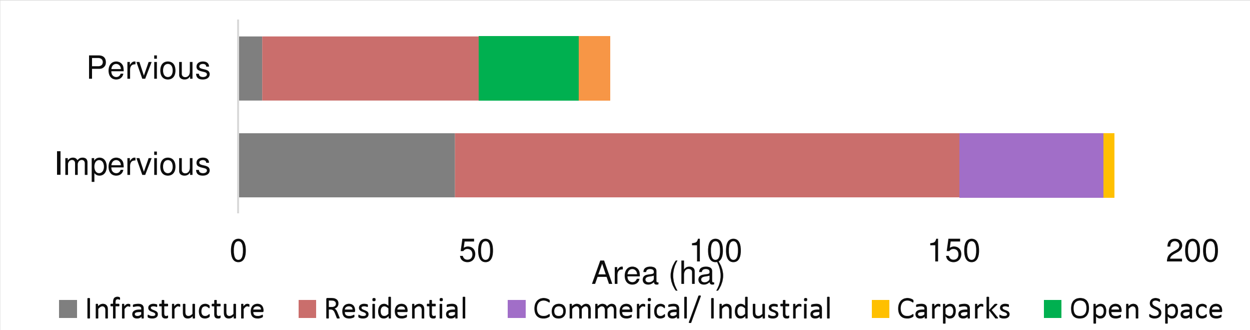
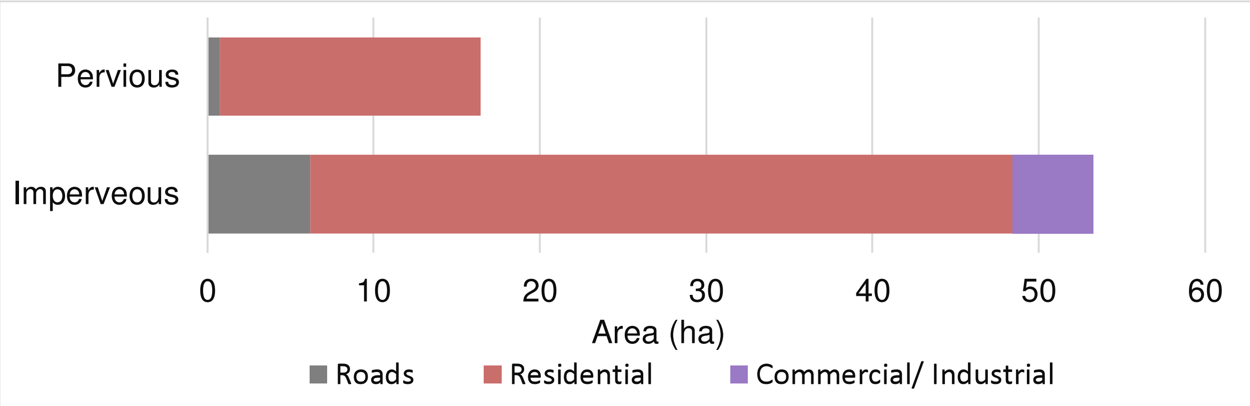


Chart 2: Whites Creek Impervious / Pervious Land-use Categories



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 12. These are consistent with the parameters adopted in the nearby catchments of Dobroyd Canal (WMAwater, 2015) and Hawthorne Canal (WMAwater, 2015).

Table 12: 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 Section2.2.1) 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).

The Johnstons Creek TUFLOW hydraulic model includes the upper portion of the Johnstons Creek Catchment within the former Marrickville Council LGA. The 2D model is bounded by Missenden Road and King Street (to the east); Enmore Road and Stanmore Road (to the south); and Crystal St (to the south-west). The boundary extends from the south-west to the north-east where the Booth Street Bridge crosses over the Johnstons Creek open channel. The total area included in the hydraulic model is 2.6 km^2.

The Whites Creek TUFLOW hydraulic model includes the upper portion of the Whites Creek Catchment within the former Marrickville Council LGA. The 2D model is bounded by Lorna Lane to the south, extending north-east to Palace Street and north-west to Annandale Street. To the north, Parramatta Road was the study area boundary and the hydraulic model extended approximately 580 m north (and downstream) of Parramatta Road. The total area included in the hydraulic model is 0.6 km^2.

The extents of the Johnstons Creek and Whites Creek TUFLOW model boundaries 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 (Flow versus time as represented in the inset graph in Figure 12) were extracted from the DRAINS model (see Section 4). 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 downstream boundaries for each catchment were located as follows:

- Whites Creek Catchment: approximately 250 m north of Parramatta Road – 30 m north of the Whites Creek Lane and Clarke Street intersection.
- Johnstons Creek Catchment: approximately 580 m downstream of Parramatta Road – Booth Street Bridge over Johnstons Creek open channel.

At these locations, a height versus time boundary is applied to both the 1D and 2D domain within the hydraulic model. The location of these boundaries, along with a representation of the height versus level boundary (inset graph) are shown in Figure 12.

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 Johnstons Creek catchment area (either overland and/or through the stormwater drainage network) and a divergent flow enters the adjacent Marrickville Valley and Hawthorne Canal catchments.

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.

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 13. 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 13: Manning's "n" values adopted in TUFLOW

Surface	Manning's "n" Adopted
Pipes	0.013
Concrete Open Channel	0.02
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 measurements and photographs taken during site inspections, and previous experience modelling similar structures.

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 each model comprises:

- Johnstons Creek
    - 652 pipes;
    - 659 pits and nodes; and
    - 111 open channel segments.
- Whites Creek
    - 114 pipes; and
    - 120 pits and nodes.

5.5. Blockage Assumptions

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

Debris availability and mobility can be influenced by factors such as channel shear stress, height of floodwaters, severity of winds, storm duration and seasonal factors relating to vegetation. The channel shear stress and height of floodwaters that influence the initial dislodgment of blockage materials are also related to the average exceedance probability (AEP) of the event. Storm duration is another influencing factor, with the mobilisation of blockage materials generally increasing with increasing storm duration (Barthelmess and Rigby 2009, cited in AR&R Revision Project 11 by 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 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 parameters 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 that 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 the Johnstons Creek and Whites Creek catchment. DRAINS was the hydrologic model used in Rose Bay and the catchment is located approximately 10 km from the Johnstons Creek 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 14.

Table 14: Specific Yield – Johnstons Creek

Sub-catchment	Johnstons Creek Catchment			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	0.7	0.6	1	0.6	0.7
2	0.3	0.2	0.5	0.4	0.2	0.6
3	0.9	0.5	0.5	0.6	0.4	0.6

Table 15: Specific Yield – Whites Creek

Sub-catchment	Whites Creek Catchment			Rose Bay		
	Area (ha)	Peak Discharge (m^3/s)	Specific Yield ($m^3/s/ha$)	Area (ha)	Peak Discharge (m^3/s)	Specific Yield ($m^3/s/ha$)
1	0.9	0.5	0.6	1	0.6	0.7
2	0.4	0.2	0.7	0.4	0.2	0.6
3	1.1	0.7	0.6	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

6.3.1. 2015 Calibration Event

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

6.3.1.1. Rainfall Distribution

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

6.3.1.2. Downstream Boundary Conditions

The ocean levels applied to the Johnstons Creek downstream boundary was a constant 0.245 m AHD, which corresponded to the levels at the time the rainfall event commenced in April 2015.

6.3.1.3. Results

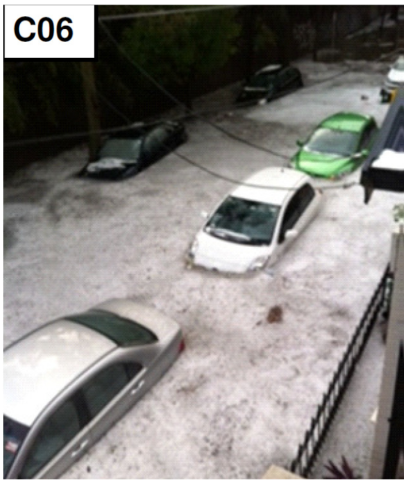
Calibration of the hydraulic model was made using photographs available from the community consultation phase (see Section 2.6.3 for more details). Flood depths were estimated from the photographs. The available photographs for the 2015 event are shown below. Refer to the Figure 14 for the corresponding location of the photograph and Table 16 for the comparison of estimated flood depths against modelled depths.

Note: the estimated depth from the photo does not necessarily correspond with the peak depth experienced at the location during the event. Photos could have been taken pre or post the peak occurring.

C01

C02

C03



C06

C07

C08

C10

C11

Table 16: Comparison of 2015 Event – Community Consultation - Photographic Evidence

Photo ID	Location	Estimated Depth (m)	Modelled Depth (m)	Difference (m)
C01	Railway Ave near Liberty St (facing east)	0.4	0.4	0.0
C02	Railway Ave near Liberty St (facing west)	0.4	0.3	0.0
C03	Liberty St near Bedford St	0.2	0.3	0.1
C06	Trafalgar St near Liberty St	1.0	1.0	0.0
C07	Probert St near Bishopgate Ln	0.6	0.5	-0.1
C08	Bridge Rd near Cruikshank St	0.1	0.1	0.0
C10	Lennox St near Mary St	0.5	0.5	0.0
C11	Lennox St near Mary St	0.6	0.6	0.0

6.4. Hydrologic/Hydraulic Model Verification

6.4.1. General Verification

From Council's database of flooding complaints, 27 locations were reported to experience flooding either during heavy rainfall events. The database covered a range of events that correspond to relatively small events. Therefore, it was assumed that the April 2015 event (roughly a 20% AEP event) would likewise produce the same flooding concerns as identified in the flooding complaints database. Figure 14 shows the modelled results for the 2015 April event along with the locations of flooding complaints. A summary of the modelled results for each location is presented in Table 17. Whilst there were no quantifiable flood marks available for the flood complaints, the results suggest that the model is able to replicate the flood affection identified at all locations, instilling confidence in the hydraulic model.

Table 17: Comparison of Historic Events – Council's Complaints Database

Location	April 2015 – Modelled Results
Australia St (near Derby Pl)	0.3 m
Australia St (near Lennox St)	0.1 m
Bedford St (near Pierce St)	< 0.1 m
Bedford St (near Probert St)	< 0.1 m
Bishopgate Ln (near Denison St)	< 0.1 m
Church St (near Lennox St)	0.1 m
Crammond Park 1	0.1 m
Crammond Park 2	0.1 m
Federation Rd (near Northwood Ln)	< 0.1 m
Gibbens St (between Tooths Pl and Fowler Ln)	< 0.1 m
Gibbens St (near Tooths Pl)	< 0.1 m
Gladstone St (between Liberty St and Phillip St)	0.1 m
Gladstone St (between Phillip Ln and Wilford St))	0.1 m
King St (near Mary St)	< 0.1 m
Lennox St (between Mary St and Eliza St)	0.1 m

Location	April 2015 – Modelled Results
Lennox St (near Church St)	< 0.1 m
Lennox St (near Mary St)	0.6 m
Liberty St (near London St)	0.1 m
Marmion St (near Kingston Ln)	0.2 m
Percival Rd (near Albany Rd)	0.3 m
Railway Av (near Cardigan St)	< 0.1 m
Stanmore Rd (near Merton St)	< 0.1 m
Wilford St (near Gladstone St)	0.1 m
Wilford St (near Station St)	< 0.1 m
Corunna Rd (between Charles St and Cannon Ln)	0.3 m
Margaret St (near Charles St)	< 0.1 m
Phillip St (near Hughes St	< 0.1 m

6.4.2. Comparison with the Dalland & Lucas Report

The ILSAX results (Dalland & Lucas, 1996, 1998 & 1999) for both Johnstons Creek and Whites Creek were compared to the TUFLOW results from the current study for the 1% AEP event, shown in Table 18. The majority of the locations verified were within ± 0.10 m. The locations are shown in Figure 15.

Table 18: Verification Comparison of the 1% AEP event – Dalland and Lucas Report

ID	Location	Dalland & Lucas Report	Current Study	Difference (m)
D01	Federation Rd (near Roberts St	30.60	30.53	-0.08
D02	Mallett St and Tooooths Pl inte	21.51	21.69	0.18
D03	Flower Ln (near Tooths Ln)	19.22	19.27	0.06
D04	Flower St (near Gibbens St)	18.60	18.66	0.06
D05	Australia St (near Derby Pl)	15.93	15.94	0.01
D06	Denison St (near Harden Pl)	14.83	14.80	-0.04
D07	Lennox St (near Mary St)	37.82	37.88	0.06
D08	Eliza St	34.69	35.78	1.09*
D09	Australia St (near Alton Ln)	34.29	34.60	0.31
D10	Weeks Ln (near Alton Ln)	32.32	33.34	1.02*
D11	Denison St (near Melville Ln)	31.66	31.64	-0.02
D12	Bedford St (near Probert St)	29.56	29.47	-0.09
D13	Augustus St	24.17	24.19	0.02
D14	Gladstone St (between Phillip St and Liberty St)	22.39	22.75	0.36
D15	Trafalgar St (between Phillip St and Liberty St)	21.75	22.18	0.43
D16	Railway Av (near Cardigan St)	19.53	19.51	-0.02
D17	Probert St (near Bishopgate Ln)	25.66	25.69	0.03
D18	Marmion St (near Kingston Rd)	18.16	18.45	0.29

D19	Margaret St (near Phillip St)	24.81	24.77	-0.04
D20	Corunna Rd (between Charles St and Cannon St)	26.74	26.81	0.06
D21	Westbourne St (near Charles St)	29.71	29.83	0.11
D22	Budds La (near Bruce Laneway)	37.70	37.62	-0.08

*It was found that at these locations, the flood level (taken from the Dalland and Lucas Report was below the ground elevation (ALS)

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 6 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.

7.2.1. Johnstons Creek

It was found that a combination of the 25 minute, 60 minute and 120 minute design storm durations were critical across the Johnstons Creek study area for the 1% AEP event. The 25 minute design storm duration was mostly critical in areas of shallow overland flow and was therefore disregarded as a critical storm burst. The 60 minute storm duration was found to dominate as the critical duration for overland flow paths including Salisbury Road and Cardigan Street. Other areas with a 60 minute critical duration were identified within the east portion of study area such as Camperdown Park and Australia Street. The open channel of Johnstons Creek beginning from Salisbury Road running parallel to Bridge Road flowing to the downstream boundary was also found to have a 60 minute duration. The 120 minute design storm duration was found to be critical in numerous streets bounded by Salisbury Road, Warrick Street and the Sydney Train Line as well as areas downstream of Parramatta Road. In locations where the 60 minute and 120 minute durations were critical, it was found that peak flood level difference was less than 0.18 m. As a result, it was determined that it was appropriate to adopt the 60 minute design storm duration as the critical duration.

7.2.2. Whites Creek

It was found that a combination of the 20 minute, 25 minute and 60 minute design storm durations were critical across the Whites Creek study area for the 1% AEP event. The 60 minute design storm was identified as critical for the lower portion of the study area, north of Parramatta Road continuing to the downstream boundary. The 25 minute storm duration was identified as the dominating critical burst duration across the catchment; remaining as the critical duration for the flow path beginning at the intersection of Fort Street and Railway Street flowing north to Parramatta Road, then continuing east. However, the 25 minute duration was mostly critical in areas of shallow overland flow and was therefore disregarded as a critical storm burst. For the primary overland flow path beginning at the intersection at Charles Street and Westbourne Street and moving in a north-east direction to Parramatta Road, the 20 minute storm duration produced the largest peak flood depths. It was also found that the peak flood levels identified in the 25 minute critical duration were no greater than 0.07 m compared against the 20 minute storm duration. Therefore, it was deemed appropriate to adopt the 20 minute design storm duration as the critical duration.

7.3. Downstream Boundary Conditions

7.3.1. Johnstons Creek

In addition to runoff from the catchment, downstream areas can also be influenced by high water levels within Rozelle 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. 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 19.

Table 19: 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

7.3.2. Whites Creek

Due to the elevation at the downstream boundary of the Whites Creek catchment, the downstream boundary was not tidal influenced. As such, a constant water level boundary was applied to the 1D and 2D domains, represented as:

- 2D domain: equivalent to the lowest ground elevation across the boundary; and
- 1D domain: elevation of the pipe obverts.

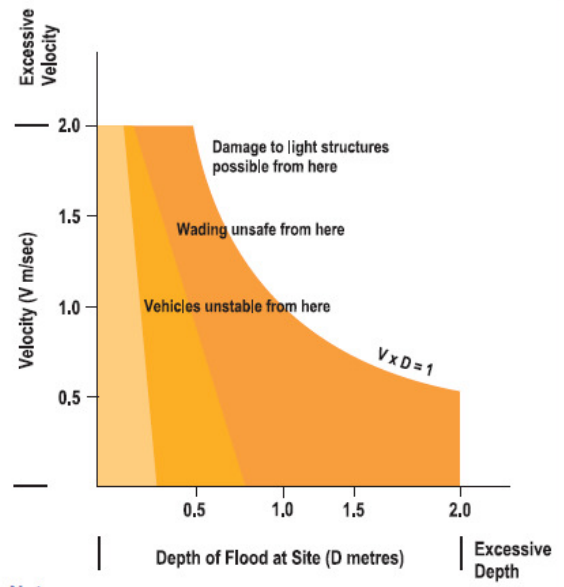
7.4. Analysis

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 Johnstons Creek and Whites Creek catchment are presented in Figure 33 to Figure 36.

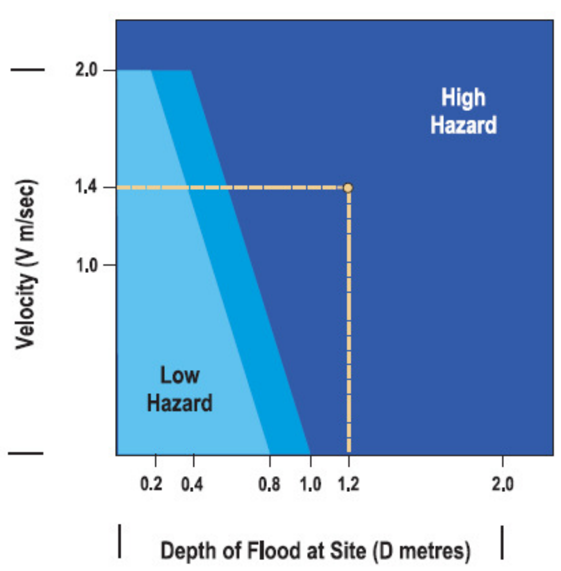
Diagram 3: (L1) Velocity and Depth Relationship; (L2) Provisional Hydraulic Hazard Categories (NSW State Government, 2005)



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 Johnstons Creek and Whites Creek 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 Classifcations (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
H01A	Parramatta Rd (near Bridge Rd)	0.1	0.2	0.2	0.3	0.5	0.7	2.0
H01B	Bridge Rd (near Corunna Rd)	0.2	0.3	0.3	0.6	1.0	1.2	2.6
H01C	Cardigan St (near Cardigan Pl)	0.6	1.2	1.6	2.5	2.8	3.1	4.5
H02	Denison St	0.1	0.4	0.6	0.7	0.8	0.9	1.4
H03	Australia St (near Camperdown Park)	0.2	0.3	0.4	0.6	0.7	0.8	2.7
H04	Fowler St	0.2	0.5	0.5	0.6	0.7	0.7	1.0
H05	Mallett St	0.6	0.8	0.9	1.1	1.1	1.2	1.8
H06	Salisbury Rd (between Bridge Rd and Cardigan St)	0.6	0.9	1.1	1.3	1.4	1.5	2.4
H07	Cardigan St (between Rowley St and Salisbury Rd)	0.1	0.3	0.4	0.5	0.5	0.6	1.2
H08	Cnr of Kingston Rd and Marmion St	0.2	0.4	0.5	0.6	0.6	0.7	1.2
H09A	Probert St (Between Bishopgate Lane and St Marys St)	0.4	0.4	0.5	0.5	0.5	0.6	1.5
H09B	Probert Ln (Between Bishopgate Lane and St Marys St)	0.0	0.1	0.4	0.6	0.7	0.8	1.4
H10	Cnr of Liberty St and Bedford St	0.3	0.4	0.4	0.5	0.6	0.6	1.1
H11	Trafalgar St (near Liberty St)	0.9	1.1	1.2	1.2	1.3	1.4	2.2
H12	Gladstone St (between Liberty St and Phillip St)	0.2	0.3	0.3	0.4	0.5	0.6	1.3
H13	Australia St (between Lennox St and Alton Ln)	0.4	0.7	0.8	0.9	0.9	1.0	1.6
H14	Eliza Street (between Lennox St and King Street)	0.7	0.9	1.0	1.1	1.2	1.2	1.7
H15	Lennox St	0.5	0.6	0.6	0.7	0.7	0.7	0.9
H16	Trafalgar St (near Crammond Park)	0.5	0.7	0.7	0.8	0.8	0.8	1.2
H17	Parramatta Rd (near Phillip St)	0.3	0.4	0.4	0.4	0.5	0.6	1.5

H18	Margaret St (between Phillip St and Cannon Ln)	0.3	0.3	0.4	0.4	0.4	0.5	1.1
H19	Corunna Rd (between Charles St and Cannon Ln)	0.4	0.4	0.4	0.5	0.5	0.5	1.1
H20	Westbourne St (between Charles St and Cannon Ln)	0.2	0.2	0.2	0.3	0.3	0.3	1.0
H21	Parramatta Rd (between Petersham St and Crystal St)	0.3	0.4	0.4	0.5	0.5	0.5	0.9

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
H01A	Parramatta Rd (near Bridge Rd)	12.0	12.1	12.2	12.3	12.5	12.6	14.0
H01B	Bridge Rd (near Corunna Rd)	11.7	11.7	11.8	12.1	12.4	12.6	14.0
H01C	Cardigan St (near Cardigan Pl)	10.2	10.8	11.2	12.1	12.4	12.6	14.0
H02	Denison St	14.1	14.4	14.6	14.7	14.8	14.8	15.3
H03	Australia St (near Camperdown Park)	14.5	14.6	14.7	14.9	15.0	15.1	16.9
H04	Fowler St	18.2	18.4	18.5	18.6	18.6	18.7	19.0
H05	Mallett St	21.1	21.3	21.4	21.5	21.6	21.7	22.3
H06	Salisbury Rd (between Bridge Rd and Cardigan St)	14.0	14.3	14.5	14.6	14.8	14.9	15.8
H07	Cardigan St (between Rowley St and Salisbury Rd)	15.1	15.3	15.3	15.4	15.5	15.5	16.2
H08	Cnr of Kingston Rd and Marmion St	18.0	18.2	18.3	18.3	18.4	18.5	18.9
H09A	Probert St (Between Bishopgate Lane and St Marys St)	25.5	25.6	25.6	25.6	25.7	25.7	26.7
H09B	Probert Ln (Between Bishopgate Lane and St Marys St)	0.0	23.6	23.8	24.0	24.2	24.3	24.9
H10	Cnr of Liberty St and Bedford St	20.8	20.9	21.0	21.1	21.1	21.2	21.7
H11	Trafalgar St (near Liberty St)	21.8	21.9	22.0	22.1	22.1	22.2	23.1
H12	Gladstone St (between Liberty St and Phillip St)	22.4	22.4	22.5	22.6	22.7	22.7	23.5
H13	Australia St (between Lennox St and Alton Ln)	34.3	34.6	34.7	34.8	34.8	34.9	35.6
H14	Eliza Street (between Lennox St and King Street)	35.3	35.5	35.5	35.7	35.7	35.8	36.2
H15	Lennox St	37.6	37.7	37.8	37.8	37.9	37.9	38.1
H16	Trafalgar St (near Crammond Park)	30.4	30.6	30.6	30.7	30.7	30.8	31.1
H17	Parramatta Rd (near Phillip St)	23.0	23.1	23.1	23.1	23.2	23.2	24.1
H18	Margaret St (between Phillip St and Cannon Ln)	24.5	24.6	24.6	24.7	24.7	24.7	25.3
H19	Corunna Rd (between Charles St and Cannon Ln)	26.6	26.7	26.7	26.7	26.8	26.8	27.4
H20	Westbourne St (between Charles St and Cannon Ln)	29.6	29.7	29.7	29.8	29.8	29.8	30.5
H21	Parramatta Rd (between Petersham St and Crystal St)	30.2	30.3	30.3	30.3	30.4	30.4	30.8

7.5.2. Peak Flows

A tabulated summary of peak flows is presented in Table 23. The below locations are shown on Figure 15.

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
Q01A	Parramatta Rd (near Bridge Rd)	4.0	10.9	14.0	25.7	23.8	34.4	207.8
Q01B	Bridge Rd (near Corunna Rd)	0.2	0.7	1.5	2.8	4.9	7.8	74.4
Q02	Denison St	0.0	0.0	0.1	0.8	1.5	2.2	14.4
Q03	Australia St (near Camperdown Park)	0.0	0.0	0.0	0.0	0.0	0.0	7.5
Q04	Fowler St	1.4	2.7	4.1	5.8	7.5	9.3	35.7
Q05	Mallett St	3.5	5.0	5.9	7.2	8.4	9.6	27.5
Q06	Salisbury Rd (between Bridge Rd and Cardigan St)	2.0	4.7	7.7	12.6	17.1	22.0	118.0
Q07	Cardigan St (between Rowley St and Salisbury Rd)	0.8	3.6	6.0	8.2	10.5	12.6	52.1
Q08	Cnr of Kingston Rd and Marmion St	0.0	0.3	0.8	1.5	2.1	2.8	15.6
Q09	Probert St (near Bishopgate Ln)	0.2	0.4	0.6	0.8	1.0	1.5	8.9
Q10	Cnr of Liberty St and Bedford St	1.6	4.2	6.0	8.2	10.3	12.1	41.9
Q11	Cnr of Liberty St and Trafalgar St	1.3	3.5	4.9	6.7	8.3	9.8	35.6
Q12	Gladstone St (between Liberty St and Phillip St)	0.9	2.3	3.2	4.4	5.4	6.5	24.7
Q13	Cnr Australia St and Alton Ln	0.0	0.1	0.5	0.8	1.4	1.9	9.2
Q14	Cnr Eliza St and Alton Ln	0.0	0.4	0.7	1.1	1.6	2.4	7.7
Q15	Lennox St	0.4	0.5	0.6	0.7	0.9	1.0	2.3
Q16	Trafalgar St (near Crammond Park)	1.0	1.4	1.7	2.1	2.4	2.8	7.5
Q17	Parramatta Rd (near Phillip St)	1.4	2.6	3.6	4.8	6.3	7.7	58.2
Q18	Margaret St (near Phillip St)	1.5	2.7	3.4	4.4	5.4	6.3	34.1
Q19	Corunna Rd (between Charles St and Cannon Ln)	0.9	1.9	2.5	3.3	4.1	4.8	28.5
Q20	Westbourne St (near Charles St)	0.0	0.3	0.5	1.0	1.6	2.0	17.4
Q21	Parramatta Rd (near Petersham St)	1.6	2.4	2.9	3.5	4.1	4.6	22.0

7.5.3. Provisional Hydraulic Hazard

In the 20% AEP event, high hazard areas were found along Johnstons Creek; at the junction of Salisbury Road and Stanford Street; along Cardigan Street (between Salisbury Road and Sandbrook Lane), Liberty Street (between Railway Avenue and Trafalgar Street), along Trafalgar Street (immediately adjacent to Liberty Street), along Tooths Place and Tooths Lane.

In the 5% AEP and 1% AEP event, the high hazard areas extend along Salisbury Road (between Stanford Street to Percival Road), along Bridge Road (between Parramatta Road and Salisbury Road), along Australia Street (between Parramatta Road and Derby Street) and Fowler Lane.

In the PMF event, the high hazard areas further extend along Marmion Street, Gladstone Street (between Liberty Street and Phillip Lane), Parramatta Road (between Bridge Street and Church Street), Parramatta Road (between Cannon Street and Petersham Street), Petersham Street (from Parramatta Road to Fort Street), and from the junction of Westbourne Street and Charles Street towards the intersection of Parramatta Road and Phillip Street.

7.5.4. Provisional Hydraulic Categorisation

In the 20% AEP event, Floodway areas were found along Johnstons Creek; along Bridge Road; along Salisbury Road (between Stanford Street and Percival Road); along Cardigan Street (between Salisbury Road and Sandbrook Lane); Liberty Street (from Railway Avenue to Trafalgar Street); and along the Tooth Place, Tooth Lane and Fowlers Lane flow path. Small localised areas of Flood Storage were located adjacent to some of these Floodway areas.

In 5% AEP and 1% AEP event, the Floodway areas extended along Gladstone Avenue (between Phillip Street and Liberty Street); Trafalgar Street (near Stanmore Train Station); along Petersham Street (from Parramatta Road to Fort Street), and from the junction of Westbourne Street and Charles Street towards the intersection of Parramatta Road and Phillip Street.

7.5.5. Flood Emergency Response Classifications

There are some areas of ‘Land Submerged in the PMF (FIS)’, such as along Bridge Street and Cardigan Street (between Parramatta Road and Salisbury Road); along Salisbury Road (between Cardigan Street and Percival Road); around the intersection of Liberty and Bedford Street; between Lennox Street and the railway line; around the intersection of Mallet Street and Salisbury Road; and from the junction of Westbourne Street and Charles Street towards the intersection of Parramatta Road and Phillip Street. ‘Land Elevated in the PMF (FIE)’ were located between Salisbury Road, Cardigan Street and the railway line; and between Gladstone Street and the railway line. Areas immediately adjacent to these FIS and FIE areas were often classified as ‘Roads Rise out of the Floodplain (FER)’. 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 variations in routing;
- Table 26 for variations in pipe blockage; and
- Table 27 for variations in climate change.

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%
H01A	Parramatta Rd (near Bridge Rd)	0.7	0.00	-0.04
H01B	Bridge Rd (near Corunna Rd)	1.2	0.01	-0.02
H01C	Cardigan St (near Cardigan Pl)	3.1	0.01	-0.02
H02	Denison St	0.9	0.01	0.00
H03	Australia St (near Camperdown Park)	0.8	0.02	-0.01
H04	Fowler St	0.7	-0.02	0.02
H05	Mallett St	1.2	0.01	0.00
H06	Salisbury Rd (between Bridge Rd and Cardigan St)	1.5	0.01	-0.01
H07	Cardigan St (between Rowley St	0.6	-0.01	0.01

ID	Location	Peak Flood Depth 1% AEP	Difference with 1% AEP (m)	
			Roughness Decreased by 20%	Roughness Increased by 20%
	and Salisbury Rd)			
H08	Cnr of Kingston Rd and Marmion St	0.7	-0.01	0.01
H09A	Probert St (Between Bishopgate Lane and St Marys St)	0.6	0.02	-0.02
H09B	Probert Ln (Between Bishopgate Lane and St Marys St)	0.8	0.00	0.00
H10	Cnr of Liberty St and Bedford St	0.6	-0.02	0.02
H11	Trafalgar St (near Liberty St)	1.4	-0.02	0.02
H12	Gladstone St (between Liberty St and Phillip St)	0.6	-0.02	0.02
H13	Australia St (between Lennox St and Alton Ln)	1.0	0.00	0.00
H14	Eliza Street (between Lennox St and King Street)	1.2	0.00	0.00
H15	Lennox St	0.7	-0.01	0.01
H16	Trafalgar St (near Crammond Park)	0.8	-0.01	0.02
H17	Parramatta Rd (near Phillip St)	0.6	-0.01	0.00
H18	Margaret St (between Phillip St and Cannon Ln)	0.5	-0.02	0.02
H19	Corunna Rd (between Charles St and Cannon Ln)	0.5	-0.01	0.01

8.3.2. Routing 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 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%
H01A	Parramatta Rd (near Bridge Rd)	0.7	-0.02	0.00
H01B	Bridge Rd (near Corunna Rd)	1.2	0.00	0.00
H01C	Cardigan St (near Cardigan Pl)	3.1	0.00	0.00
H02	Denison St	0.9	0.00	0.00
H03	Australia St (near Camperdown Park)	0.8	0.00	0.00
H04	Fowler St	0.7	0.00	0.00
H05	Mallett St	1.2	0.01	-0.01
H06	Salisbury Rd (between Bridge Rd and Cardigan St)	1.5	0.01	0.00
H07	Cardigan St (between Rowley St and Salisbury Rd)	0.6	0.00	0.00
H08	Cnr of Kingston Rd and Marmion St	0.7	0.00	0.00
H09A	Probert St (Between Bishopgate Lane and St Marys St)	0.6	0.01	0.00
H09B	Probert Ln (Between Bishopgate Lane and St Marys St)	0.8	0.01	-0.01

ID	Location	Peak Flood Depth 1% AEP	Difference with 1% AEP (m)	
			Routing Decreased by 20%	Routing Increased by 20%
H10	Cnr of Liberty St and Bedford St	0.6	0.00	0.00
H11	Trafalgar St (near Liberty St)	1.4	0.00	-0.01
H12	Gladstone St (between Liberty St and Phillip St)	0.6	0.01	-0.01
H13	Australia St (between Lennox St and Alton Ln)	1.0	0.00	0.00
H14	Eliza Street (between Lennox St and King Street)	1.2	0.00	0.00
H15	Lennox St	0.7	0.00	0.00
H16	Trafalgar St (near Crammond Park)	0.8	0.01	0.00
H17	Parramatta Rd (near Phillip St)	0.6	0.01	-0.01
H18	Margaret St (between Phillip St and Cannon Ln)	0.5	0.00	0.00
H19	Corunna Rd (between Charles St and Cannon Ln)	0.5	0.00	0.00

8.3.3. Blockage Variations

Peak flood level results were found to be relatively insensitive to blockage of pipes, with the exclusion of Australia Street (near Camperdown Park) and Probert Street (near Bishopgate Lane). At both of these locations, trapped topographical low points (in heavily urbanised areas) are drained first by the piped stormwater network and when these pipes are at capacity, the flood water accumulates until it reaches the level required to divert along a secondary overland flow path (typically another road that intersects at a perpendicular angle). At these two locations, the secondary overland flow paths are constrained in width, as they are minor laneways in similarly heavily urbanised areas. Therefore, blockage of the piped stormwater network at Australia Street and Probert Street results in increases in peak flood levels.

Table 26: Results of Blockage Analysis – Change in Level

ID	Location	Peak Flood Depth 1% AEP	Difference with 1% AEP (m)	
			Blockage of Pipes by 20%	Blockage of Pipes by 50%
H01A	Parramatta Rd (near Bridge Rd)	0.7	0.02	0.07
H01B	Bridge Rd (near Corunna Rd)	1.2	0.04	0.09
H01C	Cardigan St (near Cardigan Pl)	3.1	0.04	0.09
H02	Denison St	0.9	0.04	0.07
H03	Australia St (near Camperdown Park)	0.8	0.10	0.45
H04	Fowler St	0.7	0.04	0.08
H05	Mallett St	1.2	0.02	0.04
H06	Salisbury Rd (between Bridge Rd and Cardigan St)	1.5	0.01	0.03
H07	Cardigan St (between Rowley St and Salisbury Rd)	0.6	0.02	0.04
H08	Cnr of Kingston Rd and Marmion St	0.7	0.03	0.04
H09A	Probert St (Between Bishopgate Lane and St Marys St)	0.6	0.16	0.62

ID	Location	Peak Flood Depth 1% AEP	Difference with 1% AEP (m)	
			Blockage of Pipes by 20%	Blockage of Pipes by 50%
H09B	Probert Ln (Between Bishopgate Lane and St Marys St)	0.8	0.05	0.14
H10	Cnr of Liberty St and Bedford St	0.6	0.02	0.04
H11	Trafalgar St (near Liberty St)	1.4	0.04	0.10
H12	Gladstone St (between Liberty St and Phillip St)	0.6	0.05	0.11
H13	Australia St (between Lennox St and Alton Ln)	1.0	0.02	0.05
H14	Eliza Street (between Lennox St and King Street)	1.2	0.02	0.04
H15	Lennox St	0.7	0.01	0.02
H16	Trafalgar St (near Crammond Park)	0.8	0.02	0.04
H17	Parramatta Rd (near Phillip St)	0.6	0.02	0.06
H18	Margaret St (between Phillip St and Cannon Ln)	0.5	0.01	0.02
H19	Corunna Rd (between Charles St and Cannon Ln)	0.5	0.01	0.04

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, each incremental 10% increase in rainfall results in an approximately 0.1 m increase in peak flood levels at the more sensitive locations analysed. The 1% AEP event with a rainfall increase of 30% is approximately equivalent to a 0.2% AEP event in present day conditions and an impact on flood levels is not unexpected.

The sea level rise scenarios were found not to have a significant effect on peak flood levels upstream of Parramatta Road, which is the study area boundary.

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
H01A	Parramatta Rd (near Bridge Rd)	0.7	0.12	0.30	0.32	0.01	-0.01
H01B	Bridge Rd (near Corunna Rd)	1.2	0.14	0.26	0.37	0.00	0.00
H01C	Cardigan St (near Cardigan Pl)	3.1	0.14	0.25	0.35	0.00	0.01
H02	Denison St	0.9	0.05	0.09	0.13	0.00	0.00
H03	Australia St (near Camperdown Park)	0.8	0.10	0.20	0.30	0.00	0.00
H04	Fowler St	0.7	0.04	0.08	0.11	0.00	0.00
H05	Mallett St	1.2	0.05	0.10	0.15	0.00	0.00

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
H06	Salisbury Rd (between Bridge Rd and Cardigan St)	1.5	0.08	0.15	0.22	0.00	0.00
H07	Cardigan St (between Rowley St and Salisbury Rd)	0.6	0.04	0.09	0.14	0.00	0.00
H08	Cnr of Kingston Rd and Marmion St	0.7	0.05	0.09	0.12	0.00	0.00
H09A	Probert St (Between Bishopgate Lane and St Marys St)	0.6	0.08	0.19	0.29	0.00	0.00
H09B	Probert Ln (Between Bishopgate Lane and St Marys St)	0.8	0.05	0.08	0.12	0.00	0.00
H10	Cnr of Liberty St and Bedford St	0.6	0.04	0.08	0.11	0.00	0.00
H11	Trafalgar St (near Liberty St)	1.4	0.05	0.12	0.18	0.00	0.00
H12	Gladstone St (between Liberty St and Phillip St)	0.6	0.06	0.12	0.18	0.00	0.00
H13	Australia St (between Lennox St and Alton Ln)	1.0	0.05	0.10	0.14	0.00	0.00
H14	Eliza Street (between Lennox St and King Street)	1.2	0.04	0.09	0.12	0.00	0.00
H15	Lennox St	0.7	0.02	0.04	0.05	0.00	0.00
H16	Trafalgar St (near Crammond Park)	0.8	0.04	0.07	0.10	0.00	0.00
H17	Parramatta Rd (near Phillip St)	0.6	0.07	0.12	0.17	0.00	0.00
H18	Margaret St (between Phillip St and Cannon Ln)	0.5	0.04	0.06	0.09	0.00	0.00
H19	Corunna Rd (between Charles St and Cannon Ln)	0.5	0.04	0.07	0.10	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.

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 finalised FPA intended to be put up to Council for endorsement and inclusion in Councils DCP.

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 – Parramatta Road, Bridge Road and Cardigan Street
- Hotspot 2 – Salisbury Road near Stafford Street, Stanmore
- Hotspot 3 – Salisbury Road
- Hotspot 4 – Mallett Street, Fowler Street and Gibbens Street
- Hotspot 5 – Cardigan Street, between Salisbury Road and Railway Avenue
- Hotspot 6 – Liberty Street, Bedford Street and Railway Avenue
- Hotspot 7 – Lennox Street and Australia Street
- Hotspot 8 – Trafalgar Street near Crammond Park
- Hotspot 9 – Probert St and Probert Ln (near St Marys St)
- Hotspot 10 – Probert St and Probert Ln (near St Marys St)
- Hotspot 11– Australia St and Denison St (near Camperdown Park)
- Hotspot 12 – Parramatta Road near Phillip Street

10.1. Hotspot 1 – Parramatta Rd, Bridge Rd and Cardigan St

Hotspot 1 covers the Parramatta Road, Bridge Road and Cardigan Street area. Figure B 2 shows the 1% AEP peak flood depths and levels and Table 28 shows the results summary at this location.

In this area, the Johnstons Creek open channel runs along the property boundaries between (and parallel to) Bridge Road and Cardigan Street. The open channel becomes a closed culvert system at Parramatta Road until the intersection of Mathieson and Water Street, whereby it resumes its open channel form. The open channels and the majority of the closed culvert system are concrete lined.

Bridge Road has a low point near the junction with Corunna Road, directing flow into the open channel to the east. Similarly, Cardigan Street has a low point near the junction with Cardigan Place, directing flow into the open channel to the west. When the capacity of the open channel is exceeded, both Bridge Road and Cardigan Street back up with flow until the flood levels reach such a height as to overtop Parramatta Road.

Parramatta Road is a state-owned road, and so it is important to note that flood depths exceed 0.3 m in at least the 10% AEP event and greater. Flood depths greater than 0.3 m are currently considered to be the threshold for road accessibility.

Table 28: Hotspot 1 – Results Summary

ID	Location	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Peak Flood Depths (m)								
H01A	Parramatta Rd (near Bridge Rd)	0.1	0.2	0.2	0.3	0.5	0.7	2.0
H01B	Bridge Rd (near Corunna Rd)	0.2	0.3	0.3	0.6	1.0	1.2	2.6
Peak Flood Levels (m AHD)								
H01A	Parramatta Rd (near Bridge Rd)	12.0	12.1	12.2	12.3	12.5	12.6	14.0
H01B	Bridge Rd (near Corunna Rd)	11.7	11.7	11.8	12.1	12.4	12.6	14.0
Peak Flood Flows (m^3/s)								
Q01A	Parramatta Rd (near Bridge Rd)	4.0	10.9	14.0	25.7	23.8	34.4	207.8
Q01B	Bridge Rd (near Corunna Rd)	0.2	0.7	1.5	2.8	4.9	7.8	74.4

10.2. Hotspot 2 – Salisbury Rd near Stafford St

Hotspot 2 is Salisbury Road near Stafford Street, Stanmore. Figure B 3 shows the 1% AEP peak flood depths and levels and Table 29 shows the results summary at this location.

Two overland flow paths converge at this location; originating from along Salisbury Road to the west, and from along Cardigan Street to the south-east. On Salisbury Road, these flows accumulate in the low point between Stafford Street and Stafford Lane due to the impermeable structures either side of the open channel restricting the conveyance into the downstream open channel. A secondary downstream flow path occurs to the west of the open channel when the floodwaters on Salisbury Road accumulate to a level high enough to divert along Bridge Road.

Table 29: Hotspot 2 – Results Summary

ID	Location	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Peak Flood Depths (m)								
H06	Salisbury Rd (between Bridge Rd and Cardigan St)	0.6	0.9	1.1	1.3	1.4	1.5	2.4
Peak Flood Levels (m AHD)								
H06	Salisbury Rd (between Bridge Rd and Cardigan St)	14.0	14.3	14.5	14.6	14.8	14.9	15.8
Peak Flood Flows (m^3/s)								
Q06	Salisbury Rd (between Bridge Rd and Cardigan St)	2.0	4.7	7.7	12.6	17.1	22.0	118.0

10.3. Hotspot 3 – Salisbury Rd

Hotspot 3 is Salisbury Road. Figure B 4 shows the 1% AEP peak flood depths and levels at this location.

Two 1.05 m x 0.85 m rectangular culverts convey flow from the south-west portion of the catchment along Salisbury Road towards the open channel. An extensive pit network along

Salisbury Road as well as an extensive pipe network feeding into the two culverts results in both culverts reaching capacity towards the northern portion of the road during the 50% AEP event.

When the capacity of the culverts is exceeded, overland flow occurs along Salisbury Road. Additional flow enters Salisbury Road from overland sources including:

- Myrtle Street: Flow bifurcates at the intersection of Myrtle Street and Percival Lane, where water continues along these streets until the depth of water exceeds the kerbs, ingressing properties and continuing towards Salisbury Road.
- Myrtle Lane: An overland flow path originating from Albany Road flows in a south-east direction perpendicular to the road alignment. At Myrtle Lane, the depth of water exceeds the kerbs and flows through properties towards Salisbury Road.
- Durnham Street: Properties located along the south side of the Durnham Street and Salisbury Road intersection are impacted when floodwaters travelling north-east along Salisbury Road and north along Durnham Street converge.

Table 30: Hotspot 3 – Results Summary

ID	Location	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Peak Flood Flows (m^3/s)								
Q22	Salisbury Rd (between Myrtle St and Myrtle Ln)	2.5	4.1	5.2	6.6	7.9	9.1	42.6
Q23	Salisbury Rd (west of Bridge Rd)	3.6	6.4	8.3	11.0	13.6	15.9	62.0

Salisbury Road has a slope of approximately 1.6% that is less inclined than other parts of the catchment.

10.4. Hotspot 4 – Mallett St, Fowler St and Gibbens St

Hotspot 4 covers the area from the junction of Salisbury Road and Mallett Street to the junction of Fowler Street and Gibbens Street. Figure B 5 shows the 1% AEP peak flood depths and levels and Table 31 shows the results summary at this location.

Rainfall runoff arrives at a low point in Mallett Street from the south and south-east with a contributing catchment area of approximately 20.7 ha. At this location, the properties on the downstream side (eastern side) of Mallett Street have large building extents that restrict the ability of overland flow to continue in its natural course. Instead, overland flow is conveyed downstream via Tooths Place and Tooth Lane; and then via properties along Fowler Lane and Fowler Street.

A localised low point along Fowler Street is exacerbated by the elevated ground levels of Camperdown Park (directly downstream), thereby resulting in Fowler Street acting as an informal detention basin. As flood levels increase, flow drains around either side of oval within Camperdown Park and continues downstream.

An extensive pit and pipe network exist in the vicinity. A 1.35 m circular culvert and a 1.05 m by

0.675 m rectangular culvert convey flow downstream from the localised low point, however these reach capacity during the 50% AEP and 5% AEP event respectively.

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)								
H04	Fowler St	0.2	0.5	0.5	0.6	0.7	0.7	1.0
H05	Mallett St	0.6	0.8	0.9	1.1	1.1	1.2	1.8
Peak Flood Levels (m AHD)								
H04	Fowler St	18.2	18.4	18.5	18.6	18.6	18.7	18.2
H05	Mallett St	21.1	21.3	21.4	21.5	21.6	21.7	21.1
Peak Flood Flows (m^3/s)								
Q04	Fowler St	1.4	2.7	4.1	5.8	7.5	9.3	35.7
Q05	Mallett St	3.5	5.0	5.9	7.2	8.4	9.6	27.5

10.5. Hotspot 5 – Cardigan St, between Salisbury Rd and Railway Ave

Hotspot 5 is Cardigan Street, between Salisbury Road and Railway Avenue. Figure B 6 shows the 1% AEP peak flood depths and levels and Table 32 shows the results summary at this location.

Overland flow originates from the southern portion of the catchment and is conveyed along Cardigan Street before converging with overland flow from the east between Salisbury Road and Rowley Street. Downstream of this confluence, overland flow occurs through properties in a north-westerly direction towards Salisbury Road and the open channel.

Table 32: Hotspot 5 – Results Summary

ID	Location	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Peak Flood Depths (m)								
H07	Cardigan St (between Rowley St and Salisbury Rd)	0.1	0.3	0.4	0.5	0.5	0.6	1.2
Peak Flood Levels (m AHD)								
H07	Cardigan St (between Rowley St and Salisbury Rd)	15.1	15.3	15.3	15.4	15.5	15.5	16.2
Peak Flood Flows (m^3/s)								
Q07	Cardigan St (between Rowley St and Salisbury Rd)	0.8	3.6	6.0	8.2	10.5	12.6	52.1

10.6. Hotspot 6 – Liberty St, Bedford St and Railway Ave

Hotspot 6 covers the area around Liberty Street, Bedford Street and Railway Avenue. Figure B 7 shows the 1% AEP peak flood depths and levels and Table 33 shows the results summary at this location.

Flow from the southern portion of the catchment is conveyed through pipes and overland to Gladstone Street and Trafalgar Street (between Liberty Street and Phillip Street); both of which have topographical depressions and downstream obstructions to flow that result in relatively high ponding depths. When the flood depth on Trafalgar Street reaches a level that exceeds the ground level along Liberty Street, flow from this area is then conveyed along Liberty Street.

Liberty Street cuts through the railway embankment and intersects Bedford Street and Railway Avenue to the north. The Liberty Street and Bedford Street intersection is a topographical depression with a large building extent obstructing overland flow leaving this area. The Liberty Street and Railway Avenue intersection is then the primary overland flow path leaving this area.

Table 33: Hotspot 6 – Results Summary

ID	Location	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Peak Flood Depths (m)								
H10	Cnr of Liberty St and Bedford St	0.3	0.4	0.4	0.5	0.6	0.6	1.1
H11	Trafalgar St (near Liberty St)	0.9	1.1	1.2	1.2	1.3	1.4	2.2
H12	Gladstone St (between Liberty St and Phillip St)	0.2	0.3	0.3	0.4	0.5	0.6	1.3
Peak Flood Levels (m AHD)								
H10	Cnr of Liberty St and Bedford St	20.8	20.9	21.0	21.1	21.1	21.2	21.7
H11	Trafalgar St (near Liberty St)	21.8	21.9	22.0	22.1	22.1	22.2	23.1
H12	Gladstone St (between Liberty St and Phillip St)	22.4	22.4	22.5	22.6	22.7	22.7	23.5
Peak Flood Flows (m^3/s)								
Q10	Cnr of Liberty St and Bedford St	1.6	4.2	6.0	8.2	10.3	12.1	41.9
Q11	Cnr of Liberty St and Trafalgar St	1.3	3.5	4.9	6.7	8.3	9.8	35.6
Q12	Gladstone St (between Liberty St and Phillip St)	0.9	2.3	3.2	4.4	5.4	6.5	24.7

10.7. Hotspot 7 – Lennox St and Australia St

Hotspot 7 extends from Lennox Street (near Mary Street) to Australia Street (between Lennox Street and Alton Lane). Figure B 8 shows the 1% AEP peak flood depths and levels and Table 34 shows the results summary at this location.

Along Lennox Street, a topographical low point is exacerbated by the continuous building extent to the south of the roadway that restricts flow from draining away from the area, as well as the higher ground levels (supported by a retaining wall) within Camperdown Memorial Park restricting flow from back-flowing into this area. A drainage reserve, approximately 0.9 m wide is located between 56 and 58 Lennox Street. As such, rainfall that runs off into Lennox Street accumulates until the flood level reaches the height necessary to either:

- divert along Mary Street to the north-east

- flow through the drainage reserve between 56 and 58 Lennox Street.
- divert along Eliza Street to the south-west.

Downstream of Lennox Street, along Eliza Street and along Australia Street (between Lennox Street and Alton Lane) the topographical low points and continuous building extents result in floodwaters accumulating along the roadways until flow can diverge along the Alton Lane side-street.

Table 34: Hotspot 7 – Results Summary

ID	Location	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Peak Flood Depths (m)								
H13	Australia St (between Lennox St and Alton Ln)	0.4	0.7	0.8	0.9	0.9	1.0	1.6
H14	Eliza Street (between Lennox St and King Street)	0.7	0.9	1.0	1.1	1.2	1.2	1.7
H15	Lennox St	0.5	0.6	0.6	0.7	0.7	0.7	0.9
Peak Flood Levels (m AHD)								
H13	Australia St (between Lennox St and Alton Ln)	34.3	34.6	34.7	34.8	34.8	34.9	35.6
H14	Eliza Street (between Lennox St and King Street)	35.3	35.5	35.5	35.7	35.7	35.8	36.2
H15	Lennox St	37.6	37.7	37.8	37.8	37.9	37.9	38.1
Peak Flood Flows (m^3/s)								
Q13	Cnr Australia St and Alton Ln	0.0	0.1	0.5	0.8	1.4	1.9	9.2
Q14	Cnr Eliza St and Alton Ln	0.0	0.4	0.7	1.1	1.6	2.4	7.7
Q15	Lennox St	0.4	0.5	0.6	0.7	0.9	1.0	2.3

10.8. Hotspot 8 – Trafalgar St near Crammond Park

Hotspot 8 is Trafalgar Street near Crammond Park and Aubrey Street. Figure B 9 shows the 1% AEP peak flood depths and levels and Table 35 shows the results summary at this location.

There is a localised low point on Trafalgar Street, which is located to the south and upstream of the railway line. Portions of the railway track have a higher elevation than the roadway thereby aggravating the low point. A 1.2 m x 1.05 m rectangular culvert drains water north beneath the railway. This culvert reaches capacity during the 50% AEP event where water ponds until it reaches it overflows the rail embankment.

Table 35: Hotspot 8 – Results Summary

ID	Location	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Peak Flood Depths (m)								
H16	Trafalgar St (near Crammond Park)	0.5	0.7	0.7	0.8	0.8	0.8	1.2
Peak Flood Levels (m AHD)								
H16	Trafalgar St (near Crammond Park)	30.4	30.6	30.6	30.7	30.7	30.8	31.1
Peak Flood Flows (m^3/s)								
Q16	Trafalgar St (near Aubrey St)	1.0	1.4	1.7	2.1	2.4	2.8	7.5

10.9. Hotspot 9 – Probert St and Probert Ln (near St Marys St)

Hotspot 9 extends from Lands Lane to St Marys Street via Probert Street and Probert Lane. Figure B 10 shows the 1% AEP peak flood depths and levels and Table 36 shows the results summary at this location.

Overland flow arrives at a topographical low point in Probert Street (between Bishopgate Lane and St Marys Street) that is exacerbated by the continuous building extent to the south-west of the roadway that restricts flow from draining away from the area. As such, rainfall that runs off into Probert Street accumulates until the flood level reaches the height necessary to divert along Bishopgate Lane and Probert Lane. Further overland flow arrives at Probert Lane via Chelmsford Street and Bishopgate Lane. At Probert Lane, a topographical low point combined with a continuous building extent along Probert Lane results in accumulation of flood waters until water is able to drain towards St Marys Street.

Table 36: Hotspot 9 – Results Summary

ID	Location	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Peak Flood Depths (m)								
H09A	Probert St (Between Bishopgate Ln and St Marys St)	0.3	0.4	0.4	0.4	0.5	0.6	1.5
H09B	Probert Ln (Between Bishopgate Ln and St Marys St)	0.3	0.3	0.4	0.4	0.4	0.5	1.1
Peak Flood Levels (m AHD)								
H09A	Probert St (Between Bishopgate Ln and St Marys St)	23.0	23.1	23.1	23.1	23.2	23.2	24.1
H09B	Probert Ln (Between Bishopgate Ln and St Marys St)	24.5	24.6	24.6	24.7	24.7	24.7	25.3
Peak Flood Flows (m^3/s)								
Q09A	Probert Lane (near St Marys St)	1.0	1.4	1.6	1.8	2.1	2.3	6.0
Q09B	Bishopgate Lane (between Probert St and Probert Ln)	0.0	0.0	0.0	0.0	0.0	0.0	4.1

10.10. Hotspot 10 – Australia St and Denison St (near Camperdown Park)

Hotspot 10 covers Australia Street and Denison Street, between Derby Street and Parramatta Road. Figure B 11 shows the 1% AEP peak flood depths and levels and Table 37 shows the results summary at this location.

On Australia Street, there is a localised low point that is exacerbated by the contiguous building extent to the west of the roadway. Flow arrives at this low point on Australia Street from Camperdown Park (to the south-east), Australia Street (to the south), Derby Place and Derby Street (to the south-west). The primary form of drainage from this area is a 0.75 m diameter stormwater pipe from the roadway that drains into a 1.2 m diameter stormwater pipe through 27 - 33 Australia Street; however the 0.75 m diameter pipe reaches capacity in the 50% AEP event. In events where the stormwater pipes are operating at capacity, floodwaters accumulate along Australia Street until the secondary form of drainage is activated. This secondary form of drainage occurs via overland flow pipes through 11-17 Australia Street that discharge onto the Denison Street roadway; with a height of 0.45 m and a collective width of 20 m. The capacity of the southern set of overland flow pipes is reached in the 10% AEP event, whereas the northern set of overland flow pipes is exceeded in the PMF event. In the PMF event, a tertiary form of drainage occurs overland via pedestrian walkway between the buildings on 1-7 and 11-17 Australia Street, as well as overtopping the crest on Australia Street that in smaller events prevents flow from travelling north to Parramatta Road.

On Denison Street, there is a localised low point just north of the intersection with Hordern Place. At this location, a building to the west and increases in ground elevations to the west and north restrict flow from exiting this area. In small events (such as the 20% AEP and smaller), flow mostly arrives at this location via local drainage from the properties adjoining the roadway. However in events greater than the 10% / 20% AEP event, this local drainage is increased by upstream flow via the overland flow pipes from Australia Street. Two stormwater pipes are the primary form of drainage from the Denison Street low point; a 1.2 m diameter pipe and a 1.5 m diameter pipe that reach capacity in a 5% AEP event and 50% AEP event, respectively. In the 10% AEP event and greater, a secondary form of drainage occurs when the higher ground elevations to the west are overtopped. In the PMF event, a tertiary form of drainage occurs via the overtopping of the crest on Denison Street that in smaller events prevents flow from travelling north to Parramatta Road.

Table 37: Hotspot 10 – Results Summary

ID	Location	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Peak Flood Depths (m)								
H002	Denison St	0.1	0.4	0.6	0.7	0.8	0.9	1.4
H003	Australia St (near Camperdown Park)	0.2	0.3	0.4	0.6	0.7	0.8	2.7
Peak Flood Levels (m AHD)								
H002	Denison St	14.1	14.4	14.6	14.7	14.8	14.8	15.3
H003	Australia St (near Camperdown	14.5	14.6	14.7	14.9	15.0	15.1	16.9

	Park)							

10.11. Hotspot 11– Albany Road to Parramatta Rd near Phillip St

Hotspot 12 is a primary overland flow path originating at Albany Road, which follows the topography north-east towards Parramatta Road, to the east of Phillip Street. Figure B 12 shows the 1% AEP peak flood depths and levels and Table 38 shows the results summary at this location.

The overland flow-path from Albany Road through to Margaret Street is primarily orientated perpendicular to the roadway alignment. Consequently, overland flow accumulates in topographical low points in Westbourne Street, Corunna Road and Margaret Street where flow ingresses properties to the north once flood levels exceed the kerbs.

At Margaret Street, flow traverses north through property and continues north where an under floor flowpath under 370 Parramatta Road (AMR Motors) facilitates the conveyance of water towards Parramatta Road. In the 1% AEP event, the underfloor flowpath reaches capacity forcing water to diverted along either side of 370 Parramatta Road (AMR Motors) and continue north towards Parramatta Road.

At this location, overland flow arrives at Parramatta Road from the south and accumulates in the topographical low point where flow is restricted from exiting due to the continuous building frontages to the north of Parramatta Road.

A relatively small gap between the buildings serves as an overland flow path in the first instance, with a secondary overland flow path occurring along Catherine Street when floodwater accumulates to a level high enough to result in this flow diversion.

Table 38: Hotspot 11 – Results Summary

ID	Location	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
Peak Flood Depths (m)								
H17	Parramatta Rd (near Phillip St)	0.3	0.4	0.4	0.4	0.5	0.6	1.5
H18	Margaret St (near Phillip St)	0.3	0.3	0.4	0.4	0.4	0.5	1.1
H19	Corunna Rd	0.4	0.4	0.4	0.5	0.5	0.5	1.1
H20	Westbourne St	0.2	0.2	0.2	0.3	0.3	0.3	1.0
Peak Flood Levels (m AHD)								
H17	Parramatta Rd (near Phillip St)	23.0	23.1	23.1	23.1	23.2	23.2	24.1
H18	Margaret St (near Phillip St)	24.5	24.6	24.6	24.7	24.7	24.7	25.3
H19	Corunna Rd	26.6	26.7	26.7	26.7	26.8	26.8	27.4
H20	Westbourne St	29.6	29.7	29.7	29.8	29.8	29.8	30.5
Peak Flood Flows (m^3/s)								
Q17	Parramatta Rd (near Phillip St)	1.4	2.6	3.6	4.8	6.3	7.7	58.2

Q18	Margaret St (near Phillip St)	1.5	2.7	3.4	4.4	5.4	6.3	34.1
Q19	Corunna Road	0.9	1.9	2.5	3.3	4.1	4.8	28.5
Q20	Westbourne St	0.0	0.3	0.5	1.0	1.6	2.0	17.4

Parramatta Road is a state-owned road, and so it is important to note that flood depths exceed 0.3 m in events as small as the 50% AEP event. Flood depths greater than 0.3 m are currently considered to be the threshold for road accessibility.

11. 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 Johnstons Creek and Whites Creek Catchment. This study was jointly funded by the former Marrickville Council and the NSW Government.

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    January 1997

15. Willing & Partners

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Figures

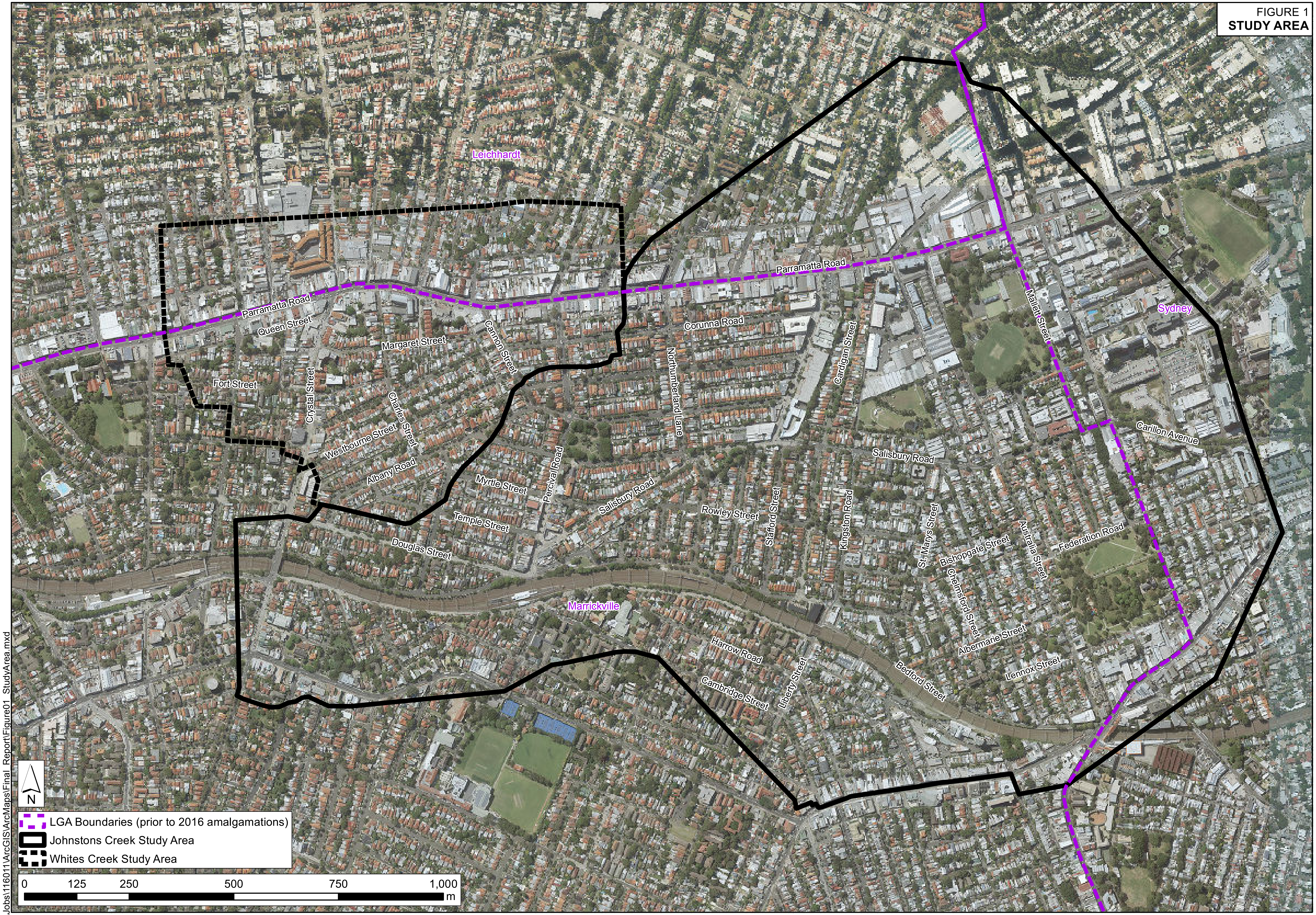

FIGURE 1
STUDY AREA

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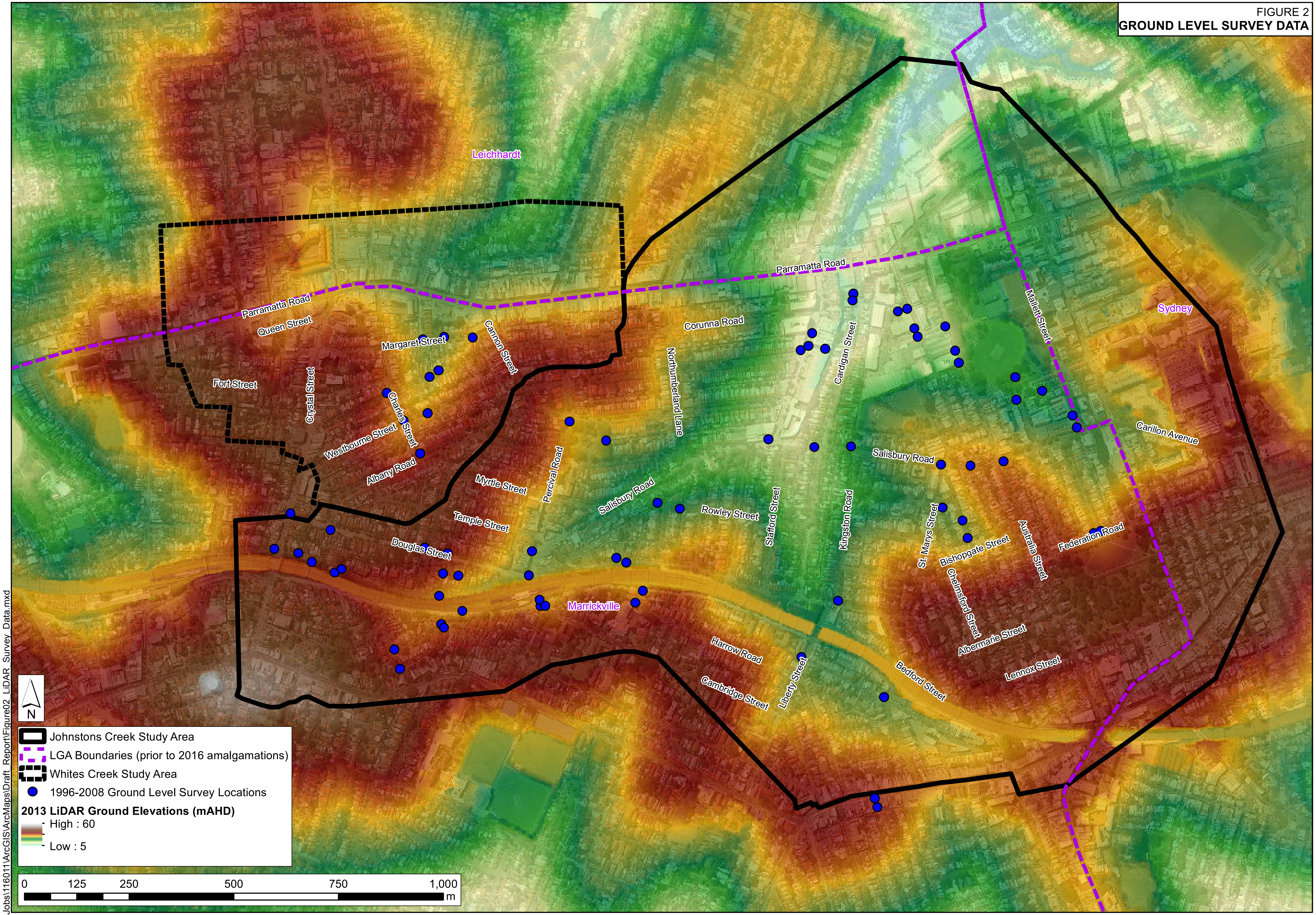
FIGURE 2
GROUND LEVEL SURVEY DATA



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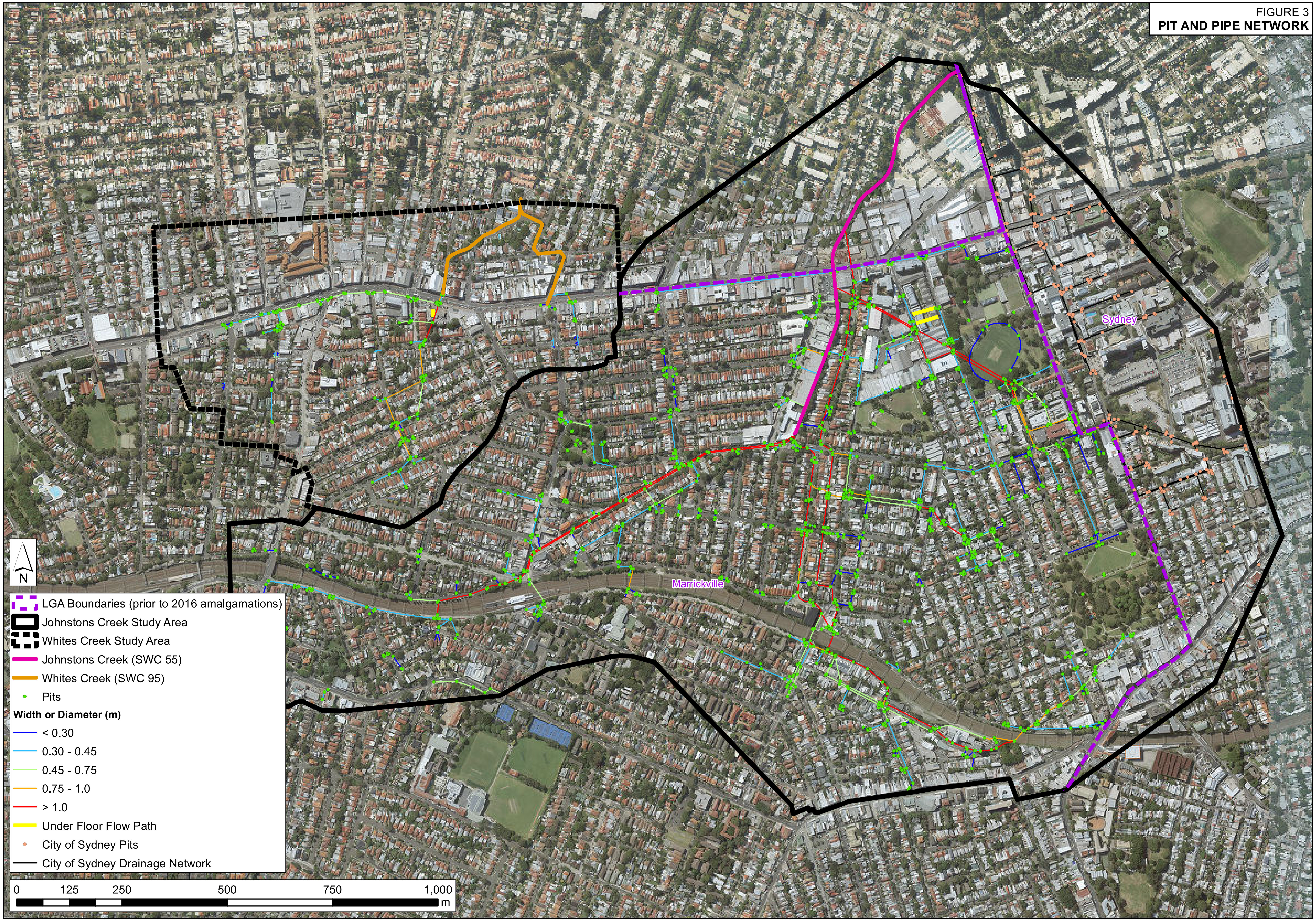


FIGURE 3
PIT AND PIPE NETWORK
Sydney
Marrickville
N
LGA Boundaries (prior to 2016 amalgamations)
Johnstons Creek Study Area
Whites Creek Study Area
Johnstons Creek (SWC 55)
Whites Creek (SWC 95)
Pits
Width or Diameter (m)
< 0.30
0.30 - 0.45
0.45 - 0.75
0.75 - 1.0
> 1.0
Under Floor Flow Path
City of Sydney Pits
City of Sydney Drainage Network
0 125 250 500 750 1,000 m
J:\Jobs\116011\ArcGIS\ArcMaps\Final_Report\Figure03_Pipe_Network.mxd

FIGURE 4
SITE VISIT PHOTOGRAPHS

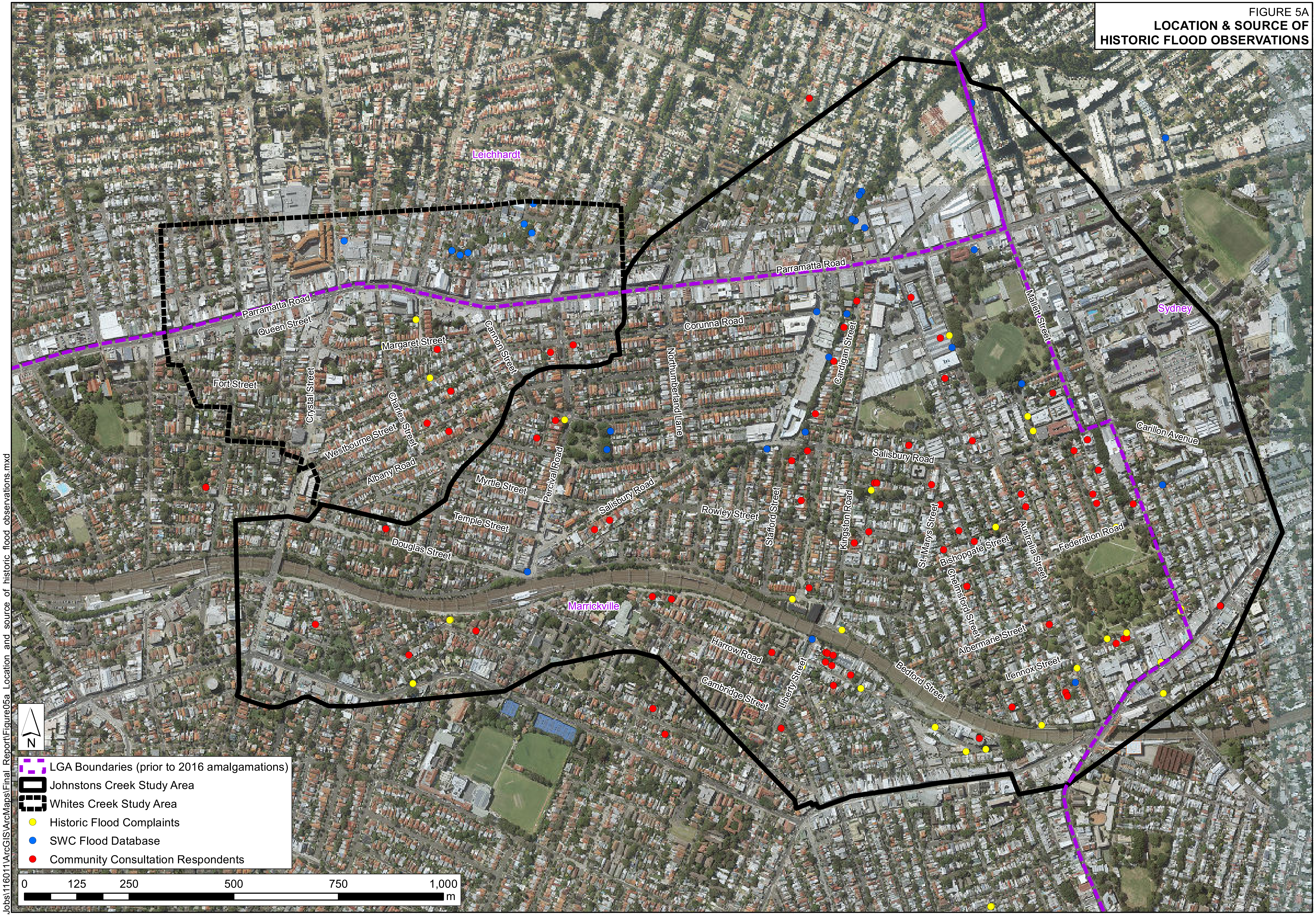
Above: Johnstons Creek downstream of Booth Street

Above: Johnstons Creek upstream of Parramatta Road

Above: Johnstons Creek upstream of the Cruikshank Street Pedestrian Bridge

Above: Johnstons Creek downstream of Salisbury Road

FIGURE 5A
LOCATION & SOURCE OF HISTORIC FLOOD OBSERVATIONS



J:\Jobs\116011\ArcGIS\ArcMaps\Final Report\Figure05a Location and source of historic flood observations.mxd

FIGURE 5B
HISTORIC FLOOD OBSERVATIONS

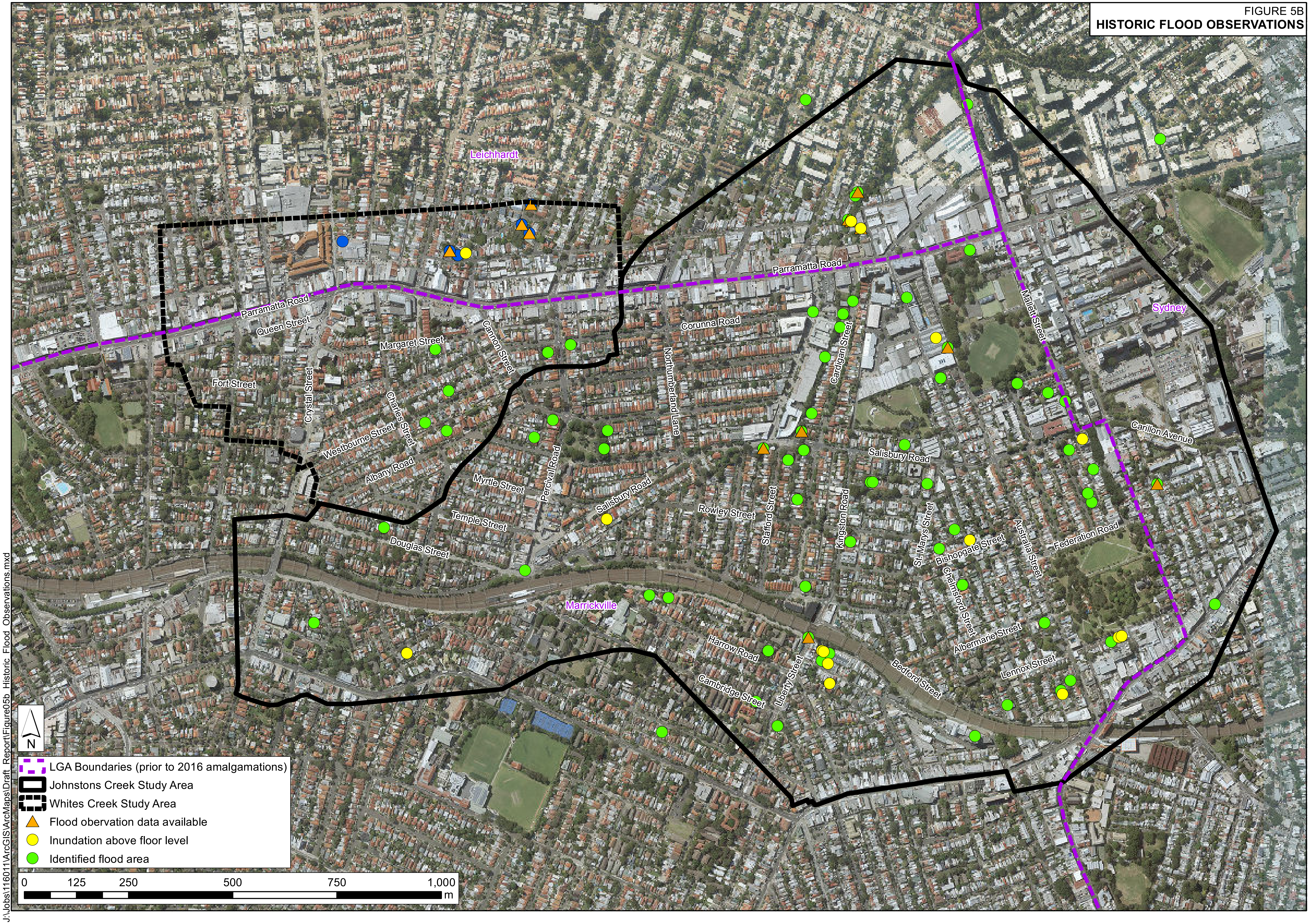
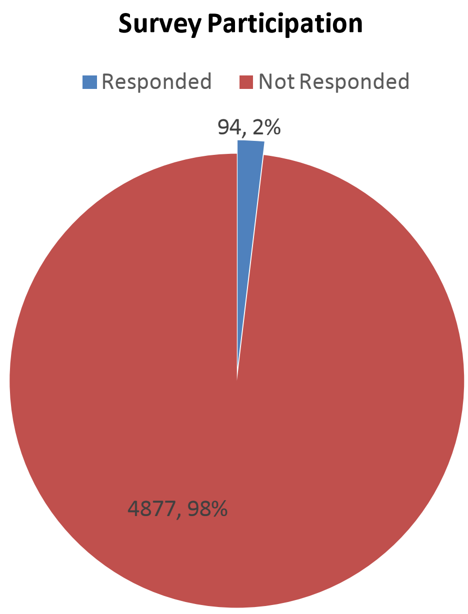
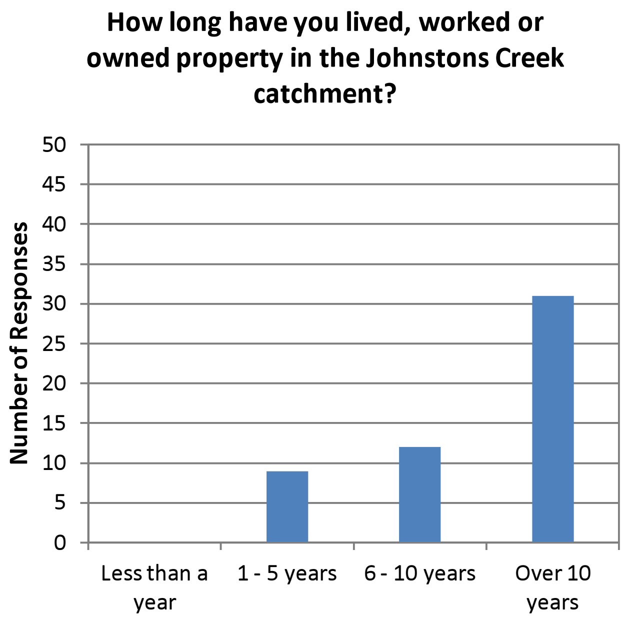
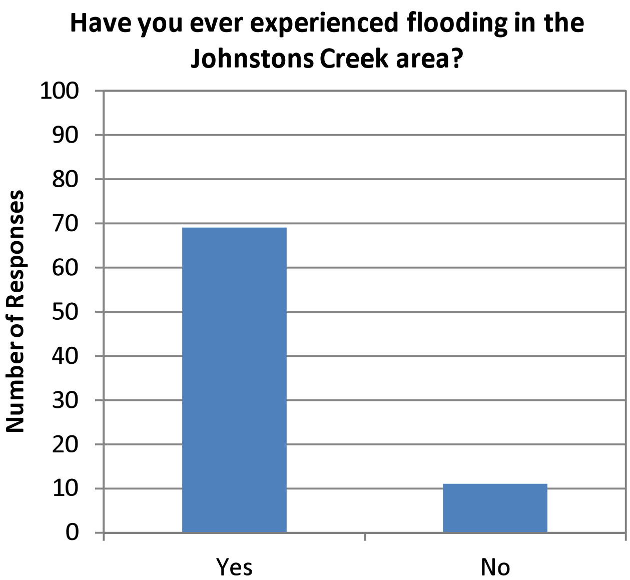
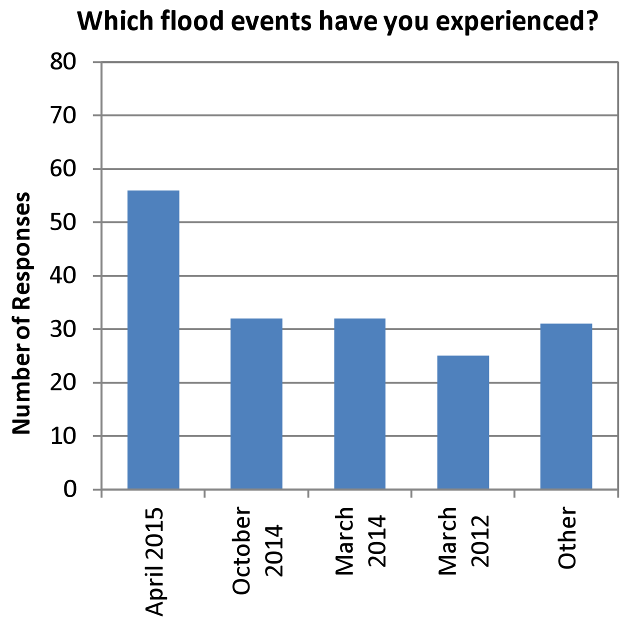


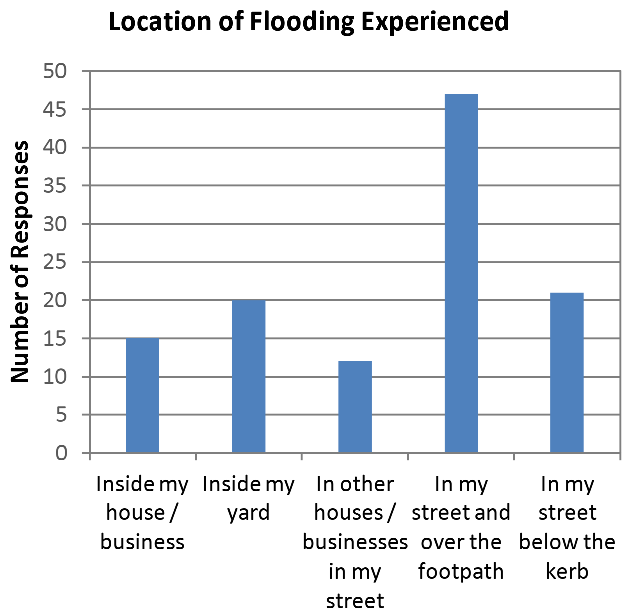
FIGURE 6
COMMUNITY CONSULTATION RESULTS

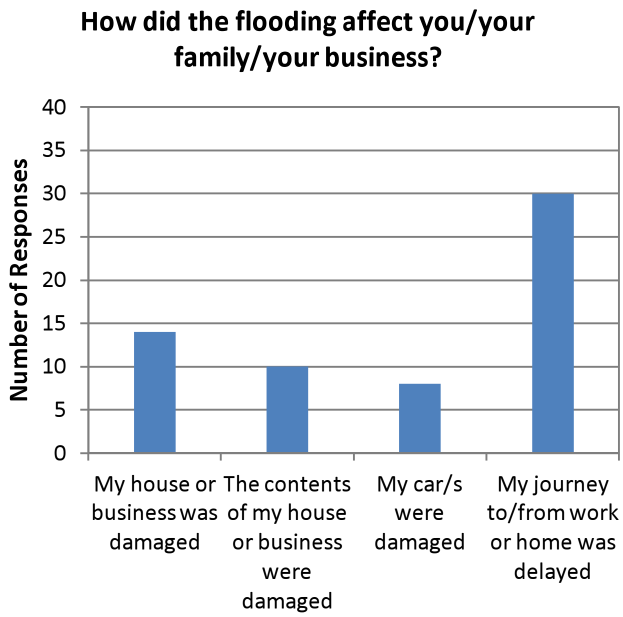












J:\Jobs\116011\Community_Consultation\Johnstons_Flood_Study_Questionnaire_Results.xlsx

FIGURE 7
RAINFALL GAUGE LOCATIONS

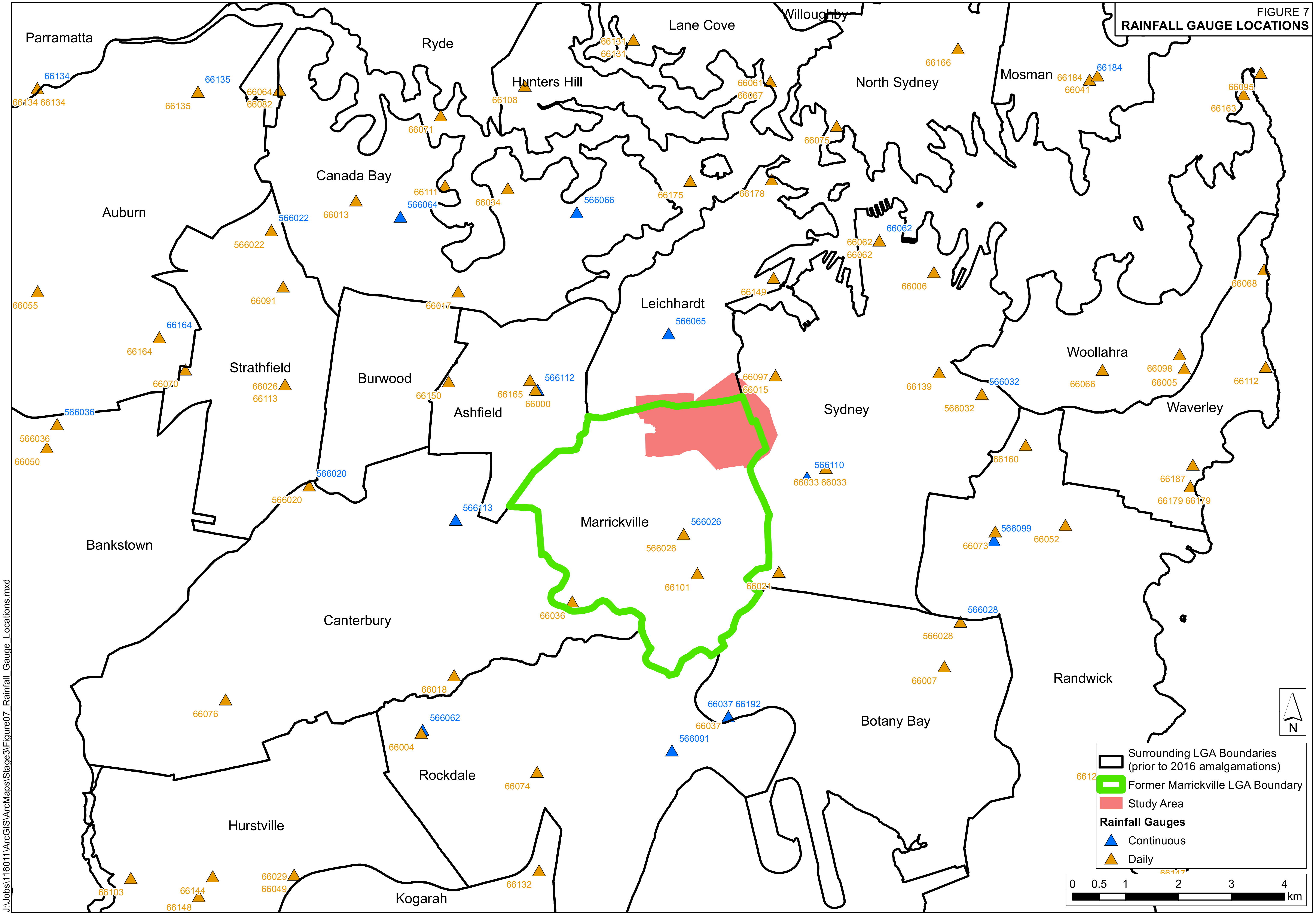
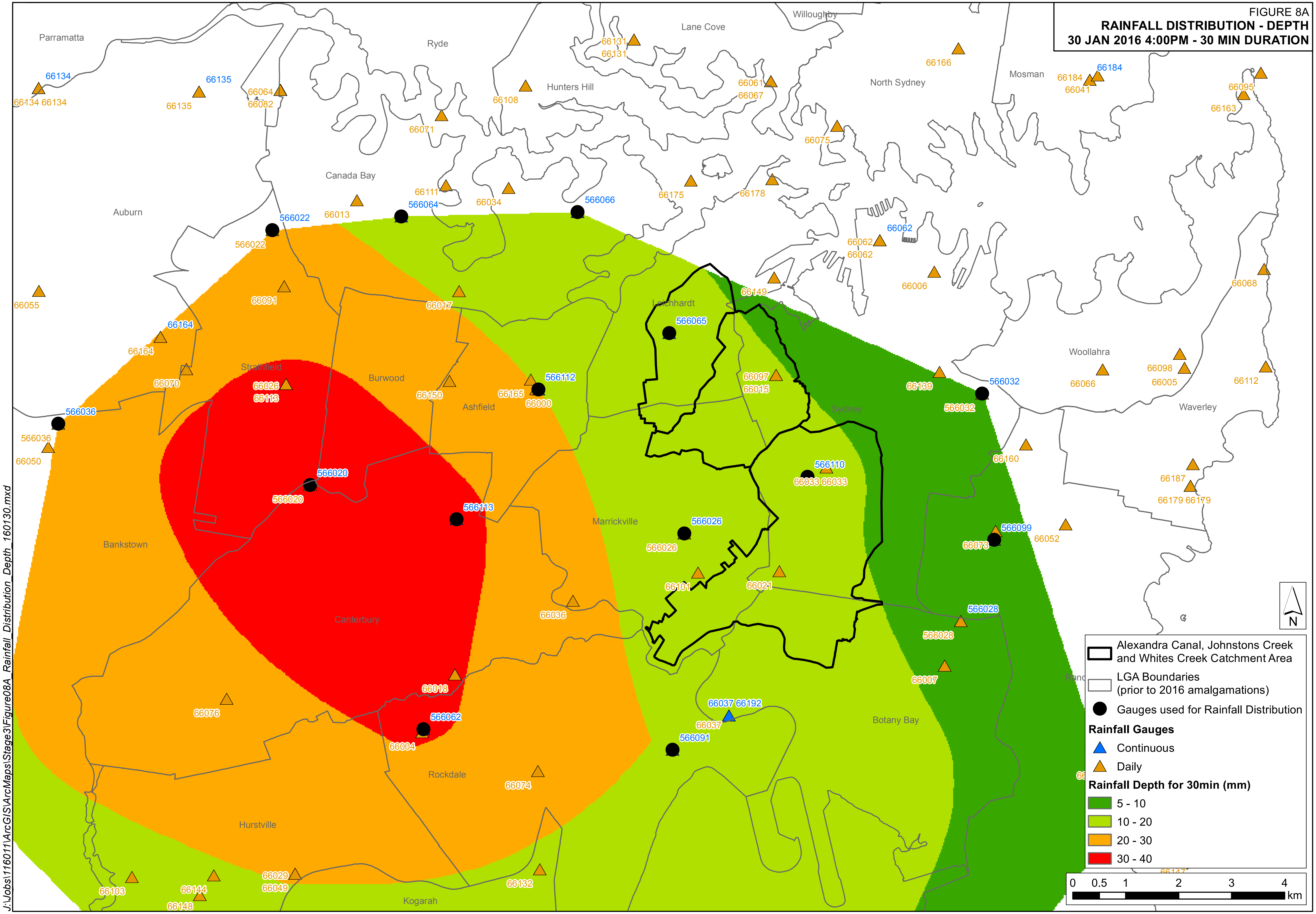


FIGURE 8A
RAINFALL DISTRIBUTION - DEPTH
30 JAN 2016 4:00PM - 30 MIN DURATION



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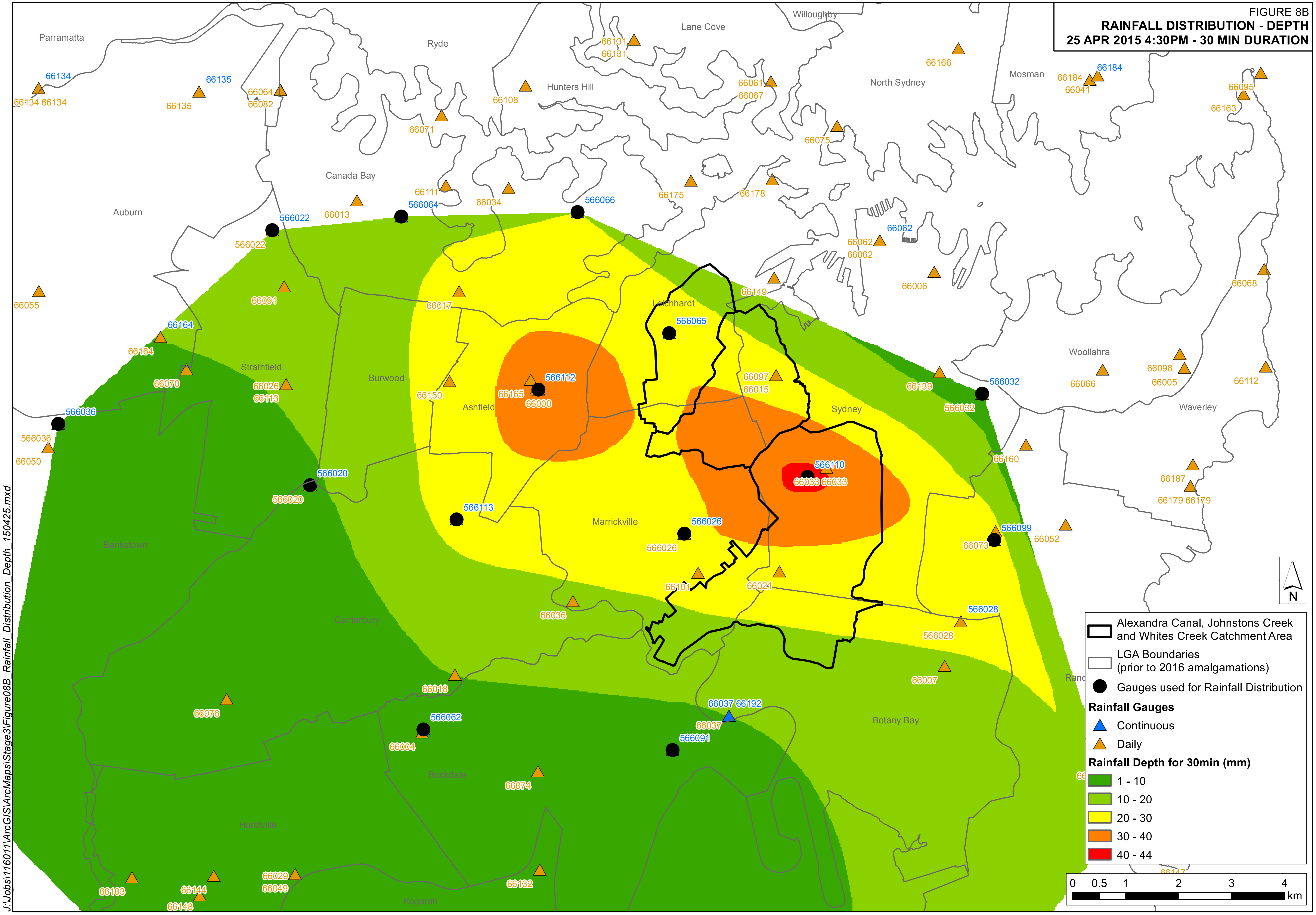

FIGURE 8B
RAINFALL DISTRIBUTION - DEPTH
25 APR 2015 4:30PM - 30 MIN DURATION
Alexandra Canal, Johnstons Creek and Whites Creek Catchment Area
LGA Boundaries (prior to 2016 amalgamations)
Gauges used for Rainfall Distribution
Rainfall Gauges
Continuous
Daily
Rainfall Depth for 30min (mm)
1 - 10
10 - 20
20 - 30
30 - 40
40 - 44
0 0.5 1 2 3 4 km
N
Parramatta
Ryde
Lane Cove
Willoughby
Hunters Hill
North Sydney
Mosman
Canada Bay
Auburn
Leichhardt
Strathfield
Burwood
Ashfield
Marrickville
Sydney
Woollahra
Waverley
Bankstown
Canterbury
Rockdale
Hurstville
Kogarah
Botany Bay
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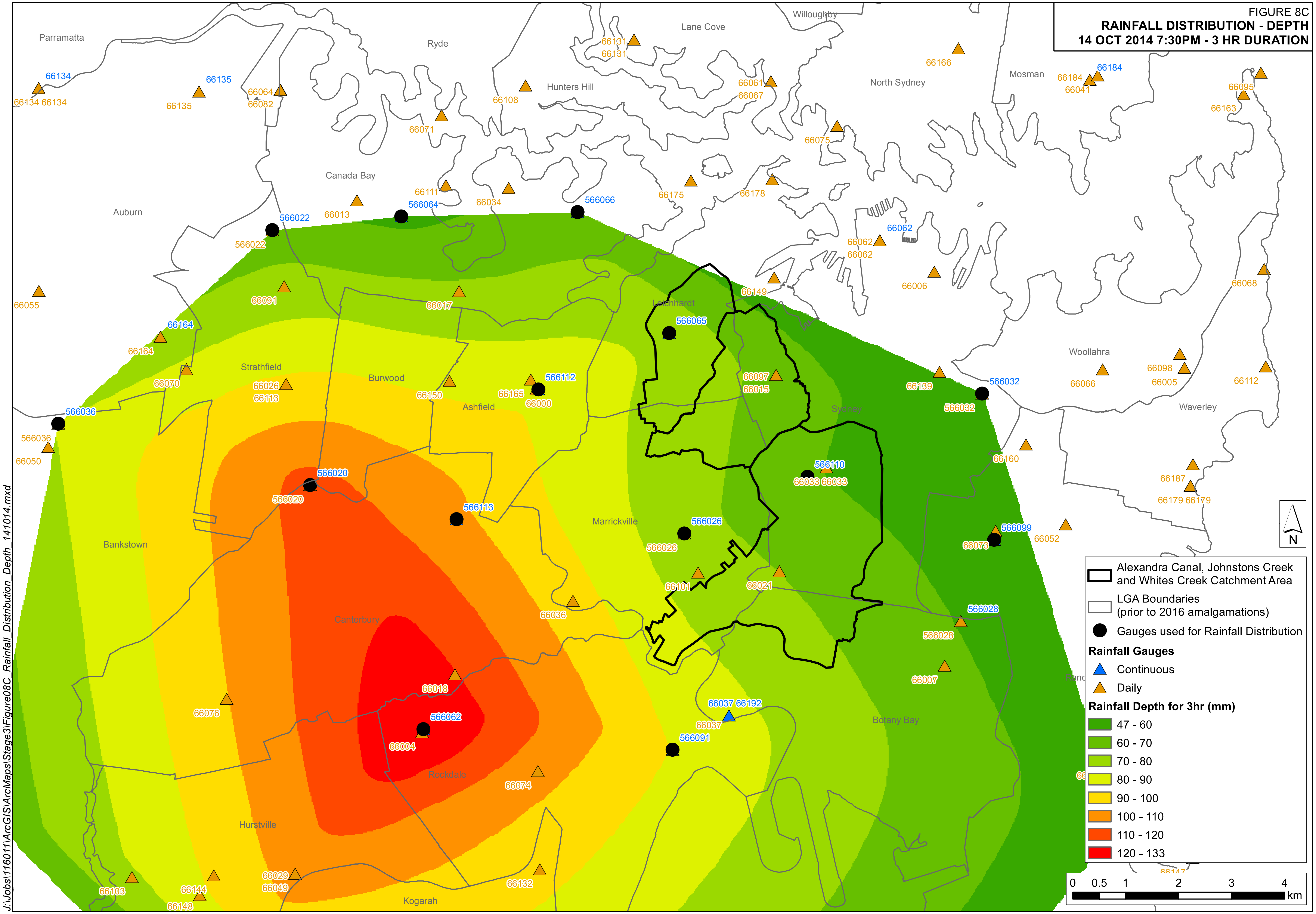

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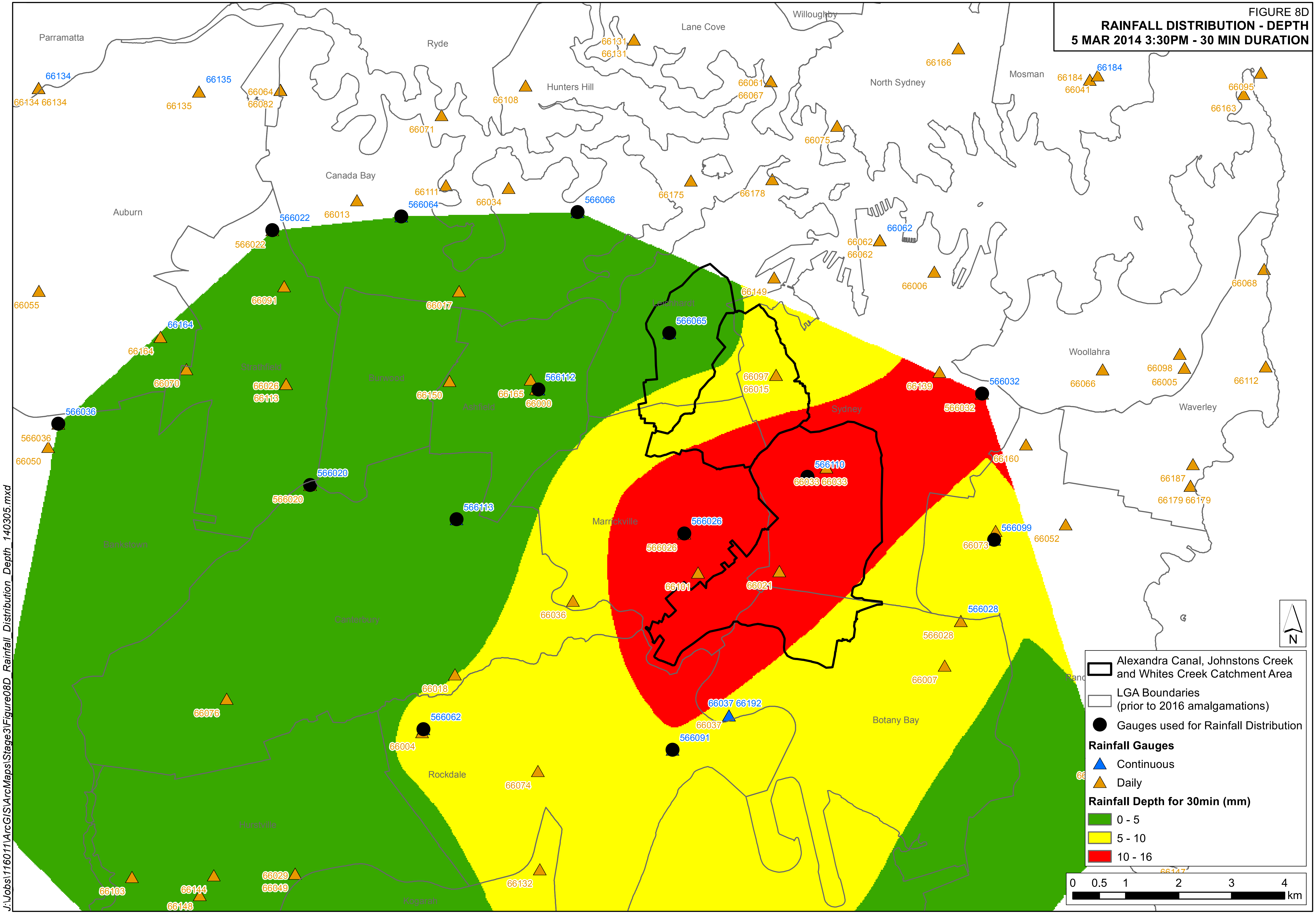
FIGURE 8D
RAINFALL DISTRIBUTION - DEPTH
5 MAR 2014 3:30PM - 30 MIN DURATION



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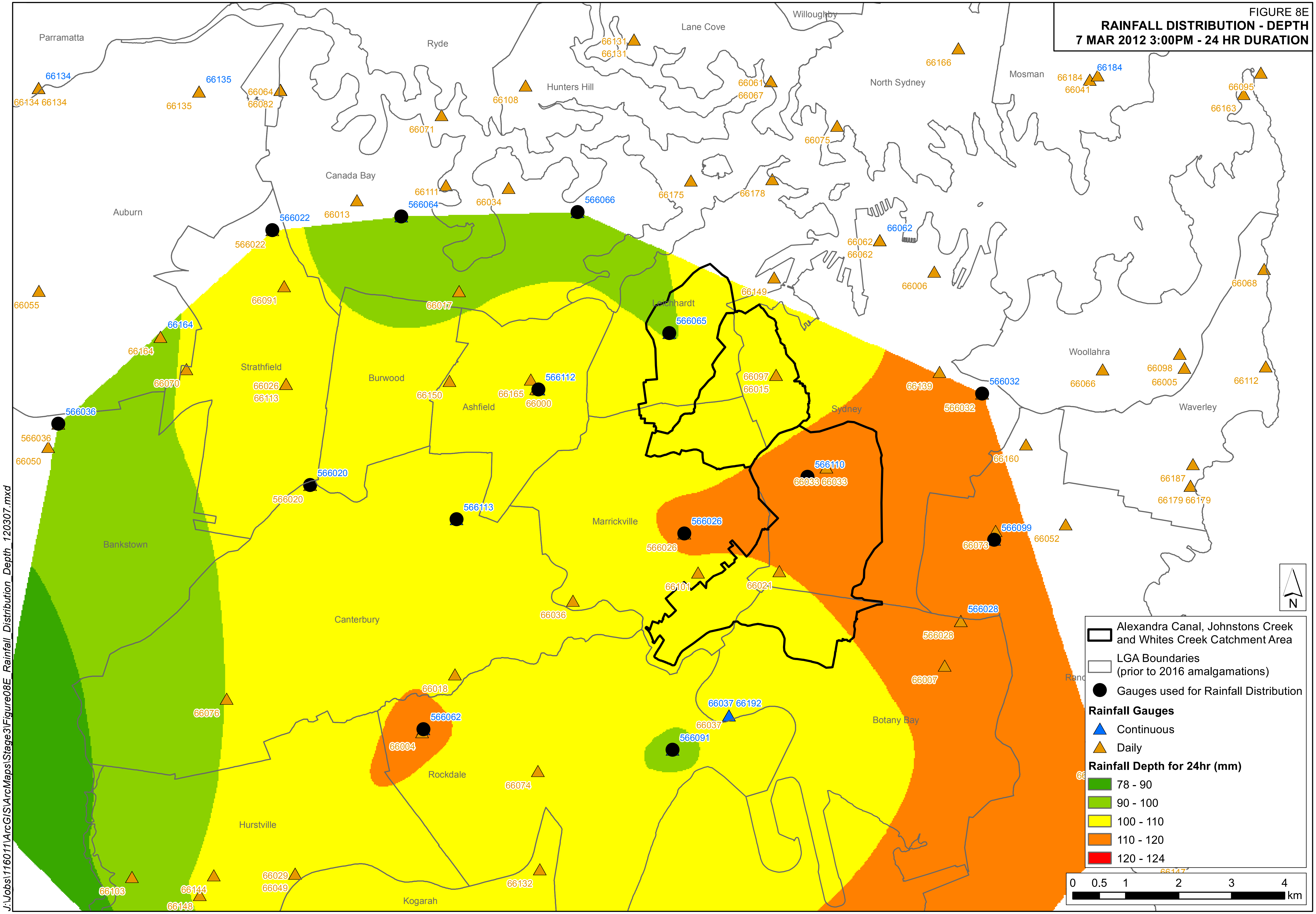

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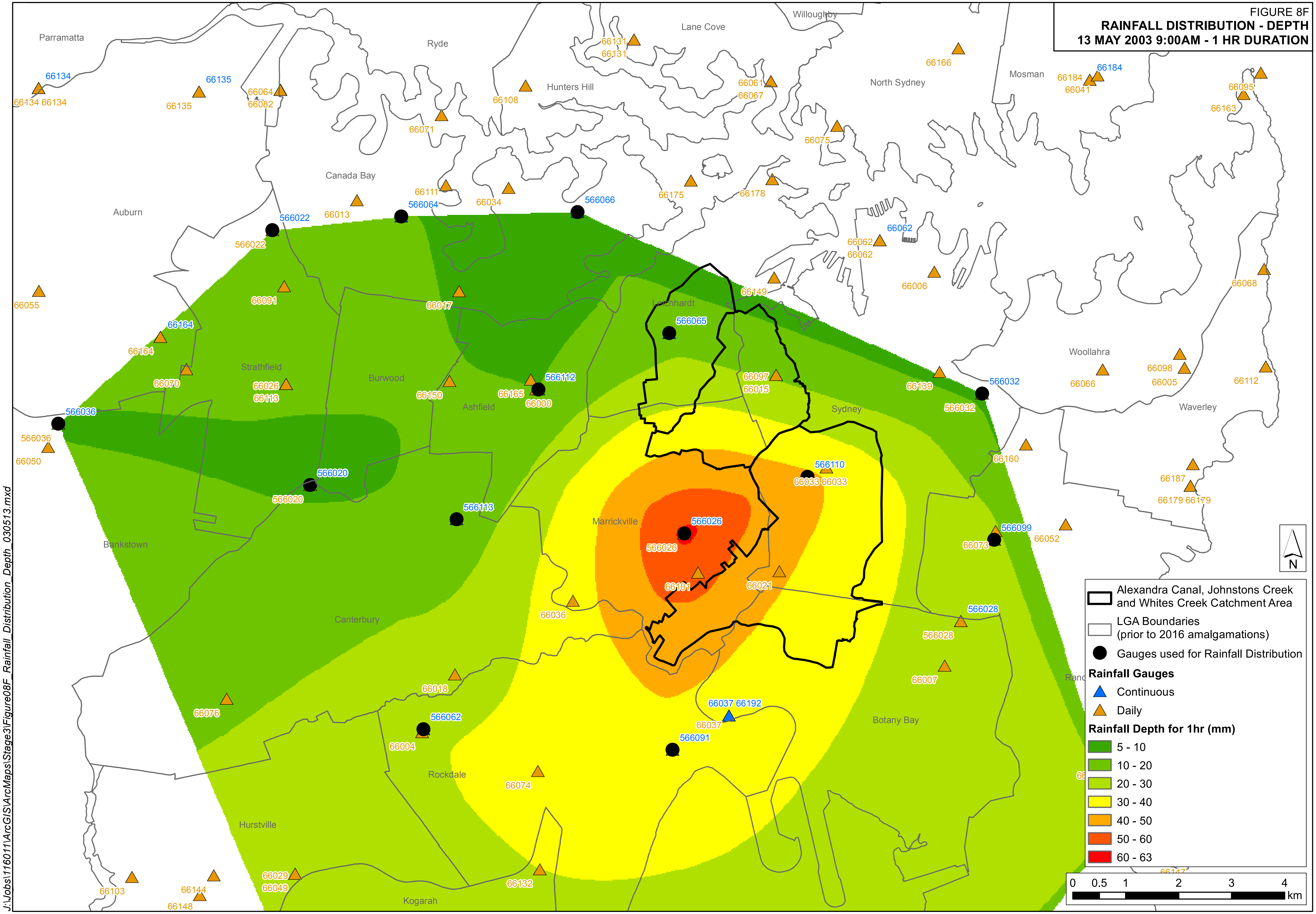
FIGURE 8F
RAINFALL DISTRIBUTION - DEPTH
13 MAY 2003 9:00AM - 1 HR DURATION



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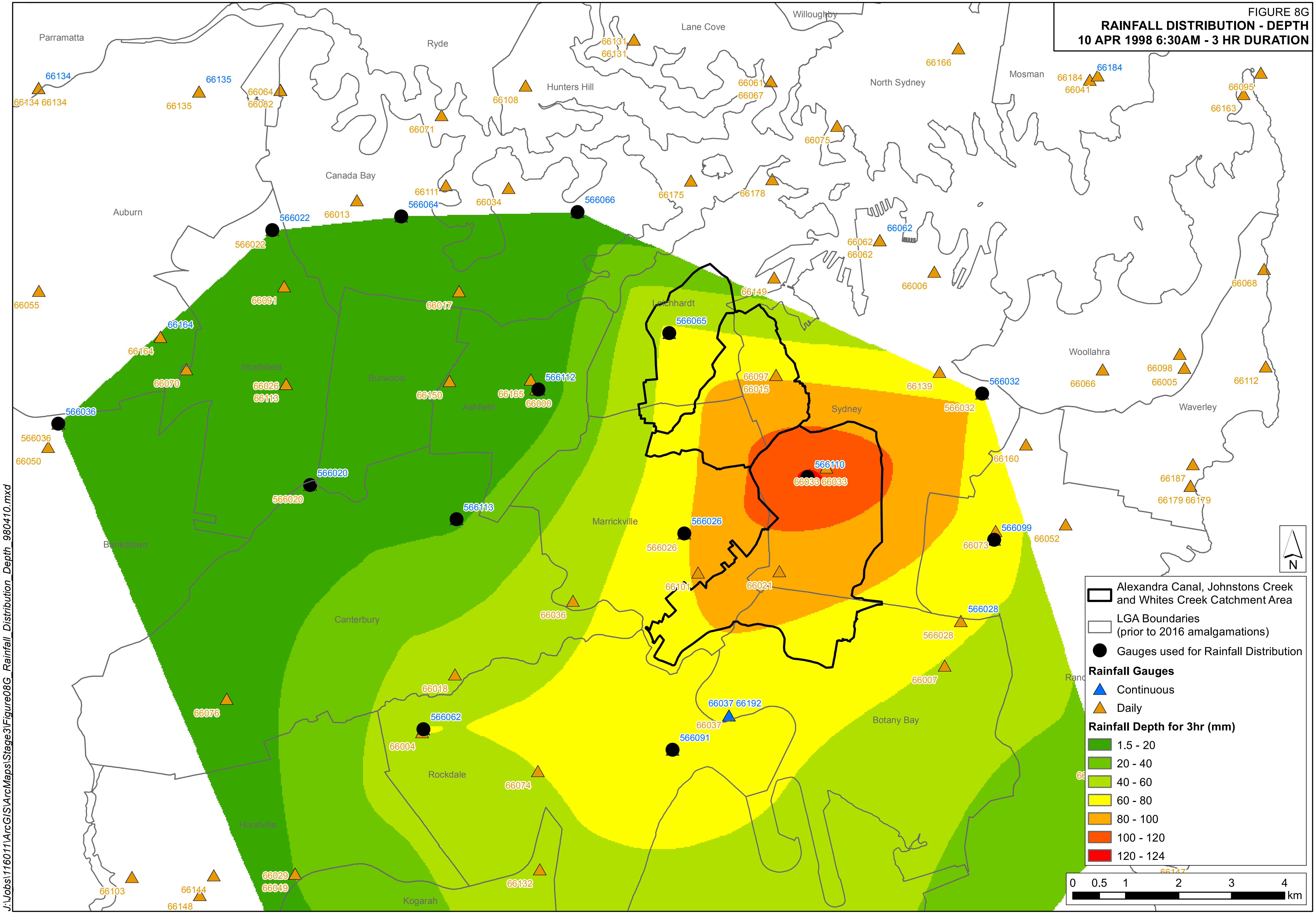
FIGURE 8G
RAINFALL DISTRIBUTION - DEPTH
10 APR 1998 6:30AM - 3 HR DURATION
Alexandra Canal, Johnstons Creek and Whites Creek Catchment Area
LGA Boundaries (prior to 2016 amalgamations)
Gauges used for Rainfall Distribution
Rainfall Gauges
Continuous
Daily
Rainfall Depth for 3hr (mm)
1.5 - 20
20 - 40
40 - 60
60 - 80
80 - 100
100 - 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
Leichhardt
Woollahra
Waverley
Sydney
Marrickville
Canterbury
Bankstown
Rockdale
Botany Bay
Hurstville
Kogarah
Strathfield
Burwood
Ashfield
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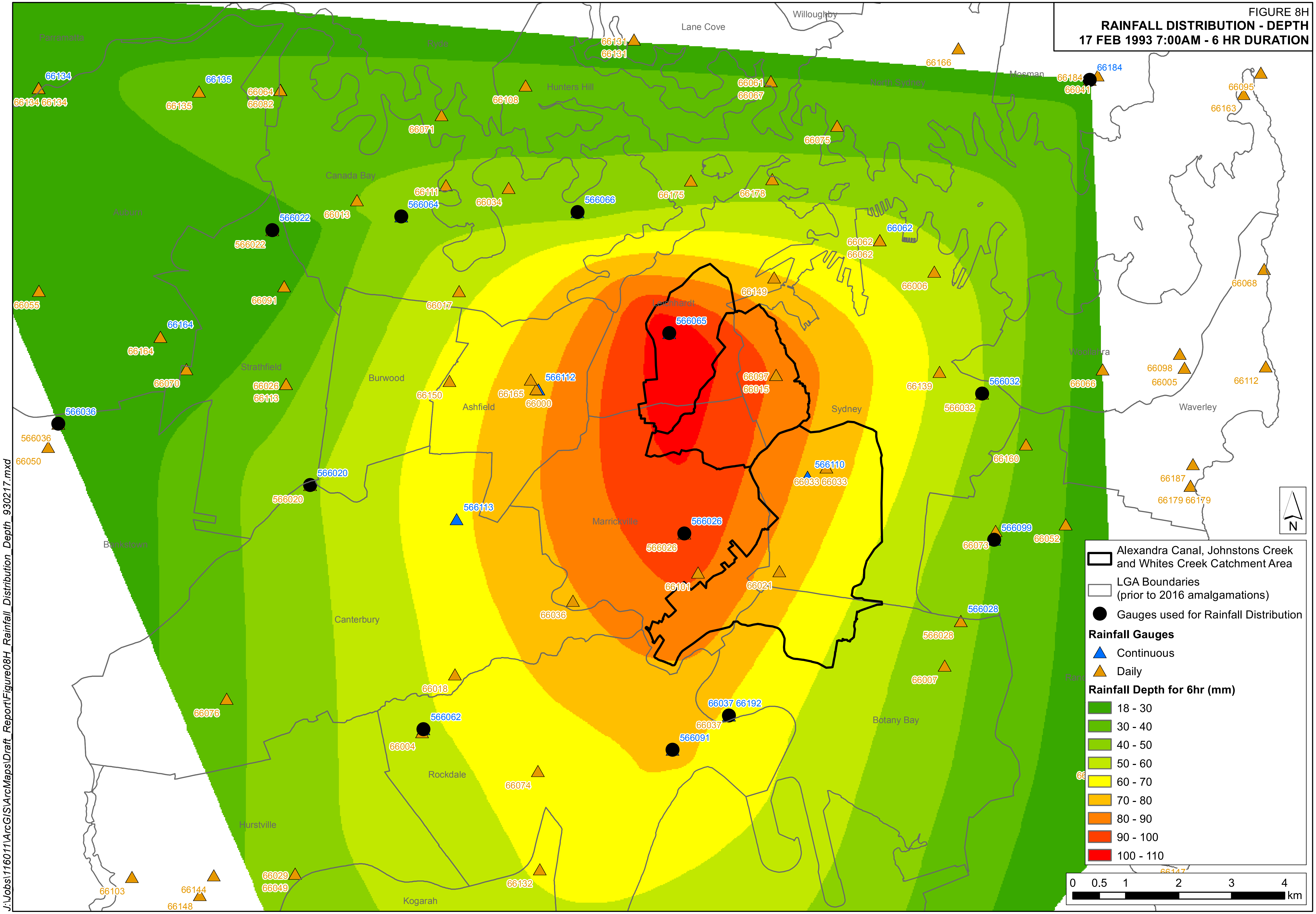

FIGURE 8H
RAINFALL DISTRIBUTION - DEPTH
17 FEB 1993 7:00AM - 6 HR DURATION

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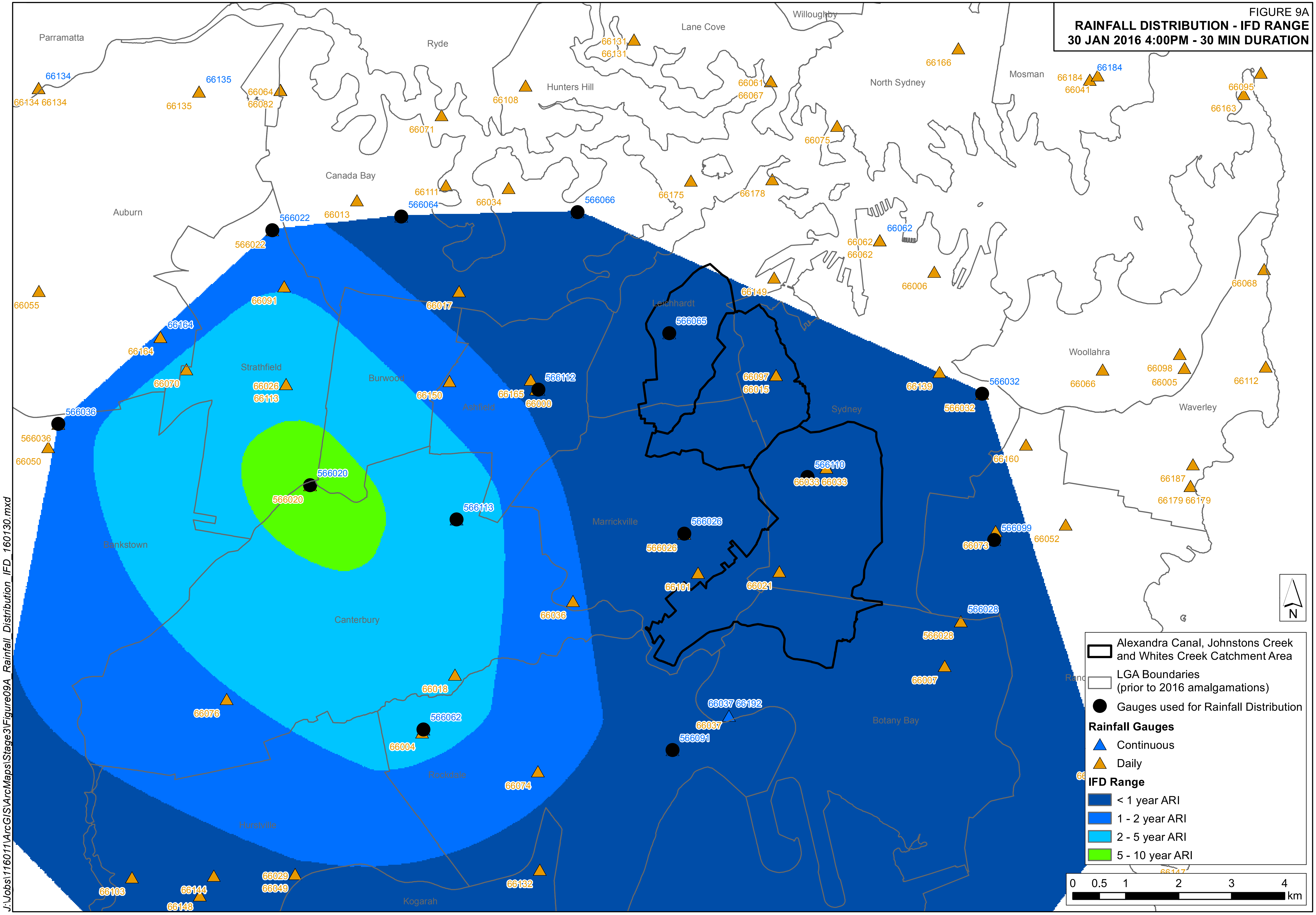
FIGURE 9A
RAINFALL DISTRIBUTION - IFD RANGE
30 JAN 2016 4:00PM - 30 MIN DURATION
Parramatta
Ryde
Lane Cove
Willoughby
Hunters Hill
North Sydney
Mosman
Canada Bay
Auburn
Strathfield
Burwood
Ashfield
Leichhardt
Sydney
Woollahra
Waverley
Marrickville
Bankstown
Canterbury
Rockdale
Hurstville
Kogarah
Botany Bay
Alexandra Canal, Johnstons Creek and Whites Creek Catchment Area
LGA Boundaries (prior to 2016 amalgamations)
Gauges used for Rainfall Distribution
Rainfall Gauges
Continuous
Daily
IFD Range
< 1 year ARI
1 - 2 year ARI
2 - 5 year ARI
5 - 10 year ARI
0 0.5 1 2 3 4
km
N
J:\Jobs\116011\ArcGIS\ArcMaps\Stage3\Figure09A_Rainfall_Distribution_IFD_160130.mxd
566020
566113
566062
566091
566026
566110
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566112
566022
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566066
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566032
566099
566028
66037 66192

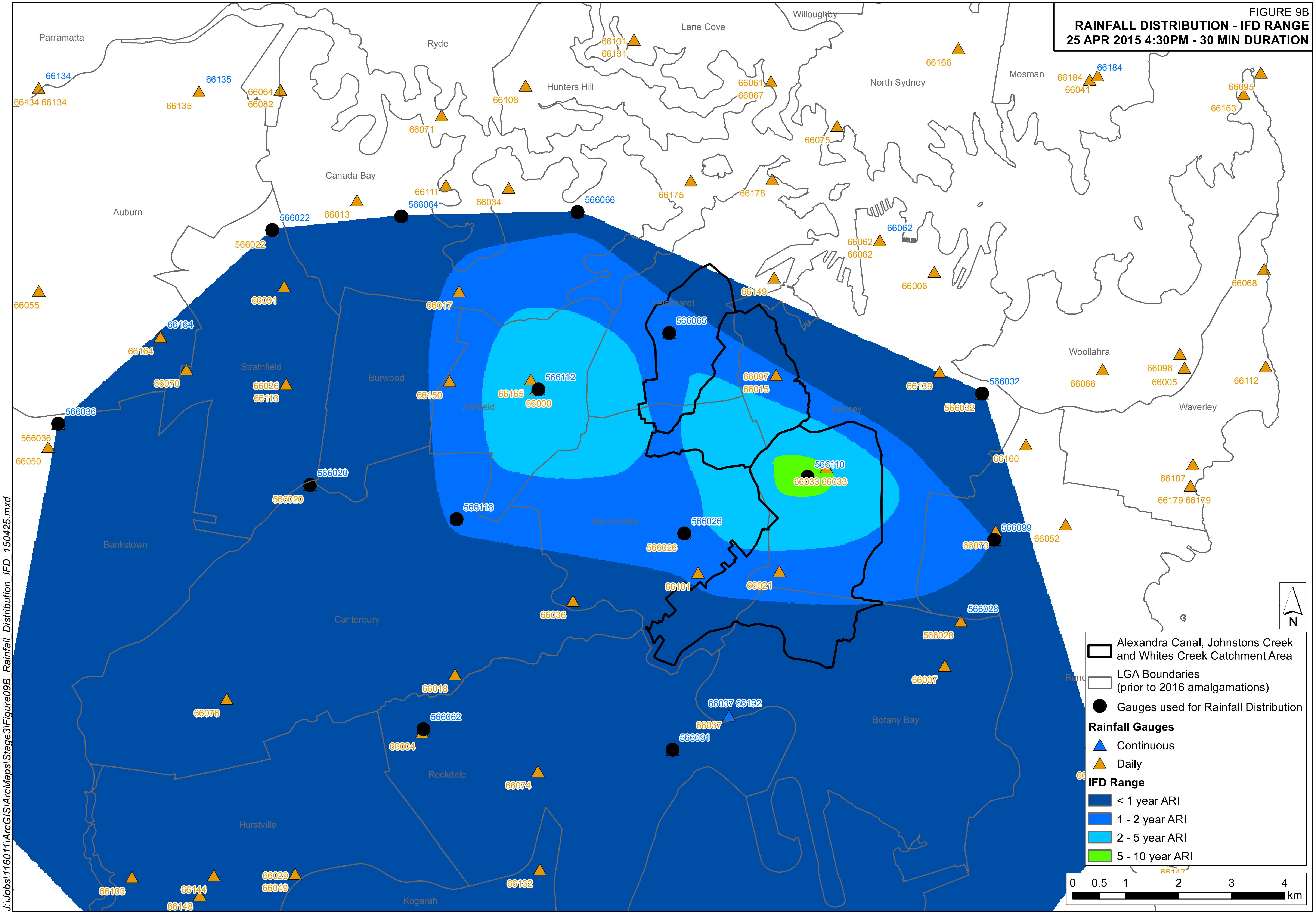
FIGURE 9B
RAINFALL DISTRIBUTION - IFD RANGE
25 APR 2015 4:30PM - 30 MIN DURATION
Parramatta
Ryde
Lane Cove
Willoughby
Hunters Hill
North Sydney
Mosman
Canada Bay
Auburn
Strathfield
Burwood
Ashfield
Leichhardt
Sydney
Woollahra
Waverley
Marrickville
Bankstown
Canterbury
Rockdale
Hurstville
Kogarah
Botany Bay
Alexandra Canal, Johnstons Creek and Whites Creek Catchment Area
LGA Boundaries (prior to 2016 amalgamations)
Gauges used for Rainfall Distribution
Rainfall Gauges
Continuous
Daily
IFD Range
< 1 year ARI
1 - 2 year ARI
2 - 5 year ARI
5 - 10 year ARI
0 0.5 1 2 3 4
km
N
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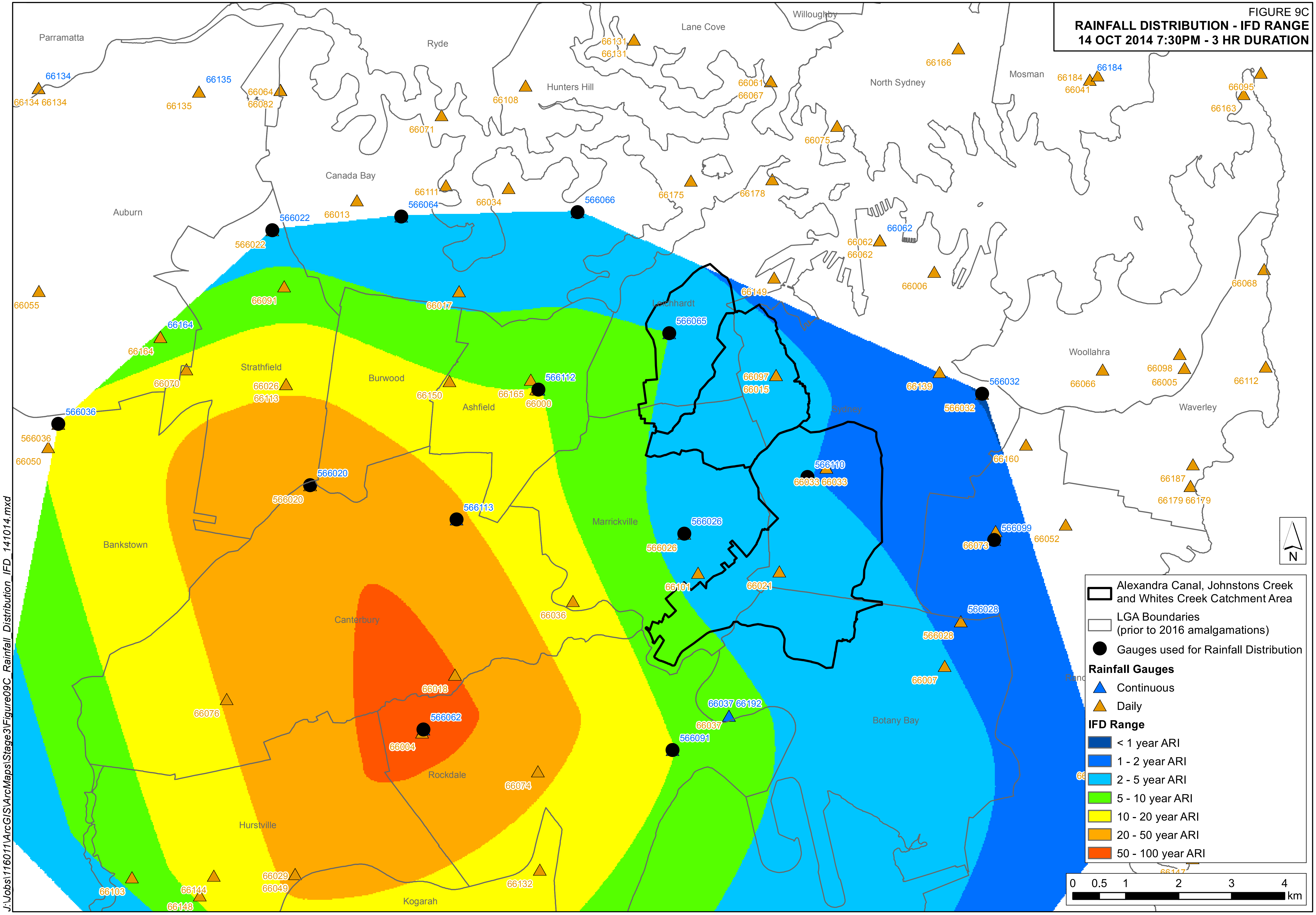

FIGURE 9C
RAINFALL DISTRIBUTION - IFD RANGE
14 OCT 2014 7:30PM - 3 HR DURATION
Alexandra Canal, Johnstons Creek and Whites Creek Catchment Area
LGA Boundaries (prior to 2016 amalgamations)
Gauges used for Rainfall Distribution
Rainfall Gauges
Continuous
Daily
IFD Range
< 1 year ARI
1 - 2 year ARI
2 - 5 year ARI
5 - 10 year ARI
10 - 20 year ARI
20 - 50 year ARI
50 - 100 year ARI
0 0.5 1 2 3 4 km
N
Parramatta
Ryde
Lane Cove
Willoughby
Hunters Hill
North Sydney
Mosman
Canada Bay
Auburn
Leichhardt
Strathfield
Burwood
Ashfield
Woollahra
Sydney
Waverley
Marrickville
Bankstown
Canterbury
Botany Bay
Rockdale
Hurstville
Kogarah
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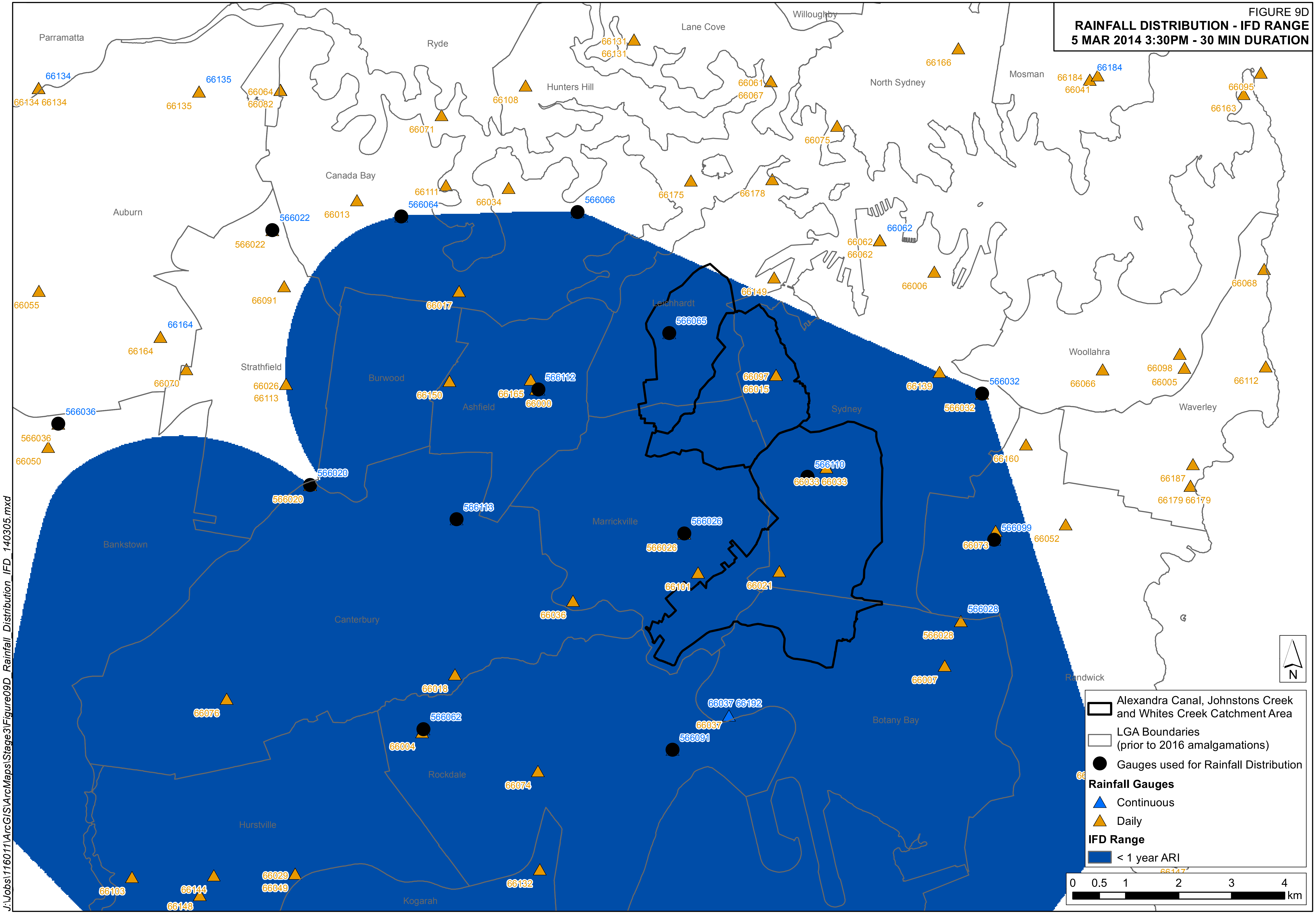
FIGURE 9D
RAINFALL DISTRIBUTION - IFD RANGE
5 MAR 2014 3:30PM - 30 MIN DURATION
Alexandra Canal, Johnstons Creek and Whites Creek Catchment Area
LGA Boundaries (prior to 2016 amalgamations)
Gauges used for Rainfall Distribution
Rainfall Gauges
Continuous
Daily
IFD Range
< 1 year ARI
0 0.5 1 2 3 4 km
N
Parramatta
Ryde
Lane Cove
Willoughby
Hunters Hill
North Sydney
Mosman
Canada Bay
Auburn
Strathfield
Burwood
Ashfield
Leichhardt
Sydney
Woollahra
Waverley
Marrickville
Bankstown
Canterbury
Randwick
Botany Bay
Rockdale
Hurstville
Kogarah
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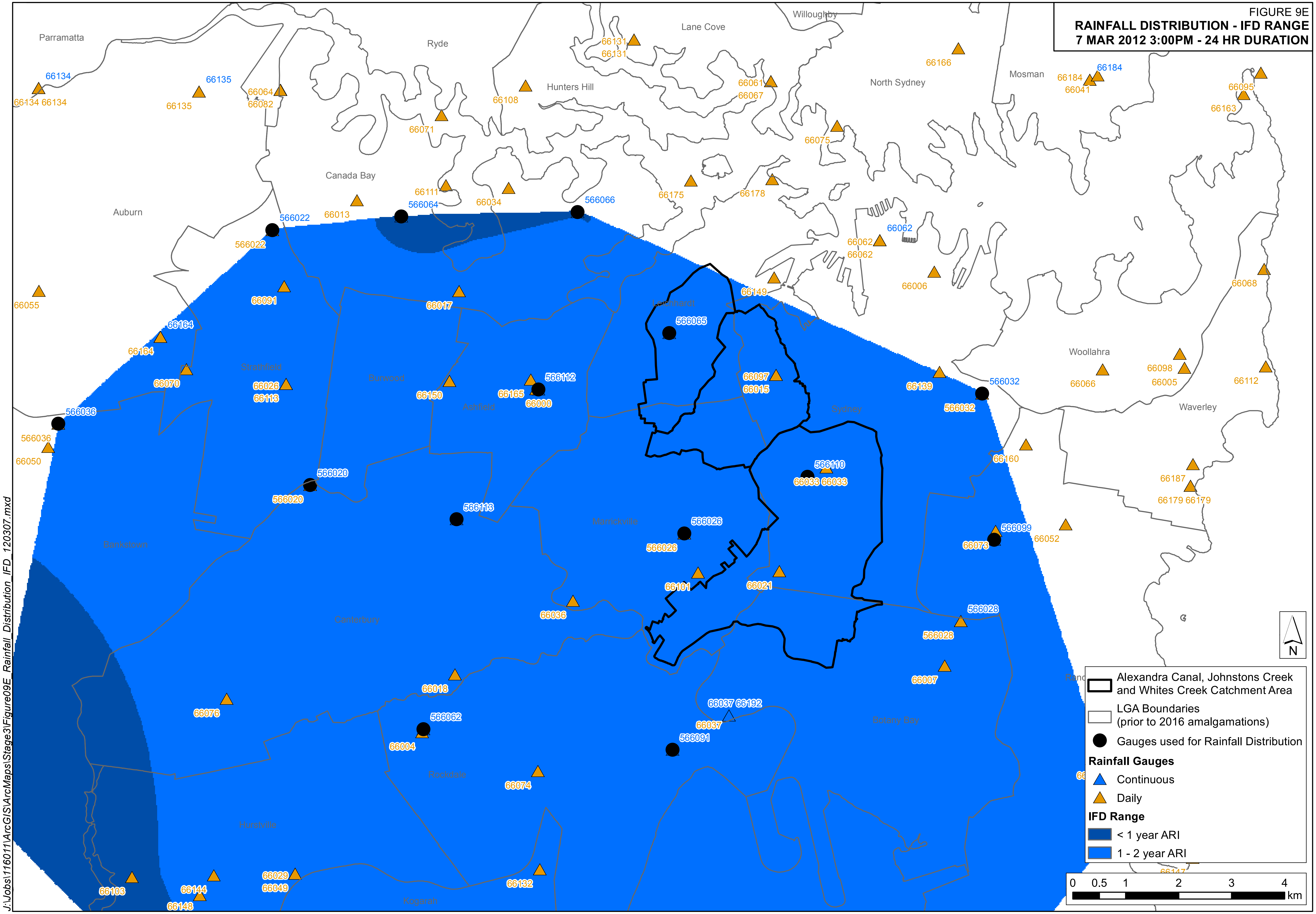
FIGURE 9E
RAINFALL DISTRIBUTION - IFD RANGE
7 MAR 2012 3:00PM - 24 HR DURATION
Alexandra Canal, Johnstons Creek and Whites Creek Catchment Area
LGA Boundaries (prior to 2016 amalgamations)
Gauges used for Rainfall Distribution
Rainfall Gauges
Continuous
Daily
IFD Range
< 1 year ARI
1 - 2 year ARI
0 0.5 1 2 3 4
km
N
Parramatta
Ryde
Lane Cove
Willoughby
Hunters Hill
North Sydney
Mosman
Canada Bay
Auburn
Woollahra
Waverley
Sydney
Leichhardt
Strathfield
Burwood
Ashfield
Marrickville
Bankstown
Canterbury
Botany Bay
Rockdale
Hurstville
Kogarah
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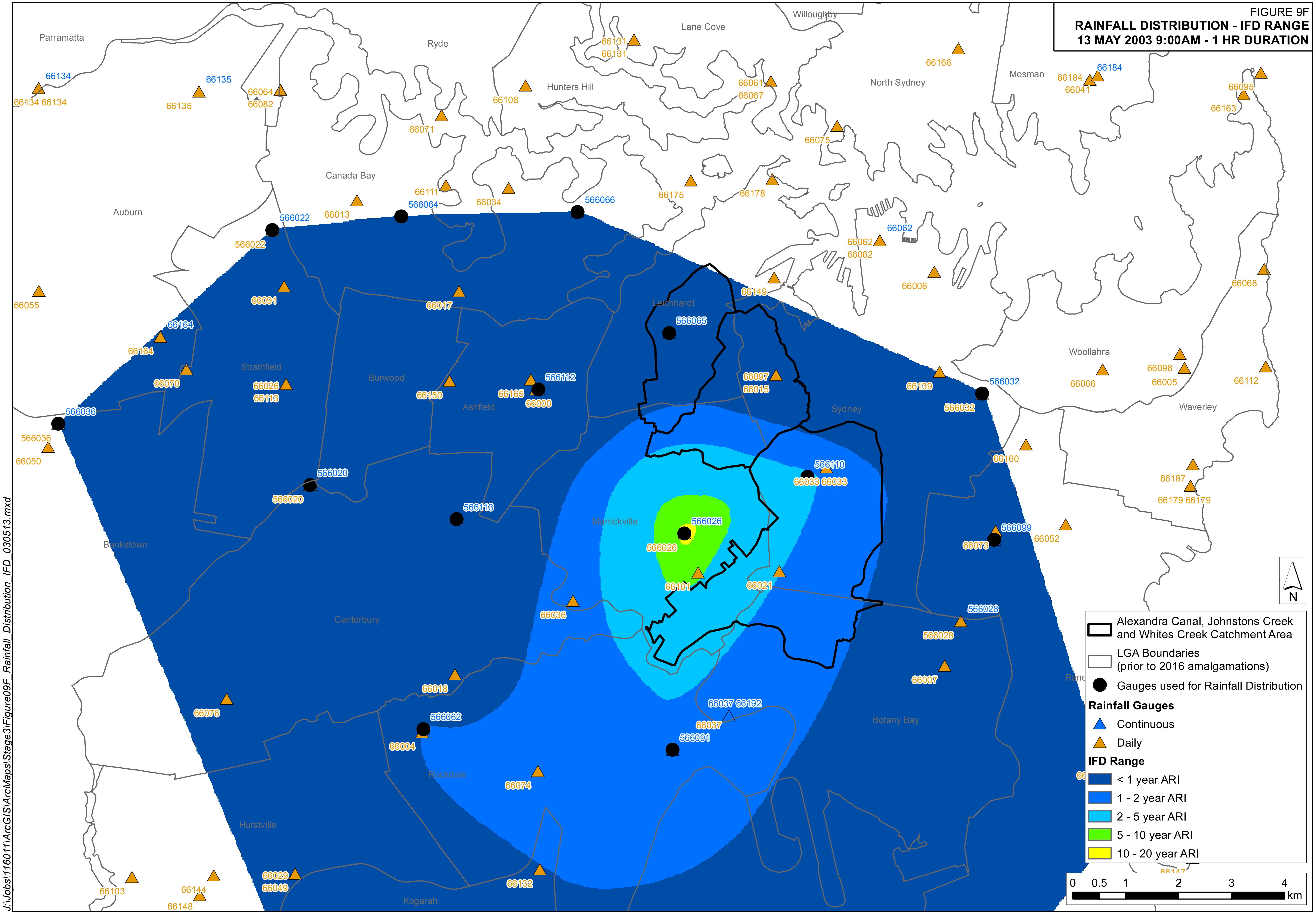

FIGURE 9F
RAINFALL DISTRIBUTION - IFD RANGE
13 MAY 2003 9:00AM - 1 HR DURATION
Parramatta
Ryde
Lane Cove
Willoughby
Hunters Hill
North Sydney
Mosman
Canada Bay
Auburn
Leichhardt
Strathfield
Burwood
Ashfield
Sydney
Woollahra
Waverley
Marrickville
Bankstown
Canterbury
Botany Bay
Rockdale
Hurstville
Kogarah
Alexandra Canal, Johnstons Creek and Whites Creek Catchment Area
LGA Boundaries (prior to 2016 amalgamations)
Gauges used for Rainfall Distribution
Rainfall Gauges
Continuous
Daily
IFD Range
< 1 year ARI
1 - 2 year ARI
2 - 5 year ARI
5 - 10 year ARI
10 - 20 year ARI
0 0.5 1 2 3 4 km
N
J:\Jobs\116011\ArcGIS\ArcMaps\Stage3\Figure09F_Rainfall_Distribution_IFD_030513.mxd

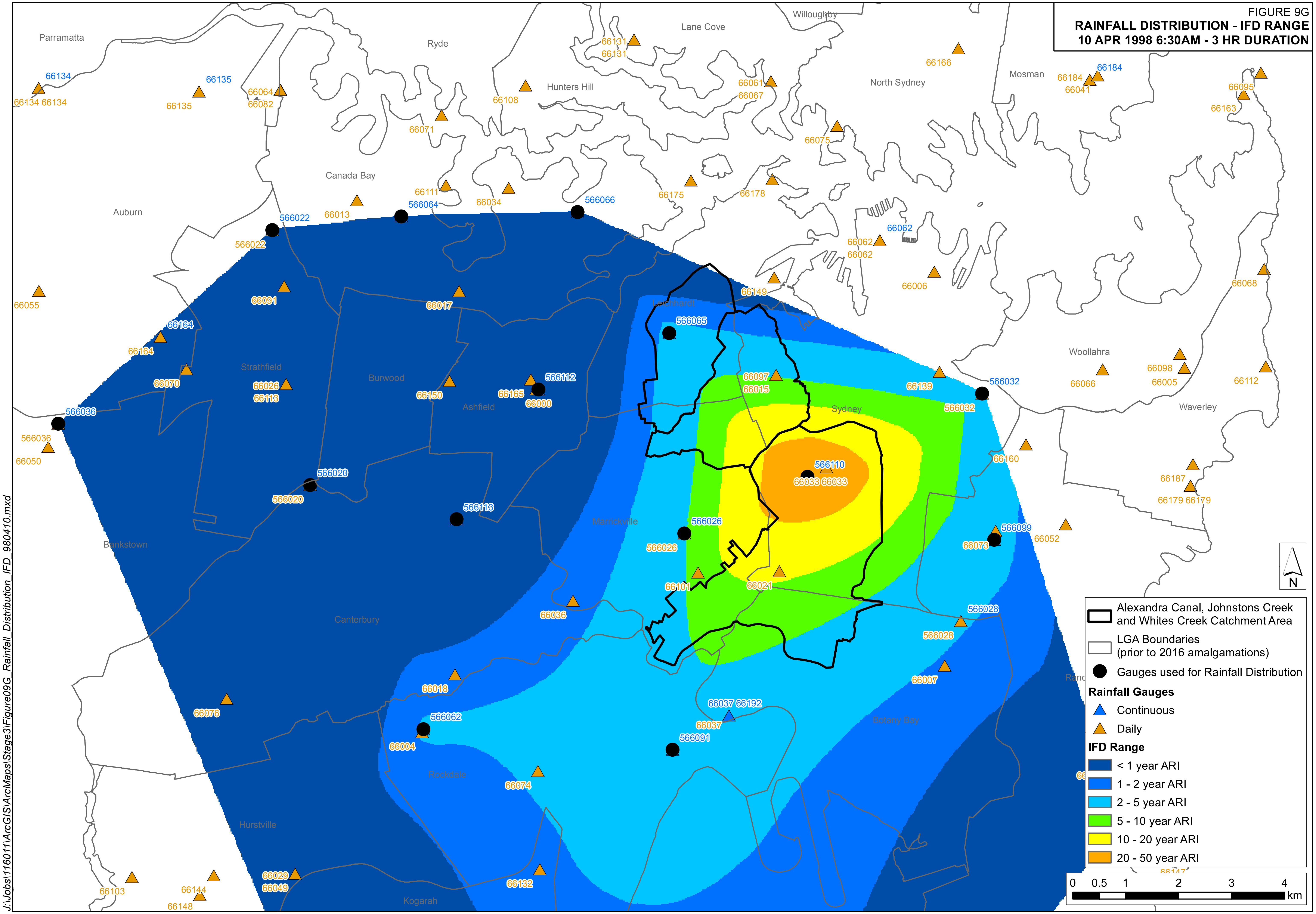
FIGURE 9G
RAINFALL DISTRIBUTION - IFD RANGE
10 APR 1998 6:30AM - 3 HR DURATION
Alexandra Canal, Johnstons Creek and Whites Creek Catchment Area
LGA Boundaries (prior to 2016 amalgamations)
Gauges used for Rainfall Distribution
Rainfall Gauges
Continuous
Daily
IFD Range
< 1 year ARI
1 - 2 year ARI
2 - 5 year ARI
5 - 10 year ARI
10 - 20 year ARI
20 - 50 year ARI
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
Sydney
Woollahra
Waverley
Marrickville
Bankstown
Canterbury
Botany Bay
Rockdale
Hurstville
Kogarah
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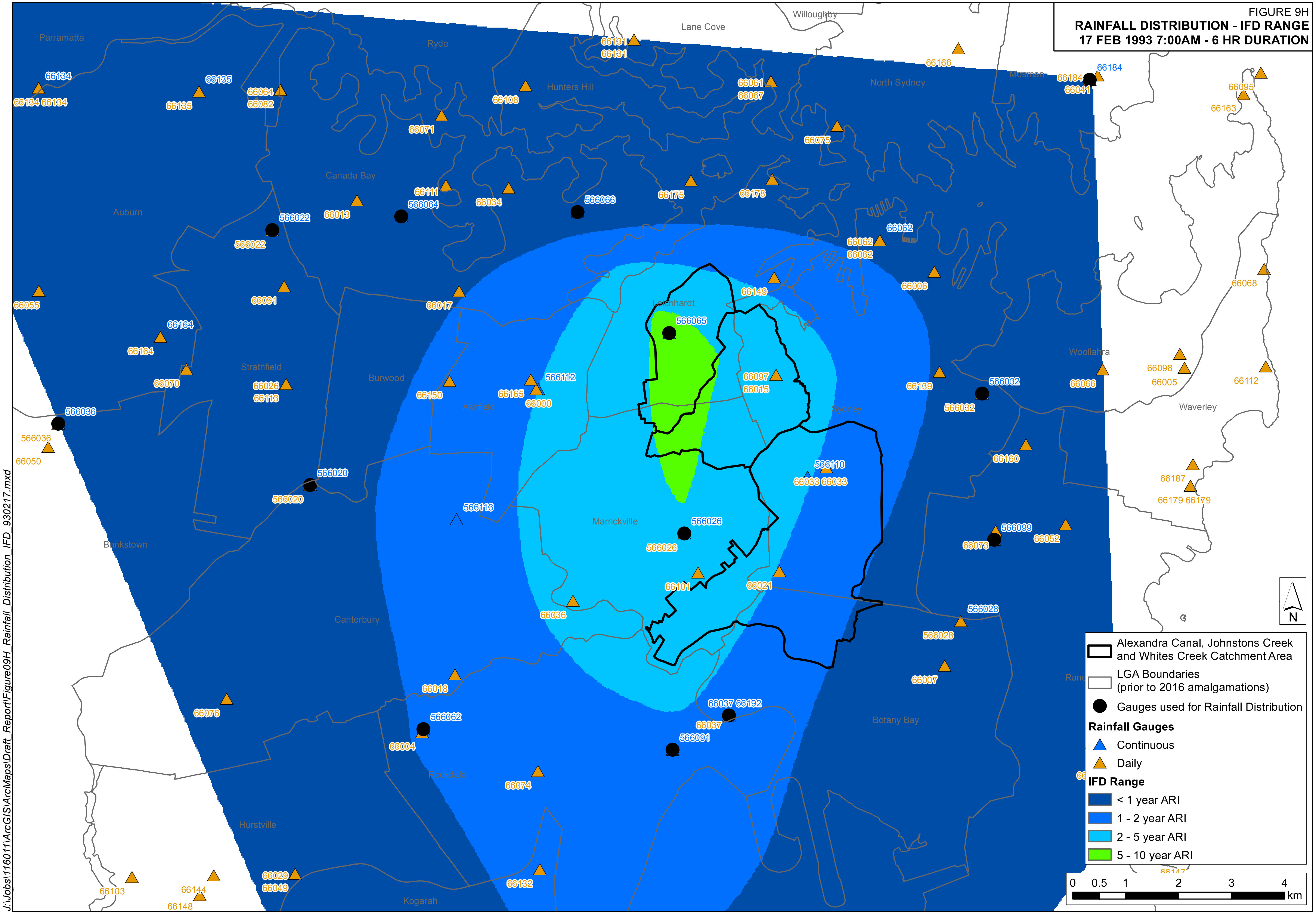


FIGURE 9H
RAINFALL DISTRIBUTION - IFD RANGE
17 FEB 1993 7:00AM - 6 HR DURATION
Parramatta
Ryde
Lane Cove
Willoughby
Hunters Hill
North Sydney
Mosman
Canada Bay
Auburn
Leichhardt
Strathfield
Burwood
Ashfield
Woollahra
Sydney
Waverley
Marrickville
Bankstown
Canterbury
Botany Bay
Rockdale
Hurstville
Kogarah
Alexandra Canal, Johnstons Creek and Whites Creek Catchment Area
LGA Boundaries (prior to 2016 amalgamations)
Gauges used for Rainfall Distribution
Rainfall Gauges
Continuous
Daily
IFD Range
< 1 year ARI
1 - 2 year ARI
2 - 5 year ARI
5 - 10 year ARI
0 0.5 1 2 3 4 km
N
J:\Jobs\116011\ArcGIS\ArcMaps\Draft_Report\Figure09H_Rainfall_Distribution_IFD_930217.mxd

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

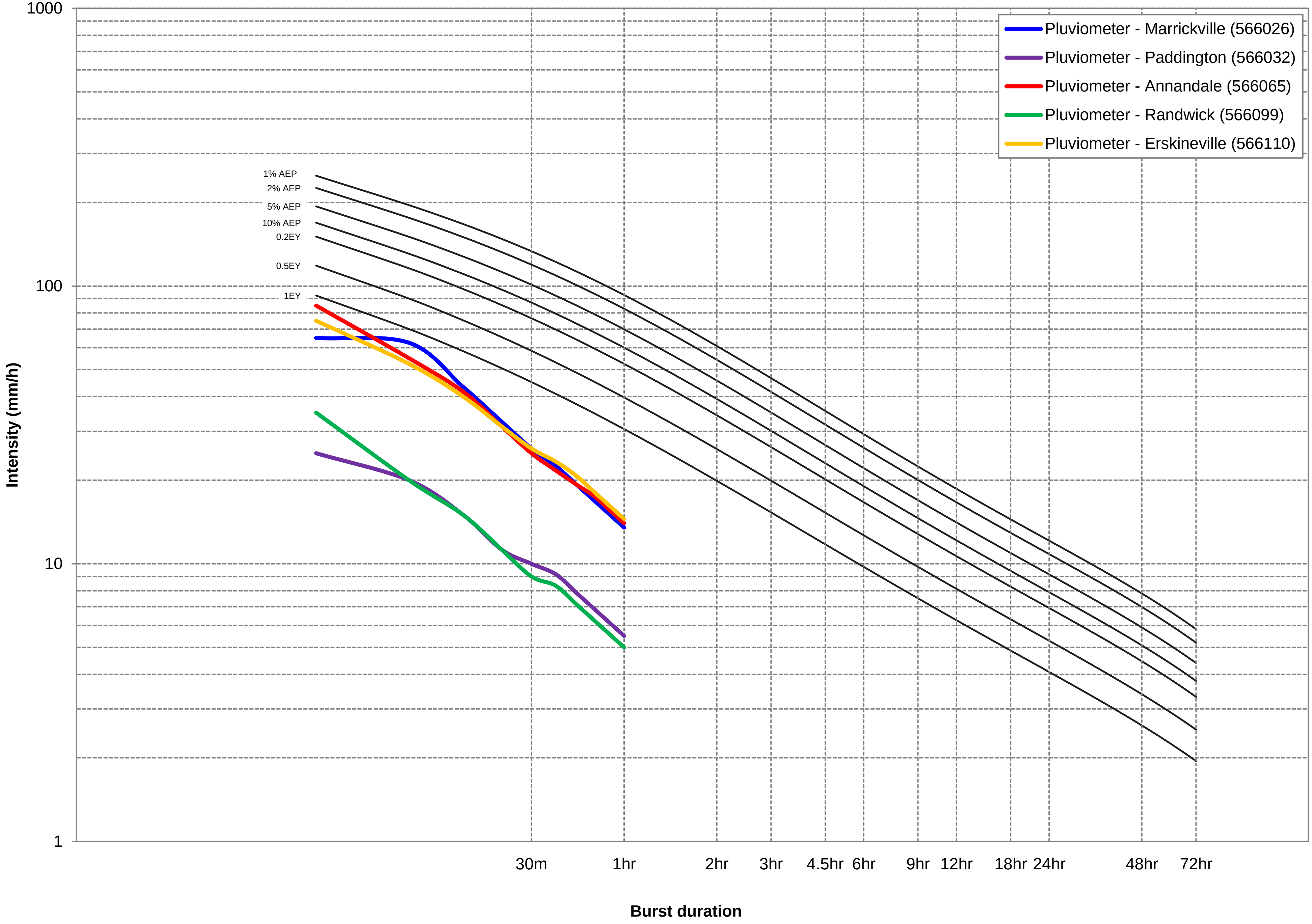


FIGURE 10A
BURST INTENSITIES AND FREQUENCIES
30 JAN 2016

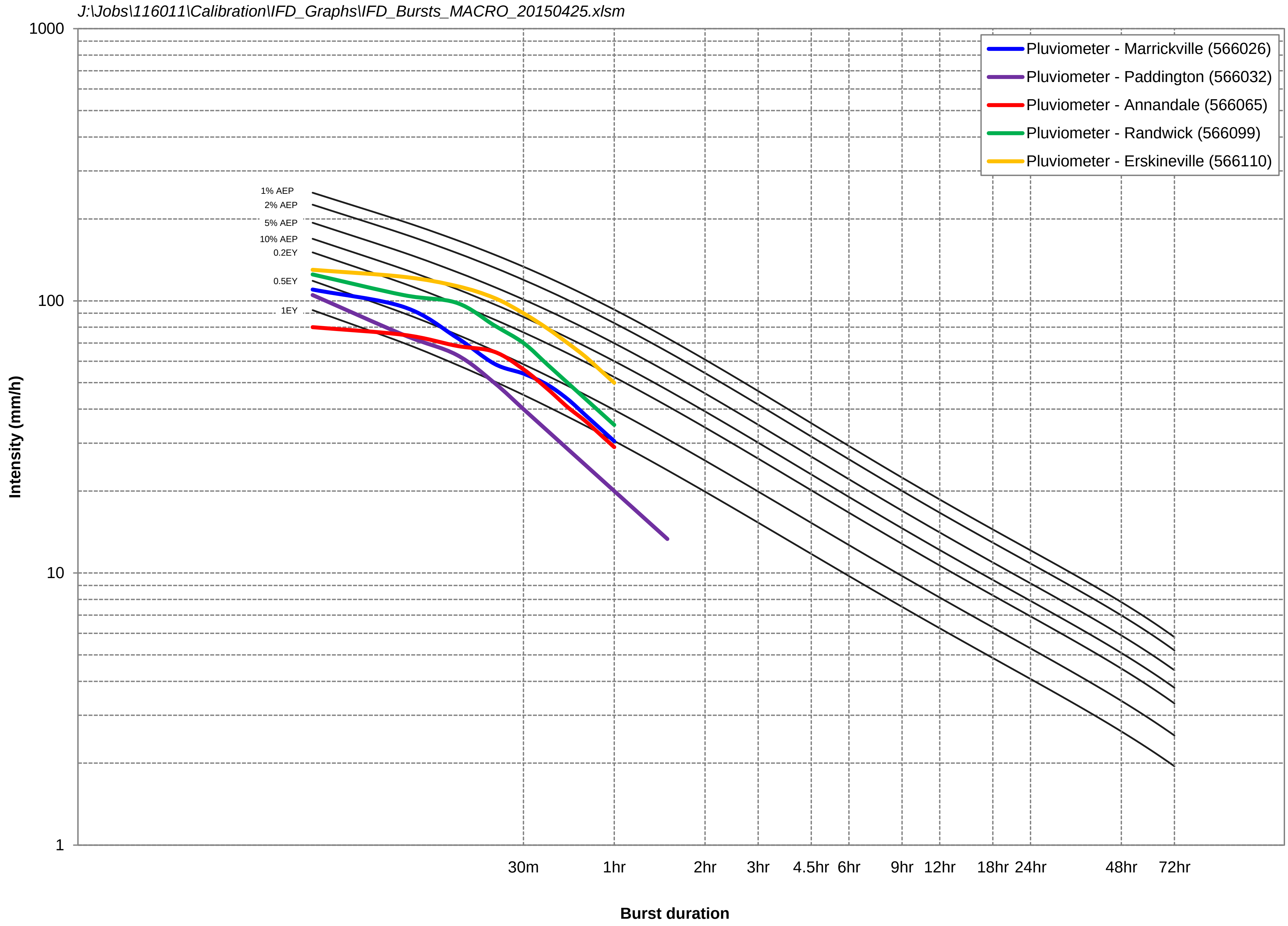


FIGURE 10B
BURST INTENSITIES AND FREQUENCIES
25 APR 2015

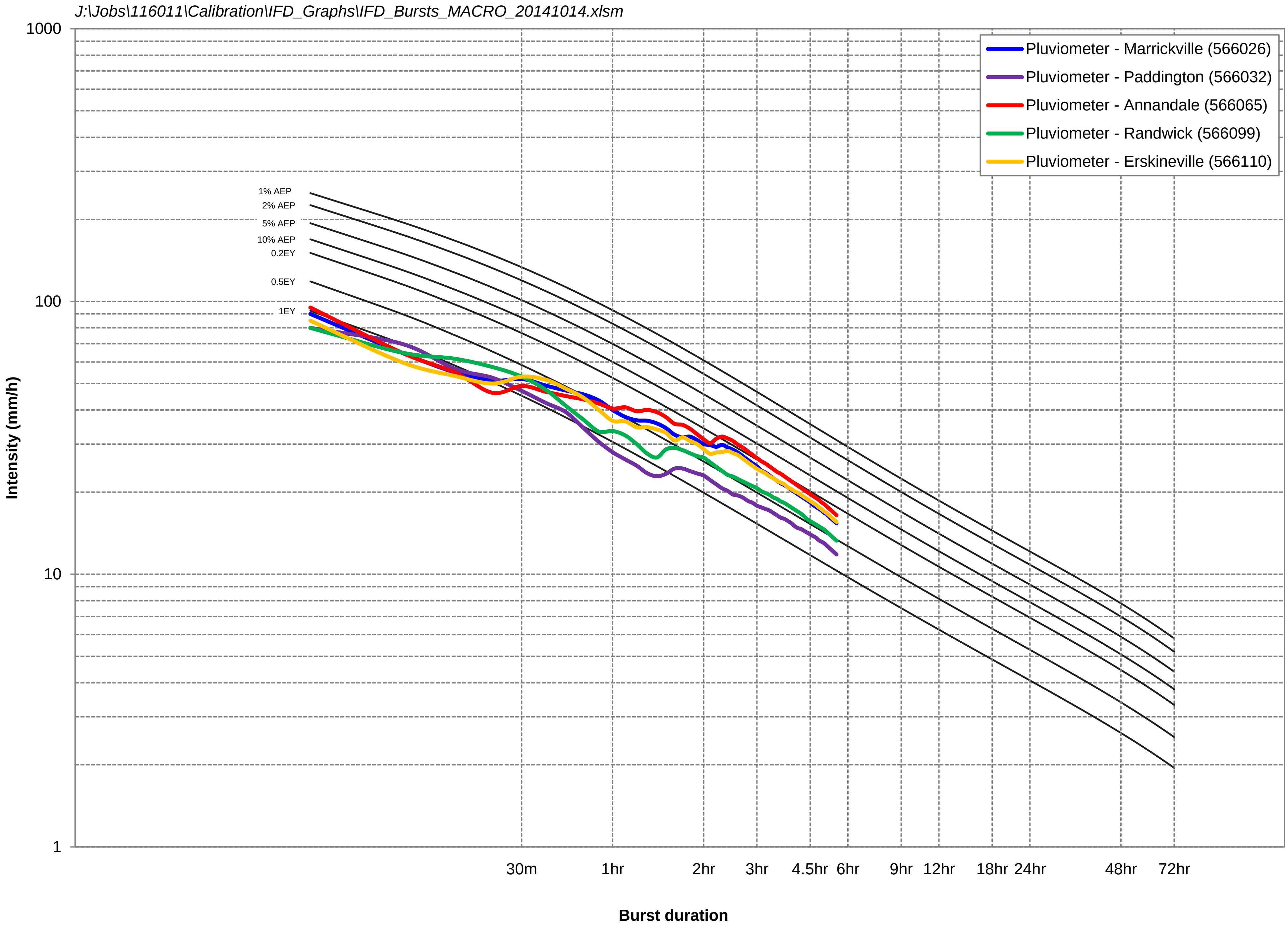


FIGURE 10C
BURST INTENSITIES AND FREQUENCIES
14 OCT 2014

J:\Jobs\116011\Calibration\IFD_Graphs\IFD_Bursts_MACRO_20140305.xlsm

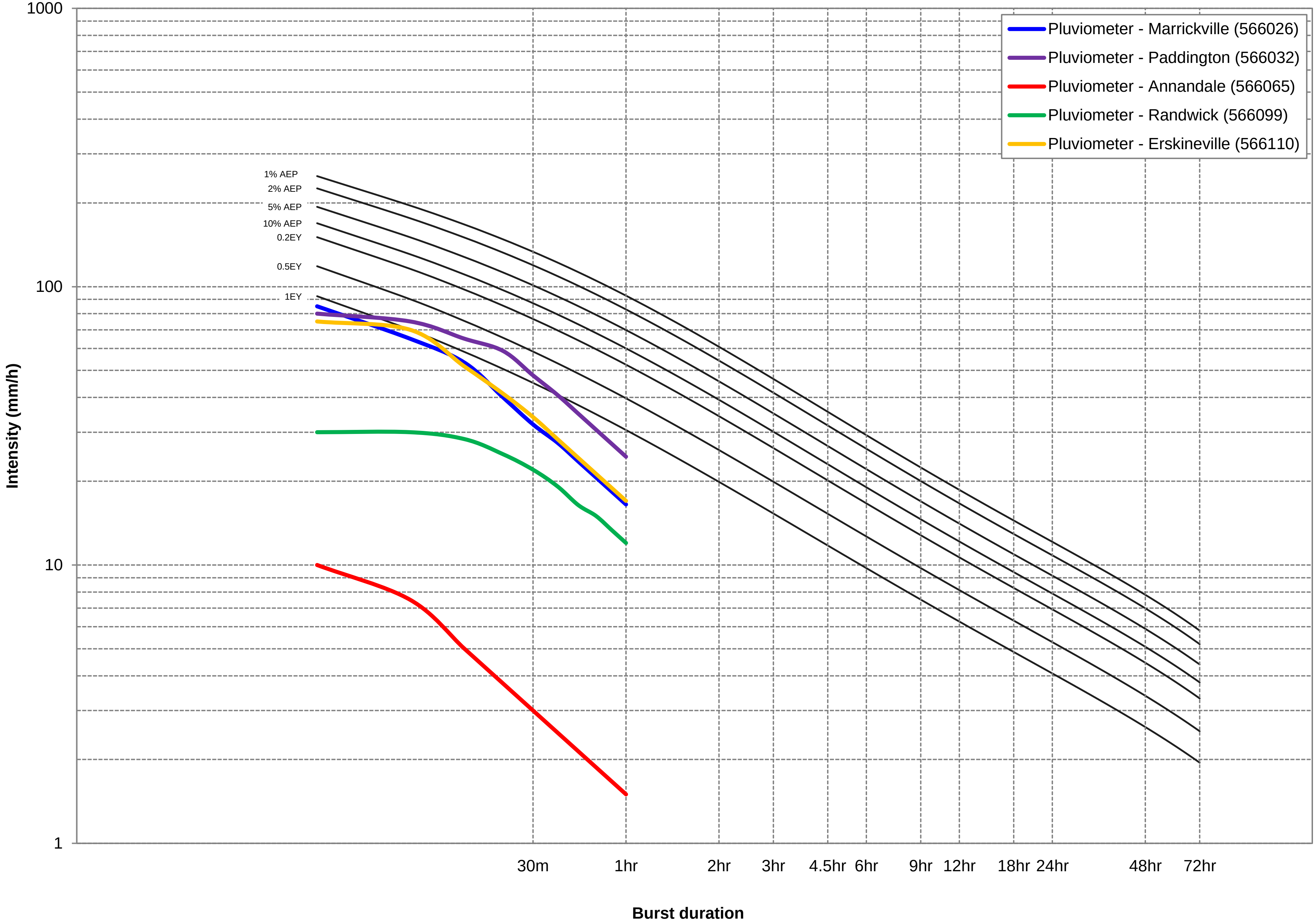


FIGURE 10D
BURST INTENSITIES AND FREQUENCIES
5 MAR 2014

J:\Jobs\116011\Calibration\IFD_Graphs\IFD_Bursts_MACRO_20120307.xlsm

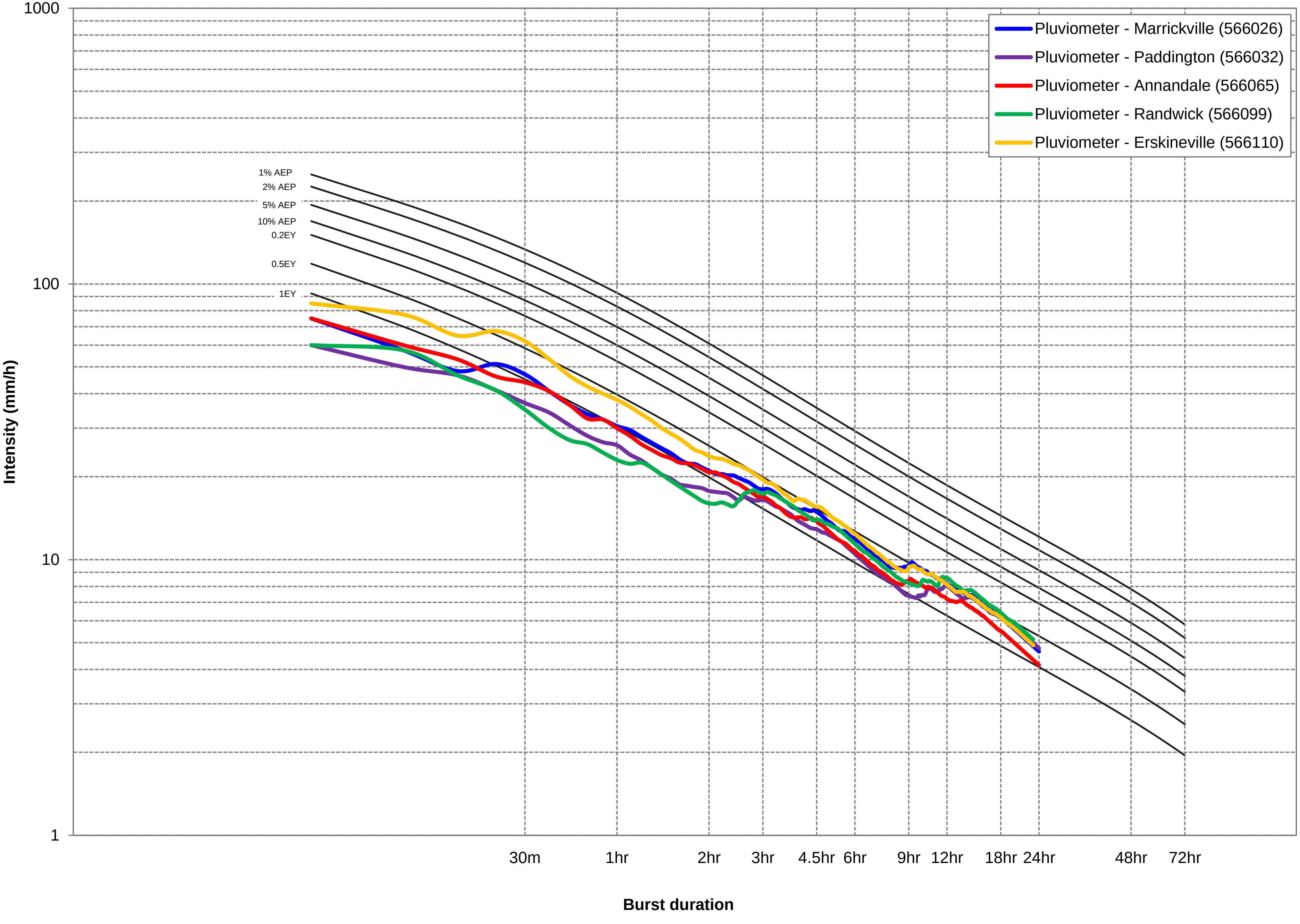


FIGURE 10E
BURST INTENSITIES AND FREQUENCIES
7 MAR 2012

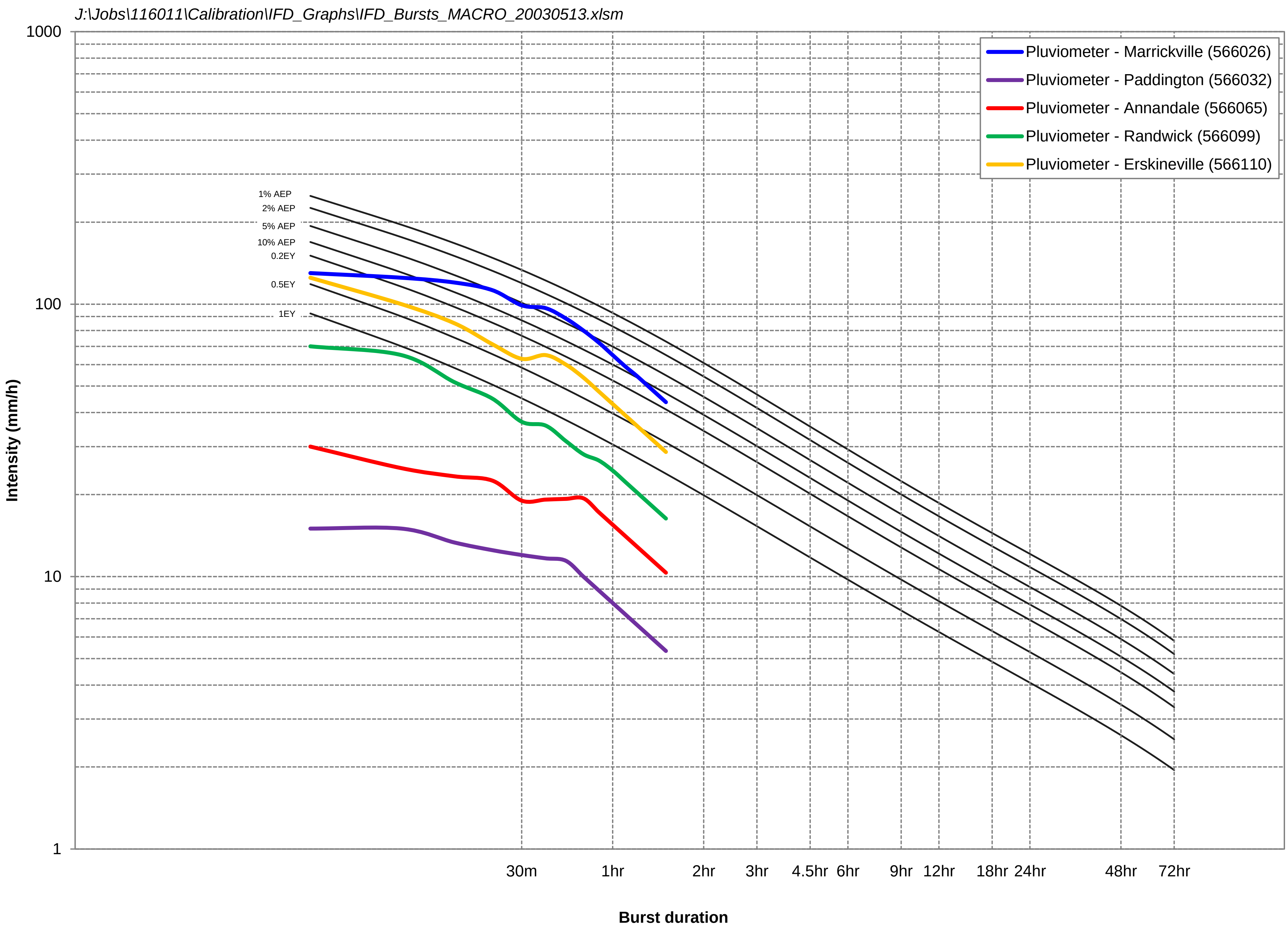


FIGURE 10F
BURST INTENSITIES AND FREQUENCIES
13 MAY 2003

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

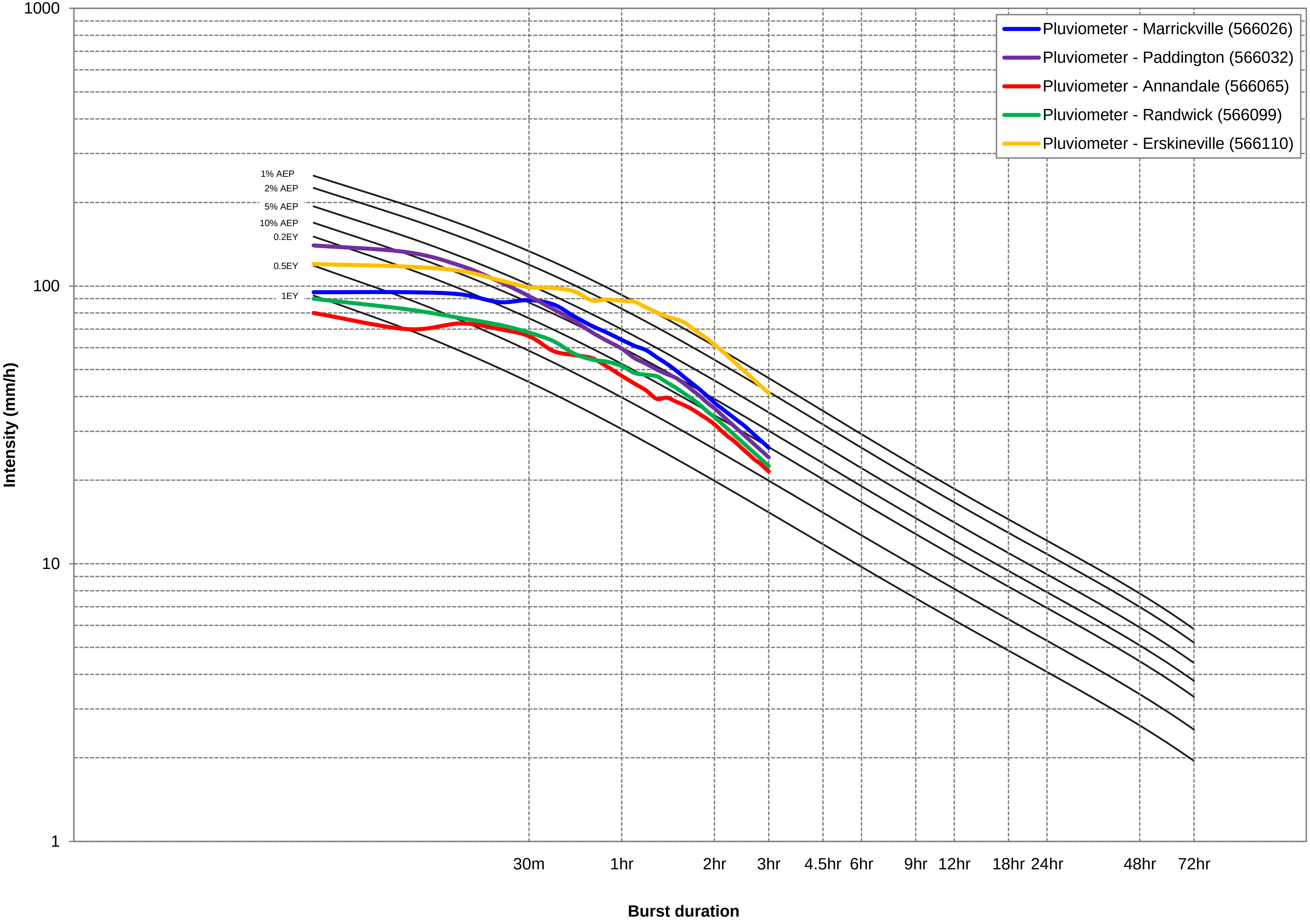


FIGURE 10G
BURST INTENSITIES AND FREQUENCIES 10 APR 1998

J:\Jobs\116011\Calibration\IFD_Graphs\IFD_Bursts_MACRO_19930217.xlsm

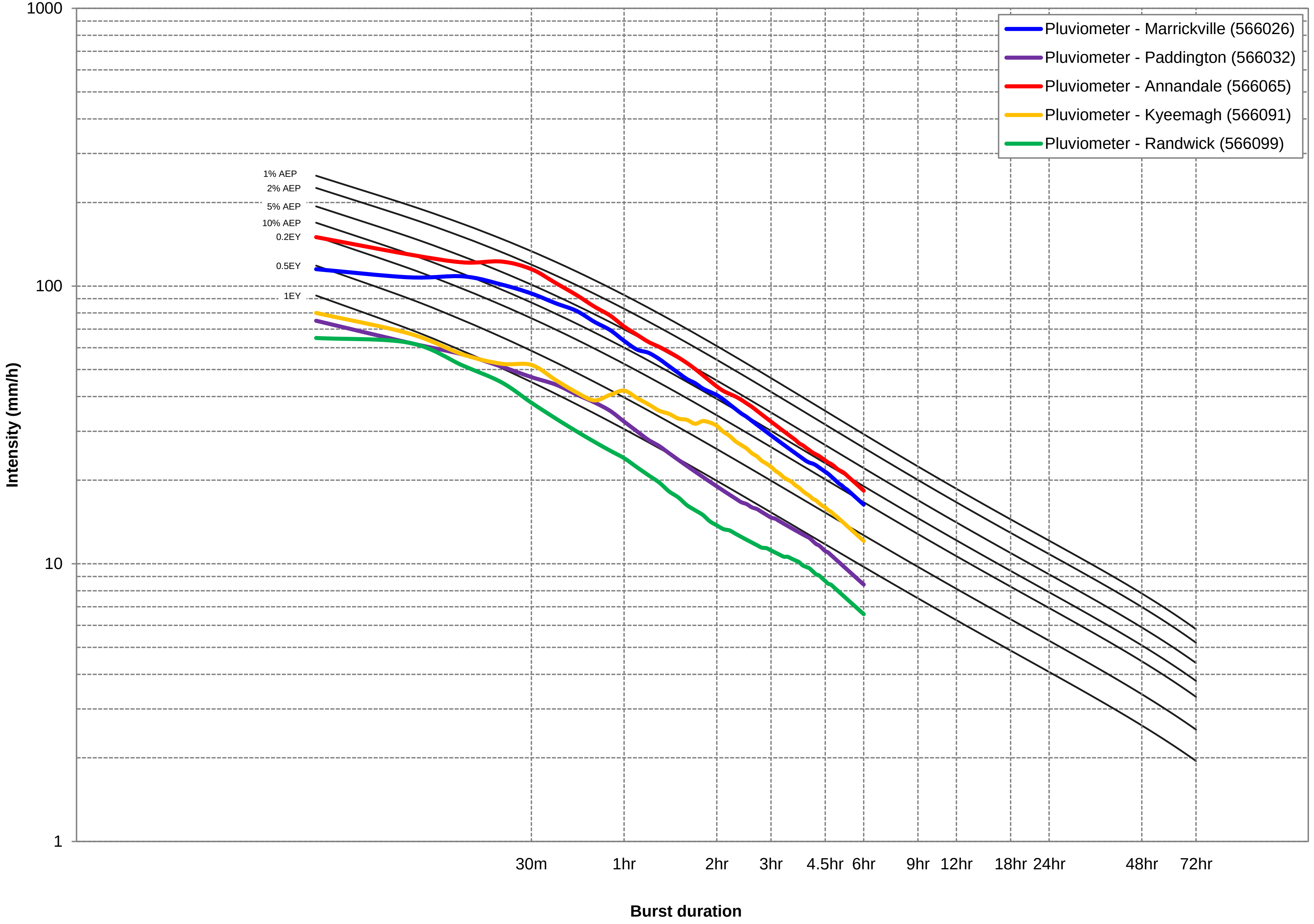
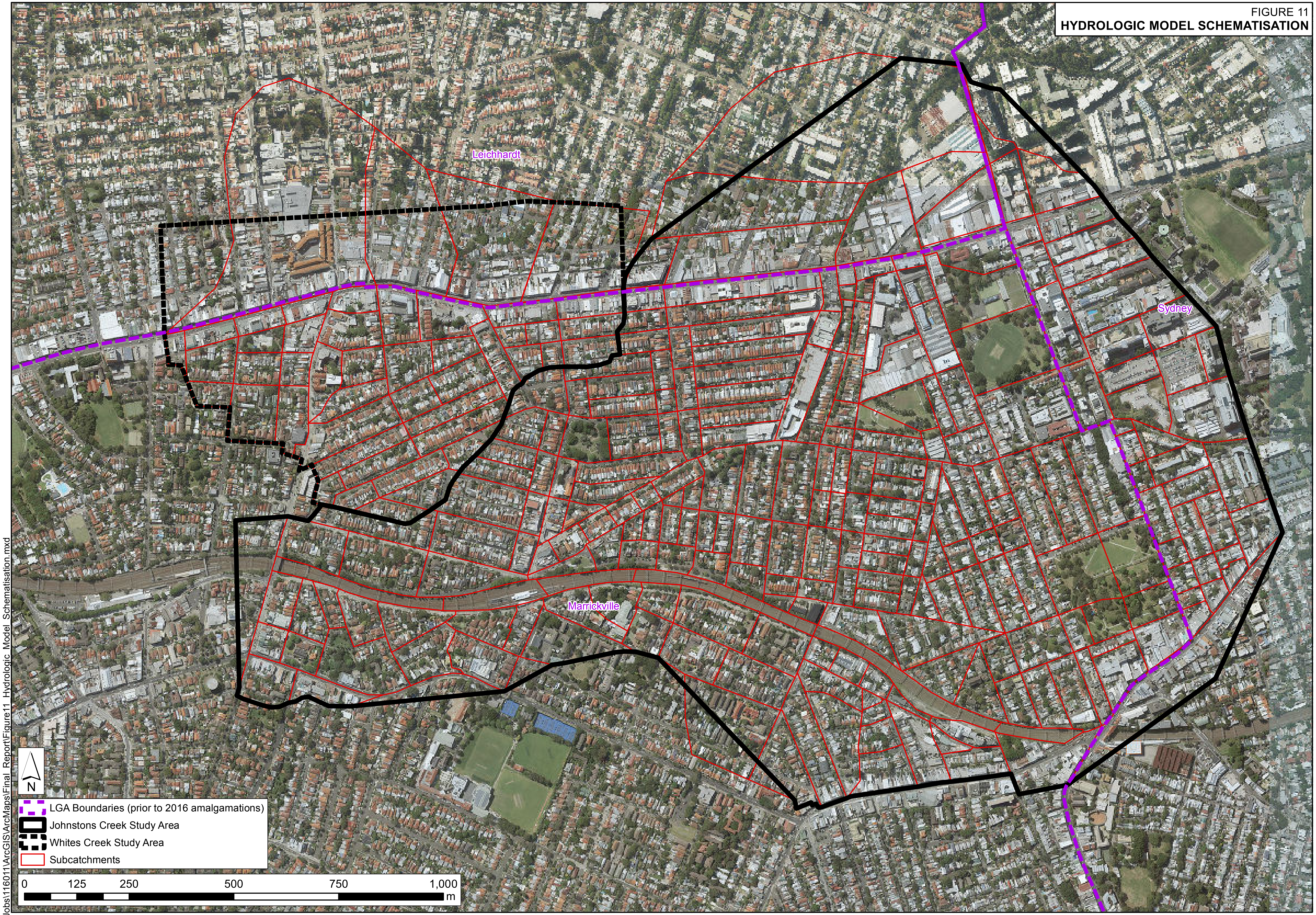


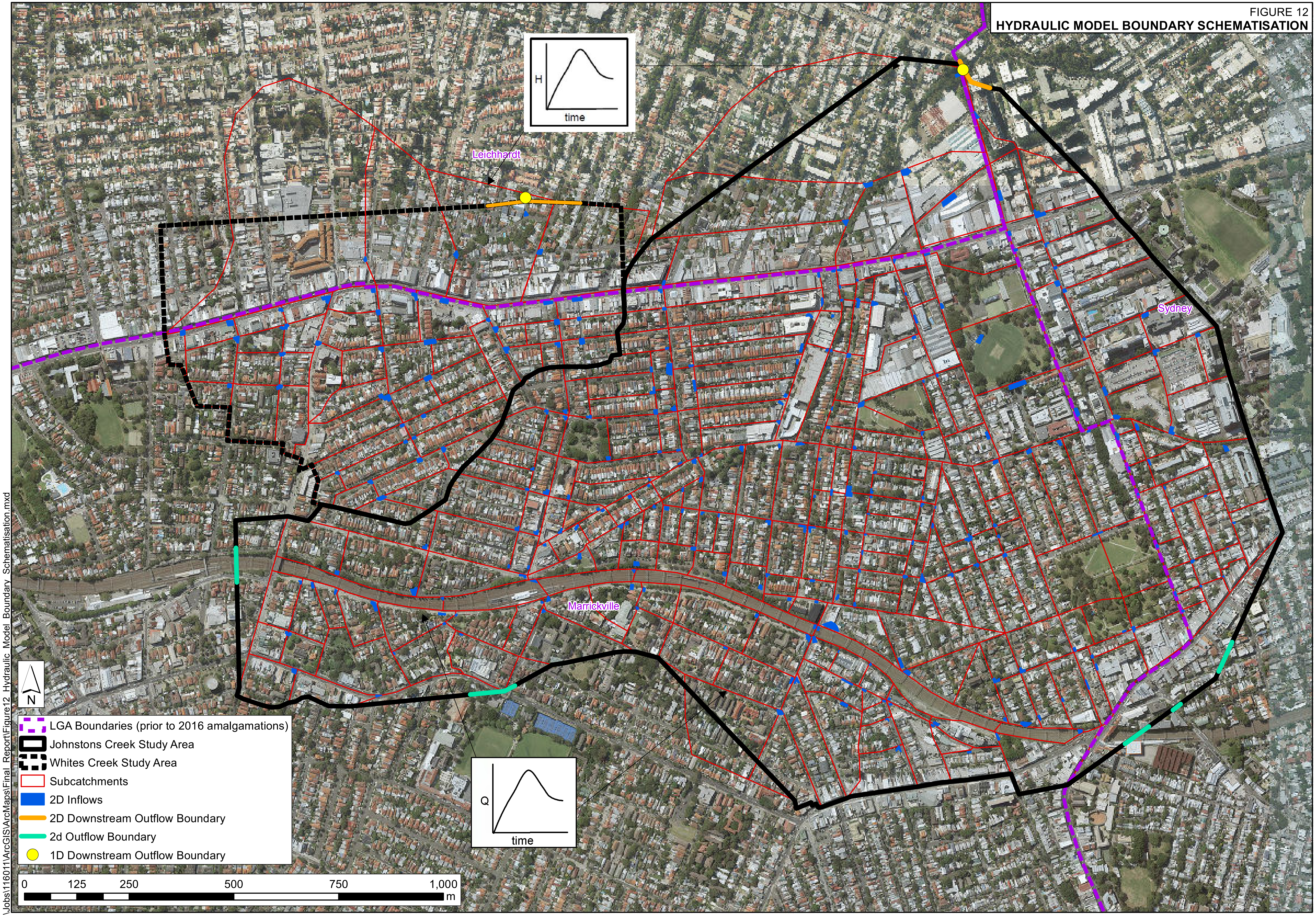
FIGURE 10H
BURST INTENSITIES AND FREQUENCIES 17 FEB 1993

FIGURE 11
HYDROLOGIC MODEL SCHEMATISATION



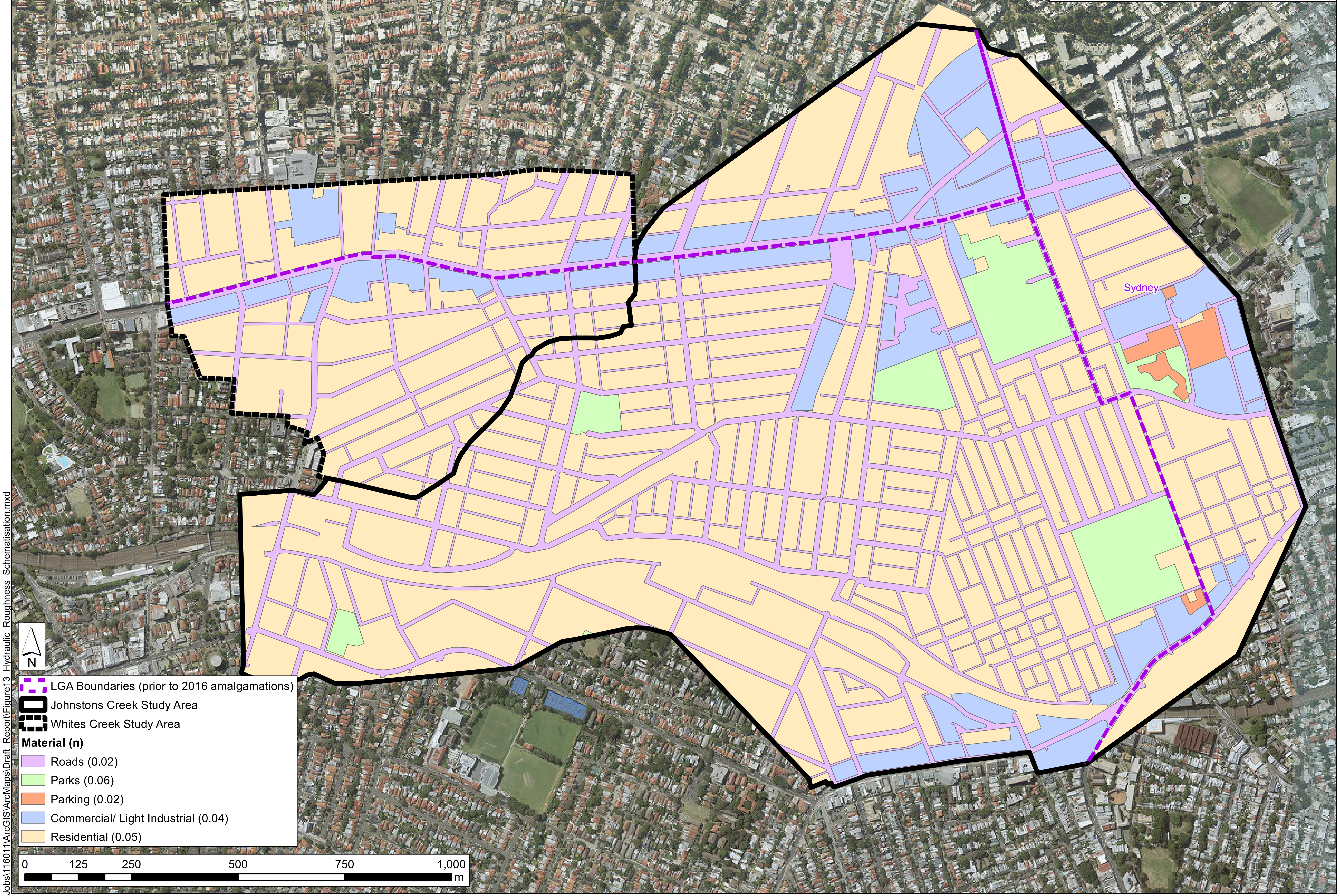
J:\Jobs\116011\ArcGIS\ArcMaps\Final_Report\Figure11_Hydrologic_Model_Schematisation.mxd

FIGURE 12
HYDRAULIC MODEL BOUNDARY SCHEMATISATION



J:\Jobs\116011\ArcGIS\ArcMaps\Final_Report\Figure12_Hydraulic_Model_Boundary_Schematisation.mxd

FIGURE 13
HYDRAULIC ROUGHNESS SCHEMATISATION

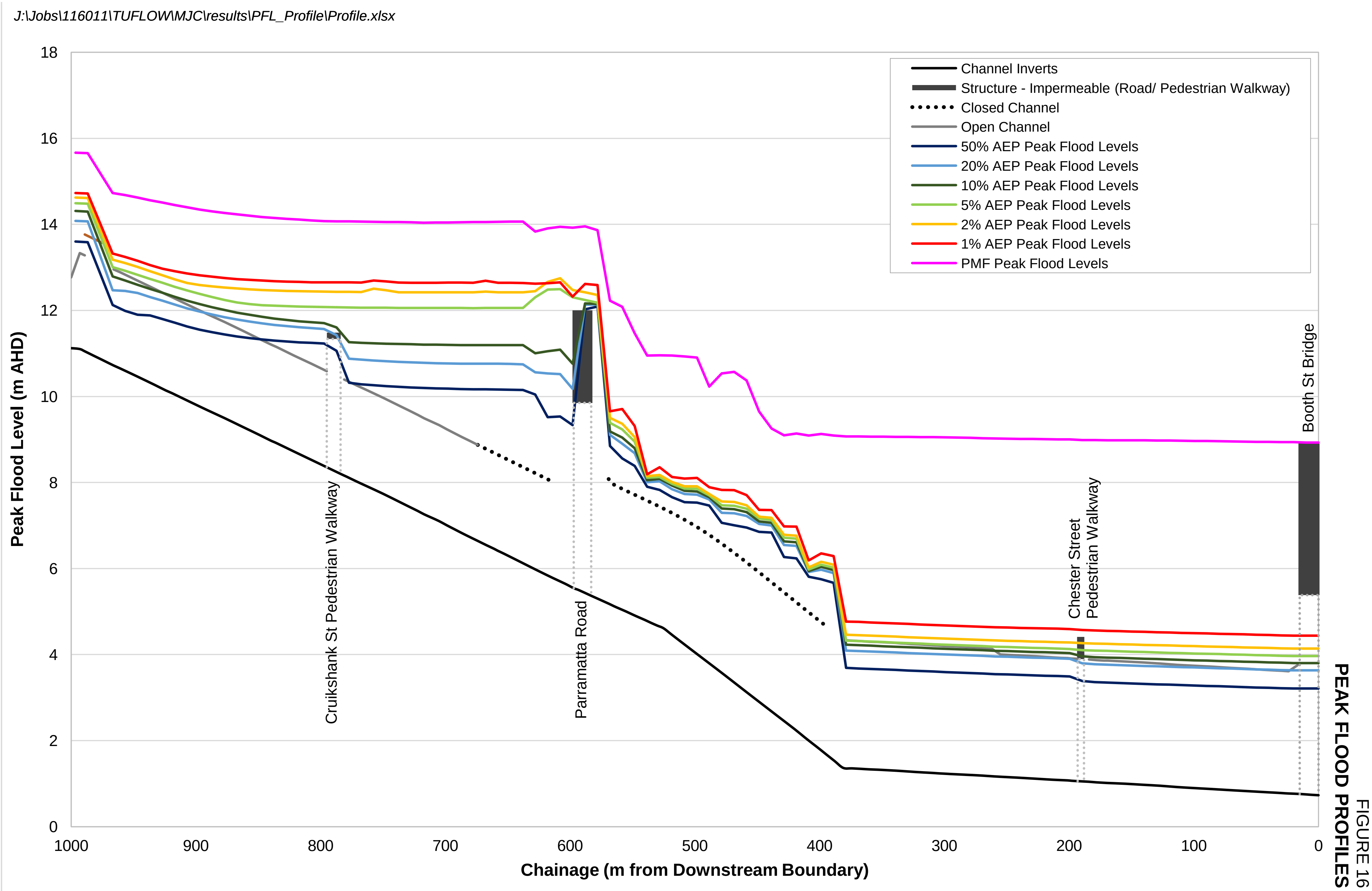


J:\Jobs\116011\ArcGIS\ArcMaps\Draft_Report\Figure13_Hydraulic_Roughness_Schematisation.mxd

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

J:\Jobs\116011\ArcGIS\ArcMaps\Final_Report\Figure14_Calibration_Peak_Depths_and_Levels_25April2015.mxd

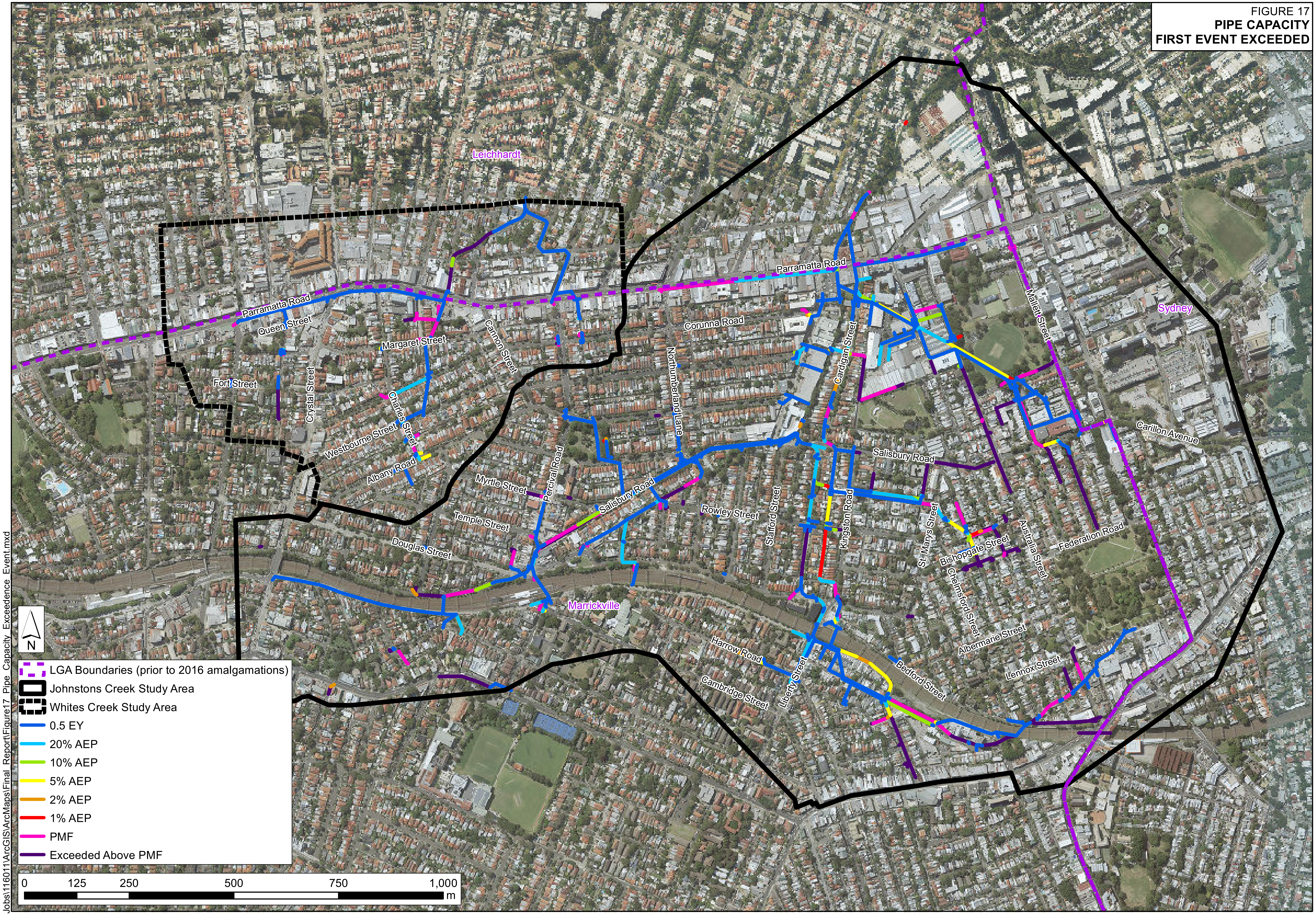
FIGURE 15
RESULTS LAYOUT



PEAK FLOOD PROFILES

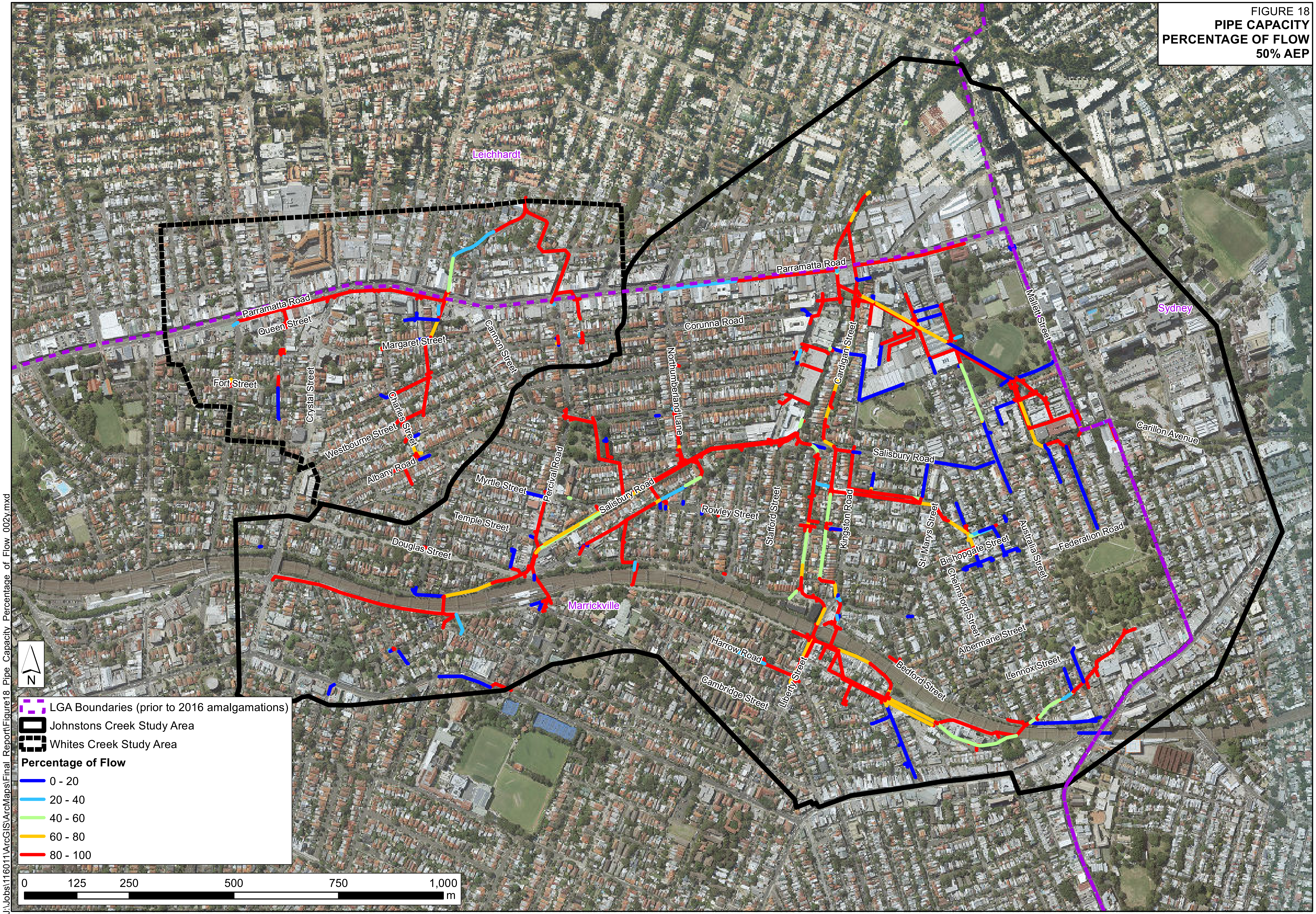
FIGURE 16

FIGURE 17
PIPE CAPACITY
FIRST EVENT EXCEEDED



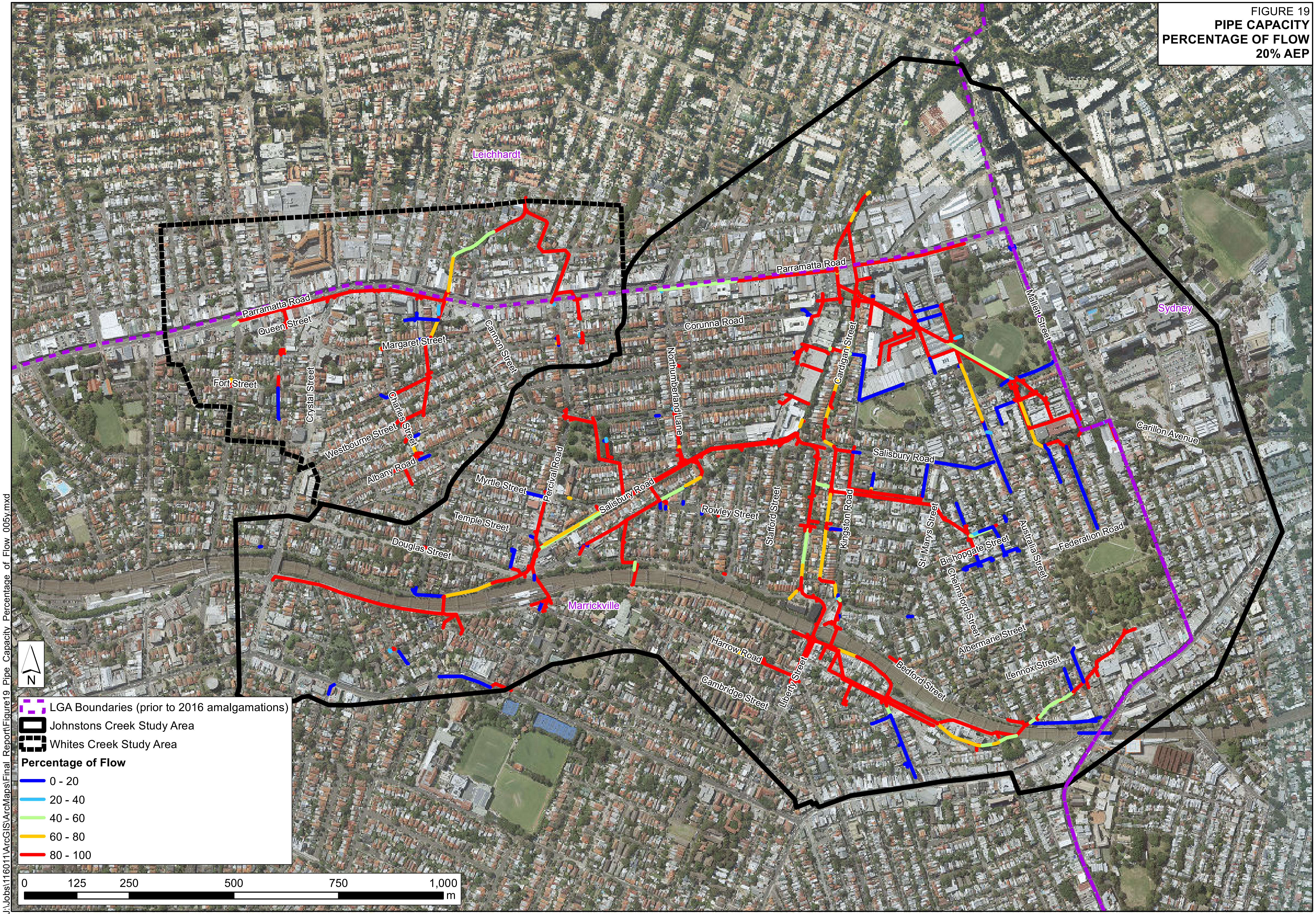
J:\Jobs\116011\ArcGIS\ArcMaps\Final_Report\Figure17_Pipe_Capacity_Exceedence_Event.mxd

FIGURE 18
PIPE CAPACITY
PERCENTAGE OF FLOW
50% AEP



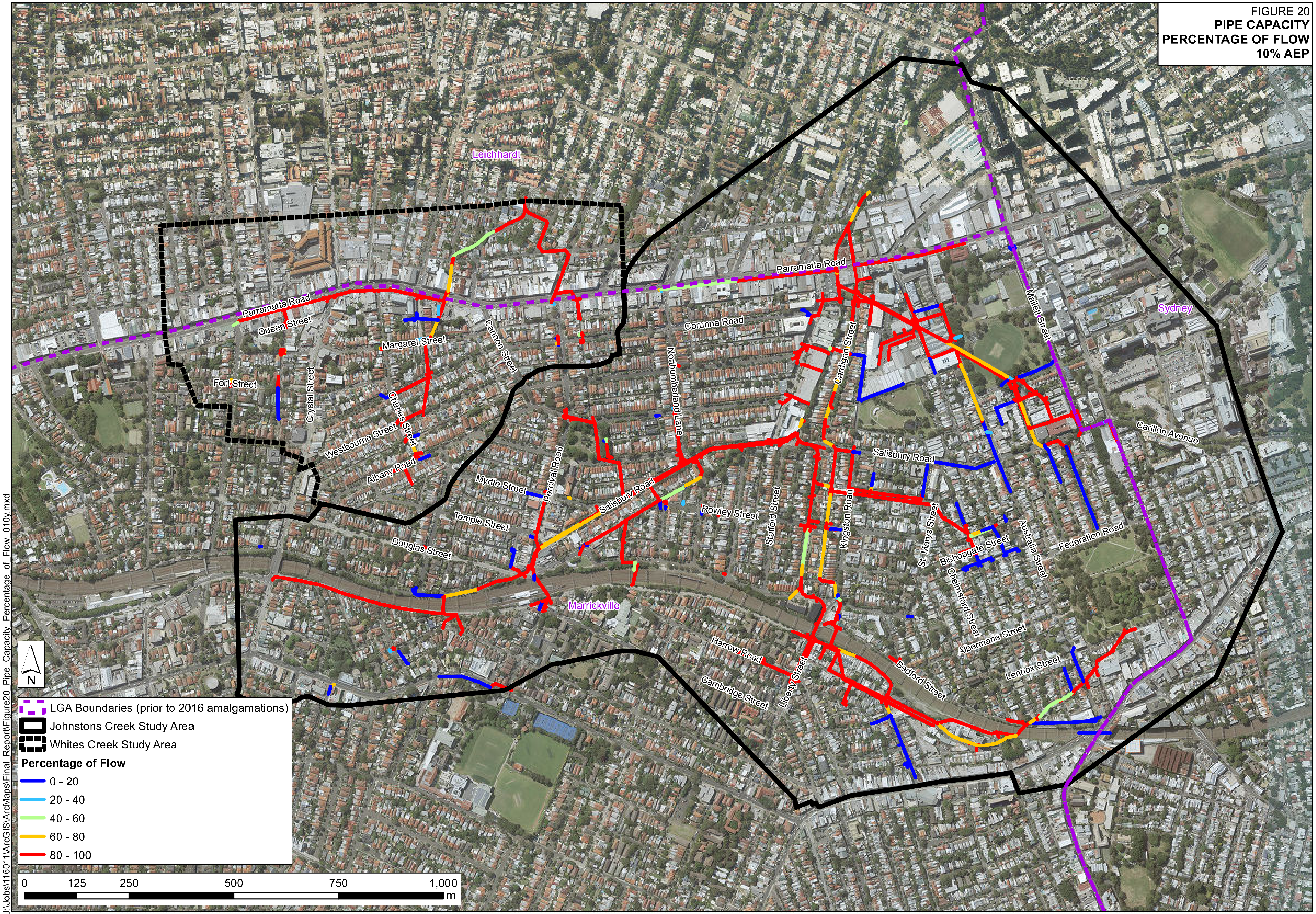
J:\Jobs\116011\ArcGIS\ArcMaps\Final Report\Figure18_Pipe_Capacity_Percentage_of_Flow_002v.mxd

FIGURE 19
PIPE CAPACITY PERCENTAGE OF FLOW 20% AEP



J:\Jobs\116011\ArcGIS\ArcMaps\Final Report\Figure19 Pipe Capacity Percentage of Flow 005v.mxd

FIGURE 20
PIPE CAPACITY PERCENTAGE OF FLOW 10% AEP



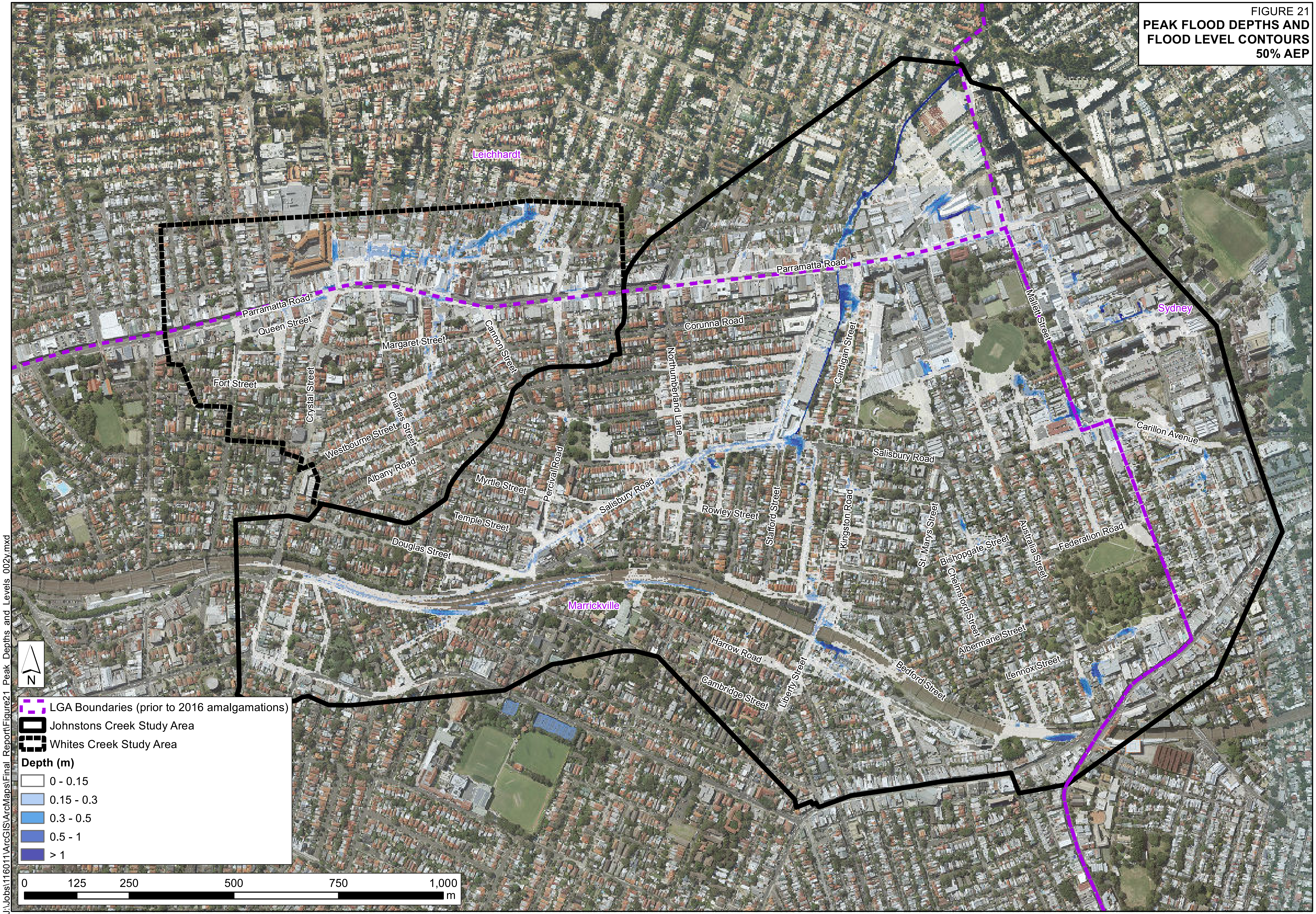


FIGURE 21
PEAK FLOOD DEPTHS AND
FLOOD LEVEL CONTOURS
50% AEP
Leichhardt
Sydney
Marrickville
Parramatta Road
Queen Street
Margaret Street
Cannon Street
Corunna Road
Northumberland Lane
Cardigan Street
Mallett Street
Fort Street
Crystal Street
Charles Street
Westbourne Street
Albany Road
Myrtle Street
Percival Road
Temple Street
Salisbury Road
Douglas Street
Rowley Street
Stafford Street
Kingston Road
St. Mary's Street
Bishopgate Street
Chelmsford Street
Australia Street
Federation Road
Carillon Avenue
Albermarie Street
Lennox Street
Harrow Road
Cambridge Street
Liberty Street
Bedford Street
LGA Boundaries (prior to 2016 amalgamations)
Johnstons Creek Study Area
Whites Creek 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\116011\ArcGIS\ArcMaps\Final_Report\Figure21_Peak_Depths_and_Levels_002v.mxd

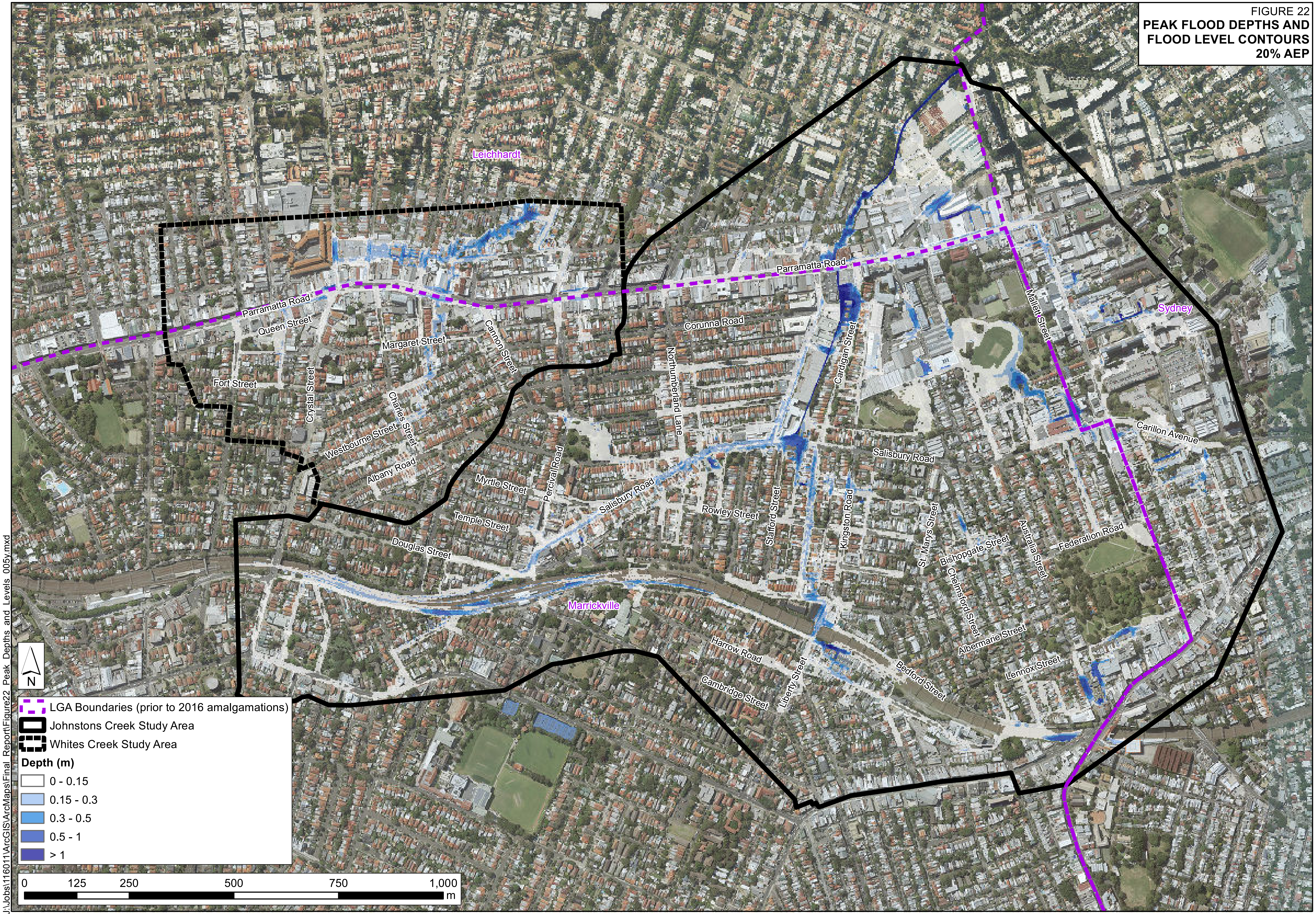
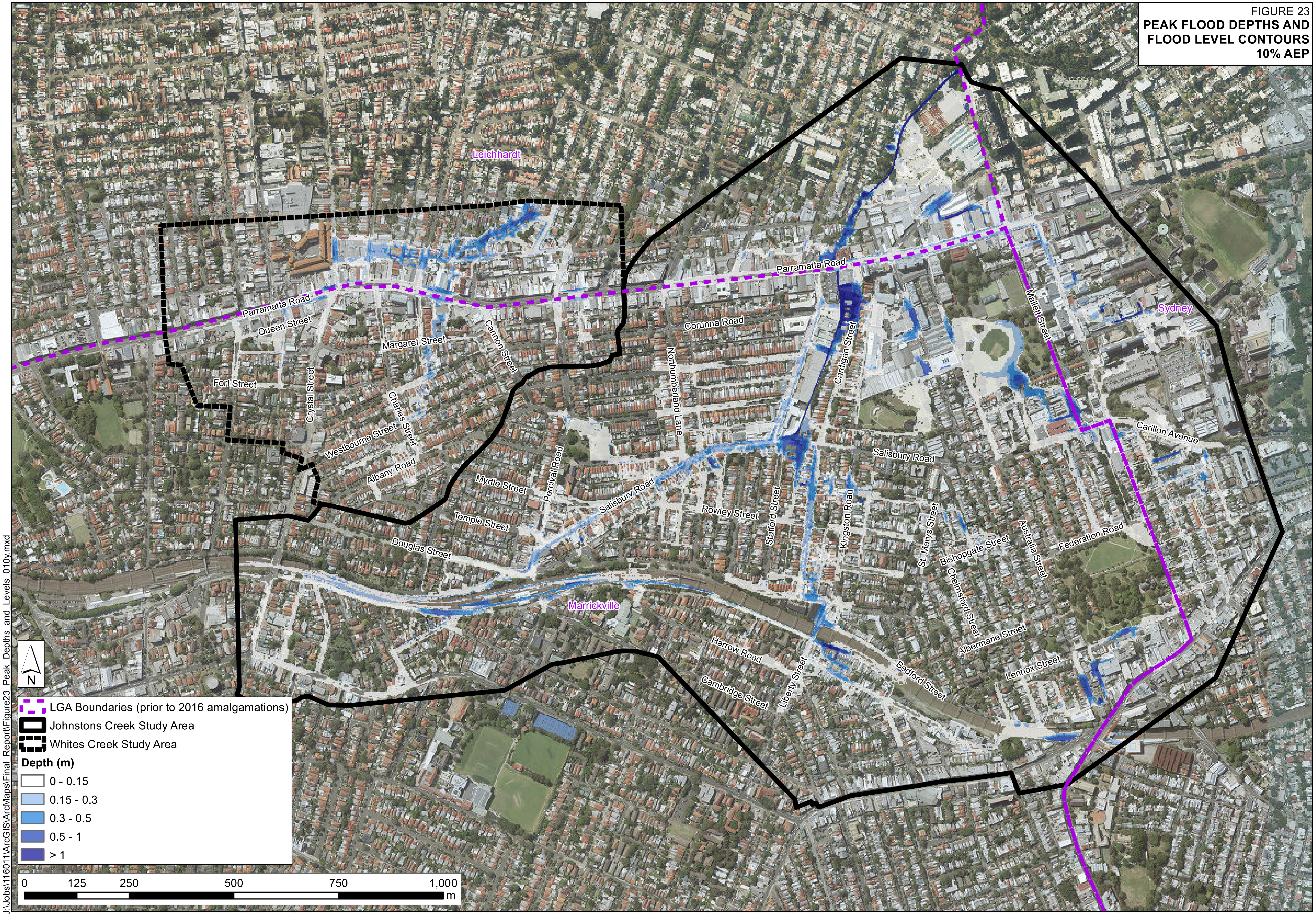


FIGURE 22
PEAK FLOOD DEPTHS AND
FLOOD LEVEL CONTOURS
20% AEP
Leichhardt
Sydney
Marrickville
Parramatta Road
Queen Street
Margaret Street
Cannon Street
Corunna Road
Northumberland Lane
Cardigan Street
Mallett Street
Fort Street
Crystal Street
Charles Street
Westbourne Street
Albany Road
Myrtle Street
Percival Road
Temple Street
Salisbury Road
Douglas Street
Rowley Street
Stafford Street
Kingston Road
St. Mary's Street
Bishopgate Street
Australia Street
Federation Road
Carillon Avenue
Chelmsford Street
Albermarle Street
Lennox Street
Harrow Road
Cambridge Street
Liberty Street
Bedford Street
N
LGA Boundaries (prior to 2016 amalgamations)
Johnstons Creek Study Area
Whites Creek 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
J:\Jobs\116011\ArcGIS\ArcMaps\Final_Report\Figure22_Peak_Depths_and_Levels_005v.mxd

FIGURE 23
PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS 10% AEP



J:\Jobs\116011\ArcGIS\ArcMaps\Final_Report\Figure23_Peak_Depths_and_Levels_010y.mxd

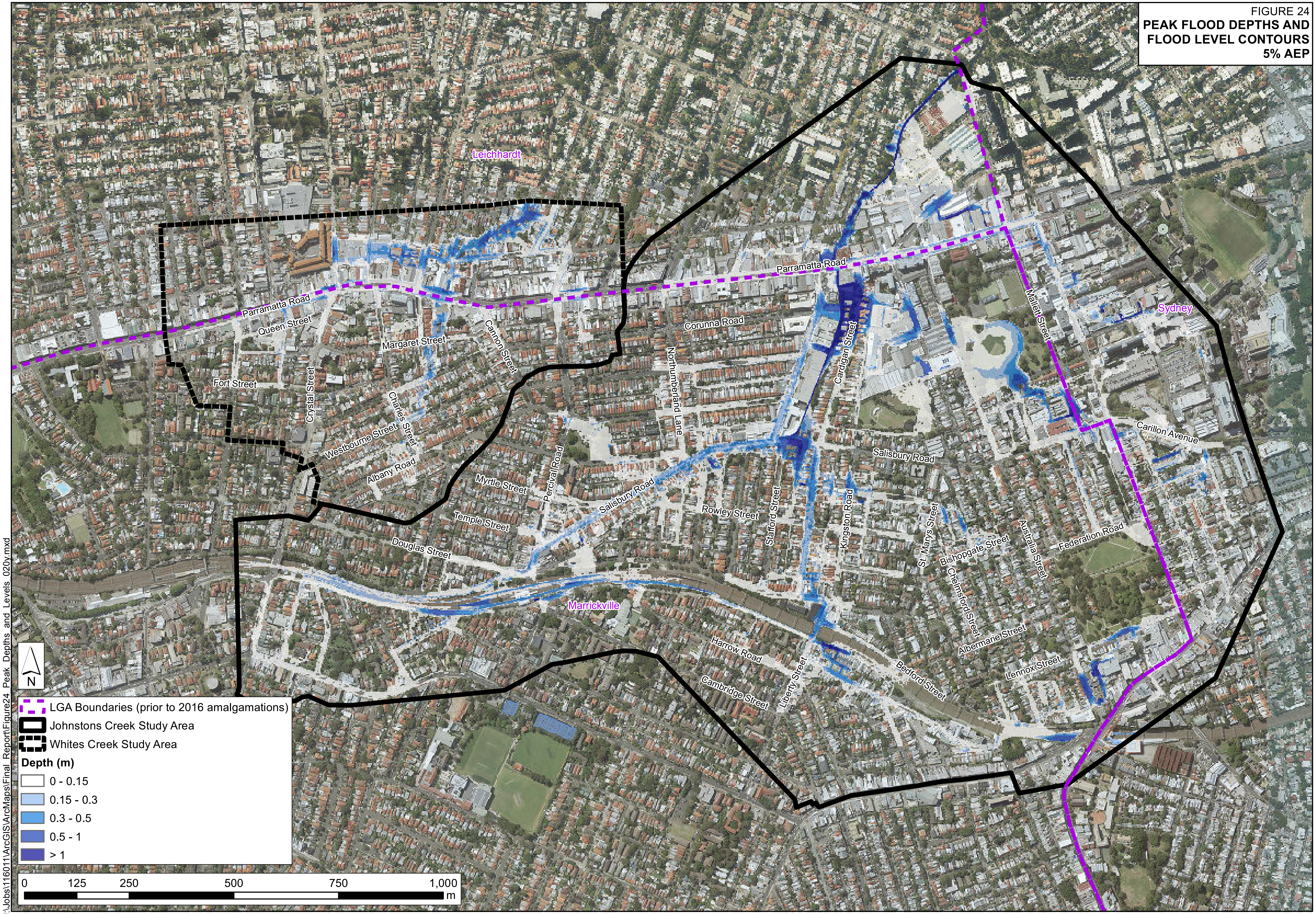
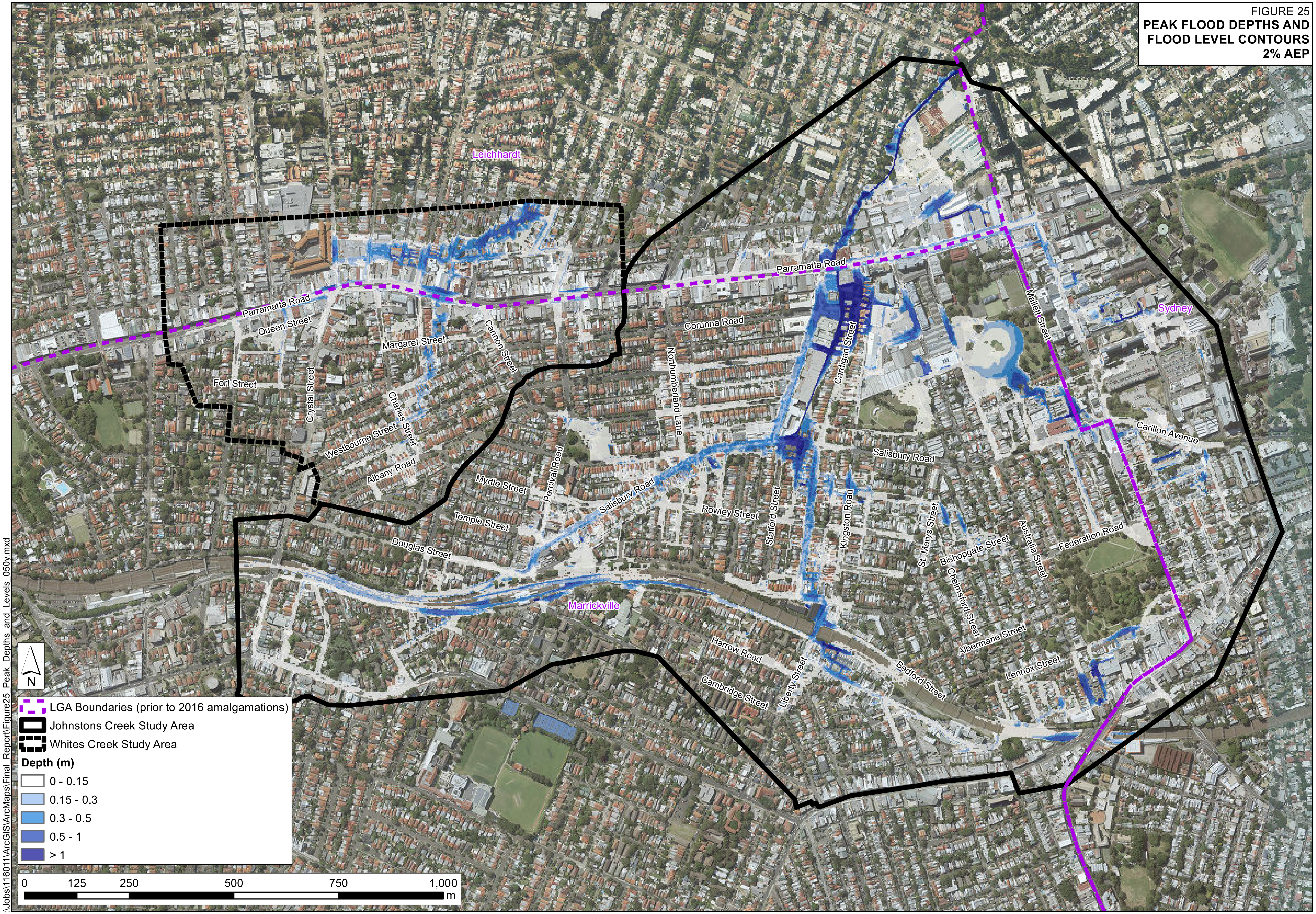
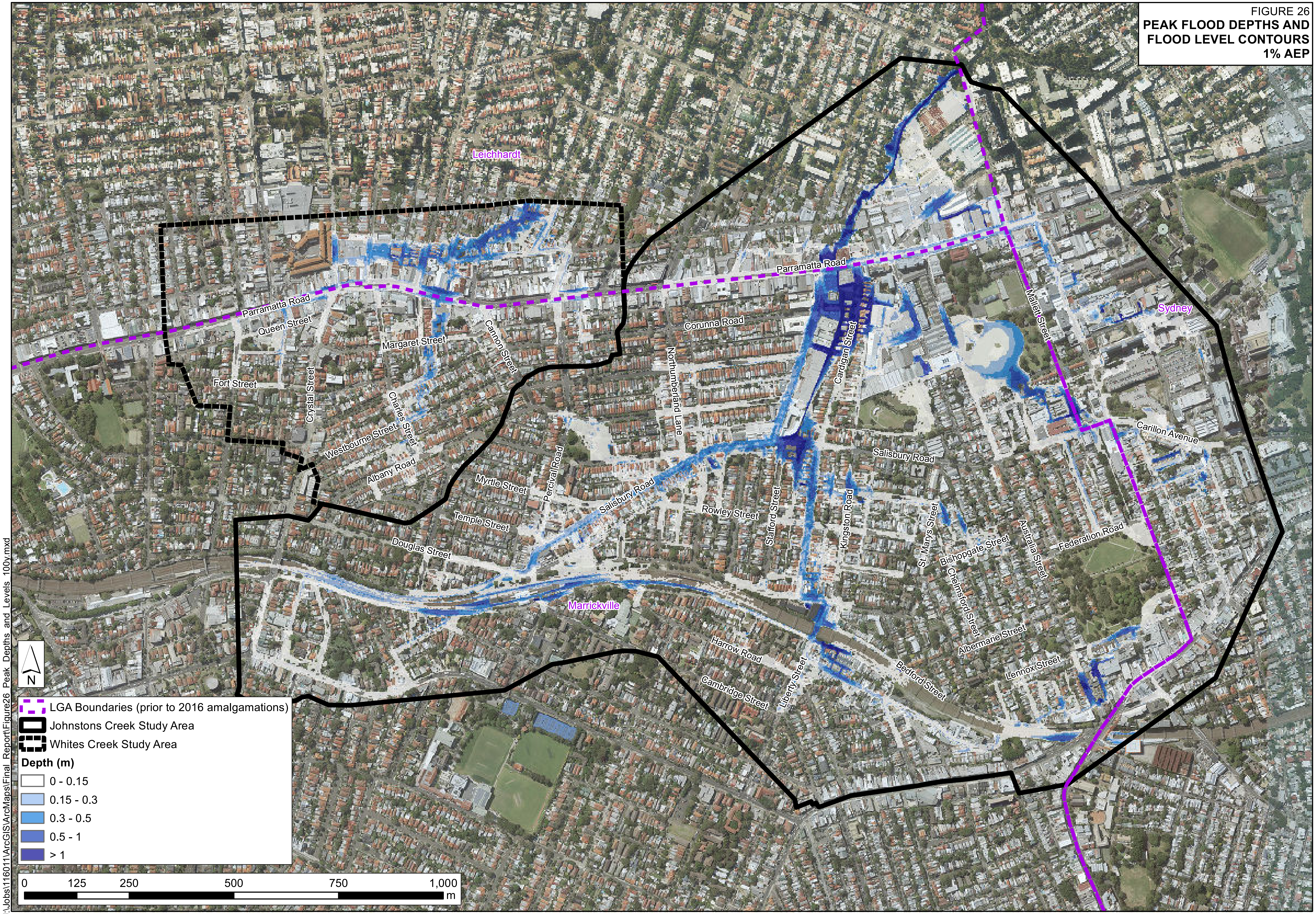


FIGURE 24
PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS 5% AEP

J:\Jobs\116011\ArcGIS\ArcMaps\Final_Report\Figure24_Peak_Depths_and_Levels_020v.mxd

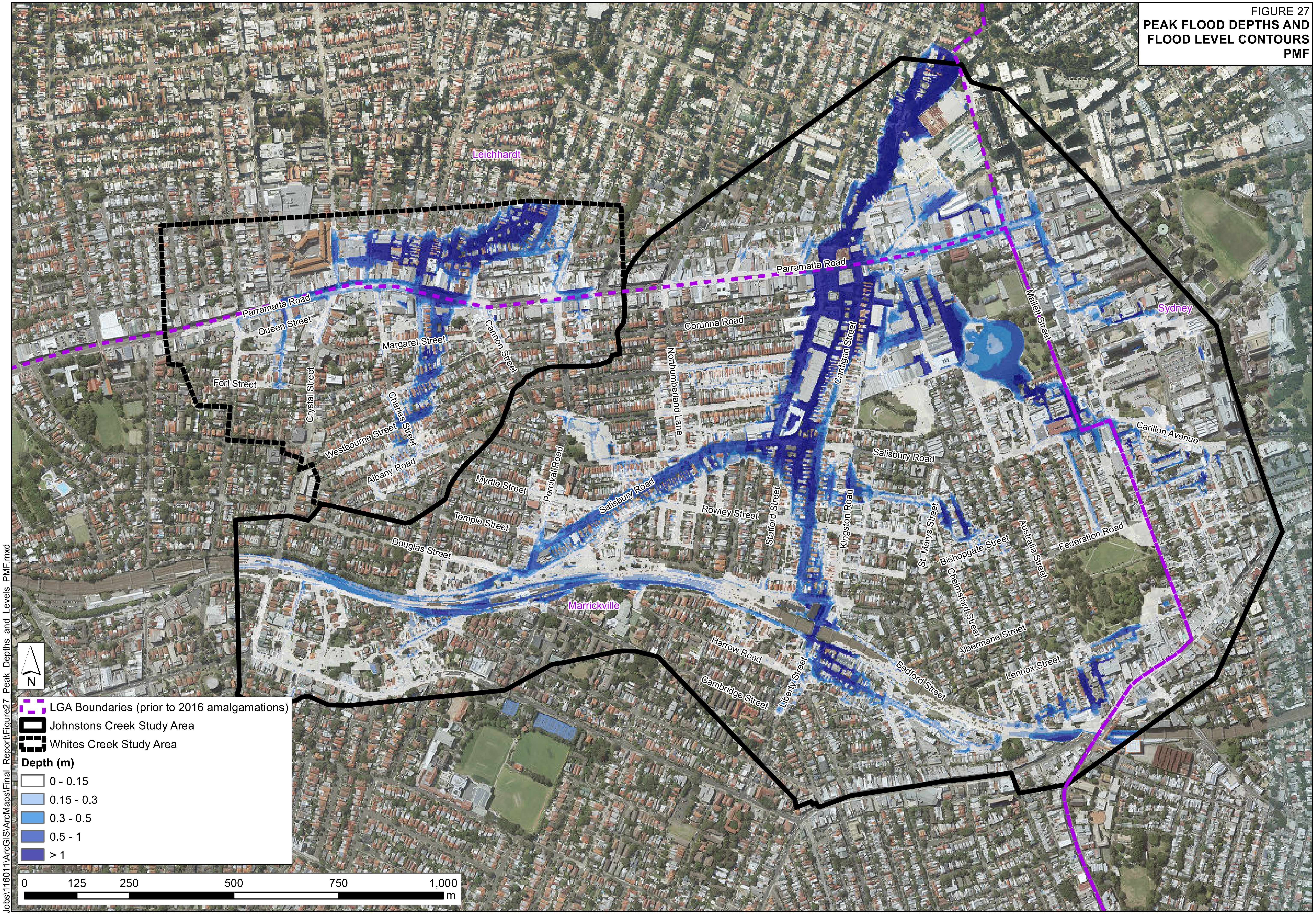


J:\Jobs\116011\ArcGIS\ArcMaps\Final_Report\Figure25_Peak_Depths_and_Levels_050y.mxd



J:\Jobs\116011\ArcGIS\ArcMaps\Final_Report\Figure26_Peak_Depths_and_Levels_100y.mxd

FIGURE 27
PEAK FLOOD DEPTHS AND FLOOD LEVEL CONTOURS PMF



J:\Jobs\116011\ArcGIS\ArcMaps\Final_Report\Figure27_Peak_Depths_and_Levels_PMF.mxd

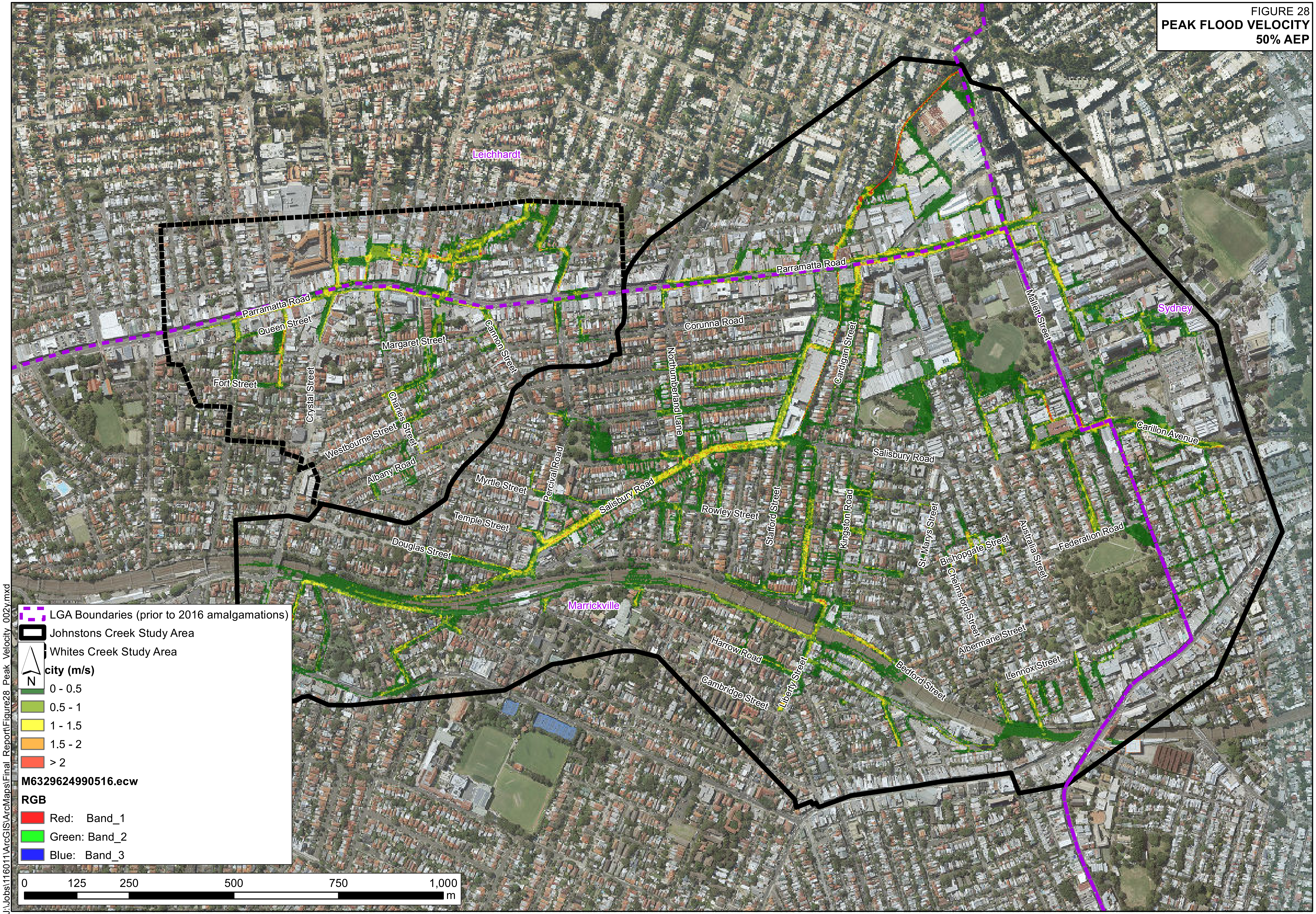
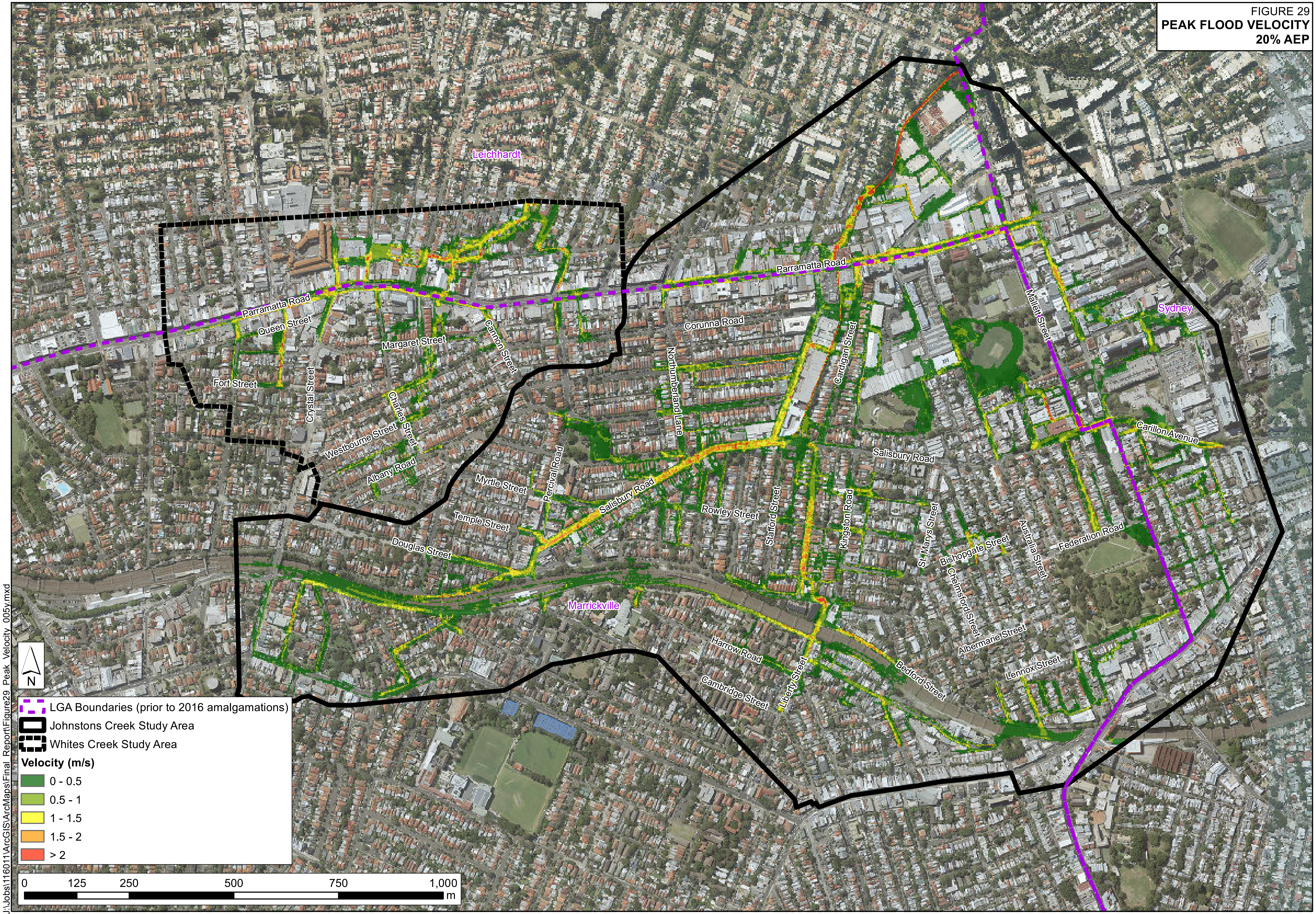


FIGURE 28
PEAK FLOOD VELOCITY
50% AEP

J:\Jobs\116011\ArcGIS\ArcMaps\Final_Report\Figure28_Peak_Velocity_002v.mxd

FIGURE 29
PEAK FLOOD VELOCITY
20% AEP



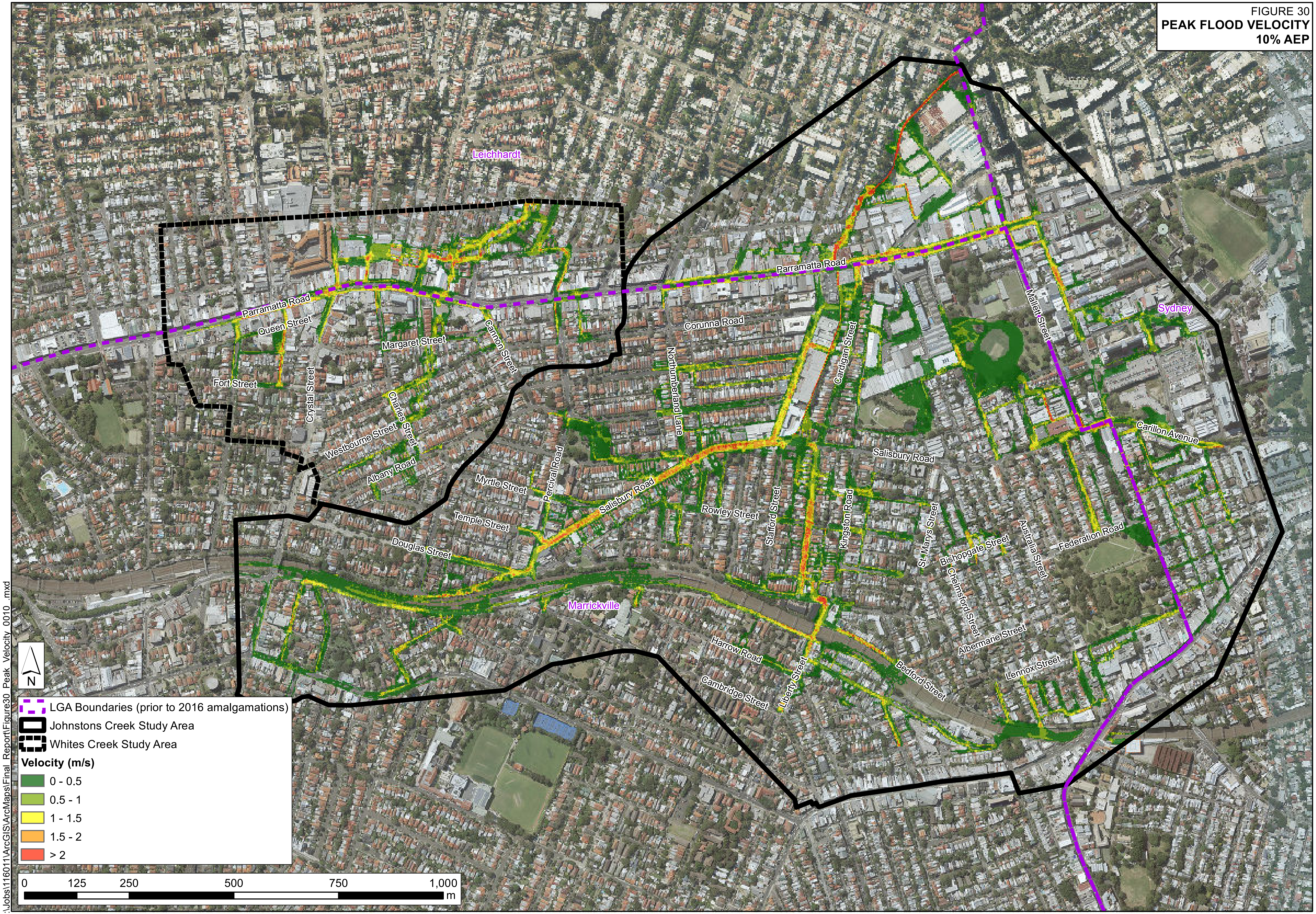


FIGURE 30
PEAK FLOOD VELOCITY
10% AEP

J:\Jobs\116011\ArcGIS\ArcMaps\Final_Report\Figure30_Peak_Velocity_0010_.mxd

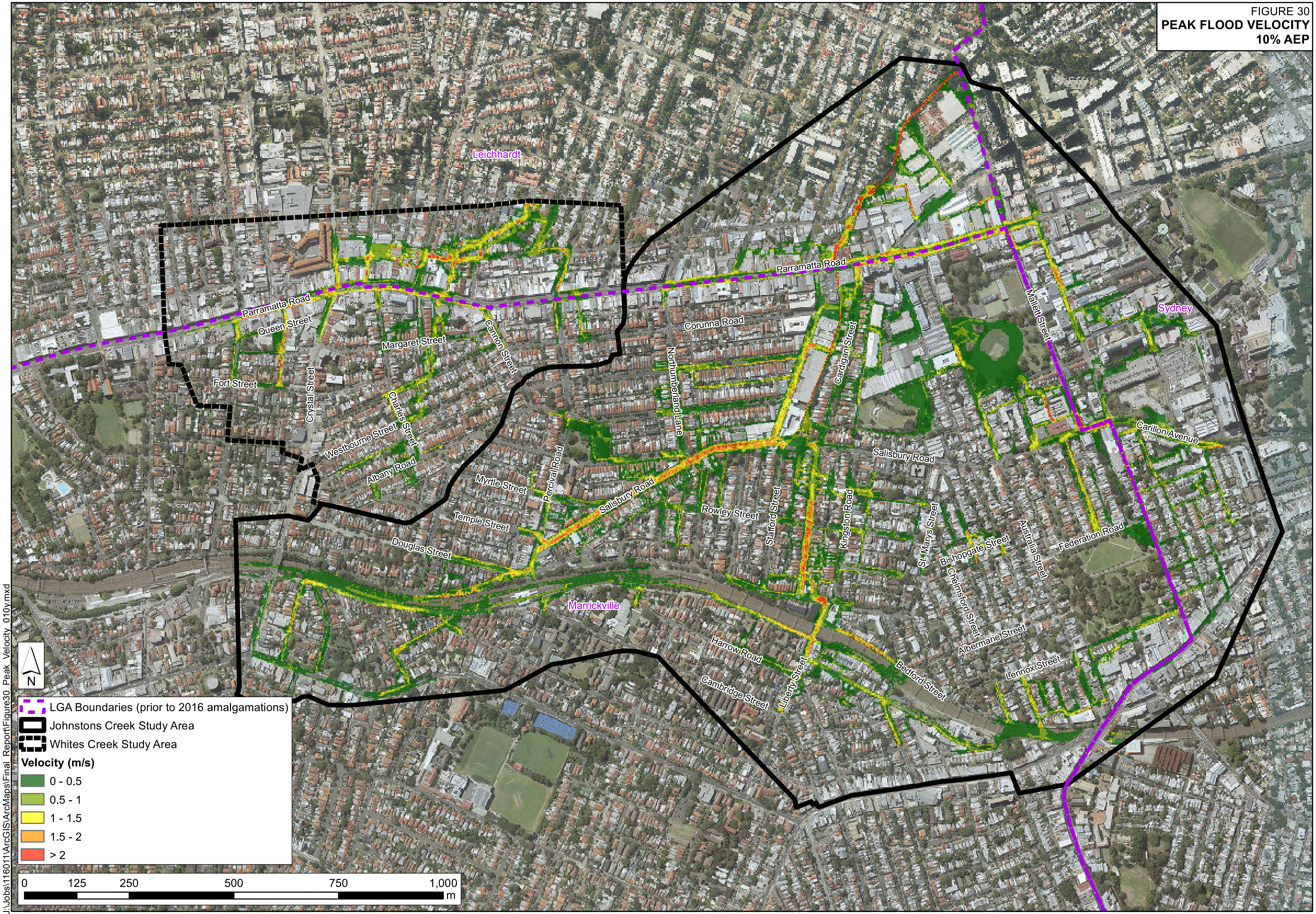


FIGURE 30
PEAK FLOOD VELOCITY
10% AEP

J:\Jobs\116011\ArcGIS\ArcMaps\Final_Report\Figure30_Peak_Velocity_010y.mxd

FIGURE 31
PEAK FLOOD VELOCITY
1% AEP

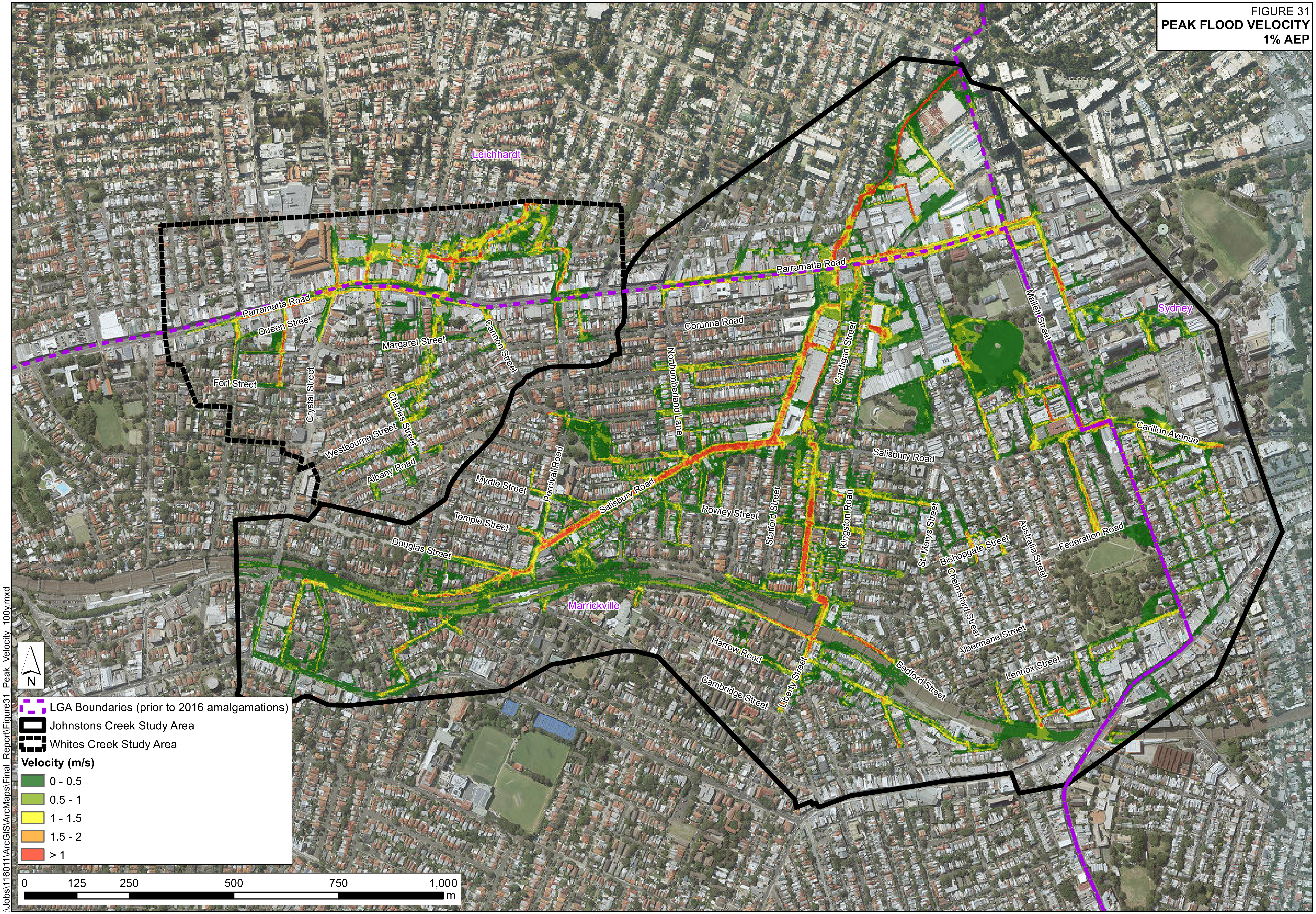
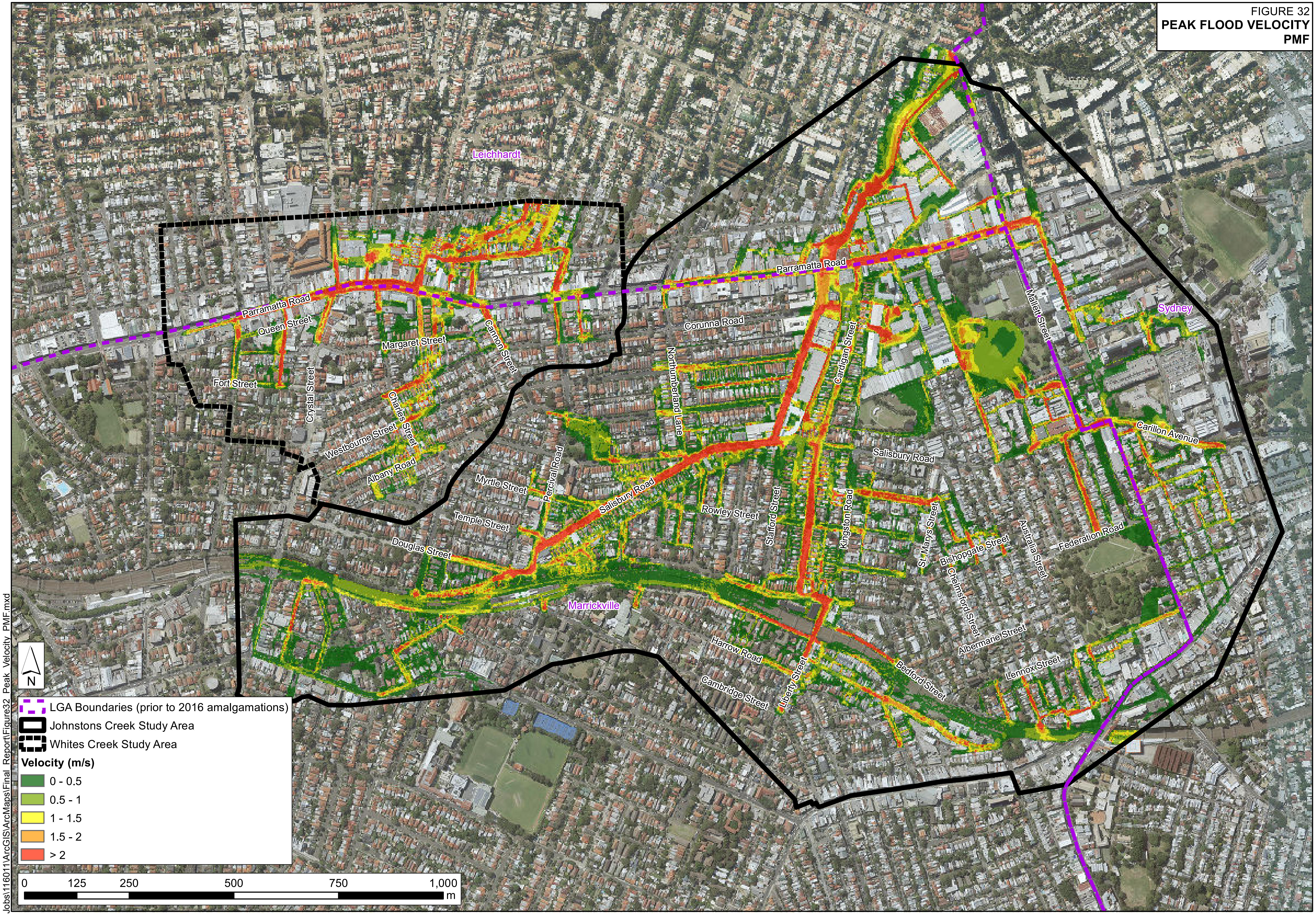
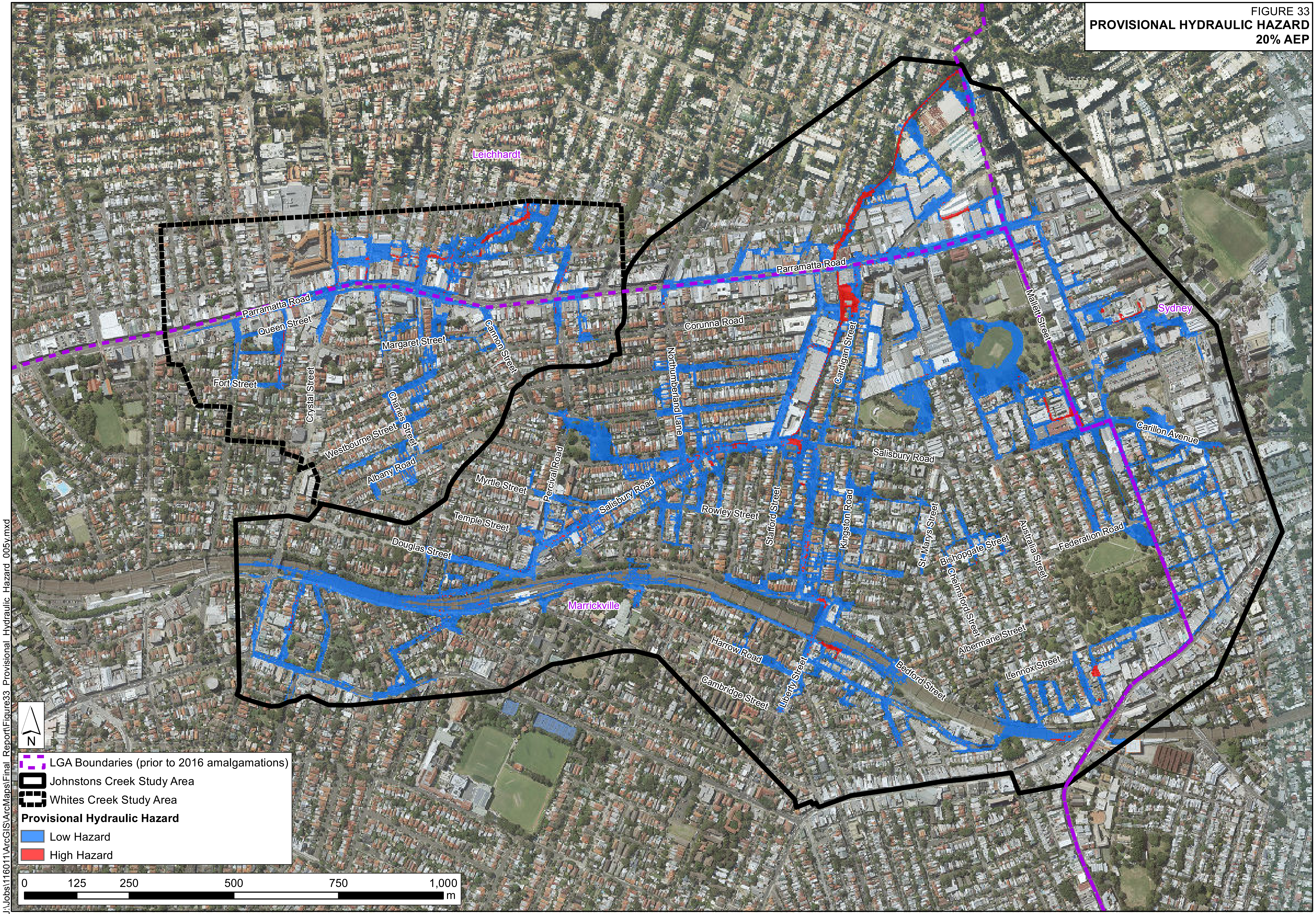


FIGURE 32
PEAK FLOOD VELOCITY
PMF



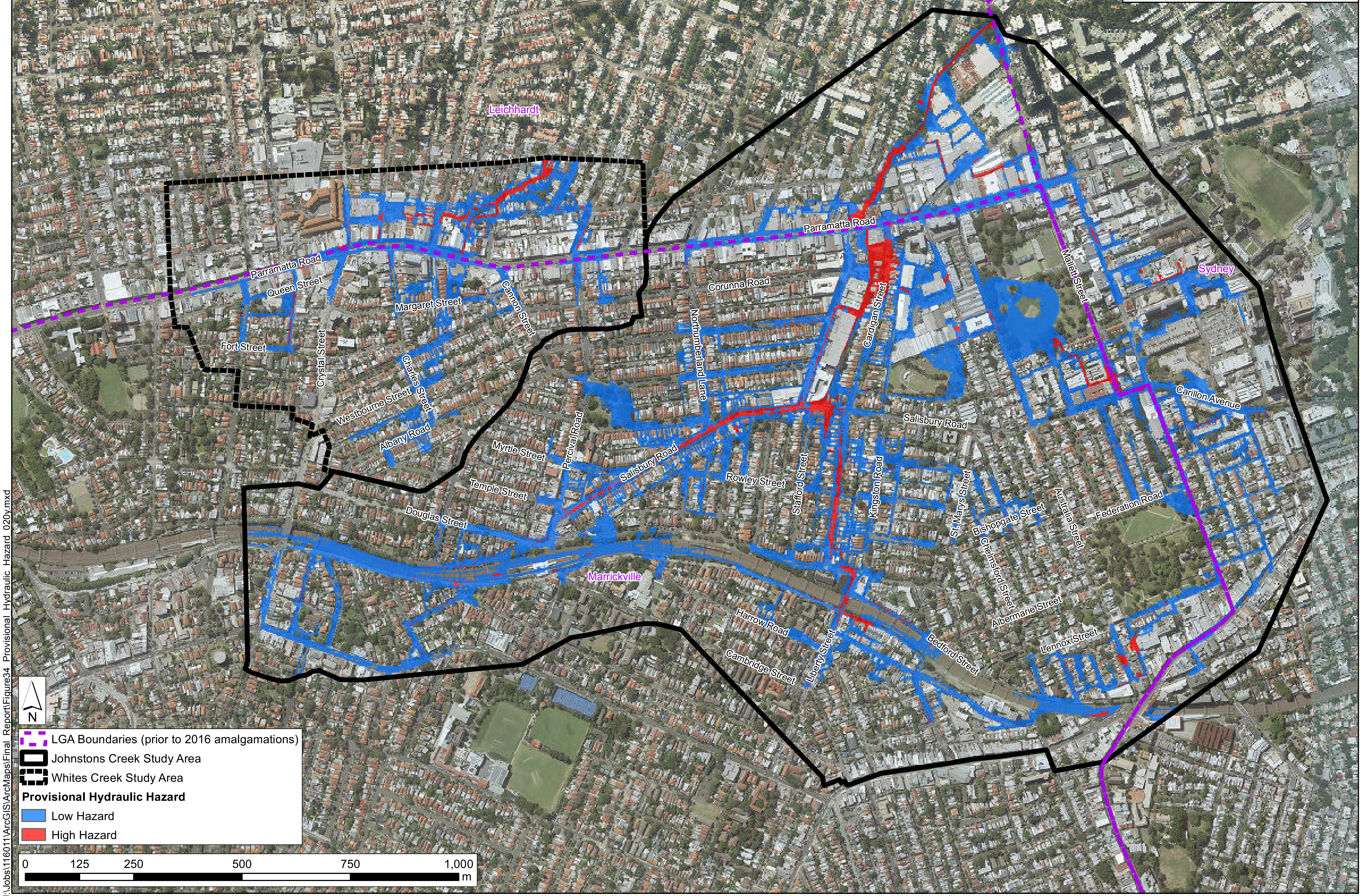
J:\Jobs\116011\ArcGIS\ArcMaps\Final_Report\Figure32_Peak_Velocity_PMF.mxd

FIGURE 33
PROVISIONAL HYDRAULIC HAZARD
20% AEP



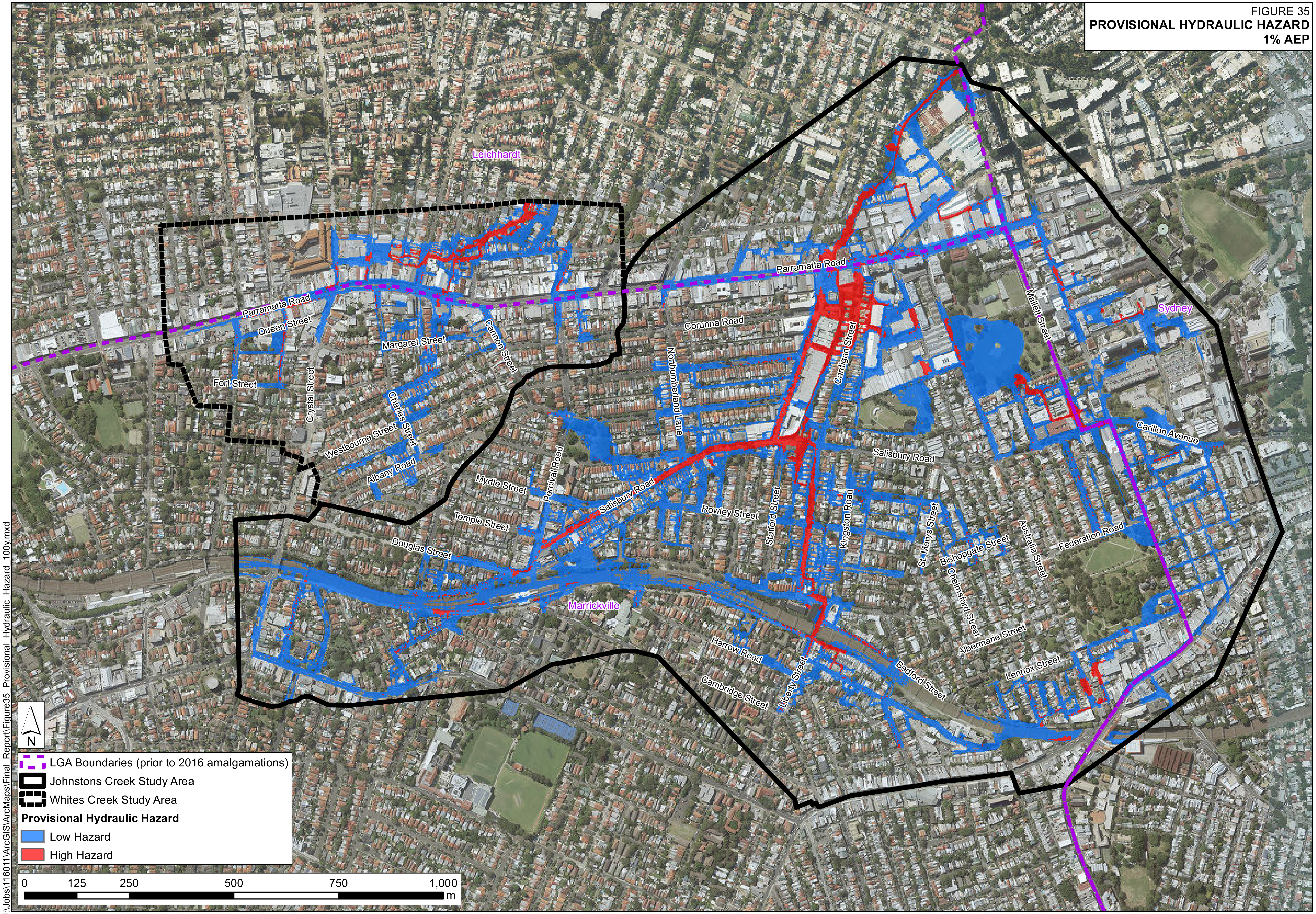
J:\Jobs\116011\ArcMaps\Final_Report\Figure33_Provisional_Hydraulic_Hazard_005v.mxd

FIGURE 34
PROVISIONAL HYDRAULIC HAZARD
5% AEP



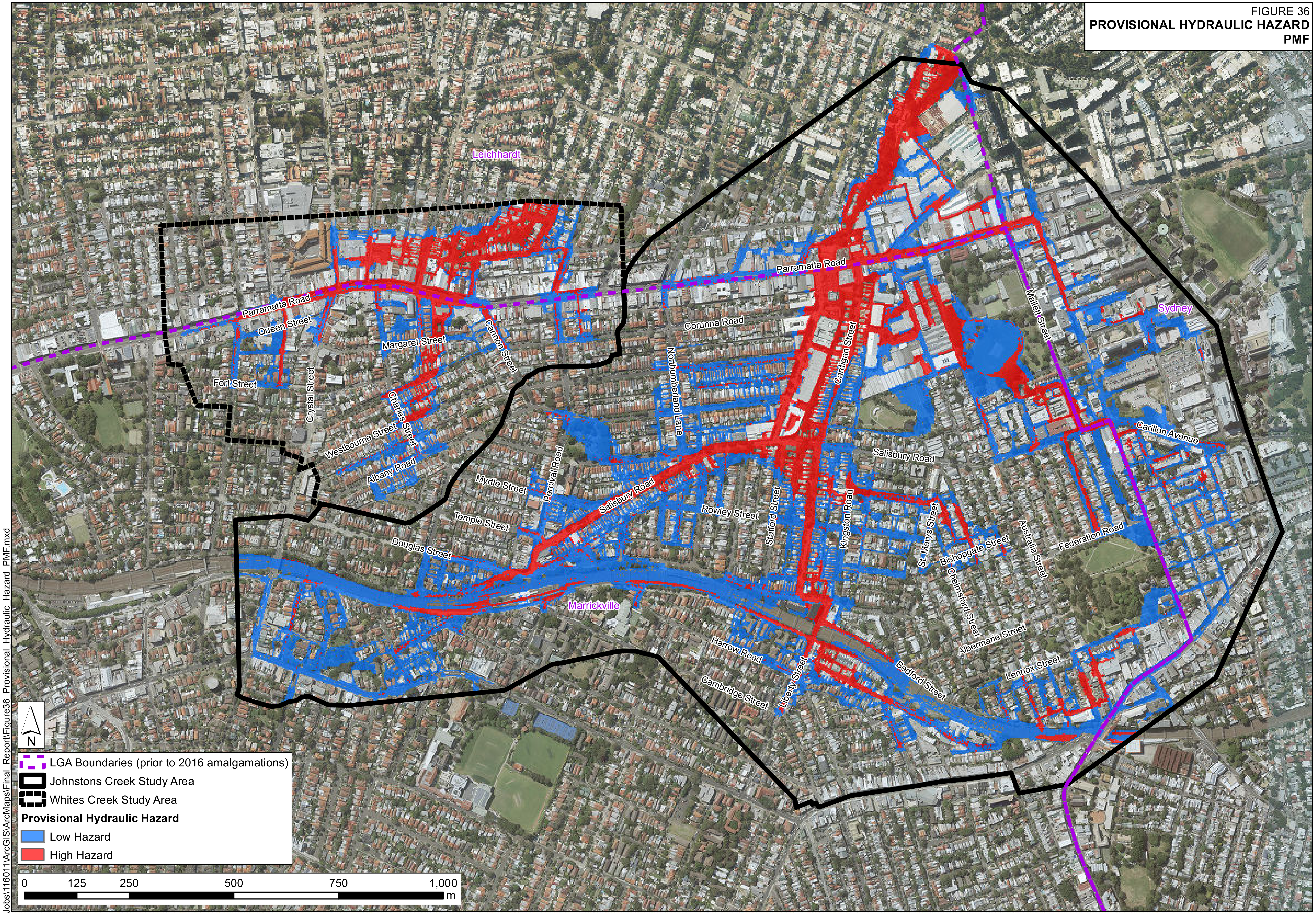
J:\Jobs\116011\ArcGIS\ArcMaps\Final Report\Figure34 Provisional Hydraulic Hazard 020v.mxd

FIGURE 35
PROVISIONAL HYDRAULIC HAZARD
1% AEP



J:\Jobs\116011\ArcGIS\ArcMaps\Final_Report\Figure35_Provisional_Hydraulic_Hazard_100y.mxd

FIGURE 36
PROVISIONAL HYDRAULIC HAZARD PMF



J:\Jobs\116011\ArcGIS\ArcMaps\Final_Report\Figure36_Provisional_Hydraulic_Hazard_PMF.mxd

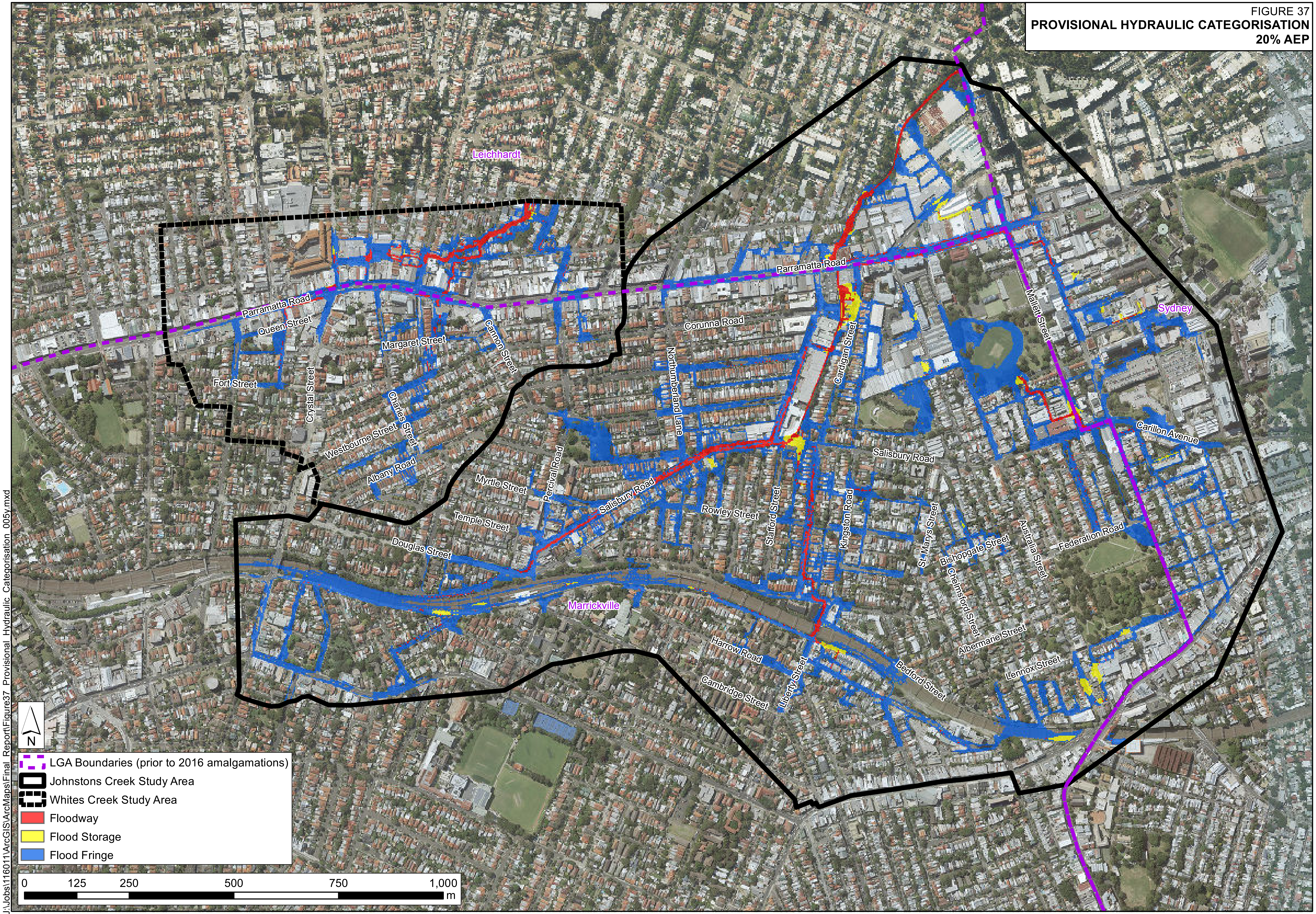
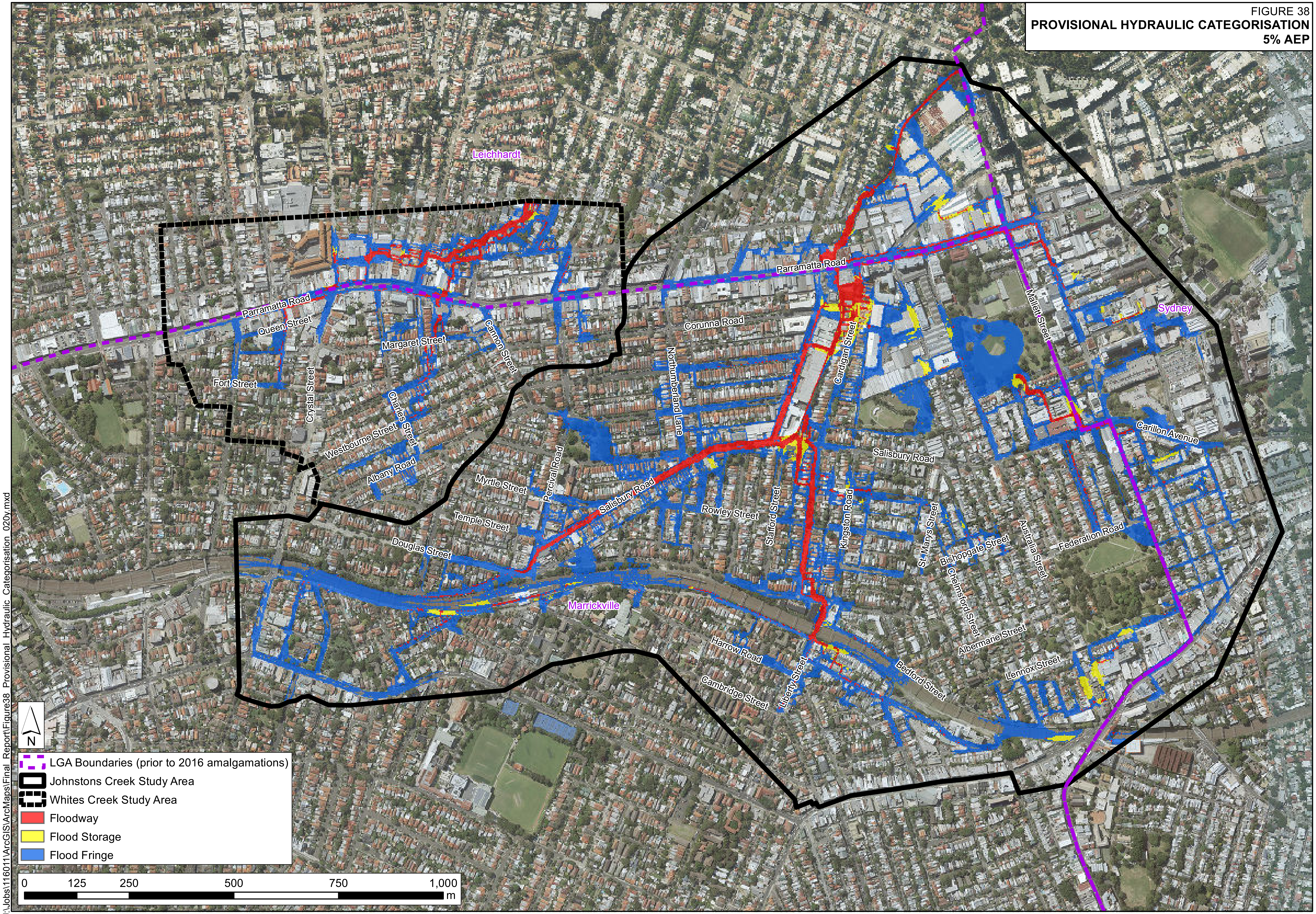


FIGURE 37
PROVISIONAL HYDRAULIC CATEGORISATION
20% AEP

J:\Jobs\116011\ArcGIS\ArcMaps\Final_Report\Figure37_Provisional_Hydraulic_Categorisation_005y.mxd



J:\Jobs\116011\ArcGIS\ArcMaps\Final_Report\Figure38_Provisional_Hydraulic_Categorisation_020v.mxd

FIGURE 39
PROVISIONAL HYDRAULIC CATEGORISATION
1% AEP

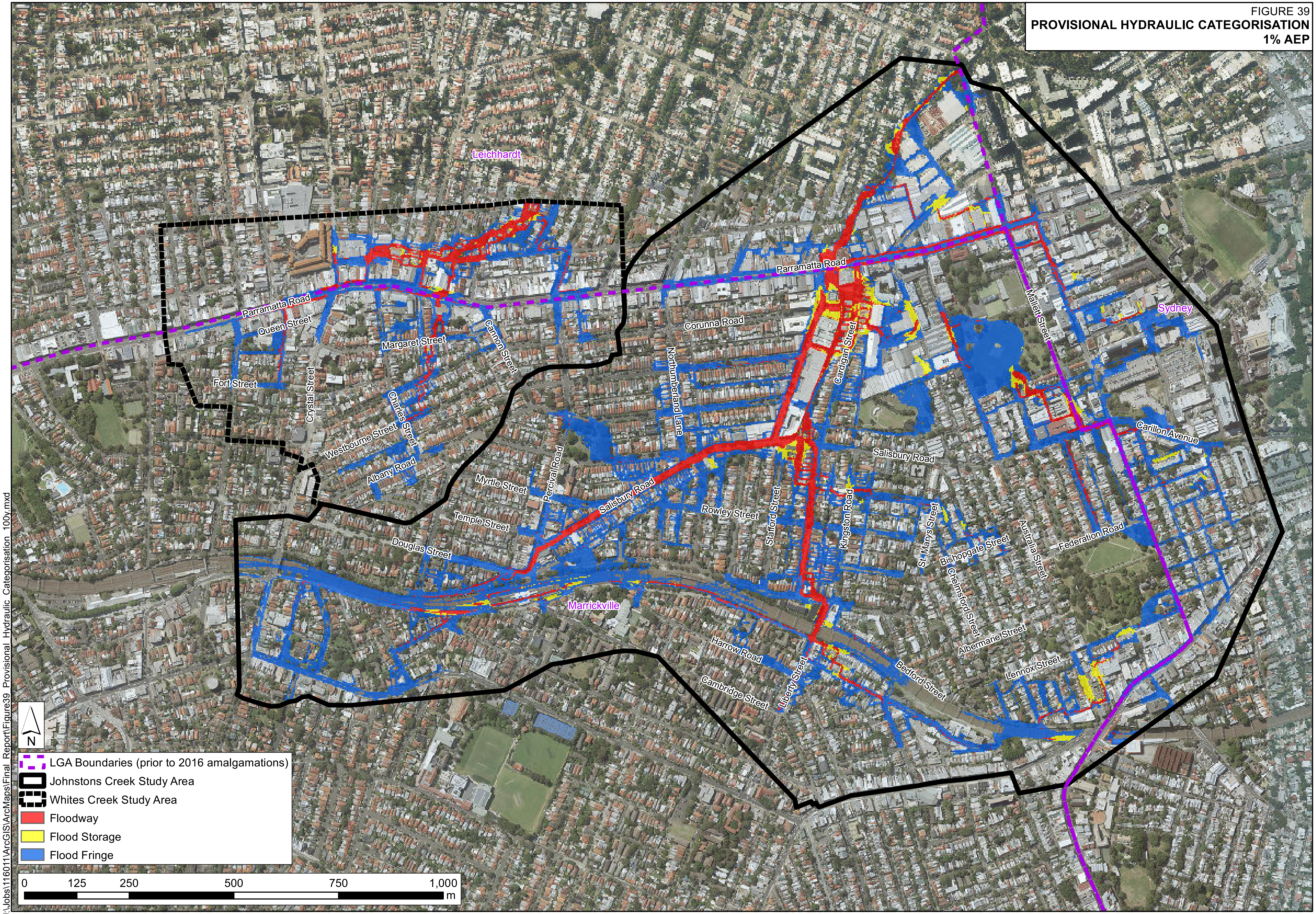
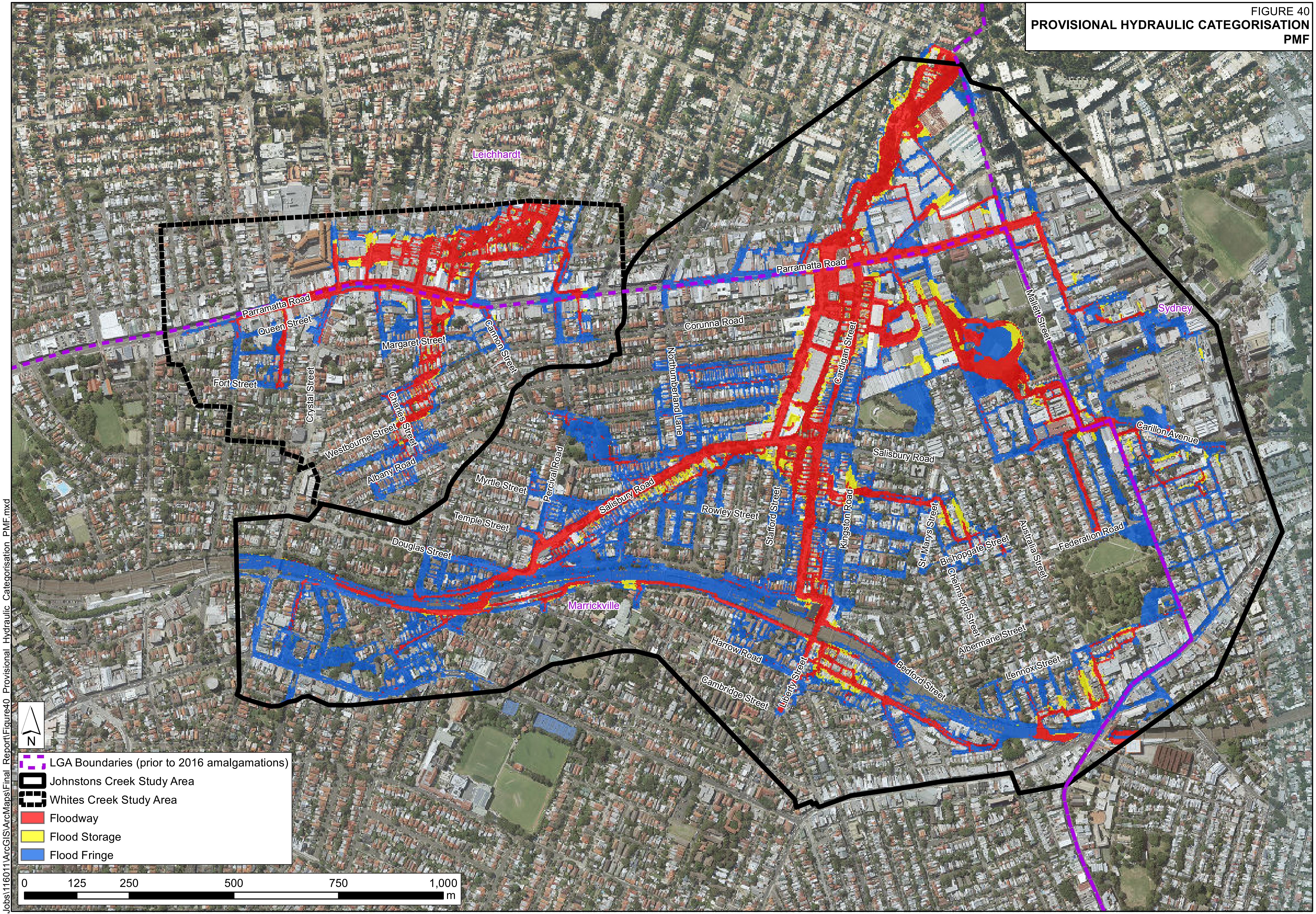
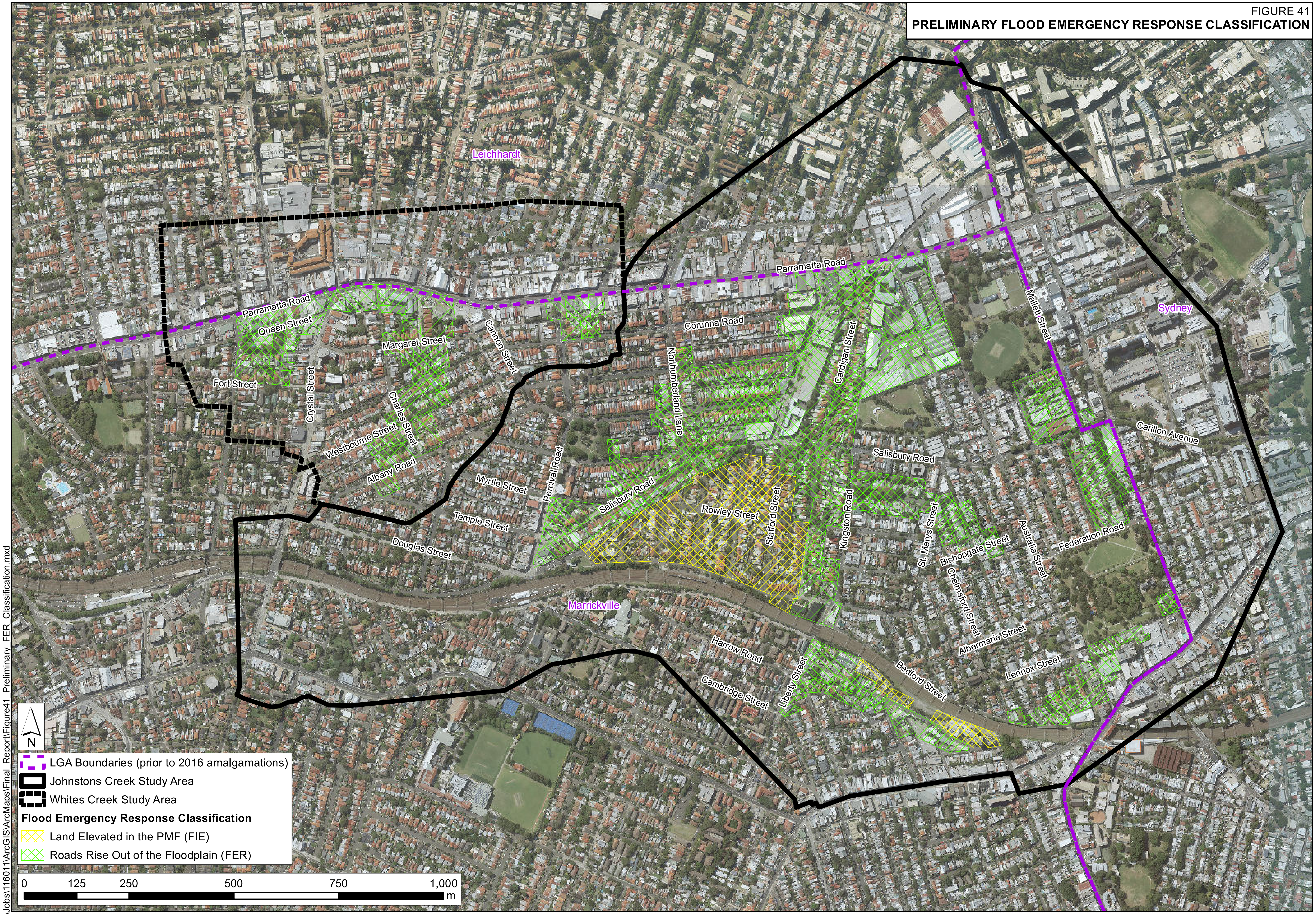


FIGURE 40
PROVISIONAL HYDRAULIC CATEGORISATION PMF



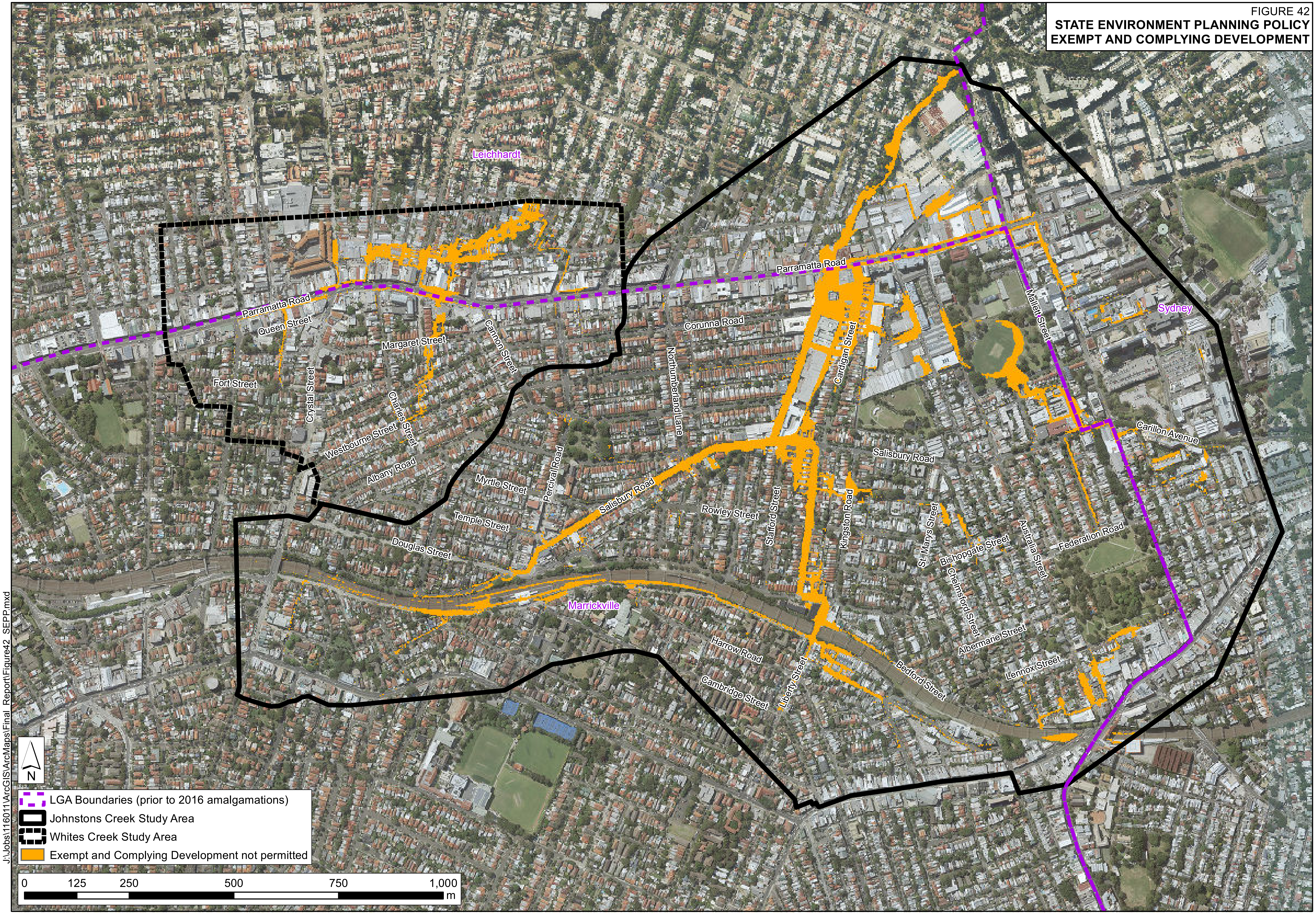
J:\Jobs\116011\ArcGIS\ArcMaps\Final_Report\Figure40_Provisional_Hydraulic_Categorisation_PMF.mxd

FIGURE 41
PRELIMINARY FLOOD EMERGENCY RESPONSE CLASSIFICATION



J:\Jobs\116011\ArcGIS\ArcMaps\Final_Report\Figure41_Preliminary_FER_Classification.mxd

FIGURE 42
STATE ENVIRONMENT PLANNING POLICY EXEMPT AND COMPLYING DEVELOPMENT



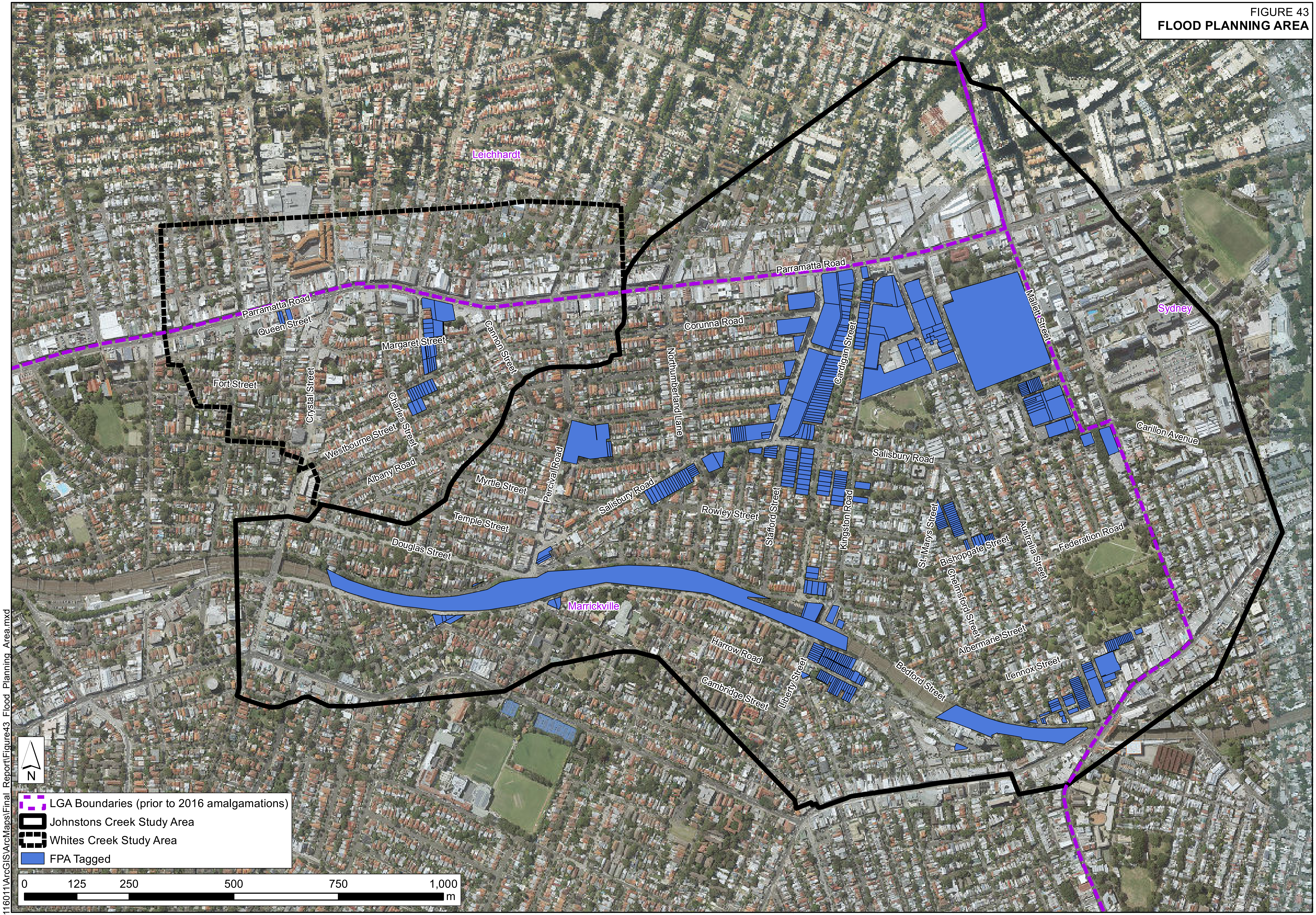


FIGURE 43
FLOOD PLANNING AREA

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Appendix A

Appendix A: Glossary

Taken from the Floodplain Development Manual (April 2005 edition)

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

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

disaster plan (DISPLAN) A step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.

discharge The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).

ecologically sustainable development (ESD) Using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act 1993. The use of sustainability and sustainable in this manual relate to ESD.

effective warning time The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.

emergency management A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.

flash flooding Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.

flood Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.

flood awareness Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.

flood education Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves an their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.

flood fringe areas The remaining area of flood prone land after floodway and flood storage areas have been defined.

flood liable land Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).

flood mitigation standard The average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.

floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
floodplain risk management options	The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
floodplain risk management plan	A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammetic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
flood plan (local)	A sub-plan of a disaster plan that deals specifically with flooding. They can exist at State, Division and local levels. Local flood plans are prepared under the leadership of the State Emergency Service.
flood planning area	The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the “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.

FIGURE B1
HOTSPOT LOCATIONS

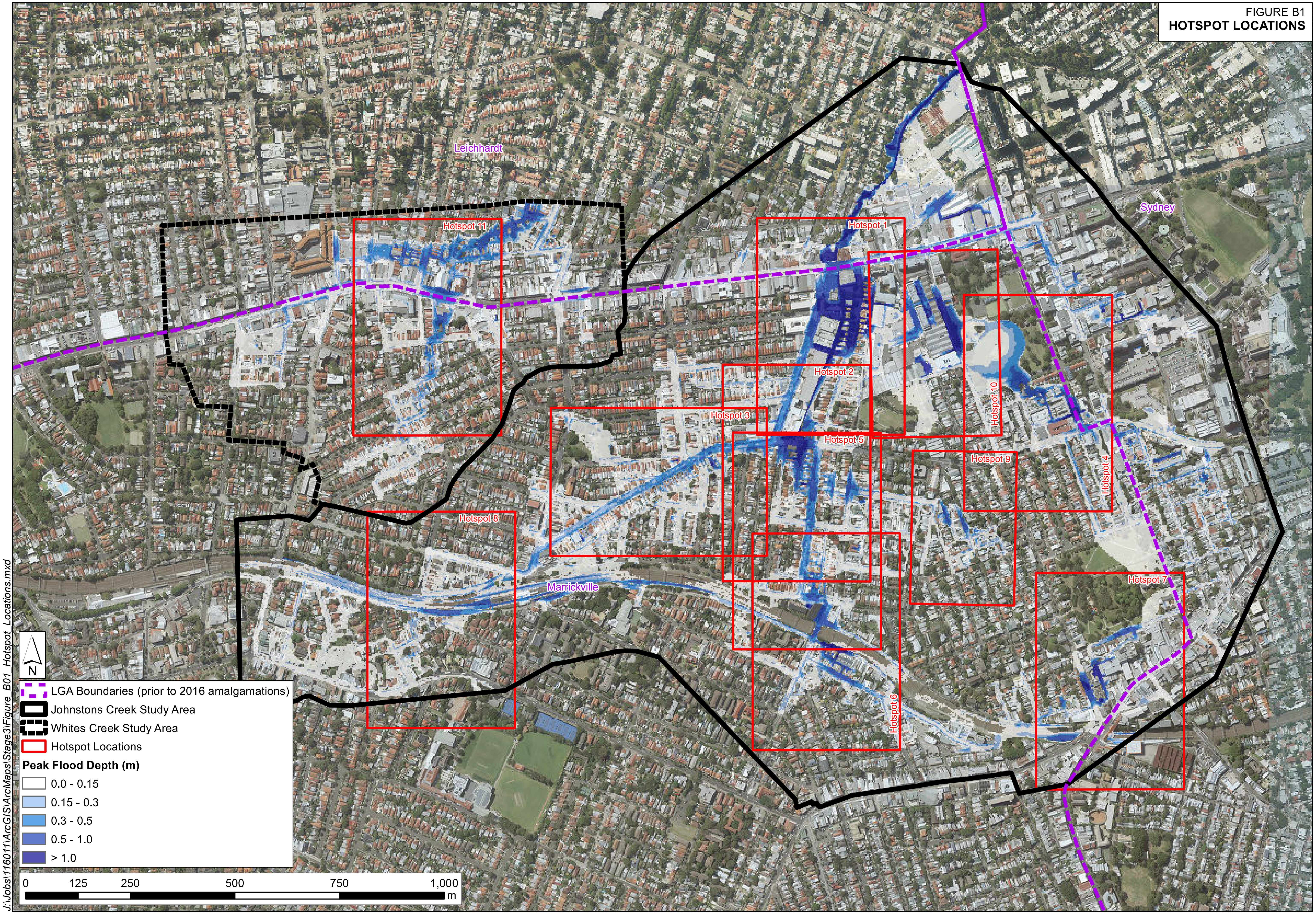

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FIGURE B2

HOTSPOT 1 - PARRAMATTA RD, BRIDGE RD AND CARDIGAN ST PEAK FLOOD DEPTHS AND LEVELS 1% AEP

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FIGURE B3

HOTSPOT 2 - SALISBURY RD NEAR STAFFORD ST PEAK FLOOD DEPTHS AND LEVELS 1% AEP

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FIGURE B4
HOTSPOT 3 - SALISBURY RD
PEAK FLOOD DEPTHS AND LEVELS
1% AEP

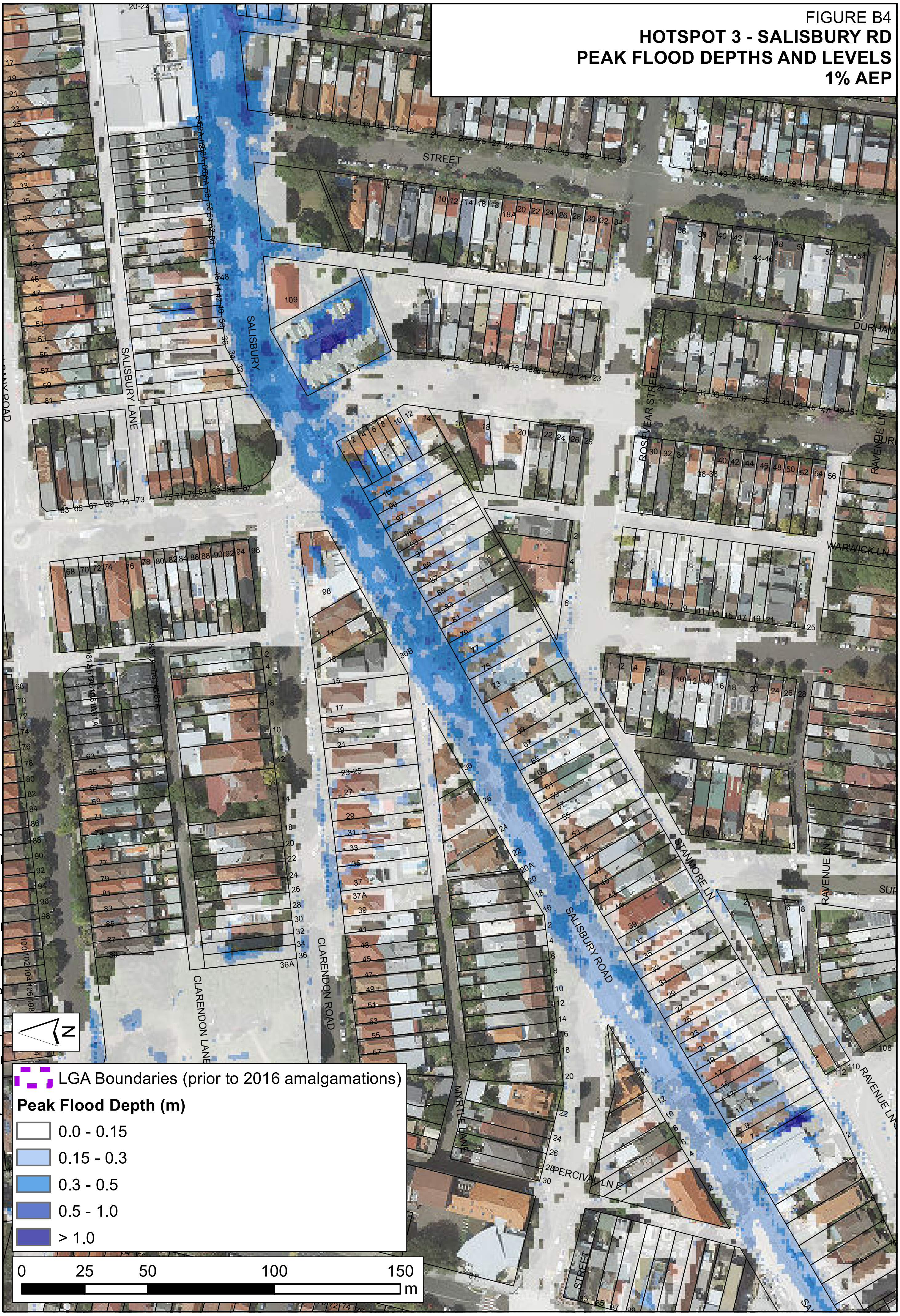

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FIGURE B5
HOTSPOT 4
PEAK FLOOD DEPTHS AND LEVELS
1% AEP

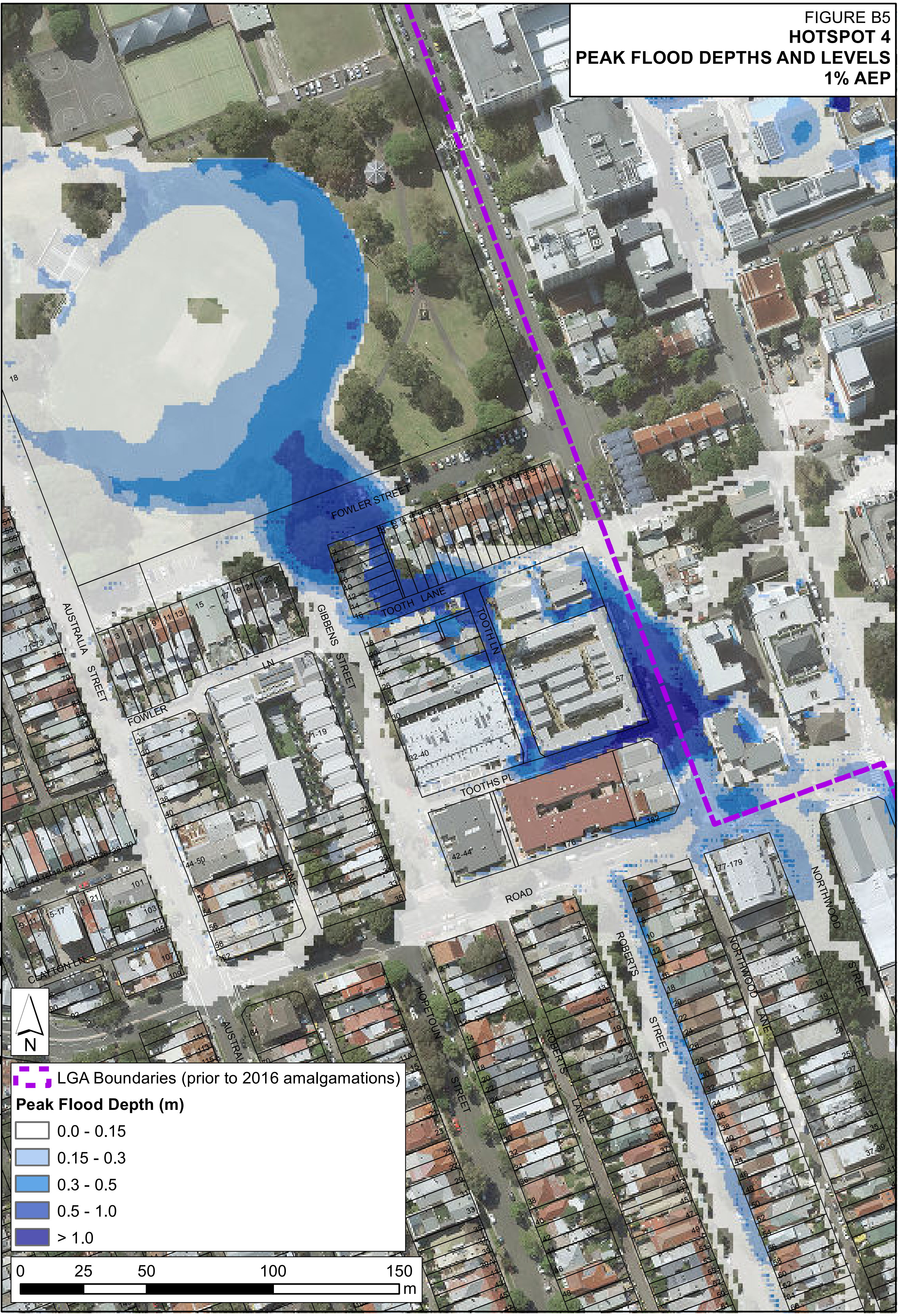

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FIGURE B6

HOTSPOT 5

PEAK FLOOD DEPTHS AND LEVELS

1% AEP

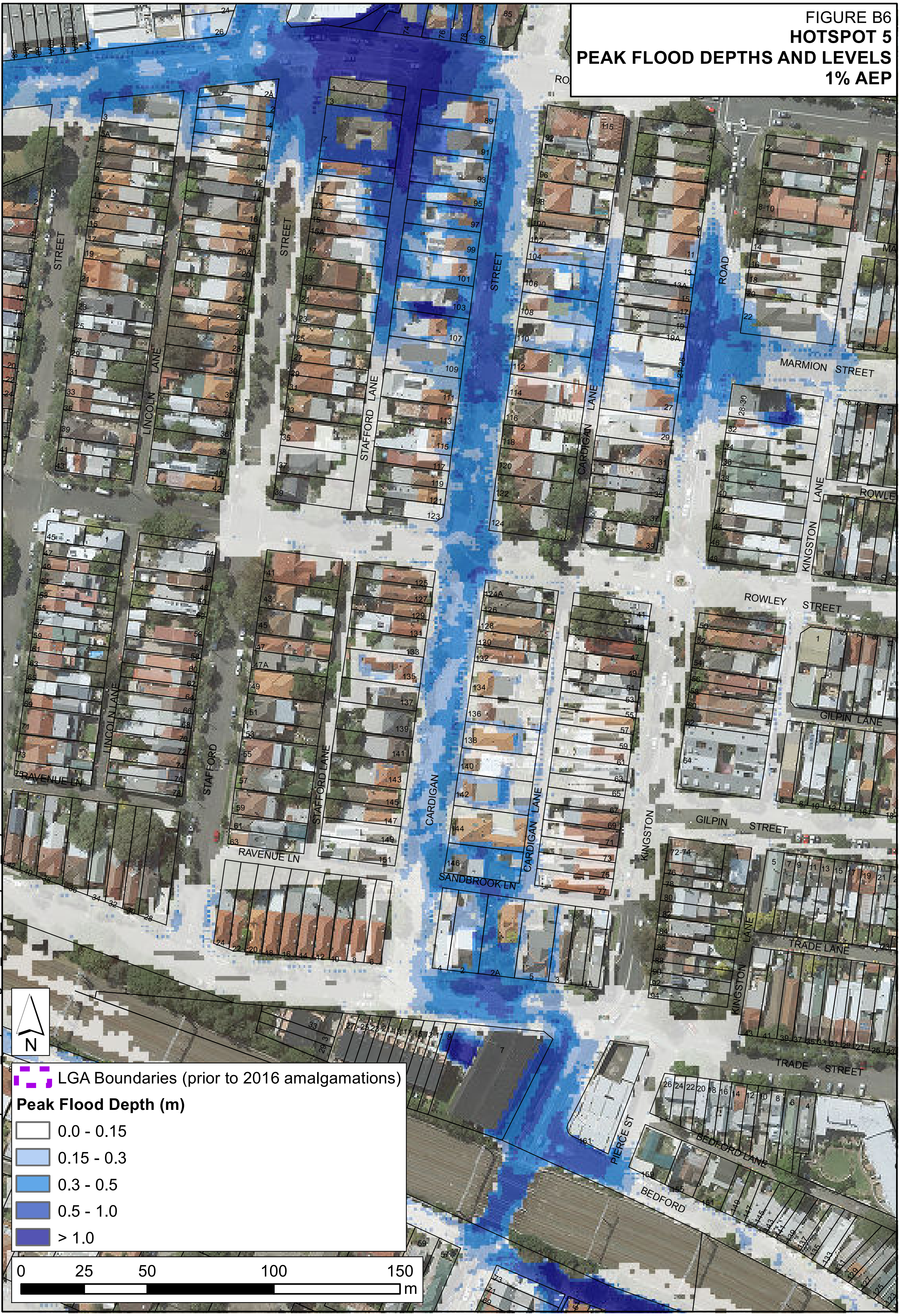

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FIGURE B7
HOTSPOT 6
PEAK FLOOD DEPTHS AND LEVELS
1% AEP

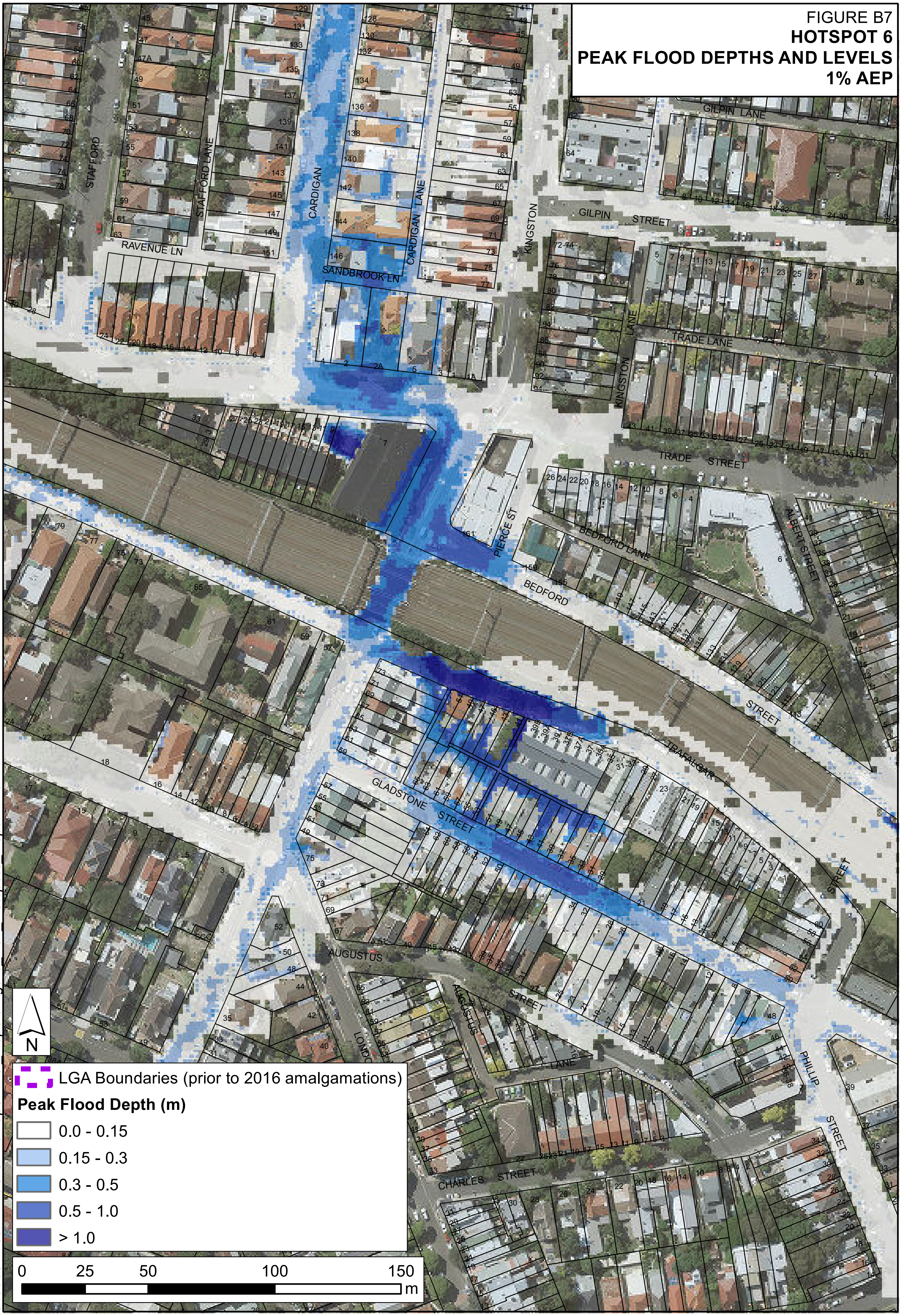

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FIGURE B8
HOTSPOT 7
PEAK FLOOD DEPTHS AND LEVELS
1% AEP

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FIGURE B9
HOTSPOT 8
PEAK FLOOD DEPTHS AND LEVELS
1% AEP

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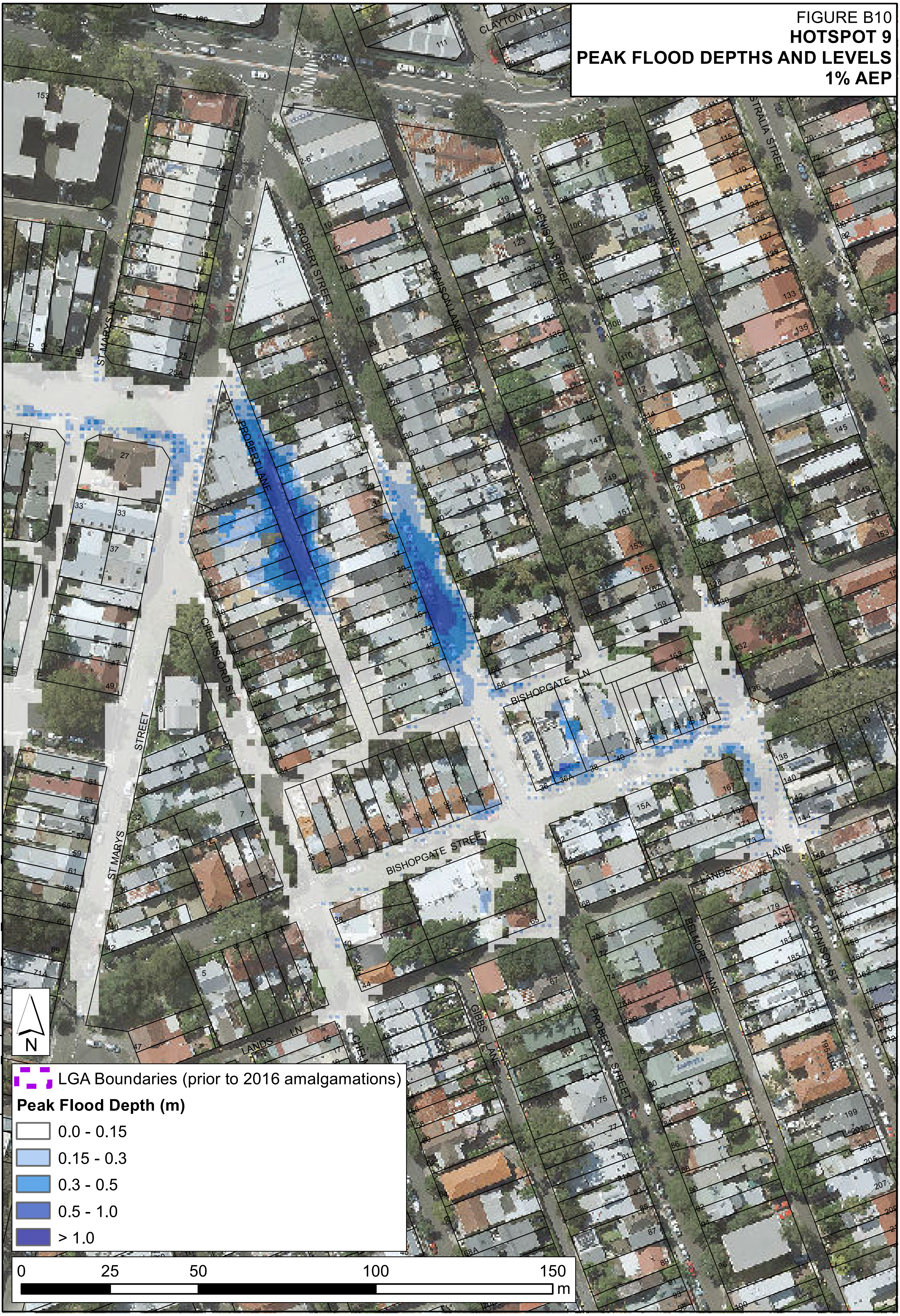

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FIGURE B11
HOTSPOT 10
PEAK FLOOD DEPTHS AND LEVELS
1% AEP

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FIGURE B12
HOTSPOT 11
PEAK FLOOD DEPTHS AND LEVELS
1% AEP

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