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KENSINGTON – CENTENNIAL PARK FLOOD STUDY

FINAL
APRIL, 2013

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LIST OF ACRONYMS

AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ARI	Average Recurrence Interval
ALS	Aerial Laser Scanning
ARR87	Australian Rainfall & Runoff 1987
BOM	Bureau of Meteorology
CoS	City of Sydney
DECC	Department of Environment and Climate Change (NSW)
DECCW	Department of Environment, Climate Change and Water (NSW)
EBD	Embedded Design Storm
FL	Friction Loss co-efficient
FPL	Flood Planning Level
GIS	Geographic Information System
LGA	Local Government Area
m	metre
m ³ /s	cubic metres per second
OC	Open Channel
OEH	Office of Environment and Heritage
PMF	Probable Maximum Flood
RCC	Randwick City Council
SW	Sydney Water
TLP	Trapped Low Point
TUFLOW	one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software program (hydraulic computer model)
UNSW	University of New South Wales
US	Upstream
1D	One dimensional hydraulic computer model
2D	Two dimensional hydraulic computer model

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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 Study**
 - Evaluates management options for the floodplain in respect of both existing and proposed development.
- 3. Floodplain Risk Management Plan**
 - Involves formal adoption by Council of a plan of management for the floodplain.
- 4. Implementation of the Plan**
 - Construction of flood mitigation works to protect existing development,
 - Use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

The following Kensington - Centennial Park Flood Study constitutes the first stage of the management process for this catchment area. WMAwater (formerly known as Webb, McKeown & Associates) were commissioned by Randwick City Council to prepare this flood study on behalf of the Kensington-Centennial Park Floodplain Risk Management Committee.

Funding for this study was provided from the Commonwealth and State Government's Flood Risk Management Program and Randwick City Council.

The following report documents the work undertaken and presents outcomes that define flood behaviour for existing catchment conditions.

EXECUTIVE SUMMARY

The Kensington – Centennial Park catchment is an urban catchment located in the eastern suburbs of Sydney (refer Figure 1). Urbanisation has significantly altered the nature of drainage within the catchment with urban development located along many of the existing drainage paths from Centennial Parklands south to Botany Bay. The study area is unique in that many trapped low points exist. These depressions historically drained only via infiltration to the underlying Botany aquifer (no overland flow path and hence termed trapped low points). With increased hard stand areas and property development, flooding in these trapped low points and along historic drainage lines needs to be properly understood in order to properly inform development and manage the flood risk.

Model Build

The overall study area was broken into two model domains:

- Upper Model – Queens Park, Centennial Park, east of Randwick Racecourse,
- Lower Model – Alison Road entrance of Randwick Racecourse south to Gardeners Road including overflow from Centennial Park.

Hydrologic modelling was undertaken using a combination of Mike-Storm and DRAINS. Hydraulic modelling was undertaken using a 2m resolution dynamically integrated 1D/2D TUFLOW model. The high resolution 2D domain is particularly advantageous in this study area to define the floodplain storage in the trapped low points and the high level relief areas.

Model Calibration / Verification

In November 1984 two flood events occurred over a period of a few days causing significant flooding and property damages in the study area.

Extensive peak flood level flood data were collected for the two storms of the 5/6th November and the 8/9th of November 1984. The 8/9th November event was utilised as a calibration event while the prior 5/6th November event was used to verify the calibrated model.

A reasonable calibration and verification outcome was achieved to the historical flood height data.

Model Sensitivity and Climate Change

The 1% AEP event was used to test model sensitivity to the following parameters:

- $\pm 20\%$ Manning's 'n' change,
- Culvert Blockage of 0%, 25% and 100%,
- 20% increase in rainfall intensity,
- Non-embedded storm versus adopted embedded storm for design hydrology,
- Rainfall increases of 10%, 20% and 30% for potential climate change projections.

Across the broader model there is typically low model sensitivity to changes in these parameters.

The trapped low points however are sensitive to the runoff volume. Immediately upstream of Gardeners Road is also sensitive to the runoff volume and culvert blockage assumptions.

As a result of a review of the sensitivity analysis to culvert blockage a 25% blockage for culverts was adopted for design.

Design Flood Levels

Design flood analysis of the calibrated model has been undertaken for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% Annual Exceedance Probability (AEP) flood events as well as for the Probable Maximum Flood (PMF).

Figures are provided showing the flood level, depth and velocity and tabular results of flood levels and flows are provided at key locations.

Flood levels, depth and velocity for all the above design events have been provided to Council in electronic format (raster) to supplement this report.

Provisional Hazard

Provisional flood hazard for the 1% AEP flood event has also been provided. High hazard floodways are predominantly confined to the road ways with minimal properties located in high flood hazard zones. The most notable exception to this is upstream of Gardeners Road. This area is a low velocity ponded water surface but with water depths greater than 1m.

Recommendations

Through much of the catchment floodwaters are conveyed via overland flow paths and hence demonstrate little sensitivity to modelled parameters. Exceptions to this are areas where no overland flow path exists or the overland flow path initiates after considerable ponding depth is reached. The Wentworth trapped low point which is drained by a single 450mm diameter pipe is a good example. Also, upstream of Gardeners Road (drained through an undersized culvert) receives high volumes of runoff from the Centennial Parklands which flow south along Anzac Parade resulting in considerable ponding depths.

The subsequent floodplain management study should consider management of the risk and augmenting the current drainage scheme to minimise flood impacts or to specifically identify high risk properties and examine local solutions.

It is recommended in the interim that design flood levels produced from this report are adopted with an additional 0.5m freeboard for Flood Planning Levels (FPL).

1. INTRODUCTION

The Kensington - Centennial Park catchment is located in the eastern suburbs of Sydney. The study catchment comprises an area of 9.7 km² and extends east to approximately Frenchmans Road/Avoca Street, south to Gardeners Road and west to South Dowling Street (Figure 1). The Centennial Parklands are located in the northern portion of the catchment.

The study area is unique within the Sydney metropolitan area given the relatively large portion of parkland and open space present within the urban catchment. The presence of sandy soils in and around the Centennial Park, Randwick Racecourse and Kensington areas, in combination with potential flood storage in many of the open spaced areas, has pronounced effects on the catchment response to rainfall and the generation of runoff. These aspects are of particular significance for the Centennial Park area. This large open space area is drained via a series of ponds and interacts with the Botany aquifer via a series of complex and poorly understood infiltration processes.

The definition of design flood behaviour for existing catchment conditions is an important first stage in the development of an overall Floodplain Risk Management Plan for the catchment. This Flood Study documents the approach and outcomes of the technical work undertaken to achieve this. In accordance with the NSW Government Floodplain Development Manual (Reference 1), the primary objectives of this Flood Study are to:

- define the flood behaviour of the study catchment by quantifying flood levels, flows and velocities for a range of design flood events under existing catchment conditions,
- establish suitable hydrologic/hydraulic model(s) that can be used in a subsequent Floodplain Risk Management Study and the assessment of development options.

This report details the methodology and results of the Flood Study with the key elements being:

- a summary of available data,
- an outline of the overall methodology adopted, including details on the numerical models established,
- a description of the design flood behaviour throughout the study area in figures and at key locations (shown on Figure 2), and
- documentation of the assumptions made to derive the information and conclusions presented herein.

1.1. Public Exhibition of Draft Report in February/March 2013

The Draft Kensington – Centennial Park Flood Study was placed on public exhibition from Tuesday 19th February 2013 to Tuesday 26th March 2013.

Public displays were placed at the following locations:

- Bowen Library, 669-673 Anzac Parade, Maroubra,
- Randwick Library, Level 1 Royal Randwick Shopping Centre, Randwick,
- Council's administration centre, 30 Frances Street, Randwick.

Exhibition material at the public displays included:

- Copies of the draft reports,
- Fact Sheets,
- Comment Sheets,
- Comment Box.

Newspaper advertisements were placed in the Southern Courier on 19th February and 5th March providing details of the public exhibition.

The public exhibition was also advertised on Council's website and included a copy of the draft Flood Study.

A letter was sent to all property owners identified as being below the 1% AEP flood level plus 0.5m freeboard or below the Probable Maximum Flood. A total of 6236 letters were sent to property owners providing details of the public exhibition and the community drop in session. A community drop in session was held at Council's Administration centre on Wednesday 13th March between 6pm and 8pm. Staff from Council, WMAWater and the Office of Environment and Heritage were available for the community to come along and find out about the study or ask questions.

A total of four written submissions were received during the public exhibition period. A summary of the feedback from residents during the public exhibition period is provided in Appendix D.

2. BACKGROUND

2.1. Catchment Description

The Kensington - Centennial Park catchment is an urban catchment located in the eastern suburbs of Sydney (refer to Figure 1). The catchment covers an area of approximately 9.7 km² and spans the local government areas (LGA) of Randwick City Council (RCC), City of Sydney (CoS) and Waverley Council. The majority of the catchment is located within the RCC LGA. The north-western portion of the catchment in and around the Moore Park area (CoS LGA) drains into the Centennial Park site and into Anzac Parade. Parts of Waverley, Bondi Junction and Queens Park (Waverley Council LGA) also drain into the RCC portion of the catchment at Centennial Park. The catchment covers the suburbs of Randwick, Kensington and Kingsford within the RCC LGA.

Much of the catchment consists of established residential areas typically consisting of single dwellings, although there are localised zones of higher density housing throughout the area, particularly in close proximity to commercial districts (e.g. Kensington). It has been estimated that the general extent of current urban development within the catchment was reached by approximately 1940, with infill/re-development type activities being typical of land-use changes since that time (Reference 2). Major commercial districts within the study area include Anzac Parade and Gardeners Road frontages (Kensington) and Clovelly Road (Randwick).

In addition to community parks and reserves, there are several significant open space areas including:

- Centennial Parklands,
- Randwick Racecourse,
- Moore Park and Sydney Cricket Ground,
- Kensington Oval, and
- Portions of the University of New South Wales (UNSW) campus at Kensington.

The catchment drains predominantly from north to south and is generally bound by Oxford Street in the north and Gardeners Road in the south. The topography throughout the catchment varies significantly. Many of the urbanised upper reaches are characterised by areas of steep terrain interspersed with localised depressions. By comparison, the lower reaches of the catchment are distinctly flatter, particularly downstream of Centennial Parklands (i.e. south of Alison Road) and west of Wansey Road (located along the eastern boundary of Randwick Racecourse). Runoff from the catchment ultimately drains into the Eastlakes Golf Course, south of Gardeners Road. The ground elevation across the study area ranges from 106 mAHD to 15 mAHD (approximately).

The study area defined by RCC also includes a smaller catchment located adjacent to the south-eastern boundary of the main catchment. This sub-catchment (termed the “Eastlakes” catchment for the purposes of this study) is effectively divided from the main catchment by a ridge that runs parallel to Aboud Avenue. It is a small residential subcatchment that discharges into Eastlakes Golf Course, to the west of the point of discharge from the main catchment.

2.2. Causes of Flooding

Urbanisation has dramatically altered the nature of drainage within the catchment. Reference 2 includes a map of historical catchment conditions circa 1850-1870 (reproduced in Appendix B). The map shows a number of natural drainage paths and low-lying depressions from the site of Centennial Park extending downstream through to Kensington and Kingsford.

The drainage paths and other water features can be aligned with current development and provides the context for many of the flood problems known to exist in the area today. For example, there is a high correlation between the historical map and RCC's database of reported flooding problems and areas known to have been flooded during the November 1984 events. Patterns of flood behaviour observed in the last twenty to thirty years reflect the historical pattern of drainage. Key examples include the major flowpaths formed in Doncaster Avenue and flooding experienced further downstream in the catchment (e.g. in and around Mooramie Avenue). It is evident that development has altered natural flowpaths and/or has occurred in areas likely to have been susceptible to flooding under pre-development conditions.

Compared to historical (pre-development) conditions, development within the catchment is likely to have exacerbated flooding as a result of:

- a major increase in the proportion of paved area and consequent reduction in pervious areas, resulting in corresponding increases in runoff (in terms of both peak flows and volumes),
- modification of natural surface drainage system including encroachment of development within flowpaths across the catchment, and
- development within trapped depressions that were once swamps, resulting in flood problems in these areas.

3. AVAILABLE DATA

3.1. Drainage Information

As part of the present study, a comprehensive drainage assets database was prepared. The database contains details of the drainage network for the catchment within the Randwick City Council LGA. This data was collected by AWT Survey and included details regarding:

- sub-surface pits and pipes,
- reaches of the Sydney Water stormwater channel in the lower catchment,
- the connectivity between components of the system.

The database used for the present study was provided in the form of ArcGIS shapefiles for various sub-catchments in the study area.

For details of both current and historical information in other areas of the catchment, the drainage network was sourced from existing models, reports, survey plans and drawings provided by both RCC and CoS.

3.2. Survey Data

3.2.1. Aerial Laser Scanning Survey

RCC provided several topographic datasets for use in the present study. Initially, topographic contours at 2m intervals were provided for the whole LGA.

Subsequent to this, RCC commissioned AAMHATCH Pty. Ltd. to undertake an Aerial Laser Scanning (ALS) survey within the extents of the Randwick LGA including parts of the study catchment (refer to Figure 3). The survey was flown in December 2005 and the resultant mapping was provided to Council in March 2006. The ALS survey provides over 1 million ground level spot heights, from which a Digital Terrain Model (DTM) can be constructed.

For well defined points mapped in clear areas, the expected nominal point accuracies (based on a 68% confidence interval) are in the order of:

- Vertical Accuracy: ± 0.15 m,
- Horizontal Accuracy: ± 0.57 m.

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

3.2.2. Detail Survey Data

Detail ground survey is available in a limited number of locations within the catchment. In the main, these additional datasets provide more accurate information compared to the ALS and

were used to define the dimensions and levels of specific features (such as road crests, channel dimensions, etc.) likely to act as hydraulic controls during a major flood. The detail survey was obtained from a combination of sources including RCC and previous studies and included:

- AWT Survey obtained as part of present study (refer to Section 3.1),
- RCC survey of road levels within several major trapped low points,
- Centennial Park survey,
- Topographic survey of Centennial Park ponds (Reference 3).

3.3. Aerial Photography

Two key aerial photographic data sets have been provided by RCC for the entire study area.

The first and most recent data set was recorded in 2006. The second data set dated approximately 1980 was used to confirm conditions for the calibration and verification modelling of the November 1984 storm events.

3.4. Rainfall Data

3.4.1. Overview

Rainfall data is recorded either daily (24hr rainfall totals to 9:00am) or continuously (pluviometers measuring depths within small time periods of typically 2 to 5 mins). 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.

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

- Rainfall gauges frequently fail to accurately record the total amount of rainfall. This can occur for a range of reasons including operator error, instrument failure, overtopping and vandalism. In particular, many gauges fail during periods of heavy rainfall and records of large events are often lost or misrepresented.
- Daily read information is usually obtained at 9:00am in the morning. Thus if the storm encompasses this period it becomes “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 9:00am reading.
- Rainfall records can frequently have “gaps” ranging from a few days to several weeks or even years.
- Pluviometer 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. These data have much fewer limitations than daily read data. The main drawback is that a number of relevant gauges have only been installed since 1990 and hence have a very short period of record compared to the daily read data. These types of gauges can also fail during storm events due to extreme conditions. There are several pluviometer records of limited length available for stations located within the study catchment.

3.4.2. Available Rainfall Data

Table 1 presents a summary of the official rainfall gauges (provided by the Bureau of Meteorology [BOM]) located close to or within the catchment. These gauges are operated either by Sydney Water (SW) or the BOM. There may also be other private gauges in the area (bowling clubs, schools) but data from these has not been collected as there is no public record of their existence. The gauge with the longest record is Observatory Hill, operating from 1858 to the present.

Table 1: Rainfall Stations with a 6km Radius of Paddington Station

Station No	Owner	Station	Elevation (mAHD)	Distance from Paddington (km)	Date Opened	Date Closed	Type
66139	BOM	Paddington	-	0.0	Jan_68	Jan_76	Daily
566041	SW	Crown Street Reservoir	40	0.8	Feb_1882	Dec_60	Daily
566032	SW	Paddington (Composite	45	1.0	Apr_61		Continuous
566032	SW	Paddington (Composite	45	1.0	Apr_61		Daily
566009	SW	Rushcutters Bay Tennis	-	1.3	May_98		Continuous
566042	SW	Sydney H.O. Pitt Street	15	1.5	Aug_49	Feb_65	Continuous
66015	BOM	Crown Street Reservoir		1.5	Feb_1882	Dec_60	Daily
66006	BOM	Sydney Botanic Gardens	15	1.9	Jan_1885		Daily
66160	BOM	Centennial Park	38	2.1	Jun_00		Daily
566011	SW	Victoria Park @	-	2.4	May_98		Continuous
66097	BOM	Randwick Bunnerong		2.4	Jan_04	Jan_24	Daily
66062	BOM	Sydney (Observatory	39	2.7	??		Continuous
66062	BOM	Sydney (Observatory	39	2.7	Jul_1858	Aug_90	Daily
66033	BOM	Alexandria (Henderson	15	2.8	May_62	Dec_63	Daily
66033	BOM	Alexandria (Henderson	15	2.8	Apr_99	Mar_02	Daily
66073	BOM	Randwick Racecourse	25	2.9	Jan_37		Daily
566110	SW	Erskineville Bowling Club	10	3.4	Jun_93	Feb_01	Continuous
566010	SW	Cranbrook School @	-	3.4	May_98		Continuous
566015	SW	Alexandria	5	3.5	May_04	Aug_89	Daily
66066	BOM	Waverley Shire Council		3.6	Sep_32	Dec_64	Daily
66149	BOM	Glebe Point Syd. Water	15	3.6	Jun_07	Dec_14	Daily
566099	SW	Randwick Racecourse	30	3.7	November_91		Continuous
66052	BOM	Randwick Bowling Club	75	3.7	Jan_1888		Daily
566141	SW	SP0057 Cremorne Point	-	4.0			Continuous
66021	BOM	Erskineville	6	4.0	May_04	Dec_73	Daily
	SW	Gladstone Park Bowling	-	4.1	Jan_01		Continuous
566114	SW	Waverley Bowling Club	-	4.1	Jan_95		Continuous
566043	SW	Randwick (Army)	30	4.3	Dec_56	Sep_70	Continuous
566077	SW	Bondi (Dickson Park)	60	4.4	Dec_89	Feb_01	Continuous
566065	SW	Annandale	20	4.5	Dec_88		Continuous
66098	BOM	Royal Sydney Golf Club	8	4.5	Mar_28		Daily
66005	BOM	Bondi Bowling Club	15	4.6	Jul_39	Dec_82	Daily
66178	BOM	Birchgrove School	10	4.8	May_04	Dec_10	Daily
66075	BOM	Waverton Bowling Club	21	5.1	Dec_55	Jan_01	Daily
66187	BOM	Tamarama (Carlisle	30	5.1	Jul_91	Mar_99	Daily
66179	BOM	Bronte Surf Club	15	5.2	Jan_18	Jan_22	Daily

566130	SW	Mosman (Reid Park)	-	5.3	Jan_98	Jun_98	Continuous
566030	SW	North Sydney Bowling	80	5.5	Apr_50	Sep_95	Daily
66007	BOM	Botany No.1 Dam	6	5.5	Jan_1870	Jan_78	Daily
66067	BOM	Wollstonecraft	53	5.8	Jan_15	Jan_75	Daily
66061	BOM	Sydney North Bowling	75	5.8	Apr_50	Dec_74	Daily
566027	SW	Mosman (Bradleys Head)	85	5.8	Jun_04		Continuous
566027	SW	Mosman (Bradleys Head)	85	5.8	Jun_04		Daily
566006	BOM	Bondi (Sydney Water)	10	5.9	Jun_97		Operational
66175	BOM	Schnapper Island	5	5.9	Mar_32	Dec_39	Daily

BOM = Bureau of Meteorology

SW = Sydney Water

3.4.3. Analysis of Daily Read Data

For the purposes of this study, an analysis of daily rainfall data was undertaken to identify and place past storm events in context relative to local rainfall patterns. All daily rainfall depths greater than 100 mm recorded at Centennial Park, Randwick Bowling Club and Randwick Racecourse gauges have been ranked (refer Table 2).

Table 2: Daily Rainfall greater than 150 mm

Centennial Park			Randwick Bowling Club (66052)			Randwick Racecourse (66073)		
Records since 1900			Records since Jan 1888			Records since Jan 1937		
Rank	Date	Rainfall (mm)	Rank	Date	Rainfall (mm)	Rank	Date	Rainfall (mm)
1	28-Mar-42	302	1	06/08/1986	297	1	10/02/1992	294
2	06-Aug-86	236	2	29/10/1959	265	2	20/11/1961	270
3	03-Feb-90	222	3	28/03/1942	243	3	30/10/1959	267
4	12-Aug-75	221	4	03/02/1990	225	4	06/08/1986	263
5	13-Oct-75	205	5	10/02/1956	213	5	11/03/1975	261
6	31-Jan-38	201	6	31/01/1938	213	6	14/05/1962	258
7	30-Apr-88	193	7	11/03/1975	201	7	10/02/1958	256
8	10-Feb-56	192	8	17/01/1988	178	8	05/02/1990	248
9	23-Jan-33	189	9	12/10/1902	178	9	03/02/1990	244
10	09-Feb-58	185	10	28/04/1966	177	10	09/11/1984	240
11	11-Mar-75	184	11	04/02/1990	175	11	20/03/1978	237
12	07-Jul-31	177	12	19/11/1900	164	12	06/11/1984	223
13	09-Apr-45	177	13	09/02/1992	162	13	28/03/1942	213
14	07-Aug-98	162	14	28/07/1908	161	14	31/01/1938	211
15	17-May-43	159	15	09/02/1958	158	15	10/02/1956	195
16	04-Feb-90	156	16	29/05/1906	155	16	30/04/1988	175
17	10-Jul-57	155	17	30/08/1963	152	17	30/08/1963	174
18	14-Nov-69	155	18	27/04/1901	150	18	07/08/1967	171
19	01-May-55	154				19	10/01/1949	170
20	09-Feb-92	151				20	14/11/1969	160
21	28-Jul-08	150				21	05/02/2002	157
22	13-Jan-11	150				22	16/06/1952	156
						23	04/03/1977	155
						24	03/05/1948	154
						25	04/04/1988	152
						26	28/04/1966	151
						27	05/03/1979	151

The main points regarding this data are:

- At Centennial Park there have been 6 days of rainfall over 200 mm between 1900 and 1995.
- From the analysis of Centennial Park data there are at least 8 events where 2 or more consecutive days have recorded rainfalls above 100 mm. These are December 1920, March 1958, November 1961, May 1962, April 1966, October 1975, August 1986 and February 1990. Of these events 7 are within the second half of the century.
- Periods with daily rainfall greater than 200 mm at Centennial Park are well known periods of heavy rainfall which caused flooding in Sydney.
- Common large events in all three gauges include 10/02/1956 and 9 to 10/02/1958. The more recent events of 11/03/1975 and 6/08/1986 occur in both Randwick gauges still operating. Only 136mm was recorded at Centennial Park on 9/11/1984.
- These records are based on 24 hour totals (to 9:00am) and show rainfall throughout the entire day, whereas the critical duration for some parts of the catchment is likely to be under two hours. Hence a large daily rainfall of greater than 200 mm may not necessarily produce severe flooding if the rain was spread evenly throughout the day.
- There can be a significant variation in rainfall between the gauges (February 1992 was 294mm at the Racecourse but 150/160mm at the other two gauges – this is difficult to believe and the Racecourse record may be in error).

3.4.4. Analysis of Recent Storms

As noted previously, pluviometer records provide a more detailed description of temporal variations in rainfall (refer to Figure 4 for November 1984 events). Table 3 lists the maximum storm intensities for several recent rainfall events from both the pluviometers and daily read gauges in proximity of the catchment.

Table 3: 5 November 1984, 8/9 November 1984, January 1989, and January 1994 Maximum Recorded Storm Depths (in mm)

Station Location	5 Nov 1984		8/9 Nov 1984		6 Jan 1989		26 Jan 1991	
	30 min	60 min	30 min	60 min	30 min	60 min	30 min	60 min
Paddington	36	51	54	91	53	54	52	53
Observatory Hill	20	32	90	119	42	42	60	65
Sydney Airport	-	-	85	100	6	6	11	12
Marrickville	28	31	26	38	1	1	37	38
Mascot Bowling Club	43	48	34	47	36	37	17	18
UNSW (Avoca Street)⁽¹⁾	65	112	41	58	-	-	-	-
UNSW (Storey Street)⁽¹⁾	65	90	33	46	-	-	-	-

Station Location	24 hour Totals to 0900 hrs				
	5 Nov 1984	8 Nov 1984 (2)	9 Nov 1984 (2)	6 Jan 1989	26 Jan 1991
Royal Botanic Gardens	-	37	248	49	59
Sydney Airport	121	20	132	85	53
Observatory Hill	98	44	234	47	65
Paddington	108	71	208	63	54

Notes:

- (1) Data interpreted from Reference 2.
- (2) November 1984 event consisted of two separate rainfall bursts (between 6:00am and 10:00am and 9:00pm and midnight). Both produced flooding but the second burst was the most intense. One possible reason why there are so few recorded flood levels is that the second burst occurred at night and thus few would have been outside to view the flood extent or record levels.

The above data indicate that for January 1989 and January 1991 the peak 30 minute rainfall comprised the majority of the daily rainfall. However for the two major events in November 1984 the 30 minute peak was part of a much larger rainfall event.

Comparison with design rainfall intensities indicate that the January 1989 and January 1991 events were less than a 5% AEP design intensity for the 30 minute and 60 minute intensities, except at Observatory Hill in January 1991 which was between a 5% and a 2% AEP event for the 30 minute intensity.

The 8-9th November 1984 storm was a significant rainfall event across the Sydney and Wollongong region and is well documented in Reference 4. Table 4 shows that this storm had an approximate 1% AEP intensity across several locations in Sydney. The storm was separated into two distinct bursts (6:00am to 10:00am and 9:00pm to midnight). The latter was the most intense period and flooding was reported throughout the catchment, though the actual timing of the flooding is unknown.

Table 4: ARI estimates of the 8-9th November 1984 Rainfall (Reference 4)

Station	Rainfall Duration				
	0.5 hour	1 hour	2 hour	3 hour	6 hour
Sydney - Observatory Hill	100y	100y	100y	100y	100y
Mosman	20y	50y	100y	20y	10y
Vaucluse	100y	100y	50y	20y	10y

3.5. Stream Flow Gauging

According to the available records there are no stream flow gauging stations present within the study catchment. In November 1991, Sydney Water (then known as the Water Board) established a gauging station at the upper end of the Lachlan Swamps (Reference 5). Since the station did not exist for the calibration events it was of little use for the current study.

3.6. Historical Flood Records

As previously stated the storms of November 1984 resulted in significant flooding. Since many houses were inundated above floor level (between Centennial Park and Gardeners Road)

appropriate attention was given and flood levels were recorded from the 5-6th November storm and the 8-9th November storm. The flood levels recorded are documented in Reference 2 and represent the most substantial and detailed record of past flooding within the catchment.

Further evidence regarding historical flood levels was also sought during this study through consultation with RCC, CoS, major organisations within the catchment (e.g. Centennial Parklands, University of New South Wales) and with members of the local community (via mail-out questionnaires and targeted door-knocking campaigns). The information obtained was used to confirm observed behaviour for the November 1984 storms and to identify/confirm other floods that had occurred previously within the catchment. Further details of the information and the community consultation process are presented in later sections.

3.7. Previous Studies

There have been a number of flood studies undertaken within the catchment. These studies range from small flood assessments covering limited areas to more complex investigations extending to the Botany Wetlands. However, the present Flood Study represents the first comprehensive investigation that specifically provides detailed design flood information throughout the study area.

A brief overview of significant previous studies follows. A full list of previous flood-related reports is provided in the references.

3.7.1. Kensington Flooding Drainage Works Investigation 1985 (Reference 2)

Many parts of the Kensington area experienced severe flooding following two major rainfall events in early November 1984. Extensive damages resulted from these floods including the inundation of numerous properties. Shortly after these events, local and state government authorities commissioned a study to examine flooding within the Kensington catchment, the scope of which included:

- documentation of observed flood behaviour from the November 1984 storms,
- technical analysis of design flood behaviour for a range of storms for this catchment,
- preparation of a flood mitigation strategy including an assessment of the feasibility of various measures in terms of economic, social and technical aspects.

Reference 2 is a comprehensive report on flood behaviour within the lower Kensington catchment at the time and made best use of the limited modelling tools then available. Importantly, this reference provides the best available record of historical catchment conditions and rainfall flood behaviour for the November 1984 events.

3.7.2. Centennial Park – Kensington Pond Stormwater Flow Control Structure Restoration Works Flood Study November 2002 (Reference 3)

After an extended period of heavy rainfall, the area in and around the lower Kensington pond in Centennial Park experienced flooding on the 4-5th February 2002. As a result of this, the main control structure at the outlet of this lower pond collapsed.

Following these events the above study was commissioned to analyse the design flood behaviour of the Centennial Parkland pond system and to develop and assess a new control structure for the outlet of the lower Kensington pond above Alison Road.

Detailed ground survey of all major ponds was obtained at the commencement of the study (this data was made available by Centennial Parklands for this Flood Study). This survey was used to define stage-volume and rating (stage-discharge) relationships for each of the ponds. A hydrologic analysis was undertaken of the catchment down to Alison Road using RAFTS-XP.

The performance of this model for various historical events (including those of November 1984 and February 2002) was assessed together with the impacts of varying assumptions regarding assumed model parameters (e.g. rainfall losses). The outcomes were then used to assess the design performance of alternative options for the re-construction of the collapsed outlet for a range of design storm events.

3.7.3. Sydney Storms November 1984 – Hydrological Aspects October 1985 (Reference 4)

This report was produced by the then Public Works and provided information on the November 1984 storms.

3.7.4. Hydrologic and Hydraulic Study Botany Wetlands June 1992 (Reference 5)

Undertaken as part of the Plan of Management of Botany Wetlands, this study established hydrologic and hydraulic models to quantify the design flood behaviour of the wetlands downstream of Gardeners Road through to Botany Bay.

The hydrologic model covered the study catchment, albeit with broadly defined sub-areas. However, the upstream extent of the hydraulic model was located downstream of Gardeners Road, outside of the present study area.

The models were calibrated and verified against minor events that occurred in December 1991 although these events were significantly smaller than the estimated 10% AEP (1 in 10 year) design flood event.

3.7.5. Assessment of Hydrological and Hydraulic Modelling of Centennial Park and Kensington Catchments May 2003 (Reference 6)

This study was prepared for RCC to address uncertainties regarding differences in assumed model parameters and corresponding design flood estimates from various flood studies of the Centennial Park/Kensington catchment. The assessment was undertaken by Dr Geoffrey O'Loughlin, a recognised expert in the field of engineering hydrology and hydraulics.

The report concludes that much of the Centennial Park and Kensington catchments are located on sandy soils and may therefore be expected to have relatively higher hydrological losses compared to 'typical' loss factors used in design flood estimation. It is noted that a number of previous studies have employed high loss rates based on calibration to historical storms such as those of November 1984.

On the basis of these studies, anecdotal evidence and infiltration testing within Centennial Park, the author concludes that for design flood estimation a continuing loss of 50mm/hr and an initial loss of 50mm is considered appropriate for sandy areas within Centennial Park and Kensington. It is also noted that these estimates are conservative and that higher rates (e.g. 100mm initial loss and 100mm/hr continuing loss) could well apply. A "typical" continuing loss used in design flood analysis in the Sydney basin is 2.5mm/hr.

3.8. Community and Local Resident Survey

3.8.1. Overview

A key objective of the current study is to describe and quantify the flood behaviour under existing catchment conditions. In this regard, an understanding and appreciation of past floods is of significant importance. Although there are a number of existing reports documenting historical events, a community awareness and consultation component was initiated by Council for this study.

A media release describing the nature of the study including a general request for flood related information was provided to Council. A more detailed flood survey/questionnaire was then distributed to over 1500 households/businesses/organisations throughout the study area. A copy of the survey questionnaire is included in Appendix C. In all, more than 100 responses were received in addition to a number of phone calls and discussions with residents by both Council and WMAwater staff. These responses were then collated by RCC to yield a range of useful information including knowledge of property/household inundation and the identification of areas perceived as being particularly susceptible to flooding.

A summary of outcomes from this initial survey is provided in Figure 5. In terms of property inundation, a number of the reported sites correspond to properties that have been previously documented as having a flood related problem in the past (e.g. in Council's existing database of stormwater reports or in studies of past floods such as the November 1984 event). It should be noted that of the 68 reports of property inundation, there were a reasonable number of instances

in which floodwaters were reported to have entered garages and houses.

Detailed records regarding the nature and extent of flooding throughout much of the lower catchment (between Centennial Park/Alison Road and south to Gardeners Road) are documented in Reference 2. Much of the data for areas in the lower reaches affected by the November 1984 event obtained for this study supported the observations reported in Reference 2, including responses from Doncaster and Mooramie Avenues. The survey conducted for this study also identified flood-related issues in a number of other areas including a number of trapped low points in the upper reaches (e.g. Market Street/Centennial Avenue and Wentworth Street) and locations adjacent to the main study catchment including parts of Duke Street and Aboud Avenue.

Following further work during the course of the project, RCC commissioned an additional series of resident surveys in major trapped low points. In addition to gathering historical flood information, a primary objective was to identify the frequency and severity of past flooding in each location. The outcomes were then used to compare against assumptions used in the modelling process (e.g. potential infiltration capacity, likely overland flow paths etc.).

These later surveys were undertaken as a “door knocking” exercise on-site with individual residents being interviewed. Where there was no answer at the time of the survey then a short questionnaire was left at each address allowing any follow up information to be submitted. The location of the additional surveys and number of respondents is indicated in Table 5.

Table 5: Locations of Additional Resident Survey

Location	No. of Properties Surveyed	No. of Respondents
Aboud Avenue and Maitland Avenue	50	20
Cottenham Avenue. (opposite Kensington Park) and Eastern Avenue.	27	4
Barker Street	24	3
Wentworth Street	42	9

Flood related information at a number of the trapped low points in the study area is presented in the following sections.

3.8.2. Aboud Avenue

Aboud Avenue is located at the downstream end of a small catchment to the west of the main catchment (refer Photo 1). The local topography is such that there are a number of properties that lie within a natural depression, which is bounded by Maitland Avenue (to the west), Aboud Avenue, Tresidder Avenue and Gardeners Road (refer Photo 2). Most properties in this area have portions of their site at levels lower than the adjacent roads, particularly those located on the western side of Aboud Avenue.

Local runoff from the road network is collected at minor low points in Aboud Avenue (opposite

22/24 Aboud Avenue) and Maitland Avenue (41/43 Maitland Avenue). These are drained to the major trunk system that flows south towards Gardeners Road. This trunk drainage system is located along the middle of the depression along the rear of properties in Aboud Avenue and Maitland Avenue. However, at the downstream end of the Aboud Avenue area, Gardeners Road is much higher than the surrounds and as a result there is no means for overland flow to exit this low point other than via the piped drainage system.

Information provided by local residents notes that minor flooding within the roadway regularly occurs and has been exacerbated by blockage of the kerb inlet pits. Reports also indicate that once the capacity of the local pipe system is exceeded, overland flows from the road network then enter properties along the western side of Aboud Avenue causing inundation of yards within the natural depression. Several residents noted extensive ponding within this area following the November 1984 event and commented that their yards were prone to flooding due to limited drainage.

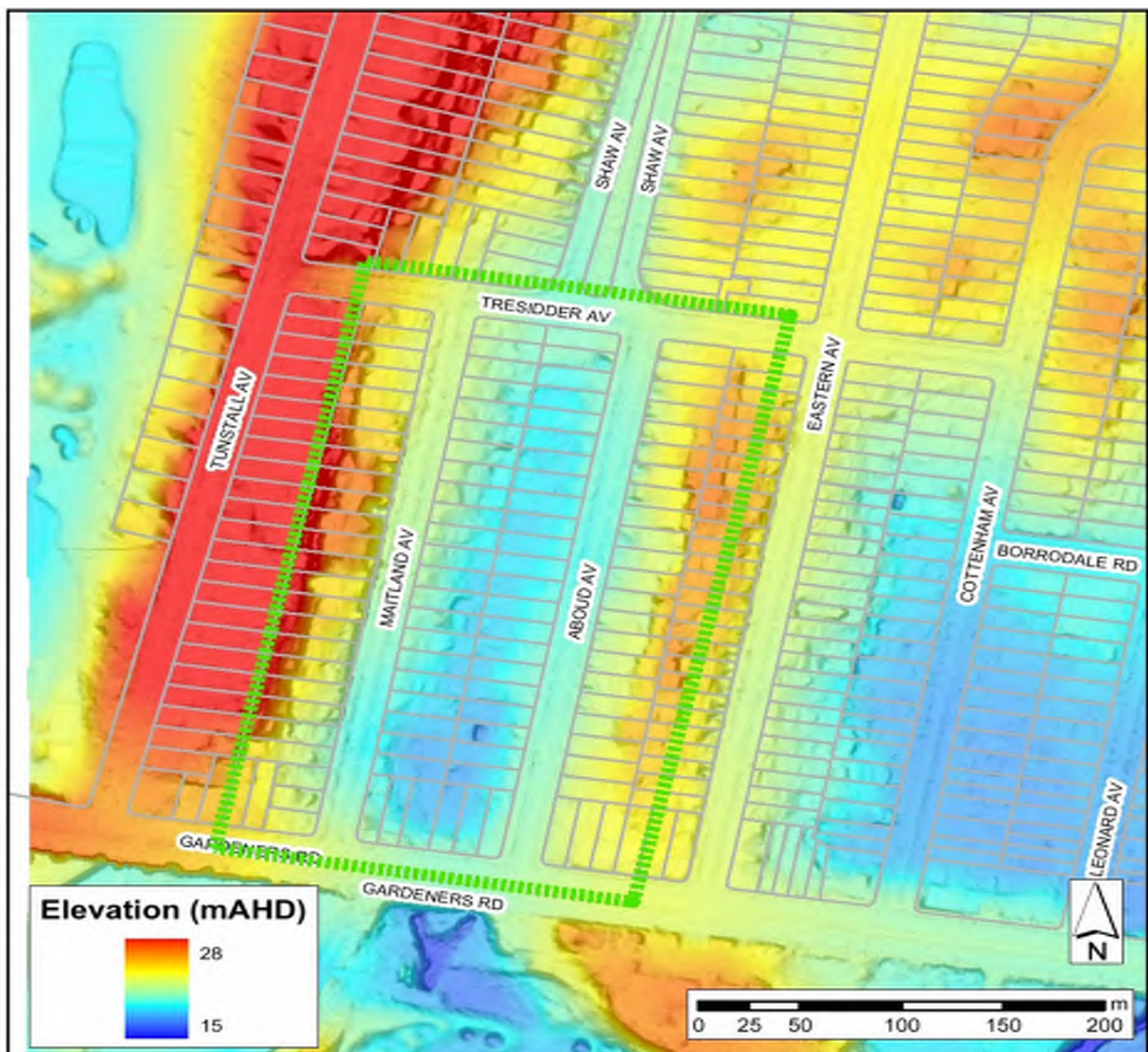


Photo 1: Ground Elevation – Aboud Avenue low point



Photo 2: Aboud Avenue looking south

3.8.3. Cottenham Avenue – Opposite Kensington Park

The extent of this low point is generally contained within residential properties along both Eastern and Cottenham Avenues (refer to Photo 3). Although this area is unlikely to be affected by mainstream flooding from the main Kensington catchment, the isolated nature of this low point has resulted in flooding of properties in past events from local runoff. Photo 4 shows the level of ponded water in the yard of an Eastern Avenue property within the low point following the November 1984 events (note water line on garage).

In this area, residents had also observed that the Cottenham Avenue low point was subject to minor flooding in the order of 0.1m to 0.2m during the 1999 event. There are observations that the inlet pits have been blocked by leaf litter in the past.

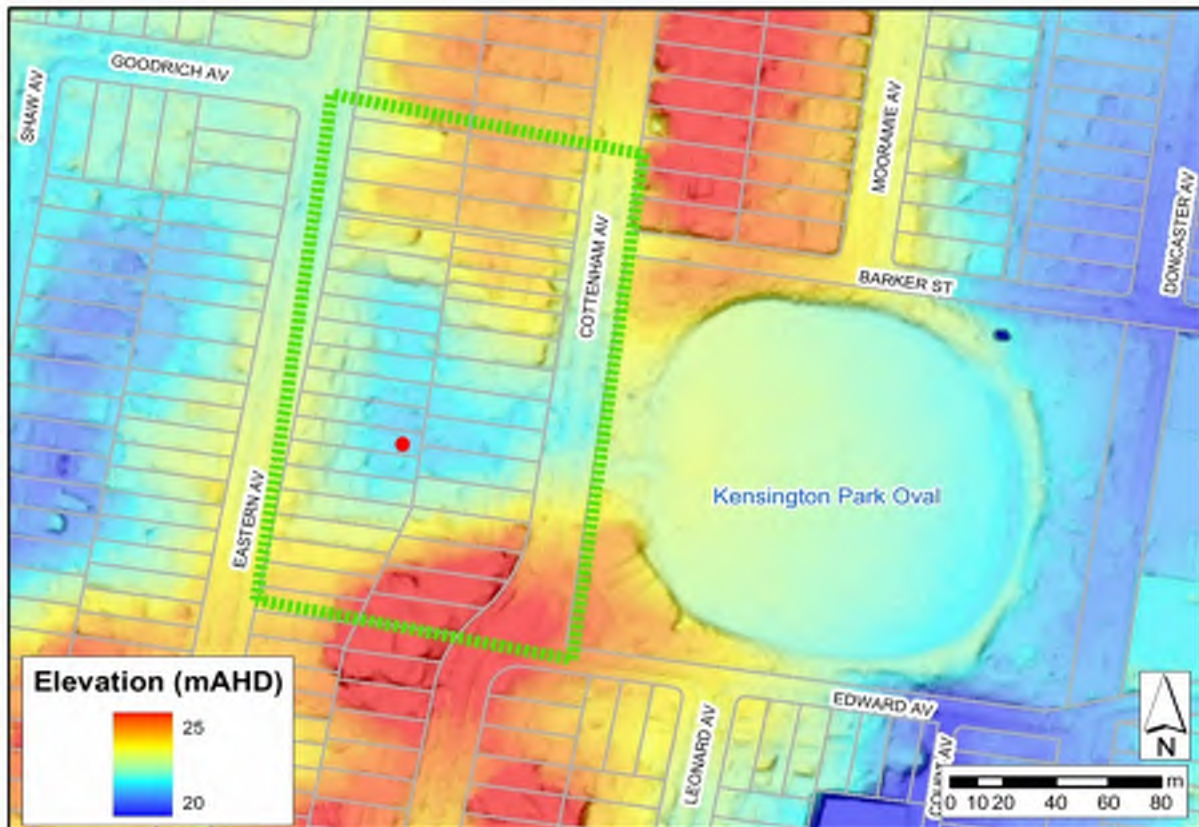


Photo 3: Ground Elevation – Cottenham Avenue trapped low point



Photo 4: Ponding in Eastern Avenue within low point following 1984 floods – note waterline on garage

3.8.4. Barker Street Trapped Low Point

Located opposite the residential colleges in the UNSW Campus, the trapped low point in Barker Street is known to be susceptible to minor flooding (refer Photo 5 and Photo 6).

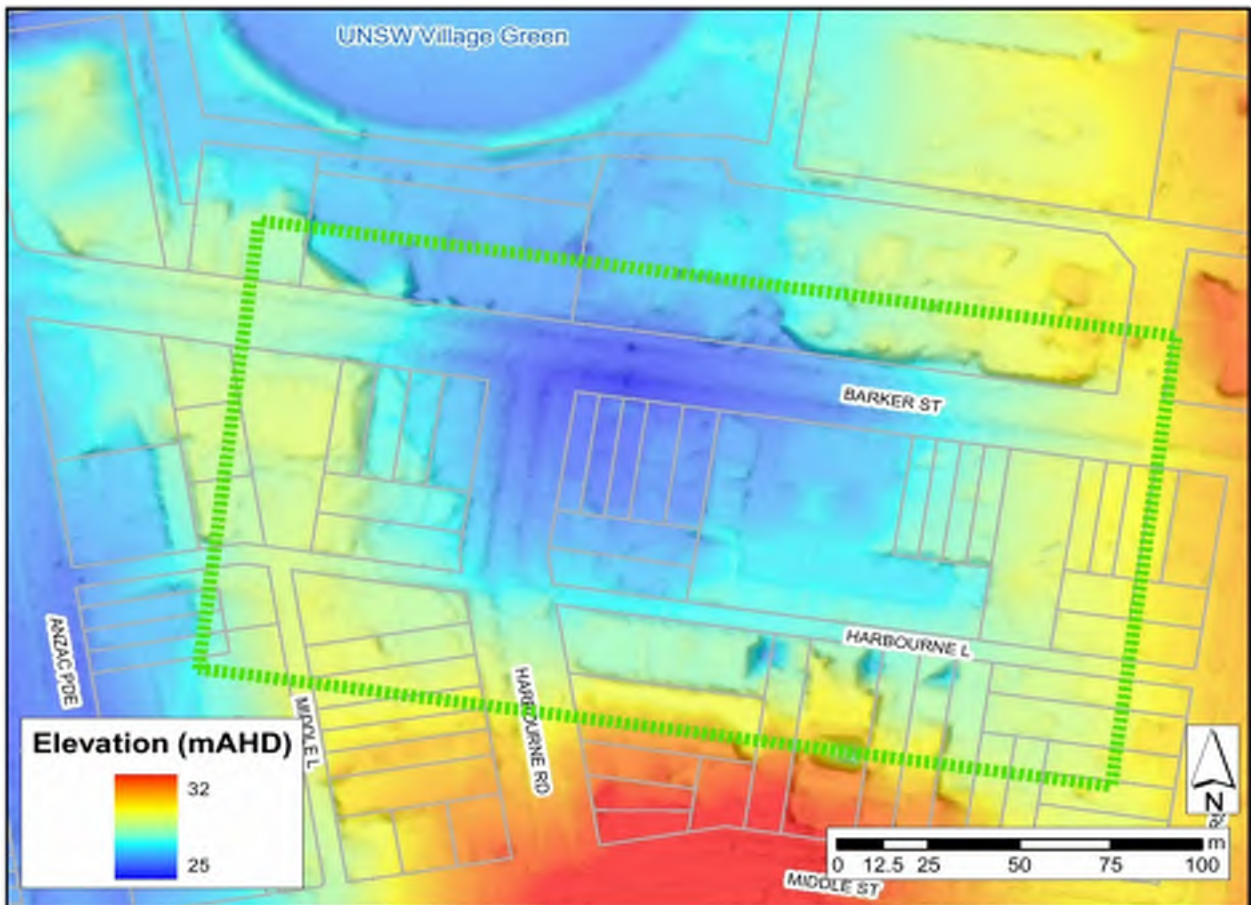


Photo 5: Ground Elevation – Barker Street trapped low point



Photo 6: Barker Street low point (looking west)

Residents have observed ponding after heavy rain sufficient to disrupt traffic through the area. Properties on the south-eastern corner of Harbourne Road and Barker Street are reported to have been inundated in the past (these are located well within the lowpoint – refer to Photo 5). In addition to the capacity of the existing trunk drainage system, any overland flow would be

expected to exit the low point through the grounds of UNSW (refer to likely overland flowpath shown in Photo 7). However, the level of ponding required to activate this flowpath would be in the order of 1 m.



Photo 7: High-level overland flowpath from Barker Street low point (looking south from UNSW campus back to road)

3.8.5. Market Street Trapped Low Point & Centennial Avenue

In the absence of any development, runoff through this area would follow the natural topography which falls in a westerly direction from Market Street through to Centennial Avenue and then Darley Road. However, there does not appear to be any allowance for an overland flowpath between Market Street and Centennial Avenue (refer to Photo 8 and Photo 9).

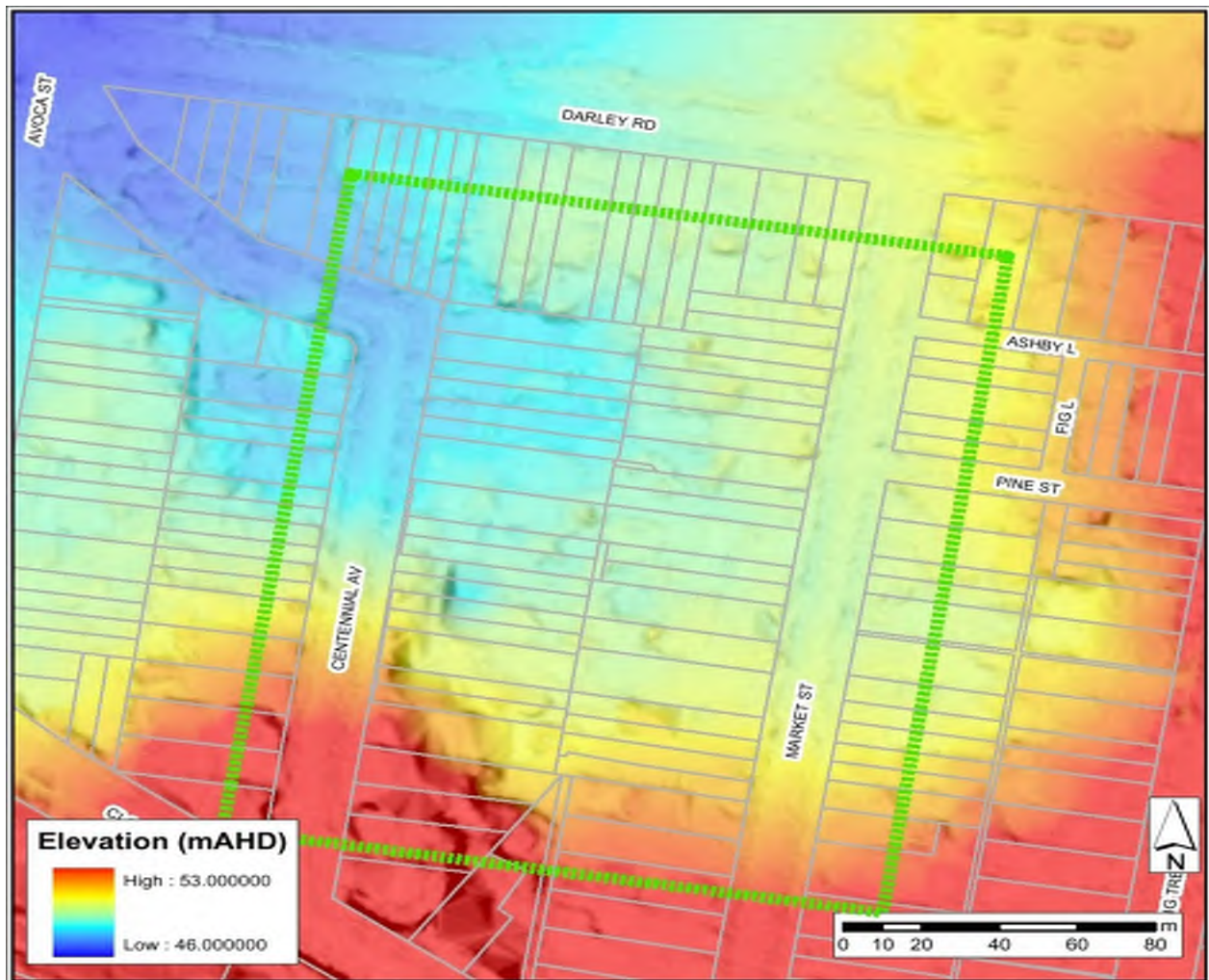


Photo 8: Ground Elevation – Market Street and Centennial Avenue

Feedback from local residents indicated that this area is known to have been susceptible to flooding in the past, particularly for those properties in close proximity to the trunk drainage line (running between Market Street and Centennial Avenue). Along the downstream (western) side of Market Street, flood depths of between 0.5m to 1m within the road reserve have been observed, with several properties experiencing flooding of garages during the 1999 event. One resident reported a burst manhole cover lid along the 1200mm diameter trunk line during one event. These reports correlate well with observations from a Centennial Avenue resident who observed flooding in the yards of several Centennial Avenue properties located immediately downstream of Market Street, within the line of the topographic depression.



Photo 9: Properties adjacent to the low point in Market Street. Note absence of any clearly defined overland flowpath.

3.8.6. Wentworth Street and Dangar Lane

Portions of Wentworth Street and Dangar Lane lie within a trapped low point formed by the natural topography of the area (Photo 10 and Photo 11). There is no natural outlet for overland flow to exit the area and drainage of runoff is via the trunk (sub-surface) system. As a result, ponding within this area is expected to take some time to recede following a storm. This accords well with observations of local residents indicating ponding within Wentworth Street can remain up to a day following small storms and up to 2 to 3 days for very large events.

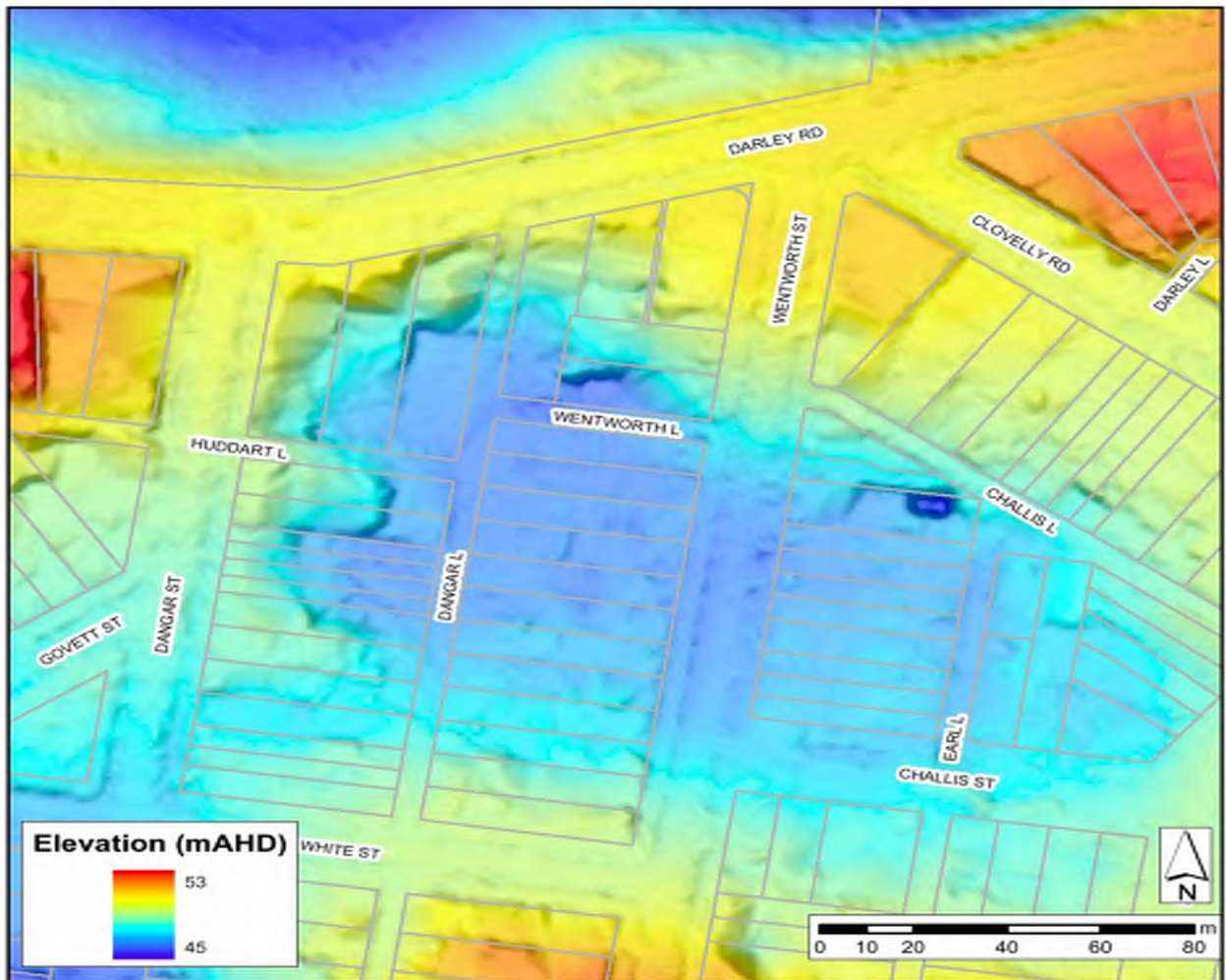


Photo 10: Ground Elevation – Wentworth Street low point



Photo 11: Wentworth Street low point (looking north)

There are a number of reports of flooding within Wentworth Avenue (up to 0.6m deep), Dangar Lane (approx 0.1m deep) and within several properties along the western side of Wentworth Street (between Wentworth Street and Dangar Lane).

3.8.7. Clovelly Road

Situated in a natural depression, the Clovelly Road trapped low point receives runoff from steeper portions of the contributing catchment to the south. The low lying area within the low point extends across several blocks and includes a mix of commercial and low-medium density residential developments. Once the capacity of the local sub-surface system is exceeded, overland flows enter the low point along the road network, including Castle Street and Earl Street (refer to Photo 12).

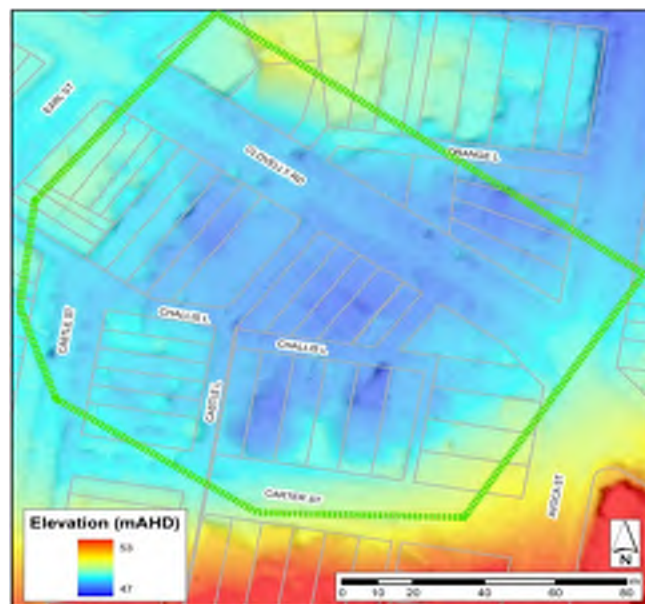


Photo 12: Ground Elevation – Clovelly Road trapped low point

A limited amount of information regarding flooding in recent years (post 2004) was provided by local residents. Ponding in this low point following a storm event in April 2007 is known to have resulted in damage to commercial premises in addition to flooding of garages and a residential property in the area (refer to Photo 13, Photo 14 and Photo 15).



Photo 13: Debris marks at residential property (April 2007)



Photo 14: Evidence of flooding along shopfronts in Clovelly Road (April 2007)



Photo 15: Damaged goods following flooding within Clovelly Road low point (April 2007)

4. APPROACH ADOPTED

4.1. General

The approach adopted for this study reflects the study objectives and the quality and quantity of available data. The urbanised nature of the catchment and its underlying soil characteristics, mixture of pervious/impervious surfaces and the construction of a piped drainage system has created a complex hydrologic-hydraulic flow system. The analysis is further complicated by:

- the presence of open space and flood storage at key locations within the catchment (such as Randwick Racecourse and Centennial Parklands),
- the complex nature of flow behaviour in the Centennial Parklands,
- the potentially high infiltration capacity of sandy soils in the majority of the catchment,
- interactions between the overland flows and the sub-surface drainage system, and
- the presence of many isolated trapped low points (e.g. Wentworth Street and Aboud Avenue).

In an urban catchment such as the Kensington - Centennial Park catchment there is rarely a sufficient historical flood record available and the use of a flood frequency approach for the estimation of design floods is not possible - this is the case for this study. Rather, the approach adopted for this study was to use a widely regarded hydrologic (converts rainfall to runoff) model (for urban situations) in conjunction with a hydraulic (converts runoff into flood levels and velocities) model.

The models were calibrated using the historical flood information from the 8-9th November 1984 event. A limited validation was then undertaken based upon the 5th November 1984 event. Subsequently the calibrated models were used to estimate design flood behaviour for a range of design events including the 1% AEP (100 year ARI) event. The sensitivity of the model to variations in adopted model parameters was also assessed for the 1% AEP (100 year ARI) design storm event.

4.2. Hydrologic Modelling

Techniques suitable for design flood estimation in an urban environment are described in Australian Rainfall and Runoff 1987 (ARR87 - Reference 7). These techniques range from simple procedures to estimate peak flows (e.g. Probabilistic Rational Method calculations), to more complex rainfall-runoff routing models that estimate complete flow hydrographs and can be calibrated to recorded flow data.

4.2.1. Mike-Storm Hydrologic Modelling Software

For the present study, the DHI software package MIKE-Storm (Reference 8) has been used to estimate the design flood hydrology within the majority of the study area. The MIKE-Storm model has been configured to utilise a runoff routing formulation that is based on methodology contained in the ILSAX/DRAINS models (References 9 and 10). The ILSAX/DRAINS type

method has been widely adopted in Australia for use in urban catchments, similar to that of the present study. Furthermore, the use of ILSAX/DRAINS style hydrology is consistent with the approaches taken in previous studies of adjacent catchments (e.g. Reference 11).

The exception to the above was for the Fox Studios/Moore Park area in the upper north-west portion of the catchment. For this area, an existing DRAINS model (supplied by CoS) was utilised to determine the hydrology. The DRAINS model utilised a pit and pipe configuration and routed rainfall excess flow to the downstream boundary control of the DRAINS model. Flow hydrographs at this location were utilised as inflow boundary conditions for the hydraulic model.

4.3. Hydraulic Modelling

4.3.1. Overview

A key objective of the present study is to produce estimates of design flood behaviour throughout the catchment suitable for the preparation of a flood study. The outcomes are to facilitate the detailed analysis of potential flood management options. Dynamic hydraulic modelling integrating the sub-surface drainage system and overland flow paths has been employed for this study.

The sub-surface drainage system was represented using a one-dimensional model that was linked to overland flow paths.

Given that drainage network data was not available for the areas of the catchment covered by Waverley Council, the drainage network and overland flow paths for this area could not be modelled in the hydraulic model. Rather this portion of the catchment was represented as a series of sub-catchments in MIKE-Storm. Runoff from these sub-catchments was applied as inflows into the hydraulic model within Queens Park. Results from the existing CoS DRAINS model of the Fox Studios/Moore Park area were used to define upstream boundary conditions for the hydraulic model at Centennial Park and Alison Road as appropriate.

The majority of overland flooding was modelled in a two-dimensional model. Exceptions include storage and cross flow in the Centennial Parkland ponds and concrete open channels in the trunk system of the lower model.

4.3.2. TUFLOW Modelling Software

The TUFLOW model established for the present study includes definition of both the trunk drainage and the majority of the minor drainage system elements as well as the overland flow paths.

The TUFLOW modelling package includes a finite difference numerical model for the solution of the depth averaged shallow water flow equations in two dimensions. The TUFLOW software is produced by BMT WBM (Reference 12) and has been widely used for a range of similar projects. The model is capable of dynamically simulating complex overland flow regimes. It is especially applicable to the hydraulic analysis of flooding in urban areas which is typically

characterised by short duration events and a combination of supercritical and subcritical flow behaviour.

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

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

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

5. HYDROLOGIC MODEL CONFIGURATION

5.1. Sub-catchment Layout

A hydrological model of the majority of the study catchment was established using the MIKE-Storm model software package (Reference 8).

A sub-catchment area was specified at each pit or node accepting inflow into the system. Sub-catchment boundaries were manually delineated based on interpretation of the available topographic data (ALS), aerial photography and drainage information.

A total catchment area of 8.2 km² comprising 300 sub-catchments was represented in the MIKE-Storm model (refer to Figure 6). As discussed previously, the existing DRAINS model of the Fox Studios/ Moore Park area was used to define the hydrology from this portion of the catchment. The total catchment area assessed for this study was 9.7 km².

5.2. Model Parameters

5.2.1. Impervious Fraction

The portion of impervious area for each sub-catchment was determined from an inspection of aerial photographs and land use types from GIS information supplied by Council. The impervious/pervious fraction defined for each sub-catchment was initially based on typical industry standard values for different land use types (refer to Table 6). These values were refined as part of the model calibration and validation process. It should also be noted the values tabulated are typical values and were sometimes varied for particular sub-catchments where appropriate.

Table 6: Initial Assumed Land Use Paved Percentage

Land Use	Percentage Paved (%)	Portion of Catchment Area (%)
General Residential	73	42
Parkland and Open Space	0-10	34
Residential and High Density Commercial	75-90	4
Open Water Bodies	100	3
Other	20-65	17

5.2.2. Rainfall Losses & Soil Type (MIKE-Storm Hydrologic Component)

Losses from paved areas are considered to comprise only of an initial loss i.e., an amount sufficient to wet the pavement and fill minor surface depressions. Losses from grassed areas are more complex. They are made up of both an initial loss and a continuing loss. The continuing loss was calculated within the model using an initial loss-continuing loss model, in accordance with previous studies. The values adopted were determined following model calibration/validation in conjunction with a review of reported findings from previous studies.

The actual rates adopted are presented in later sections.

5.2.3. Time of Concentration (MIKE-Storm Hydrologic Component)

Overland travel times for surface runoff within a sub-catchment were calculated using the kinematic wave equation. This relationship is based on the nature of the sub-catchment and accounts for different travel times with varying rainfall intensities.

5.2.4. DRAINS Model Parameters

For the DRAINS model of the Fox Studios/ Moore Park area the existing model parameters with regards to assumed land use were maintained for the present study. However, the assumed loss parameters in the DRAINS model were adjusted to ensure consistency with those adopted for the MIKE-Storm model.

6. TUFLOW MODEL CONFIGURATION

6.1. Hydraulic Model Extent

Hydraulic modelling of the study area utilised two sub models in order to optimise computation time and allow a high grid resolution to more accurately model in 2D the narrow roads, flow through properties and other such features typical for an urban context.

The approximate divide for the Upper and Lower models is Alison Road adjacent to Randwick Racecourse and Wansey Road. West of the intersection of Alison Road and Darley Road, near the racecourse entrance, the lower model supersedes.

The two hydraulic sub models are referred to as the Upper and Lower hydraulic models (refer Figure 7 and Figure 8).

6.2. Model DTM

The primary ground survey utilised to generate the digital terrain model (DTM) for the 2D hydraulic model is the ALS dataset. Grid cell resolutions for both the sub models are 2m by 2m. It should be noted that TUFLOW records ground levels for each cell at the four corners rather than as a single cell value. This means the effective resolution of the 2m model is doubled, i.e. 1m grid resolution. This level of resolution is at the limits of the ALS survey resolution and is sufficient to model most overland flow paths in 2D. At key locations such as Gardeners Road and the embankment along Alison Road, containing Centennial Parkland flows, break-lines were used to ensure the exact elevations of critical controls were used.

6.3. Centennial Parklands Storage

Centennial Parklands upstream of Alison Road are comprised of a series of cascading storages. These storage ponds are important features for flood mitigation and attenuate flow from Moore Park and areas of Randwick and Waverly LGAs via Queens Park.

1D storage nodes linked by 1D weirs were used to simulate the Centennial Parkland ponds. The embankment along Alison Road was interpreted from ALS and field survey and is represented in 2D so that the correct spilling locations are modelling, together with the correct velocity of embankment overflow. The ponds are assumed to be full prior to the design event modelling. For verification and calibration modelling the starting level of the most downstream pond was a calibration parameter.

6.4. Stormwater Assets

An extensive network of stormwater assets exist throughout the model domains which need to be incorporated into the hydraulic model. Stormwater assets include pits, pipes, concrete open channels and culverts under roads. These structures are modelled as 1D elements dynamically linked to the 2D domain overland flow. The model assumptions of each asset type are

discussed in the following sections.

6.4.1. Pipes

Asset data of pipes exist for the Randwick local government area only. The spatial database provided by Council was not 100% complete, though typically included invert levels and dimensions. Where inverts were not known they were linearly interpolated from the connected pipes. Table 7 shows the design parameters of pipes.

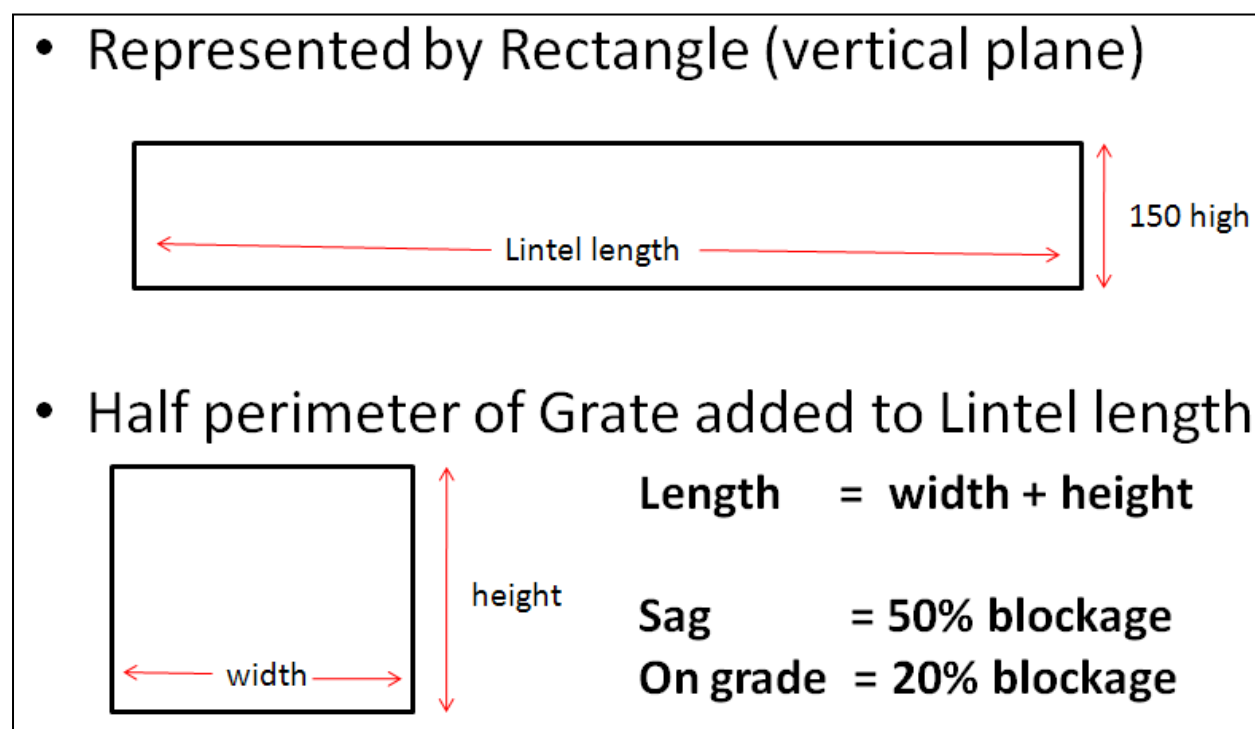
Table 7 Parameters for Buried Stormwater Pipes

Type	Man n	FL1	FL2	Entry	Exit	Block
Rectangular	0.012	0.6	0.9	0.5	1.0	0%
Circular	0.012	0.0	1.0	0.5	1.0	0%

6.4.2. Pits

Asset data of pits exist for the Randwick local government area only. The database includes details such grade/sag, lintel length, length and width of grate if present etc. Since such a high quality data set of pit details exist, pit inlets were modelled as physically representative structures. Diagram 1 shows that the pits were modelled as rectangular inlet structures in the vertical plane. The length of the rectangle was assumed equal to the lintel length with a nominal height of 150mm. To account for the additional inlet capacity made available by a grate, the lintel length was increased by half the perimeter of the grate (if present). Blockage of 20% and 50% was assumed for on grade and sag pits respectively.

Diagram 1 Pit Schematisation



6.4.3. Culverts

Three key culverts exist in the lower model. These rectangular structures convey water under Koorinda Avenue, Day Avenue and Gardeners Road. As discussed subsequently in the sensitivity analysis (Section 9), the flood levels immediately upstream of Gardeners Road are very sensitive to blockage assumptions. As a result of past flood experiences at North Wollongong - 1998, Coffs Harbour - 1996 and 2009 and Newcastle – 2007 it is considered best practice to implement some level of blockage for design events. There is no rigorous approach for determining an appropriate level of blockage, Wollongong City Council have a code for their LGA that culverts less than 6m diagonal width should be 100% blocked. For the Randwick LGA this level of blockage is considered unlikely and after discussion with Council a level of 25% was adopted. Table 8 shows the design parameters for culverts.

Table 8 Parameters for Culverts

Type	Man <i>n</i>	FL1	FL2	Entry	Exit	Block
Rectangular	0.012	0.6	0.9	0.5	1.0	25%

6.4.4. Concrete Open Channel

Concrete open channels exist between Roma Avenue and Gardeners Road. The width of these structures is not wide enough to accurately model in 2D so they were represented as 1D elements dynamically linked to the 2D domain. The Manning's 'n' of these 1D reaches is 0.015.

6.5. 2D Manning's 'n' and Overland Flow Obstructions

Based on calibration of the hydraulic models, Table 9 lists the adopted Manning's 'n' values adopted for design modelling. The flow restriction of houses was typically undertaken by removing the house footprint from the model domain. In trapped low points where ponding depths can exceed the house floor level this method would unduly remove temporary flood storage. In such areas of high depth flooding digitised houses were assigned a high Manning's 'n' which restricted flow, though did not remove flood storage.

Table 9 Overland Flow Manning's 'n'

Surface	Manning's 'n'	Surface	Manning's 'n'
Default	0.05	Buildings	1.00
Road	0.02	Parklands	0.045
Grass Reserve	0.03	Footpaths	0.03
Lots	0.06		

Where fences obstruct significant overland flow paths a method of modelling was adopted which restricted a percentage available flow area up to the height of the fence. Above the fence top, no flow area restriction was applied. Table 10 shows the typically assumed blockages for the height of the fence. If the difference in hydraulic head exceeded 1m from one side of the fence to the other a manual decision was made whether or not to maintain the fence in the hydraulic

model depending on its material of construction.

Table 10 Fence Blockage Assumptions (applied to the height of the fence)

Type	Blockage %
Brick	90
Wood	80
Wire/Metal	20

6.6. Boundary Conditions

TUFLOW model boundary conditions include both hydrologic model inputs and downstream tailwater boundaries.

6.6.1. Hydrologic Inputs

Hydrologic inputs exist for both the MIKE-Storm and DRAINS modelling of the Moore Park area.

Since such an extensive database of pit structures was available, hydrologic model inputs were delivered to the 2D domain of the hydraulic model and allowed to enter the stormwater via the pit inlet. Flow was directed to the 2D cells connected to the pit nodes to maximise the opportunity for inflow to the pit inlet. In the most upstream reaches of the stormwater system where overland flow was not concentrated; flow was allocated directly to the pipe if the flow was less than the capacity of the pipe. This is an appropriate assumption given most house roof drainage is directly connected to the road gutter.

In the Centennial Parklands, flow was allocated directly to the 1D storage nodes.

6.6.2. Downstream Tailwater

Downstream tailwater conditions exist for flow leaving the lower model to the west via Todman Avenue and Duke Street, in addition, downstream of Gardeners Road flow exits from the hydraulic model into the Eastlakes and Lakes golf courses.

For all three locations, a height/flow boundary type was utilised based on a water slope of 0.02m/m. The location of the flow boundary was always such that in the study area, flood levels were not influence by boundary conditions. Figure 8 shows the locations of the downstream boundaries.

7. MODEL CALIBRATION AND VERIFICATION

7.1. Overview

It is desirable to test the performance of the hydrological/hydraulic models against observed flood behaviour from past events within the catchment to ensure the accuracy. In this way the assumed model parameters can be adjusted so that the modelled behaviour best reproduces the historical patterns of flooding. The process of adjusting model parameters to best reproduce observed flood behaviour is known as model calibration. Usually, the models are calibrated to a single flood event for which there is sufficient flood data available (e.g. peak flood levels, observations regarding flowpaths or flood extents etc.). The performance of the calibrated model can then be tested by simulating other historical floods and comparing the ability of the calibrated models to reproduce the observed behaviour. This process is known as model validation/verification.

To calibrate/verify the models requires a sufficient amount of flood data within the modelling extent. Although other major floods are known to have occurred within the catchment (e.g. in 1933, 1958, 1975 and 2003), the two storms in November 1984 are the largest of recent events for which there is a sufficient amount of flood height data available. The records for the November 1984 events have been sourced from Reference 2. As the flood of 8-9th November was distinctly larger than the preceding 5-6th November flood, the hydrologic/hydraulic models were calibrated to the 8-9th November event and validated against the 5-6th November event.

When flooding occurs within the catchment in future, it is recommended that Council collect any available information (rainfall data, flood heights etc) as soon as practicable after the event (including after smaller, more frequent flooding such as would be expected in the 50% AEP or 2 year ARI event).

7.2. Approach

There have been a number of significant changes within the catchment since the November 1984 floods. Hence, the existing conditions hydraulic model described earlier was modified to account for these changes. For example, much of the trunk drainage network downstream of Centennial Park was upgraded following the November 1984 events (including both sub-surface drainage and the sections of open channel downstream of Roma Street). To account for these works, the TUFLOW hydraulic model was extensively modified to represent 1984 conditions on the basis of information found in Reference 2. Detailed information of the trunk drainage infrastructure present in 1984 was also obtained from surveyed data contained in Works-As-Executed drawings for the Kensington drainage works provided by RCC.

After a review of available rainfall data, the pluviometer records from the BoM station at Paddington and the UNSW station at Avoca Street were used to define the rainfall patterns for the November 1984 events (Figure 4). The data for the Avoca Street station could not be sourced directly from UNSW and was obtained from records provided in Reference 2. To account for spatial variability, the historical rainfall patterns from these two gauges were

interpolated linearly across the catchment.

For this study, calibration of the models was achieved through a tandem approach where changes to both the hydrological and hydraulic models were undertaken so that the model results reproduced observed behaviour. These changes included adjustments to the assumed hydrologic parameters e.g. loss rates, effective impervious area as well as changes to the hydraulic (TUFLOW) model e.g. initial storage levels in Centennial Park ponds.

7.3. Model Calibration

The TUFLOW models were calibrated using the peak flood level observations documented in Reference 2. A comparison of this data against the model results for the 8-9th November event is provided in Figure 9. The hydrological model parameters adopted to achieve this calibration are provided in Table 11. The typical Manning's 'n' values shown previously in Table 9 were adopted in the hydraulic model.

Table 11: MIKEStorm Hydrological Model Parameters: November 8-9th Storm Event

Land Use Types	Effective Fraction Impervious	Initial Loss (mm)	Continuing Loss (mm/hr)	Comments
Impervious Area	100%	1	0	Typical parameters consistent with ARR87
Urban Residential Development	73%	40 ¹	25 ¹	Parameters adjusted through calibration
Higher Density Urban Development	90%	40 ¹	25 ¹	Loss rates adjusted through calibration
Large Open Space Areas²	10%	50 ¹	50 ¹	Loss rates adjusted through calibration

Notes: 1 Rates for pervious area portion.

2 Includes features such as Centennial Parklands and Randwick Racecourse

In terms of outflow from the Centennial Parklands into Alison Road, Reference 2 notes observations that indicate outflow from the lower pond was unable to enter the culverts under Alison Road. As a consequence, outflows from this area were directed downstream across Alison Road rather than into the existing sub-surface drainage system. Due to the relative uncertainty regarding outlet control from the parklands system, the hydraulic (TUFLOW) model was adjusted to best represent this behaviour by blocking the Alison Road culverts downstream of the main Centennial Park outlet.

The available flood storage within the Centennial Parklands system prior to the November 1984 events is difficult to reliably determine due to the lack of suitable information. The following approach was therefore adopted for modelling the November 8-9th event:

- all ponds within the Centennial Parklands were assumed to be full, except for the Lower Kensington pond directly upstream of Alison Road,
- for the Lower Kensington pond, the initial water level in the pond was adjusted iteratively such that the outflow from the pond (in combination with inflows from other contributing catchments downstream) successfully reproduced the observed flooding behaviour in

the vicinity of Alison Road and along Doncaster Avenue. The resulting peak outflow from the Lower Kensington pond adopted to achieve this was found to be in the order of $9\text{m}^3/\text{s}$. This compares favourably with corresponding estimates reported in Reference 2.

Concurrently, preliminary model runs using industry-standard values for hydrologic parameters (e.g. rainfall losses) were found to over-estimate the level of ponding in the lower reaches of the catchment. The rainfall loss values for pervious portions of residential areas were increased iteratively until an initial loss of 40mm and continuing loss of 25mm/hr was reached. For large open space areas, these values were increased to 50mm initial loss and 50mm/hr continuing loss. These rates are considered to be the maximum that could be reasonably justified for design flood estimation in the absence of detailed rainfall/runoff data for the catchment and are consistent with previous expert reviews commissioned by RCC (Reference 6).

The outcomes of the model calibration for the 8-9th November 1984 event shown on Figure 9 compare favourably with observed behaviour and a large proportion of the modelled peak flood levels are within $\pm 0.2\text{m}$ of the corresponding observed level. The model successfully reproduced observed flood gradients in key reaches including:

- along Doncaster Avenue (between Alison Road downstream to Todman Avenue),
- in and around the intersection of Anzac Parade, Doncaster Avenue and Roma Avenue, and
- along the main stormwater easement (and adjacent roadways) from Koorinda Avenue downstream to Edward Avenue.

In other areas where there were larger discrepancies, these could be attributed to a number of features including possible localised hydraulic effects and the significant scatter in the observed levels.

7.4. Model Verification

Using the available rainfall data, the calibrated model was then used to estimate flooding from the 5-6th November 1984 event. Preliminary runs using the same loss assumptions as those adopted for the calibration event (i.e. the flood event of 8-9th November 1984) indicated that the modelled flood behaviour consistently overestimated observed flood levels for the main floodplain from downstream of Centennial Park to Gardeners Road.

It can be reasonably assumed that the pervious areas of the catchment were significantly drier before the first storm (5-6th November) than before the second storm (8-9th November). All other model parameters and assumptions remained as per that adopted for the November 8-9th calibration event. To improve this result the assumed previous area losses adopted for the 8-9th November 1984 event were increased to better reflect antecedent conditions for the earlier 5-6th November 1984 event.

Following an iterative trial/error process, a more reasonable representation of general behaviour was found when adopting the following pervious area loss assumptions:

- Pervious open space areas: initial loss = 110 mm, continuing loss 110mm/hr.

- Pervious urban areas (e.g. residential): initial loss 100mm, continuing loss 100mm/hr.

These higher loss rates are consistent with previous studies documented in Reference 6.

The results of the model validation are shown in Figure 10. Compared to the 8-9th November 1984 event, the relative differences between modelled and observed flood levels are greater and more variable. Generally, the TUFLOW model tends to overestimate levels in the lower reaches (below Roma Avenue) compared to upstream areas through to Alison Road. However, a review of each area also shows that there are significant localised variations present in the observed levels throughout the area. There are several levels which are difficult to resolve, particularly when considering corresponding flood levels in similar locations for the 8-9th November event. For example, the recorded flood level at Doncaster Avenue is 0.5m higher than the observations from the 8-9th November event despite the earlier event being recorded as a smaller storm event at the Paddington pluviometer.

Unfortunately more definitive conclusions regarding the quality of the model validation for the 5-6th November 1984 event are difficult to draw given the significant variations in observed levels, the uncertainties regarding antecedent conditions and the fact that there were only 39 recorded flood heights versus 124 recorded flood heights for the 8-9th November 1984 event.

The calibration event of 8-9th November has a high quality and quantity data set of surveyed flood levels and the modelling system provides a good overall match. Thus the model calibration is of a high quality. Discrepancies exist in isolated sections of the model verification that cannot be resolved, however the overall performance of the calibration and verification exercise gives confidence in the suitability of the models for design flood modelling.

8. DESIGN EVENT MODELLING

8.1. Approach

The calibrated models were used to estimate design flood behaviour for existing conditions (as opposed to the model setup for the November 1984 events). A number of design storms were analysed ranging from smaller events (e.g. 20% AEP or 5 year ARI event) through to large and rarer events such as the 1% AEP (100 year ARI) flood and the PMF.

The traditional ARR87 approach to design storm hydrology is based on the estimation of a peak flow generated by a critical duration peak burst rainfall pattern. This method assumes that antecedent rainfall prior to the critical duration burst does not impact upon the peak flow estimates. Several other studies indicate that a failure to incorporate antecedent conditions prior to the critical duration peak burst may result in the underestimation of peak flows for some catchments (References 13 to 15). As noted in Reference 14, this is particularly the case for catchments where the ARR87 critical burst durations are much shorter than the duration of historic flood-producing storms. It is also important for the Kensington - Centennial Park catchment as there is a significant amount of temporary floodplain storage (Centennial Park and Randwick Racecourse) and it is likely that high-intensity short duration storm bursts likely to cause major flooding will occur during a broader low intensity, longer duration storm.

To address these issues, this study adopts an alternative approach to design flood estimation whereby a critical duration design storm burst is embedded within a longer duration storm of the same AEP magnitude. This approach was originally presented Reference 14 and has been further documented in Reference 13. Initially, the critical burst is embedded to coincide with the peak of the larger duration storm. To ensure that the average intensities reflect the original AEPs the intensities of the longer duration storm are adjusted on either side of the peak burst such that the total rainfall depth is consistent with that of the original longer duration storm. Further details regarding the procedure can be found in References 13 and 14.

PMP rainfalls were obtained in accordance with Reference 16.

8.2. Embedded Design Storm Approach

8.2.1. Background

The selection of appropriate storm durations for design event modelling is complicated by the nature of the study catchment. In the Centennial Parklands area, the catchment response is a function of runoff potential in combination with the available flood storage provided by the ponds. As a result, the dominant flooding mechanism is strongly dependant upon the volume of runoff generated, hence longer duration storms are more likely to be critical. In contrast, the flood response of much of the urban areas upstream and downstream of the Centennial Parklands is primarily determined by the rainfall intensity - hence shorter duration storms (having higher intensity rainfalls) are responsible for major flooding. This variability within the catchment complicates the selection of a critical duration storm that is appropriate for the whole catchment.

Past studies have adopted peak burst storms based on ARR87 guidelines. These studies have found the critical duration of urban areas downstream of Centennial Parklands to be 2 hours, while the critical duration for the Centennial Parklands was found to be longer, in the range of 24 to 48 hours (Reference 6).

In accordance with previous studies, it was decided to adopt a shorter peak burst as the critical duration. However, for this study the peak burst was embedded in a longer duration storm. This takes into account the “impact of lead rainfall on burst response” for design events. Initially, a 2 hour peak burst was embedded into a range of longer duration storms to form a range of Embedded Design Storms (EDS). The rainfall patterns for various embedded design storms were then compared to a number of historical events to identify the most appropriate design storm for the catchment.

8.2.2. Methodology

The EDS were prepared based on the procedure outlined in Reference 14. This technique involves embedding the shorter duration peak burst storm into the longer duration storms (of 6, 12 and 24 hour durations) so that the peaks of both patterns coincided. The intensity of the storm was then adjusted so that the intensities were consistent with those for the critical burst average intensity and overall design storm average intensity for their respective durations and AEPs.

Pluviograph data for a number of large historical events was also analysed to determine an appropriate duration for the overall design storm. Information from the March 1975, and November 1984 storms were included in the analysis.

8.2.3. Outcomes

From this analysis it was concluded that a shorter peak burst (such as the 2 hour peak burst) be embedded in a 12 hour duration storm for this study. This conclusion takes into account a number of aspects including:

- The shorter duration peak burst embedded within a 6 hour duration storm was considered to be inappropriate due to insufficient overall rainfall depth. For example, when compared to recorded rainfalls from past floods, the total rainfall depth of the 6 hour duration EDS has been exceeded three times over the 32 years of limited historical data (e.g. Paddington 08/11/1984, Avoca Street 05/11/1984 and Airport 10/03/1975 – refer Figure 4). This outcome suggests that the 6 hour design storm may underestimate the magnitude of 6 hour storms experienced in this area in the past.
- The use of a longer duration storm such as the 24 hour storm was also considered inappropriate. While the total depth of the 24 hour design storm is similar to the recorded depths for large historical events, the historical storms of these durations examined generally do not exhibit the higher intensities found in this EDS.

In view of the preceding factors, the 12 hour EDS was therefore adopted for the purposes of this

study.

It is noted that the preceding analysis assumed a 2 hour peak burst since previous studies had found this to be the critical duration storm for the catchment. However, this assumption does not affect the outcomes of the above and the particular duration to be adopted as the peak burst duration was confirmed using the hydraulic model (discussed in later sections).

8.3. Key Model Parameters

The parameters adopted within the hydrologic model were based on those adopted from the model calibration (refer to Table 11). The Manning's 'n' values adopted within the hydraulic model were based on those adopted from the model calibration (refer to Table 9).

8.4. Boundary Conditions

8.4.1. Hydrologic (MIKE-Storm) Model

Design rainfall depths and temporal patterns across different storm durations for the embedded design storms were obtained in accordance with ARR87 and the embedded design storm approach presented in Section 8.2.

The resulting rainfall hyetographs were converted by the MIKE-Storm and DRAINS hydrologic models into paved area and pervious area runoff hydrographs. These hydrographs were then super-imposed for each sub-catchment to give total flow hydrographs and used to provide inflow boundary conditions to the TUFLOW hydraulic model.

8.4.2. Hydraulic (TUFLOW) Model

The runoff hydrographs for each sub-catchment were defined as point source inflow boundaries defined at the corresponding kerb inlet pit in the TUFLOW model.

Tailwater boundaries were used at the downstream limit of the TUFLOW model downstream of Gardeners Road. A stage-discharge relationship was established at each location and defined as a control relationship at these boundaries in the hydraulic (TUFLOW) model. The sensitivity of the model results to various tailwater assumptions is provided in Section 9.

8.5. Results

8.5.1. Critical Storm Duration

The determination of the critical storm duration for an urban catchment is more complex than for a rural catchment. Consideration must be taken of:

- the peak flow from the sub-catchment surface,
- the peak flow arriving at a surface inlet pit from upstream (conduit and overland flows),
- the peak flow in the pit,

- the volume temporarily collected in ponding areas,
- the location within the catchment.

To determine the critical duration(s) for the catchment, a number of design storm peak bursts ranging from 30 minutes to 3 hours were embedded within the 12 hour duration EDS for the 1% AEP event. The corresponding peak flow and water level estimates were then compared. The critical duration was found to vary across the catchment ranging from 60 minutes to 120 minutes. However, a detailed review of the results showed that the relative differences between these storm durations were only minor. The 60 minute storm was therefore adopted for all design events up to the 0.2% AEP as the representative critical duration for the study area to ensure consistency in results and reporting. However, it is recommended that the full range of storm durations are considered if undertaking detailed investigations for drainage upgrade works within the catchment.

To determine the critical duration for the PMF modelling, a number of design storm durations ranging from 30 minutes to 3 hours were run. The critical duration for the PMF modelling varied at different points in the catchment however the 120 minute event was typically the critical duration event and was used for design modelling.

8.5.2. Overview

The results from the design event modelling provide a description of the design flood behaviour of the study area. Information such as peak flood levels, flows and depths were extracted and have been documented as part of this report. In addition, the model results have also been produced in a digital format that can be readily imported into Council's GIS systems.

The results of the hydraulic modelling have been analysed and presented in accordance with the Brief. Table 12 provides a summary of design flood levels and flows at key locations for each event (refer Figure 2 for locations). Corresponding flood level and depth information is provided in Figure 11 through to Figure 26 for that portion of the floodplain represented in the 2D model. Table 13 shows the 1D levels determined for the ponds in Centennial Park and the approximate extent of flooding in Centennial Park is shown on Figure 27 for the 1% AEP event (the lateral extent does not vary much between the design events).

Table 12: Design flood levels (m AHD) and flows (m³/s) (1D and 2D) for key locations

#	LOCATION (refer Figure 2)	20% AEP			10% AEP			5% AEP			2% AEP			1% AEP			0.5% AEP			0.2% AEP			PMF 120 minute		
		Level	Q_1D	Q_2D	Level	Q_1D	Q_2D	Level	Q_1D	Q_2D	Level	Q_1D	Q_2D	Level	Q_1D	Q_2D	Level	Q_1D	Q_2D	Level	Q_1D	Q_2D	Level	Q_1D	Q_2D
5	Park	60.4	1.1	1.5	60.5	1.1	2.0	60.5	1.1	2.6	60.6	1.1	3.1	60.6	1.1	3.7	60.7	1.1	4.3	60.8	1.1	5.0	60.4	1.1	1.5
4	FigTree	52.7	0.8	2.1	52.7	0.8	2.7	52.7	0.8	3.4	52.7	0.8	3.9	52.7	0.8	4.7	52.7	0.7	5.4	52.8	0.8	6.4	52.7	0.8	2.1
3	Market St TLP	49.6	2.7	3.7	49.6	2.7	4.9	49.7	2.7	6.7	49.8	2.7	8.3	49.8	2.7	9.9	49.9	2.7	11.4	50.0	2.7	13.5	49.6	2.7	3.7
43	QnPark	45.9	20.3	NA	45.9	23.9	NA	46.0	28.6	NA	46.0	33.7	NA	46.1	39.0	NA	46.1	43.8	NA	46.2	51.1	NA	45.9	20.3	NA
2	Colvelly Rd TLP	48.4	1.2	0.1	48.5	1.3	0.2	48.6	1.4	0.4	48.6	1.4	0.9	48.7	1.4	1.4	48.7	1.4	1.8	48.8	1.4	2.6	48.4	1.2	0.1
1	Wentworth TLP	46.8	0.5	0.0	46.8	0.5	0.0	46.9	0.5	0.0	47.1	0.5	0.0	47.2	0.5	0.0	47.2	0.5	0.0	47.3	0.5	0.0	46.8	0.5	0.0
6	Govett	39.9	2.3	0.7	40.0	2.5	1.1	40.0	2.6	1.6	40.1	2.8	2.2	40.1	3.0	2.6	40.2	3.2	2.9	40.2	3.4	3.6	39.9	2.3	0.7
33	Cook St	65.9	0.6	---	65.9	0.6	---	66.0	0.7	---	66.0	0.7	---	66.0	0.7	---	66.0	0.7	---	66.0	0.7	---	65.9	0.6	---
36	Arthur St	60.2	0.1	0.1	60.2	0.1	0.1	60.2	0.1	0.1	60.2	0.1	0.1	60.2	0.1	0.1	60.2	0.1	0.1	60.2	0.1	0.2	60.2	0.1	0.1
39	AlisonRd_nr_Bradley	49.9	1.0	6.5	50.0	1.0	6.6	50.0	1.1	9.7	50.0	1.1	8.7	50.0	1.2	9.8	50.0	1.2	10.3	50.0	1.2	12.4	49.9	1.0	6.5
32	Wansey Rd	44.1	2.9	1.7	44.1	3.0	2.3	44.1	3.1	3.0	44.1	3.2	4.0	44.1	3.3	4.9	44.2	3.4	5.6	44.2	3.5	6.7	44.1	2.9	1.7
34	Cnr Alison Cowper	35.0	0.3	3.0	35.0	0.3	3.4	35.1	0.3	4.1	35.1	0.3	4.6	35.1	0.3	5.2	35.1	0.3	5.9	35.1	0.3	6.2	35.0	0.3	3.0
42	Alison nr RRR entrance	30.9	0.6	3.0	30.9	0.6	3.4	30.9	0.6	4.9	30.9	0.6	6.0	31.0	0.6	7.2	31.0	0.6	8.2	31.0	0.6	9.6	30.9	0.6	3.0
7	Cnr Donaster Carlton	28.3	2.1	2.1	28.5	2.6	5.0	28.6	2.8	10.8	28.9	2.9	19.1	29.0	3.0	25.9	29.2	3.0	32.0	29.4	3.3	38.0	28.3	2.1	2.1
10	Cnr Doncaster Todman	26.8	4.3	1.7	26.9	5.2	3.4	26.9	5.9	8.5	27.0	6.2	15.3	27.1	6.2	21.2	27.1	6.4	27.2	27.2	6.7	35.6	26.8	4.3	1.7
31	Cnr Anzac Tay	30.2	2.5	9.0	30.3	2.6	13.0	30.4	2.6	18.0	30.6	2.6	27.1	30.7	2.6	34.1	30.8	2.6	41.9	31.0	2.7	50.0	30.2	2.5	9.0
30	Cnr Anzac Carlton	28.3	2.5	9.2	28.4	2.6	13.8	28.6	2.7	21.2	28.7	2.8	32.7	28.8	2.8	41.4	28.9	2.8	49.7	29.0	2.9	58.7	28.3	2.5	9.2
28	Cnr Todman Anzac	25.5	3.0	10.6	25.6	3.0	19.2	25.7	3.0	32.6	25.9	3.0	50.9	26.0	3.0	64.2	26.1	2.9	77.5	26.2	3.0	93.8	25.5	3.0	10.6
25	Roma Av US OC	22.9	18.8	1.0	23.2	25.6	2.7	23.5	35.8	9.4	23.8	43.2	23.5	24.1	47.5	37.9	24.3	51.3	52.4	24.5	56.1	71.9	22.9	18.8	1.0
24	Koorinda Av US OC	22.0	19.5	0.4	22.4	26.7	2.3	22.8	36.3	8.9	23.2	42.8	23.0	23.4	45.0	37.3	23.6	48.1	51.8	23.8	50.7	71.1	22.0	19.5	0.4
23	Day Av nr OC	21.5	21.4	1.6	21.8	24.0	2.1	22.2	26.5	2.7	22.5	28.1	3.3	22.7	28.7	3.8	22.9	29.0	4.4	23.1	28.9	5.1	21.5	21.4	1.6
40	Edward Av	20.2	25.2	0.5	20.2	26.6	0.6	20.4	30.1	6.9	20.9	32.0	28.1	21.2	33.0	46.9	21.5	33.3	65.1	21.8	34.3	90.3	20.2	25.2	0.5
41	Borrodale	19.5	27.2	1.8	19.6	28.9	2.5	19.6	32.7	3.4	19.9	36.0	22.2	20.1	37.5	40.9	20.4	38.4	57.1	21.0	39.0	76.8	19.5	27.2	1.8
18	OC US Gardners Rd	17.6	16.0	---	17.7	17.6	---	18.0	20.8	---	18.8	31.5	---	19.8	41.7	---	20.4	46.1	---	21.1	51.1	---	17.6	16.0	---
22	Winburn Av	22.8	0.3	1.3	22.9	0.3	1.6	22.9	0.3	2.1	22.9	0.3	2.4	23.0	0.3	2.9	23.0	0.3	3.3	23.0	0.3	3.9	22.8	0.3	1.3
21	Cnr Goodrick Shaw	21.9	0.7	1.8	21.9	0.7	2.3	22.0	0.7	3.0	22.0	0.7	3.7	22.0	0.6	4.6	22.1	0.7	5.3	22.1	0.7	6.4	21.9	0.7	1.8
20	Maitland Av	19.0	1.6	0.2	19.2	1.7	0.4	19.3	1.8	0.6	19.6	1.9	0.8	19.8	1.9	0.9	19.9	1.9	0.9	20.1	1.9	1.0	19.0	1.6	0.2
12	Barker St	26.9	1.2	0.7	27.0	1.2	1.1	27.1	1.3	2.0	27.2	1.3	3.0	27.4	1.3	4.0	27.4	1.3	4.8	27.6	1.3	6.0	26.9	1.2	0.7
13	Anzac Pd Sth	26.0	0.5	0.0	26.1	0.5	0.0	26.2	0.5	0.0	26.2	0.5	0.0	26.3	0.5	0.0	26.4	0.5	0.1	26.4	0.5	0.2	26.0	0.5	0.0
14	Anzac Pd Nth	26.7	0.3	1.5	26.8	0.3	2.0	26.8	0.3	2.5	26.9	0.3	3.1	26.9	0.3	3.7	26.9	0.3	4.3	26.9	0.3	5.1	26.7	0.3	1.5
15	Houston Ln Nth	23.5	0.2	0.0	23.6	0.2	0.0	23.6	0.3	0.1	23.7	0.3	0.1	23.8	0.3	0.1	23.9	0.3	0.1	24.1	0.3	0.2	23.5	0.2	0.0
27	Barker St Kens Pk	20.6	1.1	1.1	20.8	1.3	1.3	21.6	1.3	1.6	21.9	1.0	1.9	22.1	1.1	2.3	22.2	1.1	2.6	22.4	1.1	3.0	20.6	1.1	1.1
37	Houston Ln Sth	24.4	0.2	0.4	24.5	0.2	0.5	24.5	0.1	0.6	24.5	0.1	0.7	24.5	0.1	0.8	24.5	0.1	0.9	24.5	0.1	1.1	24.4	0.2	0.4
26	Houston Rd Sth	22.8	0.3	---	22.9	0.3	---	22.9	0.3	---	22.9	0.3	---	22.9	0.2	---	22.9	0.2	---	23.0	0.2	---	22.8	0.3	---
16	Cottenham Kens Pk	22.1	NA	0.6	22.1	NA	0.8	22.2	NA	1.0	22.2	NA	1.2	22.2	NA	1.4	22.3	NA	1.5	22.4	NA	1.8	22.1	NA	0.6
17	Eastern Av Sth	21.9	0.4	0.7	21.9	0.4	1.0	22.0	0.5	1.1	22.0	0.5	1.2	22.0	0.5	1.5	22.0	0.5	1.6	22.0	0.5	1.9	21.9	0.4	0.7
19	Cottenham Sth	18.0	1.6	0.9	18.1	1.6	1.1	18.1	1.7	1.5	18.8	1.8	1.9	19.7	2.1	2.4	20.3	2.3	11.3	21.0	2.5	17.8	18.0	1.6	0.9

NA: Not applicable

OC: Open Channel

TLP: Trapped Low Point

US: Upstream

--- 2D flow path not well defined (unable to be recorded) and hence not reported

Table 13 Centennial Parkland Design Flood Levels (mAHD)

Pond Name	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF 120 min
Model Yacht	45.6	45.7	45.7	45.8	45.9	46.0	46.0	46.5
Fly Casting	40.7	40.7	40.7	40.8	40.8	40.8	40.9	41.1
Musgrave	43.9	44.0	44.0	44.1	44.1	44.2	44.2	44.5
One More Shot	41.9	42.0	42.0	42.1	42.1	42.2	42.2	42.5
Willow	40.9	40.9	41.0	41.0	41.0	41.1	41.1	41.4
Duck	37.0	37.0	37.0	37.1	37.1	37.1	37.2	37.3
Lily	36.2	36.3	36.3	36.3	36.3	36.4	36.4	36.6
Busby	36.2	36.2	36.2	36.3	36.3	36.3	36.3	36.5
Randwick	35.7	35.7	35.7	35.8	35.8	35.8	35.9	36.0
Kensington Small	31.9	31.9	32.0	32.0	32.0	32.1	32.1	32.3
Kensington Large A	31.9	31.9	32.0	32.0	32.0	32.1	32.1	32.3
Kensington Large B	31.9	31.9	32.0	32.0	32.0	32.1	32.1	32.3

8.5.3. Flood Hazard and Hydraulic Categorisation

The provisional hydraulic hazard for the 1% AEP event within the 2D model domain is shown on Figure 28. The provisional hydraulic hazard has been calculated as the product of peak depth and peak velocity in accordance with Figure L2 of the NSW Floodplain Development Manual (Reference 1). Additional areas have also been designated as being high hazard including:

- areas where the peak depth is greater than or equal to 1m, and
- areas within the Sydney Water easement downstream of Roma Avenue.

Hydraulic categorisation has been mapped and is shown on Figure 29. Hydraulic categorisation is based on the following:

- Flood Fringe (base layer):
PMF extent for peak depth greater than 0.15 m.
- Flood Storage (supersedes Flood Fringe when overlapping):
1% AEP extent for peak depth greater than 0.15 m.
- Flood Way (supersedes Flood Storage when overlapping):
*Extent of 1% AEP peak velocity depth product when greater than 0.3 m²/s; or
Extend of 1% AEP peak velocity when greater than 0.5 m/s.*

8.5.4. Comparison of Results with Previous Studies

As outlined in Section 3.7, numerous studies have previously been conducted in the catchment area. A comparison of results and parameters adopted for this flood study is compared to the previously document values in Table 14.

Table 14: Comparison of Previous Results and Parameters

Previous Parameter/ Result	Previous Value	Current Value	Reference
Flow u/s Gardeners Road - 8-9 th Nov 1984	22.6 m ³ /s	28.5 m ³ /s	2
Flow u/s Gardeners Road - 5 th Nov 1984	21.9 m ³ /s	20.5 m ³ /s	2
Flow u/s Gardeners Road - 1% AEP	26.5 m ³ /s	60.0 m ³ /s*	2
Anzac Pd u/s Doncaster Avenue - 8-9 th Nov	5.6 m ³ /s	15.5 m ³ /s	2
Anzac Pd u/s Doncaster Avenue - 5 th Nov	5.6 m ³ /s	6.9 m ³ /s	2
Doncaster Avenue U/S Anzac Pd - 8-9 th Nov	8.2 m ³ /s	5.0 m ³ /s	2
Doncaster Avenue U/S Anzac Pd - 5 th Nov	6.6 m ³ /s	3.6 m ³ /s	2
Pervious Initial Loss	100mm	50mm	5
Pervious Continuing Loss	100mm/hr	50mm/hr	5
Impervious Initial Loss	10mm and 5mm	40mm	5
Impervious Continuing Loss	5mm/hr and 2mm/hr	25mm/hr	5
Flow Gardeners Road – 1% AEP (SMEC, 1992)	41 m ³ /s	68 m ³ /s **	5
Flow d/s Gardeners Road (PMF)	199.5m ³ /s	370 m ³ /s	5

* Embedded storm

** Combined flow downstream of Gardeners Rd, embedded storm.

9. SENSITIVITY ANALYSES AND CLIMATE CHANGE

9.1. Sensitivity Analyses

The models established for the present study rely on a number of assumed parameters, the values of which are considered to be the most appropriate for the catchment based on limited calibration/validation and published studies of similar catchments. Although a limited model validation has been performed, a range of sensitivity analyses were also undertaken to quantify the potential variation in the model results due to different assumptions in the key modelling parameters adopted.

The following scenarios were considered to represent the envelope of likely parameter values:

- $\pm 20\%$ change in design rainfall,
- $\pm 20\%$ change in Manning's 'n' value for overland flow paths,
- comparisons between embedded and peak burst design storm hydrology, and
- culvert blockage.

When interpreting the results, it should also be noted that the sensitivity analysis for the drainage system may not always result in a change in peak flow attained downstream if (for instance) the size of the pipe or pit is the control and there is no change in the flow conveyed in the pipe. There may be a change in the overland flow but the effect further downstream will depend on the particular characteristics of the pit and pipe network. At some locations the change in upstream flow is not reflected downstream due to the effects of ponding at sag pits or the relative timing of overland flows.

For each of the above scenarios (excluding the peak burst hydrology scenario), the models were run for the 1% AEP 60 minute duration embedded design storm using the design model parameters. A relative comparison of the resultant changes in peak overland flows and flood heights at various locations (refer Figure 2) is provided in Table 15.

Table 15: Sensitivity of Model Assumptions to 1% AEP Design Model Results (change in depth (m) and % change in peak flow)

#	LOCATION (refer Figure 2)	Plus 20% Mannings n			Minus 20% Mannings n			Plus 20% Rainfall Depth			Minus 20% Rainfall Depth			Non Embedded Storm			0% Culvert Block			100% Culvert Block		
		Depth	Q_1D	Q_2D	Depth	Q_1D	Q_2D	Depth	Q_1D	Q_2D	Depth	Q_1D	Q_2D	Depth	Q_1D	Q_2D	Depth	Q_1D	Q_2D	Depth	Q_1D	Q_2D
5	Park	0.0	0%	1%	0.0	0%	2%	0.1	1%	31%	-0.1	-2%	-28%	-0.1	-1%	-22%	0.0	0%	0%	0.0	0%	0%
4	FigTree	0.0	-8%	-2%	0.0	7%	2%	0.1	-3%	31%	0.0	3%	-26%	0.0	35%	-20%	0.0	0%	0%	0.0	0%	0%
3	Market St TLP	0.0	-8%	-3%	0.0	12%	3%	0.1	0%	29%	-0.1	0%	-29%	-0.1	0%	-21%	0.0	0%	0%	0.0	0%	0%
43	QnParl	0.0	-2%	NA	0.0	3%	NA	0.1	27%	NA	-0.1	-24%	NA	-0.1	-20%	NA	0.0	0%	NA	0.0	0%	NA
2	Colvelly Rd TLP	0.0	-12%	7%	0.0	14%	-8%	0.1	1%	67%	-0.1	-2%	-61%	-0.1	-1%	-52%	0.0	0%	0%	0.0	0%	0%
1	Wentworth TLP	0.0	-9%	NA	0.0	10%	NA	0.2	3%	NA	-0.2	-3%	NA	-0.1	-2%	NA	0.0	0%	NA	0.0	0%	NA
6	Govett	0.0	0%	-3%	0.0	-1%	33%	0.1	10%	24%	-0.1	-12%	-35%	-0.1	-9%	-26%	0.0	0%	0%	0.0	0%	0%
33	Cook St	0.0	-9%	NA	0.0	2%	NA	0.0	3%	NA	0.0	-4%	NA	0.0	-5%	NA	0.0	0%	NA	0.0	0%	NA
36	Arthur St	0.0	-14%	-5%	0.0	17%	8%	0.0	0%	19%	0.0	1%	-22%	0.0	0%	-25%	0.0	0%	0%	0.0	0%	0%
39	AlisonRd_nr_Bradley	0.0	2%	-12%	0.2	-3%	47%	0.0	4%	17%	0.0	-6%	-10%	0.0	-5%	-7%	0.0	0%	0%	0.0	0%	0%
32	Wansey Rd	0.0	1%	5%	0.0	-1%	3%	0.0	4%	29%	0.0	-5%	-35%	0.0	-4%	-29%	0.0	0%	0%	0.0	0%	0%
34	Cnr Alison Cowper	0.0	-13%	-9%	0.0	16%	16%	0.0	0%	32%	0.0	0%	-21%	0.0	2%	-9%	0.0	0%	0%	0.0	0%	0%
42	Alison nr RRR entrance	0.0	-14%	1%	0.0	19%	1%	0.0	-1%	27%	0.0	0%	-30%	0.0	1%	-13%	0.0	0%	0%	0.0	0%	0%
7	Cnr Donaster Carlton	0.1	-2%	-3%	-0.1	1%	-3%	0.3	6%	41%	-0.3	-2%	-47%	-0.7	-14%	-91%	0.0	2%	0%	0.0	0%	0%
10	Cnr Doncaster Todman	0.0	-1%	5%	0.0	2%	5%	0.1	5%	56%	-0.1	-3%	-50%	-0.2	-22%	-85%	0.0	0%	0%	0.0	0%	0%
31	Cnr Anzac Tay	0.0	-5%	2%	0.0	6%	2%	0.2	2%	39%	-0.2	-1%	-38%	-0.5	0%	-73%	0.0	0%	0%	0.0	0%	0%
30	Cnr Anzac Carlton	0.0	-13%	3%	0.0	13%	3%	0.2	2%	36%	-0.2	-3%	-39%	-0.5	-10%	-79%	0.0	0%	0%	0.0	0%	0%
28	Cnr Todman Anzac	0.0	-13%	3%	0.0	10%	3%	0.2	-1%	39%	-0.2	1%	-39%	-0.5	1%	-78%	0.0	0%	0%	0.0	-1%	0%
25	Roma Av US OC	0.0	-3%	6%	0.0	2%	6%	0.4	15%	75%	-0.4	-18%	-65%	-0.9	-45%	-92%	0.0	1%	-1%	0.0	0%	0%
24	Koorinda Av US OC	0.0	-2%	5%	0.0	3%	5%	0.3	11%	76%	-0.5	-12%	-65%	-0.9	-39%	-93%	0.0	8%	-1%	0.1	-8%	0%
23	Day Av nr OC	0.0	-7%	0%	0.0	2%	0%	0.3	0%	29%	-0.4	-5%	-28%	-0.8	-14%	-28%	0.0	13%	0%	0.1	-27%	0%
40	Edward Av	0.0	-7%	4%	0.0	4%	4%	0.5	2%	77%	-0.6	-6%	-71%	-1.0	-12%	-98%	0.0	4%	-6%	0.2	-21%	16%
41	Borrodale	0.0	-6%	3%	0.0	3%	3%	0.7	3%	75%	-0.5	-9%	-77%	-0.6	-17%	-90%	0.0	1%	-4%	1.1	-18%	-2%
18	OC US Gardners Rd	-0.1	-2%	NA	0.0	1%	NA	1.2	20%	NA	-1.5	-40%	NA	-1.9	-52%	NA	-0.6	14%	NA	1.6	-99%	NA
22	Winburn Av	0.0	-16%	2%	0.0	23%	2%	0.0	0%	27%	-0.1	1%	-27%	-0.1	1%	-26%	0.0	0%	0%	0.0	0%	0%
21	Cnr Goodrick Shaw	0.0	-13%	1%	0.0	21%	1%	0.1	2%	32%	-0.1	2%	-31%	-0.1	7%	-28%	0.0	0%	0%	0.0	0%	0%
20	Maitland Av	0.1	-11%	-4%	-0.1	12%	-4%	0.3	1%	12%	-0.4	-4%	-24%	-0.4	1%	-25%	0.0	0%	0%	0.0	0%	0%
12	Barker St	0.0	-8%	2%	0.0	2%	2%	0.2	1%	43%	-0.2	-3%	-42%	-0.2	-1%	-34%	0.0	0%	0%	0.0	0%	0%
13	Anzac Pd Sth	0.0	-8%	6%	0.0	7%	6%	0.1	-1%	313%	-0.1	0%	-34%	-0.1	5%	-15%	0.0	0%	0%	0.0	0%	0%
14	Anzac Pd Nth	0.0	-14%	-1%	0.0	17%	-1%	0.0	1%	30%	-0.1	0%	-29%	-0.1	0%	-28%	0.0	0%	0%	0.0	0%	0%
15	Houston Ln Nth	0.1	-9%	-4%	-0.1	10%	-4%	0.2	8%	52%	-0.2	-7%	-48%	-0.1	-5%	-9%	0.0	0%	0%	0.0	0%	0%
27	Barker St Kens Pk	0.0	-11%	5%	0.0	10%	5%	0.2	1%	27%	-0.4	-6%	-29%	-0.8	30%	-27%	0.0	-3%	-2%	0.1	16%	0%
37	Houston Ln Sth	0.0	-23%	-3%	0.0	21%	-3%	0.0	-11%	22%	0.0	5%	-24%	0.0	16%	-6%	0.0	0%	0%	0.0	0%	0%
26	Houston Rd Sth	0.0	-26%	NA	0.0	24%	NA	0.0	-24%	NA	0.0	21%	NA	0.0	27%	NA	0.0	-1%	NA	0.0	-19%	NA
16	Cottenham Kens Pk	0.0	NA	-1%	0.0	NA	-1%	0.2	NA	25%	-0.1	NA	-26%	0.0	NA	-18%	0.0	NA	0%	0.0	NA	0%
17	Eastern Av Sth	0.0	0%	-6%	0.0	0%	-6%	0.0	2%	22%	0.0	-5%	-28%	0.0	-2%	-19%	0.0	0%	0%	0.0	0%	0%
19	Cottenham Sth	-0.1	-12%	29%	0.0	13%	29%	1.2	21%	581%	-1.5	-18%	-38%	-1.5	-17%	-25%	-0.5	-16%	24%	1.6	31%	192%

NA: Not applicable

OC: Open Channel

TLP: Trapped Low Point

US: Upstream

--- 2D flow path not well defined (unable to be recorded) and hence not reported

9.2. Climate Change

In accordance with the DECC Guideline October 2007 (Reference 17) and the DECCW Guideline August 2010 (Reference 18), the possible effects of climate change on flooding have been investigated. The possible effects relevant to this study are an increase in sea level and an increase in the design rainfall intensity. The guidelines suggests the following scenarios be examined:

- **ocean level rise:**
 - 2050 mean sea level rise = 0.4 m,
 - 2100 mean sea level rise = 0.9 m,
- **increase in peak rainfall and storm volume:**
 - low level rainfall increase = 10%,
 - medium level rainfall increase = 20%,
 - high level rainfall increase = 30%.

An increase in ocean level of 0.9m will have no measurable impact on design flood levels within the study area due to its altitude above sea level. For this reason the effects of sea level rise have not been considered further in this study.

A high level rainfall increase of up to 30% is recommended for consideration due to the uncertainties associated with this aspect of climate change. It is generally acknowledged that a 30% rainfall increase is probably overly conservative and that a timeframe for the provision of definitive predictions of the actual increase is unknown.

Table 16 provides an assessment of the potential increase in design rainfalls of 10%, 20% and 30% for the 1% AEP event. Figure 30 shows the change in flood extent for the three rainfall climate change scenarios modelled.

Table 16: Climate Change Results (change in depth (m) and % change in peak flow)

#	LOCATION (refer Figure 2)	Plus 10% Rainfall Depth			Plus 20% Rainfall Depth			Plus 30% Rainfall Depth		
		Depth	Q_1D	Q_2D	Depth	Q_1D	Q_2D	Depth	Q_1D	Q_2D
5	Park	0.0	1%	16%	0.1	1%	31%	0.1	2%	44%
4	FigTree	0.0	-2%	14%	0.1	-3%	31%	0.1	-1%	44%
3	Market St TLP	0.0	0%	15%	0.1	0%	29%	0.1	0%	44%
43	QnParl	0.0	12%	NA	0.1	27%	NA	0.1	37%	NA
2	Colvelly Rd TLP	0.0	1%	32%	0.1	1%	67%	0.1	1%	105%
1	Wentworth TLP	0.1	1%	NA	0.2	3%	NA	0.2	4%	NA
6	Govett	0.0	4%	20%	0.1	10%	24%	0.1	14%	46%
33	Cook St	0.0	2%	NA	0.0	3%	NA	0.0	5%	NA
36	Arthur St	0.0	0%	10%	0.0	0%	19%	0.0	0%	30%
39	AlisonRd_nr_Bradley	0.0	1%	11%	0.0	4%	17%	0.0	5%	26%
32	Wansey Rd	0.0	2%	13%	0.0	4%	29%	0.0	6%	47%
34	Cnr Alison Cowper	0.0	0%	9%	0.0	0%	32%	0.0	0%	22%
42	Alison nr RRR entrance	0.0	-1%	14%	0.0	-1%	27%	0.0	-2%	46%
7	Cnr Donaster Carlton	0.2	2%	23%	0.3	6%	41%	0.5	20%	54%
10	Cnr Doncaster Todman	0.1	3%	28%	0.1	5%	56%	0.2	8%	82%
31	Cnr Anzac Tay	0.1	1%	22%	0.2	2%	39%	0.3	2%	55%
30	Cnr Anzac Carlton	0.1	2%	20%	0.2	2%	36%	0.2	2%	49%
28	Cnr Todman Anzac	0.1	-2%	20%	0.2	-1%	39%	0.2	-1%	55%
25	Roma Av US OC	0.2	8%	38%	0.4	15%	75%	0.5	22%	109%
24	Koorinda Av US OC	0.2	7%	38%	0.3	11%	76%	0.5	15%	111%
23	Day Av nr OC	0.2	0%	14%	0.3	0%	29%	0.4	0%	42%
40	Edward Av	0.3	1%	38%	0.5	2%	77%	0.7	4%	113%
41	Borrodale	0.2	2%	39%	0.7	3%	75%	1.0	4%	106%
18	OC US Gardners Rd	0.6	11%	NA	1.2	20%	NA	1.5	25%	NA
22	Winburn Av	0.0	0%	14%	0.0	0%	27%	0.0	0%	40%
21	Cnr Goodrick Shaw	0.0	1%	15%	0.1	2%	32%	0.1	2%	48%
20	Maitland Av	0.2	1%	5%	0.3	1%	12%	0.4	1%	19%
12	Barker St	0.1	1%	21%	0.2	1%	43%	0.3	1%	64%
13	Anzac Pd Sth	0.1	0%	68%	0.1	-1%	313%	0.1	-1%	630%
14	Anzac Pd Nth	0.0	0%	14%	0.0	1%	30%	0.1	1%	48%
15	Houston Ln Nth	0.1	4%	29%	0.2	8%	52%	0.3	11%	104%
27	Barker St Kens Pk	0.1	2%	14%	0.2	1%	27%	0.3	0%	40%
37	Houston Ln Sth	0.0	-7%	11%	0.0	-11%	22%	0.0	-7%	37%
26	Houston Rd Sth	0.0	-7%	NA	0.0	-25%	NA	0.0	-21%	NA
16	Cottenham Kens Pk	0.1	NA	12%	0.2	NA	25%	0.2	NA	37%
17	Eastern Av Sth	0.0	1%	8%	0.0	2%	22%	0.0	4%	36%
19	Cottenham Sth	0.6	12%	362%	1.2	21%	581%	1.5	22%	680%

NA: Not applicable

OC: Open Channel

TLP: Trapped Low Point

US: Upstream

--- 2D flow path not well defined (unable to be recorded) and hence not reported

10. ACKNOWLEDGEMENTS

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- Members of the Kensington - Centennial Park Floodplain Risk Management Committee,
- Local residents and members of the general public, many of who contributed information to this Study,
- Randwick City Council,
- City of Sydney,
- NSW Office of Environment and Heritage (formerly the NSW Department of Environment, Climate Change and Water),
- Sydney Water.

11. REFERENCES

1. NSW State Government
Floodplain Development Manual
April 2005
2. Public Works Department NSW Civil Engineering Division
Kensington Flooding Drainage Works Investigation
PWD Report No. 84030 January 1985
3. NSW Department of Public Works and Services
Centennial Park – Kensington Pond Stormwater Flow Control Structure Restoration Works Flood Study (Summary of RAFTS Modelling)
Technical Report No. DC002245 prepared for Centennial Park and Moore Park Trust and Randwick City Council, November 2002
4. NSW Department of Public Works Civil Engineering Division
Sydney Storms November 1984 – Hydrological Aspects
PWD Report No. 85014, October 1985
5. Snowy Mountains Engineering Corporation Limited
Hydrologic and Hydraulic Study – Botany Wetland – Volumes 1 and 2
Technical Report prepared for Sydney Water Board, June 1992
6. WP Brown & Partners Pty Ltd
Assessment of Hydrological and Hydraulic Modelling of Centennial Park and Kensington Catchments
May 2003
7. Institution of Engineers, Australia
Australian Rainfall and Runoff – Third Edition
1987
8. DHI Water and Environment
MIKE-Storm User Guide
2004
9. G. G. O'Loughlin
The ILSAX program for urban drainage design and analysis
School of Civil Engineering, NSW Institute of Technology 1986
10. Watercom Pty. Ltd. and Dr G. G. O'Loughlin
DRAINS Software Manual v2006.02
2006

11. Webb McKeown and Associates Pty. Ltd.
Sheas Creek Flood Study
Technical Report prepared for the Water Board and the City of South Sydney, August 1991
12. BMT WBM
TUFLOW User Manual
2008
13. Rigby, E., Boyd, M., Roso, S. and VanDrie, S.
Storms, Storm Bursts and Flood Estimation - A Need for Review of the AR&R Procedures
Proc. 28th Hydrology and Water Resources Symposium (IEAust), Wollongong, 2003
14. Rigby, E. and Bannigan, D.
The Embedded Design Storm Concept - A Critical Review
Proc. 23rd Hydrology and Water Resources Symposium (IEAust), Hobart, 1996
15. Phillips, B., Lees, S., Lynch, S.
Embedded Design Storms - An Improved Procedure For Design Flood Level Estimation
Proc. Water Down Under (IEAust.), Adelaide, 1994
16. Bureau of Meteorology
The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method
Melbourne, Australia, June 2003 (39pp)
17. NSW Department of Environment and Climate Change (DECC)
Floodplain Risk Management Guidelines – Practical Consideration of Climate Change
October 2007
18. NSW Department of Environment, Climate Change and Water (DECCW)
Floodplain Risk Management Guideline – Incorporating sea level rise benchmarks in flood risk assessments
August 2010





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	<p>Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act).</p> <p>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.</p> <p>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.</p> <p>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.</p>
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

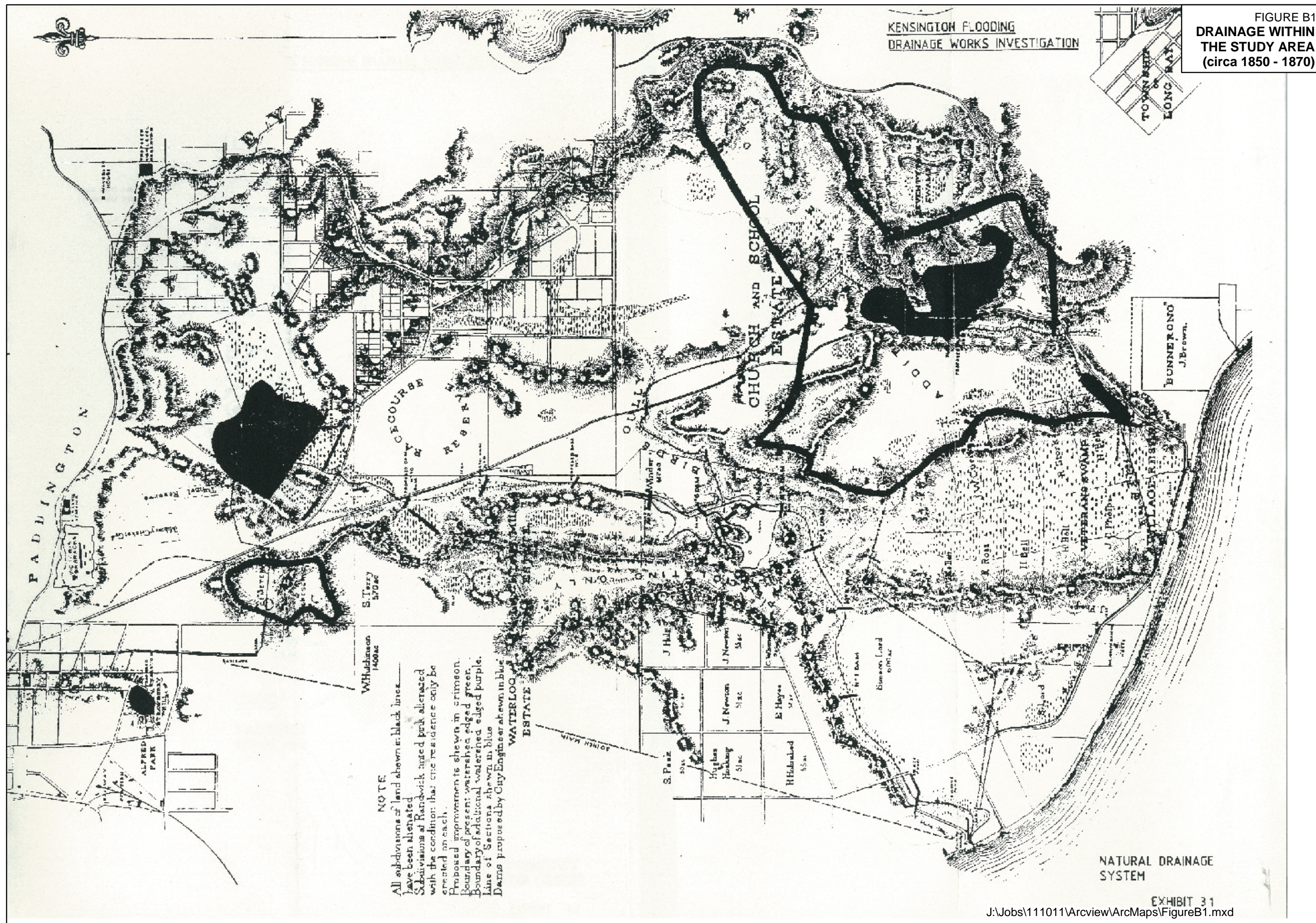
	connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.
discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m ³ /s). Discharge is different 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 tsunamis.
flood awareness	Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.
flood education	Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves and their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.
flood fringe areas	The remaining area of flood prone land after floodway and flood storage areas have been defined.
flood liable land	Is synonymous with flood prone land (i.e. land susceptible to flooding by the 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 PMF 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 diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
flood plan (local)	A sub-plan of a disaster plan that deals specifically with flooding. They can exist at State, Division and local levels. Local flood plans are prepared under the

	leadership of the State Emergency Service.
flood planning area	The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the “flood liable land” concept in the 1986 Manual.
Flood Planning Levels (FPLs)	FPLs are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the “standard flood event” in the 1986 manual.
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	Island susceptible to flooding by the 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	<p>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.</p> <p>existing flood risk: the risk a community is exposed to as a result of its location on the floodplain.</p> <p>future flood risk: the risk a community may be exposed to as a result of new development on the floodplain.</p> <p>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.</p>
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	<p>in a residential situation: a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom.</p> <p>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.</p>
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	<p>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:</p> <ul style="list-style-type: none"> 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	<p>The merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well being of the State's rivers and floodplains.</p> <p>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.</p>
minor, moderate and major flooding	<p>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:</p> <p>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.</p> <p>moderate flooding: low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered.</p> <p>major flooding: appreciable urban areas are flooded and/or extensive rural areas</p>

	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.









SOUTH SYDNEY – CENTENNIAL PARK FLOOD STUDY (ON BEHALF OF RANDWICK CITY COUNCIL)

HOUSE NUMBER: _____ STREET: _____

HOW LONG HAVE YOU LIVED AT THIS ADDRESS? _____

DURING THIS TIME, CAN YOU RECALL ANY SIGNIFICANT FLOODING EVENTS (i.e. greater than 100mm)
ON OR AROUND THIS PROPERTY, IN PARTICULAR DURING NOVEMBER 1984?

HAS YOUR FLOOR LEVEL EVER BEEN INUNDATED BY ONE OF THESE EVENTS, AND IF SO, WHAT TYPE
OF DAMAGES WERE INCURRED?

COMMENTS:

WMAwater is undertaking a flood study in your area on behalf of *Randwick City Council*. Unfortunately we missed you today, but if you would like to provide us with any information about flooding in your area, please do not hesitate to return this questionnaire in the reply paid envelope provided. Alternatively you can contact us via the following:

contact: Matt Chadwick
email: chadwick@wmawater.com.au
telephone: (02) 9299 2855
facsimile: (02) 9262 6208

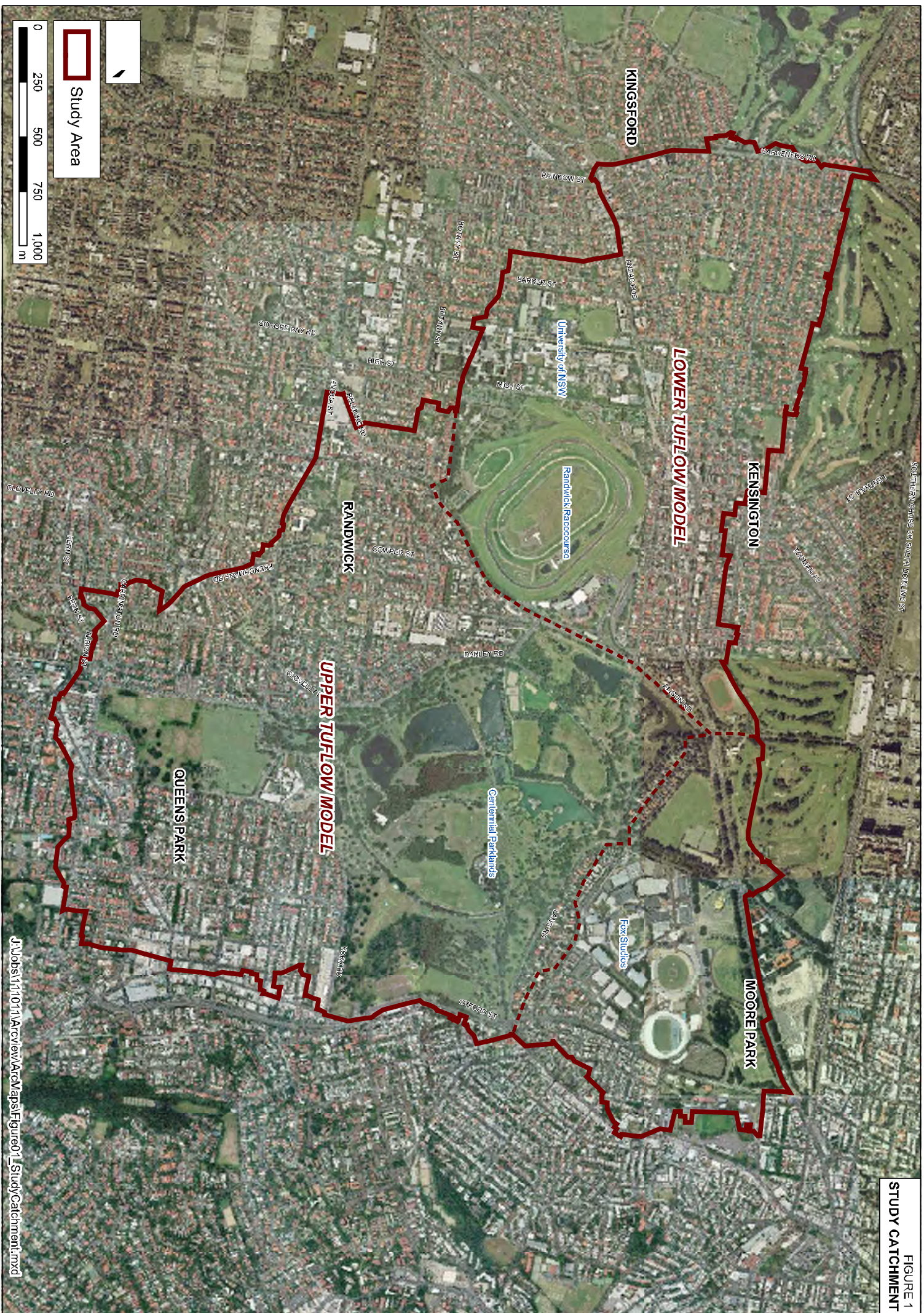
NAME (OPTIONAL): _____ ADDRESS: _____ _____	DATE: ____/____/_____ TELEPHONE: _____ EMAIL: _____ _____
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Personal Details requested on this form are being collected and will only be used for the purpose of analyzing information obtained from this survey. The supply of information by you is voluntary. If you cannot provide or do not wish to provide the information sought, the council may not be able to include your particular survey information when analyzing all the survey data collected. Access to the information is restricted to Council officers and other authorized people. You may make application for access or amendment to information held by the council. You may also request Council to suppress your personal information from a public register.



APPENDIX D: SUMMARY OF SUBMISSIONS FROM PUBLIC EXHIBITION

Issue	Action
Query regarding Leonard Avenue's classification as a floodway and request for information about future process.	The flood study shows that the floodway is generally confined to the road reserve however in instances where the depth and/or velocity are significant the floodway may extend into the front yards of properties. Once reaching the low point on the road, flood waters will flow east through properties towards the flood channel and this is also reflected in the floodway extent. A response was provided advising that the next step is the Floodplain Risk Management Study that will consider measures for managing flooding.
Concern over the potential impact of the study on insurance premiums.	Flooding insurance is progressively becoming available in Australia. Insurance companies undertake their own studies and use their own methodologies independent of Council to determine premiums. The flood study is part of the process undertaken in good faith and aims to determine methods of minimising private and public losses. The identification of areas at risk of flooding is necessary to achieve this and does not change any property owner's actual risk but does enable them to become informed of the risk.
Resident Experience of flooding and SES boat motoring down Doncaster Avenue in 1984	A review of the information contained within the Kensington – Centennial Park Flood Study indicates that the resident's experience is consistent with the flooding simulated by the hydraulic modelling.
Request that consideration be given to aquifer recharge as a mitigation measure during the subsequent Floodplain Risk Management Study	The benefits of groundwater infiltration as a management measure will be considered as part of the Floodplain Risk Management Study
Request for stormwater diagram in Maitland Avenue	Diagram of Council's drainage network in Maitland Avenue was provided to the resident.
Congratulations on the amount of information and detailed mapping provided in the study	Feedback noted





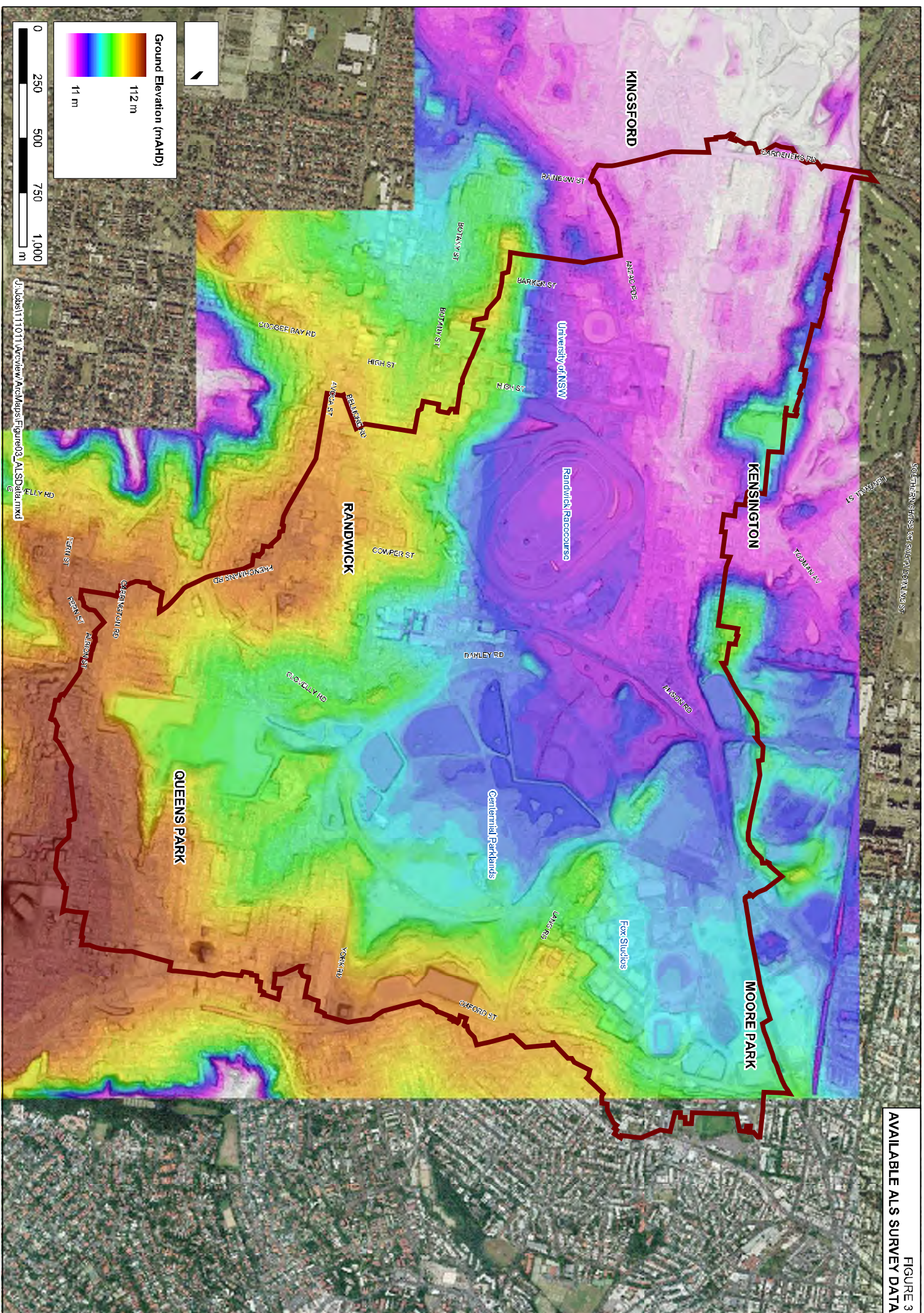
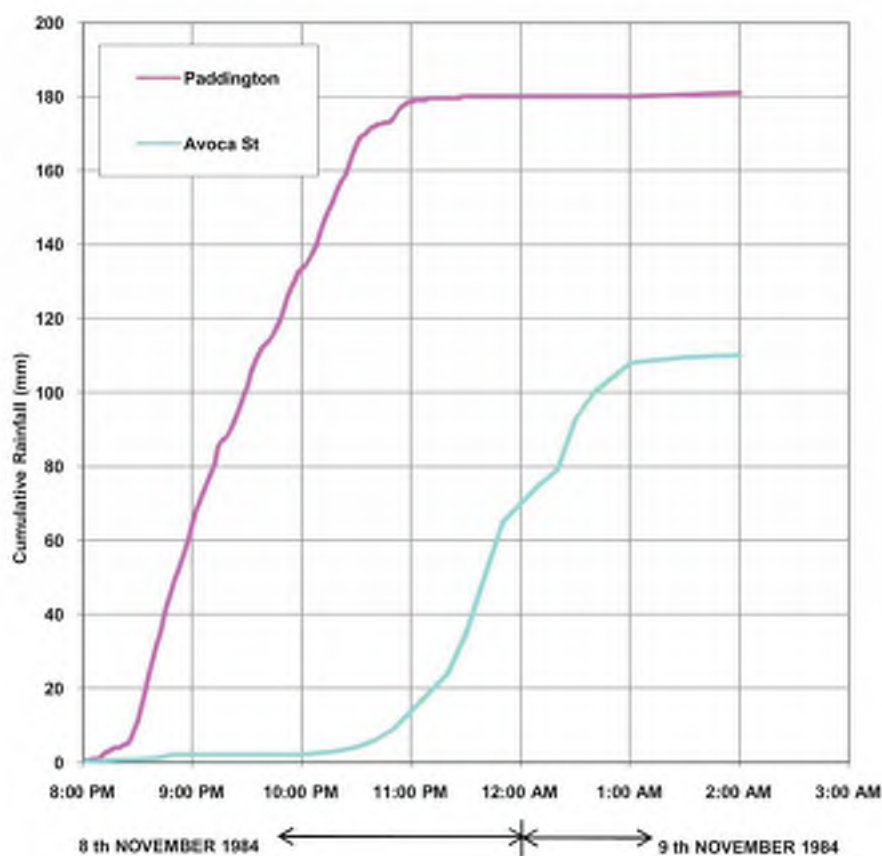
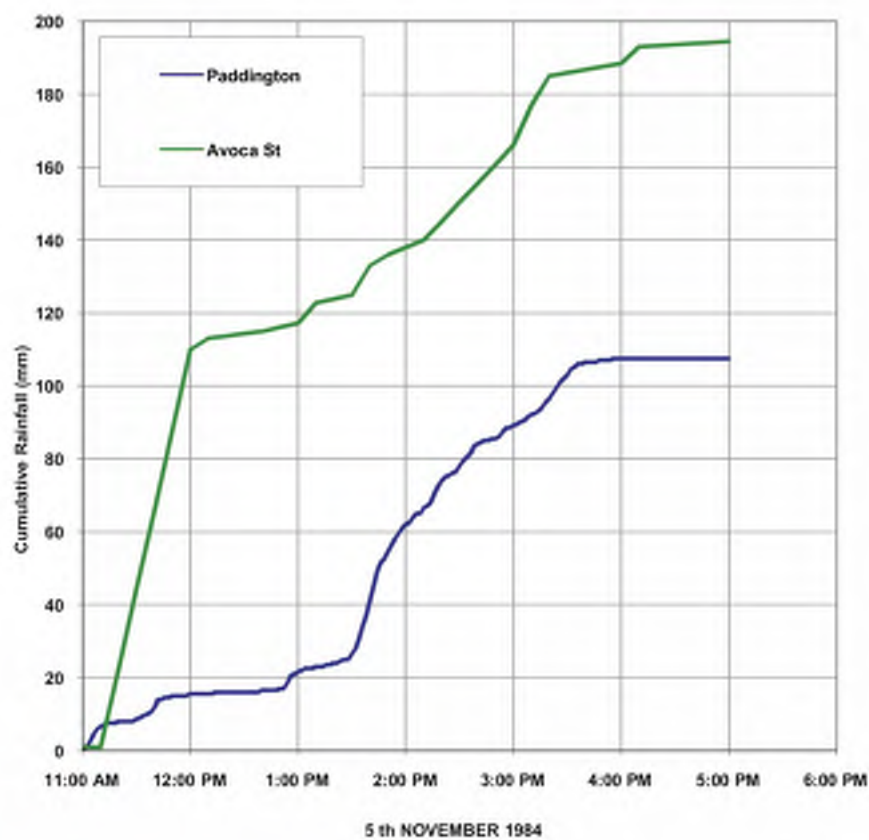
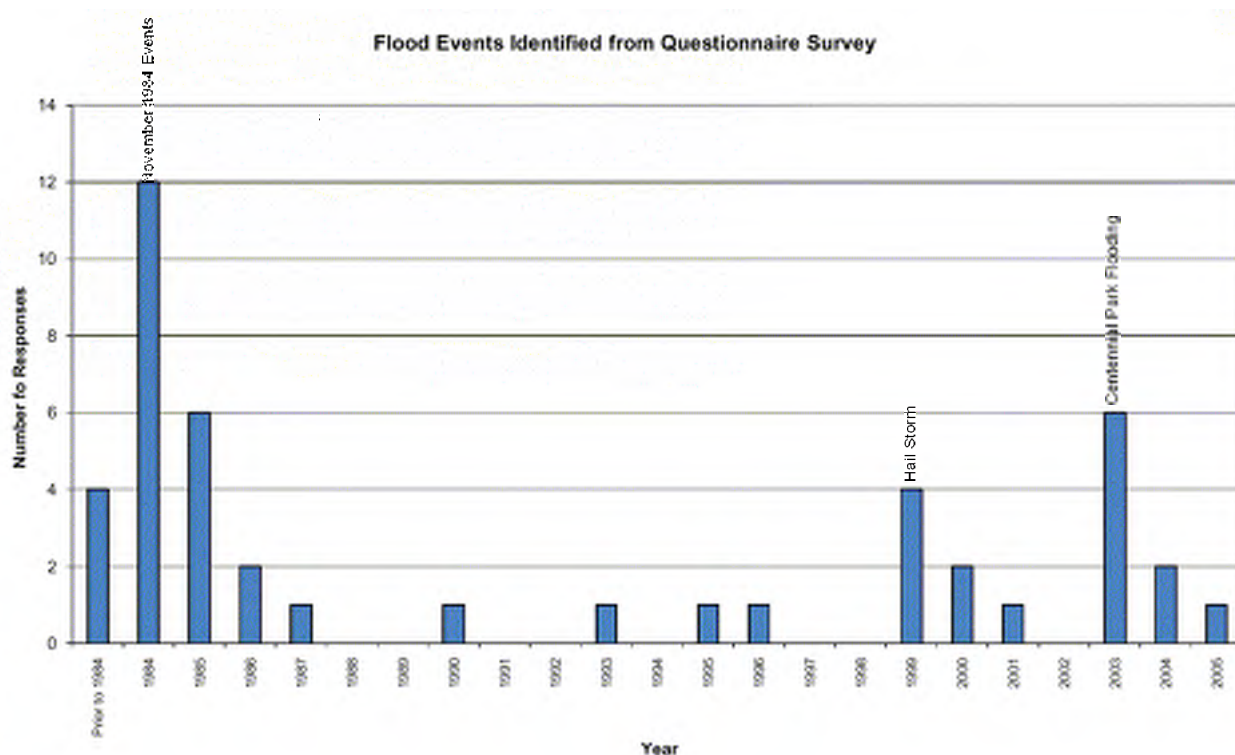


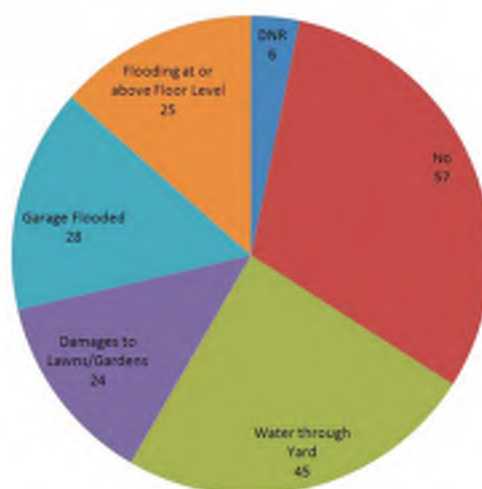
FIGURE 4
RECORDED RAINFALL COMPARISON
NOVEMBER 1984 EVENTS



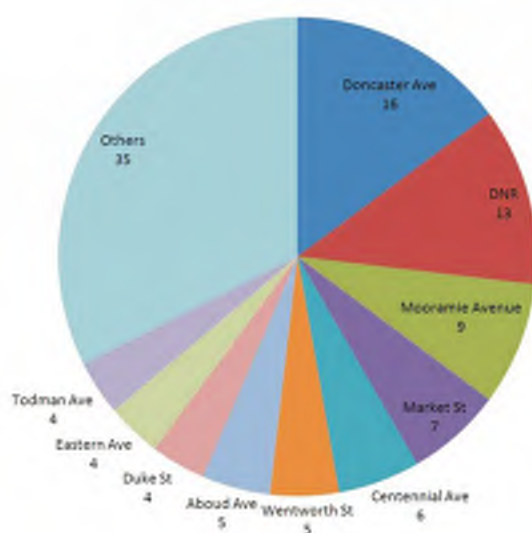
COMMUNITY SURVEY RESULTS



Experience of Flooding on Property



Location of Respondents



Years in Residence

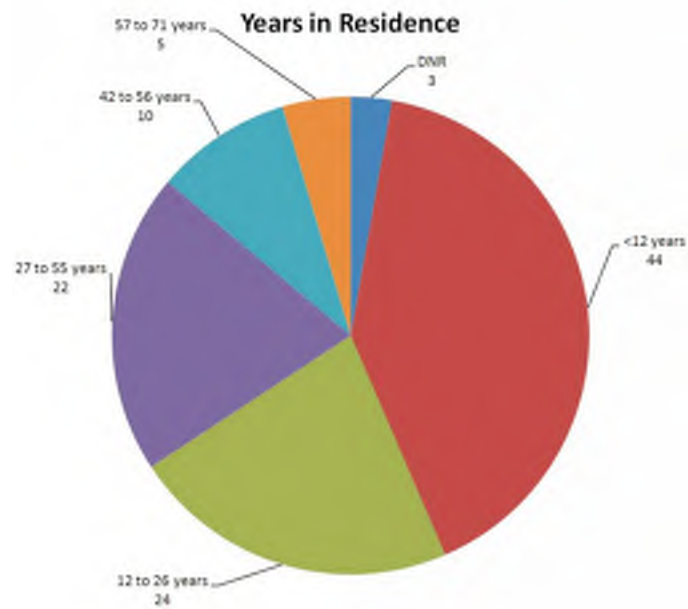
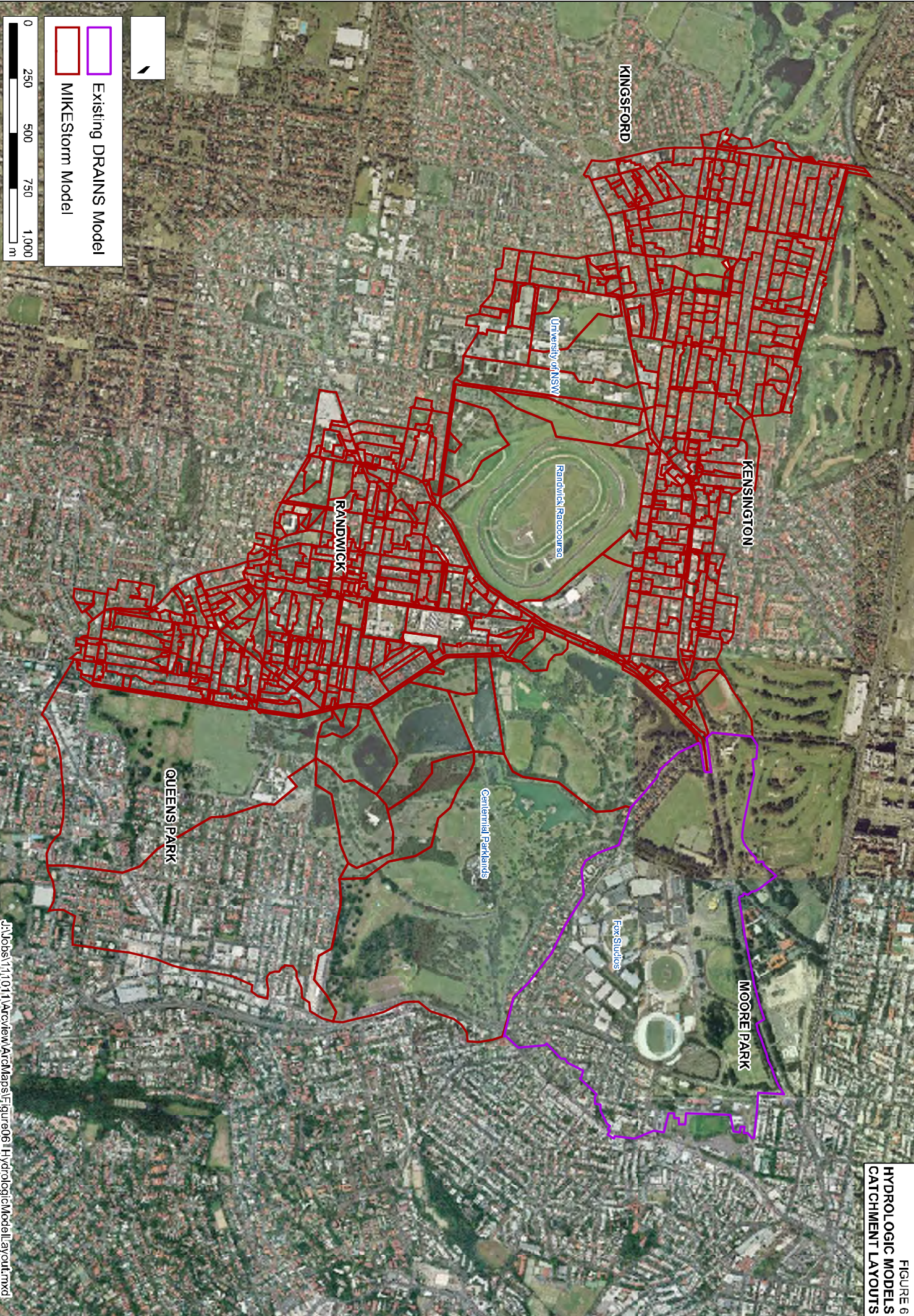


FIGURE 6
HYDROLOGIC MODELS
CATCHMENT LAYOUTS



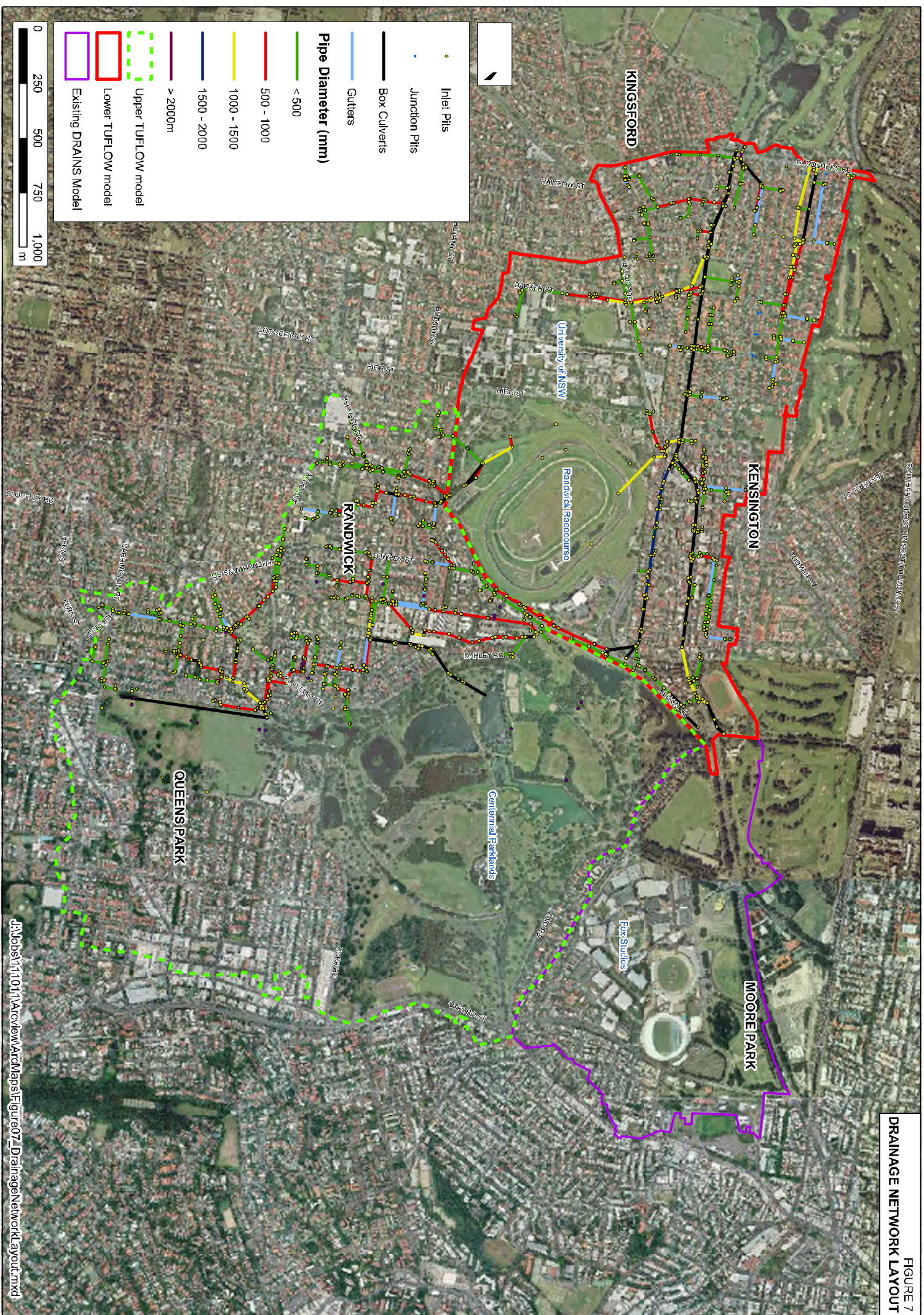


FIGURE 8
OVERLAND FLOW MODEL LAYOUT

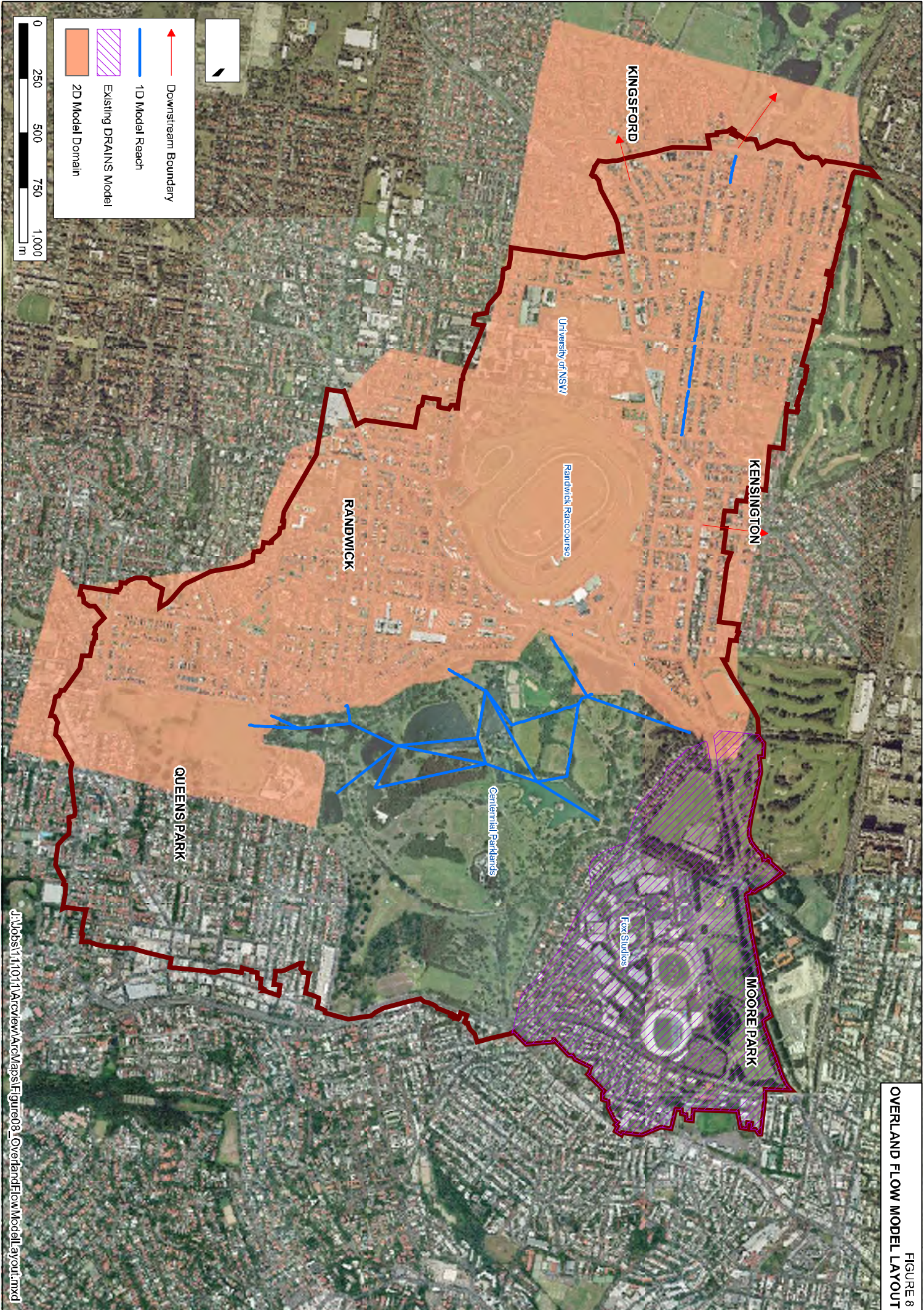


FIGURE 9A
MODEL CALIBRATION
8-9 NOVEMBER EVENT



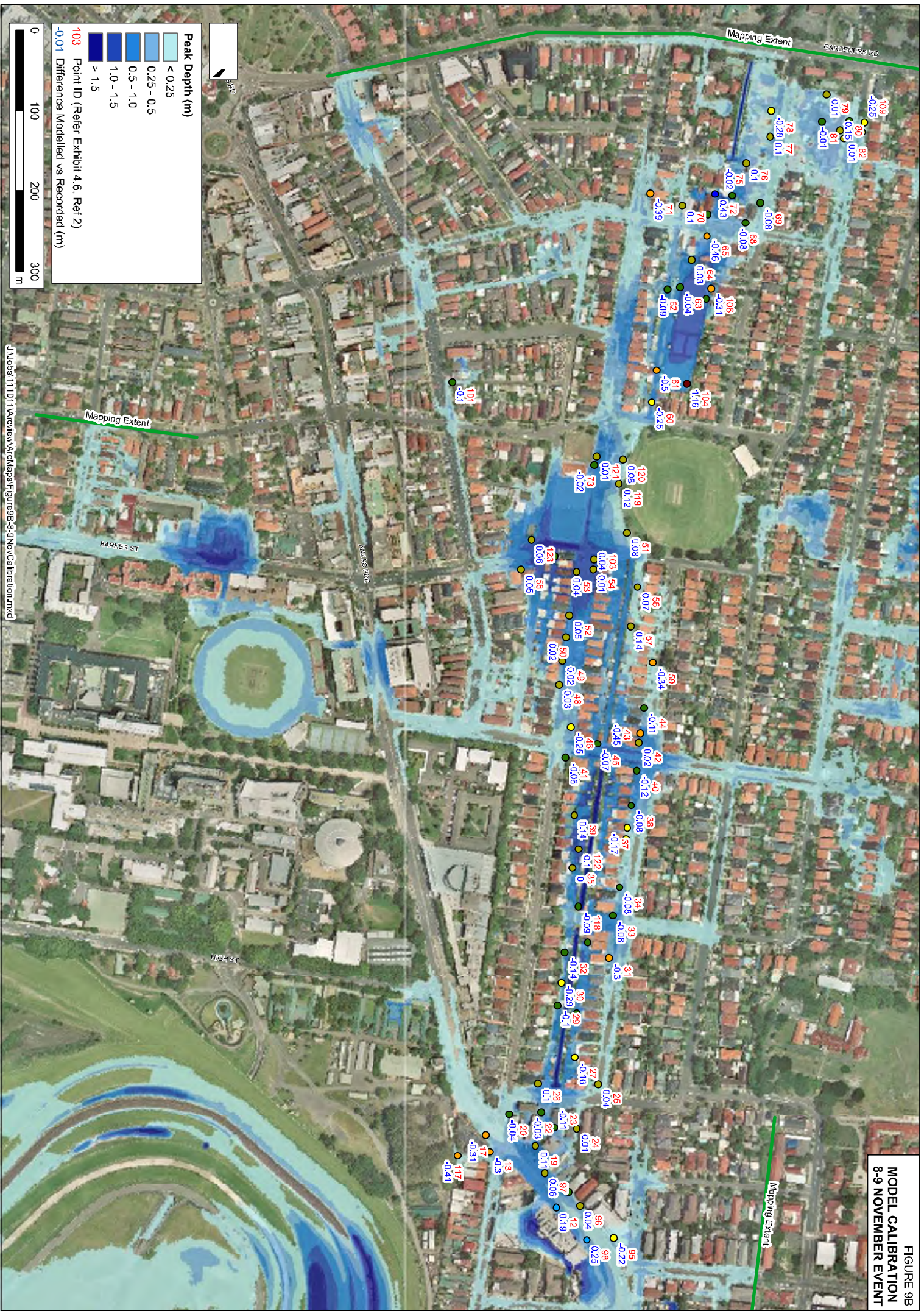


FIGURE 10A
MODEL VALIDATION
5-6 NOVEMBER EVENT





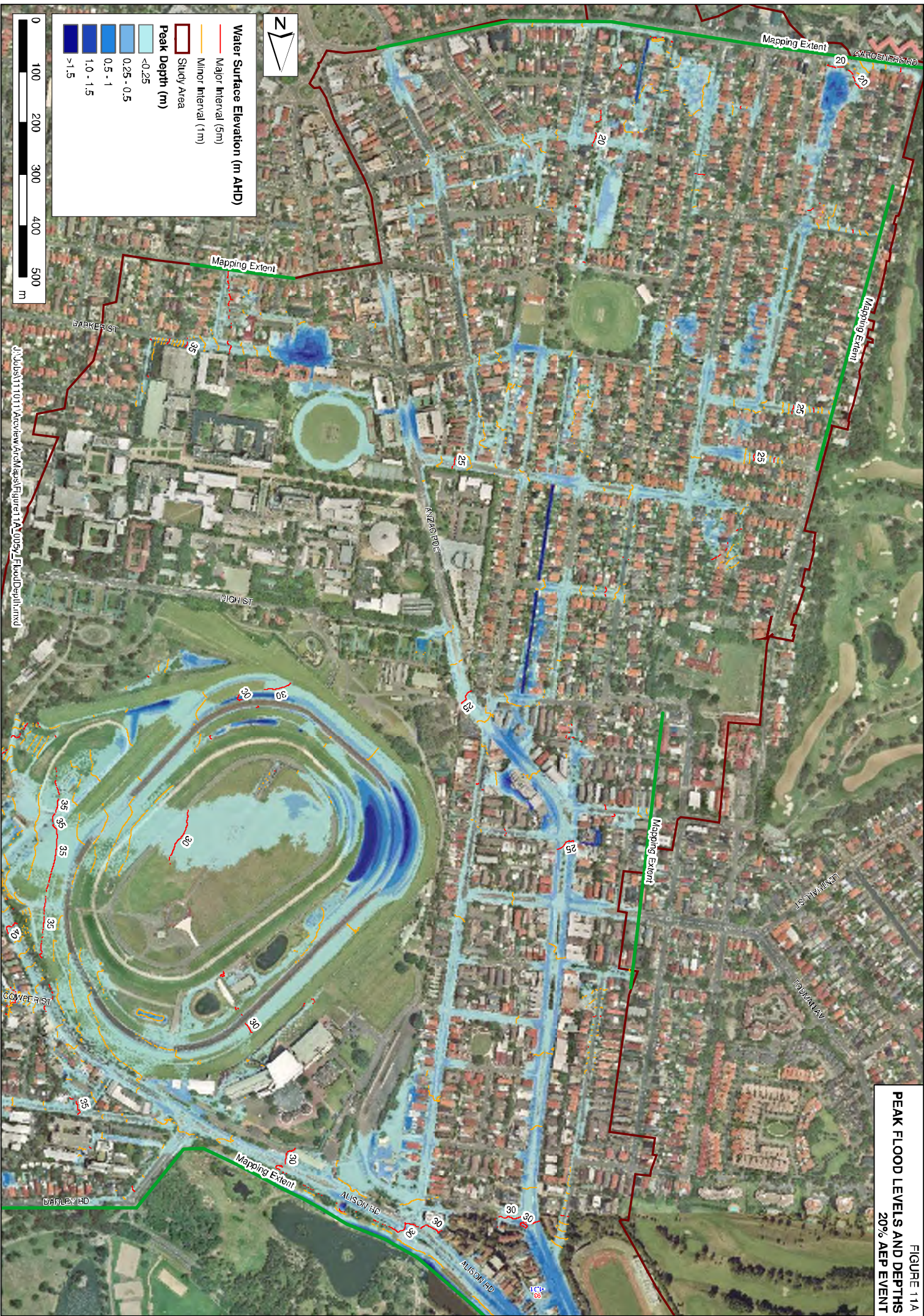




FIGURE 11B
PEAK FLOOD LEVELS AND DEPTHS
20% AEP EVENT

Water Surface Elevation (m AHD)

- Major Interval (5m)
- Minor Interval (1m)

Peak Depth (m)

- 0 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- >1.5

Study Area



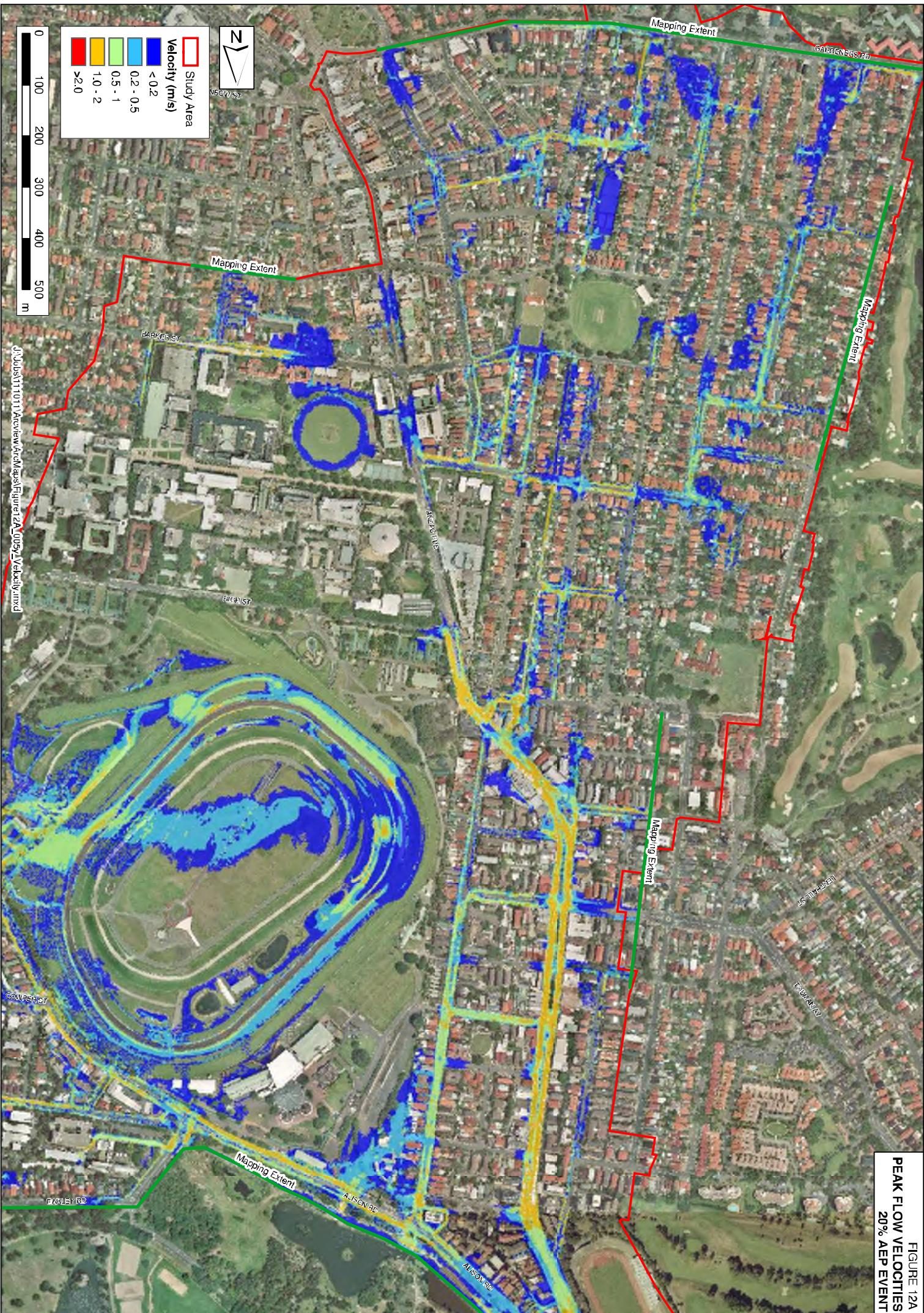
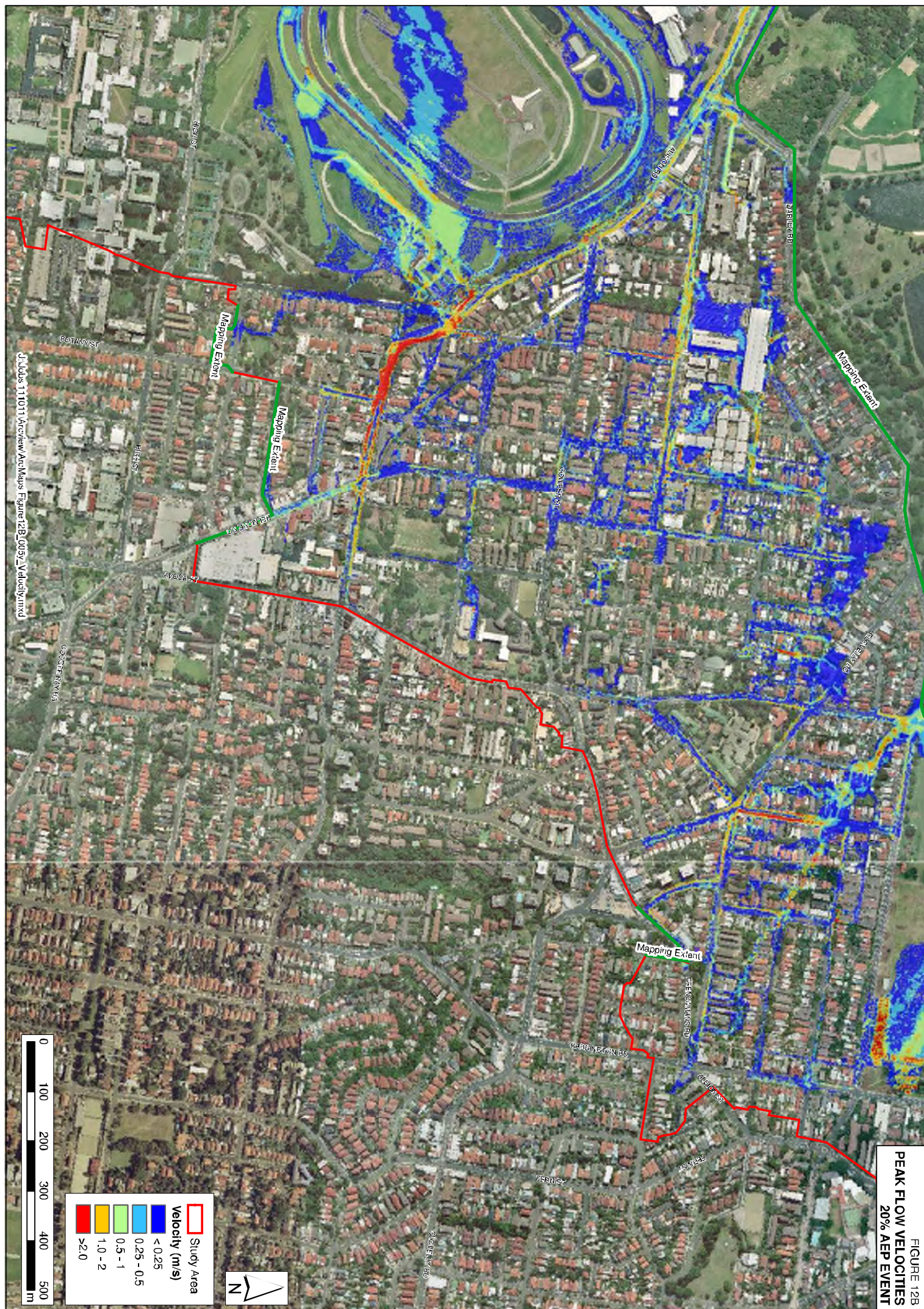


FIGURE 12A
PEAK FLOW VELOCITIES
20% AEP EVENT



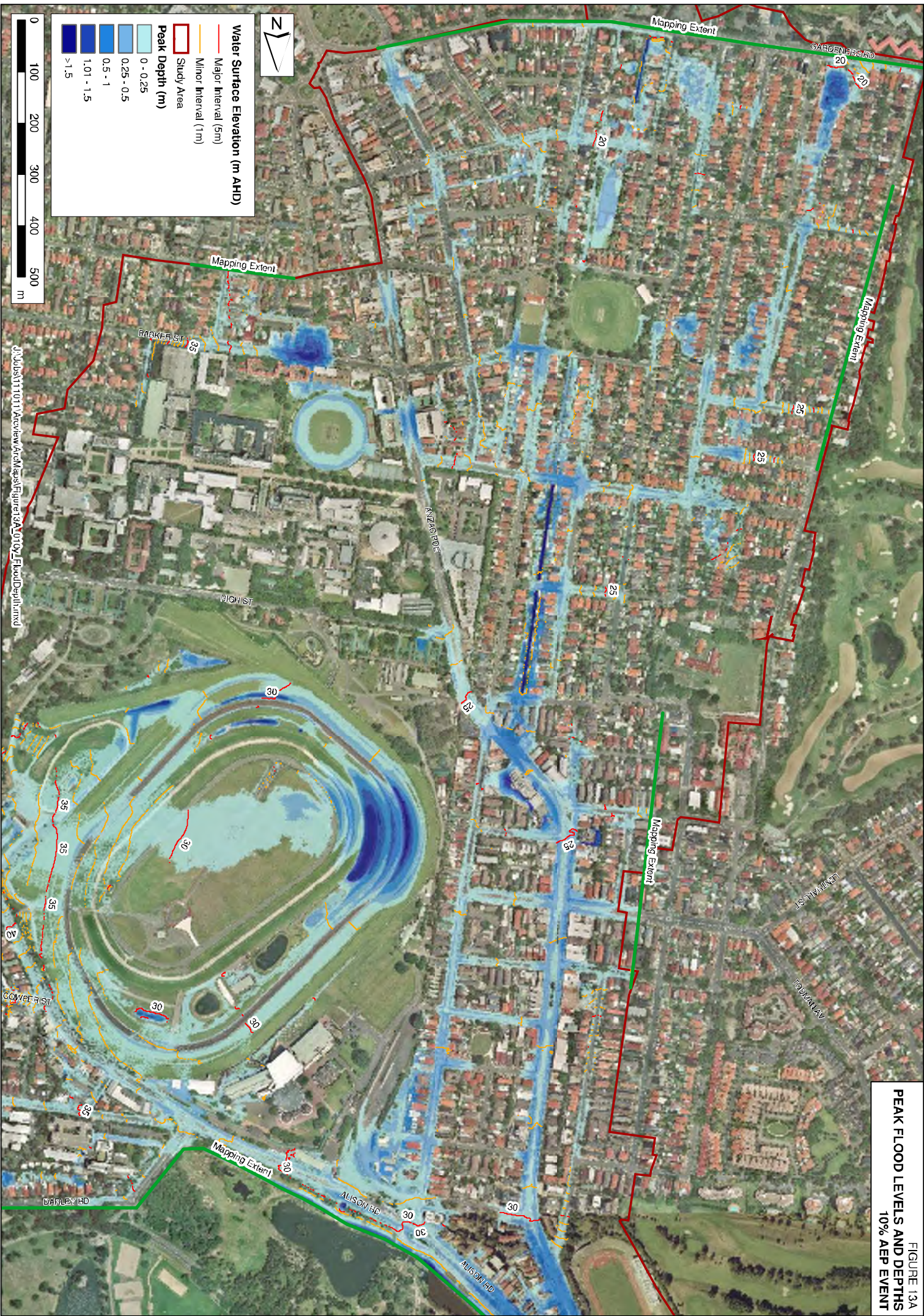
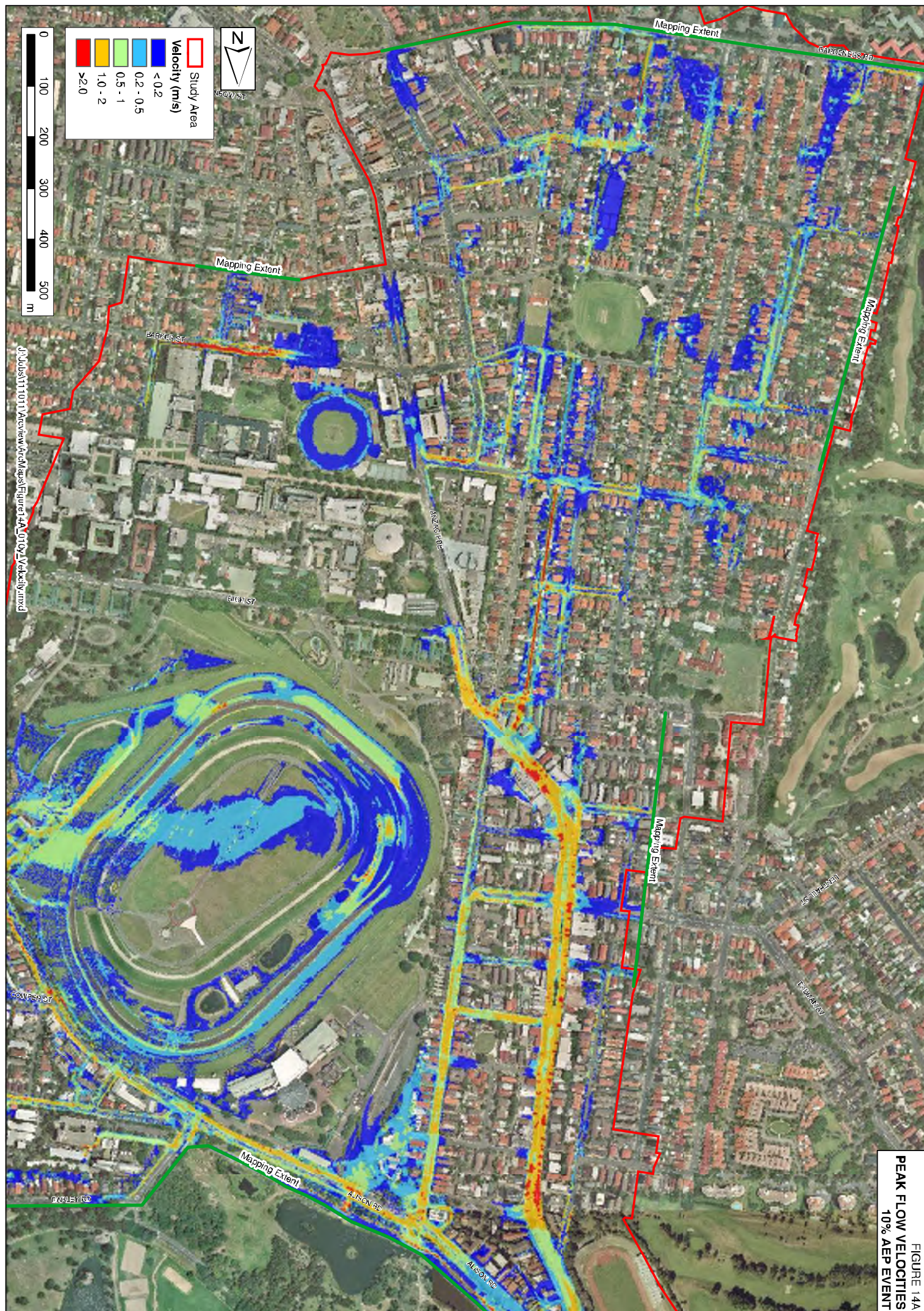
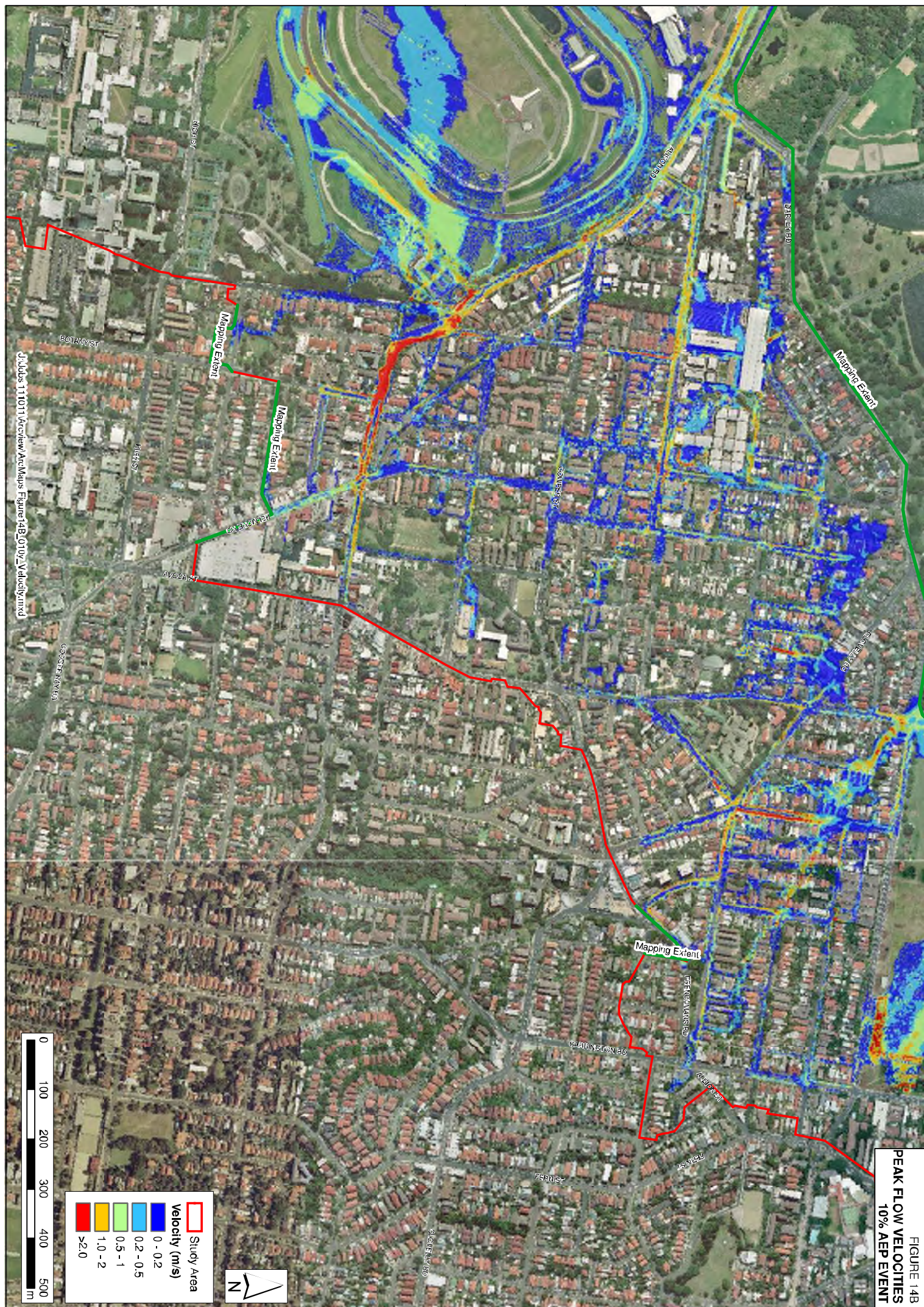
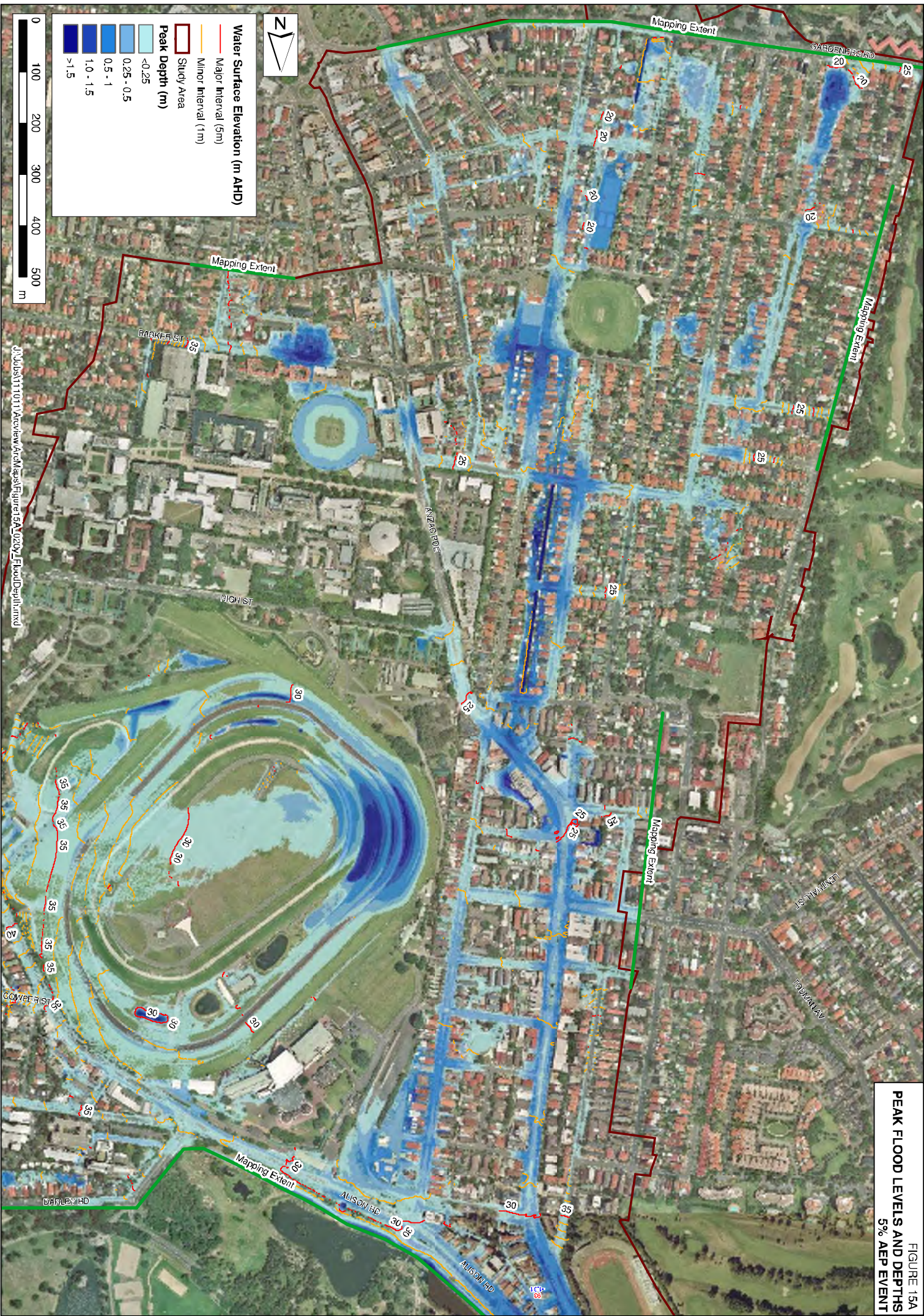


FIGURE 13A
PEAK FLOOD LEVELS AND DEPTHS
10% AEP EVENT









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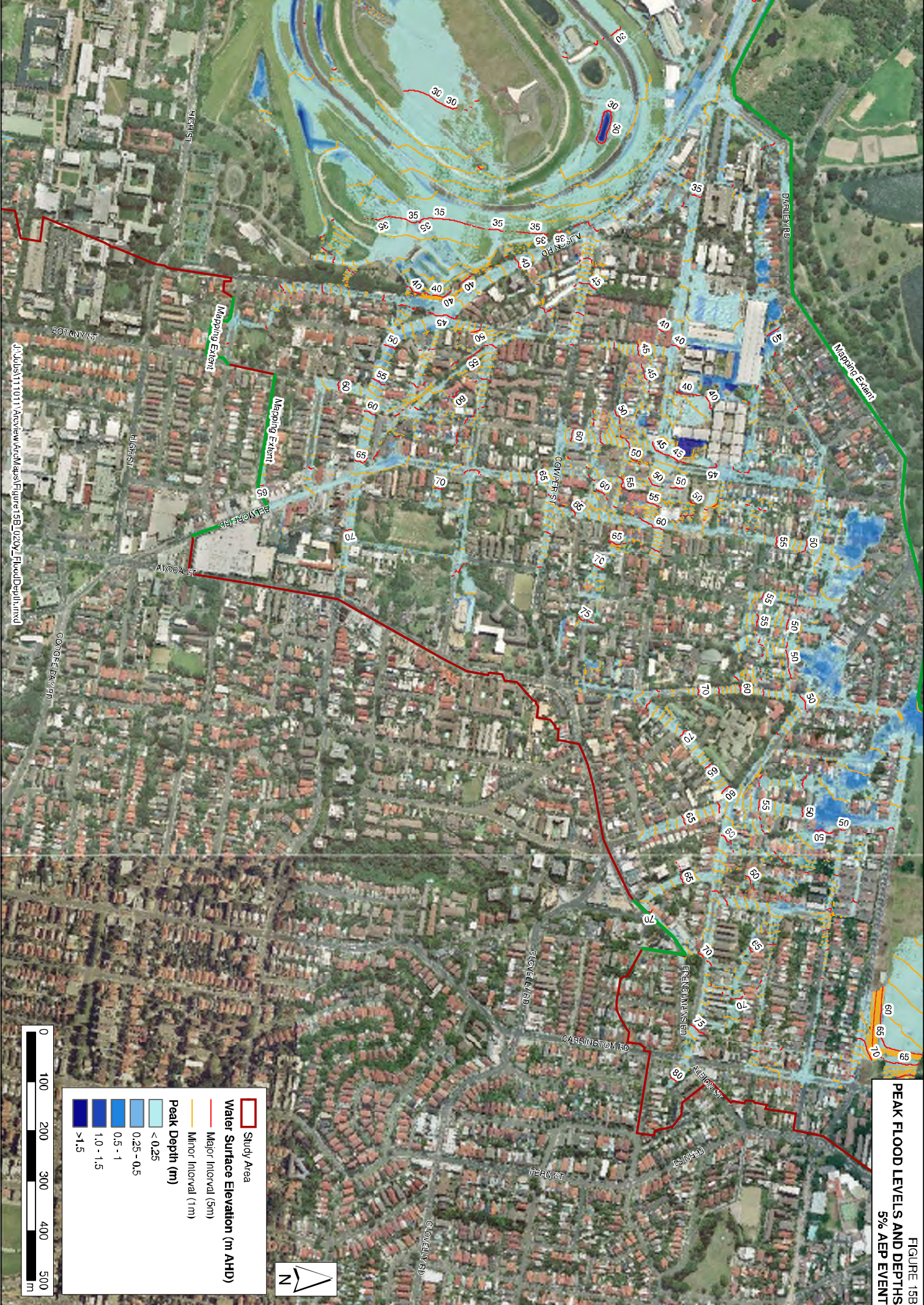


FIGURE 15B
PEAK FLOOD LEVELS AND DEPTHS
5% AEP EVENT

0 100 200 300 400 500
m

Study Area

Water Surface Elevation (m AHD)

Major Interval (5m)

Minor Interval (1m)

Peak Depth (m)

< 0.25

0.25 - 0.5

0.5 - 1

1.0 - 1.5

> 1.5



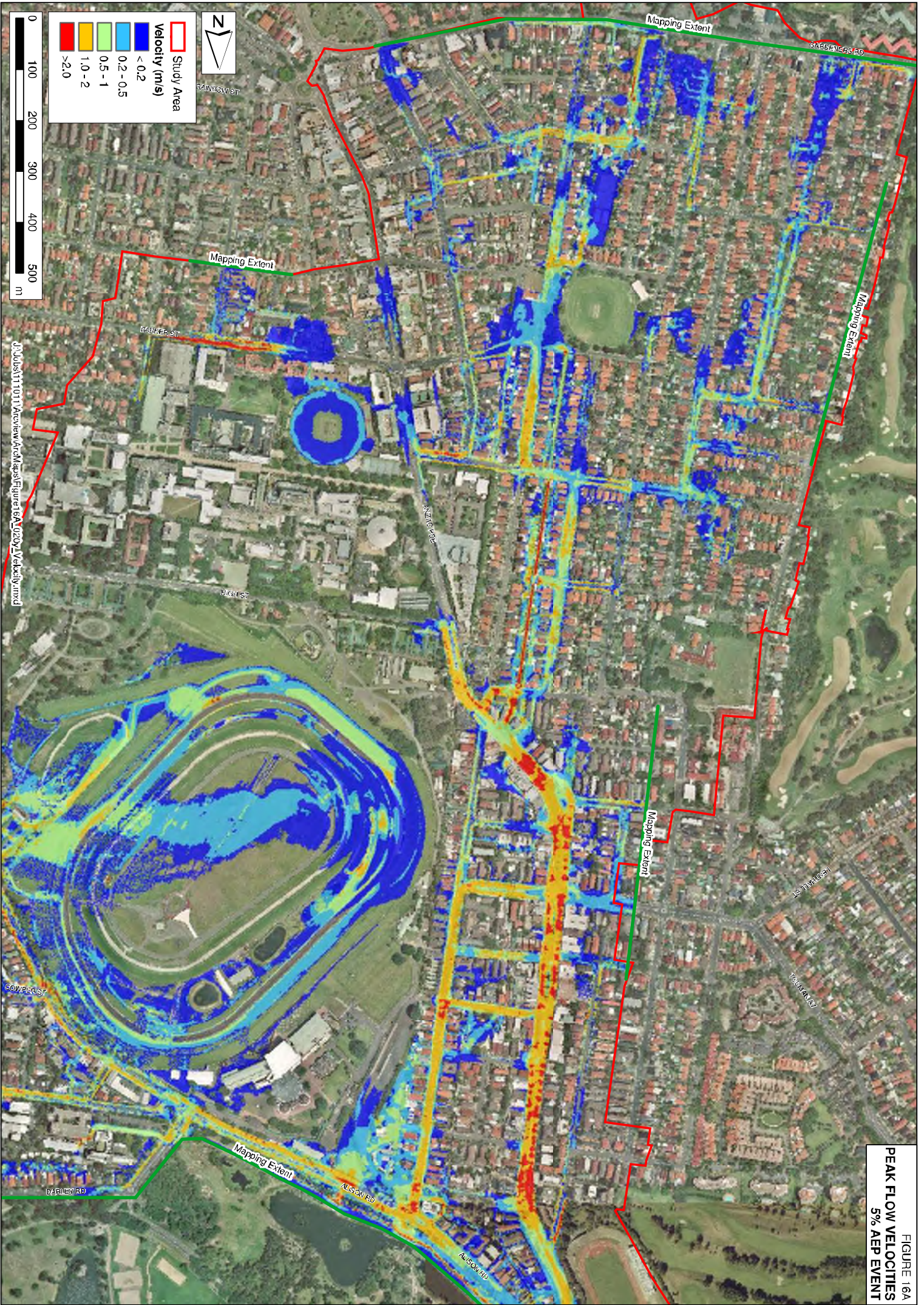
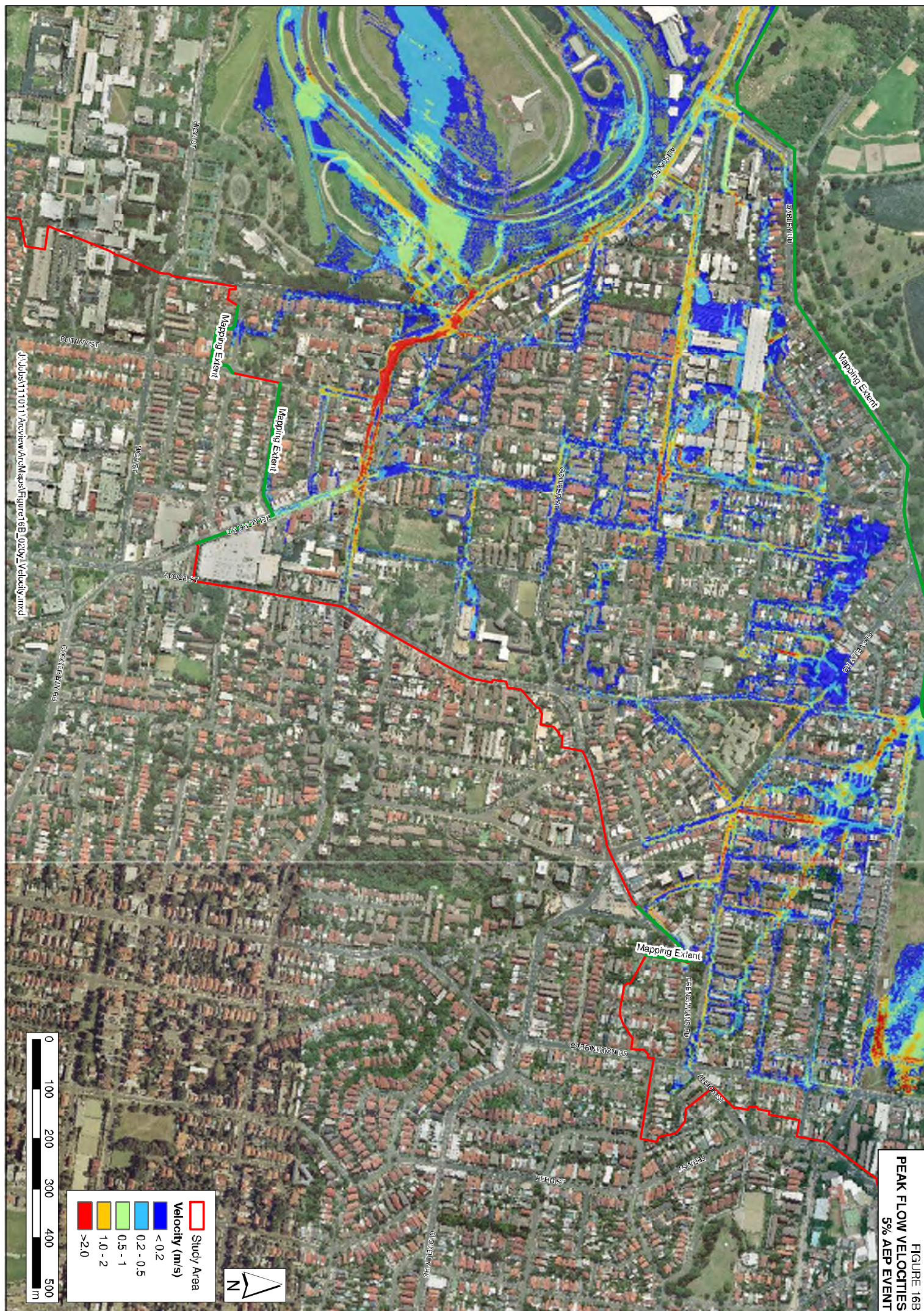


FIGURE 16A
PEAK FLOW VELOCITIES
5% AEP EVENT



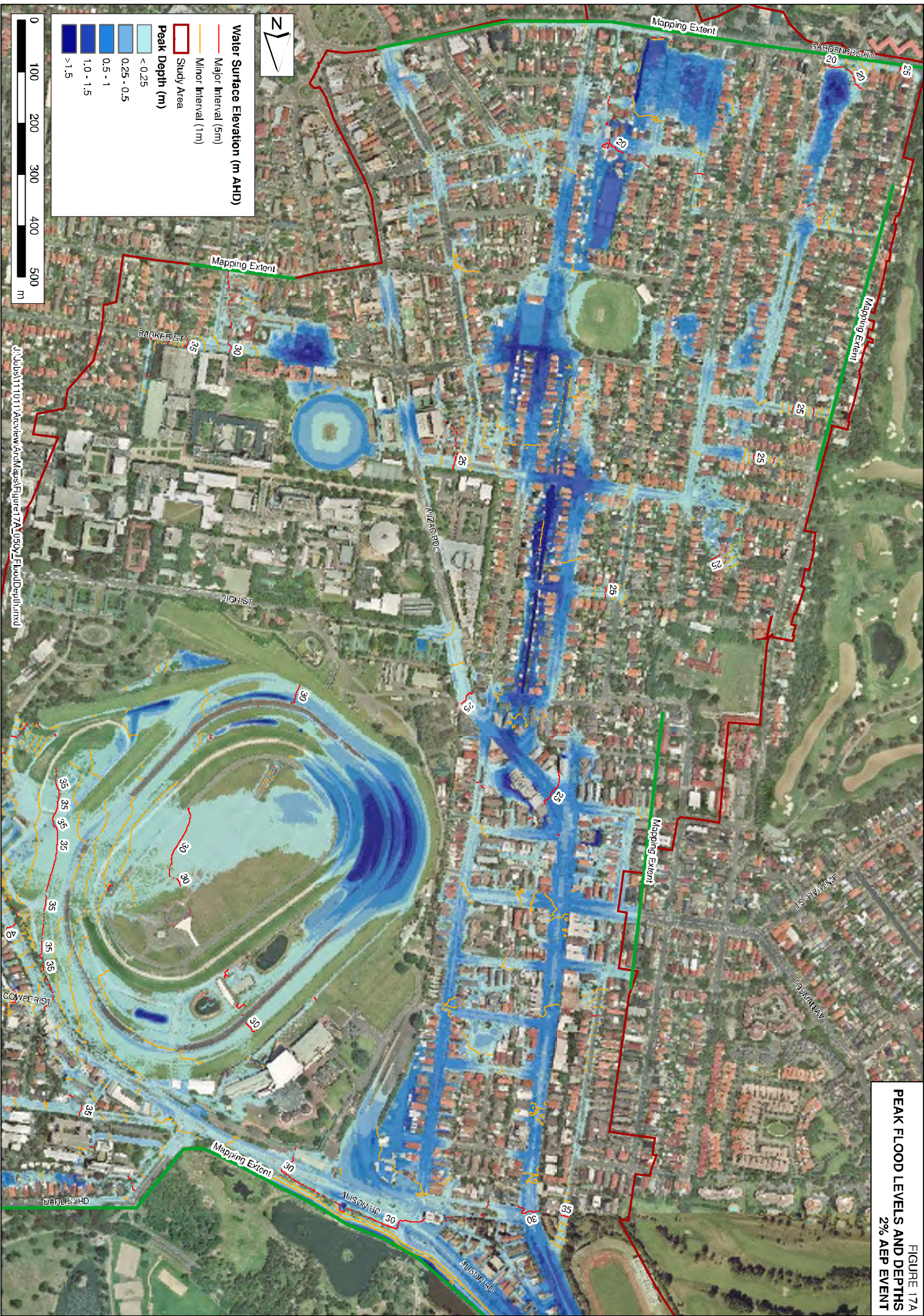
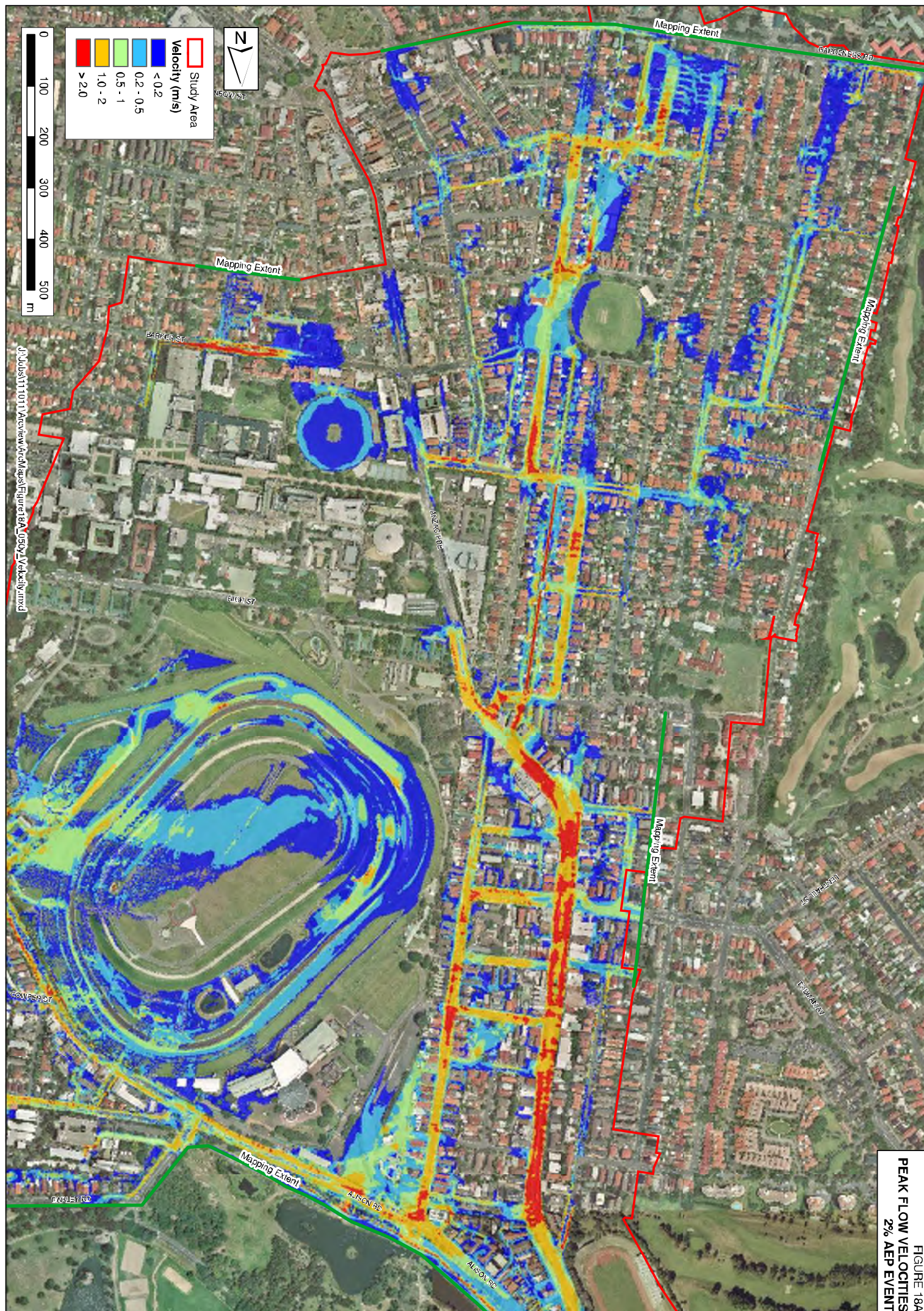


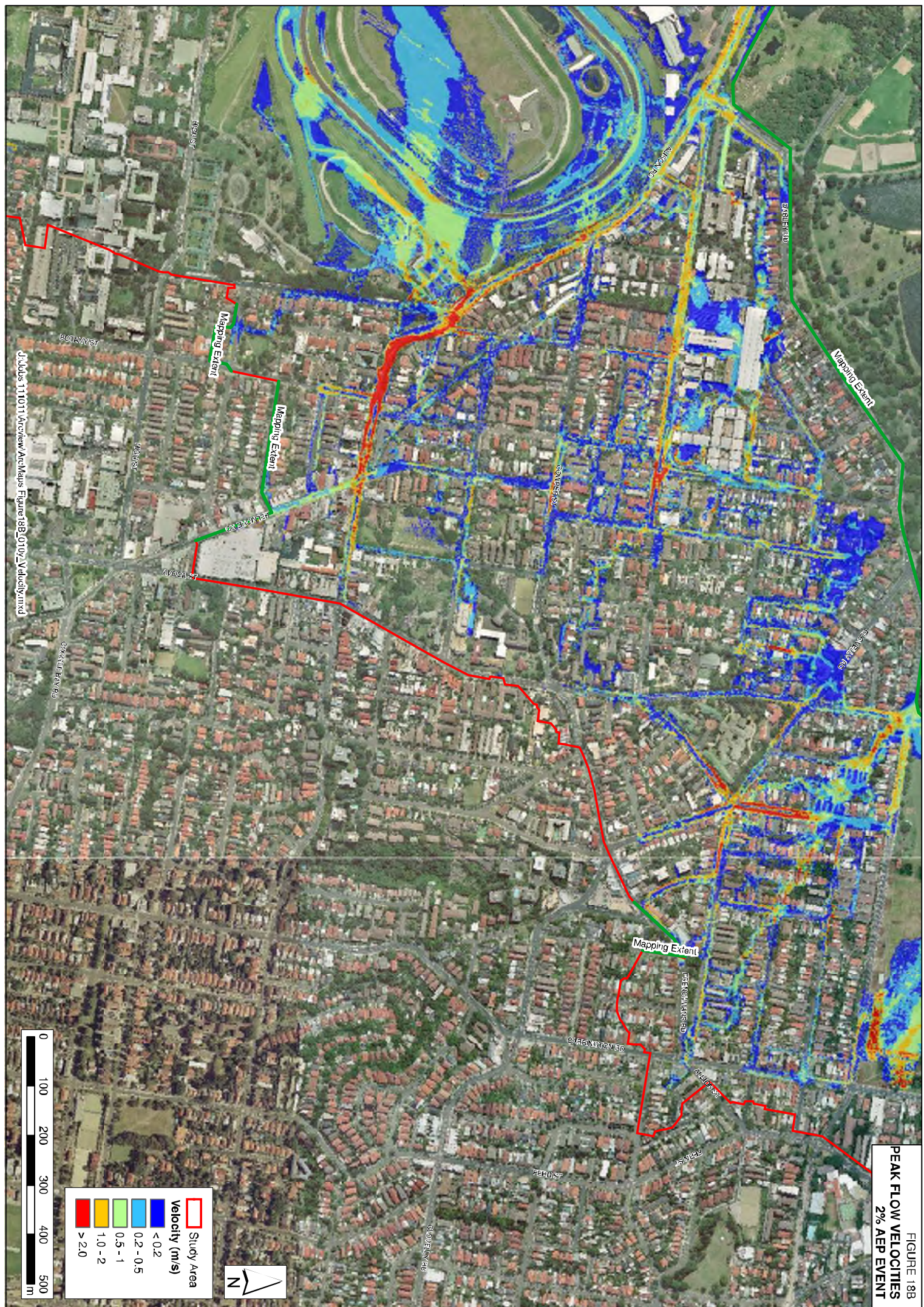
FIGURE 17A
PEAK FLOOD LEVELS AND DEPTHS
2% AEP EVENT

FIGURE 17B
PEAK FLOOD LEVELS AND DEPTHS
2% AEP EVENT



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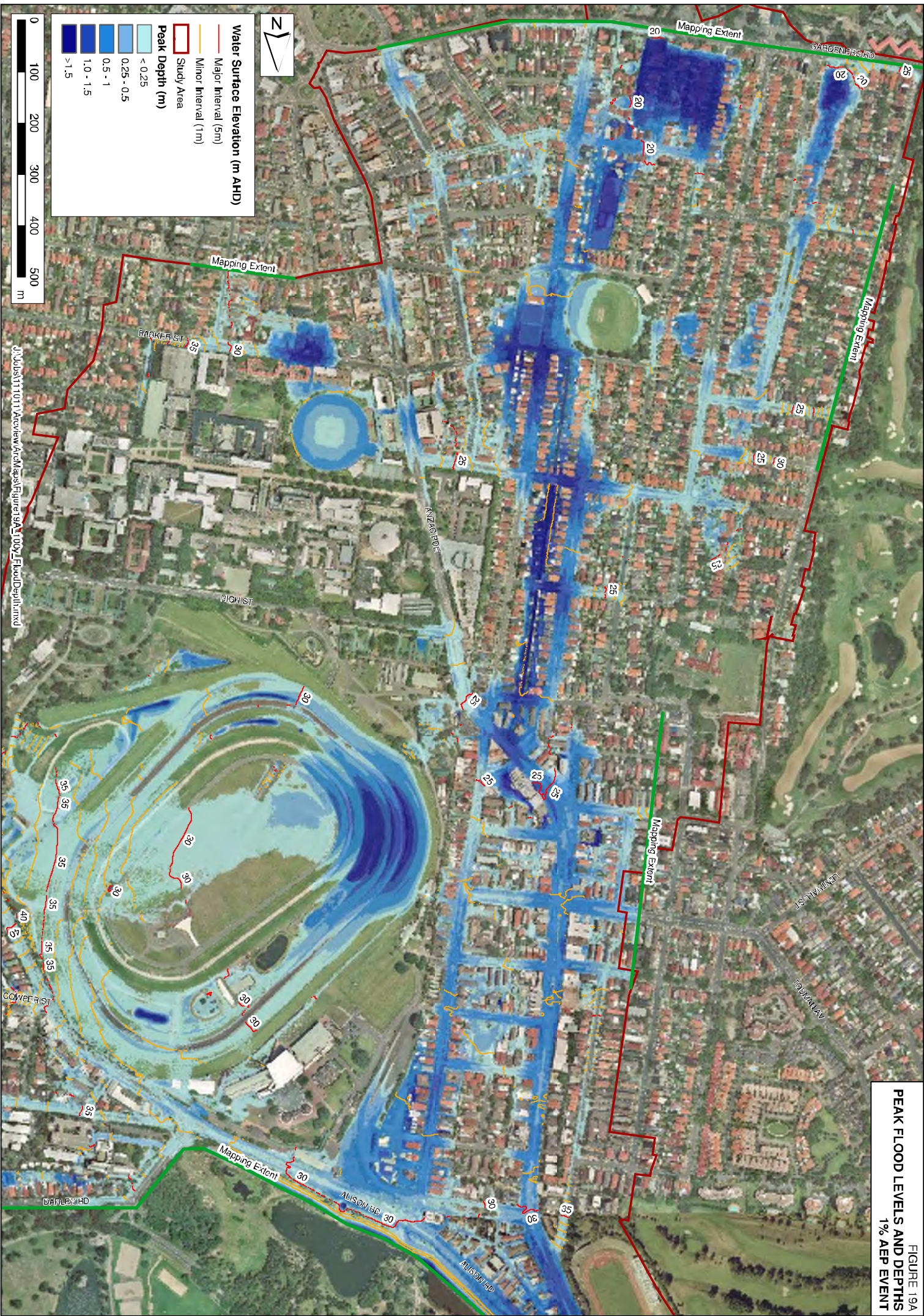
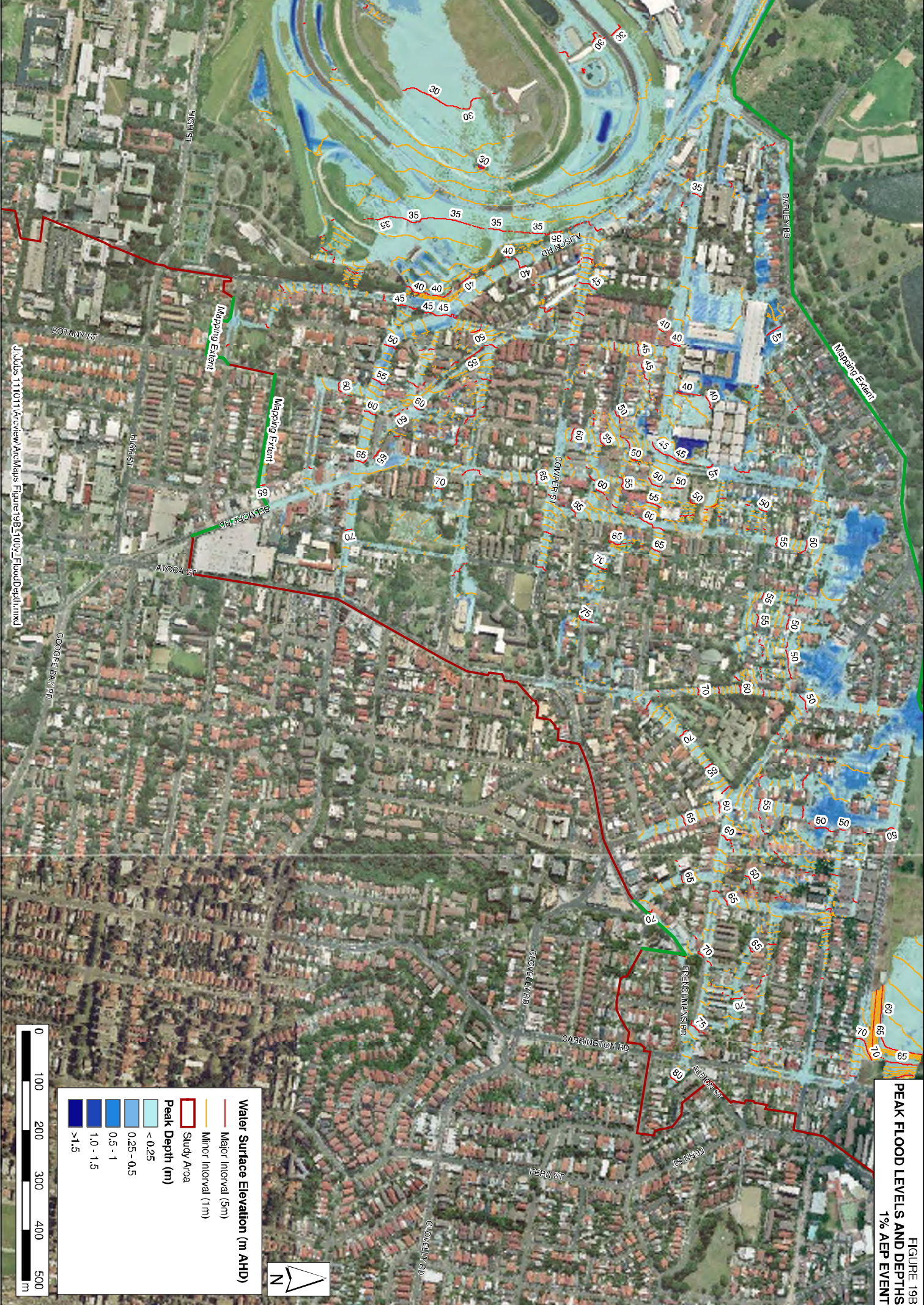
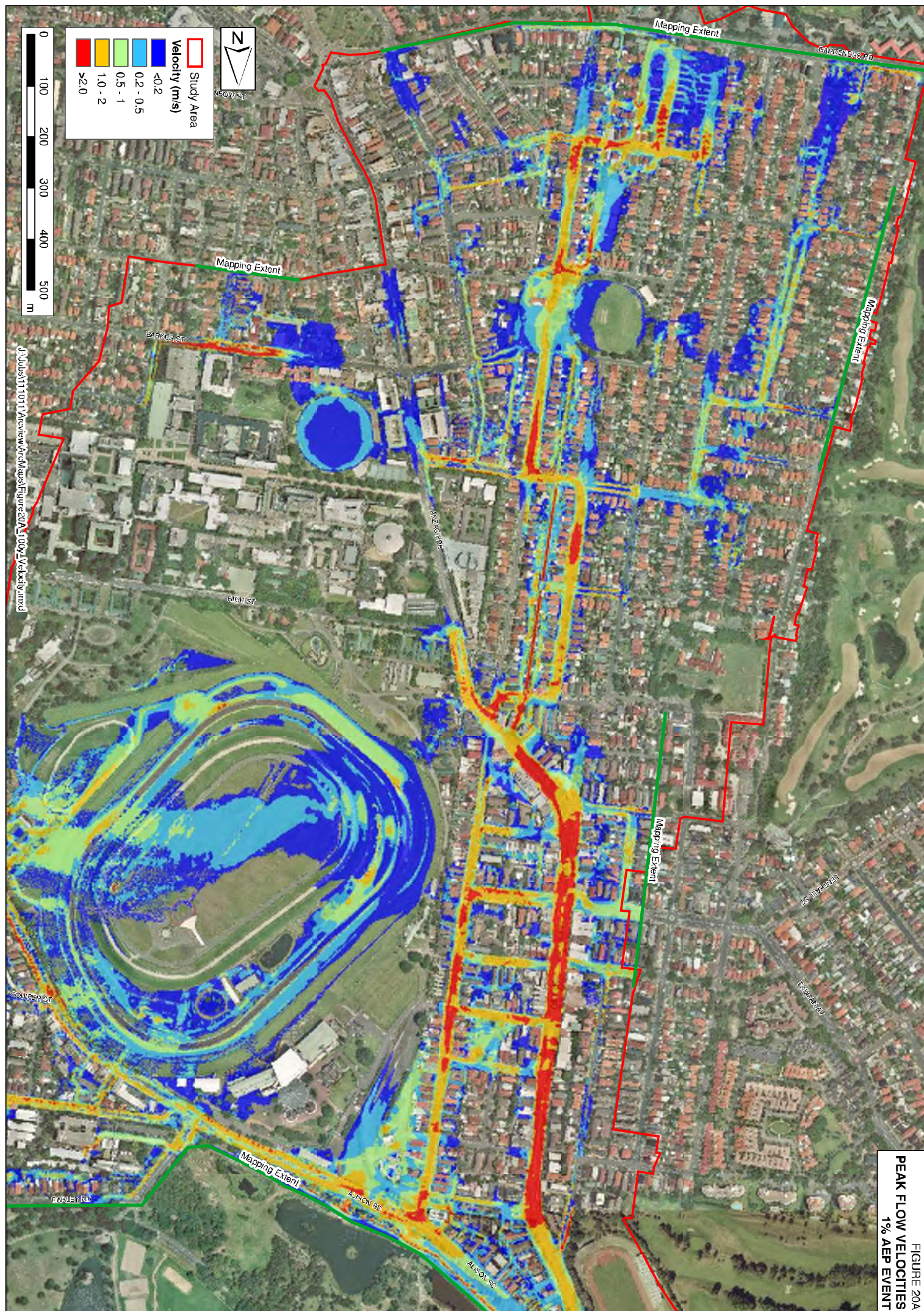


FIGURE 19A
PEAK FLOOD LEVELS AND DEPTHS
1% AEP EVENT



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FIGURE 19B
PEAK FLOOD LEVELS AND DEPTHS
1% AEP EVENT



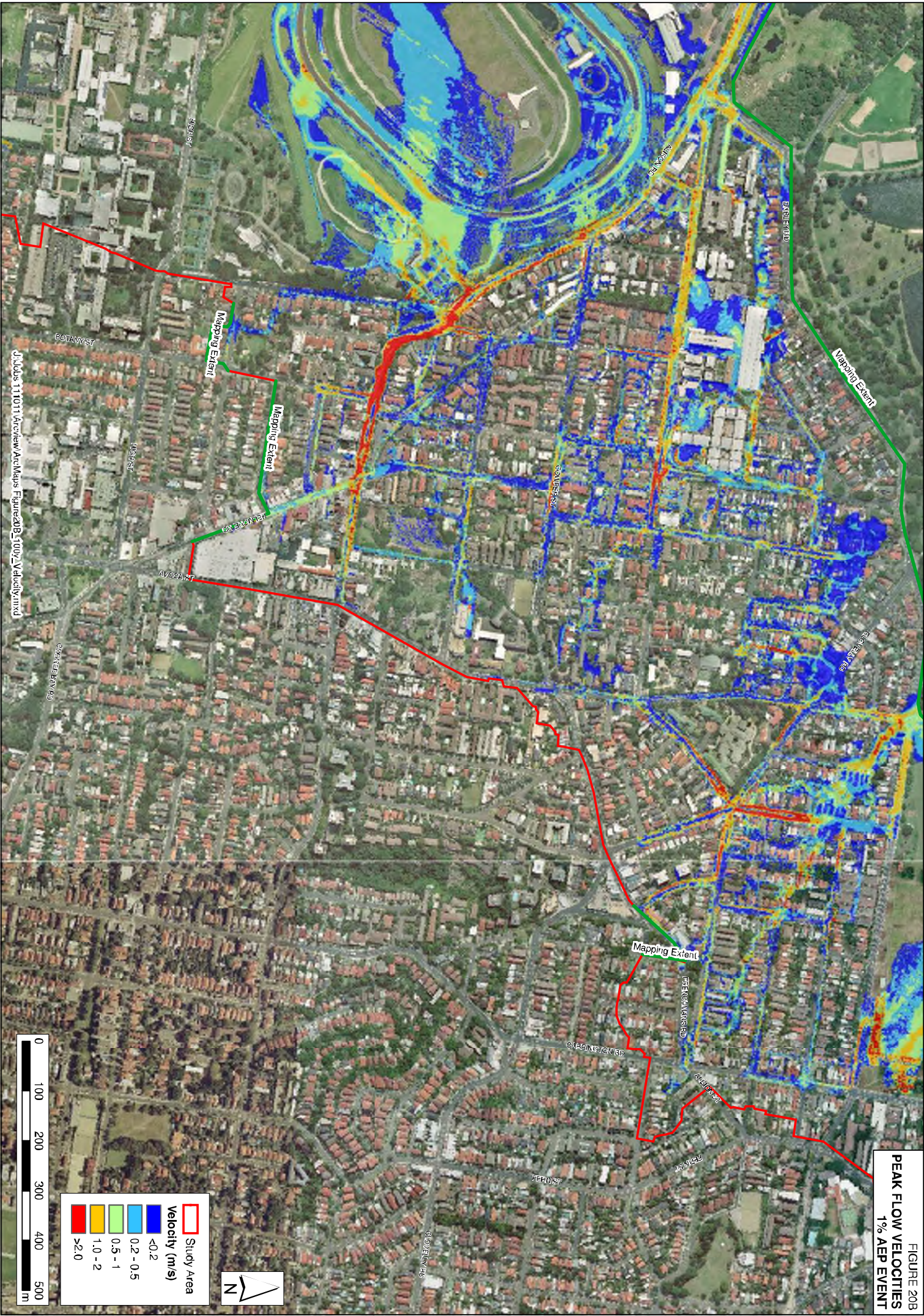


FIGURE 203
PEAK FLOW VELOCITIES
1% AEP EVENT

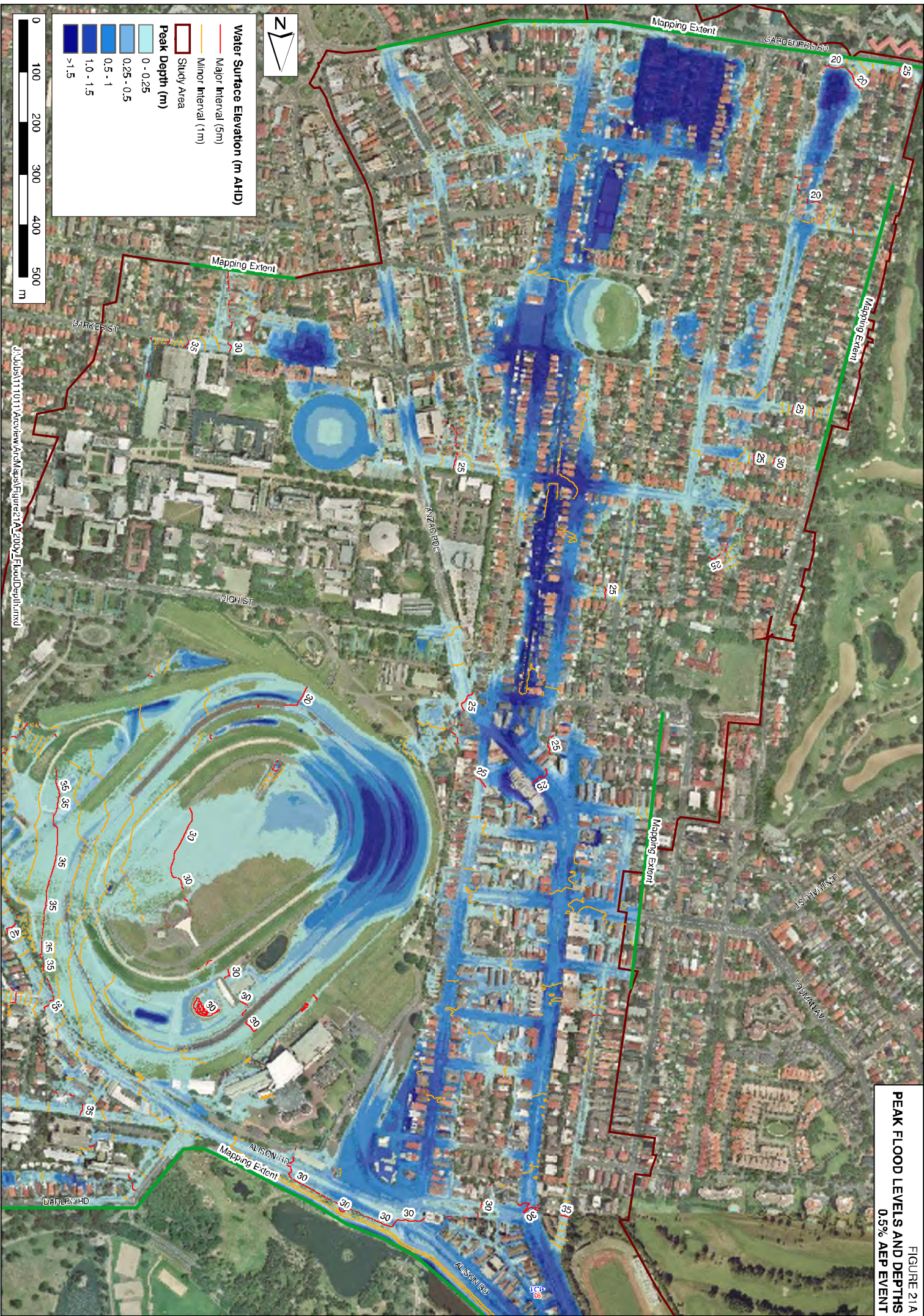


FIGURE 21A
PEAK FLOOD LEVELS AND DEPTHS
0.5% AEP EVENT

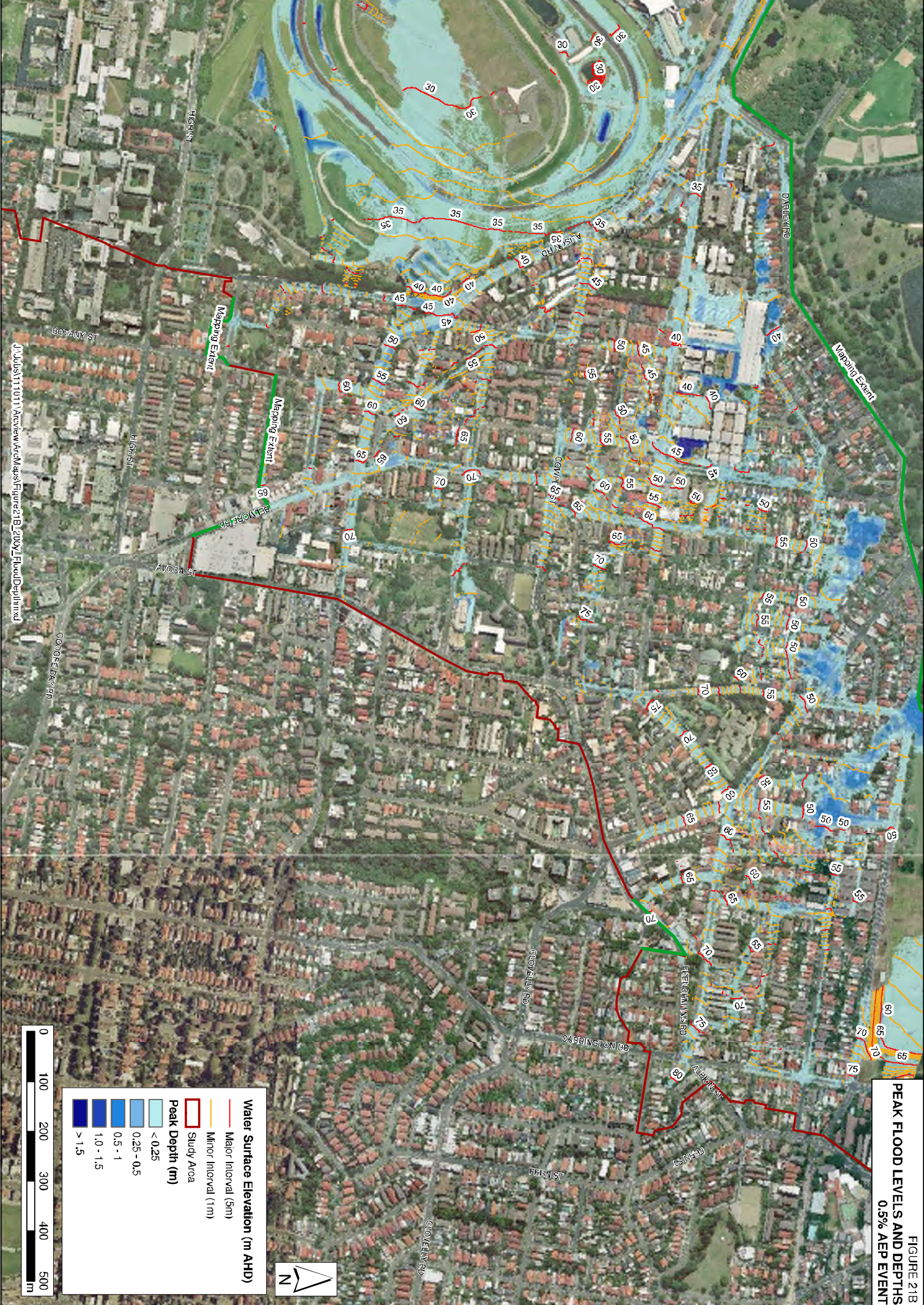
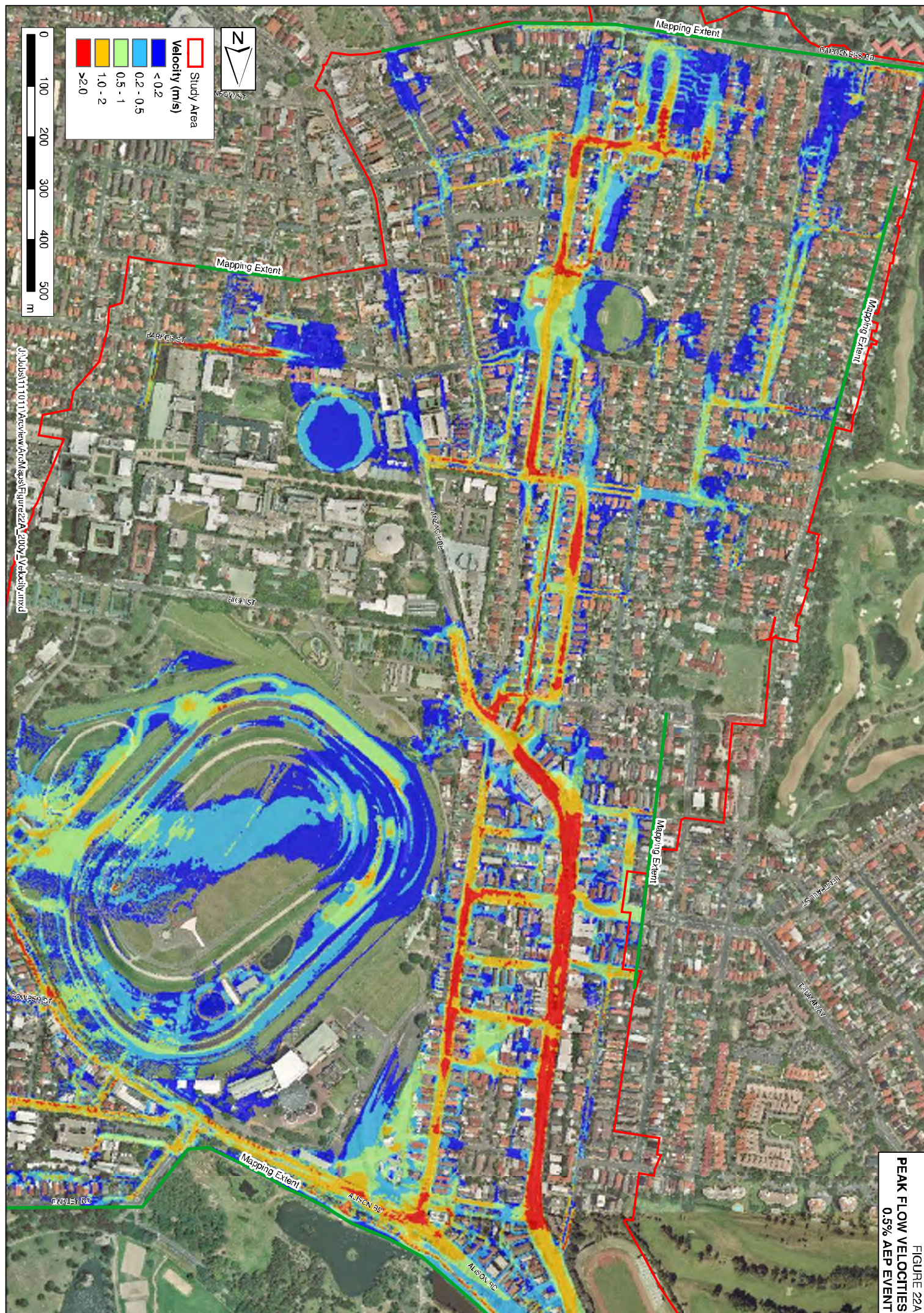
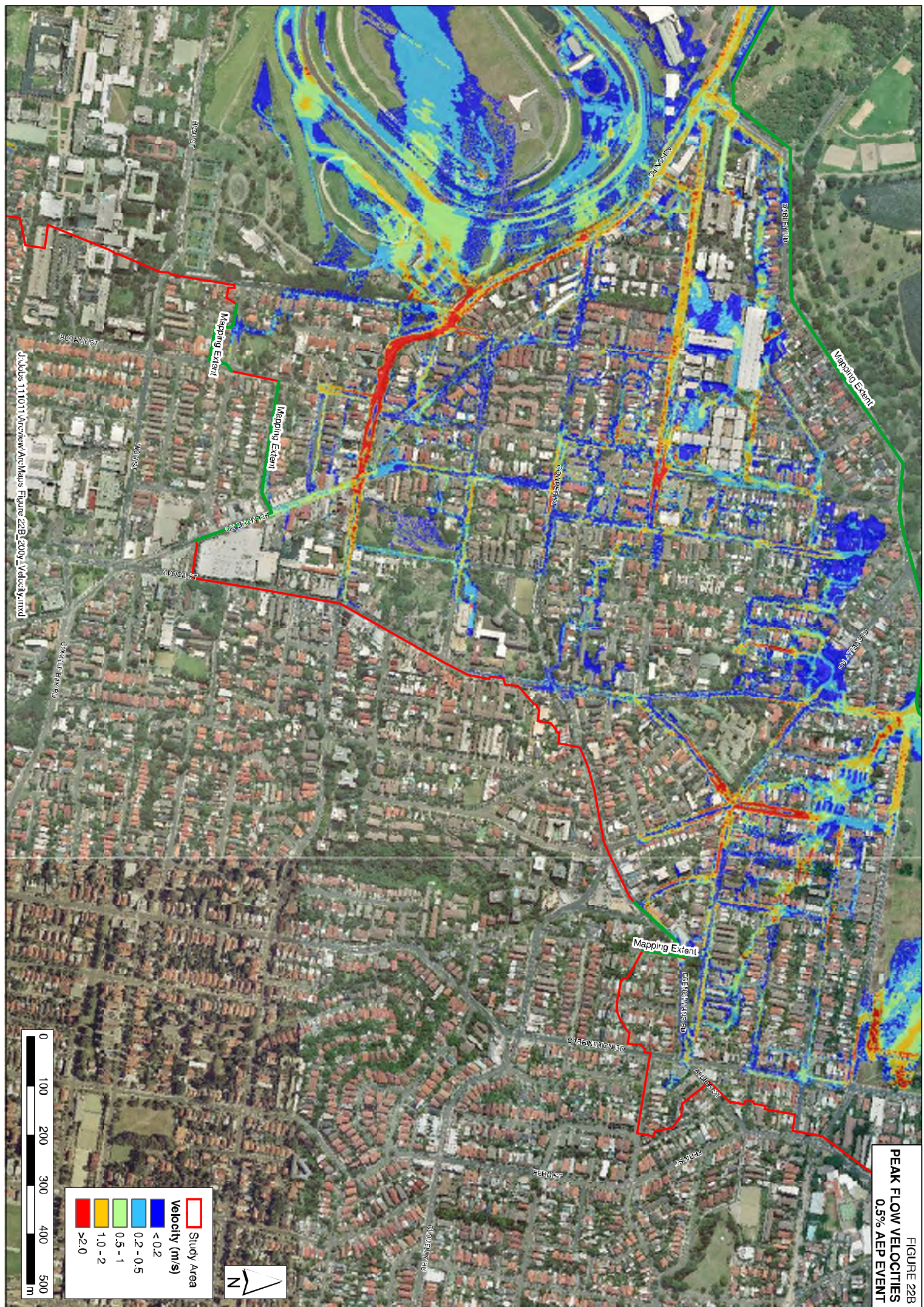


FIGURE 21B
PEAK FLOOD LEVELS AND DEPTHS
0.5% AEP EVENT



Water Surface Elevation (m AHD)	
Major Interval (5m)	Minor Interval (1m)
Study Area	
Peak Depth (m)	
< 0.25	0.25 - 0.5
0.5 - 1	1.0 - 1.5
> 1.5	





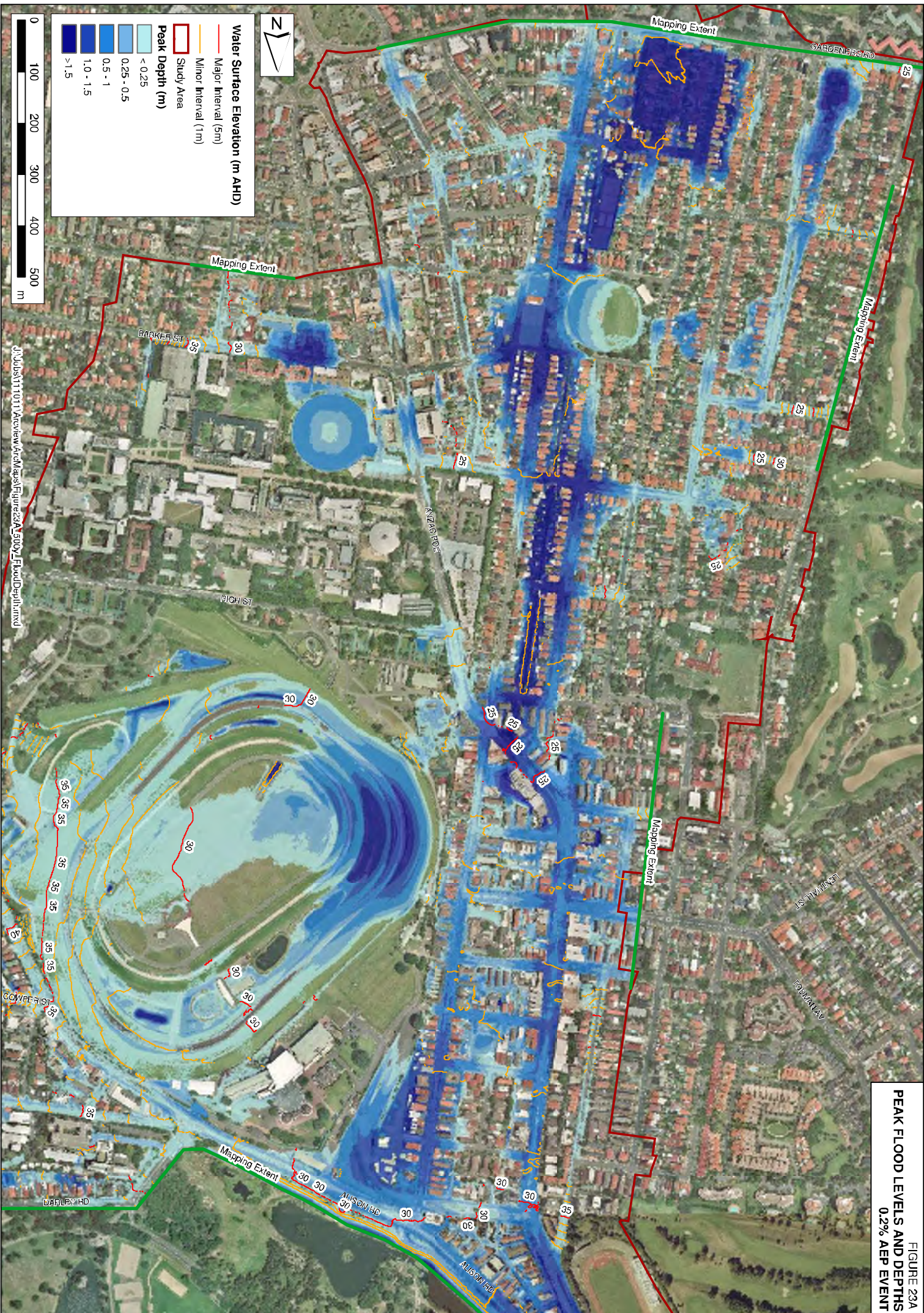
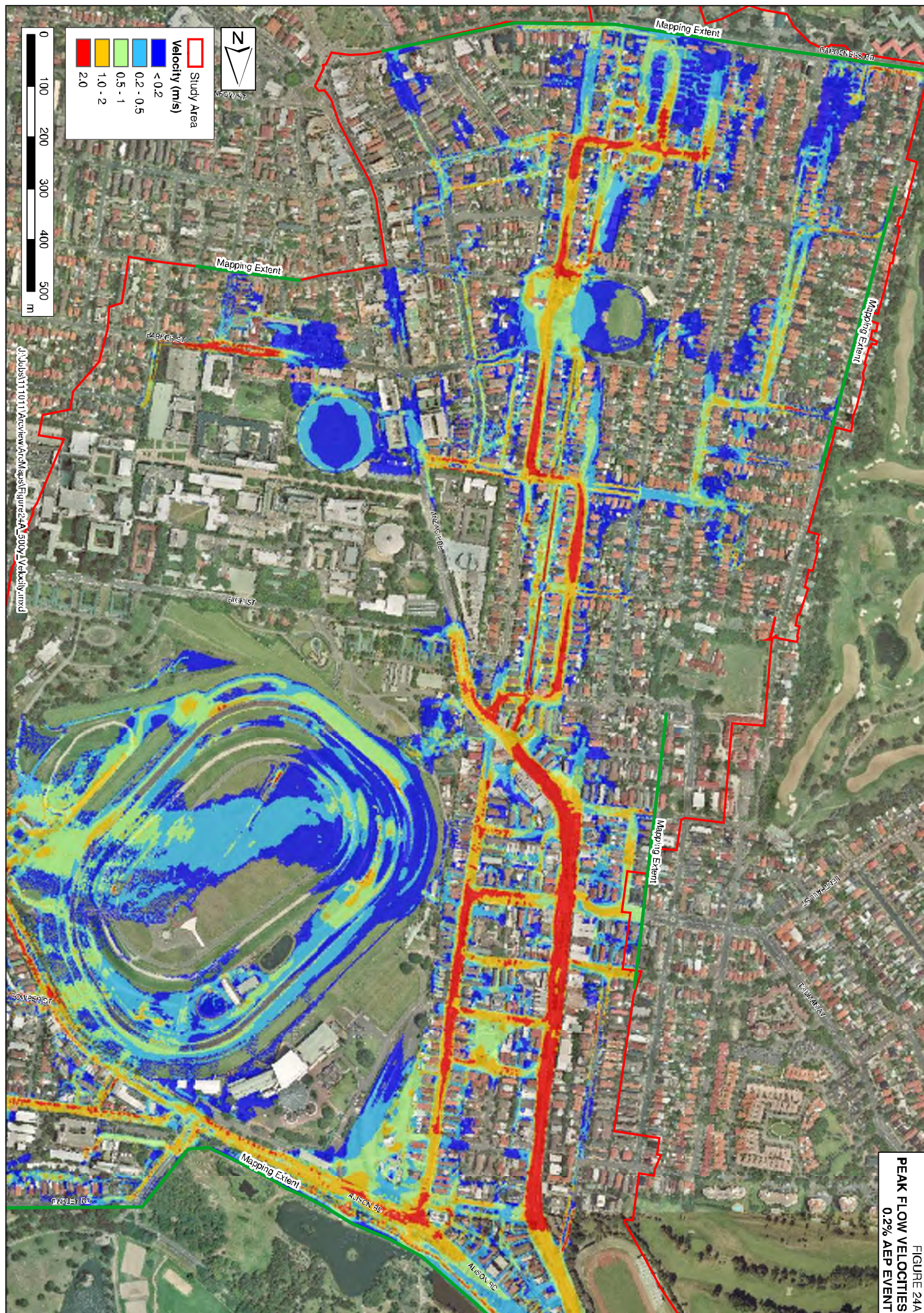


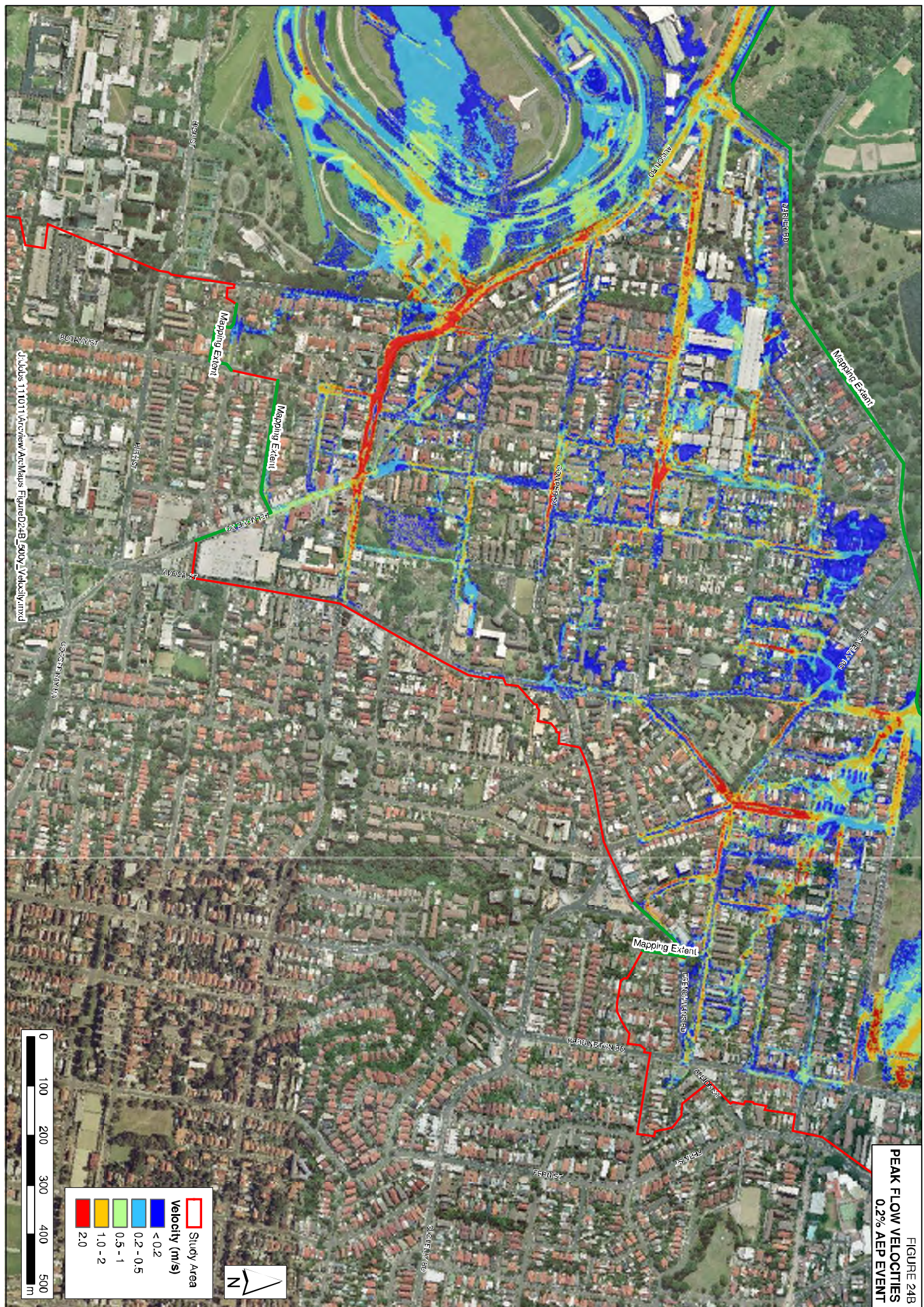
FIGURE 29A
PEAK FLOOD LEVELS AND DEPTHS
0.2% AEP EVENT

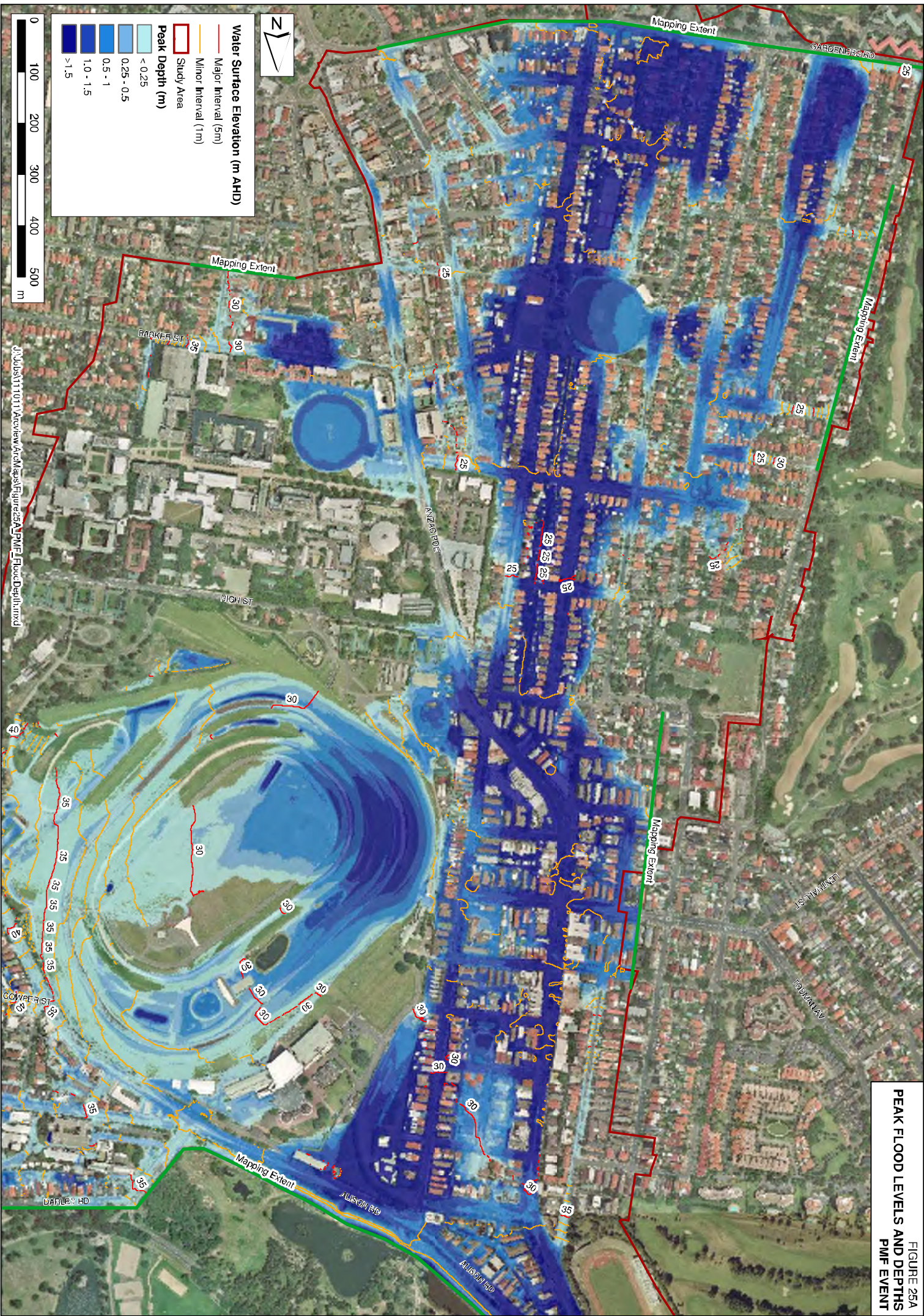


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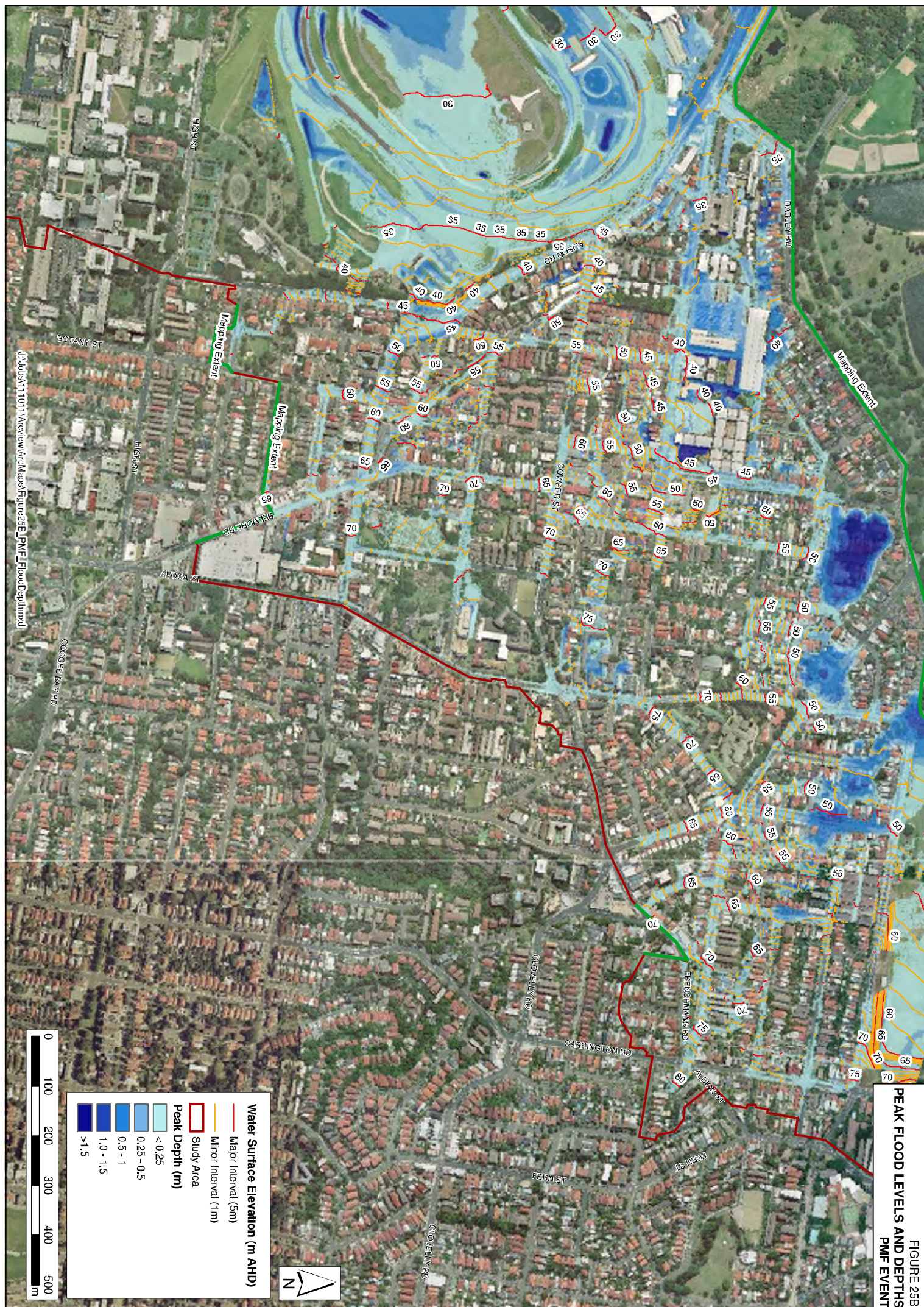
FIGURE 23B
PEAK FLOOD LEVELS AND DEPTHS
0.2% AEP EVENT

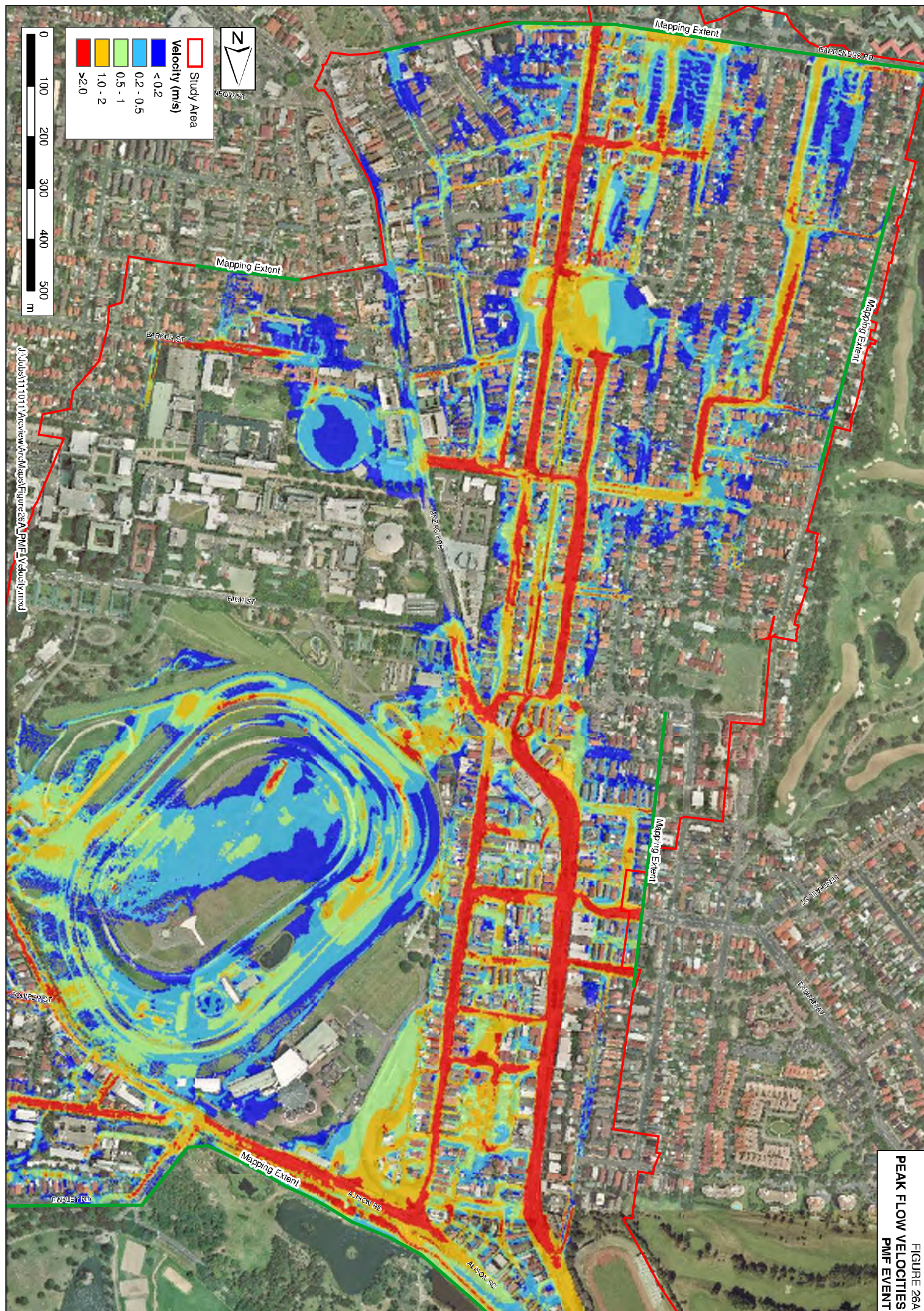


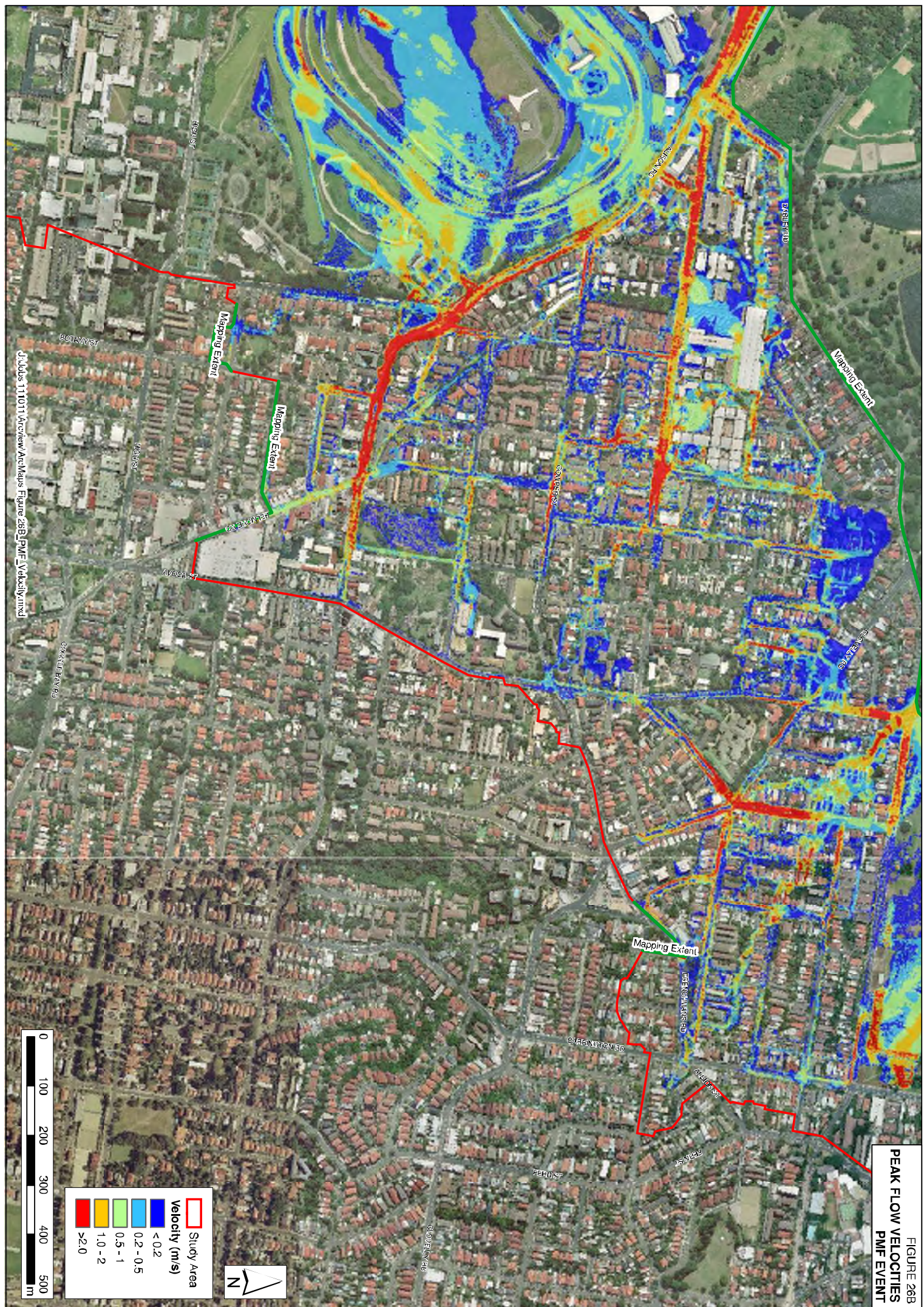




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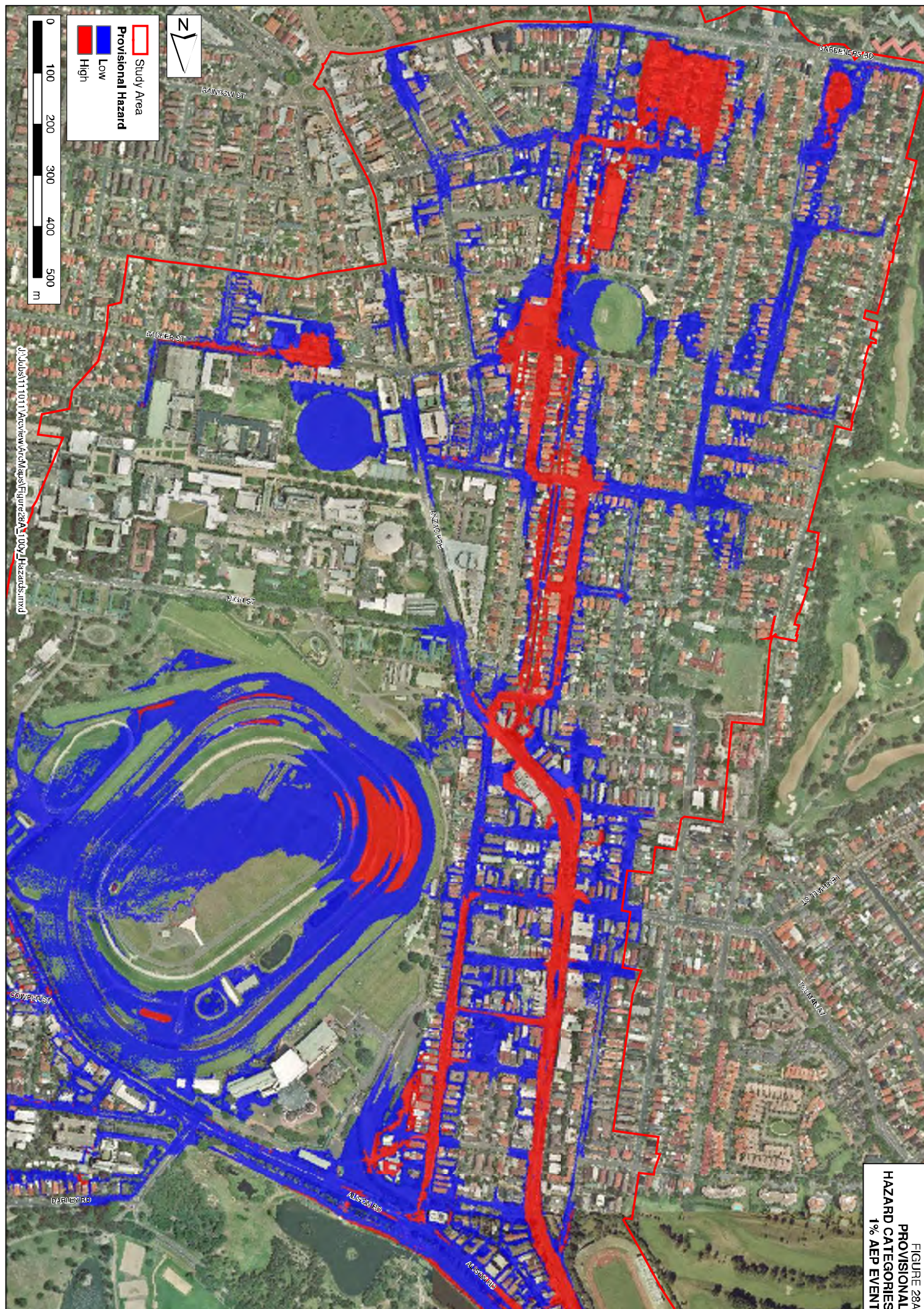




Note:
1% AEP peak flood extents are approximate only based on results of 1D levels mapped on the DTM.
Flow paths between Ponds are not mapped.



FIGURE 27
CENTENNIAL PARKLAND PONDS
1% AEP PEAK FLOOD EXTENT



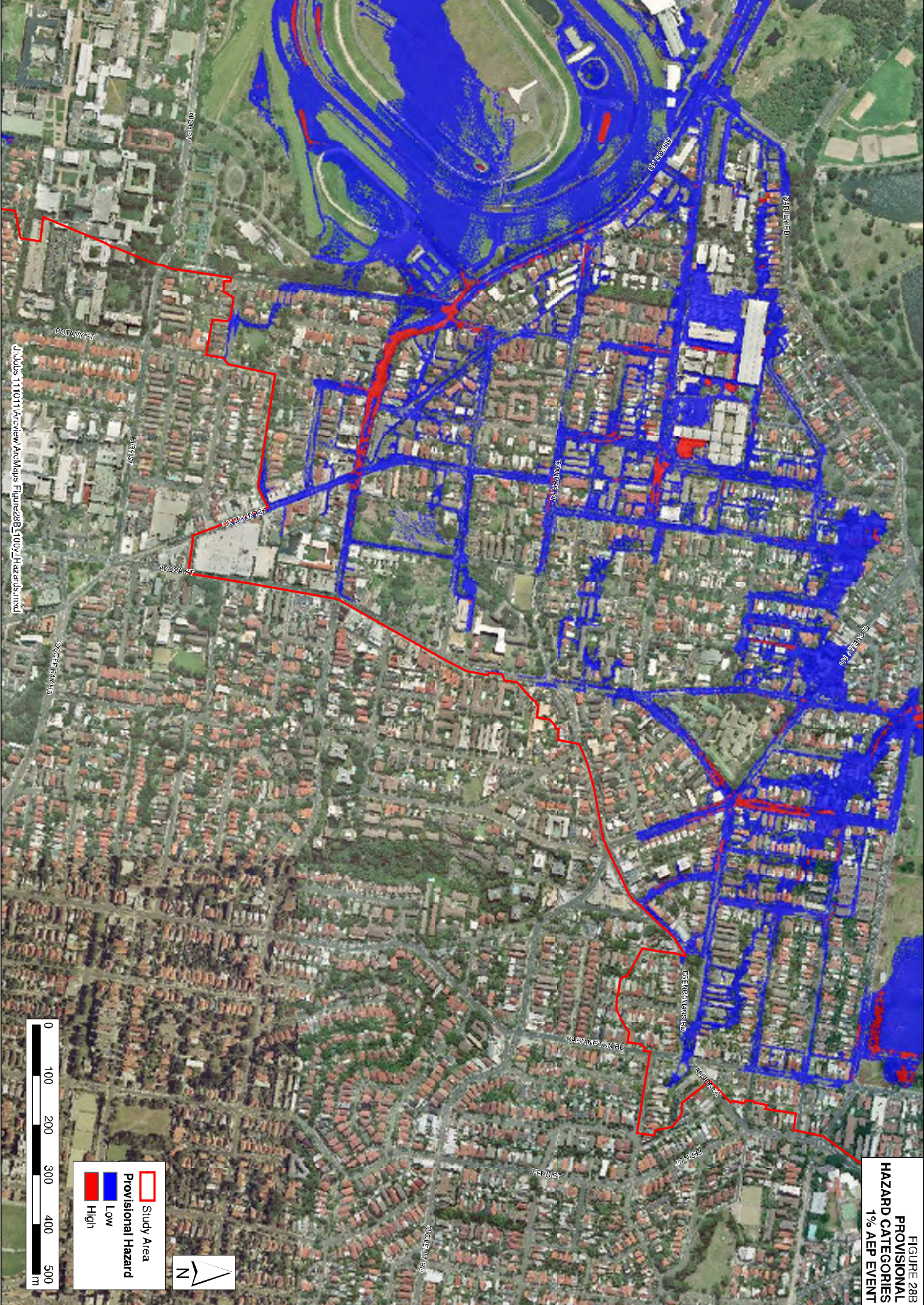


FIGURE 288
PROVISIONAL
HAZARD CATEGORIES
1% AEP EVENT

Study Area
Provisional Hazard
Low
High

0 100 200 300 400 500 m

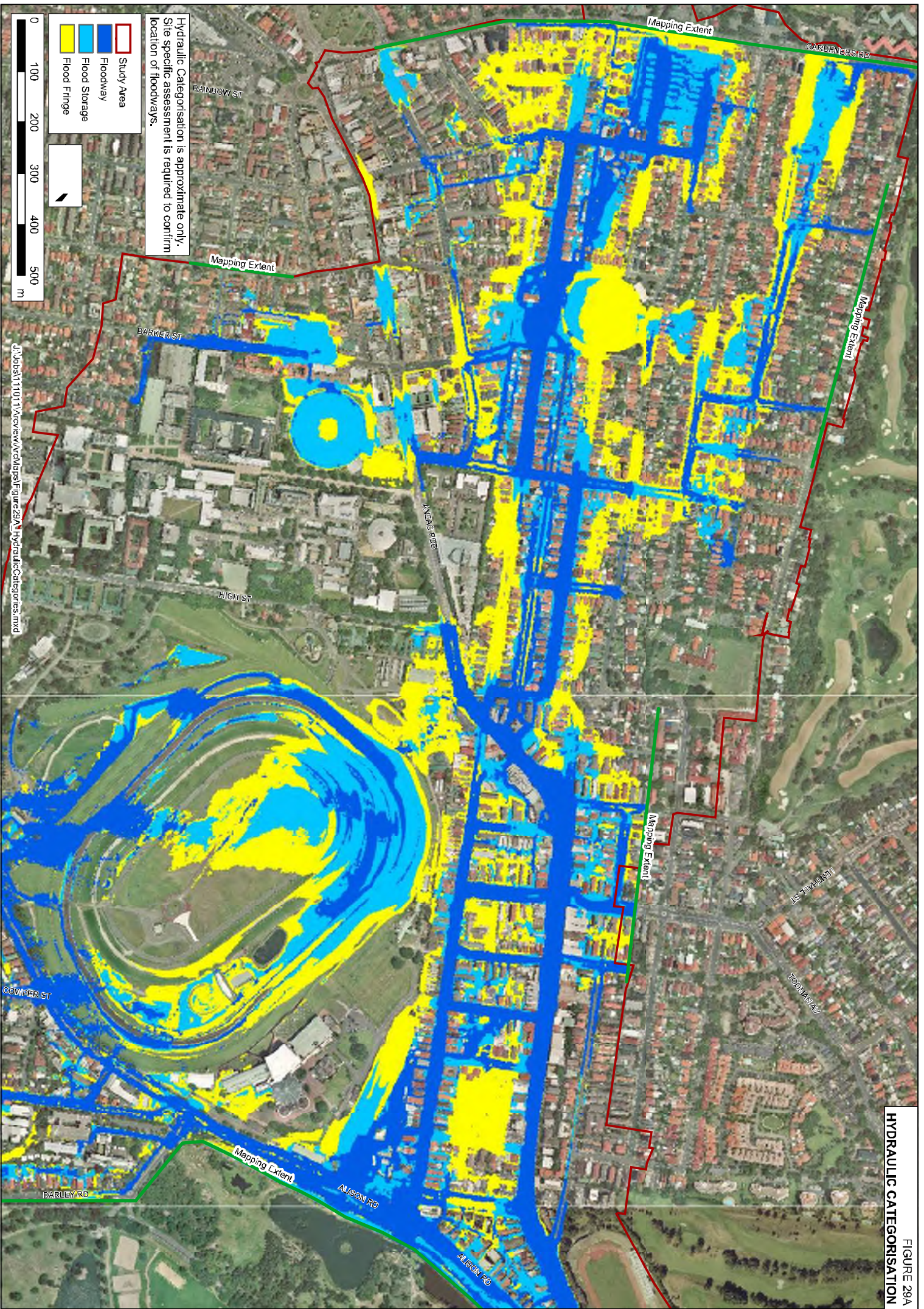


FIGURE 29A
HYDRAULIC CATEGORISATION

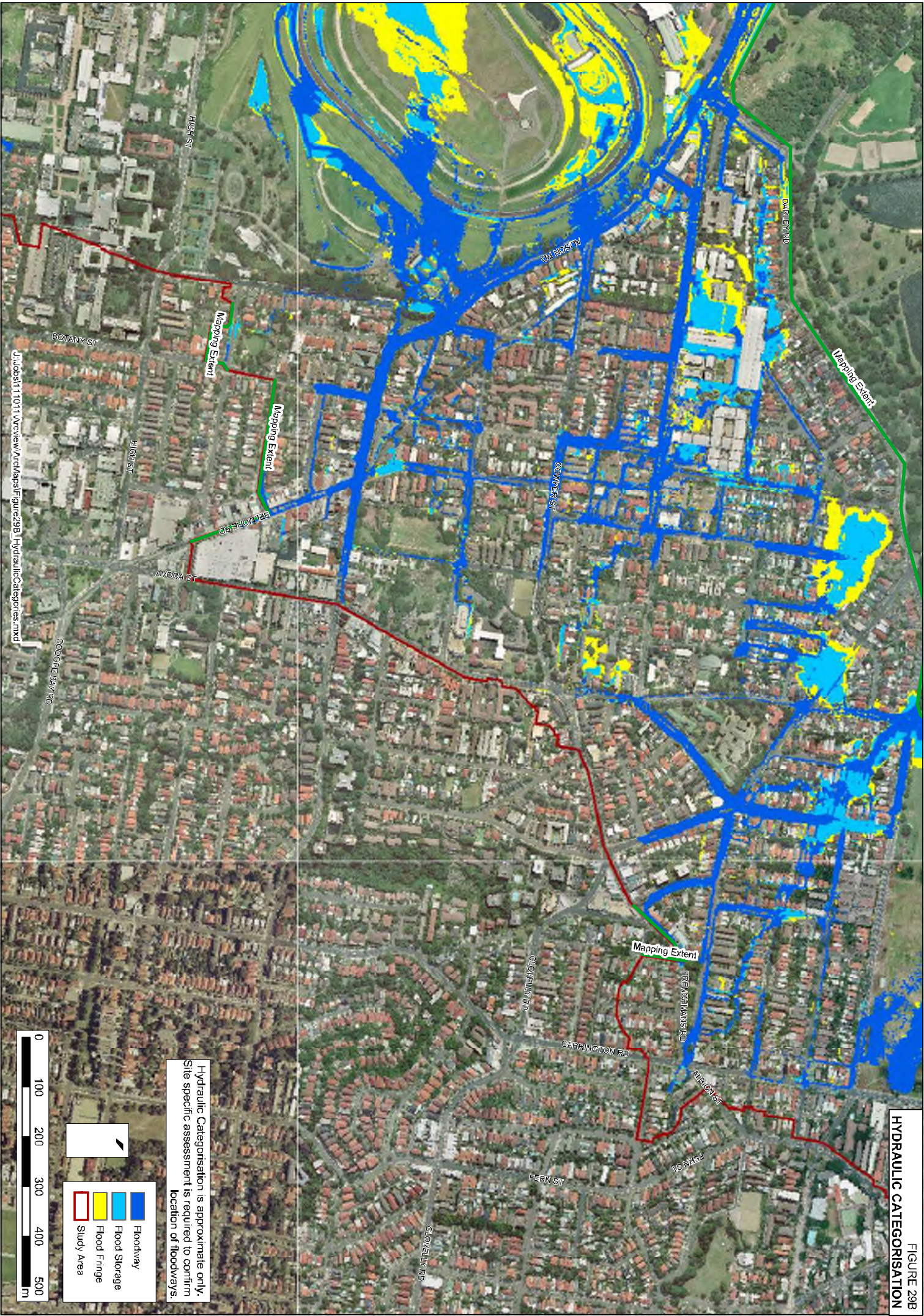


FIGURE 29B
HYDRAULIC CATEGORISATION

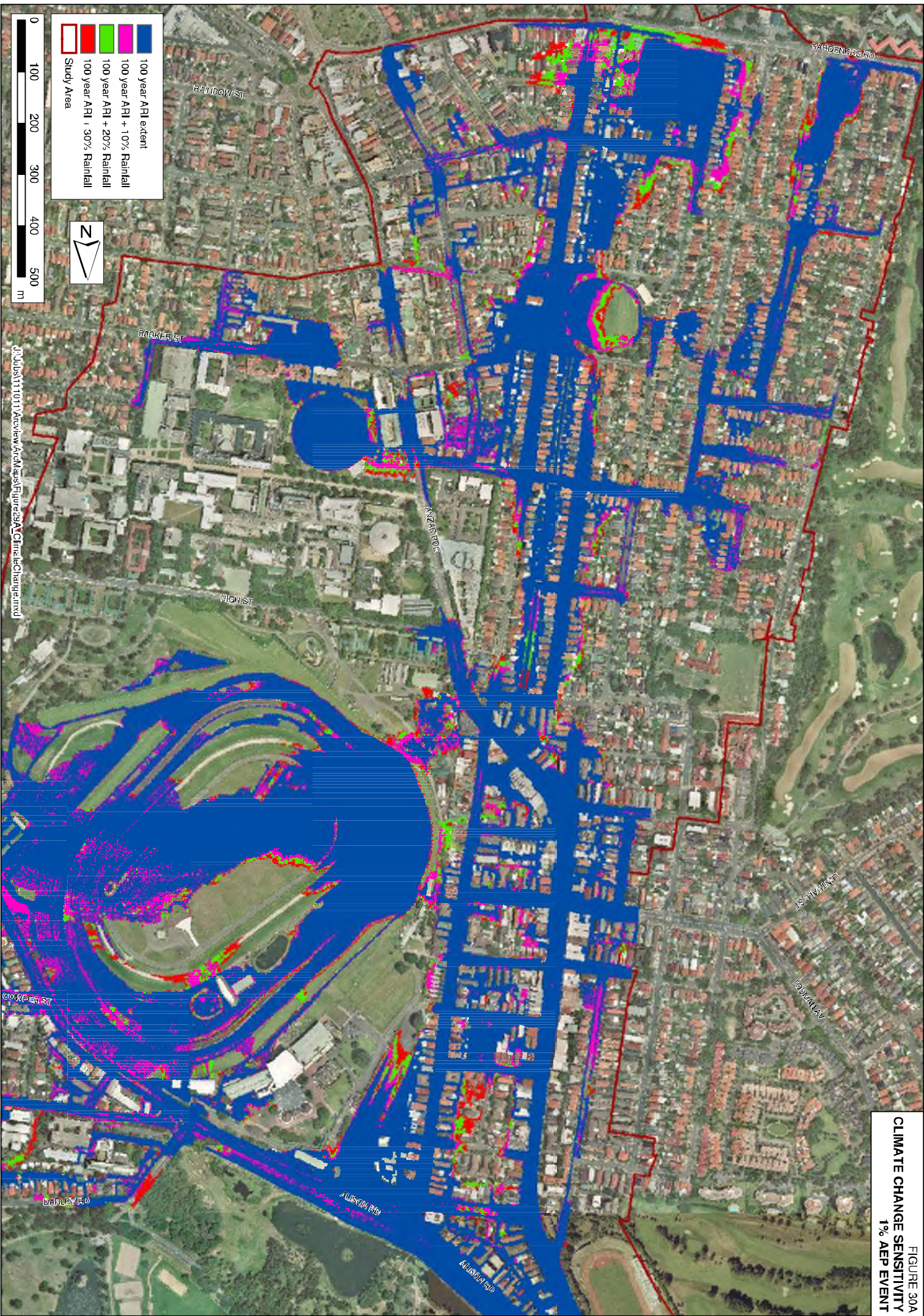


FIGURE 30A
CLIMATE CHANGE SENSITIVITY
1% AEP EVENT

