CITY OF CANADA BAY COUNCIL

POWELLS CREEK FLOOD STUDY

December 2022

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POWELLS CREEK FLOOD STUDY

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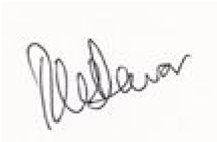
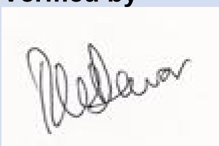
Authors Fabien Joly Richard Dewar	**Prepared by** 
Date 20 December 2022	**Verified by** 

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LIST OF ACRONYMS

AEP Annual Exceedance Probability

AHD	Australian Height Datum
ARI	Average Recurrence Interval
ARR	Australian Rainfall and Runoff (ARR1987 and ARR2019)
ALS	Airborne Laser Scanning sometimes known as LiDAR
BoM	Bureau of Meteorology
CBD	Central Business District
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CFERP	Community Flood Emergency Response Plan
DEM	Digital Elevation Model
DRAINS	Hydrologic computer model developed from ILSAX
ELVIS	Elevation and Depth – Foundation Spatial Data - website
ERP	Emergency Response Planning
EPR	Entire Period of Record of gauge data at Elva Street gauge
EY	Exceedances per Year
FFA	Flood Frequency Analysis
GEV	Generalised Extreme Value probability distribution
GIS	Geographic Information System
GSDM	Generalised Short Duration Method
HEC-RAS	1D hydraulic computer model
HGL	Hydraulic Grade Line
ILSAX	Hydrologic model - a precursor to DRAINS
IFD	Intensity, Frequency and Duration of Rainfall
IPCC	Intergovernmental Panel on Climate Change
LEP	Local Environmental Plan
LGA	Local Government Area
LiDAR	Light Detection and Radar
LP3	Log Pearson III probability distribution
m	metre
MHL	Manly Hydraulics Laboratory
m^3/s	cubic metres per second (flow measurement)
m/s	metres per second (velocity measurement)
NSRUP	North Strathfield Rail Underpass Project
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
SEPP	State Environmental Planning Policy
SMC	Strathfield Municipal Council
SWC	Sydney Water Corporation
TIN	Triangular Irregular Network
TUFLOW	one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software program (hydraulic computer model)
UNSW	University of New South Wales
1D	One dimensional hydraulic computer model
2D	Two dimensional hydraulic computer model

FOREWORD

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

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

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

1. ***Flood Study***
   - Determine the nature and extent of the flood problem.
2. ***Floodplain Risk Management 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 Powells Creek Flood Study constitutes the first stage of the management process for the City of Canada Bay Council and is based on the prior flood study for the wider Powells Creek and Saleyards Creek catchment undertaken by Strathfield Council, Burwood Council and Sydney Water Corporation.

TERMINOLOGY USED IN REPORT

Australian Rainfall and Runoff (ARR) have produced a set of guidelines for appropriate terminology when referring to the probability of floods. In the past, AEP has generally been used for those events with greater than 10% probability of occurring in any one year, and ARI used for events more frequent than this. However, the ARI terminology is to be replaced with a new term, EY.

Annual Exceedance Probability (AEP) is expressed using percentage probability. It expresses the probability that an event of a certain size or larger will occur in any one year, thus a 1% AEP event has a 1% chance of being equalled or exceeded in any one year. For events smaller than the 10% AEP event however, an annualised exceedance probability can be misleading, especially where strong seasonality is experienced. Consequently, events more frequent than the 10% AEP event are expressed as X Exceedances per Year (EY). Statistically a 0.5 EY event is not the same as a 50% AEP event, and likewise an event with a 20% AEP is not the same as a 0.2 EY event. For example, an event of 0.5 EY is an event which would, on average, occur every two years. A 2 EY event is equivalent to a design event with a 6-month average recurrence interval where there is no seasonality, or an event that is likely to occur twice in one year.

While AEP has long been used for larger events, the use of EY is to replace the use of ARI, which has previously been used in smaller magnitude events. The use of ARI, the Average Recurrence Interval, which indicates the long-term average number of years between events, is now discouraged. It can incorrectly lead people to believe that because a 100-year ARI (1% AEP) event occurred last year it will not happen for another 99 years. For example, there are several instances of 1% AEP events occurring within a short period, for example the 1949 and 1950 events at Kempsey.

Where the % AEP of an event becomes very small, for example in events greater than the 0.02 % AEP, the ARR terminology suggest the use of 1 in X AEP so a 0.02 % AEP event would be the same as a 1 in 5,000 AEP.

The PMF is a term also used in describing floods. This is the Probable Maximum Flood that is likely to occur. It is related to the PMP, the Probable Maximum Precipitation.

This report has adopted the approach of the ARR terminology guidelines and uses % AEP for all events the 50% AEP and greater and EY for all events smaller and more frequent than this. The image below provides the relationship between the various terminologies.

Australian Rainfall and Runoff (ARR) is a technical document which provides guidelines for flood related hydrologic and hydraulic processes. There have been 4 editions of ARR in 1958, 1987, 2016 and 2019. The 2016 and 2019 editions are very similar but provide significant upgrades to the 1987 edition and particularly regarding design rainfall depths and temporal patterns.

Frequency Descriptor	EY	AEP (%)	AEP (1 in x)	ARI
Very Frequent	12			
	6	99.75	1.002	0.17
	4	98.17	1.02	0.25
	3	95.02	1.05	0.33
	2	86.47	1.16	0.5
	1	63.21	1.58	1
Frequent	0.69	50	2	1.44
	0.5	39.35	2.54	2
	0.22	20	5	4.48
	0.2	18.13	5.52	5
	0.11	10	10	9.49
Rare	0.05	5	20	20
	0.02	2	50	50
	0.01	1	100	100
Very Rare	0.005	0.5	200	200
	0.002	0.2	500	500
	0.001	0.1	1000	1000
	0.0005	0.05	2000	2000
Extreme	0.0002	0.02	5000	5000
			↓	
			PMP/ PMPDF	

The blue shaded areas represent the terminology adopted in this report.

BRIEF OUTLINE OF HOW DESIGN FLOOD LEVELS ARE CALCULATED

There are two broad approaches for calculating design events (floods of a known probability of occurrence such as the old 100-year event now termed the 1% AEP). The first is to undertake statistical analysis (termed flood frequency analysis) of a long record of peak flood levels (such as recorded for over 100 years at Windsor). This approach is rarely used for catchment wide studies as is only applicable at the location of the records. The alternative method (termed rainfall runoff modelling) is to use computer models of the catchment which calculate peak flood levels (based on equations of flow) from design rainfall data provided by the Bureau of Meteorology (BoM). The BoM can calculate design rainfall depths across Australia based on an extensive and long-term record of historical rainfalls. The accuracy of the computer models is increased by "calibrating" them to historical flood height data using the actual rainfall records from that historical event. The models include detailed definition of the topography derived from laser aerial scanning of the ground (this data has a vertical accuracy of around +/- 150mm and is available at approximately 1m spacings).

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EXECUTIVE SUMMARY

BACKGROUND

Powells Creek is a small southern tributary of the Parramatta River and Saleyards Creek is the major tributary of Powells Creek (Figure 1). The total catchment area of Powells Creek to Homebush Bay Drive is 8.1km^2 and Saleyards Creek to the confluence with Powells Creek is 3.2km^2.

The Powells Creek catchment is in Sydney's Inner West region, approximately 12 kilometres west of the CBD. The catchment includes the suburbs (or parts) of Burwood, Concord West, Homebush, Homebush West, North Strathfield, Strathfield, and Rookwood (cemetery). Approximately 77% of the catchment is within the Strathfield Municipal Council (SMC) local government area (LGA), 15% is within City of Canada Bay Council LGA, 5% is within Burwood Council LGA and 3% (Rookwood cemetery) within Auburn LGA. Saleyards Creek is predominantly within the SMC LGA, apart from Rookwood cemetery.

The Powells Creek catchment drains to Homebush Bay on the Parramatta River via an open channel. Sydney Water Corporation (SWC) owns the larger "trunk" drainage assets including the open concrete lined channel with the smaller pipe and pit networks owned by the various councils.

The study area of this Flood Study is that part of the City of Canada Bay LGA within the Powells Creek catchment.

OBJECTIVES

The purpose of this Flood Study is to identify mainstream and overland flow flooding (assumed as where there is no defined channel) to define the existing flood liability within the City of Canada Bay part of the catchment. This objective is achieved through the development of a suitable hydrologic and hydraulic modelling platform that can subsequently be used as the basis for a future Floodplain Risk Management Study and Plan for the study area, and to assist Council when undertaking flood-related planning decisions for existing and future developments.

This project involves conducting a flood study:

- Which is a comprehensive investigation of flood behaviour that provides the main technical foundation for the development of a robust floodplain risk management plan.
- It aims to provide a better understanding of the full range of flood behaviour, risks, and consequences in the study area.
- It involves consideration of the local flood history, available collected flood data, and the development of hydrologic and hydraulic models that are calibrated and verified, where possible, against historic flood events and extended, where appropriate, to determine the full range of flood behaviour.

FLOODING HISTORY

From the flooding history it must be noted that the drainage characteristics of this catchment have been significantly altered because of urbanisation and as such older flood extents and depths for a given storm may not apply to present day conditions. There have been many instances of flooding in the past with November 1961, March 1975 and March 1983 having the greatest number of records. Archival records also mention several prior large floods including a particularly severe event in 1860. More recently, reports of minor property inundation from overland flow in 2015 and 2016 in the Burwood LGA have been received as well as in the Canada Bay LGA.

A water level gauge at Elva Street was operated from 1958 to approximately 2010 by the University of New South Wales (UNSW). The records have been digitised up to 1997 and were used for calibration of the modelling system upstream of the gauge as well as flood frequency analysis.

PAST STUDIES

Initially a review of the available reports and data was undertaken. The Powells Creek Flood Study undertaken for SMC in 1998 (Reference 1) was the first study covering the entire catchment and providing detailed flood levels. Subsequently a Flood Study was completed for Sydney Water in 2015. That Flood Study then formed the basis of the Powells Creek Revised Flood Study (Reference 2) for SMC (2016) and Burwood Council (2019). The City of Canada Bay commissioned Jacobs to undertake the 2015 Concord West Precinct Master Plan Flood Study (Reference 3), however this only covered the City of Canada Bay LGA.

All past studies relied upon Australian Rainfall and Runoff 1987 (ARR1987 – Reference 4) which has now been superseded by ARR2019 (Reference 5).

RAINFALL AND FLOOD HEIGHT DATA

There is a limited amount of rainfall data covering the catchment, particularly pluviometer data which is needed to describe the temporal pattern of historical events. A reasonable amount of historical flood height data is available from SWC records as well as the 1998 Powells Creek Flood Study (Reference 1). Water level data is available from the water level gauge at Elva Street from 1958 to 2010. As no significant floods have occurred since the completion of the 1998 Flood Study, no further attempt at obtaining historical flood data from the residents was made as part of the present study.

HYDROLOGIC AND HYDRAULIC MODELLING PROCESS

The hydrologic modelling was undertaken using DRAINS and the hydraulic model was undertaken using TUFLOW. These models were verified by comparison to six historical events (3rd, 7th, 10th and 17th February 1990, 18th March 1990 and 2nd January 1996).

The design rainfall events modelled were the 1EY, 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP design events and the Probable Maximum Flood (PMF). The temporal patterns for the design events were sourced from ARR2019 (Reference 5) and the rainfall data was obtained from the Bureau of Meteorology's (BoM) internet-based tool. The PMP estimates were derived according to the BoM guidelines.

FLOOD FREQUENCY ANALYSIS

An extensive flood frequency analysis (FFA) was carried out in the 2016 Powells Creek Revised Flood Study (Reference 2) at the Elva Street water level gauge. When compared to FFA design flow estimates, those from TUFLOW overestimate flows for more frequent events and generally accord with the FFA greater events.

SENSITIVITY ANALYSIS, BLOCKAGE AND CLIMATE CHANGE

Sensitivity analysis and blockage assessments were undertaken to assess the effects of varying key model parameters. In addition, assessments of the effects of a sea level rise elevating the adopted design water levels in the Parramatta River and an increase in design rainfall intensities were undertaken. Sea level rise made little difference in the upstream developed areas; however, rainfall increases (potentially due to climate change) will produce a significant increase in flood levels.

OUTCOMES

The results from this study provide design flood data (levels, depths, velocity, hazard, hydraulic classification) which supersede those derived in the 2016 Powells Creek Revised Flood Study (Reference 2) and the 2015 Concord West Precinct Master Plan Flood Study (Reference 3).

Immediately following the next large flood event (10% AEP or greater) water level and rainfall data should be collected and used to verify the hydrologic and hydraulic model calibrations.

1. INTRODUCTION

1.1. Background

The Powells Creek catchment (Figure 1) is located on the southern bank of the Parramatta River at Homebush Bay, approximately 12 kilometres west of the Sydney CBD. The main tributary of Powells Creek is Saleyards Creek which enters immediately upstream of Homebush Bay Drive. Downstream of Homebush Bay Drive, Powells Creek is a natural channel surrounded by dense mangrove vegetation on both sides. Upstream Powells and Saleyards Creeks are concrete lined channels with Powells Creek bounded on the east by the City of Canada Bay LGA; largely comprising of residential development with residential, light industry and open space on the western SMC side. Saleyards Creek is bounded on both sides by open space until reaching Underwood Road where it is largely bordered by commercial developments.

The total catchment area of Powells Creek to Homebush Bay Drive is 8.1km^2 and Saleyards Creek to the confluence with Powells Creek is 3.2km^2. The study area is limited to the City of Canada Bay LGA as shown on Figure 1.

The Powells Creek catchment includes the suburbs (or parts) of Burwood, Concord West, Homebush, Homebush West, North Strathfield, Strathfield and Rookwood (cemetery). Approximately 77% of the catchment is within the SMC LGA, 15% is within City of Canada Bay Council, 5% is within Burwood Council LGA and 3% (Rookwood cemetery) within Auburn LGA (herein termed the Councils). Saleyards Creek is predominantly within the SMC LGA apart from Rookwood cemetery.

Drainage elements in the Powells Creek catchment include kerbs and gutters, pits and pipes, and a network of trunk drainage elements including culverts and open channels. Ownership of the assets is split between SWC and the Councils, with SWC owning the larger "trunk" elements. Amongst the drainage assets is a length of brickwork drain that was one of the first purpose-built stormwater drains in Sydney and constructed in the 1890's. Open channel sections extend from Powells Creek under the railway lines to Elva Street, to just beyond Ismay Avenue on the small tributary, and up Saleyards Creek under Flemington markets to upstream of the railway line.

The primary drivers that highlighted the need for this flood study are

- The City of Canada Bay Council's Concord West Precinct project includes the rezoning and redevelopment of certain industrial zoned sites for medium density residential development (i.e. residential flat/apartment buildings), and associated public domain improvements.
- Implementation of suitable planning controls for the City of Canada Bay to inform and protect the public, residents and property from future flooding impacts and hazards, including flooding of habitable floor levels.
- Several significant changes within the catchment have occurred since the prior flood studies were carried out. There is a requirement to examine the flood effects of these changes within the catchment.
- The revised study area is to include the entire Canada Bay LGA within the Powells Creek catchment and thus includes the overland flow areas not previously modelled in the 2016

Powells Creek Revised Flood Study (Reference 2).

Probable or known drainage “hotspots’ include.

- The low-lying area to the north of, and including, the new Canada Bay Public School is situated in a trapped depression, caused mainly by the Homebush Bay Drive embankment and by slightly higher ground levels on Sydney Olympic Park land, between Victoria Avenue and Powells Creek.
- The trapped sag point on George Street to the north of the Rothwell Avenue junction, where an existing industrial building at 176 – 184 George Street prevents floodwaters from flowing overland towards Powells Creek; and
- The separation of the northern floodplain (sub catchment areas in Sydney Olympic Park and Bicentennial Park) from the rest of the catchment by Homebush Bay Drive. This feature has created an effective barrier where cross drainage through the northern catchment is dependent on the capacity of outlet / culvert structures to covey flows.

There have been many instances of flooding in the past with the greatest number of records existing in relation to the November 1961, March 1975, and March 1983 floods events.

The present study has been commissioned by the City of Canada Bay Council to extend upon the previous flood studies of Powells Creek commissioned by SWC, SMC and Burwood Council, and to define mainstream and overland flood behaviour in the catchment. This report covers the part of the catchment lying in the City of Canada Bay LGA. Mainstream is generally defined as flooding occurring from open channels, either lined or natural, whereas overland is mainly flooding where there is no defined open channel and drainage is via the pit and pipe system and overland through private and public properties. However, there are exceptions to these definitions.

1.2. Description of Catchment

The study area’s catchment is fully urbanised. Within the Strathfield LGA approximately 79% of the LGA is zoned for residential development, 9% for special purpose, 6% for open space areas (parks and recreation areas) and the remaining 7% for business/commercial and industrial areas. Within the Burwood LGA, approximately 90% is zoned for residential development (mix of low density and general) with remaining areas containing mixed use, public recreation and infrastructure. Within the City of Canada Bay LGA approximately 61% of the LGA is zoned for residential development, 8% for special purpose, 18% for open space areas (parks and recreation areas) and the remaining 13% for business/commercial and industrial areas.

A land use zone map is provided as Figure 2. Upstream of the Parramatta railway the catchment is predominantly occupied by residential development with areas of open space, schools, and active recreation. The residential developments are largely detached dwellings constructed prior to 1960 but there are also several recent higher density developments. Significant commercial development is located near Strathfield railway station at Strathfield Plaza.

Downstream of the railway line the catchments of both Powells and Saleyards creeks are a mixture of residential, commercial (Flemington Markets) and light industrial developments. There are also significant areas of open space surrounding the lower parts of both creeks. The road transport routes (M4 Motorway, Parramatta Road, Homebush Bay Drive) and the railway lines have influenced the flow paths in the lower reaches.

Very little information is available in the City of Canada Bay Council's records regarding the existing site drainage for the catchment in general (i.e., are there rubble pits? If so what size? Is the existing roof drainage connected directly to the street drainage?). On-site detention has been introduced by all Councils since the mid-1990s.

Diagram 1 indicates the significant change in alignment of Powells Creek with construction of the concrete lined SWC channel.

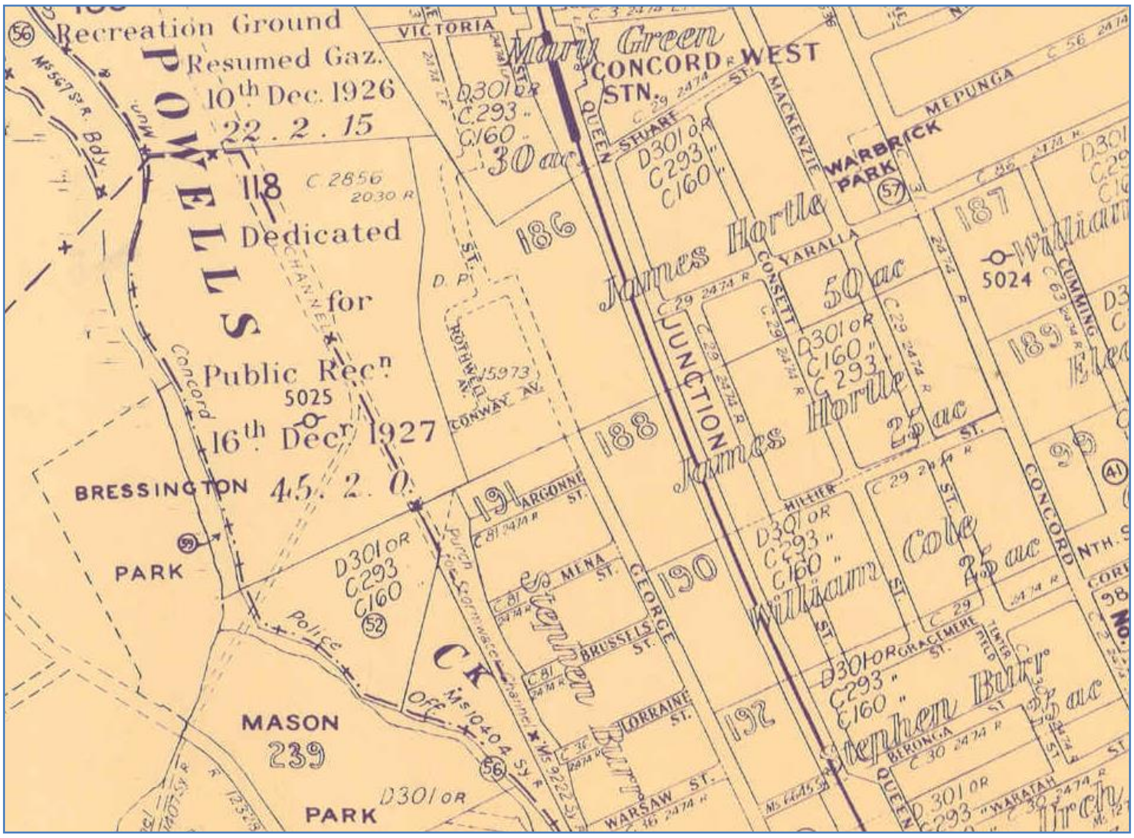


Diagram 1: Cadastral Plan near the time of Construction of the SWC Concrete Channel

Elevations in the upper part of the catchment (Figure 3) reach approximately 55 m AHD near Arthur Street and some reaches are relative steep with 2% to 4% grades. However, the overall catchment slope averages 0.8% along the main flow-path from headwaters to outlet. The main channel is tidal to upstream of Parramatta Road and the lined channel width varies from approximately 2 m in the upper areas to 22 m at Homebush Bay Drive.

Construction of buildings and structures over the open lined channel, as shown on Figure 4, has significantly reduced the capacity of the natural waterways. As a result, flooding has occurred in the past (Figure 5) causing significant tangible and intangible damages.

1.3. Changes to the Study Area

The following major works in the study area have been undertaken since completion of the previous flood studies (Section 2.2),

- North Strathfield Rail Underpass Project.
- Sydney Water Powells Creek Naturalisation.
- Canada Bay Primary School Victoria Avenue Concord West.
- Filling of Powells Creek Reserve North Field; and
- Reconstruction of the west end of Victoria Avenue including drainage upgrade.
- Filling of Powells Creek Reserve Southern Field.
- North Sydney Freight Corridor Project (Stage 2A) and
- West Connex.

1.4. Objectives

The primary objective of the Flood Study was to develop a suitably robust hydrologic and hydraulic modelling system to be used to define flood behaviour, peak flood levels and inundation extents within the study area. This modelling system may subsequently be used within a Floodplain Risk Management Study to assess the effectiveness and suitability of flood mitigation works.

The key stages in the flood study process are.

- undertake a comprehensive review of the available flood related data including previous studies, available survey data and historical rainfall and flood level data.
- establish a hydrologic model for the entire Powells Creek catchment to Homebush Bay Drive.
- develop a suitable hydraulic model of Powells Creek and major tributaries within the study area.
- calibration of the hydrologic and hydraulic models to historic flood data.
- define the flood behaviour and produce information on flood levels, extents, velocities and flows for a full range of design flood events under existing conditions.
- assess the sensitivity of blockage and other assumptions on peak flood flows and levels.
- assess the impacts of sea level rise and increase in rainfall and runoff intensities due to climate change; and,
- prepare hydraulic hazard and category mapping.

This report details the results and findings of the above investigations.

1.5. Floodplain Risk Management Process

As described in the 2005 NSW Government's Floodplain Development Manual (Reference 6), the Floodplain Risk Management Process entails four sequential stages:

Stage 1:	*Flood Study*
Stage 2:	*Floodplain Risk Management Study*
Stage 3:	*Floodplain Risk Management Plan*
Stage 4:	*Implementation of the Plan*

The above first three stages were completed with publication of 2016 Powells Creek Revised

Flood Study (Reference 2) and the 2003 Powells Creek Floodplain Risk Management Study and Plan (Reference 7). However, these studies were primarily focused on the Strathfield LGA. Several other flood studies have also been undertaken and these are reviewed in Section 2.2.

This present document is primarily for the City of Canada Bay LGA, it provides a review of the past flood studies and updates the design flood analysis to current best practice. The most significant change is the adoption of ARR2019 design flood methodology as all prior studies adopted ARR1987 methodology.

A Flood Study is a technical document and is not always easily understood by the public. A glossary of flood related terms is provided in Appendix A to assist. If more explanation of terms or a better understanding of the approach is required, type "*NSW Government Floodplain Development Manual*" into an internet search engine and you will be directed to the NSW Government web site which provides a copy of this manual (Reference 6) and further explanation.

All levels in this report are in metres to Australian Height Datum (AHD). Mean sea level is approximately 0 m AHD and an approximate tidal range in Homebush Bay is +0.6 m AHD to -0.4 m AHD. The highest tide in a year can reach 1.1 m AHD.

1.6. Accuracy of Model Results

The accuracy of all model results provided in this report is dependent on the input data sets and the ability of the modelling approach to replicate recorded historical flood data. As modelling approaches improve over time and additional flood data becomes available from future flood events the accuracy of the results will improve.

A key input data set is the topographic information provided by SWC and the Councils for use in this study. The topographic information was derived from Airborne Laser Scanning (ALS also known as LiDAR) with an estimated accuracy of ± 0.15m in cleared areas, such as car parks or on roads. In locations with more complex terrain, such as vegetated areas, the accuracy of the ALS is likely to be much lower and could vary significantly, by up to ± 1m. It is cost prohibitive to obtain detailed field survey throughout the entire study area and the ALS is assumed to be correct. However due to these potential accuracy limitations, some of the floodway extents, depth estimates, and design flood levels may change if more accurate field survey is obtained. It is estimated that an order of accuracy of the design flood levels is ± 0.3 m where quality historical calibration data are available nearby and up to ± 0.5 m where no such data are available.

The results from the present study incorporate best practice in design flood estimation at this time but it is acknowledged that changes in approach in the future will cause changes to design flood levels. A good example of this is the collection of rainfall data which forms the basis of design flood estimation. ARR2019 (Reference 5) provides an updated version of the 1987 edition of ARR (Reference 4) and introduced new approaches and guidelines which have changed design flood levels.

2. AVAILABLE DATA

2.1. Overview

The first stage in the investigation of flooding matters is to establish the nature, size, and frequency of the problem. On large river systems such as the Hawkesbury or Parramatta Rivers there are generally stream height and historical records dating back to the early 1900's, or in some cases even further. However, in most small urban catchments there are no stream gauges or official historical records available.

The Powells Creek catchment is unique in Sydney because a stream gauge has been operated by the UNSW at Elva Street for a long period (50 years). The records from this gauge have been used for many technical papers and university undergraduate and graduate theses.

An overview of historical of flooding is also available from an examination of the Councils' and SMC records, previous reports, internet search of newspapers, rainfall records and local knowledge.

2.2. Previous Studies

Several previous studies (Table 1) have been undertaken in the Powells Creek catchment as described in Reference 2. Numbers 1 to 6 (Table 1) used ILSAX hydrologic models to assess solutions to drainage problems with the majority distributing a questionnaire to the residents to obtain information about past drainage problems. Only numbers 7 to 11 determined design flood levels. No. 1 provides a summary of the more recent studies.

Table 1: Previous Studies Listed in Reference 2

Title	Consultant	Branches	Date	Comment	No.
Strathfield Local Flooding Issues	Kinhill Engineers	Wentworth Rd, Strathfield Ck, Albyn Rd	March 1997	Expanded upon No's 2 and 3. Undertook HGL.	1
Redmyre Road/Florence Street Catchment Study	Giammarco	Albyn Rd	November 1993	Undertook HGL.	2
Rochester Street Catchment Drainage Investigation	Bewsher Consulting	Strathfield Ck	December 1990	Undertook HGL.	3
Stormwater Drainage Upgrading Programme - Rochester Street Catchment - Feasibility Study and Design Report	Taylor, Thomson, Whitting	Strathfield Ck	1992	Expanded on No. 3. Undertook HGL.	4
Rochester Street Drainage Investigation Report	Rankine and Hill	Strathfield Ck	May 1985	Examined upgrading of pipe system.	5
Arthur Street Catchment Study	Bewsher Consulting	Saleyards Ck	July 1996	Only upstream of the railway line.	6
Saleyards Creek at Park Road, Flemington	Bewsher Consulting	Saleyards Ck	October 1996	Determined design flood levels.	7
12-14 Wentworth Road, Homebush	Bewsher Consulting	Saleyards Ck	February 1995	Determined design flood levels.	8

Title	Consultant	Branches	Date	Comment	No.
32-36 Burlington Road, Homebush	B Lysenko	Strathfield Ck	February 1994	Determined design flood levels.	9
Lower Parramatta River Flood Study	Willing & Partners	Powells Creek to approximately Pomeroy Street	February 1986	Determined design flood levels.	10
Powells Creek at Underwood Street Site Flood Study	Tierney & Partners	Powells Creek at Pomeroy Street	November 1993	Determined design flood levels.	11

The references listed in Table 1 are of little value in the current study as they provide little historical data, and the results cannot be easily compared. The 2016 Powells Creek Revised Flood Study (Reference 2), however, is a comparable study to the current one and extensive use has been made of the data and results which were originally contained in the prior 1998 Powells Creek Flood Study (Reference 1).

The City of Canada Bay commissioned Jacobs to undertake the 2015 Concord West Precinct Master Plan Flood Study (Reference 3), however this only covered the City of Canada Bay LGA.

2.2.1. 1998 Powells Creek Flood Study (Reference 1)

The 1998 Powells Creek Flood Study was undertaken under the NSW Government's Floodplain Management Program and used best practice techniques available at the time. A field survey was undertaken to provide approximately 100 cross sections of the creek channel as well as to collect historical flood height data. Some of the cross-section data have been used in the current study and the historical flood height data is provided in Section 2.10.

A comprehensive data search was undertaken including:

- a review of previous studies.
- interviews with residents.
- discussions with Council Officers.
- contact with SWC, the then Roads & Traffic Authority, the then State Rail Authority, the then Department of Land & Water Conservation and the UNSW.
- review of aerial photographs.
- provision of a questionnaire and review of all previous questionnaires.
- obtaining height and rainfall data from the stream and rainfall gauges operated by the UNSW and SWC.

An ILSAX hydrologic model of the entire Powells and Saleyards Creeks catchment was constructed using ILSAX files from some of the studies listed in Table 1. Inflows from ILSAX were then input into the 1D HEC-RAS hydraulic model which determined flood levels and velocities. Flood extents were not defined; however, this was subsequently undertaken using the peak levels and ALS for the Strathfield LGA.

The ILSAX model was calibrated to the events of 3rd February, 7th February, 10th February, 17th February and 18th March 1990 using rainfall from two pluviometers at St Sabina College and at the Elva Street gauge. Calibration to the Elva Street gauge for the January 1996 event could not be undertaken as the gauge malfunctioned. The results are summarised in the 2016 Powells

Creek Revised Flood Study (Reference 2).

The study concluded that accuracy of the design flood data depended upon several factors including.

- quality of the survey data.
- downstream boundary conditions.
- accuracy of design rainfall data.
- ability of the models to accurately represent the channel hydraulics.
- quantity and quality of available historical data.

The main factors affecting the accuracy of the design data were the ability of the models to simulate the channel hydraulics and the quantity and quality of the historical data. Based upon the above considerations the accuracy of the design flood levels was ±0.4 m. This could be improved if further calibration of the models to future flood events was undertaken.

2.2.2. 2016 Powells Creek Revised Flood Study (Reference 2)

This study provided a significant upgrade to the prior 1998 Powells Creek Flood Study (Reference 1). Its purpose was to define mainstream and overland (where there is no defined channel) flood behaviour under historical and existing floodplain conditions in the study area while addressing possible future variation in flood behaviour due to climate change and provide information for its management. The main features of this study compared to the prior 1998 study were:

- The same historical rainfall and flood data was relied upon as there had been no floods of significance since 1998.
- The modelling approach was similar, adopting flood frequency analysis of the historical flood record at the Elva Street gauge and incorporating a runoff routing approach to define flood levels, extents, and velocities across the entire Powells Creek catchment.
- The flood frequency analysis (based on the same flood record) was re-done using updated approaches which analysed several different distribution procedures.
- The 1998 study relied upon cross section data obtained from field survey to define the topography with the 2016 study relying upon Airborne Laser Scanning (ALS). ALS only became available since approximately the year 2000 and provides ground levels at approximately 1m spacing. It therefore provides a much more detailed and accurate definition of the topography, though cross section data was still used for definition of the lined channels.
- In the 1998 study a HEC-RAS 1 dimensional (1D) computer model based on cross section data was adopted as the hydraulic model to determine design flood levels. In the 2016 study the 2D TUFLOW hydraulic model was adopted which relied upon defining the topography using a 2m-by-2m grid based on the ALS data. This change represents a significant upgrade to the modelling approach as it ensures accurate consideration of both the temporary floodplain storage and conveyance characteristics of the catchment. It also ensures more accurate definition of flow paths, velocities, flood depths and flood extents across the entire floodplain, rather than just at cross sections as in the 1998 study.
- The ILSAX hydrologic model was adopted the 1998 study, and this was converted to a DRAINS hydrologic model for the 2016 study. However, as DRAINS uses the same basic hydrologic approach as ILSAX this change did not result in a significant change to the

inflows but was adopted as it allows more efficient and flexible incorporation of the flow hydrographs into TUFLOW.

- The 2016 study provided significantly improved definition of flood behaviour across the floodplain, including both overland and mainstream flooding. Maps were produced showing information on flood levels, depths, extents, velocities and flows for a range of flood events up to the probable maximum flood (PMF) events and included flood emergency response classification of communities and the sensitivity of flood behaviour to changes in flood producing rainfall events due to climate change (rainfall increase and sea level rise).

A comparison of the results from this study and the present study along the main channel of Powells Creek is provided in Table 31.

2.2.3. 2015 Concord West Precinct Master Plan Flood Study (Reference 3)

This study was initiated by the City of Canada Bay and several landowners, at the time of the proposed naturalisation of the lower parts of Powells Creek by SWC and proposed rezoning of several industrial lots. Jacobs were engaged to undertake a flood study and prepare a concept design for flood mitigation measures for the Master Plan. This study has not been adopted by the City of Canada Bay Council. The study area was defined as:

- Powells Creek from approximately Parramatta Road to Homebush Bay.
- Saleyards Creek from M4 Motorway to Powells Creek; and
- Strathfield Creek from 100m upstream of Ismay Avenue to Powells Creek.

The following were allowed for in the study, based on the design information available at the time, but have since been completed:

- North Strathfield Rail Underpass Project (NSRUP).
- Sydney Water Powells Creek naturalisation.
- Canada Bay Primary School Victoria Avenue Concord West.
- Filling of Powells Creek Reserve North Field; and
- Reconstruction of the west end of Victoria Avenue including drainage upgrade.

Several flood mitigation options were identified and assessed to mitigate flood impacts with the Master Plan. These options have not been discussed in this present report as it is a Flood Study and is therefore only concerned with determining design flood conditions based on the existing conditions at this time (2021). Mitigation options will be considered and investigated in any subsequent Floodplain Risk Management Study and Plan (refer Foreword and Section 1.5).

The study relied upon upstream inflow hydrographs on Powells Creek based on ILSAX from the 1998 Powells Creek Flood Study (Reference 1) and local inflow hydrographs from a DRAINS model incorporating the NSRUP works. It was not possible to undertake an independent calibration of the hydrologic model and the hydraulic model was only calibrated to the one available data point from the 10 February 1990 event (data point taken from Reference 1). The results from comparison of recorded overland peak depths with model depths are shown in Table 2.

Table 2: Comparison of TUFLOW Results to Observed Flood Depths (Reference 3)

Location	Year of Observation	Observed Depth (m)	Modelled Depth (m)	Difference (m)
20 Brussels St	1990	0.5	0.6	0.1
17 Lorraine Ave	2012	0.3	0.18	-0.12
20 Lorraine Ave	2011	0.3	0.34	0.04
30 King St	1985	0.75	0.84	0.09
38 King St	1986?	0.75	0.66	-0.09
40 King St	1988	0.75	0.49	-0.26
End of Victoria Ave	2013	0.3	0.31	0.01

A detailed review of the results from Reference 3 has not been undertaken as the modelling approach along Powells Creek has been superseded by the results from the 2016 Powells Creek Revised Flood Study (Reference 2).

2.3. Data Sources

Data utilised in the present study has been sourced from a variety of organisations. Table 3 lists the type of data and where it has been sourced.

Table 3: Data Sources

Type of Data	Format Provided (Source)	Format Stored
Location, description and invert depths of pits, pipes and trunk drainage network	GIS (Councils)	DRAINS and TUFLOW models
Ground levels from ALS data	GIS (Councils and ELVIS)	GIS and TUFLOW model
Detailed survey data	GIS (Councils)	GIS and TUFLOW model
GIS information (cadastre, drainage pipe layout)	GIS (Councils)	GIS and TUFLOW model
Design rainfall	ARR2019 and Datahub	DRAINS
Recorded flood data	Observation by Councils, Sydney Water, and previous reports	Report

2.4. Topographic Data

ALS or LiDAR survey of the catchment and its immediate surroundings was provided for the study by SWC and SMC but was updated where more recent data was available from ELVIS. These data typically have accuracy in the order of:

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

The accuracy of the ALS data can be influenced by the presence of open water or vegetation (tree or shrub canopy) at the time of the survey. From this data, a Triangular Irregular Network (TIN) was generated as part of this study. This TIN was sampled at a regular spacing of 1 m by 1 m to create a Digital Elevation Model (DEM), which formed the basis of the two-dimensional hydraulic modelling for the study.

2.5. Structure Survey

All bridges and structures within the open channel extent of the study area were inspected in May 2014 as part of Reference 2. Survey data collected as part of Reference 1 were used to define the structures. Photographs on Figure 4 provide a descriptive overview of the key characteristics of the open channel system.

2.6. Floor Level Survey

Floor level data are used to determine flood damages estimates (see Section 11). Given the large catchment area and number of flood affected properties, theodolite-based survey of all properties was not financially feasible. Details of how building floor levels were estimated are presented below:

- No surveyed floor levels data were available from previous studies.
- Floor level estimation was undertaken by WMAwater for approximately 700 properties for the properties inundated in the 1% AEP event.
- The floor levels were estimated based on the ground level at the front door obtained by ALS plus the height of the floor above the ground (by counting bricks etc.).
- The height of the floor levels above the ground were estimated by visual inspection based on analysis of available digital imagery (Google Street View).

2.7. Rainfall Data

2.7.1. Overview

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

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

- 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. Many gauges fail during periods of heavy rainfall and records of large events are often lost or misrepresented.
- Daily read information is usually obtained at 9:00 am in the morning. Thus, if a single storm is experienced both before and after 9:00 am, then the rainfall is "split" between two days of record and a large single day total cannot be identified.
- In the past, rainfall over weekends was often erroneously accumulated and recorded as a combined Monday 9:00 am reading.
- The duration of intense rainfall required to produce overland flooding in the study area is

typically less than 4 hours (though this rainfall may be contained within a longer period of rainfall). This is termed the “critical storm duration”. For a larger catchment (such as the Parramatta River) the critical storm duration may be greater (say 12 hours). For the study area a short intense period of rainfall can produce flooding but if the rain stops quickly, the daily rainfall total may not necessarily reflect the magnitude of the intensity and subsequent flooding. Alternatively, the rainfall may be relatively consistent throughout the day, producing a large total but only minor flooding.

- Rainfall records can frequently have “gaps” ranging from a few days to several weeks or even years.
- Pluviometer (continuous) records provide a much greater insight into the intensity (depth vs. time) of rainfall events and have the advantage that the data can generally be analysed electronically. This data has much fewer limitations than daily read data. However, pluviometers can also fail during storm events due to the extreme weather conditions.
- Rainfall events which cause overland flooding (as opposed to mainstream flooding) in the Powells Creek catchment are usually localised and as such are only accurately represented by a nearby gauge. Gauges sited even only a kilometre away can show very different intensities and total rainfall depths.

2.7.2. Rainfall Stations

There are several daily read rainfall stations within the catchment and surrounding area. Data were not collected from these stations as more suitable data were available from six pluviometers (Table 4). The two UNSW pluviometers have operated since approximately 1977 but the dates shown in Table 4 are the periods for which digital data are available. No correction has been made in the digital records for the UNSW gauges to account for errors in the clock speed. Thus, the time of the recorded rainfall can be out by several hours. This has not been corrected for in this report; however, Reference 8 provides an approach that can be used.

Table 4: Pluviometers

Gauge No.	Operator	Operating Period	Location
566005	UNSW	Mar 1981 to Feb 1996 (period when digital records available)	St Sabina College (Russell Street, The Boulevarde)
566004	UNSW	Dec 1980 to June 1993 (period when digital records available)	Stream gauge at Elva Street/Beresford Road
566022	SWC	May 1969 to August 1983, July 1990 to Present	Homebush Bowling Club (Pomeroy Street)
566020	SWC	Oct 1958 to Present	Enfield (Belfield Bowling Club - Margaret Street)
566036	SWC	February 1970 to Present	Potts Hill Reservoir
566064	SWC	June 1988 to Present	Concord (Western Suburbs Club).

2.7.3. Analysis of Pluviometer Data

Rainfall data were collected from some of the available pluviometers for the significant flood events with the peak bursts provided in Table 5 and Figure 9. An estimate of the rainfall frequency for each event can be obtained from comparison with the design rainfalls (Table 6).

Table 5: Historical Rainfall - Maximum Rainfall Depths (mm)

	Duration						
	5 or 6 min	10 min	20 min	30 min	60 min	90 min	120 min
			2nd January 1996:				
Homebush	15	23	36	44	52	54	58
Enfield	17	25	45	57	81	83	88
Potts Hill	11	17	31	42	49	52	54
Concord	7	11	21	30	46	49	52
Elva Street	Instrument Failed						
St Sabina	11	22	37	50	64	n/a	71
			8th February 1992:				
Homebush	Instrument Failed						
Enfield	4	6	10	13	22	28	33
Elva Street	Instrument Failed						
St Sabina	2	5	6	11	16	n/a	n/a
			11th March 1991:				
Homebush	No Significant Rain						
Enfield	13	19	34	37	-	-	-
Potts Hill	11	18	33	35	-	-	-
Concord	10	16	24	24	-	-	-
Elva Street	Instrument Failed						
St Sabina	Instrument Failed						
			18th March 1990:				
Elva Street	20	34	41	44	45	47	50
St Sabina	8	23	26	31	36	43	46
			10th February 1990:				
Homebush	Gauge Not in Operation						
Enfield	11	15	23	26	40	45	50
Potts Hill	12	19	31	36	44	48	52
Concord	7	11	17	25	31	33	38
Elva Street	9	13	22	28	39	n/a	50
St Sabina	6	11	21	31	42	n/a	52
			4-6th August 1986:				
Homebush	Gauge Not in Operation						
Enfield	12	17	27	36	50	59	64
Potts Hill	11	16	27	37	52	60	64
Concord	Gauge Not in Operation						
Elva Street	10	13	17	21			
St Sabina	Very Little Rain						

Note: Data for January 1989 are not shown as the Enfield pluviometer record indicated no significant rainfall events. Data from other pluviometers may be available but were not collected.

2.8. Design Rainfall

Design rainfall intensities for the study area were taken at Pomeroy Street based on procedures in ARR2019 (Reference 5) and are provided in Table 6.

Table 6: ARR2019 Design Rainfall Depths at Pomeroy Street (mm)

	Duration							
Event	15 min	30 min	60 min	90 min	120 min	180 min	360 min	720 min
1 EY	15	22	26	29	34	37	40	46
20% AEP	21	30	35	39	45	49	54	61
10% AEP	27	38	43	49	56	62	68	77
5% AEP	31	43	49	56	64	71	77	88
2% AEP	34	47	54	61	71	78	85	97
1% AEP	40	55	63	71	83	92	100	113
0.5% AEP	52	73	85	97	114	127	138	155
0.2% AEP	69	77	102	120	139	165	186	227
PMP	-	220	326	372	416	-	-	-

Probable Maximum Precipitation (PMP) design rainfall depths were calculated using the 2003 BoM Generalised Short Duration Method (Reference 9) for durations up to 6 hours.

Areal variation of the design rainfalls across the entire Powells Creek catchment was considered but was not adopted as the variation is small (a few percent) and therefore could not be justified.

2.9. Water Level Gauges

2.9.1. UNSW (Elva Street Gauge)

Flood levels have been recorded continuously from September 1958 until 2010 at the Elva Street gauge (Photo 1). Apart from this gauge there are no other long-term flood records for the catchment. SWC operated a gauge on Powells Creek (under the M4), but records are only available from October 1995.

Photo 1: Powells Creek water level gauge at Elva Street

At the time of completion of the 1998 Powells Creek Flood Study (Reference 1) only a limited amount of water level and rainfall data were available from the UNSW as only parts of the historical records were digitised, or quality checked.

Subsequently the entire water level and pluviometer record (both at St Sabina and at Elva Street) have been digitised and a rating table adopted to assign flows to the recorded levels. However, there are many gaps in the digital record, and this means that the record is only complete to November 1997. The digital record has also not been corrected for timing errors and no error correction has been undertaken for this study.

A summary of the water level data is provided on Figure 6 and below indicates the number of days where the water level has exceeded a threshold (1958 to November 1997).

- >3m - 1 day.
- >2.5m - 3 days.
- >2m - 6 days.
- >1.5m - 31 days.
- >1m - 116 days.

The coping of the channel is approximately 3m above the invert and thus only one event (February 1959) has exceeded the capacity of the channel in approximately 62 years of record (1958 to 2020). A review of Figure 6 indicates that since 1974 (46 years) no event has exceeded 2m on the gauge but 5 events did in the period from 1958 to 1974. Unfortunately, this means that calibration can only be undertaken on events smaller than 2m gauge height as the two UNSW pluviometers were not in operation until 1980.

Reference 1 included Table 7 which listed the largest events recorded on the UNSW gauge above 2.0 m. These height data were obtained from inspection of the gauge charts or estimated from debris (Reference 8). The corresponding digital records are shown alongside in Table 7.

Table 7: UNSW Gauge at Elva Street - Major Floods (> 2.0 m) taken from Reference 2

Rank	Year	Date	Gauge Height (m)	Peak Level (m AHD)	Gauge Height (m) from Digital Record
1	1961	18 Nov	4.18 *	9.43	**No Record**
2	1964	10 Jun	3.52 *	8.77	**1.8**
3	1959	18 Feb	3.29 *	8.54	**3.26**
4	1972	29 Oct	3.20	8.45	**0.9**
5	1970	9 Dec	3.09	8.34	**Gauge failed**
6	1963	13 Dec	2.40	7.65	**2.47**
7	1973	9 Apr	2.35	7.60	**0.7**
8	1974	25 May	2.34	7.59	**2.23**

* Estimated from debris.
Gauge zero is RL 5.25 m AHD.

A limited number of gaugings (height v velocity measurements) have been undertaken enabling the construction of a rating curve (height versus flow). Whilst in theory this approach appears very simple it becomes complex for several reasons, including:

- the events occur within a few hours and thus it was very hard for the UNSW staff to get to the gauge whilst a flood was in progress.
- the above means that there are several low flow gaugings but very few high flow gaugings which are more relevant for use in a flood study.
- a gauging was taken by the UNSW at high flows which produced velocities above the rating of the instrument (say above 5 m/s). Thus, even this gauging could not confidently determine the peak flow.

Rating curves from various sources are provided on Figure 7.

2.9.2. Sydney Water Gauge

This gauge, which is located on Powells Creek under the M4, has only recorded one significant flood (January 1996) since it was installed in 1995. The gauge zero is RL 2.15 m AHD and the January 1996 flood peaked at 2.04 m (4.19 m AHD) at 14:05 hours. Three streamflow gaugings have been undertaken. All gaugings are below 0.1 m gauge height (flow <2 m^3/s). Extrapolation of the rating curve based on these data is not appropriate and as a result flow data from this gauge have not been used for calibration of the hydrologic model.

2.10. Flood Levels from Debris or Other Marks

2.10.1. Resident Interviews

As part of the 1998 Powells Creek Flood Study (Reference 1) and earlier studies (refer Table 1) questionnaires were distributed to residents to collect information about past flood events. Prior to the 1998 Powells Creek Flood Study the responses were generally concerned with drainage issues (blocked pits, minor overland flow) and not with identifying historical flood levels. The only exception to this was at Airey Park (Saleyards Creek) for the January 1996 event.

Data obtained from residents should be used with caution for several reasons, including:

- residents may have only been in the study area for a short period.
- residents may have “missed” a flood whilst they were away.
- the more recent events are remembered more clearly than (say) a larger event several years ago.
- some events noted by residents may be because of a blocked drain or other local factors and are more typically referred to as local drainage problems rather than flood related.
- residents can easily forget the date of a flood or become confused about the extent and nature of the problem. Experience has shown that water entering a house may have resulted from a leak in the gutter or a local drainage problem in the yard rather than overbank flow from the main creek.

Table 8 provides the most widely remembered events obtained from the results of the 1998 Powells Creek Flood Study (Reference 1) and previous questionnaire surveys. Note the questionnaire surveys were not provided to Canada Bay residents.

Table 8: Significant Floods Obtained from 1998 Flood Study Questionnaire

Approximate Date	Comment
? 1930's	Infrequently mentioned.
1943	Infrequently mentioned.
18 February 1959	Infrequently mentioned.
? 1960's	Infrequently mentioned.
November 1961	Infrequently mentioned.
? 1964	Infrequently mentioned.
? 1973	Infrequently mentioned.
August 1986	Appears to be the largest event in the last 30 years
March/April and July 1988	Infrequently mentioned.
January 1989	Widely remembered.
February 1990	Widely remembered, larger than 1996 in Saleyards Creek
March 1990	Infrequently mentioned.
April 1990	Infrequently mentioned.
March 1991	Widely remembered.
2 December 1992	Infrequently mentioned.
February 1995	Infrequently mentioned.
October 1995	Infrequently mentioned.
June 1995	Infrequently mentioned.
December 1995	Infrequently mentioned.

Table 8 indicates that 50% of the most widely remembered events are in the 1990's. This could suggest that flooding in the 1990's has been a major issue compared to other periods. This is unlikely to be the case, and merely reflects some of the points noted previously regarding obtaining data from residents. Clearly the gauge record (Figure 6) indicates the period from 1958 to 1974 had more large floods.

As part of the 1998 Powells Creek Flood Study (Reference 1) 125 questionnaires were returned out of approximately 800 hand delivered or mailed (to non-resident owners) with some followed up by telephone or field interview. Table 9 summarises the results from this survey.

Table 9: 1998 Flood Study Questionnaire Results

Total number of questionnaires returned (Note SMC LGA only)	125 (approx.15%)
Number who responded indicating that their property had been inundated by a water depth greater than 100 mm.	60 (49%)
Number not inundated.	65 (52%)
Number who could indicate a historical flood level.	39 (31%)
Number of buildings inundated above floor level*.	6 (5%)

Note: * Previous questionnaire surveys have indicated that other buildings have been inundated above floor level.

A questionnaire was distributed as part of the 2016 Powells Creek Revised Flood Study (Reference 2) with several responses identifying recent occurrences of flooding. The reported flooding was generally less than 0.1 m and would be considered nuisance flooding and has only been for general verification of model results. Further details of prior community consultation are given in Section 2.12.

2.10.2. Surveyed Flood Levels

Several historical flood levels were collected from field interviews as part of the 1998 Powells Creek Flood Study (Reference 1). Many levels were for either the January 1996 or the February 1990 events. These are shown in Table 10 and on Figure 8.

Table 10: Historical Flood Data from Field Interviews in August 1997 as part of Reference 1

Address	Date of Flood	Depth (m)	Description	Flood Level (m AHD)
No. 21 Llandilo Avenue	Approx 1990	0.05-0.08	Garage Floor Level	29.96
	Approx. 1990	0.8	North-West Corner	28.8
No. 8 Agnes Street	Jan-96	0.1	Driveway and Front Boundary	26.71
No. 41 Albyn Road	Jan-96	0.08	Crest of Driveway	22.54
	Jan-96	0.35	Low Point along West. Boundary	21.64
No. 47 Albyn Road	Jan-96	0.25	Garage Floor Level	21.18
No. 35 Redmyre Road	Jan-96	0.05-0.1	Crest of Driveway	13.26
	Jan-96	0.5	Ground Level at Back Fence	12.13
No. 37 Redmyre Road	Jan-96	0.05-0.1	Crest of Driveway	13.27
	Jan-96	0.3	Ground Level at Garage	12.21
No. 45 Churchill Avenue	Jan-96	0.1	Base Steps at Front House	10.74
No. 60 Churchill Avenue	Jan-96	0.2	Ground Level at Path Granny Flat	11.49
No. 66 Churchill Avenue	18th February 1959	0.3	Floor Level	12.06
Upstream Railway crossing near Elva Street	Unknown		Top coping LHS looking Downstream	8.1
			Top coping RHS looking Downstream	7.83
Pharmacy adjoining Plaza Entrance, The Boulevarde	Jan-96		Floor Level - water entered shop	12.29
No. 11 The Boulevarde (Gumbleys Butchery - now gone)	Nov-61	0.3	Estimated Floor Level	12.55
No. 26 Barker Road	Regularly	0.1	Drive at Boundary	25.83
No. 65 Oxford Street	Jan-96	0.45	Carport Slab	24.16
No. 63 Oxford Street	Jan-96	0.3	South-West corner of house	23.75
No. 61 Oxford Street	Jan-96	0.5	Garage Floor Level	23.24
No. 59 Oxford Street	Jan-96	-	Patio Level	23.14
No. 141 Albert Street	Approx. 1990	0.3	Ground level along eastern fence	19.51

Address	Date of Flood	Depth (m)	Description	Flood Level (m AHD)
No. 135 Albert Street	Approx. 1990	0.5	Bottom steps rear of house	18.49
No. 137 Albert Street	Feb-90	-	Crest of driveway	19.24
	Feb-90	-	Water reached floor level	19.01
No. 100 Beresford Road	Feb-90	0.1	Driveway at entrance to house	15.91
No. 102 Beresford Road	Feb-90	0.12	Ground level at back door	16.43
No. 104 Beresford Road	Feb-90	0.55	Ground level rear house	17
No. 110 Beresford Road	Feb-90	0.35	Midway along eastern fence	17.5
No. 53 Beresford Road	Feb-90	0.05	Garage floor level	15.29
No. 108 Beresford Road	Feb-90	0.34	Base steps rear house	17.49
No. 89 Rochester Street	Feb-90	0.1	Floor level shop	12.84
No. 107 Rochester Street	Jan-89	0.45	GL at rear of house	14.12
No. 109 Rochester Street	Feb-90	0.42	Base steps rear house	14.33
	Jan-96	0.24	Base steps rear house	14.15
No. 57 Rochester Street	Jan-96	0.41	Ground level back yard	9.92
No. 28 Broughton Road	Approx. 1992	0.24	North east corner of house	12.88
No. 33-35 Burlington Road	1989	0.3	Garage Floor Level	9.14
No. 38-46 Burlington Road (Hairdresser)	Feb-90	0.48	Ground level at rear shed	9.71
No. 48 Burlington Road	Jan-96	0.1	Ground Floor Level	9.55
No. 29 Burlington Road	Feb-90	-	Stormwater reached this level at rear of factory	9.16
No. 30 The Crescent (Unit No. 2)	Jan-96	0.4	Garage Floor Level	8.7
No. 31 The Crescent	Jan-96	0.2	Garage Floor Level	8.33
No. 79 The Crescent	Feb-90	0.3	Floor level	8.2
	Jan-96	0.28	Base patio at rear	7.75
No. 12 Loftus Crescent	Feb-90	0.15	Ground level backyard	7.87
No. 82 Underwood Road	Feb-90	0.45	Ground level at front house and driveway	4.97
No. 86 Underwood Road	Jan-96	0.3	Base steps front house	4.89
No. 90 Underwood Road	Jan-96	0.16	Base steps front of house	4.74
No. 22 Ismay Avenue	Approx. 1986	0.3	Ground at back fence	2.2
No. 34 Ismay Avenue	Jan-90	0.35	Path at back door	2.57
No. 60 Ismay Avenue	Jan-96	0.1	Ground level at front of house	3.83
No. 55 Ismay Avenue	Feb-90	0.37	Base front steps	4.3
	Jan-96	0.18	Base front steps	4.11
No. 51 Ismay Avenue	Feb-90	0.3	Base front steps	4.19

Address	Date of Flood	Depth (m)	Description	Flood Level (m AHD)
No. 56 Ismay Avenue	Feb-90	0.2	Base front steps	3.83
No. 49 Ismay Avenue	Jan-96	0.22	Base front steps	4.16
No. 48 Ismay Avenue	Jan-96	0.15	Base front steps	3.43
No. 41 Ismay Avenue	Feb-90	0.14	Base front steps	3.71
	Jan-96	0.07	Base front steps	3.64
No. 17 Pemberton Street	1992	0.4	Ground level backyard	16.95
No. 27 Pemberton Street	1992	0.17	Base steps rear house	18.72
No. 10 Mitchell Road	Jan-96	0.28	Ground level low side house	14.75
No. 6 Mitchell Road	Jan-96	0.24	Ground level low side house	14.35
No. 104 Arthur Street	Jan-96	0.27	Ground level front of house	13.87
No.106 Arthur Street	Jan-96	0.34	Ground level at boundary	13.85
No. 105 Arthur Street	Jan-96	0.55	Ground level at house steps side house	13.89
No. 29 Arthur Street	Jan-96	0.16	Base front steps	13.23
	Jan-96	0.4-0.5	Ground level at rear fence	12.98
No. 6 Kessell Avenue	Jan-96	0.44	Ground level at fence	7.76
	Feb-90	-	Water reached floor level	8.42
Airey Park Photos	Jan-96	0.75	Base wall No. 77	7.65

2.10.3. Sydney Water Data

SWC holds records of flooding on Powells Creek and the relevant information is provided in Table 11. These records show no instances of flooding in 1990 and only one record (Feb 1996) since 1988.

Table 11: Sydney Water Records of Flooding in the Powells Creek Catchment

Date Flooded From	Address	Depth (m)	Level Above Floor (m)	Level Above Coping (m)	Property Inundation	Comments
?/07/1952	135 Albert Road, Strathfield				Y	Flooding due to construction activity-water supply. Loss of goods.
6/05/1953	Lot 3, Allen St, Homebush					Flooding occurred where Council's bridge restricts the flow
6/05/1953	4-6 Elva St, Strathfield					Flooding occurred where the channel is deficient in capacity
6/05/1953	36 Minna St, Burwood					Flooding occurred where the channel & Council's subsidiary drainage works are deficient
6/05/1953	Lot 2 Bates St, Homebush (cnr The Crescent)					Flood waters crossed the road where Council's culvert is deficient in capacity
6/05/1953	103 Parramatta Rd, Strathfield					Flooding occurred where the channel is covered at coping level.
9/02/1956	8-10 Elva St, Strathfield			0.45	Y	At the future gauging site

Date Flooded From	Address	Depth (m)	Level Above Floor (m)	Level Above Coping (m)	Property Inundation	Comments
9/03/1958	2A Belgrave St, Burwood	0.37				Flooding of road only?
9/03/1958	4-6 Elva St, Strathfield			0.75		Flooding
9/03/1958	9 Bold St, Burwood (Minna St, Burwood - west of its intersection with Bold St)	0.53			Y	Water banked up to a max. of 0.53m deep against the northern fence of Minna St.
9/03/1958	33 Nicholson St, Burwood	0.1				Flooding of road only?
9/03/1958	20 Woodside Ave, Burwood	0.15				Flooding of road only?
9/03/1958	36A Nicholson St, Burwood	0.05			Y	Water (0.05) deep northern side Nicholson St & sewer surcharge in No. 6A
9/03/1958	24 The Boulevard, Strathfield	0.6			Y	Flood entered the shop and damaged the stock- insufficient inlets
17/02/1959	5 Bold St, Burwood		0.45		Y	Flooding occurred above garage floor level at rear of house, but 0.65m below floor level of house
17/02/1959	7 Bold St, Burwood		0.56		Y	Flooding occurred above garage floor level at rear of house, but .28m below floor level of house
18/02/1959	4-6 Elva St, Strathfield			1.14	Y	1.14m above the coping level of the Stormwater channel at Gauging Station. Floodwater entered the Elva Street and carried some of the timbers away
18/02/1959	2 Elva Street, Strathfield			1.24	Y	
18/02/1959	58 Churchill Avenue		1.5		Y	1.5 m above the kitchen floor. No damage was reported and the kitchen floor is considerably lower than the back yard.
18/02/1959	66 Churchill Avenue		0.3		Y	0.3 m above the floor. Water coming from Redmyre Road has swept through the house and damaged carpets and furniture. Many premises had been flooded.
18/02/1959	27 Minna St, Burwood	0.84			Y	Flooding occurred above the yard level at N/W corner of house but was 0.35m below floor level of house
30/10/1959	7 Bold St, Burwood					Slight flooding only. Flood water rose to 0.30m above footpath level, no houses flooded
17/11/1961	53 Ismay Ave, Homebush				Y	Flooding of homes reported.
19/11/1961	19 Oxford St, Burwood		0.15		Y	Above floor flooding
19/11/1961	21 Morwick St, Strathfield		0.3		Y	Above floor flooding
19/11/1961	26 Morwick St, Strathfield		0.025		Y	New block of home units, water rose to within .025m of floor level & 0.38m above laundry floor.
19/11/1961	41 Woodside Ave, Burwood				Y	Brick fence along the frontage collapsed
19/11/1961	19 Oxford St, Burwood		0.15		Y	Above floor flooding
19/11/1961	62/64 Oxford St, Burwood				Y	Extensive damage to fencing & back gardens

Date Flooded From	Address	Depth (m)	Level Above Floor (m)	Level Above Coping (m)	Property Inundation	Comments
19/11/1961	4-6 Elva St, Strathfield		0.87		Y	Harrisons Timber P/L flooded. Damage to motors & furniture.
19/11/1961	8-10 Elva Street				Y	Flood water was just below the floor level. Garden was ruined. Photos available
19/11/1961	7 Bold St, Burwood.				Y	Severe flooding. Flood water rose to 0.75m above footpath level on North side of Minna St - 19th 4.00 a.m. The water was held back by the side palings of the house No.7 Bold Street but eventually found an outlet through No. 27 Minna Street.
19/11/1961	27 Minna Street				Y	Water rose .1m below the floor level of the rear house
19/11/1961	35 Nicholson Street	0.73			Y	Water level was 0.73 m above ground level and .3 m below the floor level.
19/11/1961	11 The Boulevarde (Gumbleys Butchery), Strathfield.		0.3		Y	Water entered several shops & rose to about 0.30m above floor in Gumbleys Butchery at No. 11
19/11/1961	2 Elva St, Strathfield (U/S main Western Railway Line)					Considerable damage done along route of main channel. S/water unable to reach underground drains flowed over ground surface to low lying areas & followed course of original creek downstream.
7/05/1963	2 Elva Street, Strathfield			0.6	Y	Observed at 8.15am. High tide at 7.15 am= 1.4m?
20/12/1963	12, 13, 14, 15, 16 & 17 Brunswick St, Strathfield				Y	Flooding of roadway & front yards did not enter premises. Date of rain- not clear
20/12/1963	2 Elva St, Strathfield, (Railway viaduct on Main Western Line)			0.75	Y	No apparent damage to properties.
9/06/1964	2 Elva St, Strathfield - Sydney Night Patrol			1.52	Y	Flooding caused by culvert under railway + 2 curves immediately upstream. Property flooding = .9m above ground
11/06/1964	2 Elva St, Strathfield - Sydney Night Patrol			0.46	Y	Flooding caused by culvert under railway + 2 curves immediately upstream.
15/04/1969	177 Parramatta Rd, Homebush				Y	A brick retaining wall collapsed at Saleyards Ck Bch. Poor foundation
29/10/1972	2 Elva St, Strathfield - Sydney Night Patrol				Y	Water rose to 1.22m above brickwork recently added to walls within this property. Vehicles were submerged & a wooden bridge lifted & dumped 9m downstream.
29/10/1972	11 Pilgrim Avenue				Y	Basement of a block of home units was flooded by approximately 1 metre.
29/10/1972	2 Elva St, Strathfield (Railway Culvert under the Main Western Line)					Embankment surcharged - see photo
17/03/1983	167-173 Parramatta Road, Homebush	0.3			Y	Flood level 300 mm above footpath. Above floor flood in one work-shop-150mm
8/11/1984	7-9 Underwood Road, Homebush			0.6	Y	Debris mark on the fence
8/11/1984	Lot 2 Bates St, Strathfield (cnr The Crescent, Railway Culvert upstream)			0.6	Y	Debris on the embankment

Date Flooded From	Address	Depth (m)	Level Above Floor (m)	Level Above Coping (m)	Property Inundation	Comments
29/04/1988	53 Ismay St, Homebush				Y	Surface flooding of 5 houses in Ismay Ave & overland flow at Powell St.
29/04/1988	Flemington Markets, Parramatta Rd, Homebush					Channel overflowed near markets.
29/04/1988	Lot 2 Bates St, Homebush (U/S of The Crescent, Homebush)			0.3	Y	Was contained within the banks. Flood debris 800 mm above the ground at upstream railway line culvert
7/05/1988	32 The Crescent, Homebush				Y	Above floor flooding. Damage $10,000
2/02/1996	Lot C Allen St, Nth Strathfield					Debris on adjacent fences indicated water flowed 500mm above upstream headwall. Flooding confined to adjacent park.
2/02/1996	24 Pomeroy St, Strathfield			0.3	Y	

2.11. Flood Photographs

Several flood photographs taken during floods were provided by SMC (all these are within the Strathfield LGA) and these are shown on Figure 5. Canada Bay Council provided two flood photographs as shown on Photo 2.

Photo 2: Flood Photographs provided by Canada Bay Council

2.12. Community Consultation

2.12.1. Consultation Undertaken Prior to the Present Study

Community consultation was undertaken as part of the 2016 Powells Creek Revised Flood Study (Reference 2) to inform the community about the study and gather information on historical flood events. A one-page newsletter detailing the study's purpose was sent to approximately 300 addresses in the study area which excluded Burwood and Canada Bay LGA.

From the questionnaire, twelve responses were received, constituting a response-rate of around 5%. The results from the questionnaires are as follows:

- All responses were from residential properties, with most having lived there for more than 15 years.

- 7 respondents had experienced flooding, with all instances involving water above floor level of the house or other buildings.
- Approximately 9 events in the last 20 years were identified as causing flooding, with flooding reported in 1995, 1996, 1998, 2005, 2010, three times in 2014 and 2015. However, most events had only one reported instance of flooding, and apart from a 0.3 m depth reported for 1995, all depths were 0.2 m or less. No event was consistently mentioned in the responses which suggests that some variation in flood behaviour occurred between similar events, for example due to pit or pipe blockage, location of the rainfall burst or localised effects on flow behaviour.

Figure 8 shows the location of the respondents, alongside the previous consultation and the Sydney Water historical data.

2.12.2. Public Consultation as Part of the Present Study

The Draft Flood Study was placed on public exhibition in May and June 2022 with Council advising residents via the following means.

- Letters informing residents of the public exhibition period together with a list of “frequently asked questions”.
- Draft reports provided in Five Dock and Concord libraries and the Civic Centre reception.
- Details on Council’s web site.

Ten respondents contacted Council and WMAwater. The key issue was asking for details why their property was tagged as being within the flood planning area when they had lived in the area for many years and had not experienced flooding. These and other issues were responded by Council and WMAwater. No changes were made to the report.

3. APPROACH

The approach adopted in flood studies to determine design flood levels largely depends upon the objectives of the study and the quantity and quality of the data (survey, flood, rainfall, flow etc.). Whilst there is a limited flood record from the Elva Street gauge there is no extensive historical flood record elsewhere on Powells Creek or on Saleyards Creek. A flood frequency approach can be undertaken at the Elva Street gauge. However, reliance must also be made on the use of design rainfalls and establishment of a hydrologic/hydraulic modelling system to determine design flood levels away from the gauge. A diagrammatic representation of the flood study process undertaken in this manner is shown on Diagram 2.

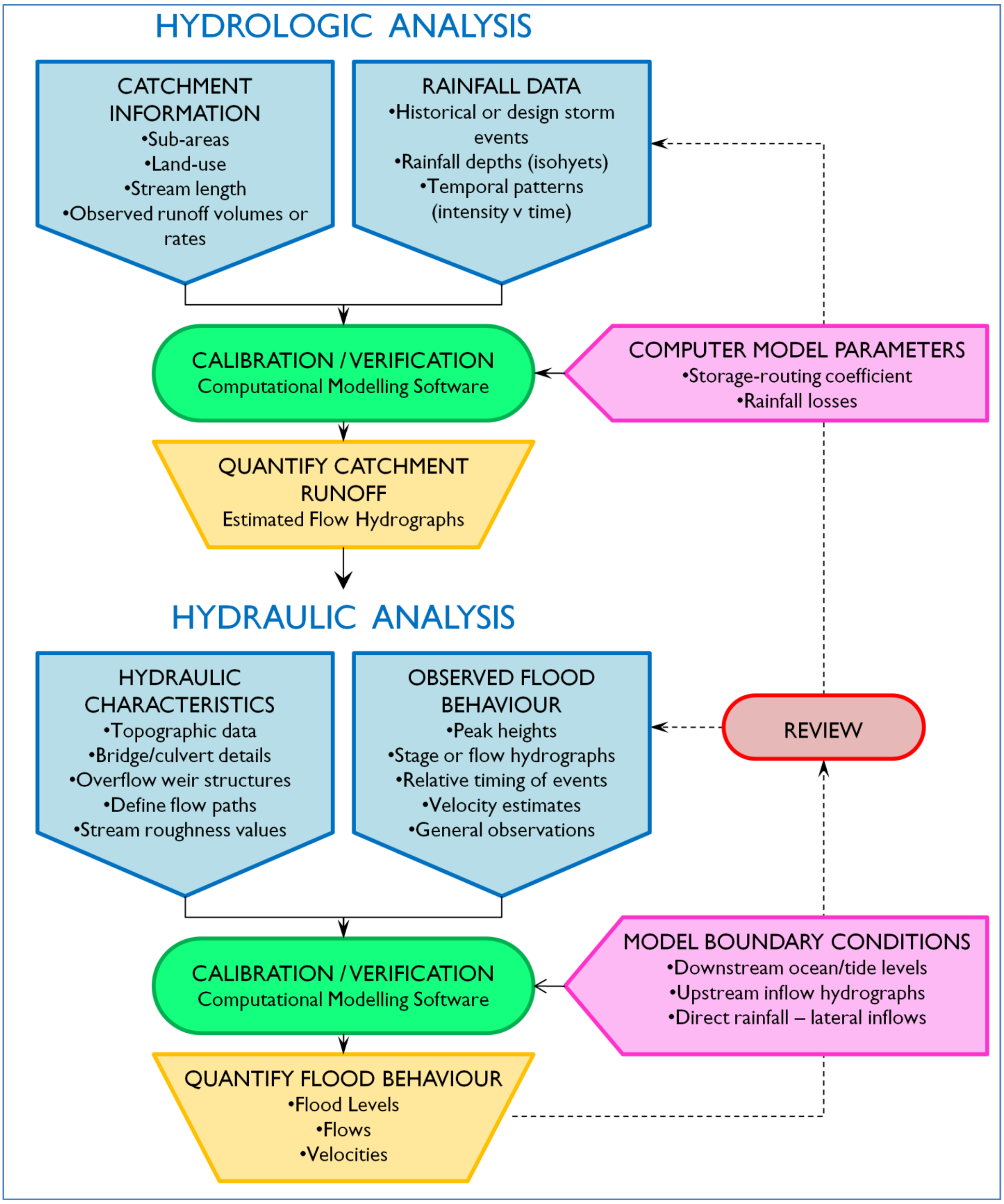


Diagram 2: Flood Study Process

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

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

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

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

The use of a flood frequency approach for the estimation of design floods and/or independent calibration of the hydrologic model is possible for the Powells Creek catchment using the Elva Street water level gauge data.

The broad approach adopted for this study was to use a widely utilised and well-regarded hydrologic model to conceptually model the rainfall concentration phase (including runoff from roof drainage systems, gutters, etc.). The hydrologic model (DRAINS - Reference 5) used design rainfall patterns specified in ARR2019 (Reference 5) and the runoff hydrographs were then used in a hydraulic model (TUFLOW - Reference 10) to estimate flood depths, extents, velocities and hazard in the study area.

The sub-catchments in the hydrologic model were kept small such that the overland flow behaviour for the study area was generally defined by the hydraulic model. This joint modelling approach was then verified against previous studies and historical data where possible.

3.1. Hydrologic Model

Inflow hydrographs are required as inputs at the boundaries of the hydraulic model. Typically, in flood studies a rainfall-runoff hydrologic model (converts rainfall to runoff) is used to provide these inflows. A range of runoff routing hydrologic models is available as described in ARR2019 (Reference 5). These models allow the rainfall depth to vary both spatially and temporarily over the catchment and readily lend themselves to calibration against recorded data.

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

Runoff hydrographs for each sub-catchment area are calculated using the time area method and the conveyance of flow through the drainage system is then modelled using the Hydraulic Grade Line method. DRAINS is limited to development of hydrological inputs into the downstream TUFLOW model and is not used to determine flood levels.

3.2. Hydraulic Model

The availability of high-quality LiDAR/ALS data means that the study area is suitable for two-dimensional (2D) hydraulic modelling. Various 2D software packages are available and the TUFLOW package (Reference 10) was adopted as it is widely used in Australia.

The TUFLOW software is produced by BMT WBM and has been widely used for a range of similar projects. The model is capable of dynamically simulating complex overland flow regimes. It is especially applicable to the hydraulic analysis of flooding in urban areas which is typically characterised by short duration events and a combination of supercritical and subcritical flow behaviour.

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

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

- provide localised detail of any topographic and/or structural features that may influence flood behaviour.
- better facilitate the identification of the potential overland flow paths and flood problem areas.
- dynamically models the interaction between hydraulic structures such as culverts and complex overland flow paths; and
- inherently represent the available floodplain storage within the 2D model geometry.

Importantly, a 2D hydraulic model can better define the spatial variations in flood behaviour across the study area. Information such as flow velocity, flood levels and hydraulic hazard can be readily mapped across the model extent. This information can then be easily integrated into a GIS based environment enabling the outcomes to be readily incorporated into planning activities. The model developed for the present study provides a flexible modelling platform to properly assess the impacts of any overland flow management strategies within the floodplain as part of the ongoing floodplain management process.

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

3.3. Australian Rainfall and Runoff 2019

ARR2019 (Reference 5) has introduced many changes to the data and methodology used on flood studies compared to ARR1987 (Reference 4).

3.3.1. Overview

The ARR guidelines were updated in 2019 due to the availability of numerous technological developments, a significantly larger rainfall dataset since the previous edition in 1987 and development of updated methodologies. The rainfall dataset includes a larger number of rainfall gauges which continuously recorded rainfall (pluviometers) and a longer record of storms (events from 1985 to 2015 are included).

This study updates the flood study of the entire Powells Creek catchment in accordance with the ARR2019 methodologies.

3.3.2. ARR2019 – Design Rainfall Update

Three major changes have been made to the approach adopted in ARR1987 (Reference 4) in ARR2019 (References 5).

1. The recommended Intensity, Frequency and Duration (IFD) rainfall data and initial and continuing loss values across Australia have been updated based on analysis of available records (available on the BoM website).
2. ARR2019 recommends the analysis of 10 temporal patterns for each storm duration to determine the critical storm event. The critical storm event for a duration corresponds to the temporal pattern which produces the maximum average peak value from the 10 storms: and
3. The inclusion of Areal Reduction Factors (ARFs) based on Australian data for short (12 hours and less) and long durations (larger than 12 hours). ARFs are an estimate of how design rainfall intensity varies over a catchment, based on the assumption that large catchments will not have a uniform depth of rainfall across their entire area. Based on the size of the Powells Creek catchment an ARF was not used for this study.

3.3.3. IFD Data

Revised IFD curves are available on the BoM website. Diagram 3 indicates the change in rainfall intensities between the ARR1987 and ARR2019 IFD data sets for the study area. The following are noted.

- there is an overall decrease in design intensities for the catchment for all durations greater than 10 minutes.
- the decrease in design intensities is much higher (decreases up to 34%) for durations up to 6 hours.

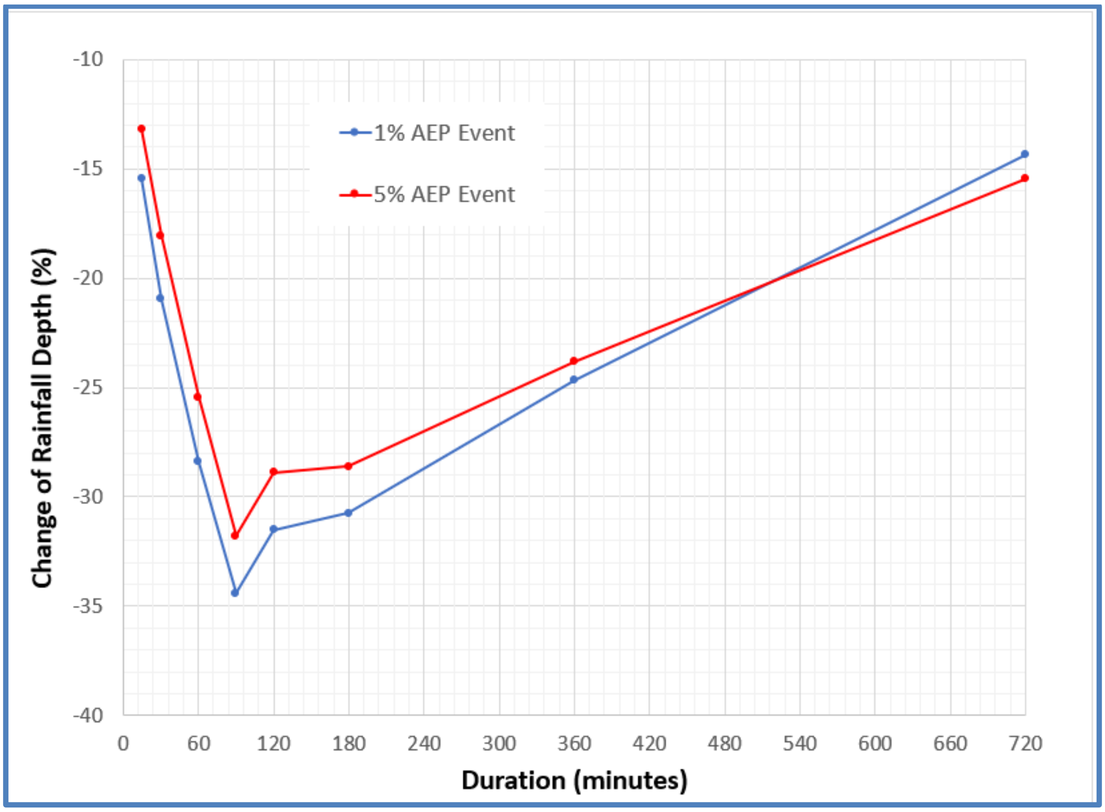


Diagram 3: Change in Rainfall Intensity for 1% AEP and 5 % AEP 2019 v 1987 IFD

It is important to note that the rainfall duration which produces the peak flood levels (termed the critical duration) varies across the catchment. In the upper parts of the Powells Creek catchment, where the catchments are small, the critical duration may be 30 minutes but as the catchment size increases so does the critical duration. In the lower parts of the catchment the critical duration may approach 6 hours. Thus, based on Diagram 3 the volume of rainfall and likely runoff volumes (affected by loss rates) are reduced with the revised ARR2019 IFD data. The change in intensity for longer duration events (12 hours or more) is of little consequence for flooding in this catchment as these events do not produce the highest flood level.

3.3.4. Accuracy of the 2019 IFD Data

The 2019 IFD data can vary significantly from the previous 1987 IFD data (Diagram 3). This issue is addressed by the text below taken from the BoM's web site (May 2019).

> The 2016 IFDs are based on a greatly expanded rainfall database and use contemporary methods for analysis of the rainfall data. In addition, the length of record available for each station has been maximised through quality control processes and Region of Influence methods. The 2016 IFDs provide a better overall fit to the current rainfall database than the old IFDs.
>
> As with all statistical methods, there is a level of uncertainty in the derived results due to the variability inherent in the data sample. In the 2016 IFDs this uncertainty has been reduced through the increased sample size afforded by the additional years of recorded data and inclusion of significant amounts of rainfall data from water agencies around the country.

The process of developing the new IFDs was guided and reviewed by a panel of experts set up by Engineers Australia. The differences in methods between the new IFDs and the ARR1987 IFDs are summarised in the table below:

Method	New IFDs	ARR1987 IFDs
Number of rainfall stations	Daily read - 8074 Continuous - 2280	Daily read - 7500 Continuous - 600
Period of record	All available records up to 2012	All available records to up ~ 1983
Length of record used in analyses	Daily read >= 30 years Continuous > 8 years	Daily read >= 30 years Continuous > 6 years
Source of data	Bureau of Meteorology & other organisations collecting rainfall data	Primarily Bureau of Meteorology
Extreme value series	Annual Maximum Series (AMS)	Annual Maximum Series (AMS)
Frequency analysis	Generalised Extreme Value (GEV) distribution fitted using L-moments	Log-Pearson Type III (LPIII) distribution fitted using method of moments
Extension of sub-daily rainfall statistics to daily read stations	Bayesian Generalised Least Squares Regression (BGLSR)	Principal Component Analysis
Gridding	Regionalised at-site distribution parameters gridded using ANUSPLIN	Maps hand-drawn to at-site distribution parameters, digitised and gridded using an early version of ANUSPLIN

3.3.5. Comparison of At Site Frequency Analysis from a Specific Rain Gauge to the IFD Data on the BoM's Website

A frequent question asked is why does the at site frequency analysis of a specific rain gauge within a catchment not always match up with the IFD data obtained from the BoM web site. This issue is addressed by the text below taken from the BoM's web site (May 2019).

Although at-site frequency analysis of the Annual Maximum Series (AMS) of observed rainfall was an integral part of the method adopted for the 2016 IFDs, it was only one of many steps used to produce the new gridded, regional IFDs.

A regionalisation method was applied to give more weight to longer record stations within each region. This improved the estimates of rare (less frequent) events. A spline interpolation method was then applied to the regionalised rainfall data from across Australia to estimate gridded values for the whole country. Factors including latitude, longitude, elevation and consistency with neighbouring sites were used, in addition to rainfall characteristics at recording sites, thus allowing more reliable interpolation of rainfall depths in data sparse areas.

Rainfall values from a Generalised Extreme Value (GEV) distribution fitted to the AMS at a specific duration for a particular site will vary from the point values extracted from the grid of IFD values. Although each event in the AMS is a record of the actual rainfall at a site, these measured rainfall values are effectively point samples of the rainfall distribution across Australia. Each point sample has its own uncertainty and does not represent completely the underlying population of rainfall values. The extracted grid values, created from the regionalised rainfall inputs, will generally fall within the 95% confidence limits of the GEV distribution for the specific duration at each location.

The length and period of record at a site makes a significant difference in the level of uncertainty of any at-site comparisons. Regionalisation was applied to the measured rainfall data to effectively smooth out the effects of sampling uncertainty.

3.3.6. Design Loss Data

Design initial and continuing loss values are available from the ARR2019 data hub. The Elva Street gauge has a flow rating curve but it is not considered viable to derive the design rainfall loss values from the limited historical events that are available. For calibration different loss rates can be adopted.

Current guidelines for design recommend using a range of initial losses (Table 12) that depend on the duration and the storm AEP. The data hub suggests a continuing loss of 1.8mm/h but Reference 11 suggests applying a factor of 0.4 to this value. The AEP neutral initial loss in Table 12 were used for the assessment as well as a continuing loss of 0.7 mm/h (0.4*1.8).

Table 12: Design Initial Loss Values from the Data Hub

Duration (min)	Annual Exceedance Probability					
	50%	20%	10%	5%	2%	1%
60	17.1	8.9	8.6	9.5	8.8	6.8
90	15.4	9.1	9.2	10.1	9.8	8.8
120	15.7	9.1	9.3	9.7	8.8	6.9
180	16.6	9.8	10.3	10.1	9.6	6.7
360	16.5	9.7	10.6	9.8	8.9	4.1

In an urban environment such as Powells Creek the effect of the initial loss is minimal due to the impervious nature of the catchment. Moreover, the small size of the Powells Creek catchment results in a short critical duration time (less than 6 hours) and therefore the influence of the continuous loss on the flows is also small.

3.3.7. Storm Temporal Patterns

ARR1987 provided a single temporal pattern for each storm duration for:

- events less than a 30-year ARI; and
- for events greater than a 30-year ARI.

ARR2019 provides several patterns for each storm duration. The temporal patterns were extracted from storms occurring across Australia and are different for each region. The data hub provides a table with all the temporal patterns that could be used at a given location. The temporal patterns are grouped in bins based on the intensity of the recorded storms as shown in Diagram 4.

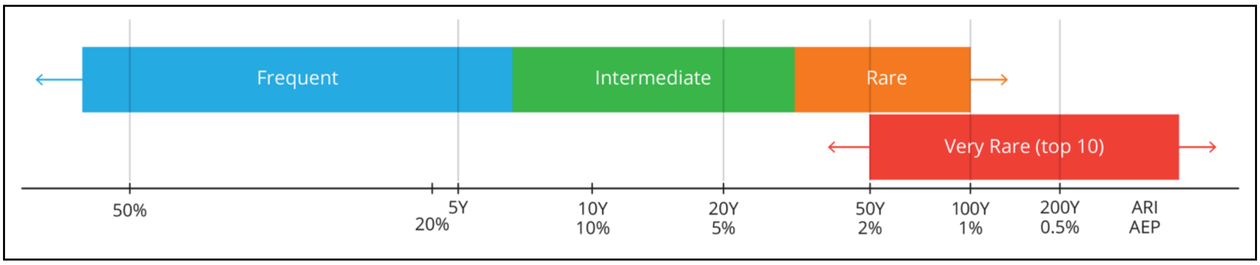


Diagram 4: Rainfall Temporal Pattern Bins

ARR2019 recommends the use of 10 temporal patterns for design storm analysis. The 10 patterns have the same total rainfall depth, but there are differences in rainfall distribution across the storm duration. Some patterns may represent storms with intense bursts at the start, middle or end of the storm duration, others represent storms with multiple bursts, and some may represent storms with constant rainfall. Different patterns can produce different peak flood levels for the same catchment area depending on the catchment topography and response.

The representative temporal pattern (used as part of the critical duration analysis) is the pattern which produces peak flood levels just greater than the average of the 10 temporal patterns (not the temporal pattern which produces the largest peak level) for each storm duration. This can be determined by running each of the 10 temporal patterns through the hydrologic and hydraulic models and obtaining the average flood level or peak flow produced. The critical storm duration for the catchment is the duration whose representative temporal pattern produces the maximum flow or level (i.e., the highest of the average values for all storm durations).

For this study peak flood levels were considered rather than peak flows. For each duration, a grid of the mean peak level at each grid cell was calculated, and from this a maximum grid was calculated taking the highest peak mean level for each grid cell. The adopted critical duration temporal pattern was the pattern which best matched or slightly exceeded this maximum grid at each grid cell.

3.4. Assessment of Data from UNSW Elva Street Gauge

3.4.1. Overview

It is important that the best possible use is made of the available data as this is the only urban catchment in Sydney where there is a long-term record for use in flood frequency analysis and which can be used to calibrate hydrologic (flows) and hydraulic (water level) models. However, there are several issues with the data, and these are discussed below.

3.4.2. Gaugings and Rating Curve

The cross-sectional area of the channel has not changed (lined ‘U’ shaped channel) since 1958 although the coping has been raised. The gauge zero is at RL 5.25 m AHD and over 29 stream gaugings (velocity measurements using a current meter) have been taken. The channel is well gauged below 1 m (RL 6.25 m AHD); there are 14 gaugings below 0.5 m (RL 5.75 m AHD); 14 gaugings between 0.5 m and 1.0 m; and the highest gauging is at 1.35 m (RL 6.6 m AHD). The gaugings show very little scatter and fit as a smooth line on log-log paper. Above 0.2 m depth the flow tends to be supercritical, and velocities are very high (above 4 m/s). This is the greatest source of uncertainty in the gauging as the velocity is above the normal range of the current meter used to take velocity measurements.

There are four rating curves (Figure 7) namely:

- used in Reference 8 and taken from UNSW records at the time.
- used in the 1998 Powells Creek Flood Study (Reference 1).
- used in the digital records.
- used in the 2016 Powells Creek Revised Flood Study (Reference 2) referred to as the TUFLOW model rating curve.

The 1998 Powells Creek Flood Study (Reference 1) and digital record curves are practically identical and shown as the same on Figure 7. As part of the 2016 Powells Creek Revised Flood Study (Reference 2) a rating curve was produced from the TUFLOW model. All the prior curves, whilst based on various velocity gaugings aimed to extend the rating curve beyond the highest flow gauging height of 1.35 m (RL 6.6 m AHD).

It is interesting to note that the Reference 1 rating curve and the TUFLOW model rating curves are relatively similar in magnitude at a given height. The TUFLOW model rating produces a smaller flow up to approximately 1.8 m before transitioning to produce larger flows than the Reference 1 rating above this level.

Uncertainty between the prior rating curves listed above increases once the flow breaks out of the channel (approximately at 2.5 m or RL 7.75 m AHD). The channel may also choke downstream at very high depths. Since approximately the year 2000 there have been significant changes in the number and size of the bridges across the channel in the immediate reach upstream from the railway line. There is no complete record of the dates when bridges have been removed or installed. The presence of bridges will influence the high flow rating but for most of the historic record the events were not above the coping and thus not influenced by these changes.

3.4.3. For Use in Flood Frequency Analysis

Flood frequency analysis is the fitting of a statistical distribution to either the annual maxima peaks or a partial series (events above a threshold). Partial series analysis is not possible as there are too many gaps in the record. Whilst the gaps in the record also affect the annual maxima series it is expected that this approach will still provide a robust result. Derivation of the annual maxima needs to address whether the record should be based on just the digital record or whether it should be extended to include the data shown in Table 7, and whether the record should be extended from the end of the digital record (1997) to date. It is known that there have been no large events since 1997.

The present study has adopted the flood frequency analysis derived in the 2016 Powells Creek Revised Flood Study (Reference 2). A tabulation of the annual maxima from the various sources is provided on Table 13.

Table 13: Annual Maxima Peaks

Year	Peak Stage (m) from Reference 8	Peak Stage (m) from Digital Records	Difference in Peak Stage (m)	Peak Flows from Reference 8 (m³/s)	Peak Flows from 1998 Flood Study Reference 1 (m³/s)	Peak Flows from Digital Record (m³/s)
1958		1.48			16.0	16.1
1959	3.29	3.26	0.03	29.9	48.2	49.1
1960	1.30	1.12	0.18	11.1	10.8	10.6
1961	4.18	0.79	3.39	38.3	7.0	5.9
1962	1.69	1.74	-0.05	14.8	20.0	20.3
1963	2.40	2.47	-0.07	22.0	33.0	32.1
1964	3.52	1.88	1.64	32.1	25.3	22.5
1965	1.02	0.88	0.14	8.0	8.8	7.2
1966	1.28	1.23	0.05	10.9	12.6	12.3
1967	1.52	1.40	0.12	13.2	17.2	14.9
1968	0.84	0.70	0.14	5.9	5.3	4.7
1969	1.71	1.62	0.09	15.1	18.3	18.4
1970	3.09	1.43	1.66	28.0	17.4	15.4
1971	1.93	1.10	0.83	17.8	12.1	10.3
1972	3.20	2.76	0.44	29.1	38.0	37.3
1973	2.35	2.17	0.18	21.5	33.5	27.1
1974	2.34	2.23	0.11	21.4	28.9	28.0
1975	1.58	1.52	0.06	13.8	17.0	16.7
1976	1.70	1.25	0.45	14.9	14.9	12.6
1977	1.15	1.49	-0.34	9.6	16.5	16.3
1978	1.47	1.38	0.09	12.7	15.1	14.6
1979	1.27	1.22	0.05	10.8	12.6	12.1
1980	1.26	1.27	0.00	10.7	12.7	12.8
1981	1.41	1.38	0.03	12.1	14.6	14.6
1982	1.71	1.67	0.04	15.1	19.3	19.1
1983	1.83	1.80	0.03	16.8	21.3	21.2
1984	1.84	1.81	0.03	16.9	21.3	21.4
1985	1.30	1.21	0.09	11.1	13.1	11.9
1986	1.93	1.73	0.20	17.8	20.2	20.1
1987		1.18			11.8	11.4
1988		1.92			23.1	23.1
1989		1.28			13.9	13.0
1990		1.92			23.3	23.1
1991		1.68			19.2	19.2
1992		1.53			17.1	16.9
1993		1.88				22.4
1994		1.44			6.9	15.4
1995		1.31			13.3	13.4
1996		0.90			7.8	7.4
1997		0.86			7.6	6.9

3.5. Calibration and Verification of the Modelling Process

3.5.1. Approach

As flow data is available from the Elva Street gauge this means that the catchment hydrology (flows) can be calibrated and verified at this location. This is a significant advantage for this catchment as this is possible for only approximately 10 urban catchments in Australia and less than 5 in NSW. TUFLOW model peak levels and the shape of the hydrograph can also be calibrated to water level data from the Elva Street gauge.

In addition, peak levels from TUFLOW can be calibrated to observed water level data provided by

Council and Sydney Water (Section 2.10 and Figure 8).

The stages in the modelling calibration approach were as follows (the same as adopted in Reference 2):

1. collect available historical rainfall and water level data from prior references.
2. select events for calibration and verification based on the quality and quantity of available data (same events as adopted in Reference 2).
3. input historical rainfall data for calibration event to DRAINS.
4. input output of above DRAINS model to TUFLOW.
5. run TUFLOW for historical event.
6. compare output from TUFLOW for calibration event at the Elva Street gauge and other locations where historical flood height data are available.
7. rerun steps 3 to 6 and adjust model parameters until a suitable match is obtained.
8. rerun steps 3 to 6 for verification events without adjustment of model parameters.
9. compare output from TUFLOW from verification events at the Elva Street gauge and other locations where historical flood height data are available.
10. re-run steps 3 to 9 until a satisfactory calibration/verification is achieved.

3.5.2. Calibration Events

The choice of floods used in calibration depends upon several factors including the:

- *time since the flood occurred.* The longer the time since a flood occurred, the greater the likelihood of subsequent changes to the catchment. The major changes in the upper catchment in recent times have been construction/alterations to buildings and fences in the floodplain and to the piped drainage system. The most significant change in recent times at the Elva Street gauge is construction of several bridges across the channel. However, as all the recent events suitable for calibration did not overtop the coping the impact of new bridges is not relevant.
- *quantity and quality of rainfall and streamflow data which are available*. This should have been of lesser importance in this study as data are available from two well placed pluviometers and the Elva Street water level gauge. However, problems with the UNSW rainfall and water level data meant that this became the most important factor in determining the choice of events.
- *quantity, quality, and location of recorded levels along the creeks*. It may be preferable to use a small flood with several levels which define a profile rather than a large flood with only one level. This issue is of little significance as there are few events with suitable recorded levels, apart from at the gauge.
- *magnitude of the flood levels*. The larger the flood the more suitable it is for calibration as it is closer to the larger design flood events.

The following is a summary of the available data considered suitable for calibration in the 2016 Powells Creek Revised Flood Study (Reference 2).

2 January 1996

- the Elva Street water level gauge malfunctioned, and the Elva Street pluviometer had no digital record. The St Sabina pluviometer recorded 62 mm in 45 minutes.

- only record available for Sydney Water gauge under the M4.
- 39 flood levels are available (Table 10).
- at Enfield this event approached a 1% AEP (20 min to 60 min duration) but was approximately only a 5% AEP (or less) at the other gauges.

8 or 9 February 1992

- the Elva Street gauge recorded a peak level of 1.5m and it would appear from the available pluviometer records that this was not a large event. For this reason, it is not suitable for calibration purposes.

11 March 1991

- the Elva Street gauge recorded a peak level of 1.7m and the rainfall intensity approached a 10% AEP (30-minute duration) at Enfield but the lack of other flood height data and failure of both the UNSW pluviometers meant this flood was not suitable for calibration purposes.

18 March 1990

- the flood was approximately a 20% AEP event at the St Sabina pluviometer and a 5% AEP (30-minute duration) at the Elva Street pluviometer. The peak levels and flows at the Elva Street gauge are 1.92 m and approximately 23 m^3/s (based on the UNSW rating curve).
- the availability of water level and pluviometer records from the UNSW gauges meant that this event could be used for calibration at the Elva Street gauge. However, no flood height data were available for calibration of the TUFLOW model elsewhere.

February 1990

- four peaks occurred during February 1990 (3^{rd}, 7^{th}, $10^{th,}$ and 17^{th}). The water level and pluviometer data (UNSW gauges) are shown on Figure 9. The peak levels and flows (based on the UNSW rating curve) at the Elva Street gauge are:
  - 3^{rd} Feb 1990 - 1.4 m - 14 m^3/s.
  - 7^{th} Feb 1990 - 1.4 m - 15 m^3/s.
  - 10^{th} Feb 1990 - 1.8 m - 21 m^3/s.
  - 17^{th} Feb 1990 - 1.1 m - 11 m^3/s.
- several flood levels (assumed to be for 10^{th} February 1990) are available (Table 10).
- the 10^{th} of February event was approximately a 20% AEP rainfall event (30-minute and 60-minute durations).
- the water level records indicate a peak on the morning of 8^{th} February 1990. This is not compatible with the rainfall record which indicates that the peak was approximately 24 hours earlier. It has been assumed that the timing on the water level gauge malfunctioned.
- the availability of pluviometer and water level data from the UNSW gauges meant that all four events could be used for calibration at the Elva Street gauge. The largest event (10^{th} February) was suitable for calibration of the TUFLOW model as it is presumed the recorded flood levels relate to this event.

4-6 August 1986:

- digital records from the Elva Street gauge show no record for this event. However, Reference 1 indicates a peak of 1.95 m obtained from data collected as part of Reference 8.
- the St Sabina pluviometer malfunctioned, and the Elva Street pluviometer recorded a maximum of 21 mm in 30 minutes which is only modest rainfall. For this reason, this event could not be used for calibration.

Summary

Five events (3rd, 7th, 10th and 17th February 1990 and 18th March 1990) were available for calibration of the Elva Street gauge and two events (10th February 1990 and 2nd January 1996) for calibration of the TUFLOW model in the 2016 Powells Creek Revised Flood Study (Reference 2). These same events were used in the current calibration process.

3.6. Design Flood Modelling

Following model establishment and calibration the following steps were undertaken:

- design tributary inflows were obtained from the DRAINS hydrologic model and included in the TUFLOW model.
- assessment of the design event causing the maximum water levels which is termed the critical storm duration.
- sensitivity analyses to assess the effect of changing model parameters and the assumed water level in the Parramatta River.
- assessment of possible effects of climate change on design flood levels.

4. HYDROLOGIC MODELLING

4.1. Sub-catchment Definition

The total catchment represented by the current DRAINS model is 9.14 km^2. This area has been represented by 781 sub-catchments (Figure 10) giving an average sub-catchment size of approximately 1.17 hectares. The sub-catchment delineation ensures that where hydraulic controls exist that these are accounted for and able to be appropriately incorporated into hydraulic routing. The pit and pipe network is shown on Figure 11. The drainage system defined in the model comprises:

- 1457 pipes.
- 1593 inlet pits.
- 487 junction pits.

4.2. Impervious Surface Area

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

DRAINS categorises these surface areas as either:

- Paved areas (impervious areas directly connected to the drainage system).
- Supplementary areas (impervious areas not directly connected to the drainage system; instead, connected to the drainage system via the pervious areas) and
- Grassed areas (pervious areas).

Within the Powells Creek catchment, the impervious value was determined using the Table 14 and the land types within each sub catchment. The proportion of pervious area and remaining impervious area was defined as:

- For sub catchments with imperviousness below 25% (typically parks), the pervious area is defined as 70% of the non-impervious area and the remaining impervious area is defined as 30% of the non-impervious area.
- For sub catchments with imperviousness above 25% (typically residential properties), the pervious area is defined as 30% of the non-impervious area and the remaining impervious area is define as 70% of the non-impervious area.

Table 14: Impervious Percentage per Land-use

Land-use Category	Impervious Percentage
Residential/Commercial property	60% Impervious
Non-bitumen road reserve	60% Impervious
Vacant non hard surface land	0% Impervious
Green space (such as public parks)	0% Impervious
Roadway/Car parks	100% Impervious
Urbanised land within Canada Bay LGA	70% Impervious
Waterways	0% Impervious

4.3. Rainfall Losses

Methods for modelling the proportion of rainfall that is “lost” to infiltration are outlined in ARR2019 (Reference 5). The methods are of varying degrees of complexity, with the more complex options only suitable if sufficient data are available. The method most typically used for design flood estimation is to apply an initial and continuing loss to the rainfall. The initial loss represents the wetting of the catchment prior to runoff starting to occur and the continuing loss represents the ongoing infiltration of water into the saturated soils while rainfall continues.

Rainfall losses from a paved or impervious area are considered to consist of only an initial loss (an amount sufficient to wet the pavement and fill minor surface depressions). Losses from grassed areas are comprised of an initial loss and a continuing loss as indicated in Section 3.3.6.

4.4. Design Rainfall Data

Rainfall intensities were derived from the BoM website using ARR (Reference 5) data (Table 6). Calculation of the Probable Maximum Precipitation (PMP) was undertaken using the Generalised Short Duration Method (GSDM) according to Reference 9.

For the PMP estimate the following criteria applied:

- as the catchment area is less than 1000 km^2 and located in the coastal transitional area the Generalised Short Duration Method (GSDM) was adopted.
- zero adjustment for elevation was assumed as the catchment topography is less than 1500 m AHD.
- a moisture adjustment factor of 0.7 was adopted.
- the catchment is assumed to be 100% 'smooth'.

5. HYDRAULIC MODELLING

5.1. TUFLOW

The TUFLOW modelling package includes numerical scheme for the solution of the depth averaged shallow water equations in two dimensions. The TUFLOW software has been widely used for a range of similar floodplain projects both internationally and within Australia and is capable of dynamically simulating complex overland flow regimes. The TUFLOW model build used in this study is 2020-10-AA-iSP-w64 and further details regarding TUFLOW software can be found in the User Manual (Reference 10).

The model uses a regularly spaced computational grid, with a cell size of 2 m by 2 m. This resolution was adopted as it provides an appropriate balance between providing sufficient detail for roads and overland flow paths, while still resulting in workable computational run-times. The model grid was established by sampling from a DEM generated from a triangulation of filtered ground points from the ALS dataset, discussed in Section 2.4 and shown in Figure 3.

The TUFLOW hydraulic model includes the Powells Creek catchment to Homebush Bay with the open channel in 1D and the overland areas in 2D. The total area included in the 2D model is approximately 10 km^2. The extents of the TUFLOW model are shown in Figure 12.

5.2. Boundary Locations

Local runoff hydrographs were extracted from the DRAINS model for inclusion within the TUFLOW model domain. These were applied to the downstream end of the sub-catchments within the 2D domain of the hydraulic model. The inflow locations typically corresponded with inlet pits on the roadway as this is where most rainfall is directed.

The downstream boundary was located at the Parramatta River, as shown in Figure 12.

5.3. Roughness Co-efficient

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

The Manning's "n" values adopted, including flow paths (overland, pipe and in-channel), are shown in Table 15 and were based on site inspection and past experience in similar floodplain environments.

Table 15: Manning's "n" values adopted in TUFLOW

Material	Manning's "n" Value
Bitumen road reserve and some car parks	0.02
Green space - golf course, parks, vacant lots	0.04
Residential/urban area	0.03
Non-bitumen road reserve	0.032
Waterways	0.015
Pipes	0.012

5.4. Hydraulic Structures

5.4.1. Buildings

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

5.4.2. Fencing and Obstructions

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

5.4.3. Bridges

Key hydraulic structures were included in the hydraulic model, as shown in Figure 12, bridges were modelled as 1D features within the 1D channels, with the purpose of maintaining continuity within the model.

The modelling parameter values for the culverts and bridges were based on the geometrical properties of the structures, which were obtained from detailed survey, photographs taken during site inspections, and previous experience modelling similar structures.

5.5. Blockage Assumptions

Blockage of hydraulic structures can occur with the transportation of several materials by flood waters. This includes vegetation, garbage bins, building materials and cars, the latter occurred in the Newcastle area in the June 2007 floods. However, the disparity in materials that may be mobilised within a catchment can vary greatly.

Debris availability and mobility can be influenced by factors such as channel shear stress, height of floodwaters, severity of winds, storm duration and seasonal factors relating to vegetation. The channel shear stress and height of floodwaters that influence the initial dislodgment of blockage materials are also related to the AEP of the event. Storm duration is another influencing factor, with the mobilisation of blockage materials generally increasing with increasing storm duration.

The potential effects of blockage include:

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

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

- ARR Revision Project 11 Blockage of Hydraulic Structures (Reference 12); and
- the policies of various local authorities and infrastructure agencies.

Current modelling has been undertaken assuming no blockage of pipes, culverts and bridges greater than 225 mm in diameter. Pipes less than or equal to 225 mm in diameter were conservatively assumed to be completely blocked. On grade pits were assumed as 20% blockage and sag pits were assumed as 50% blocked. These blockage values were adopted for all events in this report unless stated otherwise.

Various scenarios have been investigated to assess the catchment's sensitivity to blockage and the results of this are discussed in Section 9. These scenarios included blockage of all pipes, blockage of bridges/culverts over the open channel, and blockage of the drainage infrastructure.

No historical evidence of blocking of structures in the catchment is available; however, it is possible that changed activities on the floodplain may mean that there may be a higher chance of blockage today than in the past. For example, colorbond fencing is much less permeable and less likely to collapse than the more traditional paling fencing. Individual palings becoming mobile in a flood are also less likely to cause blockage than a panel of colorbond fencing. In some council areas garbage bins are known to become mobile during floods and can cause blockage. In summary, it is impossible to accurately determine whether blockage will or will not be an issue in the next flood.

5.6. Ground Truthing

Inspection of the above-ground features along the catchment's overland flow paths was undertaken following calibration of the hydraulic model as part of the 2016 Powells Creek Revised Flood Study (Reference 2). This entailed producing design flood results and mapping the peak flood depth in detail across the catchment. This allowed identification of features (largely buildings) that blocked or partially blocked overland flow. Model schematisation of these features was then compared to the actual features on a site visit and the model was updated where any discrepancy was identified. Changes were minor and only impacted results in the vicinity of the modification.

6. MODEL CALIBRATION AND VERIFICATION

6.1. Introduction

It is important that the performance of the overall modelling system be substantiated prior to defining design flood behaviour. Typically, in urban areas such information is lacking. Issues which may prevent a thorough calibration of hydrologic and hydraulic models are:

- there is only a limited amount of historical flood information available for the study area; and
- rainfall records for past floods are limited and there is a lack of temporal information describing historical rainfall patterns within the catchment.

The adopted rainfall parameters for calibration of the DRAINS model are shown in Table 17. These parameters are different to those in the 2016 Powells Creek Revised Flood Study (Reference 2). They were chosen to eliminate the high storage volume at each drainage pit in TUFLOW adopted in Reference 2 to achieve a calibration.

The rainfall loss values adopted in the 2016 Powells Creek Revised Flood Study (Reference 2) for calibration and design are shown in Table 16.

Table 16: Rainfall Loss Values Adopted in the 2016 Powells Creek Revised Flood Study (Reference 2)

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

The rainfall loss values adopted for calibration in the present study are provided on Table 17.

Table 17: Rainfall Loss Values Adopted in the Present Study

RAINFALL LOSSES	
Paved Area Depression Storage (Initial Loss)	1.0 mm
Grassed Area Depression Storage (Initial Loss)	5.0 mm
SOIL TYPE	**1**
Low runoff potential, high infiltration rates (consists of sand and gravel)	
ANTECEDENT MOISTURE CONDITONS	**3**
Description	Rather wet
Total Rainfall in 5 Days Preceding the Storm	12.5 to 25 mm

6.2. Results

The results of the calibration and verification process using the six historical events are shown on Figure 13 (Elva Street Gauge) and Figure 14 (across catchment) and on Table 18 (Elva Street Gauge) and Table 19 (across the catchment).

Table 18: Calibration Results - Elva Street Gauge

Date	Recorded Level (m AHD)	Modelled Level St Sabina Pluviometer (m AHD)	Difference (m)	Modelled Level Elva St Pluviometer (m AHD)	Difference (m)
3-Feb-90	6.58	6.63	0.05	6.63	0.05
7-Feb-90	6.62	6.65	0.03	6.59	-0.03
10-Feb-90	7.00	6.96	-0.14	6.91	-0.09
17-Feb-90	6.38	6.54	0.16	-	-
18-Mar-90	7.14	6.86	-0.28	-	-
2-Jan-96	-	7.91	-	-	-

Table 19: Calibration Results - Peak Heights

Address	Location	Surveyed Level 1990 February 10 (m AHD)	Surveyed Level 1996 January 2 (m AHD)	Modelled Level 1990 February 10 (m AHD)	Modelled Level 1996 January 2 (m AHD)	Difference-1990 February 10 (m AHD)	Difference-1996 January 2 (m AHD)
21 Llandilo Avenue	Garage Floor Level	29.90	-	29.93	-	0.03	-
21 Llandilo Avenue	North-West Corner	28.80	-	28.60	-	-0.20	-
8 Agnes Street	Driveway and Front Boundary	-	26.71	-	26.52	-	-0.19
41 Albyn Road	Crest of Driveway	-	22.54	-	22.48	-	-0.06
41 Albyn Road	Low Point along West. Boundary	-	21.64	-	21.56	-	-0.08
47 Albyn Road	Garage Floor Level	-	21.18	-	21.16	-	-0.02
37 Redmyre Road	Crest of Driveway	-	13.27	-	13.21	-	-0.06
37 Redmyre Road	Ground Level at Garage	-	12.21	-	12.23	-	0.02
35 Redymre Road	Crest of Driveway	-	13.26	-	13.20	-	-0.06
35 Redymre Road	Ground Level at Back Fence	-	12.13	-	12.11	-	-0.02
45 Churchill Avenue	Base Steps at Front House	-	10.74	-	11.06	-	0.32
60 Churchill Avenue	Ground Level at Path Granny Flat	-	11.49	-	11.47	-	-0.02
Pharmacy adjoining Plaza Entrance, The Boulevarde		-	12.29	-	12.54	-	0.25
65 Oxford Street	Carport Slab	-	24.16	-	23.95	-	-0.22
63 Oxford Street	South-West corner of house	-	23.75	-	23.61	-	-0.14
61 Oxford Street	Garage Floor Level	-	23.24	-	22.99	-	-0.25
59 Oxford Street	Patio Level	-	23.14	-	23.04	-	-0.10

Address	Location	Surveyed Level 1990 February 10 (m AHD)	Surveyed Level 1996 January 2 (m AHD)	Modelled Level 1990 February 10 (m AHD)	Modelled Level 1996 January 2 (m AHD)	Difference-1990 February 10 (m AHD)	Difference-1996 January 2 (m AHD)
141Albert Street	Ground level along eastern fence	19.51	-	19.28	-	-0.24	-
135 Albert Street	Bottom steps rear of house	18.49	-	Not Flooded	-	Not Flooded	-
137 Albert Street	Crest of driveway	19.24	-	Not Flooded	-	Not Flooded	-
137 Albert Street	Water reached floor level	19.01	-	Not Flooded	-	Not Flooded	-
100 Beresford Road	Driveway at entrance to house	15.91	-	15.77	-	-0.14	-
102 Beresford Road	Ground level at back door	16.43	-	16.23	-	-0.20	-
104 Beresford Road	Ground level rear house	17.00	-	16.59	-	-0.41	-
110 Beresford Road	Midway along eastern fence	17.50	-	17.63	-	0.13	-
108 Beresford Road	Base steps rear house	17.49	-	17.26	-	-0.23	-
53 Beresford Road	Garage floor level	15.29	-	15.05	-	-0.24	-
89 Rochester Street	Floor level shop	12.84	-	12.68	-	-0.16	-
109 Rochester Street	Base steps rear house	14.33	-	14.19	-	-0.14	-
109 Rochester Street	Base steps rear house	-	14.15	-	14.33	-	0.18
57 Rochester Street	Ground level back yard	-	9.92	-	10.10	-	0.18
38-46 Burlington Road	Ground level at rear shed	9.71	-	9.55	-	-0.16	-
48 Burlington Road	Ground Floor Level	-	9.55	-	9.54	-	-0.01
29 Burlington Road	Stormwater reached this level at rear of factory	9.16	-	8.88	-	-0.28	-
30 The Crescent	Garage Floor Level	-	8.70	-	8.75	-	0.05
31 The Crescent	Garage Floor Level	-	8.33	-	8.24	-	-0.09
79 The Crescent	Floor level	8.20	-	7.02	-	-1.18	-
79 The Crescent	Base patio at rear	-	7.75	-	7.78	-	0.03
12 Loftus Crescent	Ground level backyard	7.87	-	Local runoff	-	Local runoff	-
86 Underwood Road	Base steps front house	-	4.89	-	4.65	-	-0.24
82 Underwood Road	Ground level at front house and driveway	4.97	-	4.44	-	-0.53	-
90 Underwood Road	Base steps front of house	-	4.74	-	4.41	-	-0.33

Address	Location	Surveyed Level 1990 February 10 (m AHD)	Surveyed Level 1996 January 2 (m AHD)	Modelled Level 1990 February 10 (m AHD)	Modelled Level 1996 January 2 (m AHD)	Difference-1990 February 10 (m AHD)	Difference-1996 January 2 (m AHD)
60 Ismay Avenue	Ground level at front of house	-	3.83	-	3.80	-	-0.03
55 Ismay Avenue	Base front steps	4.30	4.11	3.32	4.11	-0.98	0.00
51 Ismay Avenue	Base front steps	4.19	Local runoff	-	-	Local runoff	-
56 Ismay Avenue	Base front steps	3.83	-	3.66	-	-0.17	-
49 Ismay Avenue	Base front steps	-	4.16	-	4.00	-	-0.16
48 Ismay Avenue	Base front steps	-	3.43	-	3.36	-	-0.07
41 Ismay Avenue	Base front steps	3.71	Local runoff	-	-	Local runoff	-
10 Mitchell Road	Ground level low side house	-	14.75	-	14.75	-	0.00
6 Mitchell Road	Ground level low side house	-	14.35	-	14.18	-	-0.17
104 Arthur Street	Ground level front of house	-	13.87	-	13.62	-	-0.25
106 Arthur Street	Ground level at boundary	-	13.85	-	13.62	-	-0.23
105 Arthur Street	Ground level at house steps side house	-	13.89	-	13.81	-	-0.08
29 Arthur Street	Base front steps	-	13.23	-	13.22	-	-0.01
29 Arthur Street	Ground level at rear fence	-	12.98	-	12.70	-	-0.28
6 Kessell Avenue	Ground level at fence	8.42	-	8.14	-	-0.28	-
6 Kessell Avenue	Water reached floor level	-	7.76	-	7.79	-	0.03

Note: Local runoff denotes when the flooding is very localised and is therefore not identified in the TUFLOW model.

6.3. Discussion of Results

6.3.1. Elva Street Gauge - Table 18 and Figure 13

Apart from 18th March 1990 and to a lesser extent 10th February 1990, there is a good match to the peak at the Elva Street gauge using the St Sabina pluviometer. The use of the Elva Street pluviometer significantly improves the match for the 10th February 1990 event compared to using the St Sabina pluviometer.

For all events, the relative timings of the water level gauge and the pluviometer are incorrect due to timing errors with the instruments. This was recognised in Reference 8 and an attempt was made to correct this by assuming that the "clocks" decrease or increase in speed linearly (this can be calculated as the on and off times are recorded and the elapsed real time can be compared to the chart time).

In general, the gauge shows a more rapid rise and fall than the model results. Thus, the model assumes a greater volume of runoff than recorded.

Where comparisons can be made, the results from the St Sabina and Elva Street pluviometer show similar shapes of hydrographs. The timing of the two pluviometers is also similar suggesting that the error in timing is the water level gauge. The two pluviometers are only 800 m apart, but timing differences may reflect the passage of a storm across the area.

6.3.2. Across the Catchment Table 19 and Figure 14

For the historical event of 10th February 1990, most of the differences between surveyed and modelled levels were within 0.2 m. However, the modelled flood level at 79 The Crescent was 1.18 m below the level recorded at the floor. The ALS at this location was 7.05 m AHD which was far lower than the recorded flood level of 8.2 m AHD.

The differences were also generally within 0.2 m for the historical event of 2nd January 1996.

In summary the results appear reasonable for these two events, but it should be noted that as both events had shallow overland depths (generally less than 0.5m) a difference of 0.2m is significant. Unfortunately, it is impossible to resurvey the locations or review whether the recorded levels are reliable. However, some confidence in the results is provided in that (certainly for 2nd January 1996) the model produces results above and below the recorded level which suggests that there is no consistent error in the modelling (e.g the peak flows are consistently too low or too high).

7. DESIGN EVENT MODELLING

7.1. Overview

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

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

The *flood frequency* approach requires a reasonably complete homogenous record of flood levels and flows over several decades to give satisfactory results. Powells Creek is one of the two catchments in the Sydney basin that has a reasonably reliable water level record over a long period and has had velocity gaugings undertaken (required to derive a rating curve). Thus, flood frequency analysis can be undertaken. However, this approach only provides results at the gauge location and a *rainfall and runoff routing* approach, using DRAINS model results, is also required to derive inflow hydrographs to the TUFLOW hydraulic model, which determines design flood levels, flows and velocities in areas beyond the actual gauge location. This approach reflects current engineering best practice and is consistent with the quality and quantity of available data.

7.2. Critical Duration for Rainfall Runoff Approach

To determine the critical storm duration for various parts of the catchment, modelling of the range of design events was undertaken using temporal patterns from ARR2019 with the approach described in Section 3.3.7. The adopted critical storm durations are provided in Table 20.

Table 20: Adopted Critical Storm Duration Events

Design Rainfall Event	Adopted Critical Storm Duration
0.5EY	45 minutes
20% AEP	45 minutes
10% AEP	60 minutes
5% AEP	60 minutes
2% AEP	60 minutes
1% AEP	60 minutes
0.5% AEP	60 minutes
0.2% AEP	60 minutes
PMF	60 minutes

7.3. Downstream Boundary Conditions

In addition to runoff from the catchment, downstream areas can also be influenced by high water levels at the confluence of the Parramatta River and Powells Creek. Consideration must therefore also be given to accounting for the joint probability of coincident flooding from both catchment runoff and backwater effects.

A full joint probability analysis to consider the interaction of these two mechanisms is beyond the scope of the present study. It is accepted practice to estimate design flood levels in these situations using a 'peak envelope' approach that adopts the highest of the predicted levels from the two mechanisms. However, the 1986 Parramatta River Flood Study (Reference 13) indicates that in this reach of the river the design water level is determined by the tide level and no design flood levels are provided. For the present study, a constant water level of was applied to the downstream boundary for each design rainfall event as shown on Table 21. The typical tidal in Homebush Bay is +0.6 m AHD to -0.4 m AHD and the maximum ocean tide in a year is 1.1 m AHD.

Table 21: Adopted Tailwater Levels for Design Events

Design Rainfall Event (AEP)	Downstream Design Level (AEP)	Downstream Water Level (m AHD)
0.5EY	0.5EY	1.2
20%	20%	1.2
10%	10%	1.2
5%	5%	1.4
2%	5%	1.4
1%	5%	1.4
0.5%	1%	1.43
0.2%	1%	1.43
PMF	1%	1.43

7.4. Design Results

The results from this study are presented on figures as summarised below.

- Peak flood level profiles in Figure 15.
- Peak flood depths and level contours in Figure 16.
- Peak flood velocities in Figure 17.
- Provisional hydraulic hazard in Figure 18 and
- Provisional hydraulic categorisation in Figure 19.

The definition and methodology used to derive these categorisations from the results are discussed below.

7.4.1. Summary of Results

Peak flood levels, depths and velocities at key locations within the catchment are summarised in Table 22, Table 23 and Table 24 for the design events. These key locations coincide with the key locations used for the sensitivity analysis discussed in Section 9 and are shown on Figure 4.

Table 25 provides the peak flows at Homebush Bay Drive for the design events.

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

ID	Location	1.0 EY	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
H01	Pedestrian Bridge 2	1.34	1.42	1.51	1.66	1.70	1.74	1.78	1.82	2.67
H02	Pedestrian Bridge 1	1.30	1.36	1.42	1.59	1.63	1.66	1.70	1.74	2.48
H03	Front of community Centre	1.97	2.00	2.01	2.02	2.03	2.03	2.06	2.15	3.55
H04	Railway underpass 2 East side	7.41	7.44	7.46	7.47	7.49	7.50	7.52	7.53	8.56
H05	Railway underpass east side	6.08	6.23	6.34	6.41	6.55	6.63	6.72	6.84	8.36
H06	Railway underpass west Side	5.88	6.06	6.14	6.20	6.32	6.36	6.43	6.52	6.58
H07	7 Concord Avenue low point	1.55	1.72	1.79	1.88	1.93	2.00	2.06	2.14	3.55
H08	George Street low point near soccer field	2.44	2.89	2.98	3.16	3.29	3.43	3.59	3.89	4.56
H09	Powells Creek @ Argonne Street	1.83	1.84	1.85	2.00	2.09	2.16	2.23	2.32	4.10
H10	Powells Creek @ Pomeroy Bridge		2.40	2.53	2.55	2.60	2.64	2.67	2.71	3.85
H11	Powells Creek @ Allen Street	2.98	3.32	3.44	3.54	3.63	3.70	3.76	3.87	5.28
H12	Powells Creek @ Brussels Street	1.69	1.79	1.87	2.02	2.11	2.19	2.25	2.34	4.12
H13	Powells Creek @ Warsaw Street	1.79	1.85	1.93	2.07	2.17	2.25	2.31	2.40	4.17

Table 23 Peak Flood Depths (m) at Key Locations – Design Events

ID	Location	1.0 EY	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
H01	Pedestrian Bridge 2	0.30	0.38	0.47	0.63	0.67	0.71	0.75	0.79	1.63
H02	Pedestrian Bridge 1	0.74	0.80	0.86	1.04	1.07	1.11	1.15	1.18	1.92
H03	Front of community Centre	0.16	0.18	0.20	0.20	0.21	0.22	0.24	0.33	1.73
H04	Railway underpass 2 East side	0.06	0.10	0.11	0.12	0.14	0.16	0.17	0.18	1.21
H05	Railway underpass east side	0.13	0.29	0.40	0.47	0.60	0.68	0.77	0.89	2.42
H06	Railway underpass west Side	0.24	0.42	0.51	0.57	0.68	0.72	0.79	0.88	0.94
H07	7 Concord Avenue low point	0.16	0.27	0.35	0.44	0.49	0.55	0.61	0.70	2.11
H08	George Street low point near soccer field	0.09	0.54	0.63	0.81	0.93	1.08	1.24	1.54	2.21
H09	Powells Creek @ Argonne Street	0.02	0.03	0.04	0.19	0.28	0.35	0.42	0.50	2.28
H10	Powells Creek @ Pomeroy Bridge		0.05	0.18	0.20	0.25	0.29	0.32	0.37	1.50
H11	Powells Creek @ Allen Street	1.36	1.71	1.83	1.92	2.02	2.09	2.14	2.25	3.66
H12	Powells Creek @ Brussels Street	0.07	0.16	0.25	0.40	0.49	0.56	0.62	0.71	2.49
H13	Powells Creek @ Warsaw Street	0.47	0.53	0.60	0.75	0.85	0.92	0.98	1.07	2.85

Table 24 Peak Flood Velocity (m/s) at Key Locations – Design Events

ID	Location	1.0 EY	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
H01	Pedestrian Bridge 2	0.10	0.09	0.10	0.14	0.18	0.21	0.22	0.25	0.80
H02	Pedestrian Bridge 1	0.57	0.16	0.65	0.93	0.93	0.93	0.96	0.96	0.95
H03	Front of community Centre	0.07	0.11	0.17	0.15	0.16	0.17	0.17	0.19	0.28
H04	Railway underpass 2 East side	1.47	1.93	2.06	2.15	2.28	2.34	2.43	2.49	2.88
H05	Railway underpass east side	0.48	0.44	0.51	0.57	0.74	0.78	0.80	0.82	1.13
H06	Railway underpass west Side	0.24	0.74	0.78	0.80	0.87	0.84	0.97	1.03	1.14
H07	7 Concord Avenue low point	0.10	0.29	0.24	0.21	0.23	0.22	0.21	0.11	0.61
H08	George Street low point near soccer field	0.02	0.39	0.34	0.35	0.33	0.37	0.37	0.40	0.23
H09	Powells Creek @ Argonne Street	0.20	0.26	0.07	0.09	0.11	0.13	0.14	0.15	0.34
H10	Powells Creek @ Pomeroy Bridge		0.24	1.67	1.81	1.88	1.81	1.53	1.64	3.26
H11	Powells Creek @ Allen Street	1.77	1.87	1.90	1.93	1.98	2.01	2.03	2.05	2.32
H12	Powells Creek @ Brussels Street	0.42	0.50	0.48	0.46	0.50	0.50	0.50	0.51	0.60
H13	Powells Creek @ Warsaw Street	0.04	0.05	0.05	0.05	0.10	0.14	0.16	0.19	0.33

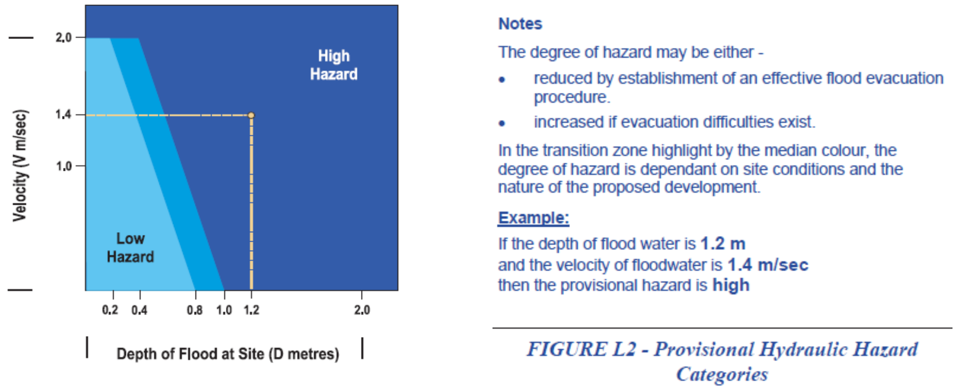
Table 25 Peak Flood flow (m^3/s) through Homebush Bay Drive Bridge – Design Events

Location	1.0 EY	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
Homebush Bay Drive Bridge	45	57	69	83	95	107	116	129	503

7.4.2. Provisional Flood Hazard Categorisation

The 2016 Powells Creek Revised Flood Study (Reference 2) defined provisional flood hazard categories in accordance with the NSW Floodplain Development Manual (Reference 6). Provisional hazards only take account of the hydraulic aspects of flood hazard; depth and velocity (Diagram 5), while true hazard takes into account additional factors such as size of flood, effective warning time, flood readiness, rate of rise of floodwaters, duration of flooding, evacuation problems, effective flood access, type of development within the floodplain, complexity of the stream network and the inter-relationship between flows.

Diagram 5: Provisional Hydraulic Hazard Categories



Extracted from The Floodplain Development Manual (Reference 6*)*

In recent years there has been several developments in the classification of hazard. *Managing the floodplain: a guide to best practice in flood risk management in Australia* (Reference 14) provides revised hazard classifications. These add clarity to the description hazard categories and what they mean in practice. This new methodology for determining hazard has been used in this study.

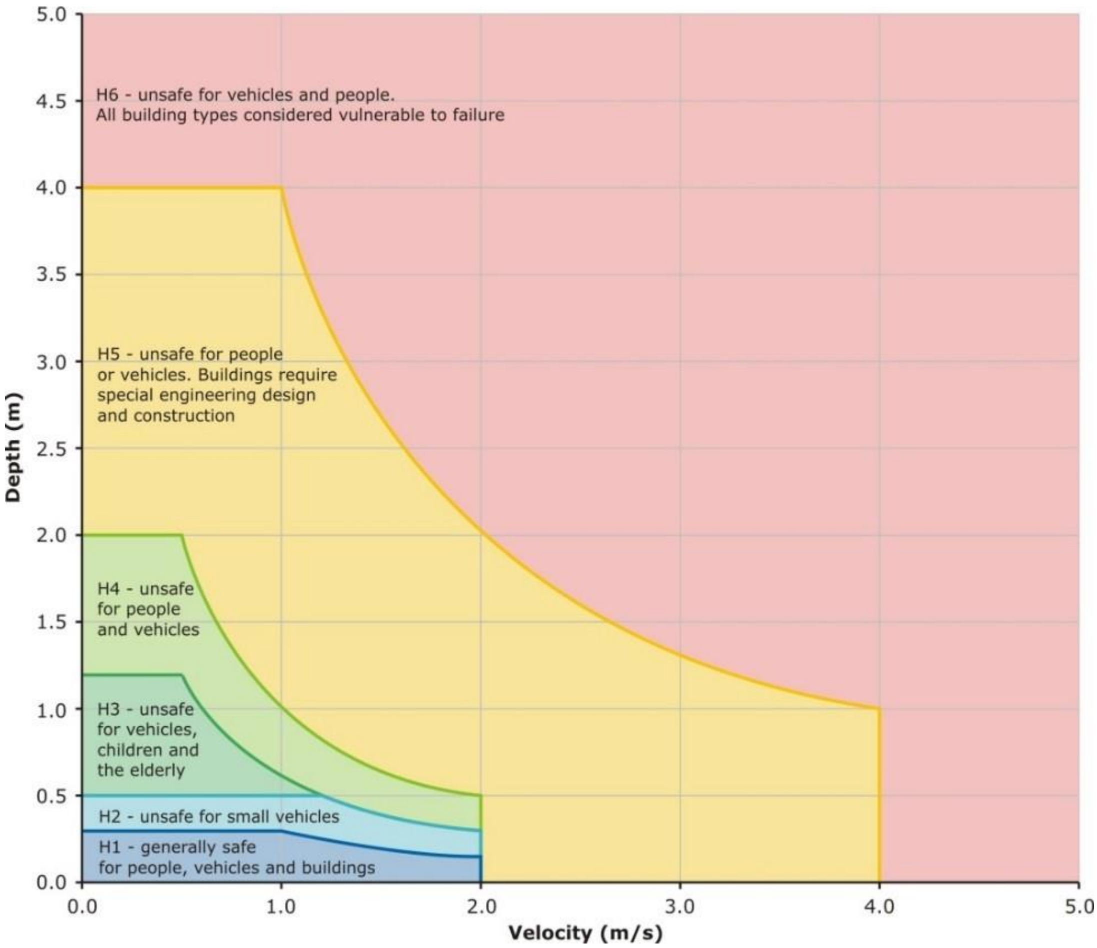
The hazard classifications are divided into six categories (Diagram 6) which indicate the restrictions on people, buildings and vehicles:

- H1 - Generally safe for vehicles, people and buildings.
- H2 - Unsafe for small vehicles.
- H3 - Unsafe for vehicles, children and the elderly.
- H4 - Unsafe for people and vehicles.
- H5 - Unsafe for people or vehicles. Buildings require special engineering design and construction, and
- H6 - Unsafe for vehicles and people. All building types considered vulnerable to failure.

Figure 18 provides the hazard classifications based on the H1 – H6 delineations for the design events. A summary of the 1% AEP (Figure 18F) mapping indicates:

- the H5 and H6 classifications are predominantly within the Powells Creek open channel;
- most of the land in the residential areas are H1 (note the land adjacent to the Powells Creek open channel may have a higher classification).

Diagram 6: Hazard Classifications (Reference 14)



7.4.3. Provisional Hydraulic Categorisation

The hydraulic categories, namely floodway, flood storage and flood fringe, are described in the Floodplain Development Manual (Reference 6). However, there is no technical definition of hydraulic categorisation that would be suitable for all catchments, and different approaches are used by different consultants and authorities, based on the specific features of the study catchment in question.

For this study, hydraulic categories were defined by the following criteria (Reference 15) which have been adopted by consultants in many flood studies in NSW:

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

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

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

7.4.4. Preliminary Flood Emergency Response Classification of Communities

The Floodplain Development Manual, 2005 (Reference 6) requires flood studies to address the management of continuing flood risk to both existing and future development areas. As continuing flood risk varies across the floodplain so does the type and scale of the emergency response problem and therefore the information necessary for effective Emergency Response Planning (ERP). Classification provides an indication of the vulnerability of the community in flood emergency response and identifies the type and scale of information needed by the SES to assist in ERP.

Criteria for determining flood ERP classifications and an indication of the emergency response required for these classifications are provided in the Floodplain Risk Management Guideline, 2007 (Reference 16). Table 26 summarises the response required for areas of different classification. However, these may vary depending on local flood characteristics and resultant flood behaviour, i.e., in flash flooding or overland flood areas.

Table 26: Flood ERP Classifications (taken from Reference 16)

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

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

ERP classification for the study area is shown in Figure 20.

8. FLOOD FREQUENCY ANALYSIS

8.1. Overview

Flood frequency analysis (FFA) enables the magnitudes of floods (5%, 1% AEP etc.) to be estimated based on statistical analysis of recorded flows. It can be undertaken graphically or using a mathematical distribution.

The reliability of the flood frequency approach depends largely upon the length and quality of the observed record and accuracy of the rating curve. In addition, flood frequency inherently accounts for many assumptions which are required in rainfall-runoff routing for determining the magnitude of floods for annual exceedance probabilities.

This approach has the following advantages in design flood estimation:

- no assumptions are required regarding the relationship between probabilities of rainfall and runoff.
- all factors affecting flood magnitude are already integrated into the data.
- estimation of rainfall losses is not required.
- confidence limits can be estimated.
- historic rainfall data is not required.

The flood frequency approach does, however, have some limitations. These are:

- there is no “perfect” distribution”, thus different distributions will provide different answers.
- as most flood records are relatively short (compared to the design event for which a magnitude is required) there is considerable uncertainty. Whilst rainfall records at a particular location are also short, data can be used by the BoM from other gauges to accurately estimate design intensities much greater than the period of record at a single gauge.
- changes to the local topography such as levee banks, hydraulic controls and the construction of retarding basins or bridges can affect the homogeneity of the data set.
- short to medium term climatic changes may influence the flood record; and
- there are many issues with the accuracy of rating curves, especially at high flows. However, this is less of an issue with the use of hydraulic models based on high quality survey (ALS) to obtain site rating curves.

While some of these factors can affect the quality of the flood frequency analysis, for the purpose of providing confirmation for the runoff routing results they are considered reasonable.

The following is a summary of the flood frequency approach undertaken in the 2016 Powells Creek Revised Flood Study (Reference 2).

8.2. Examined Annual Series

Utilising the data presented in Table 13, various data sets of annual maximum levels are available for converting to flows for the purpose of FFA. These levels can be converted into flows using one of the rating curves described in Section 3.4.2 and presented in Figure 7. Eight potential scenarios were evaluated for FFA.

8.3. Probability Distribution

ARR (Reference 5) recommends that FFA should be applied to peak flows rather than heights. In frequency analysis of flows, the fitting of a particular distribution may be carried out analytically or by fitting a probability distribution. The data may consist of an annual series, where the largest peak in each year is used, or a partial series, where all flows above a selected base value are used. The relative merits of each method are discussed in detail in ARR (Reference 5). In general, an annual series is preferable as there are more methods and experience available.

Many probability distributions have been applied to FFA and this is a very active field of research. However, it is not possible to determine the “correct” form of the distribution as there is no robust evidence that any distribution is more appropriate than another. ARR (Reference 5) provides further discussion on this issue.

Since publication of ARR (Reference 4) in 1987 there have been significant developments in the field of FFA both in Australia and overseas. The approach adopted in the 2016 Powells Creek Revised Flood Study (Reference 2) reflects these developments. Recent research has suggested that the fitting method is as important as the adopted distribution. The Flike flood frequency analysis software developed by Kuczera (Reference 17) uses the Bayesian approach and was utilised in this study.

The rating curve (height-discharge relationship) adopted for the estimation of stream flows from the recorded gauge heights is critical to the success of FFA. The FFA was conducted using the rating curve derived from the calibrated hydraulic model (refer Section 3.4).

Two probability distributions were tested, Log Pearson III (LP3) and Generalised Extreme Value (GEV) distributions and it was found that the LP3 distribution produced a better curve fit to the data.

8.4. Design Flow Results

The results of the FFA are provided on Figure 21 for the LP3 distribution. The choice of distribution was found to have some influence on design flow estimates. It was found that the LP3 distribution fit the annual series data better than the GEV distribution and was therefore selected in preference for determining design flows.

8.5. Reconciling Flood Frequency and Rainfall Runoff Results

An extensive flood frequency analysis (FFA) was carried out in the 2016 Powells Creek Revised Flood Study (Reference 2) at the Elva Street water level gauge. When compared to FFA design flow estimates (Figure 21), those from TUFLOW overestimate flows for more frequent events and generally accord with the FFA greater events.

There are many explanations as to why the flood frequency and rainfall runoff modelling do not reconcile. These are primarily due to data limitations as well as the adequacy of the hydrologic model in representing the runoff routing behaviour of the catchment. Some of the main limitations of the FFA are the limited period of record as well as rating curve errors. Due to the nature of the rating curve, high flow estimates at the Elva Street gauge are very sensitive to small changes in the water level.

In addition to potential uncertainty of the analysis it is important to realise that the flood frequency relationship may not be representative of the greater Powells Creek catchment given that the Elva Street catchment only covers a proportion of the catchment.

As FFA estimates become more uncertain for less frequent flooding such as the 1% AEP which is generally adopted for development control purposes, flow estimates from TUFLOW modelling were adopted for the current study.

9. SENSITIVITY ANALYSIS

9.1. Overview

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

- Manning's "n": The hydraulic roughness values were increased and decreased by 20%.
- Blockage (pipes): Sensitivity to blockage of all pipes was assessed for 20% and 50% blockage.
- Climate change (rainfall increase): Sensitivity to rainfall/runoff estimates were assessed by increasing the rainfall intensities by 10%, 20% and 30% as recommended under current guidelines.
- Climate change (sea level rise): Sea level rise scenarios (elevated levels in the Parramatta River) of 0.4 m and 0.9 m were assessed.
- Comparison of results with the ARR 1987 methodology 2016 Powells Creek Revised Flood Study (Reference 2).

These sensitivity scenarios were undertaken for the 1% AEP rainfall event with a tailwater level of 1.4 m AHD in the Parramatta River.

9.2. Climate Change Background

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

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

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

9.2.1. Rainfall Increase

The BoM has indicated that there is no intention at present to revise design rainfalls to take account of the potential climate change, as the implications of temperature changes on extreme rainfall intensities are presently unclear, and there is no certainty that the changes would in fact increase design rainfalls for major flood producing storms. There is some recent literature by CSIRO that suggests extreme rainfalls may increase by up to 30% in parts of NSW (in other places the projected increases are much less or even decrease); however, this information is not of sufficient accuracy for use yet (Reference 18).

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

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

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

In light of this uncertainty, the NSW State Government (Reference 18) advice recommends sensitivity analysis on flood modelling should be undertaken to develop an understanding of the effect of various levels of change in the hydrologic regime on the project at hand. Specifically, it is suggested that increases of 10%, 20% and 30% to rainfall intensity be considered.

9.2.2. Sea Level Rise

The *NSW Sea Level Rise Policy Statement* was released by the NSW Government in October 2009 (Reference 19). This Policy Statement was accompanied by the *Derivation of the NSW Government's sea level rise planning benchmarks* (Reference 20) which provided technical details on how the sea level rise assessment was undertaken. Additional guidelines were issued by OEH, including the *Flood Risk Management Guide: Incorporating sea level rise benchmarks in flood risk assessments* (Reference 21).

The Policy Statement says:

> *"Over the period 1870-2001, global sea levels rose by 20 cm, with a current global average rate of increase approximately twice the historical average. Sea levels are expected to continue rising throughout the twenty-first century and there is no scientific evidence to suggest that sea levels will stop rising beyond 2100 or that current trends will be reversed… However, the 4th Intergovernmental Panel on Climate Change in 2007 also acknowledged that higher rates of sea level rise are possible"* (Reference 19).

In light of this uncertainty, the NSW State Government's advice is subject to periodical review. As of October 2012 the NSW State Government withdrew endorsement of sea level rise predictions but still require sea level rise to be considered. This was taken as a 0.4 m rise by the year 2050 and a 0.9 m rise by the year 2100.

9.3. Results

The sensitivity scenario results were compared to the 1% AEP rainfall event and a summary of peak flood level and peak flow differences at various locations are provided in the sections below.

9.3.1. Roughness Variations

Overall peak flood level results were shown to be relatively insensitive to variations in the roughness parameter. Generally, these results were found to be within ± 0.1 m.

Table 27: Results of Roughness Variation – Change in Peak Depth (m)

ID	Location	Peak Flood Depth 5% AEP	Difference with 5% AEP (m)		Peak Flood Depth 1% AEP	Difference with 1% AEP (m)	
			Decrease roughness by 25%	Increase roughness by 25%		Decrease roughness by 25%	Increase roughness by 25%
H01	Pedestrian Bridge 2	0.63	-0.01	0.00	0.71	-0.02	0.01
H02	Pedestrian Bridge 1	1.04	-0.02	0.01	1.11	-0.02	0.01
H03	Front of community Centre	0.20	0.00	0.00	0.22	0.00	0.00
H04	Railway underpass 2 East side	0.12	-0.01	0.01	0.16	-0.01	0.01
H05	Railway underpass east side	0.47	0.00	-0.01	0.68	0.02	-0.02
H06	Railway underpass west Side	0.57	-0.01	0.01	0.72	-0.01	0.01
H07	7 Concord Avenue low point	0.44	0.00	0.00	0.55	0.00	0.00
H08	George Street low point near soccer field	0.81	0.12	-0.01	1.08	0.08	0.03
H09	Powells Creek @ Argonne Street	0.19	0.00	-0.01	0.35	0.00	-0.01
H10	Powells Creek @ Pomeroy Bridge	0.20	0.00	0.00	0.29	-0.02	0.01
H11	Powells Creek @ Allen Street	1.92	0.00	-0.01	2.09	0.00	0.00
H12	Powells Creek @ Brussels Street	0.40	0.00	-0.01	0.56	0.00	0.00
H13	Powells Creek @ Warsaw Street	0.75	0.00	-0.01	0.92	-0.01	0.00

9.3.2. Blockage Variations

Peak flood level results were found to be relatively insensitive to blockage of pipes; although generally peak flood levels increased in the upstream areas and decreased in the downstream areas (due to the retarding effect in the upstream areas).

Table 28: Results of Blockage Variation – Change in Peak Depth (m)

ID	Location	Peak Flood Depth 5% AEP	Difference with 5% AEP (m)		Peak Flood Depth 1% AEP	Difference with 1% AEP (m)	
			Decrease blockage by 25%	Increase blockage by 25%		Decrease blockage by 25%	Increase blockage by 25%
H01	Pedestrian Bridge 2	0.63	0.00	0.00	0.71	-0.01	0.00
H02	Pedestrian Bridge 1	1.04	0.00	0.00	1.11	-0.01	0.00
H03	Front of community Centre	0.20	0.00	0.00	0.22	0.00	0.00
H04	Railway underpass 2 East side	0.12	0.00	0.00	0.16	0.00	0.00
H05	Railway underpass east side	0.47	0.00	0.00	0.68	0.02	0.00
H06	Railway underpass west Side	0.57	0.00	0.00	0.72	0.01	0.00
H07	7 Concord Avenue low point	0.44	0.01	-0.02	0.55	0.02	-0.02
H08	George Street low point near soccer field	0.81	0.10	-0.21	1.08	0.14	-0.18
H09	Powells Creek @ Argonne Street	0.19	0.00	0.00	0.35	-0.01	-0.01
H10	Powells Creek @ Pomeroy Bridge	0.20	0.01	-0.01	0.29	0.00	-0.01
H11	Powells Creek @ Allen Street	1.92	0.01	-0.01	2.09	0.00	-0.01
H12	Powells Creek @ Brussels Street	0.40	0.01	0.00	0.56	-0.01	-0.01
H13	Powells Creek @ Warsaw Street	0.75	0.02	0.00	0.92	-0.02	-0.01

An additional blockage scenario investigated was the effect of 100% blockage of the culverts under Homebush Bay Drive with the results for the 1% AEP event shown on Figure 25. The figure shows that flood levels will rise by up to 0.7m. The two main areas are:

- between Victoria Avenue to the south and Concord Avenue to the north and
- the area termed Village Green surrounded by Settlers Boulevard.

9.3.3. Sea Level Rise Variations

The sea level rise scenarios were found to have an insignificant effect on peak flood levels, except in the most downstream reaches of the catchment. The open channels upstream of Underwood Road and Pomeroy Street have channel inverts of 0.35 m AHD and 0.45 m AHD (respectively) and were therefore tidally affected under current tidal conditions. Under sea level rise conditions, these locations were found to have increased peak flood levels. At Pomeroy Street the increase in peak level reduces to less than 0.1m with a 0.9m increase. The attenuation of sea level rise impacts is because of the retarding effect of the downstream mangroves and the restrictive effect of bridge structures crossing the open channel.

Table 29: Results of Sea Level Rise – Change in Peak Depth (m)

ID	Location	Peak Flood Depth 1% AEP (tailwater level of 1.4 m AHD)	Difference with 1% AEP (m)	
			Tailwater increase to 1.835 m AHD	Tailwater increase to 2.335 m AHD
H01	Pedestrian Bridge 2	0.63	0.18	0.63
H02	Pedestrian Bridge 1	1.04	0.22	0.69
H03	Front of community Centre	0.20	0.06	0.43
H04	Railway underpass 2 East side	0.12	0.00	0.00
H05	Railway underpass east side	0.47	0.00	0.00
H06	Railway underpass west Side	0.57	0.00	0.00
H07	7 Concord Avenue low point	0.44	0.10	0.46
H08	George Street low point near soccer field	0.81	0.09	0.28
H09	Powells Creek @ Argonne Street	0.19	0.13	0.46
H10	Powells Creek @ Pomeroy Bridge	0.20	0.00	0.09
H11	Powells Creek @ Allen Street	1.92	0.00	0.02
H12	Powells Creek @ Brussels Street	0.40	0.13	0.45
H13	Powells Creek @ Warsaw Street	0.75	0.12	0.42

9.3.4. Rainfall Variations

The effects of increasing the design rainfalls by 10%, 20% and 30% have been evaluated for the 1% AEP rainfall event with impacts on peak flood levels observed throughout the study area (shown in Table 30). Each incremental 10% increase in rainfall results in an approximately 0.05m to 0.08m increase in peak flood levels at most of the locations analysed. The 1% AEP event with a rainfall increase of 30% is approximately equivalent to a 0.2% AEP event in present day rainfall conditions and a significant impact on flood levels is not unexpected.

Table 30: Results of Rainfall Increase – Change in Peak Depth – 1% AEP

ID	Location	Peak Flood Depth 1% AEP	Difference with 1% AEP (m)		
			10% Rainfall increase	20% Rainfall increase	30% Rainfall increase
H01	Pedestrian Bridge 2	0.63	0.03	0.06	0.09
H02	Pedestrian Bridge 1	1.04	0.03	0.05	0.08
H03	Front of community Centre	0.2	0.02	0.08	0.14
H04	Railway underpass 2 East side	0.12	0.01	0.02	0.03
H05	Railway underpass east side	0.47	0.08	0.16	0.21
H06	Railway underpass west Side	0.57	0.07	0.11	0.14
H07	7 Concord Avenue low point	0.44	0.06	0.11	0.18
H08	George Street low point near soccer field	0.81	0.22	0.33	0.48
H09	Powells Creek @ Argonne Street	0.19	0.06	0.12	0.18
H10	Powells Creek @ Pomeroy Bridge	0.2	0.03	0.06	0.09
H11	Powells Creek @ Allen Street	1.92	0.05	0.13	0.2
H12	Powells Creek @ Brussels Street	0.4	0.06	0.12	0.18
H13	Powells Creek @ Warsaw Street	0.75	0.05	0.12	0.18

9.3.5. Comparison of 1% AEP Results with the 2016 Powells Creek Revised Flood Study (Reference 2)

A comparison of the 1% AEP peak levels and peak flows are provided in Table 31. The results indicate that along Powells Creek (where levels are available from Reference 2) there is a slight increase in peak level. This has occurred due to slightly different modelling approaches adopted (refer Sections 4 and 5).

Table 31: Comparison of 1% AEP Results with 2016 Powells Creek Revised Flood Study (Reference 2)

ID	Location	Present Study Peak Level (m AHD)	Reference 2 Peak Level (m AHD)	Present Study Peak Flow (m³/s)	Reference 2 Peak Flow (m³/s)
H01	Pedestrian Bridge 2	1.74	1.60	-	-
H02	Pedestrian Bridge 1	1.66	1.45	-	-
H03	Front of community Centre	2.03	NF	-	-
H04	Railway underpass 2 East side	7.50	NF	-	-
H05	Railway underpass east side	6.63	NF	-	-
H06	Railway underpass west Side	6.36	NF	-	-
H07	7 Concord Avenue low point	2.00	NF	-	-
H08	George Street low point near soccer field	3.43	NF	-	-
H09	Powells Creek @ Argonne Street	2.16	2.09	36.33	31.16
H10	Powells Creek @ Pomeroy Bridge	2.64	2.47	78.01	78.37
H11	Powells Creek @ Allen Street	3.70	3.55	55.04	60.65
H12	Powells Creek @ Brussels Street	2.19	2.12	47.58	69.95
H13	Powells Creek @ Warsaw Street	2.25	2.22	78.3	82.57

10. FLOOD PLANNING ISSUES

10.1. Preliminary Flood Planning Areas

10.1.1. Background

Land use planning is one of the most effective means of minimising flood risk and damages from flooding. The Flood Planning Area (FPA) identifies land that is subject to flood related development controls via Section 10.7 notifications under the 1979 EP&A Act. The Flood Planning Level (FPL) is the minimum floor level applied to new developments within the FPA.

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

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

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

The Floodplain Development Manual (Reference 6) suggests that the FPL generally be based on the 1% AEP event plus an appropriate freeboard. The typical freeboard cited in the manual is that of 0.5 m; however, it also recognises that different freeboards may be deemed more appropriate due to local conditions. In these circumstances, some justification is called for where a lower value is adopted.

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

10.1.2. Methodology and Criteria

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

- **Mainstream flooding:** Any property within the open channel section of Powells Creek that has land below the peak 1% AEP flood level plus a 0.5 m freeboard, with the level extended perpendicular to the flow direction.

- **Overland flooding:** Peak flood depth of greater than 0.15 m in the 1% AEP.

In situations where a cadastral lot is subject to both mainstream flooding and overland flooding, the mechanism that produces the highest FPL should be taken.

10.1.3. Results

The provisional FPA is shown in Figure 22. The mainstream and overland flood affectation was limited to the Canada Bay LGA portion of the Powells Creek catchment. A total of 217 properties were identified for flood related development controls in Canada Bay as follows:

- Mainstream only 20
- Overland only 136
- Mainstream & overland 61

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

It should be noted that the above approach does not include any sea level rise component. This information can be obtained from Table 29.

10.2. Cumulative Impact Assessment

Cumulative impact assessment was introduced to determine and address the small increases in flood level resulting from catchment wide development. Each development will cause an increase in flood level and whilst this is small, when the entire catchment is developed, the cumulative impacts may result in significant increases in flood level, thus adversely affect floodplain users.

However, the value of cumulative impact assessment has been significantly reduced as Councils now can ensure all private and public developments undertake a rigorous flood impact assessment. The threshold that is adopted is generally taken as no increase in the 1% AEP flood level by greater than 0.01m. This threshold means that the cumulative impact of all developments will still be very small.

10.3. Flood Risk Precincts

Figure 24 provides the flood risk precincts which are defined as follows:

High Flood Risk Precinct = Land within the 1% AEP Hazard categories H4, H5 and H6.
Medium Flood Risk Precinct = Remaining land within the 1% AEP extent and not in the High Flood Risk precinct.
Low Flood Risk Precinct = All land outside the 1% AEP and within the PMF extent.

11. ECONOMIC IMPACTS OF FLOODING

11.1. Overview

The impact of flooding can be quantified through the calculation of flood damages. Flood damage calculations do not include all impacts associated with flooding (for example it does not include worry, risk to life or injury). They do, however, provide a basis for assessing the economic loss of flooding and a non-subjective means of assessing the merit of flood mitigation works such as retarding basins, levees, drainage enhancement etc. The quantification of flood damages is an important part of the floodplain risk management process. By quantifying flood damages for a range of design events, appropriate cost-effective management measures can be analysed in terms of their benefits (reduction in damages) versus the cost of implementation. The cost of damage and the degree of disruption to the community caused by flooding depends upon many factors including:

- The magnitude (depth, velocity, and duration) of the flood.
- Land use and susceptibility to damages.
- Awareness of the community to flooding.
- Effective warning time.
- The availability of an evacuation plan or damage minimisation program.
- Physical factors such as failure of services (sewerage), flood borne debris, sedimentation, and
- The types of assets and infrastructure affected.

The estimation of flood damages tends to focus on the physical impact of damages on the human environment but there is also a need to consider the ecological cost and benefits associated with flooding. Flood damages can be defined as being tangible or intangible. Tangible damages are those for which a monetary value can be easily assigned, while intangible damages are those to which a monetary value cannot easily be attributed. Types of flood damages are shown in Table 32.

Table 32: Categories of Flood Damages

DAMAGE FROM FLOODING

- **TANGIBLE** → **FINANCIAL**: Costs which can be expressed in dollars.
  - **DIRECT**: Damage caused by floodwaters coming into contact with items. This can be expressed as "Potential" (max. damage) and "Actual" (reduced damages due to moving items).
    - INTERNAL, EXTERNAL, STRUCTURAL
  - **INDIRECT**: Costs associated with the flood event occurring, but not as readily quantifiable.
    - CLEANUP, FINANCIAL, OPPORTUNITY
- **INTANGIBLE** → **SOCIAL**: Costs which cannot be expressed in dollars, eg:
  - stress,
  - loss of life,
  - serious injury,
  - depression,
  - inconvenience,
  - insecurity.

	INTERNAL	EXTERNAL	STRUCTURAL	CLEANUP	FINANCIAL	OPPORTUNITY
RESIDENTIAL	Contents of Buildings: Clothes, Carpets, Furniture, Valuables, Fittings, Appliances	External Items: Vehicles, Laundries, Caravans, Sheds, Tools, Gardens, Fences	Physical Damage to Buildings: Gyprock, Cupboards, Scour of Footings, Houses becoming buoyant (floating off footings)	Clean Carpets, Walls, Clothes; Re-instate Furniture; Remove Mud and Debris	Loss of wages, Living costs (temporary accomodation and food), Time to repair/replace damaged items	Not Applicable
RURAL	Contents of Buildings: Clothes, Carpets, Furniture, Valuables, Fittings, Appliances	External Items: Vehicles, Sheds (stables/barns), Machinery, Tools, Fences, Feed storage, Saddles, Crops &/or Stock, Irrigation Systems	Physical Damage to Structures: Damage to Homestead, Sheds, Access tracks, Protection levees	Clean Homestead and Out-buildings; Remove Debris; Dispose of affected crops &/or stock	Loss of Farm Production and Income, Re-instatement of Pastures, Supplementary feeding of stock (by hand or outside agistment), Stock movement/ transport, Living costs (temporary accomodation and food)	Sowing or harvesting of Crops, Sale of Stock (at depreciated value or dependent on market influences)
COMMERCIAL	Contents of Buildings: Products, Stock, Fittings, Tools, Machinery, Raw Materials	External Items: Vehicles, Machinery, Display, Raw Materials/Stockpiles, Fences	Physical Damage to Buildings	Dispose of damaged products, stock, materials; Cleaning and Re-instatement	Loss of Productivity and Income, Bank Interest Charges	Loss of existing &/or Potential Trade
PUBLIC AUTHORITIES	Contents of Public Buildings and Facilities	Public Property and Facilities: Parks, Signs, Machinery, Equipment	Physical Damage to Infrastructure: Electricity, Water, Telephone, Gas, Road & Rail Transport Links	Remove Mud & Debris from Facilities, Public & Private Property Repairs (temporary & permanent)	Disruption of Services, Community Service Relief Grants	Provision of Public Service

11.2. Tangible Flood Damages

Tangible flood damages are comprised of two basic categories; direct and indirect damages (refer Table 32). Direct damages are caused by floodwaters wetting goods, structures and possessions thereby damaging them and resulting in either costs to replace or repair or in a reduction to their value. Direct damages are further classified as either internal (damage to the contents of a building including carpets, furniture), structural (referring to the structural fabric of a building such as foundations, walls, floors, windows) or external (damage to all items outside the building such as cars, garages). Indirect damages are the additional financial losses caused by the flood for example the cost of temporary accommodation, loss of wages by employees, etc.

Given the variability of flooding and property and content values, the total likely damages figure in any given flood event is useful to get a feel for the magnitude of the flood problem, however it is of limited value for absolute economic evaluation. Flood damage estimates are also useful when studying the economic effectiveness of proposed mitigation options, however difficulties arise when trying to assess intangible damages such as loss of life or inconvenience. Understanding the total damages prevented over the life of the option in relation to current damages, or to an alternative option, can assist in the decision-making process.

The standard way of expressing flood damages is in terms of average annual damages (AAD). AAD represents the equivalent average damages that would be experienced by the community on an annual basis, by considering the probability of a flood occurrence. This means the smaller floods, which occur more frequently, are given a greater weighting than the rare catastrophic floods.

To quantify the damages caused by inundation for existing development a floor level survey was undertaken (see Section 2.6). This was used in conjunction with modelled flood level information from the updated flood information (Section 7.4) to calculate damages. Damage calculations were carried out for all properties within the PMF extent.

The damages were calculated using height-damage curves which relate the depth of water above the floor with tangible damages. Each component of tangible damages is allocated a maximum value and a maximum depth at which this value occurs. Any flood depths greater than this allocated value do not incur additional damages as it is assumed that, by this level, all potential damages have already occurred.

Damages were calculated for residential and commercial/industrial properties, discussed separately below. This flood damages estimate does not include the cost of restoring or maintaining public services and infrastructure. It should be noted that damages calculations do not consider flood damages to any basements or cellars, hence where properties have basements, damages can be underestimated.

11.2.1. Residential Properties

Residential properties suffer damages from flooding in several ways. Direct damages include loss of property contents and/or damage to the structure of the property. Indirect damage costs can be incurred when property occupiers live elsewhere while repairs are being made. A flood damages assessment for residential properties was undertaken for the floor level data obtained by the methods outlined in Section 2.6. A summary of the flood damages assessment is provided in Table 33 with the properties shown on Figure 23.

Table 33: Flood Damages (Residential)

Event	No. Properties Affected	No. Flooded Above Floor Level	Total Damages for Event	% Contribution to AAD	Ave. Damage Per Flood Affected Property
20% AEP	60	8	$ 622,000	31	$ 10,000
10% AEP	69	10	$ 820,000	24	$ 12,000
5% AEP	81	13	$ 1,107,000	16	$ 14,000
2% AEP	94	18	$ 1,507,000	13	$ 16,000
1% AEP	100	20	$ 1,821,000	6	$ 18,000
0.5% AEP	117	22	$ 2,026,000	3	$ 17,000
0.2% AEP	132	25	$ 2,261,000	2	$ 17,000
PMF	366	133	$ 13,212,000	5	$ 36,000
Average Annual Damages (AAD)			$ 301,000		$ 1,000

Table 33 indicates a moderate degree of flood liability for more frequent events with 20 residential properties flooded above floor level in the 1% AEP event with the properties shown on Figure 23. In the PMF there are an estimated 133 residential properties flooded above floor level indicating a significant degree of flood risk and associated flood damages. On average, flooding to residential properties in the study area catchment costs Council and the community approximately $300,000 per annum.

11.2.2. Non-Residential – Commercial and Industrial

Non-residential land uses in the study area are predominantly situated on land above the extent of inundation from mainstream flooding from Powells Creek. As overland flow is general shallow depth the extent of damages is relatively small.

Non-residential properties are affected either directly by flood damage or indirectly by loss of business due to restricted customer and/or employee access. Costs vary significantly depending on the type of activity.

- Type of business – stock based or not, costs of damages to goods.
- Duration of flooding – affects how long a business may be closed for not just whether the business itself is closed, but when access to it is restored.
- Ability to move stock or assets before onset of flooding. Some large machinery will not be able to be moved and in other instances there may be insufficient warning time to move stock to dry locations; and
- Ability to transfer business to a temporary location.

Table 34: Flood Damages (Commercial and Industrial)

Event	No. Properties Affected	No. Flooded Above Floor Level	Total Damages for Event	% Contribution to AAD	Ave. Damage Per Flood Affected Property
20% AEP	10	2	$ 163,000	27	$ 16,000
10% AEP	13	4	$ 270,000	24	$ 21,000
5% AEP	17	5	$ 407,000	19	$ 24,000
2% AEP	23	6	$ 477,000	15	$ 21,000
1% AEP	24	7	$ 588,000	6	$ 25,000
0.5% AEP	25	8	$ 626,000	3	$ 25,000
0.2% AEP	25	9	$ 721,000	2	$ 29,000
PMF	36	21	$ 2,103,000	3	$ 58,000
Average Annual Damages (AAD)			$ 89,000		$ 2,000

A summary of the flood damages assessment for commercial and industrial properties is provided in Table 34 with the properties shown on Figure 23. Table 34 indicates relatively limited flood liability for non-residential properties.

11.2.3. Critical Infrastructure and Vulnerable Facilities

Public sector (non-building) damages include recreational/tourist facilities; water and sewerage supply; gas supply; telephone supply; electricity supply including transmission poles/lines, sub-stations, and underground cables; rail; roads and bridges including traffic lights/signs; and costs to employ emergency services and assist in cleaning up. Public sector damages can contribute a significant proportion to total flood costs but are difficult to accurately calculate or predict.

Costs to Councils from flooding typically comprise;

- Clean-up costs.
- Erosion and siltation.
- Drain cleanout and maintenance.
- Removing fallen trees.
- Inundation of Council buildings.
- Direct damage to roads, bridges and culverts.
- Removing vehicles washed away.
- Assistance to ratepayers.
- Increases in insurance premiums.
- Closures of streets.
- Loss of working life of road pavements; and
- Operational costs following and during flood events.

There are three vulnerable properties in the catchment which are described below the 1% AEP flood extent and another three properties are within the PMF extent as shown Table 35.

Table 35: Vulnerable Properties within the Floodplain

Type	Address	Flood- Affectation	PMF-Hazard	1% AEP-Hazard
Aged Care	124/23 George Street	No		
Child Care	31B George Street	Yes	1	0
Child Care	27/29 George Street	No		
Child Care	13 George Street	Yes	1	0
Church	3-5 Carrington Street	No		
Church	15 George Street	No		
Church	2A Napier Street	No		
College	17 George Street	No		
Community Centre	64-66 Victoria Street	Yes	5	2
Medical Practice	27/29 George Street	No		
Medical Practice	117 Queen Street	No		
School	345-347 Queen Street	No		
School	1/23 George Street	No		
School	1A Hamilton Street East	Yes	1	1
School	3 Bakehouse Lane	Yes	3	0
School	64-66 Victoria Street	Yes	5	1

Note: The Hazard shown is the highest / peak hazard on the whole property (lot) and it may be only a small part of the land affected. Individual lot information can be obtained from Council.

Flooding to schools, and to similar institutions, would have different impacts depending on the time of day and obviously during school hours response would be more critical due to the number of persons on the site. It is important that the affected schools have effective flood plans implemented.

11.2.4. Basement Car Parks

In the last 10+ years there has been an increasing construction of basement car parks for residential (unit and detached housing) and to a lesser extent for commercial buildings. No assessment of the damages to underground car parks has been undertaken.

11.3. Intangible Flood Damages

The intangible damages associated with flooding, by their nature, are inherently more difficult to estimate in monetary terms. In addition to the tangible damages discussed previously, additional costs/damages are incurred by residents affected by flooding, such as stress, risk/loss to life, injury, loss of sentimental items, etc. It is not possible to put a monetary value on the intangible damages as they are likely to vary dramatically between each flood (from a negligible amount to several hundred times greater than the tangible damages) and depend on a range of factors such as the size of flood, the individuals affected, and community preparedness. However, it is still important that the consideration of intangible damages is included when considering the impacts of flooding on a community.

Post-flood damages surveys in mainly rural areas (the effect in urban areas such as Woolooware Bay is likely to be much less) have linked flooding to stress, ill-health, and trauma for the residents. For example, the loss of memorabilia, pets, insurance papers and other items without fixed costs and of sentimental value may cause stress and subsequent ill-health. In addition, flooding may affect personal relationships and lead to stress in domestic and work situations. As well as the stress caused during an event (from concern over property damage, risk to life for the individuals or their family, clean up, etc.) many residents in rural areas who have experienced a major flood are fearful of the occurrence of another flood event and the associated damage (this impact is less so in urban areas). The extent of the stress depends on the individual and although most flood victims recover, these effects can lead to a reduction in quality of life for the flood victims.

Flood affectation to many of the critical infrastructure and vulnerable facilities may also result in significant intangible damages. For example, damage to service supply (water, sewage) will affect households as will the temporary closure of schools or childcare facilities as repairs are carried out. The flood affectation to these facilities will not necessarily occur at the site of the facility. Thus, just because the facility is not directly affected by flooding does not mean that flooding will not have a bearing on the facilities activities and the resulting community. For example, with schools, childcare and aged care the main issue is with access to the facility, and this may be some distance from the building.

With service infrastructure (sewer, water, electricity) the main facility will likely not be directly affected by floodwaters, but the supply will be affected by say fallen trees hitting power lines or closure of the sewer system as floodwaters are entering the system in the flooded area. Many of these affectations to the critical infrastructure and vulnerable facilities are variable and will not necessarily occur in all floods or at the same locations. It is only through review of past floods that the true affectation to critical infrastructure and vulnerable facilities can be addressed.

12. HOTSPOT DISCUSSION

Hotspots are defined as those locations where there is a known flood issue. They are identified by considering accounts of previous floods and by examining the flood behaviour. The latter involves identifying areas of high hazard flow where flooding of property occurs frequently, where inundation of main roads occurs and through consideration of subsurface drainage capacity. The identification of hotspots is largely based upon the results from this study as there is only limited historical data. As floods occur a review of these hotspot areas should be undertaken.

It should be noted that this report is a Flood Study and merely describes the issues which should be investigated in detail in the subsequent Floodplain Risk Management Study and Plan.

A. **Victoria Avenue underpass** (Photo 3). The issue at this area is that runoff from the east flows west down Victoria Avenue, reaching the underpass but high ground on the west side of Homebush Bay Drive prevents adequate drainage to escape into Homebush Bay. Runoff ponds in the relatively low-lying land to the north of the road and east of Homebush Bay Drive. Additional culverts under Homebush Bay Drive are likely to be cost prohibitive and whilst the west side of Homebush Bay Drive is predominantly open space, it would be expensive to create an open swale to discharge floodwaters to the Powells Creek channel due to the heavy vegetation and road network.

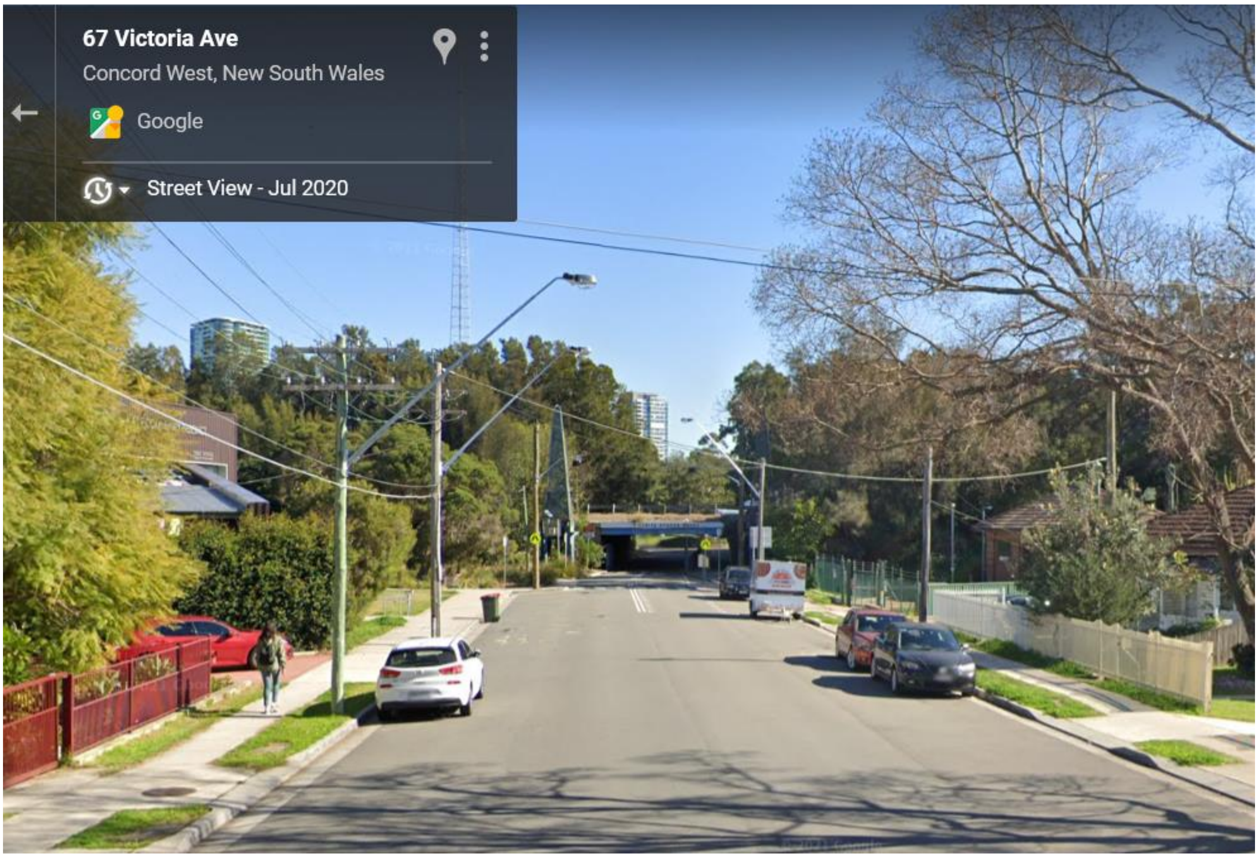


Photo 3: Victoria Avenue underpass

B. **George Street sag point** (Photo 4). This sag point is a known hot spot created by construction of the building on the west side leaving no exit path for overland flow collecting at the low point. There is no simple solution to this problem until redevelopment of the building is undertaken. Fortunately, the impact of flooding is confined to the road and the building itself. The simplest mitigation strategy is to flood proof inlets to the building.

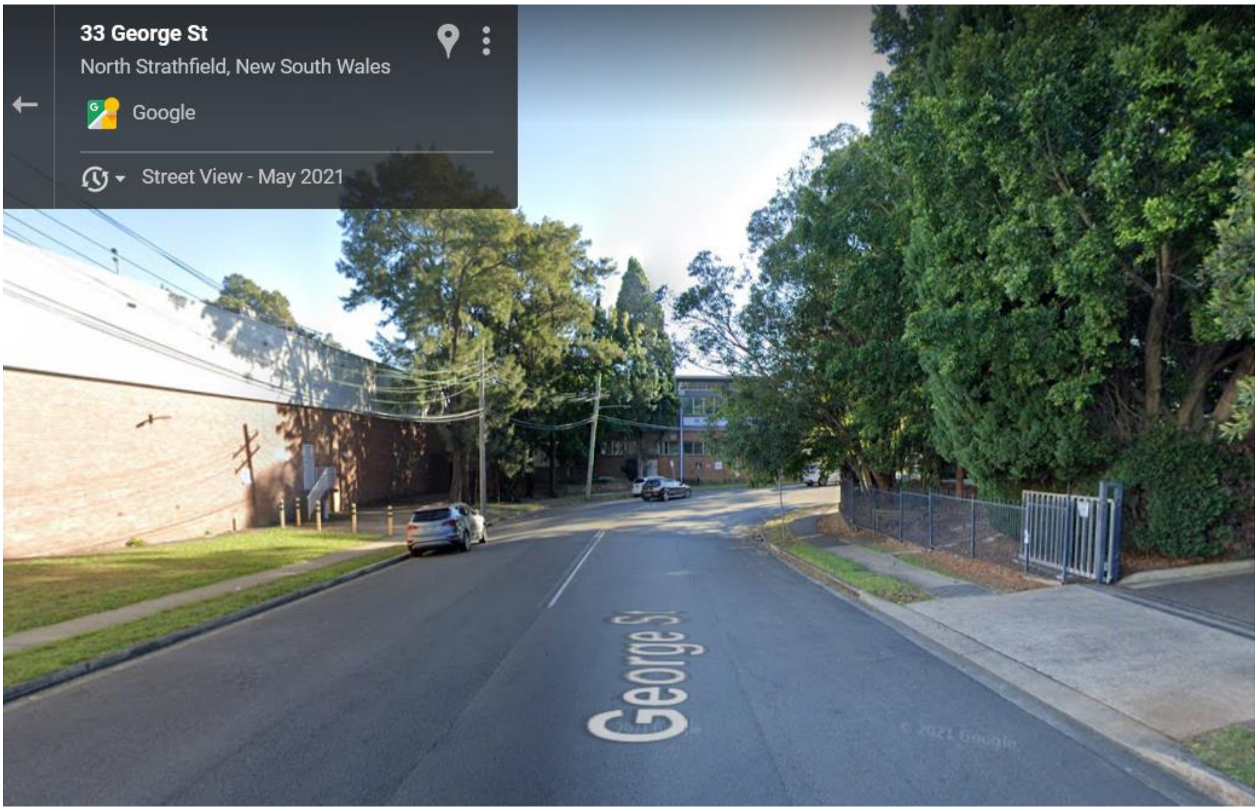


Photo 4: George Street sag point

C. **Adjacent to Powells Creek Channel** (Brussels Street to Allen Street - Photo 5). In a large flood, greater than the 1% AEP, all properties adjacent to the Powells Creek channel within Canada Bay LGA will be subject to inundation with some above floor inundation. There is relatively easy access to high ground by moving to the east but there will be yard and building damages as well as risk to life issues. Whilst Sydney Water has relined the channel in the last 5 years this has not resulted in increased flow capacity. There is also no proposal to increase the capacity as this would require purchase of private properties.

   Re-development is the only practical solution as this would ensure that the buildings are constructed with floors levels at the required flood planning levels.

Photo 5: Adjacent to Powells Creek Channel (Brussels Street to Allen Street)

D. **Raw Square Rail Underpass** (Photo 6): This location is on the boundary with Strathfield Municipal Council. Typically, all road and rail underpasses are sag points which collect runoff and thus are inundated in floods causing significant traffic disruption though no or very little damage to property. There is no simple solution to this issue as the road level is below the surrounding ground level and thus runoff cannot drain effectively by gravity. Constructing additional pipes will provide some benefit but will be technically difficult and expensive.

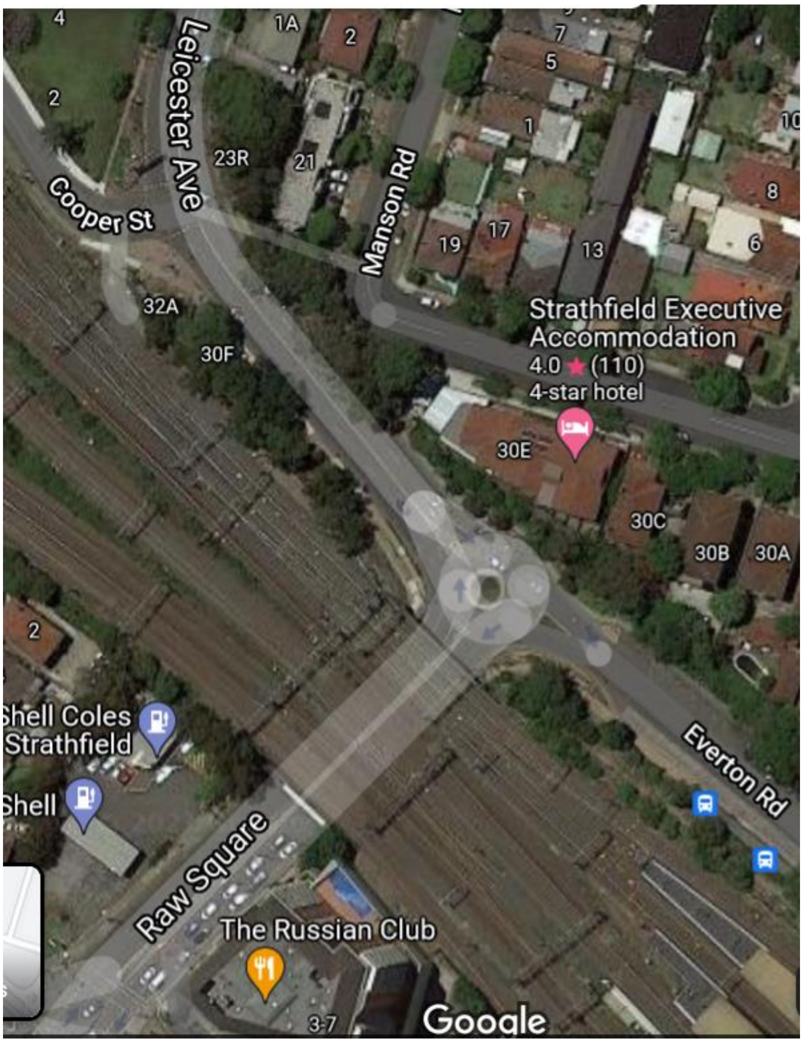


Photo 6: Raw Square Rail Underpass

13. ACKNOWLEDGEMENTS

The City of Canada Bay Council and the State Government funded this report. The assistance of the following in providing data and guidance to the study is gratefully acknowledged.

- City of Canada Bay Council.
- Strathfield Municipal Council.
- Burwood Council.
- Sydney Water.
- Bureau of Meteorology.
- Residents of the Powells Creek catchment.

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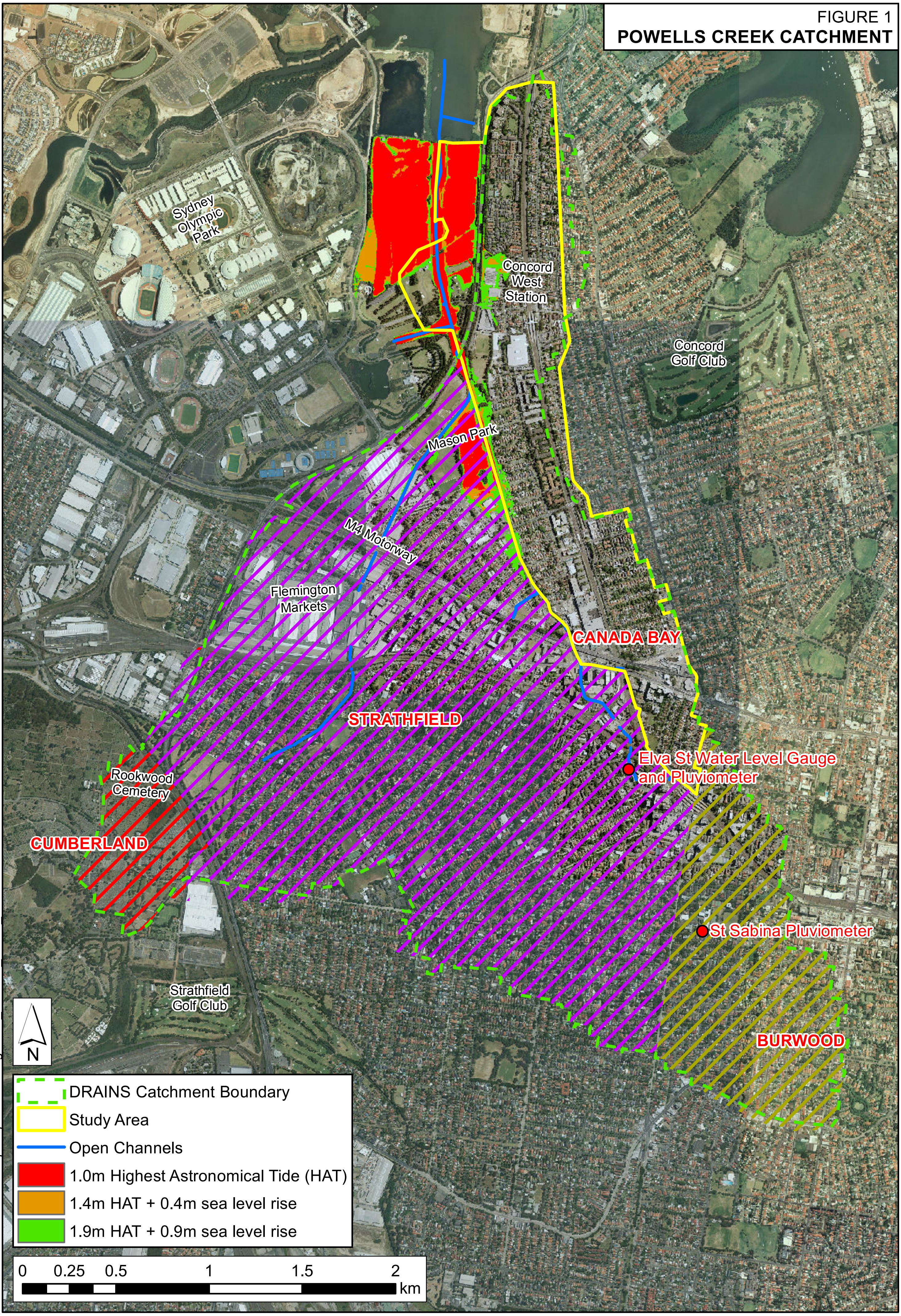
Figures



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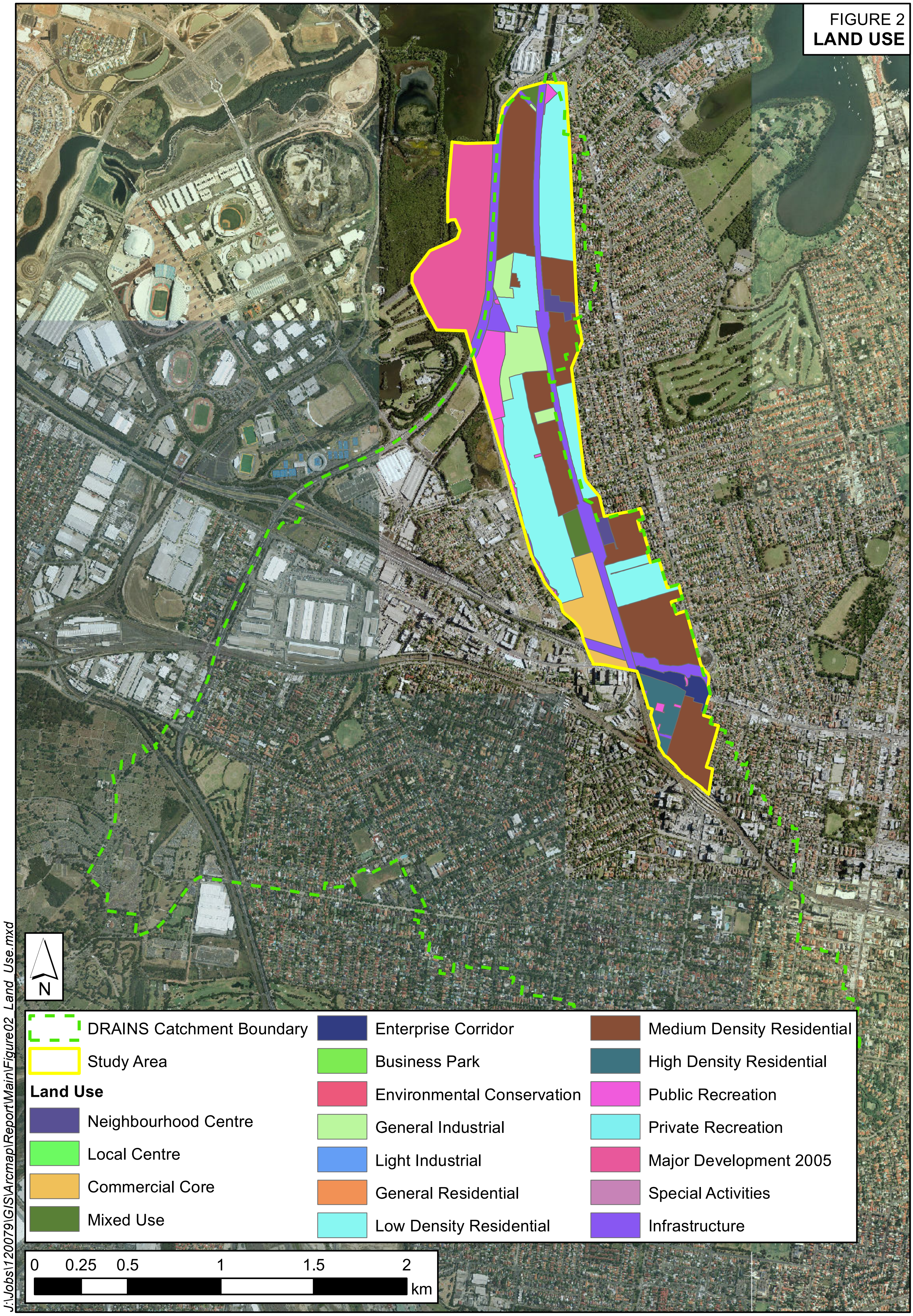


FIGURE 2
LAND USE
N
DRAINS Catchment Boundary
Study Area
Land Use
Neighbourhood Centre
Local Centre
Commercial Core
Mixed Use
Enterprise Corridor
Business Park
Environmental Conservation
General Industrial
Light Industrial
General Residential
Low Density Residential
Medium Density Residential
High Density Residential
Public Recreation
Private Recreation
Major Development 2005
Special Activities
Infrastructure
0 0.25 0.5 1 1.5 2
km
J:\Jobs\120079\GIS\Arcmap\Report\Main\Figure02_Land_Use.mxd

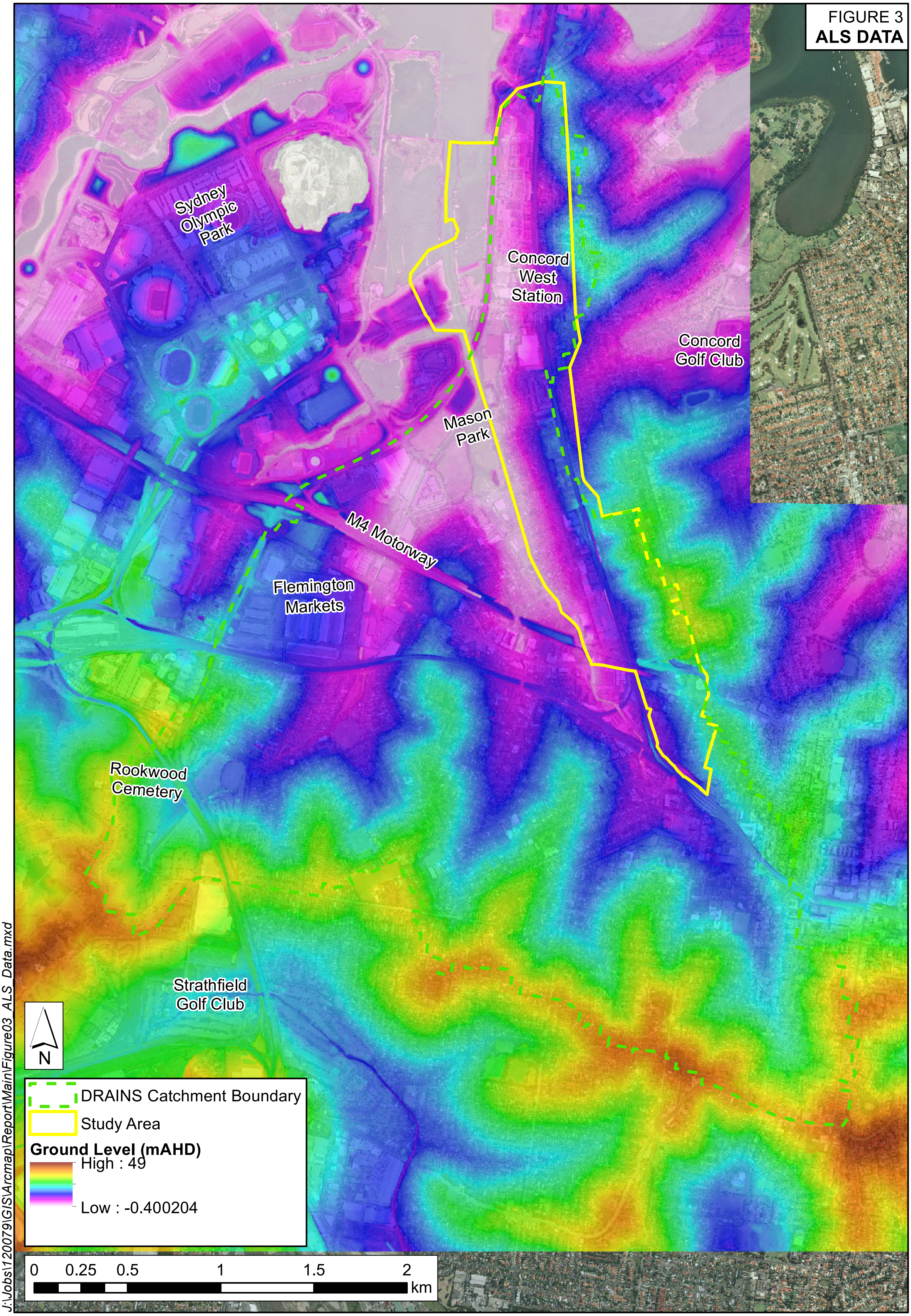
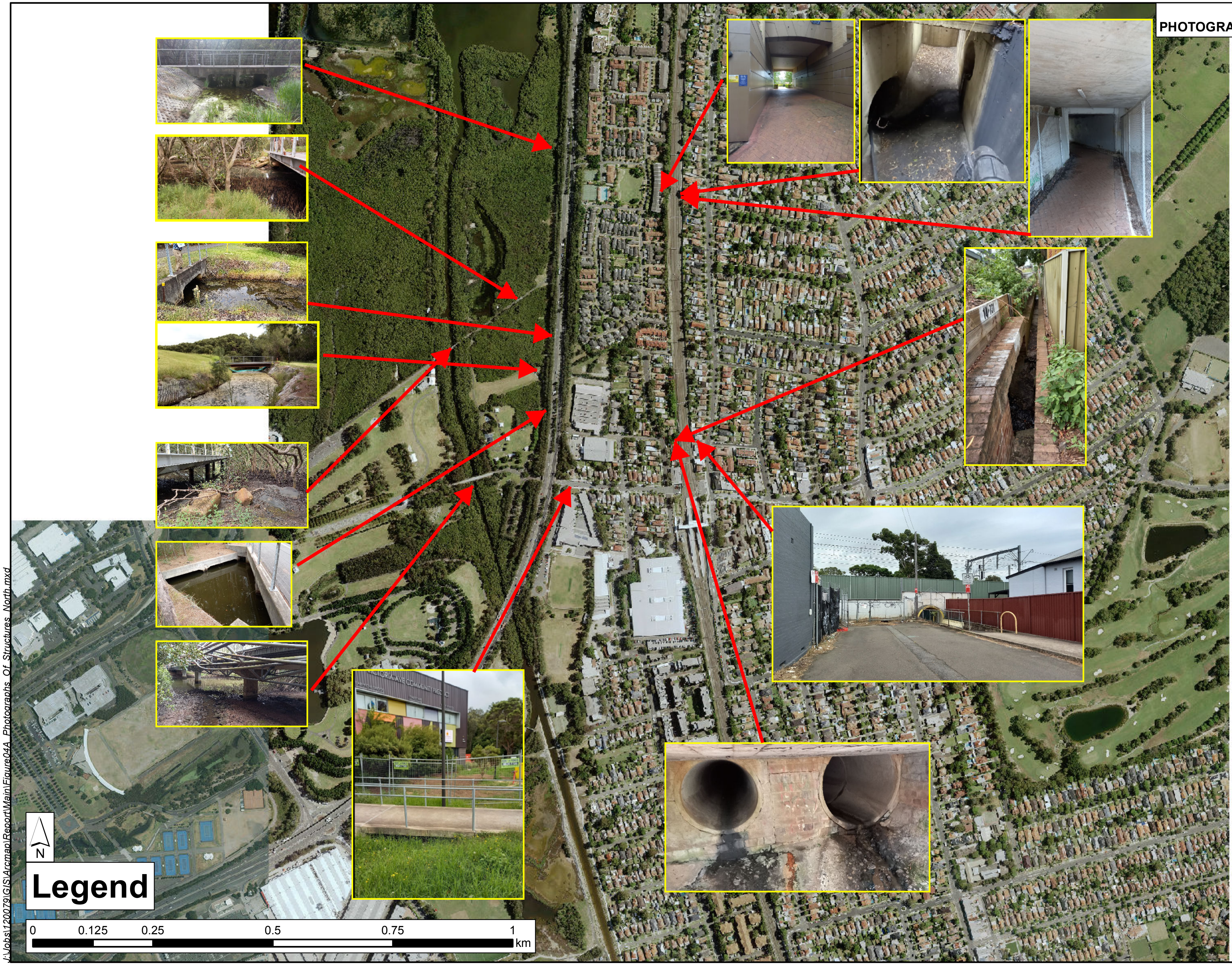


FIGURE 3
ALS DATA
Sydney Olympic Park
Concord West Station
Concord Golf Club
Mason Park
M4 Motorway
Flemington Markets
Rookwood Cemetery
Strathfield Golf Club
N
DRAINS Catchment Boundary
Study Area
Ground Level (mAHD)
High : 49
Low : -0.400204
0
0.25
0.5
1
1.5
2
km
J:\Jobs\120079\GIS\Arcmap\Report\Main\Figure03_ALS_Data.mxd

FIGURE 4A
PHOTOGRAPHS OF STRUCTURES



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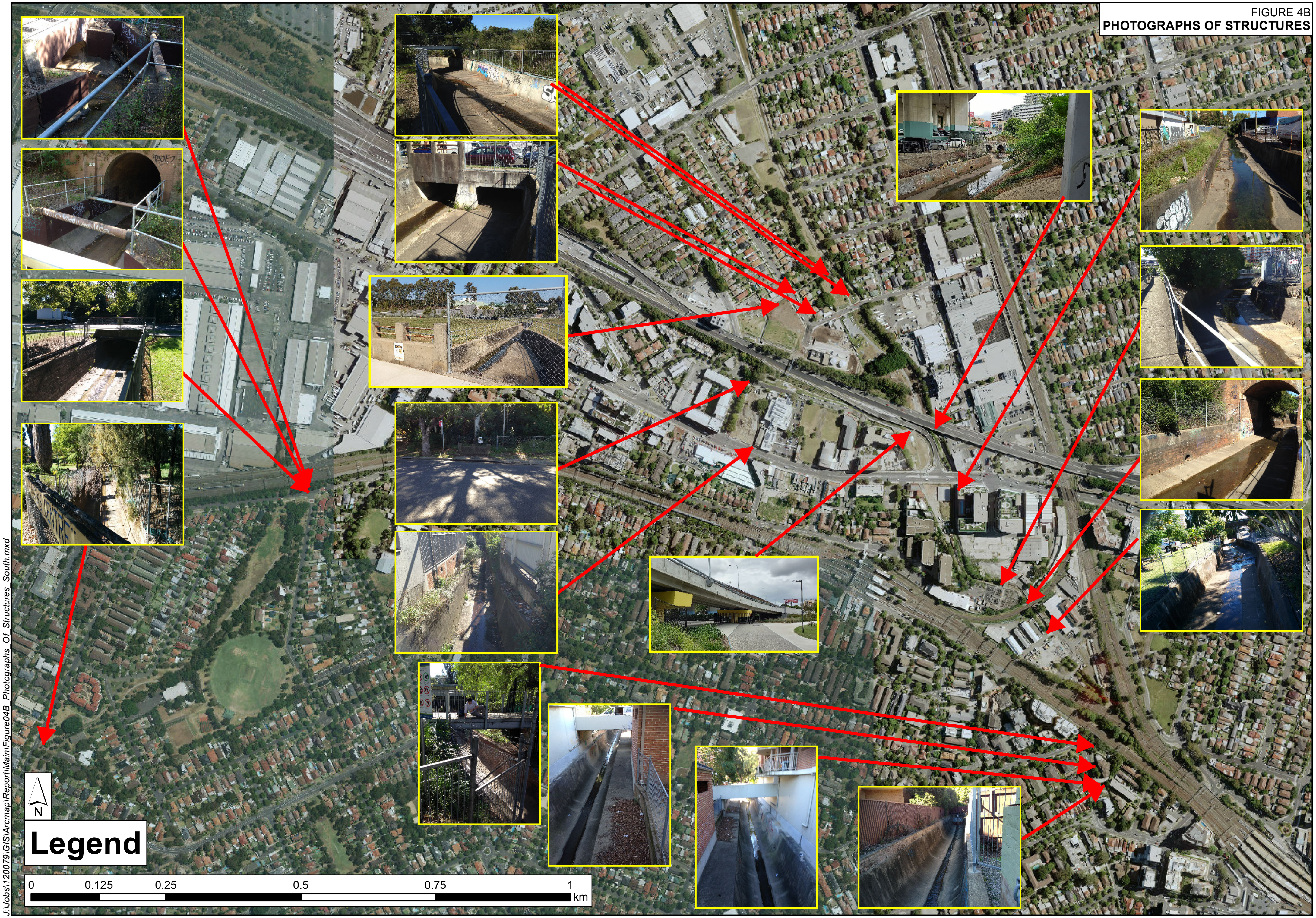

J:\Jobs\120079\GIS\Arcmap\Report\Main\Figure04B_Photographs_Of_Structures_South.mxd

FIGURE 5A
HISTORICAL FLOOD PHOTOGRAPHS
SHEET 1


Airey Park 2/01/96


Airey Park 2/01/96


The Crescent opposite Airey Park 2/01/96


19 Shortland Ave 10/02/1990


Airey Park The Crescent 2/01/96


Oxford Road 2/01/96


1 Heyde Ave 2/01/96


Rochester Street eastern side, Mirabooka Ave & Broughton Rd


Redmyre Road 2/01/96


62 Beresford Road 10/02/1990


19 Shortland Ave 10/02/1990


Corner of Todman Ave; and Oxford Rd: eastern side

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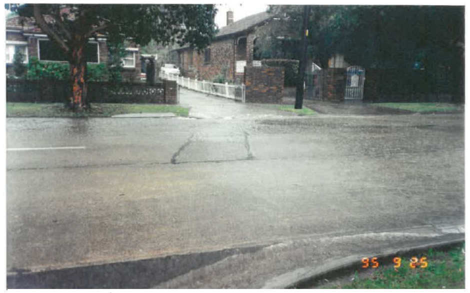
FIGURE 5B
HISTORICAL FLOOD PHOTOGRAPHS
SHEET 2



Barker Road, Southern side

Todman Ave; at Barker Road

Corner of Badgery Ave; and Bates Street


29 Badgery Avenue


Outside 29 Badgery Avenue


139 Albert Road 10.2.90


139 Albert Road 10.2.90


139 Albert Road 10.2.90


139 Albert Road 10.2.90


139 Albert Road 10.2.90


Underwood Road 18/03/1990


Underwood Road 18/03/1990

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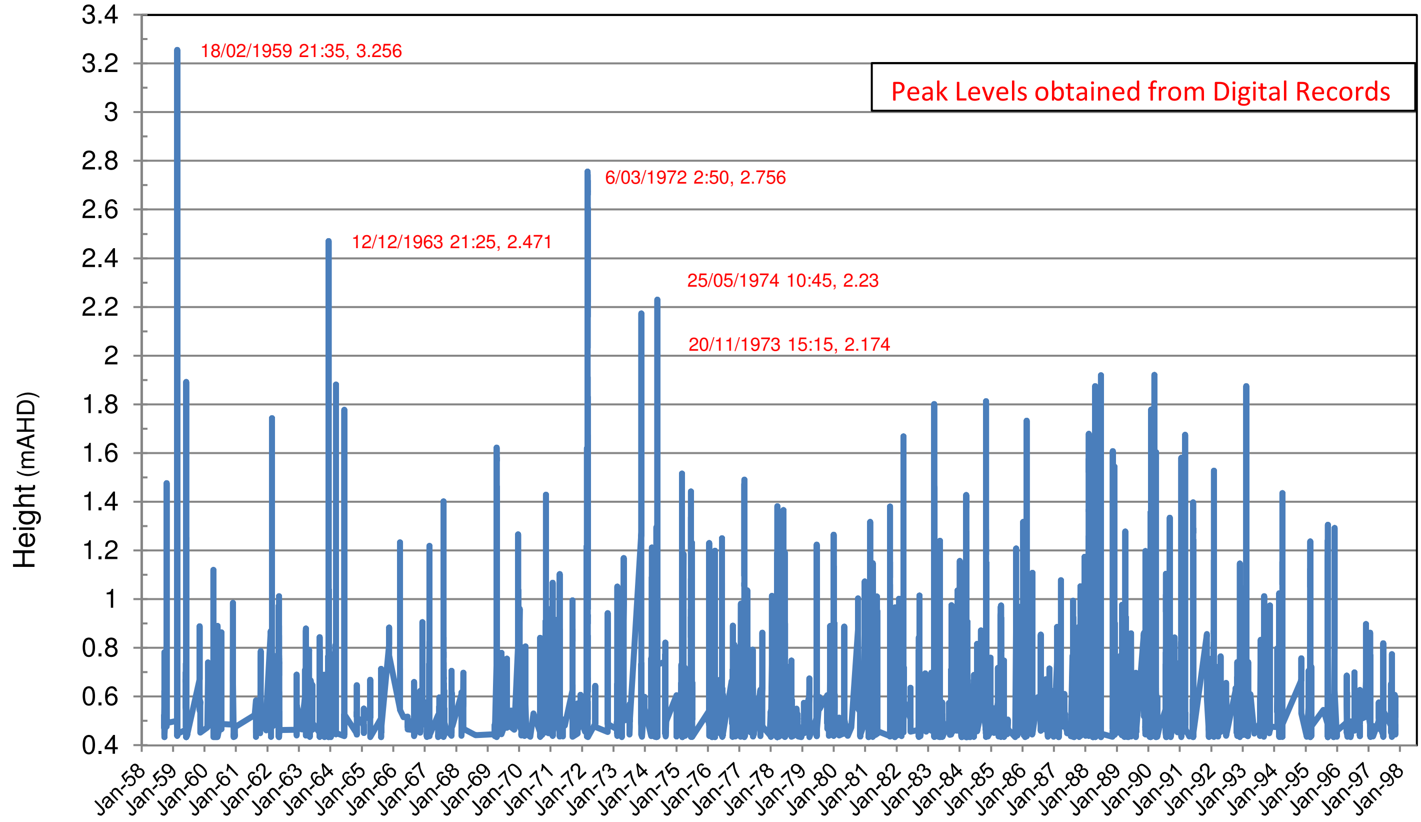
WATER LEVEL GAUGE RECORDS



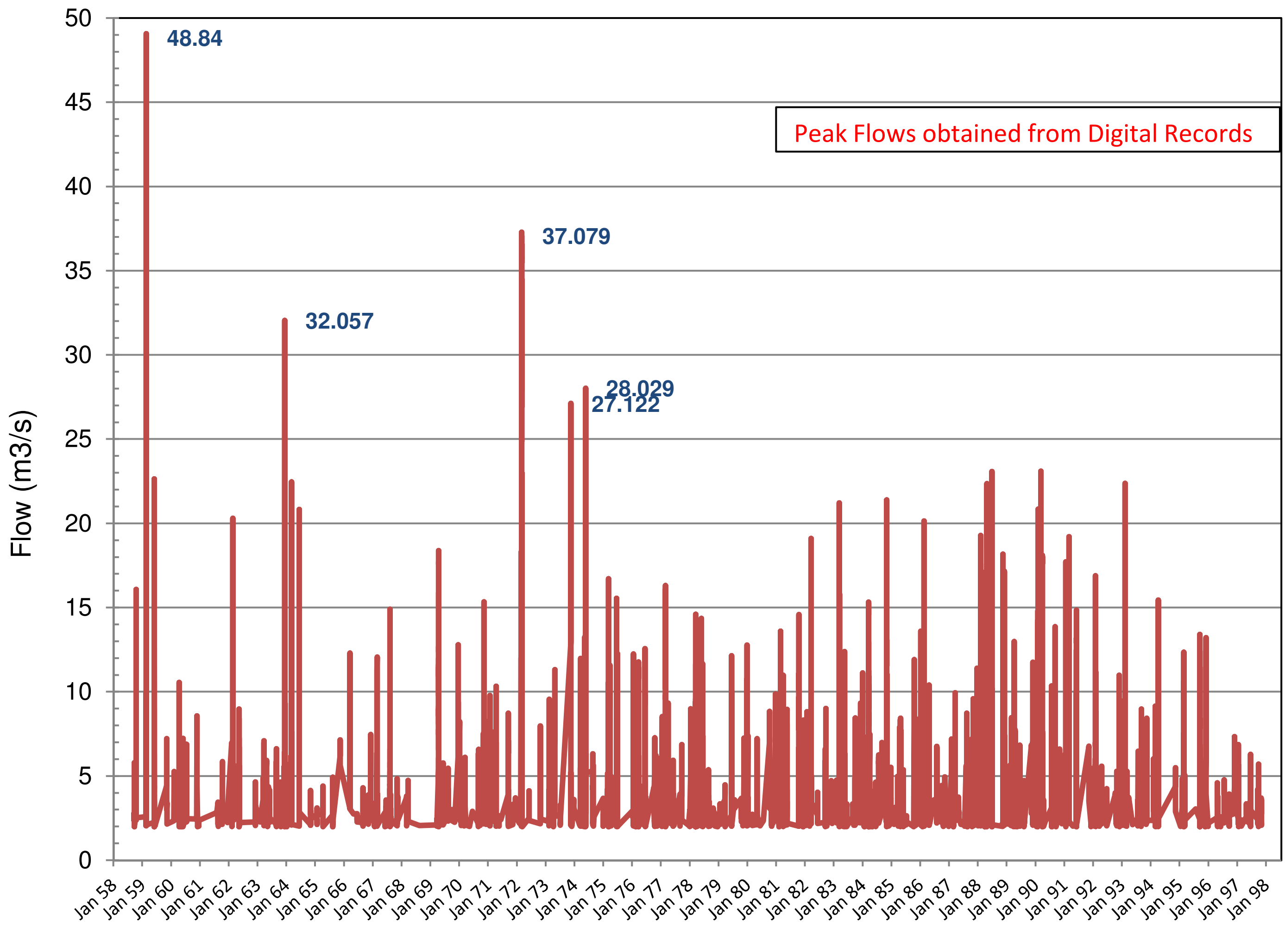
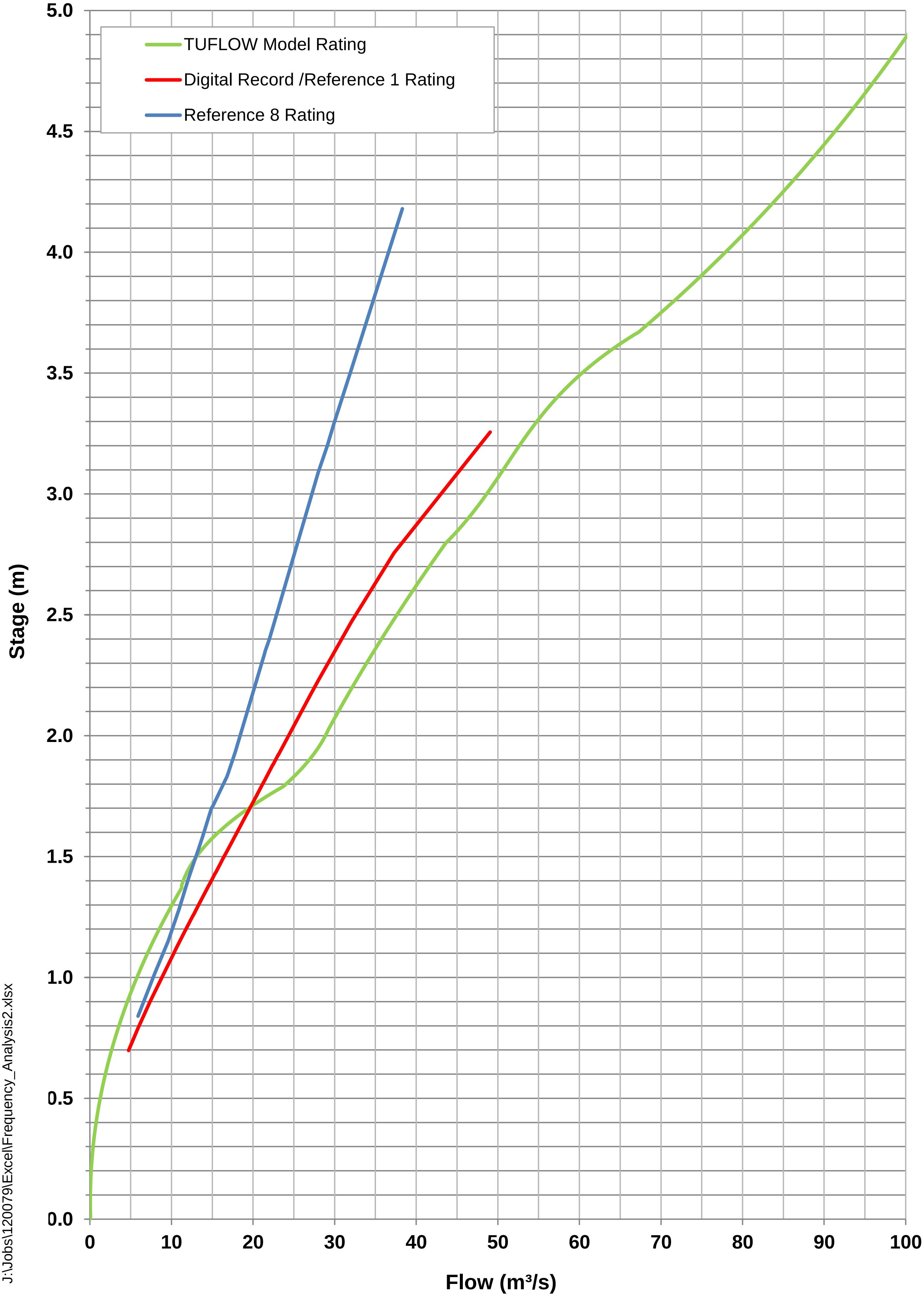


FIGURE 7
RATING CURVES AT ELVA STREET GAUGE



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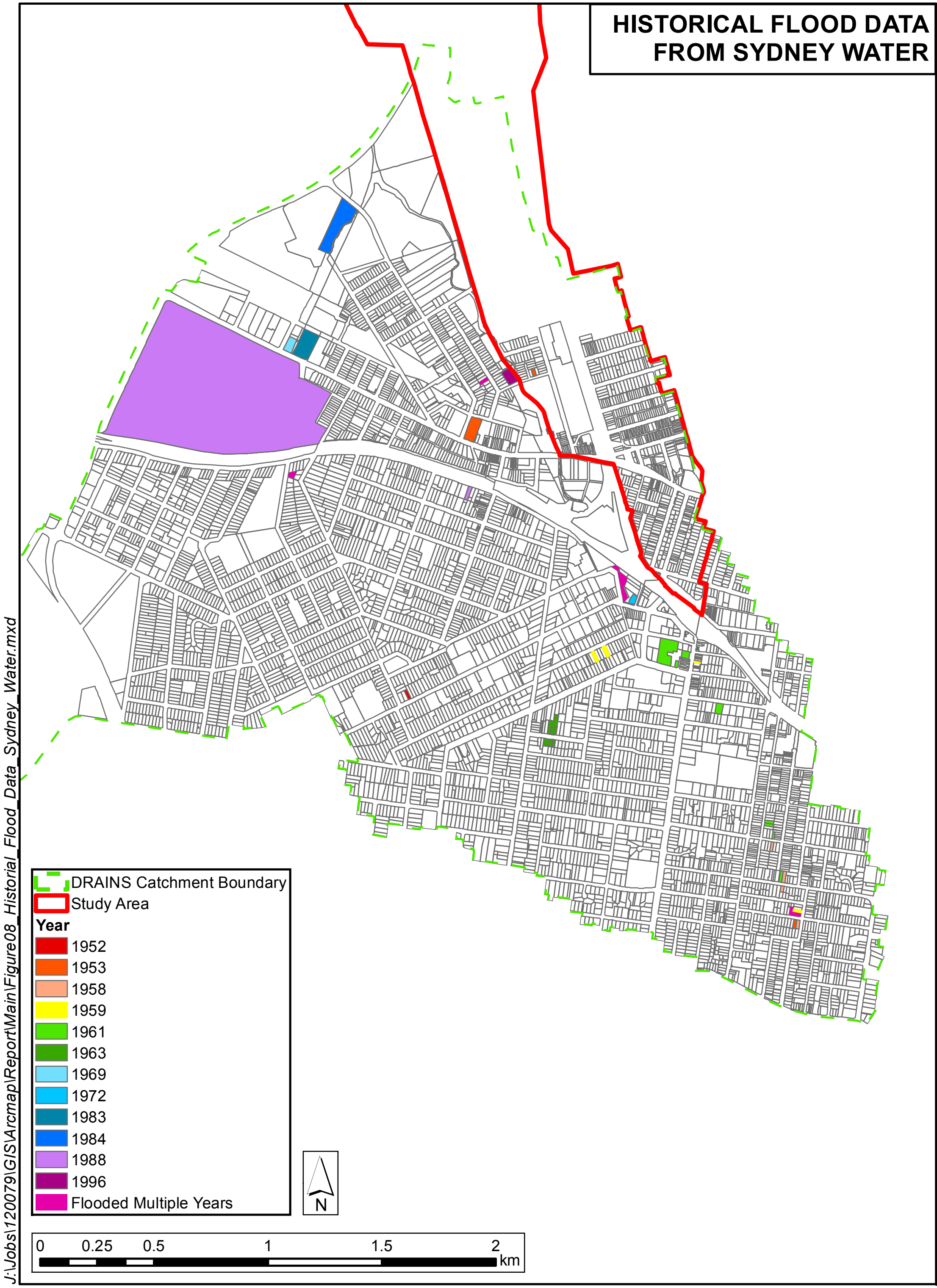

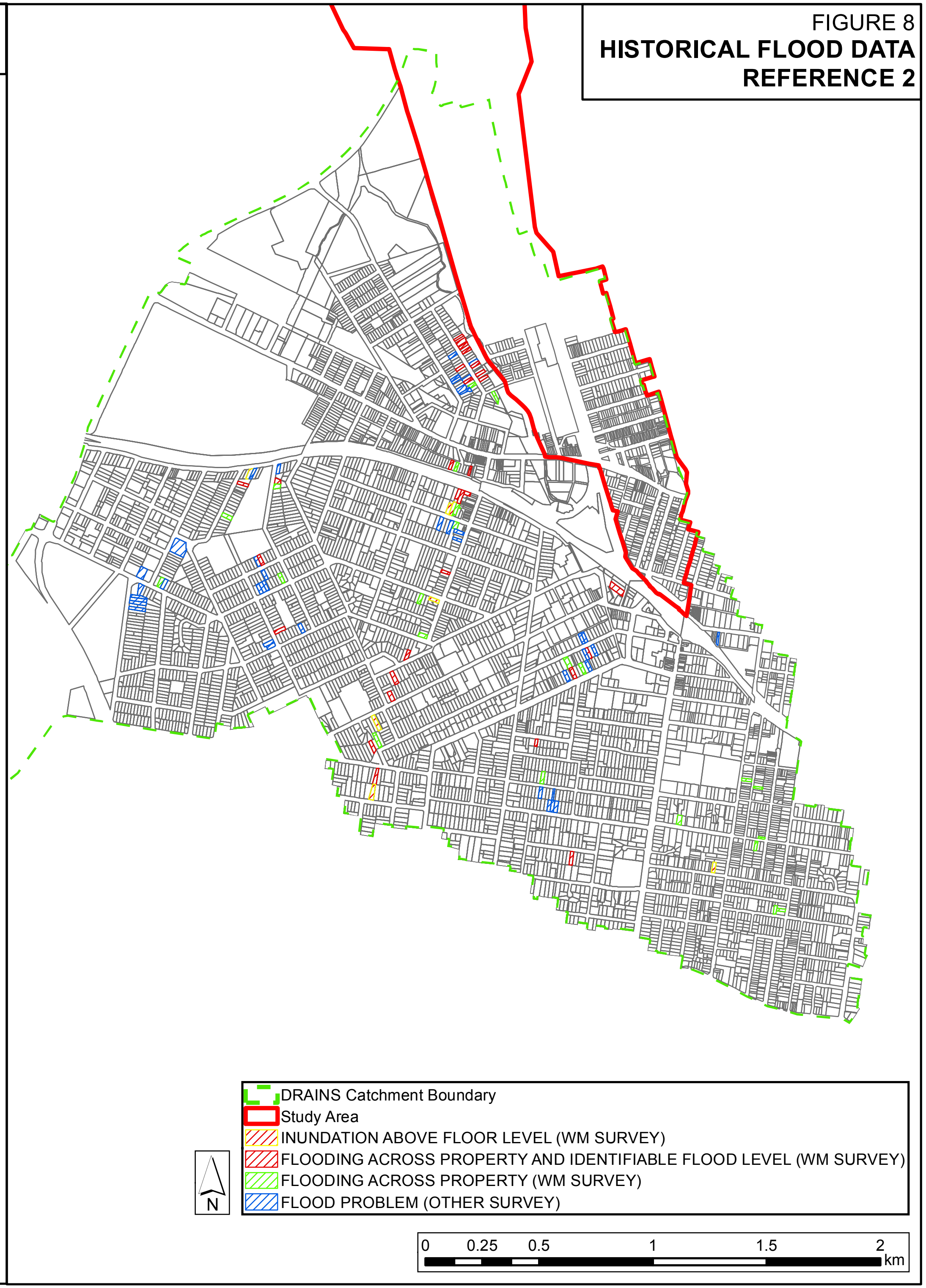

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EVENTS OF FEBRUARY 1990

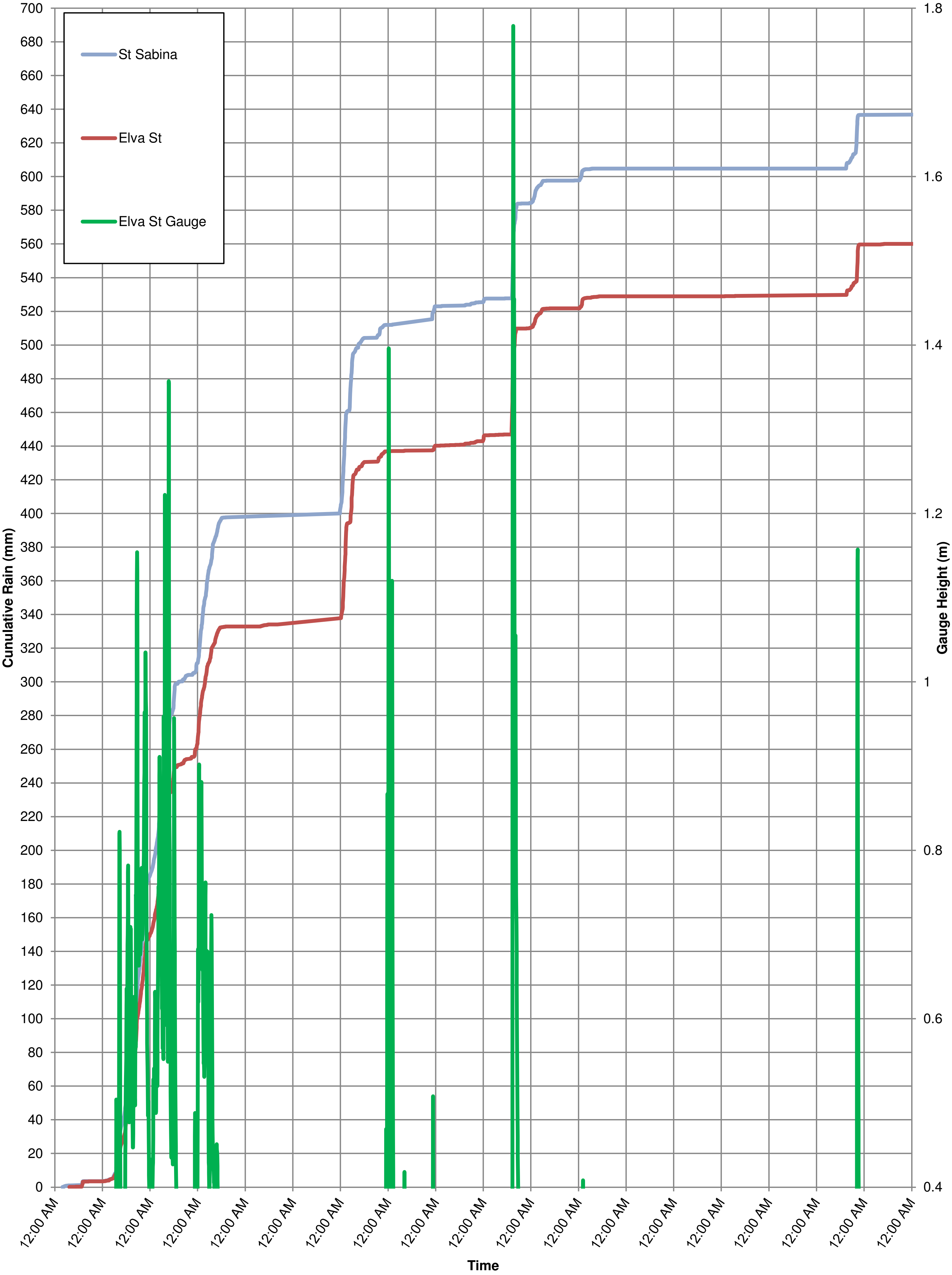

FIGURE 9B

PLUVIOMETER DATA
2-4 FEBRUARY 1990

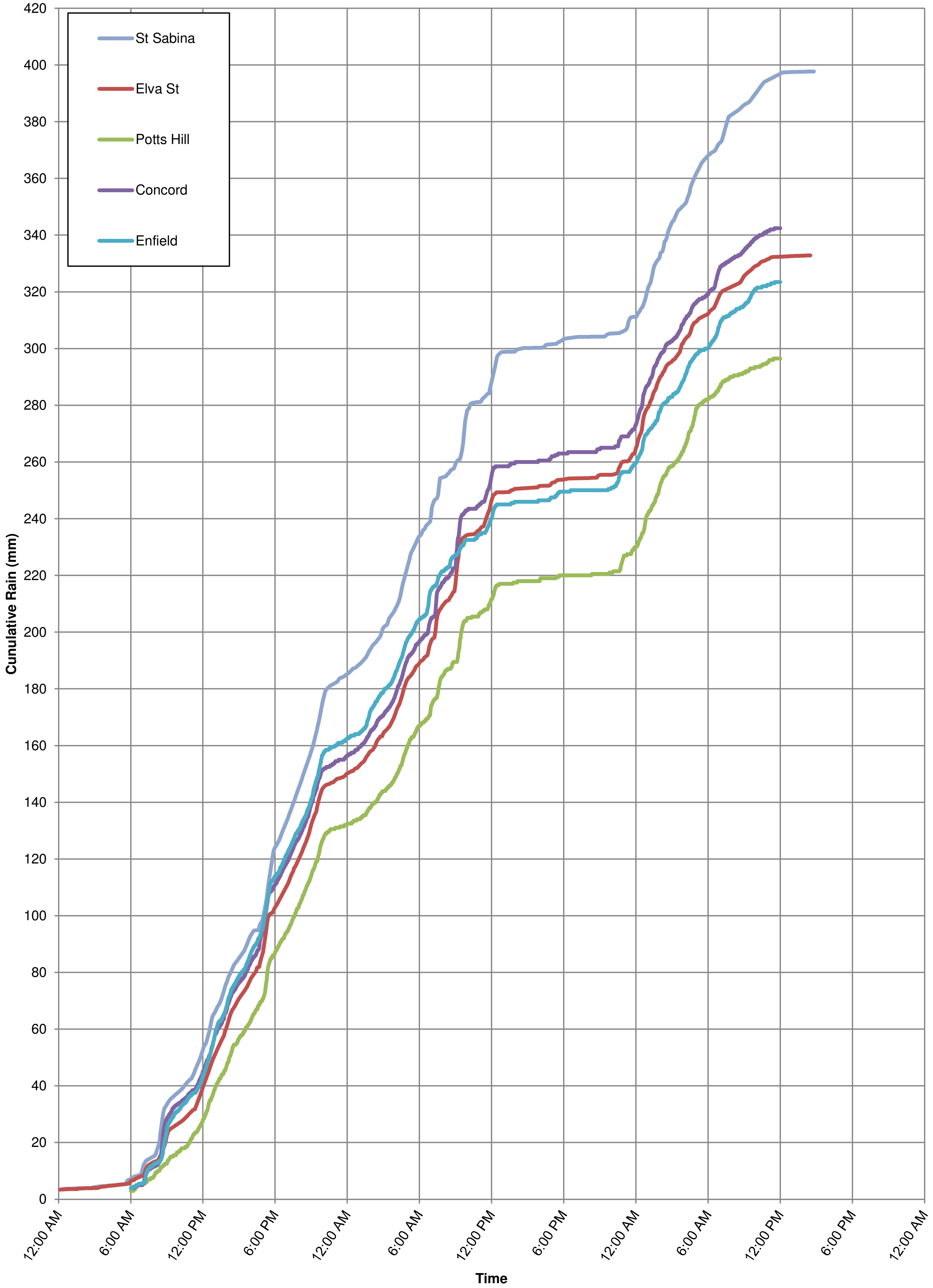

FIGURE 9C
PLUVIOMETER DATA
7 FEBRUARY 1990

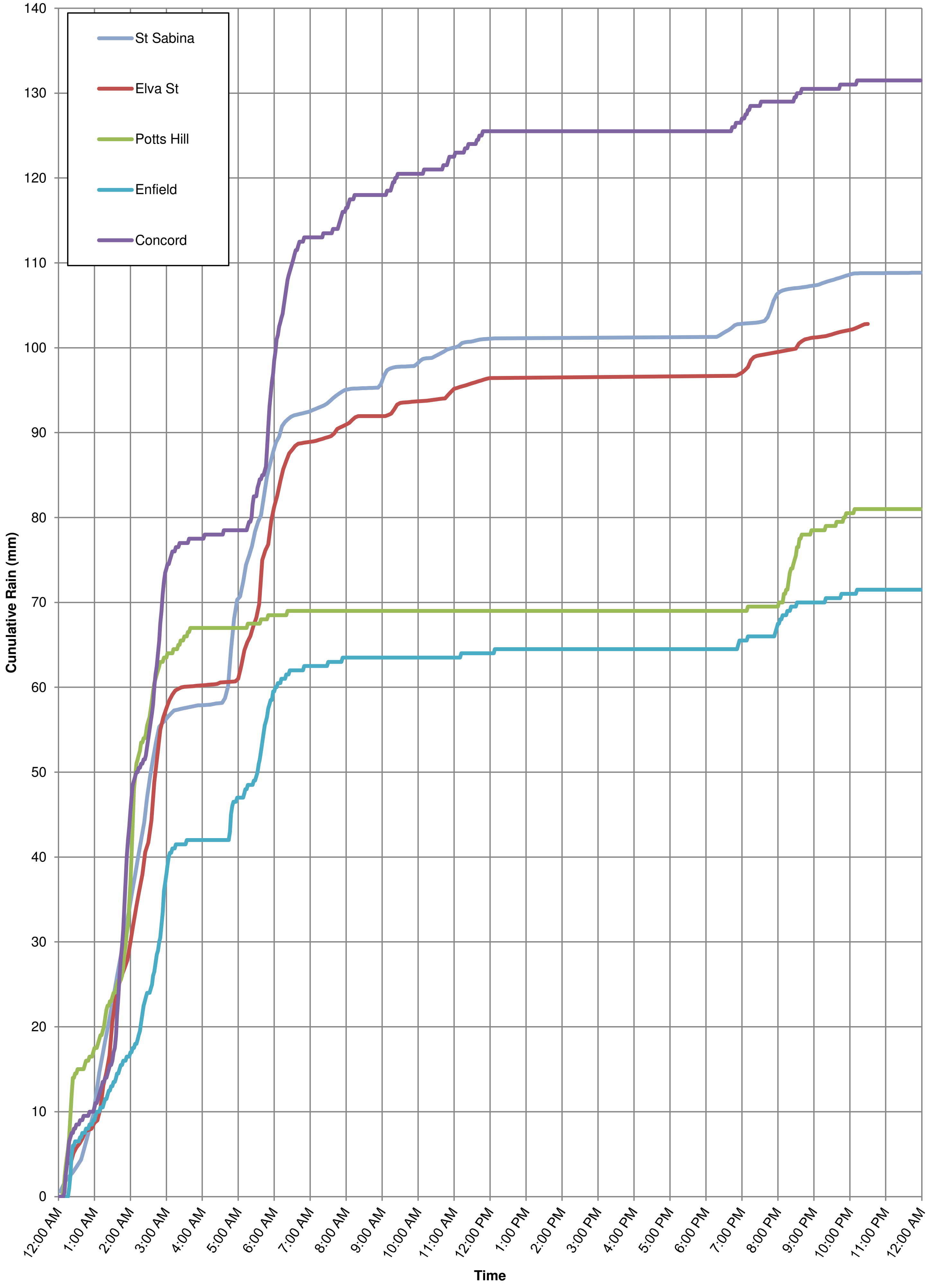

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FIGURE 9D

PLUVIOMETER DATA
17 FEBRUARY 1990

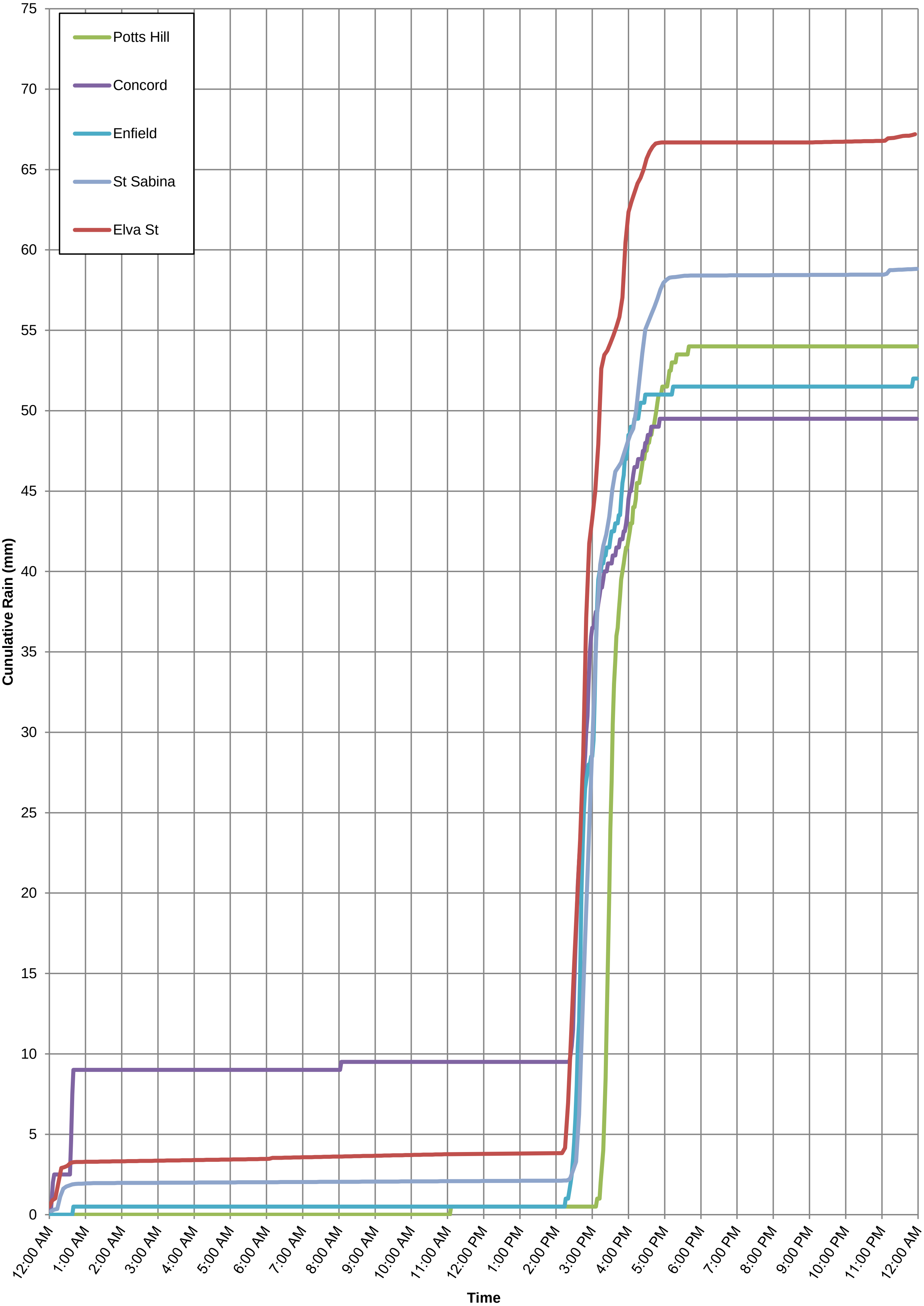

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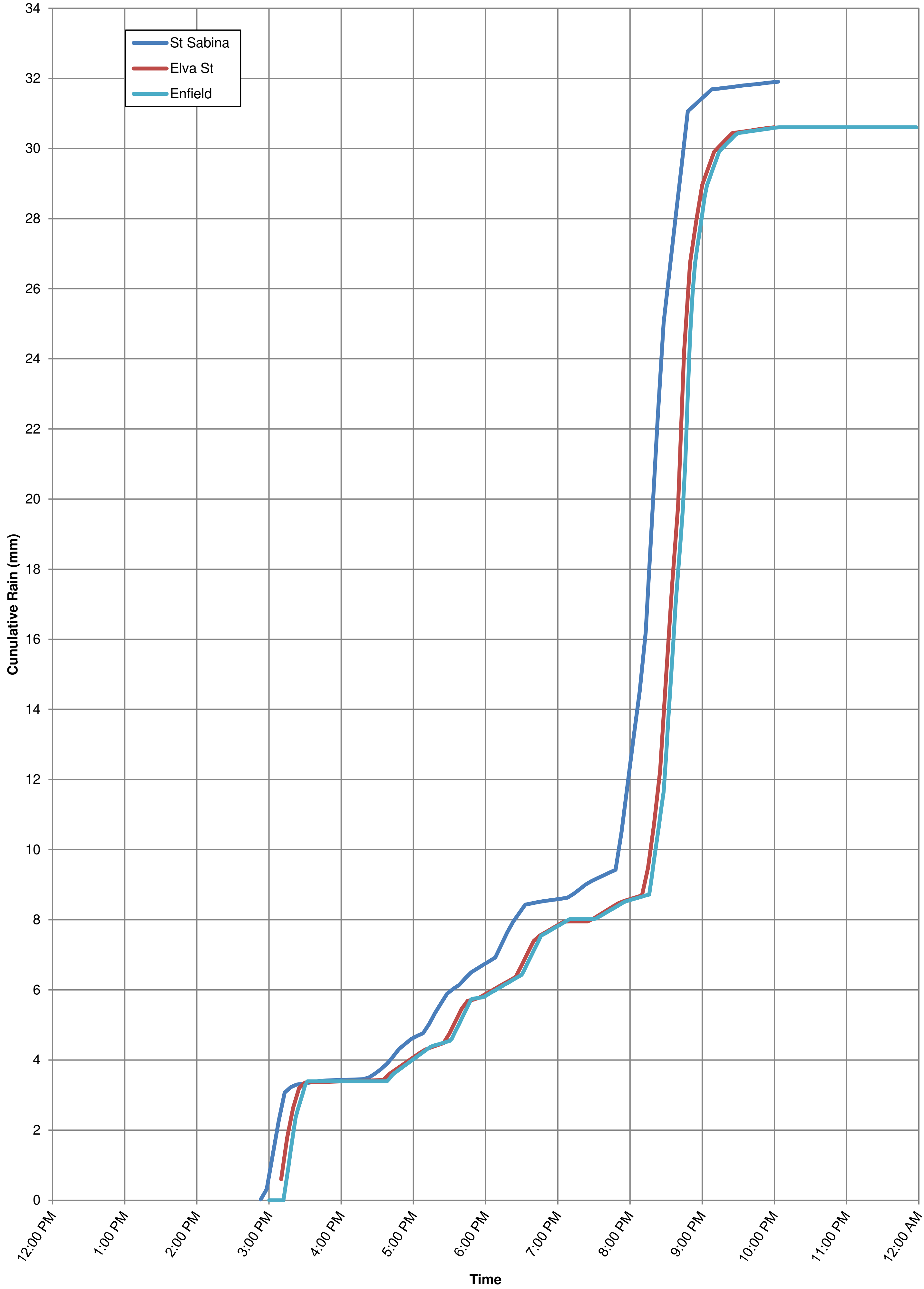
FIGURE 9E

PLUVIOMETER DATA
17 FEBRUARY 1990



J:\Jobs\120079\Excel\Calibration\PowellsCkWaterlevel.xlsx

FIGURE 9F

PLUVIOMETER DATA
18 MARCH 1990

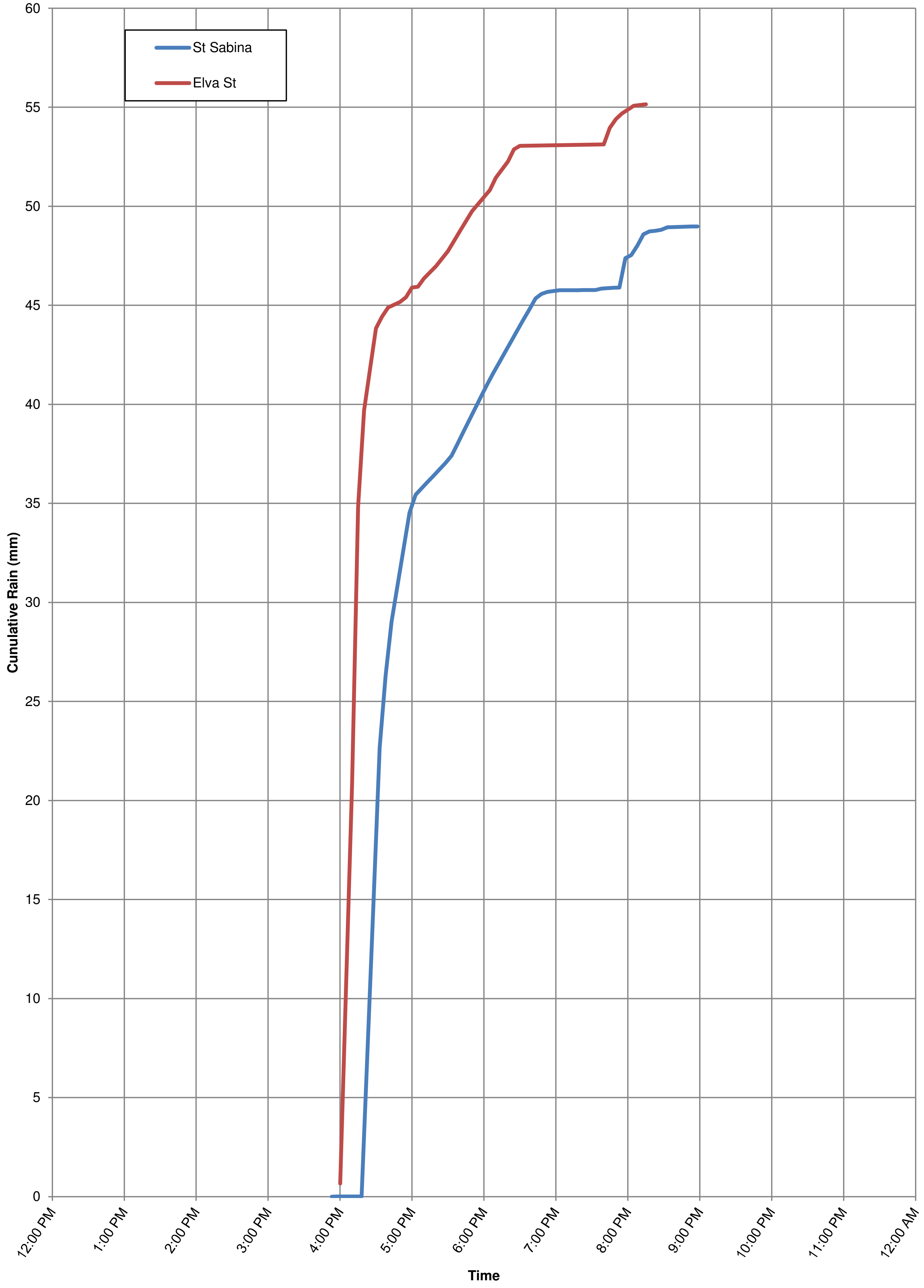


FIGURE 9G

PLUVIOMETER DATA
2 JANUARY 1996

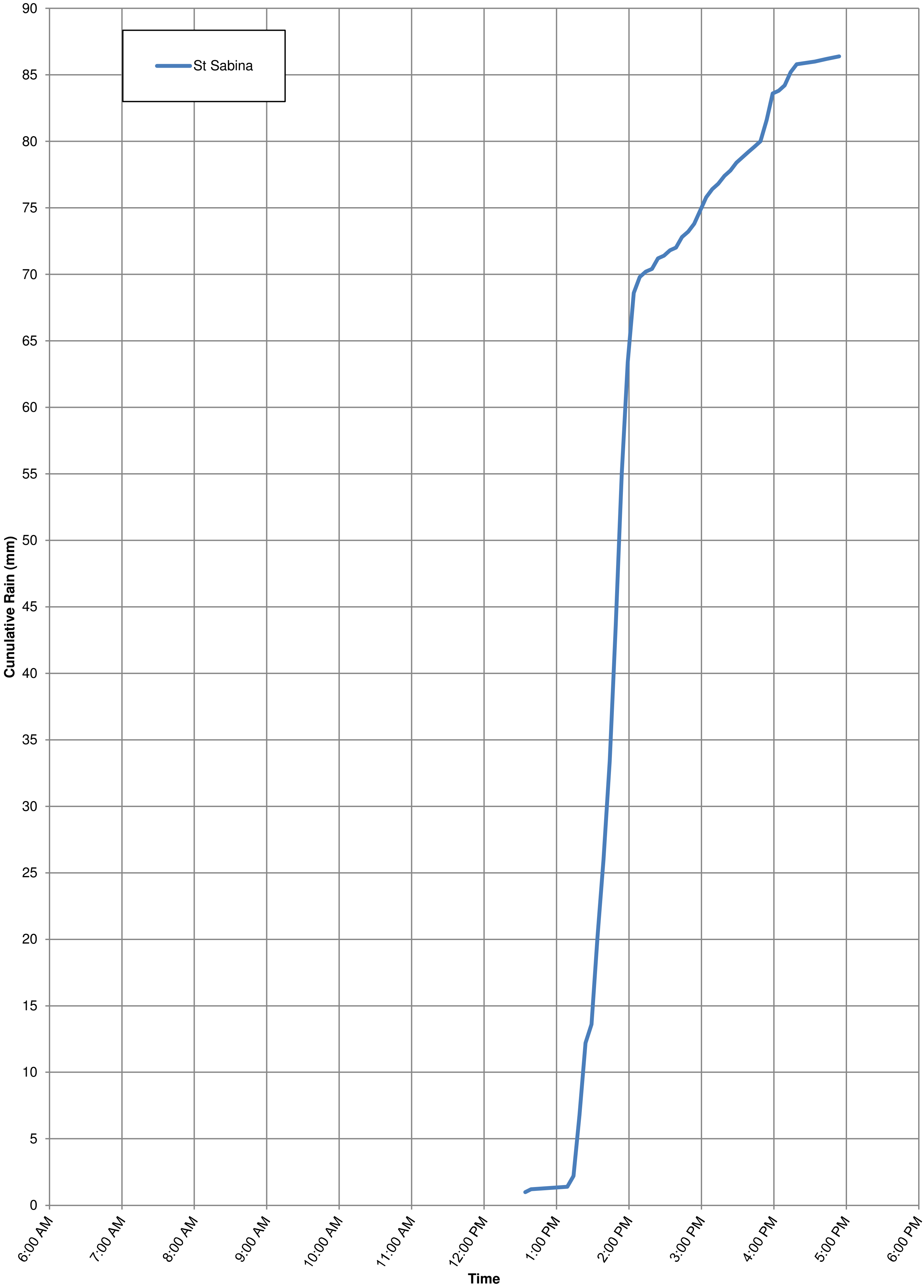


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FIGURE 10
DRAINS SUBCATCHMENTS

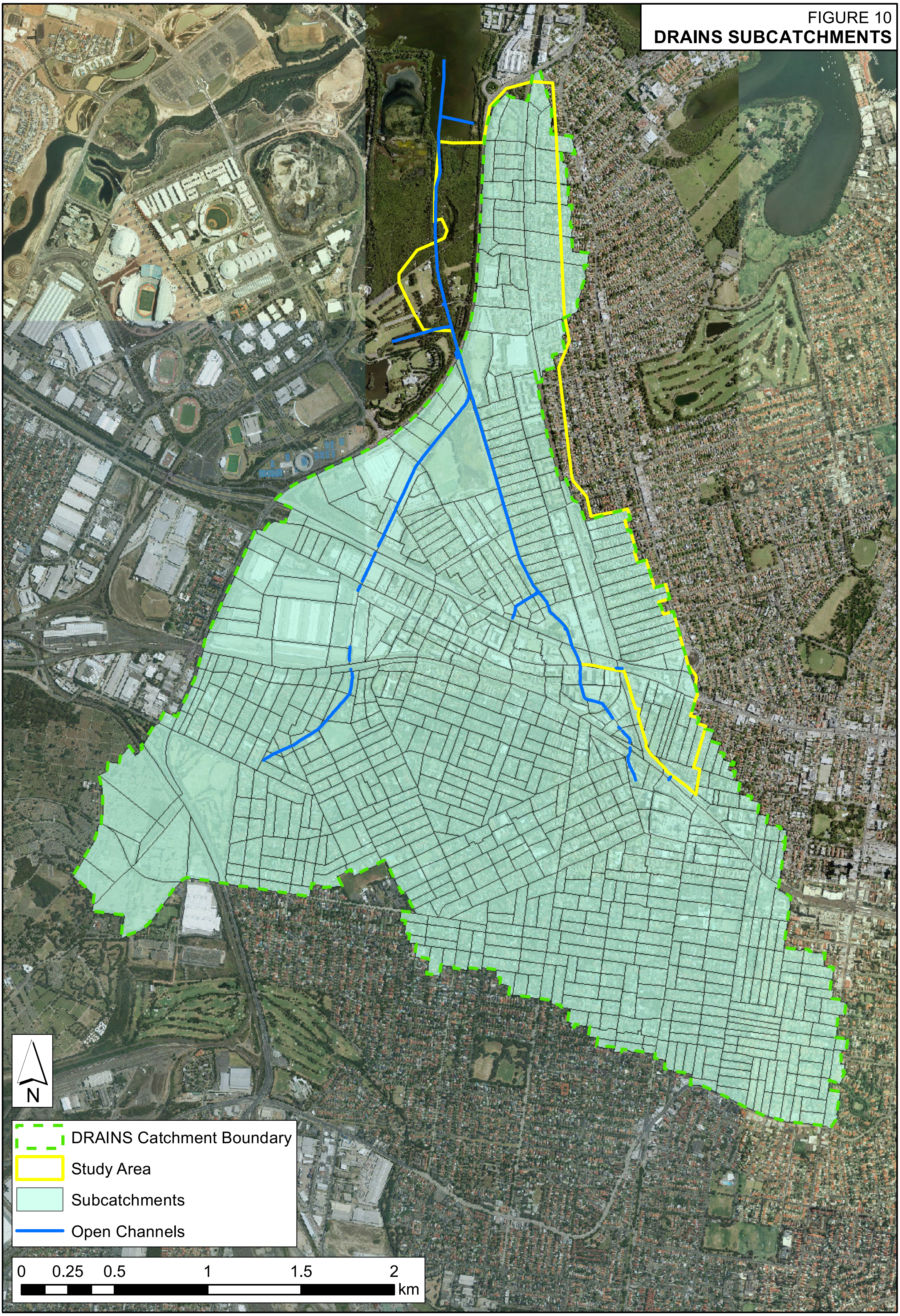

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FIGURE 11
TUFLOW PITS AND PIPES

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FIGURE 12
TUFLOW MODEL EXTENT

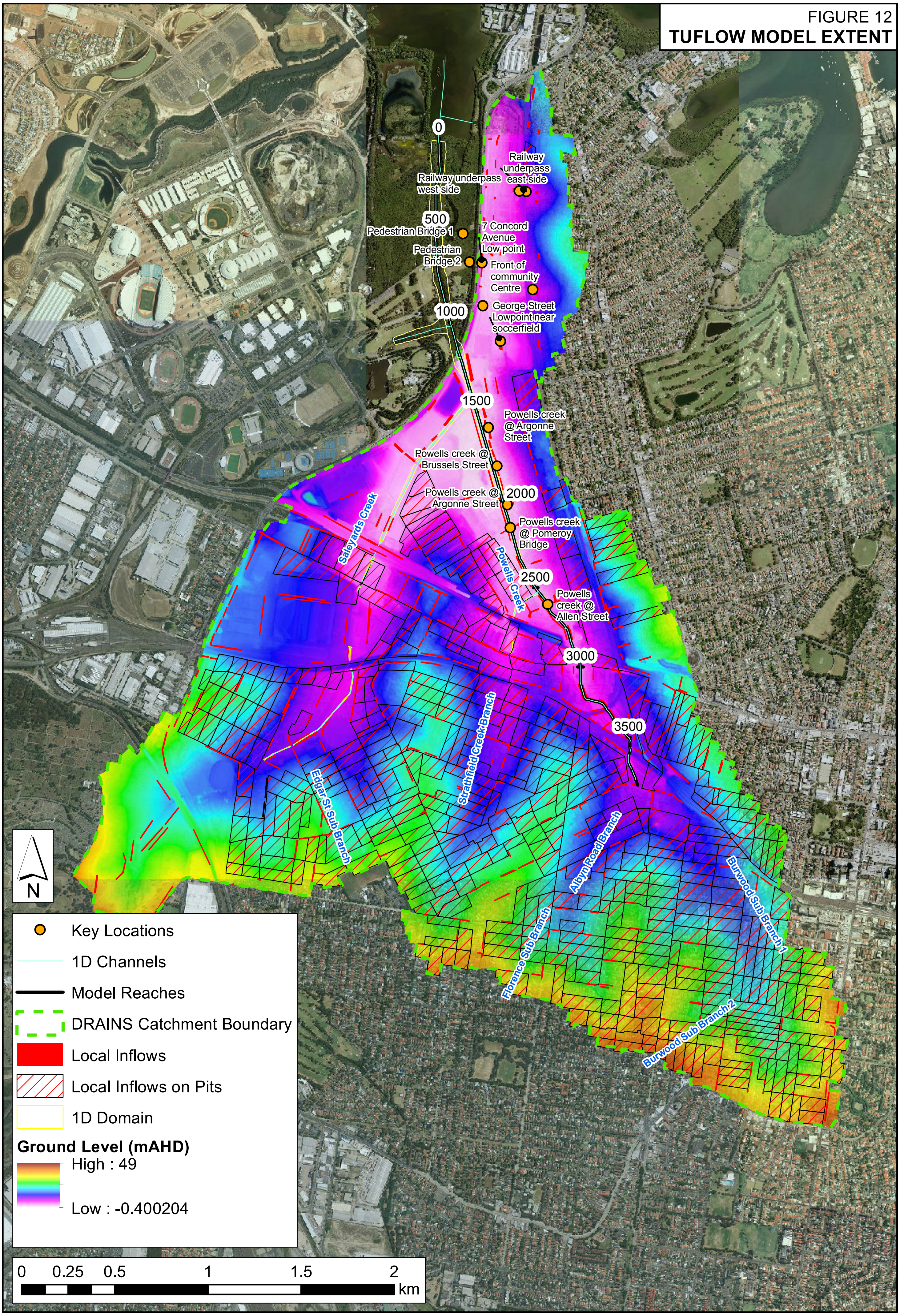

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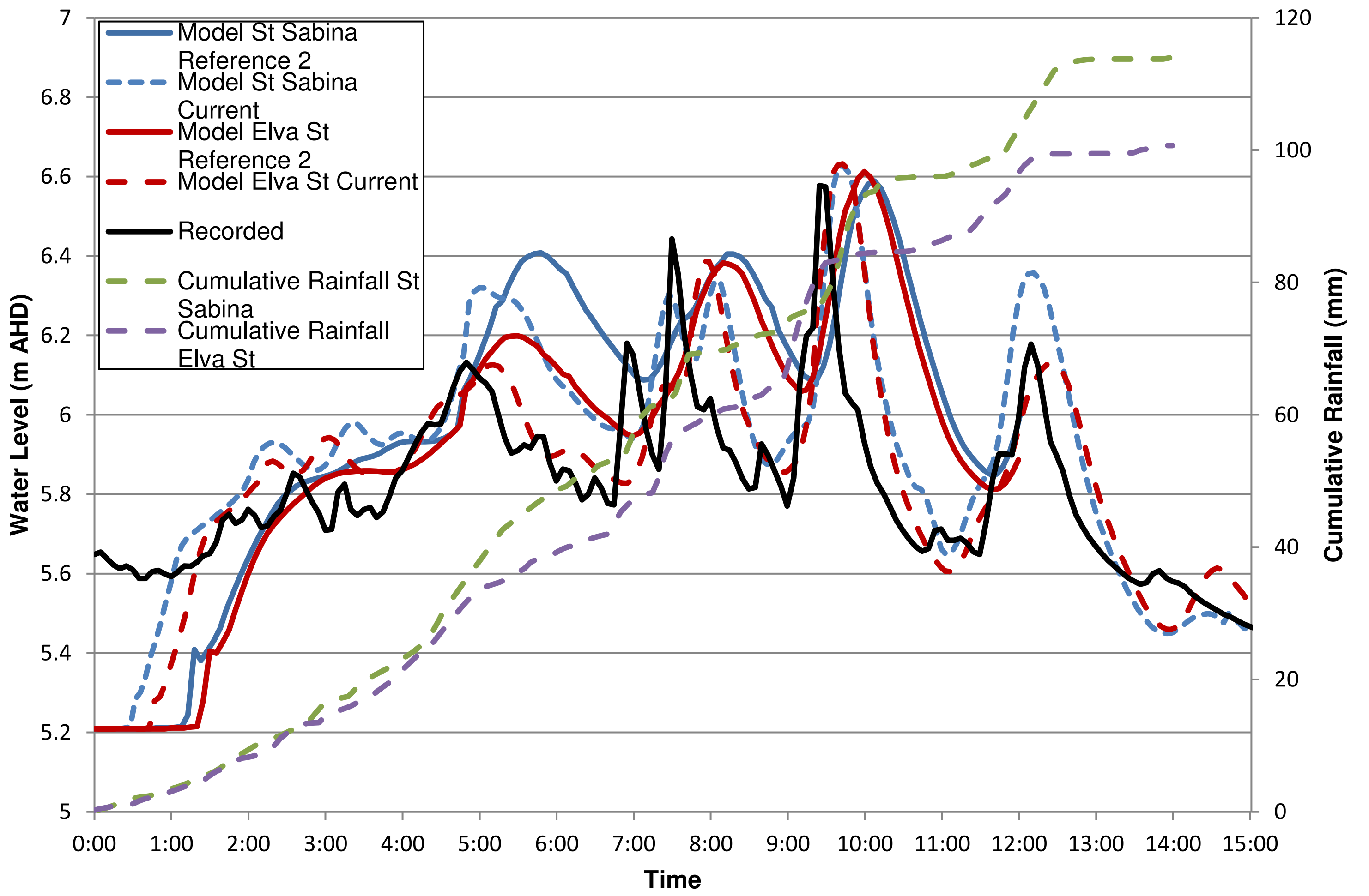
FIGURE 13A

CALIBRATION RESULTS--ELVA STREET GAUGE

3 FEBRUARY 1990



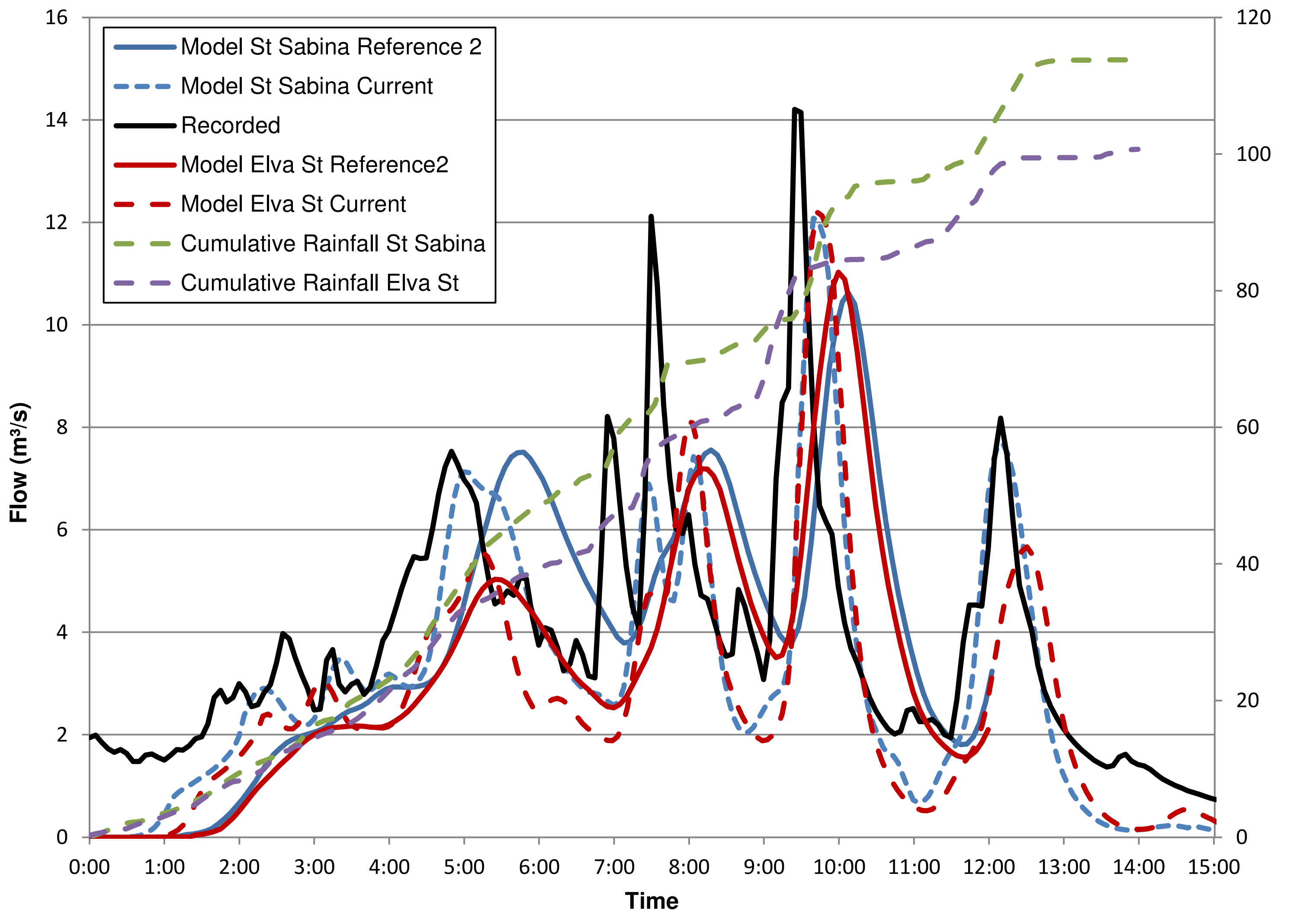
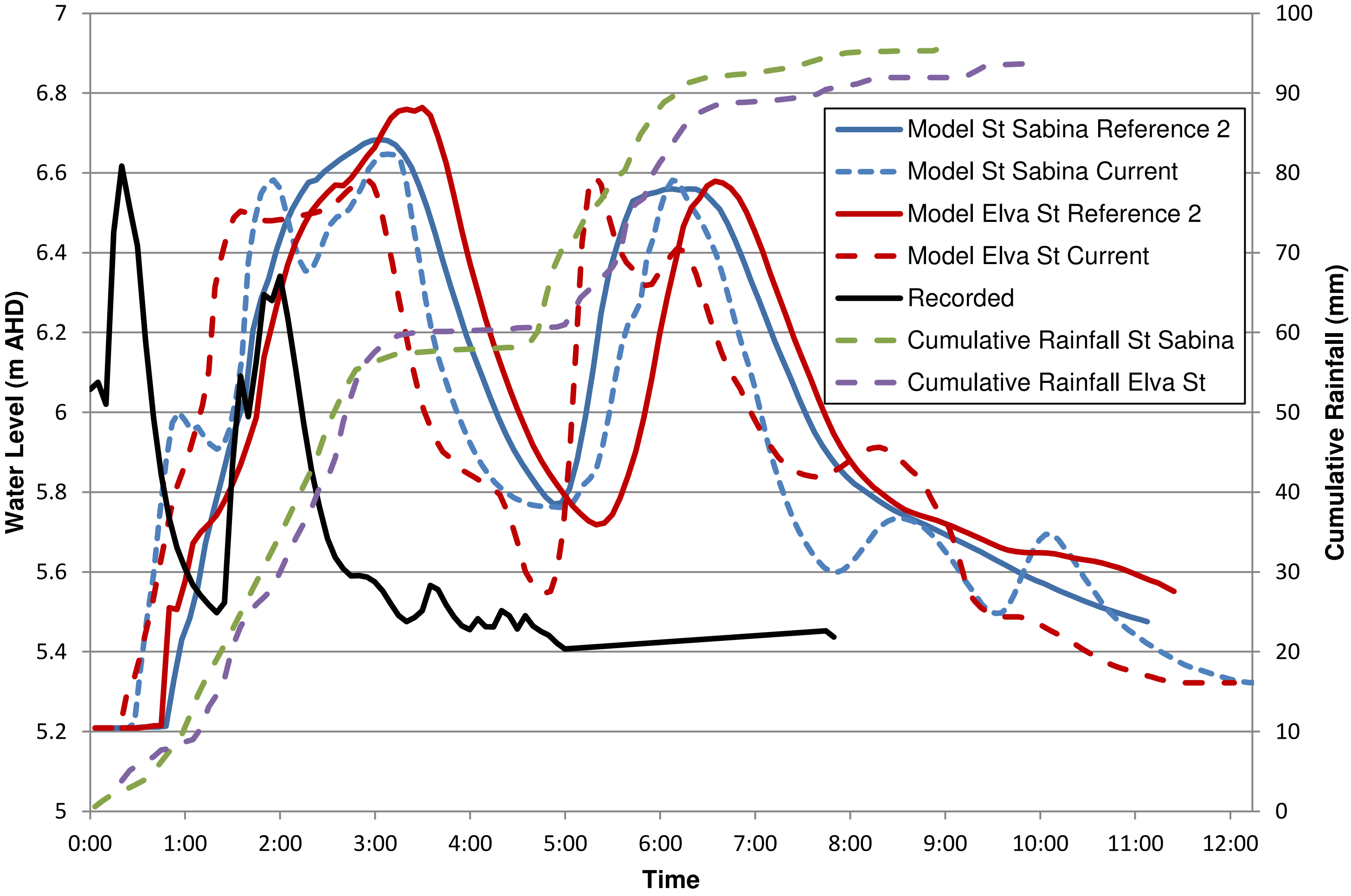


FIGURE 13B

CALIBRATION RESULTS--ELVA STREET GAUGE
7 FEBRUARY 1990



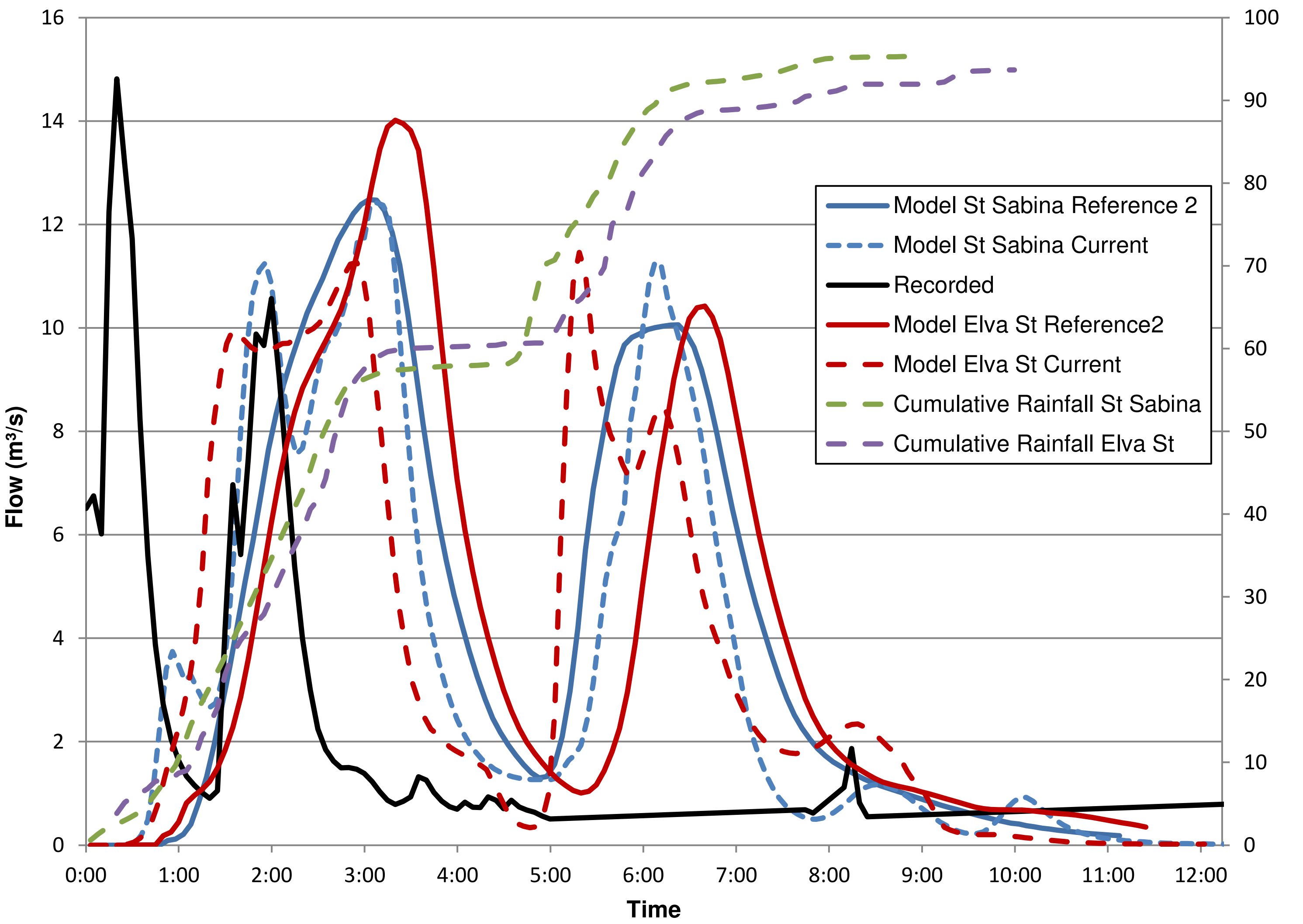
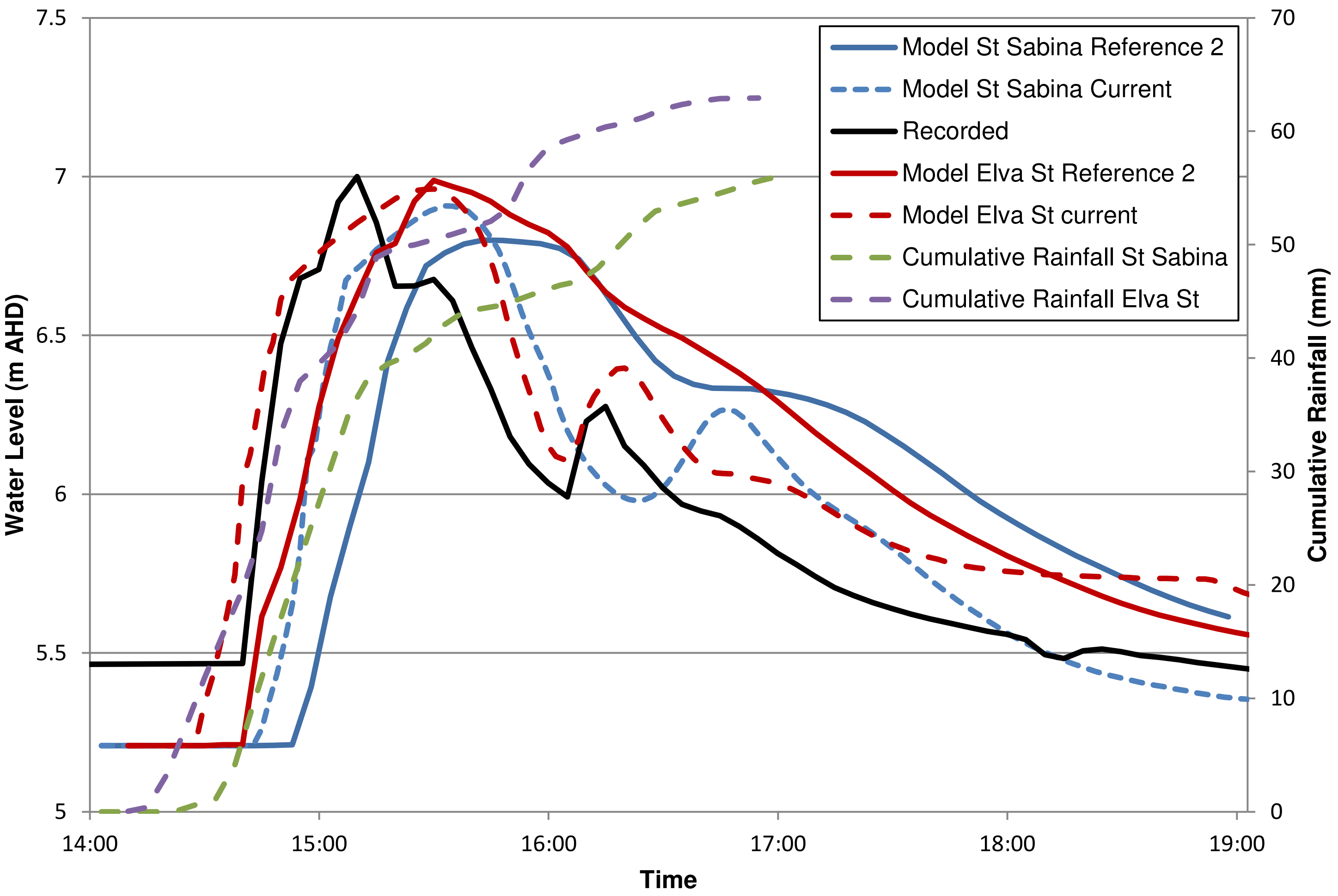


FIGURE 13C

CALIBRATION RESULTS--ELVA STREET GAUGE
10 FEBRUARY 1990



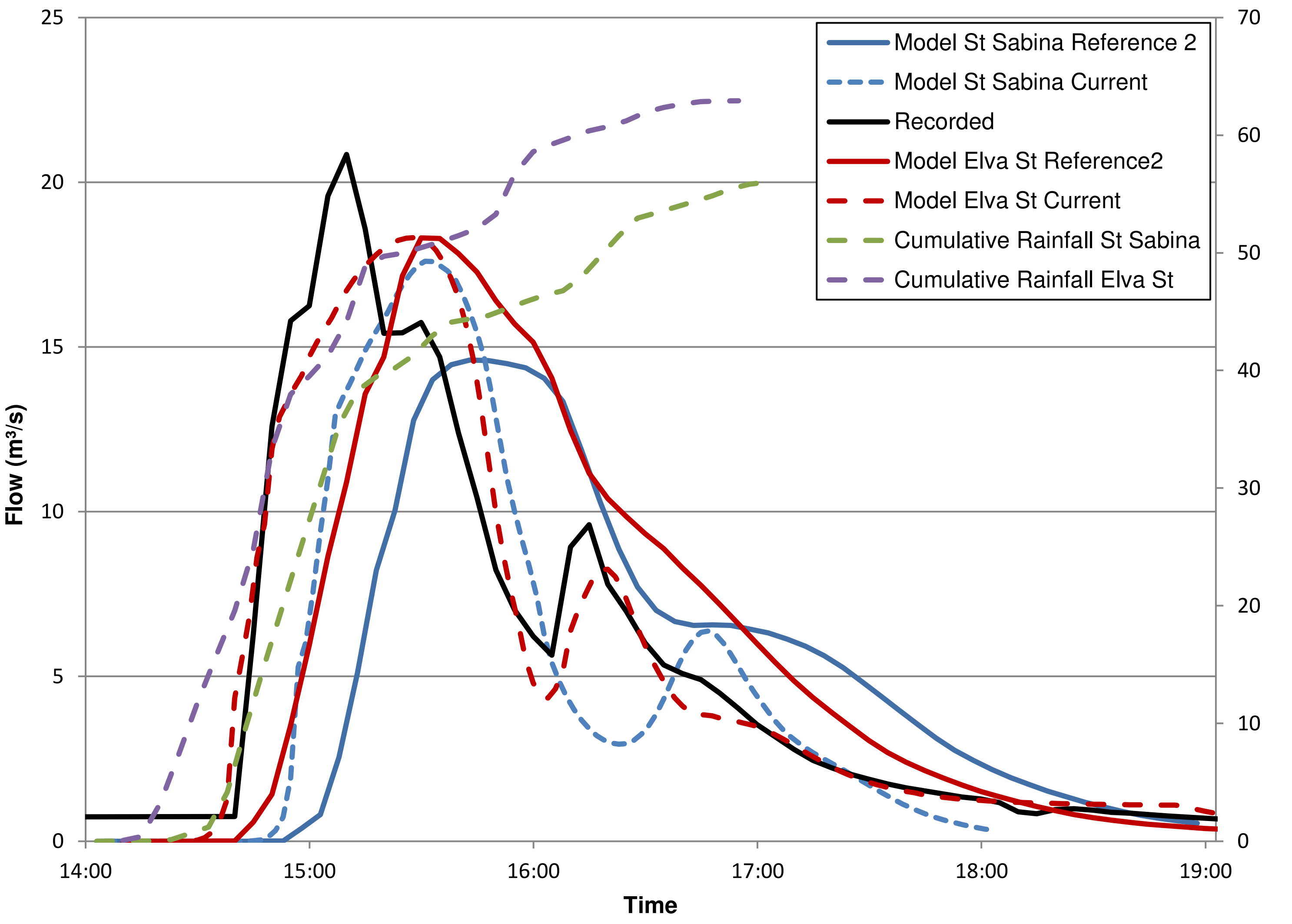
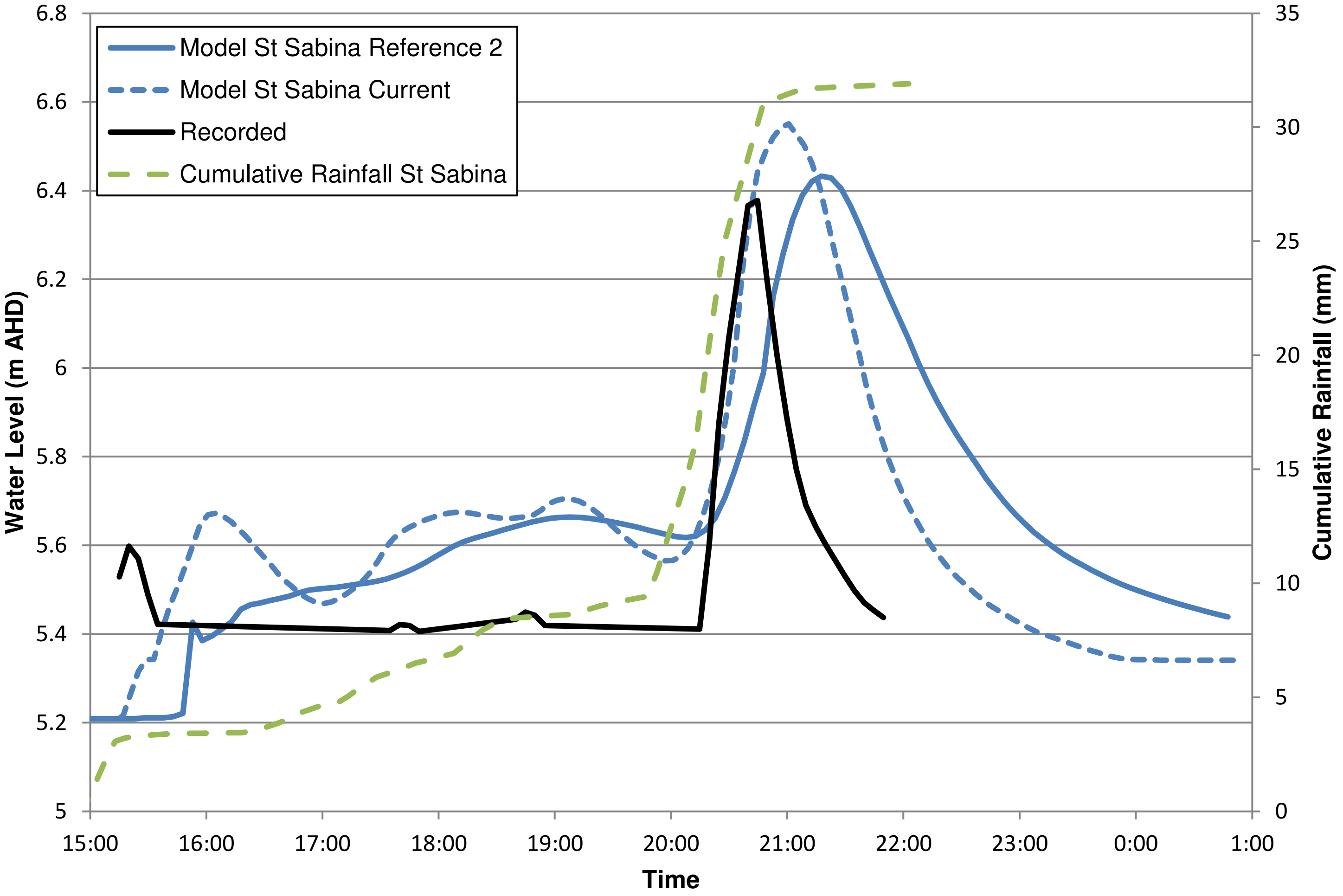


FIGURE 13D

CALIBRATION RESULTS--ELVA STREET GAUGE

17 FEBRUARY 1990



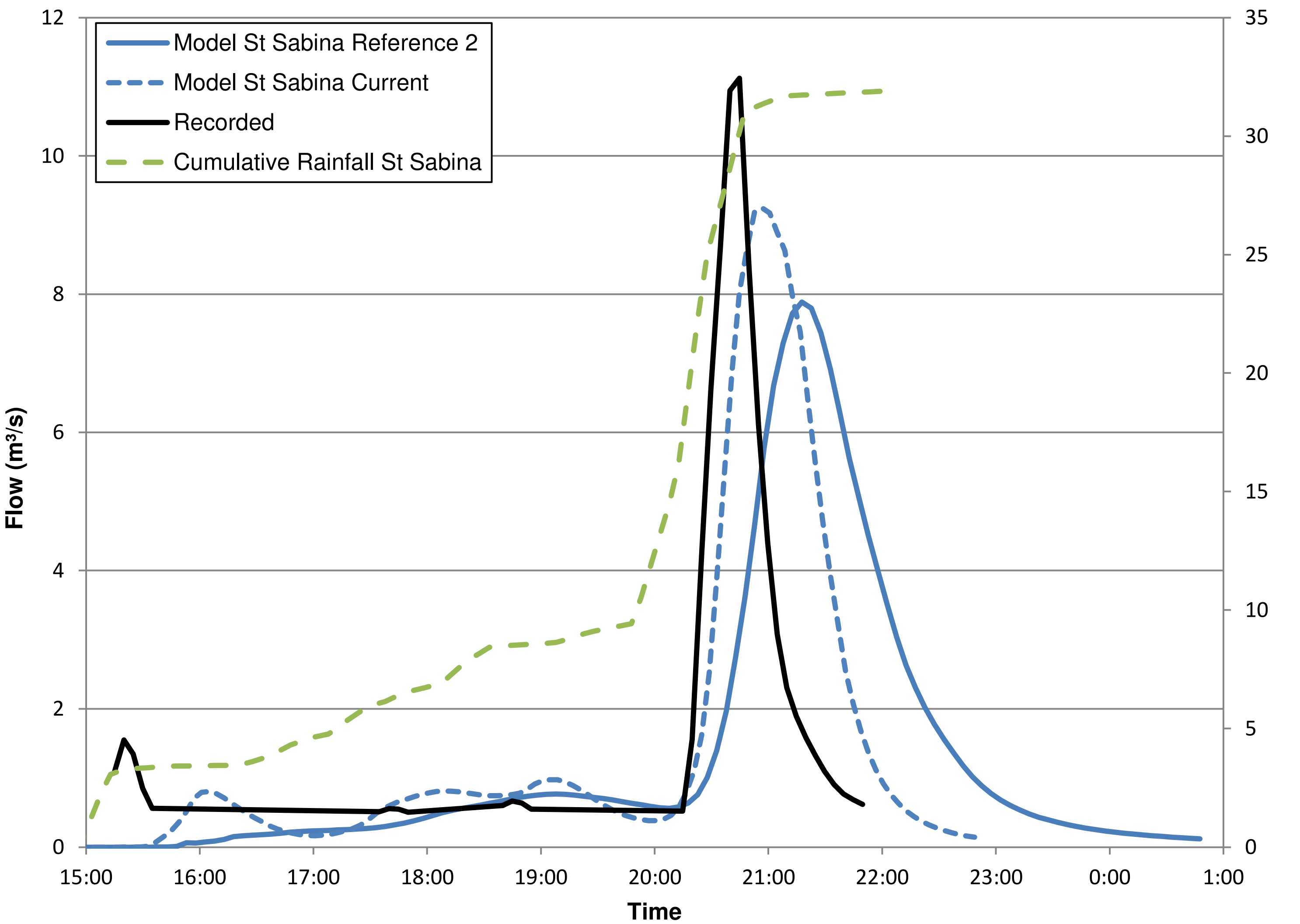
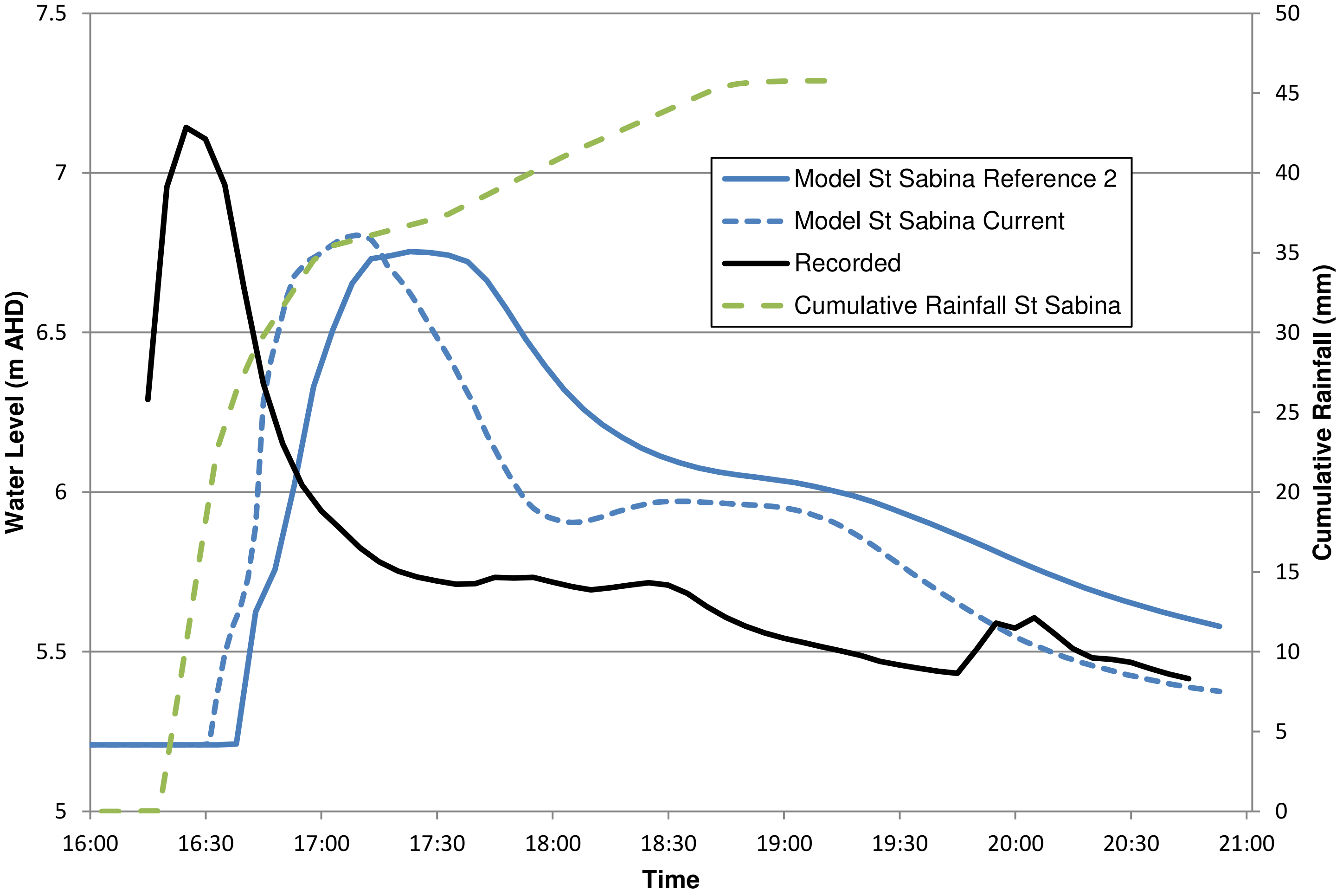


FIGURE 13E
CALIBRATION RESULTS--ELVA STREET GAUGE
18 MARCH 1990



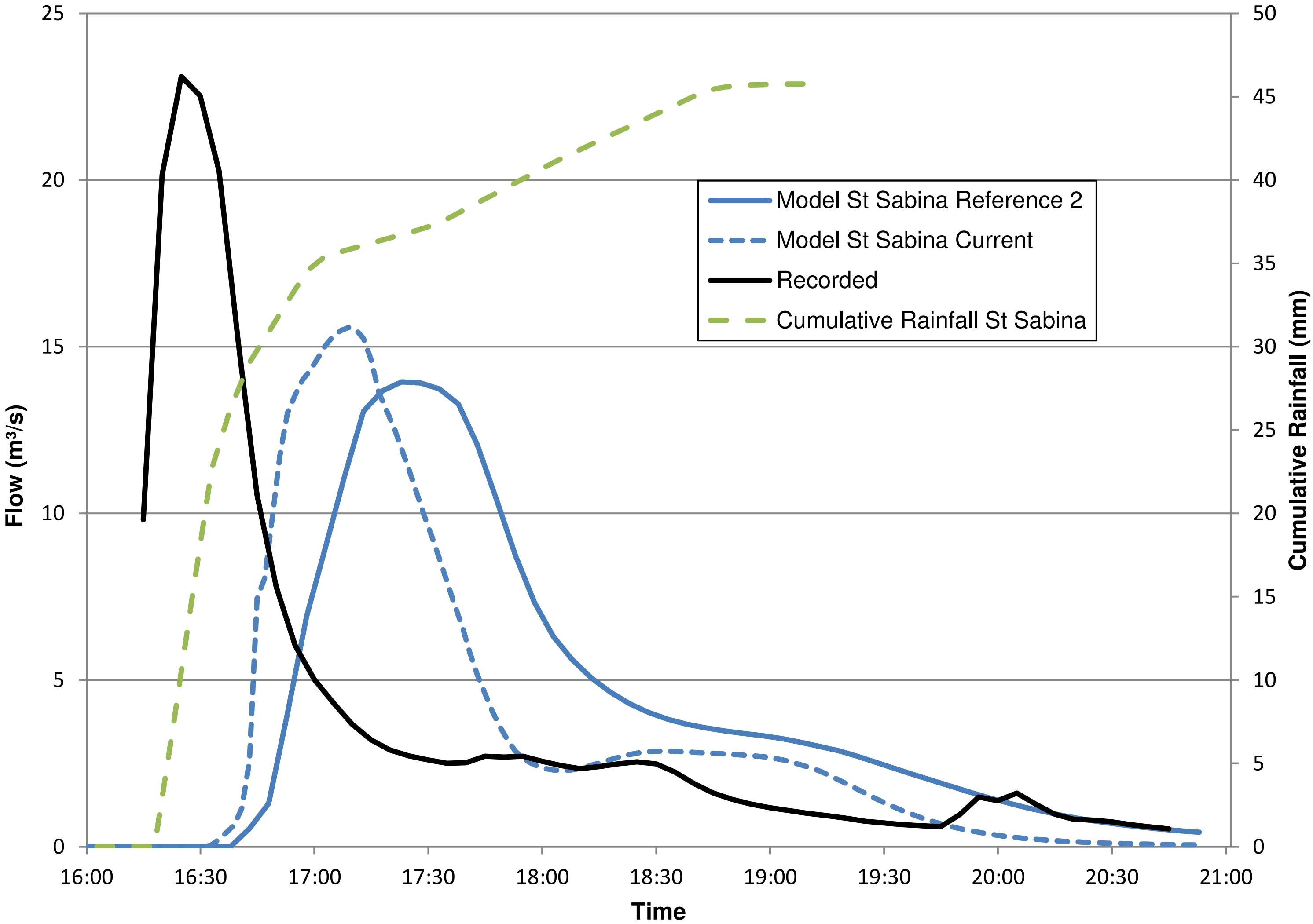
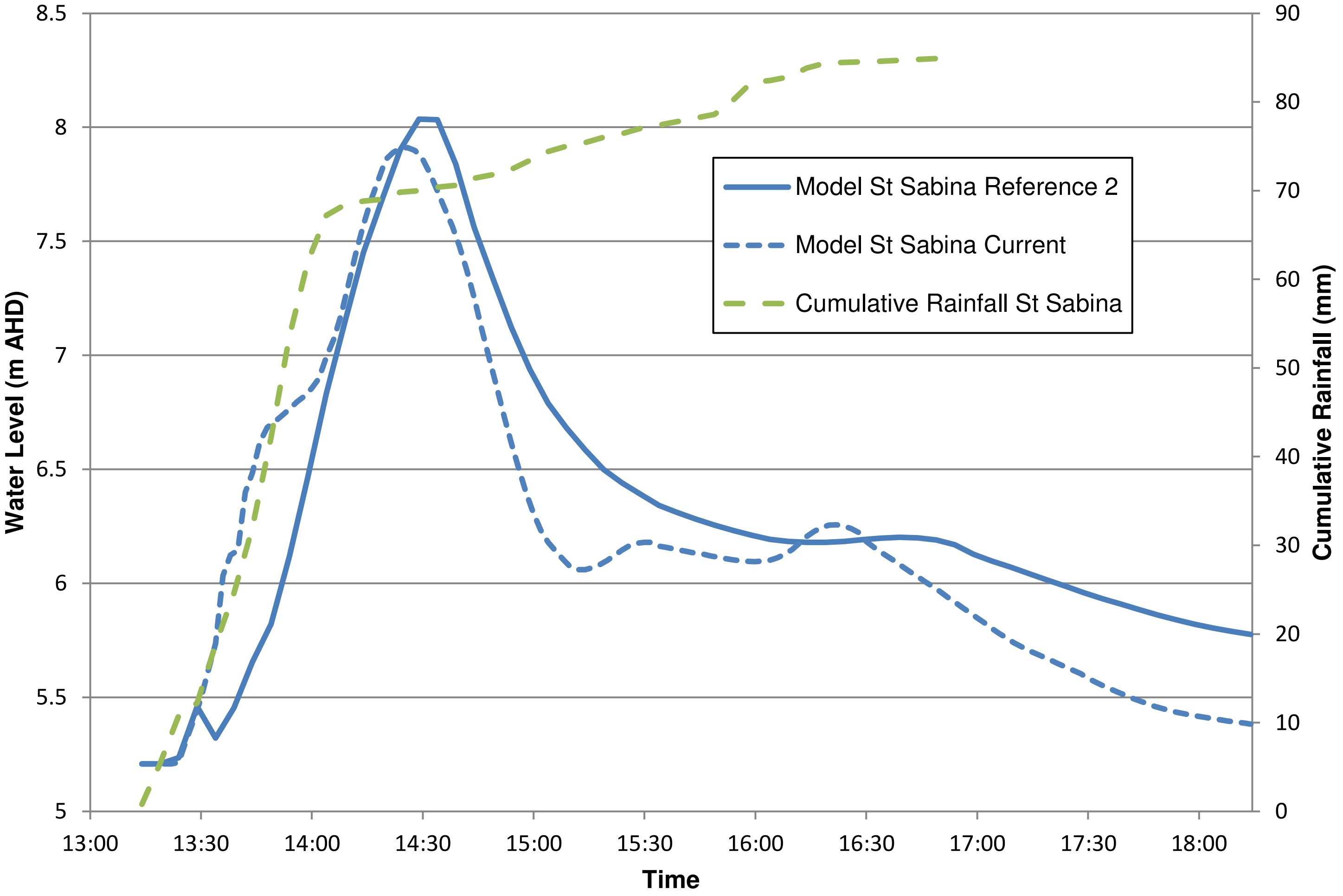
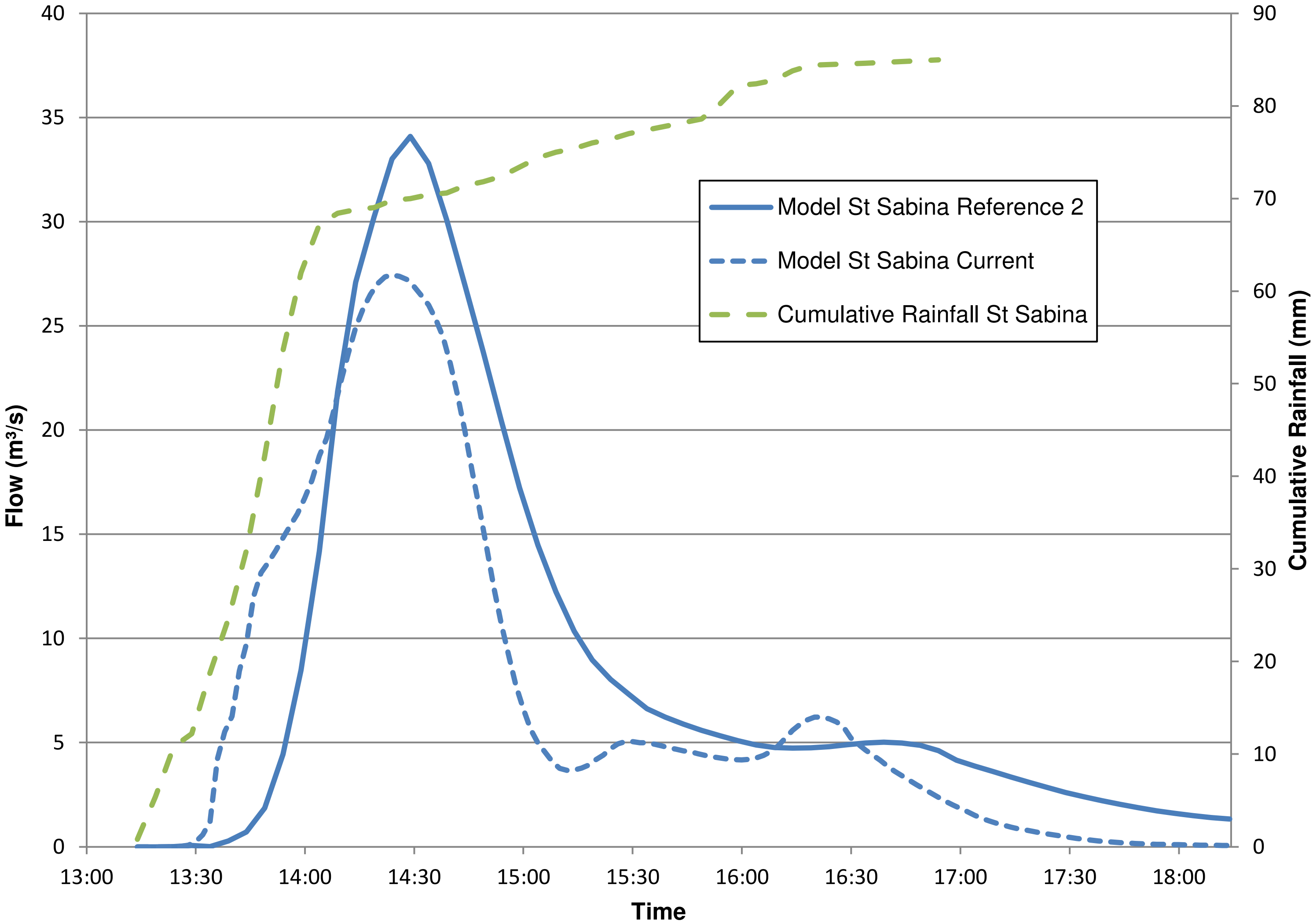


FIGURE 13F
CALIBRATION RESULTS--ELVA STREET GAUGE
2 JANUARY 1996





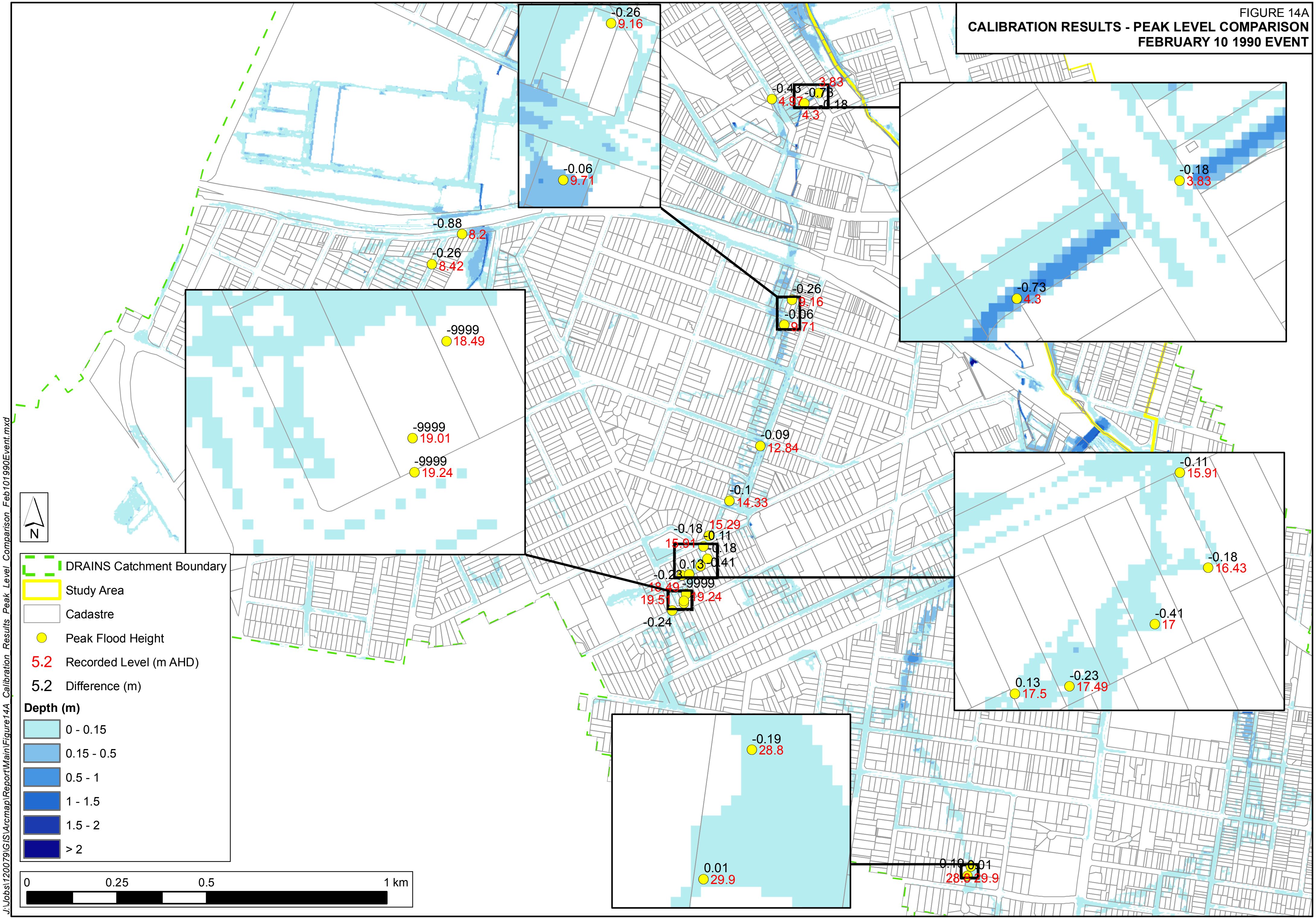
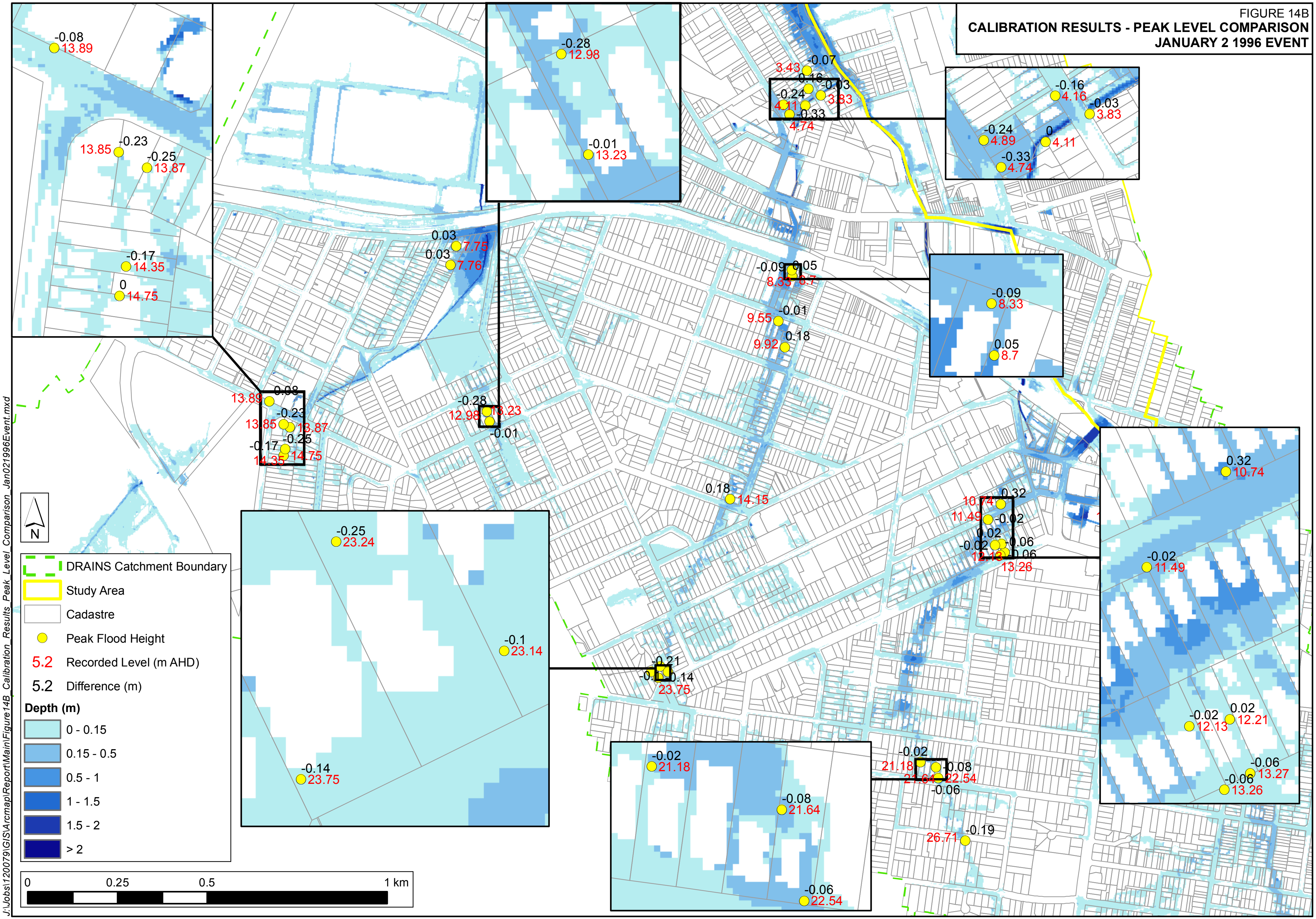
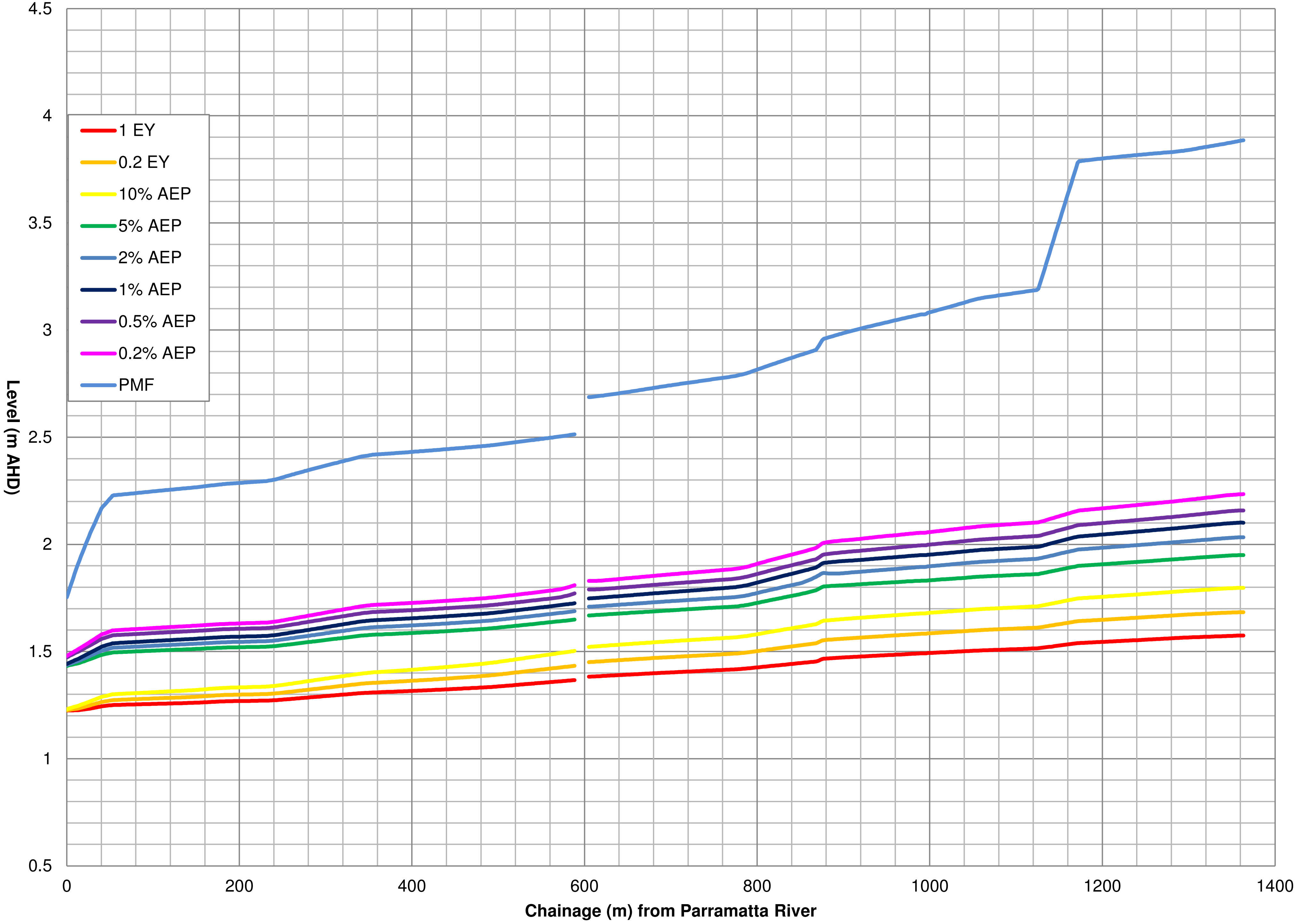


FIGURE 14A
CALIBRATION RESULTS - PEAK LEVEL COMPARISON
FEBRUARY 10 1990 EVENT
DRAINS Catchment Boundary
Study Area
Cadastre
Peak Flood Height
5.2 Recorded Level (m AHD)
5.2 Difference (m)
Depth (m)
0 - 0.15
0.15 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
> 2
N
0 0.25 0.5 1 km
-0.26 9.16
-0.06 9.71
-0.88 8.2
-0.26 8.42
-0.18 3.83
-0.73 4.3
-9999 18.49
-9999 19.01
-9999 19.24
-0.09 12.84
-0.1 14.33
-0.11 15.91
-0.18 16.43
-0.41 17
0.13 17.5
-0.23 17.49
-0.24
-0.19 28.8
0.01 29.9
J:\Jobs\120079\GIS\Arcmap\Report\Main\Figure14A_Calibration_Results_Peak_Level_Comparison_Feb101990Event.mxd

FIGURE 14B

CALIBRATION RESULTS - PEAK LEVEL COMPARISON
JANUARY 2 1996 EVENT





J:\Jobs\120079\Excel\120079_profile.xlsx

FIGURE 15A
DESIGN RESULTS
PEAK HEIGHT PROFILES - POWELLS CREEK

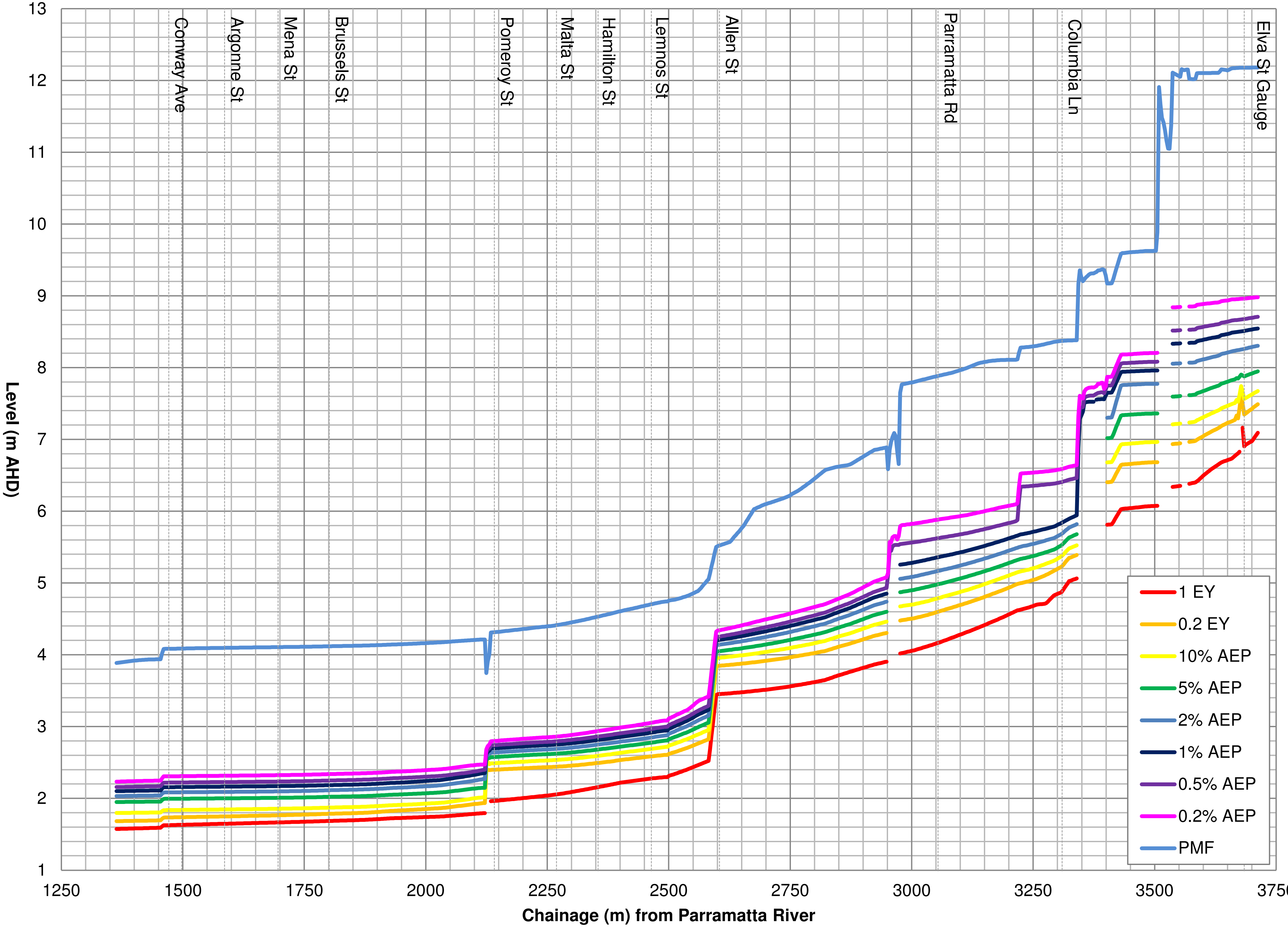


FIGURE 15B
DESIGN RESULTS
PEAK HEIGHT PROFILES - POWELLS CREEK

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FIGURE 16Ai

PEAK FLOOD DEPTH AND LEVEL CONTOUR
1 EY STORM EVENT

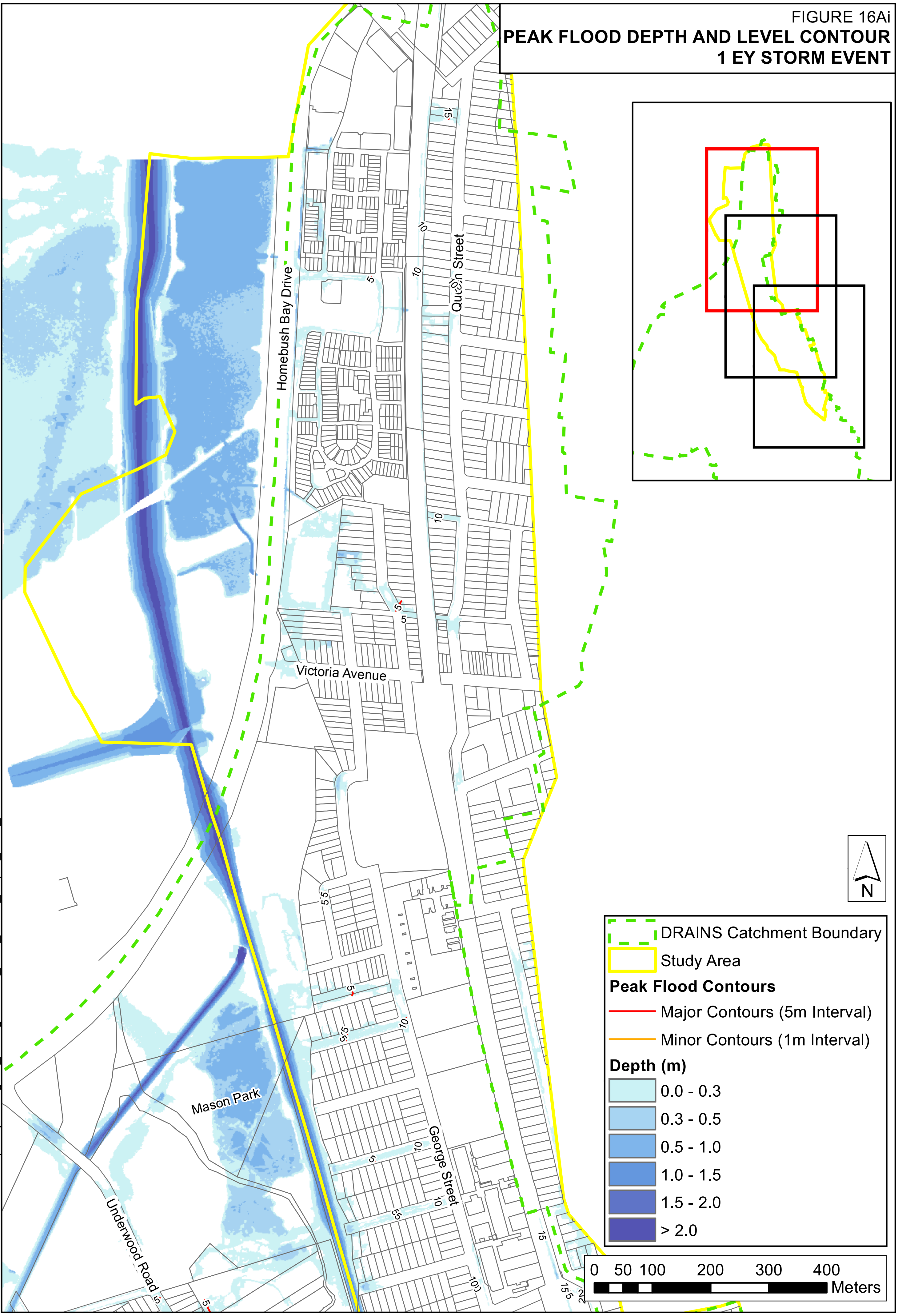


FIGURE 16Aii

PEAK FLOOD DEPTH AND LEVEL CONTOUR
1 EY STORM EVENT

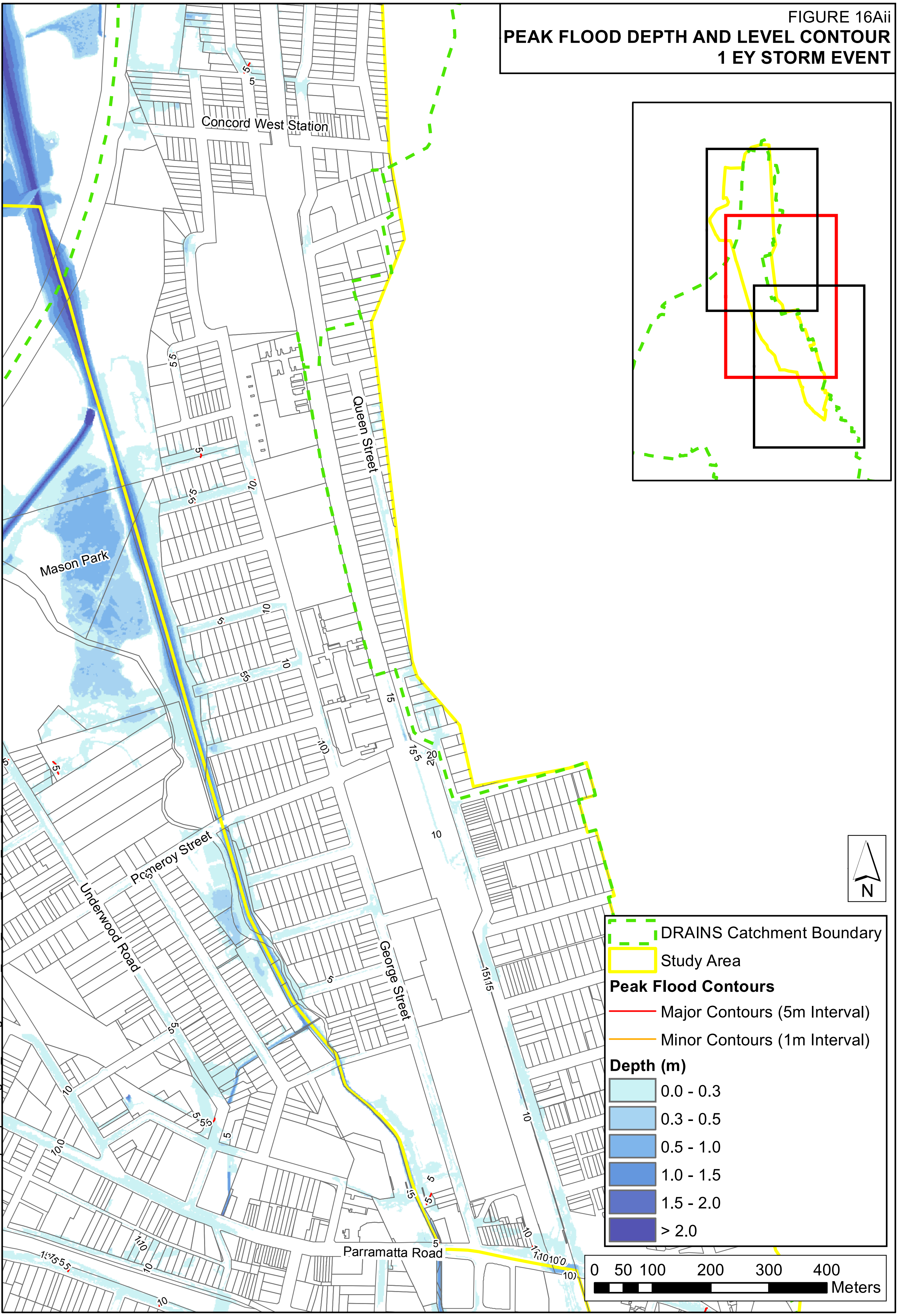
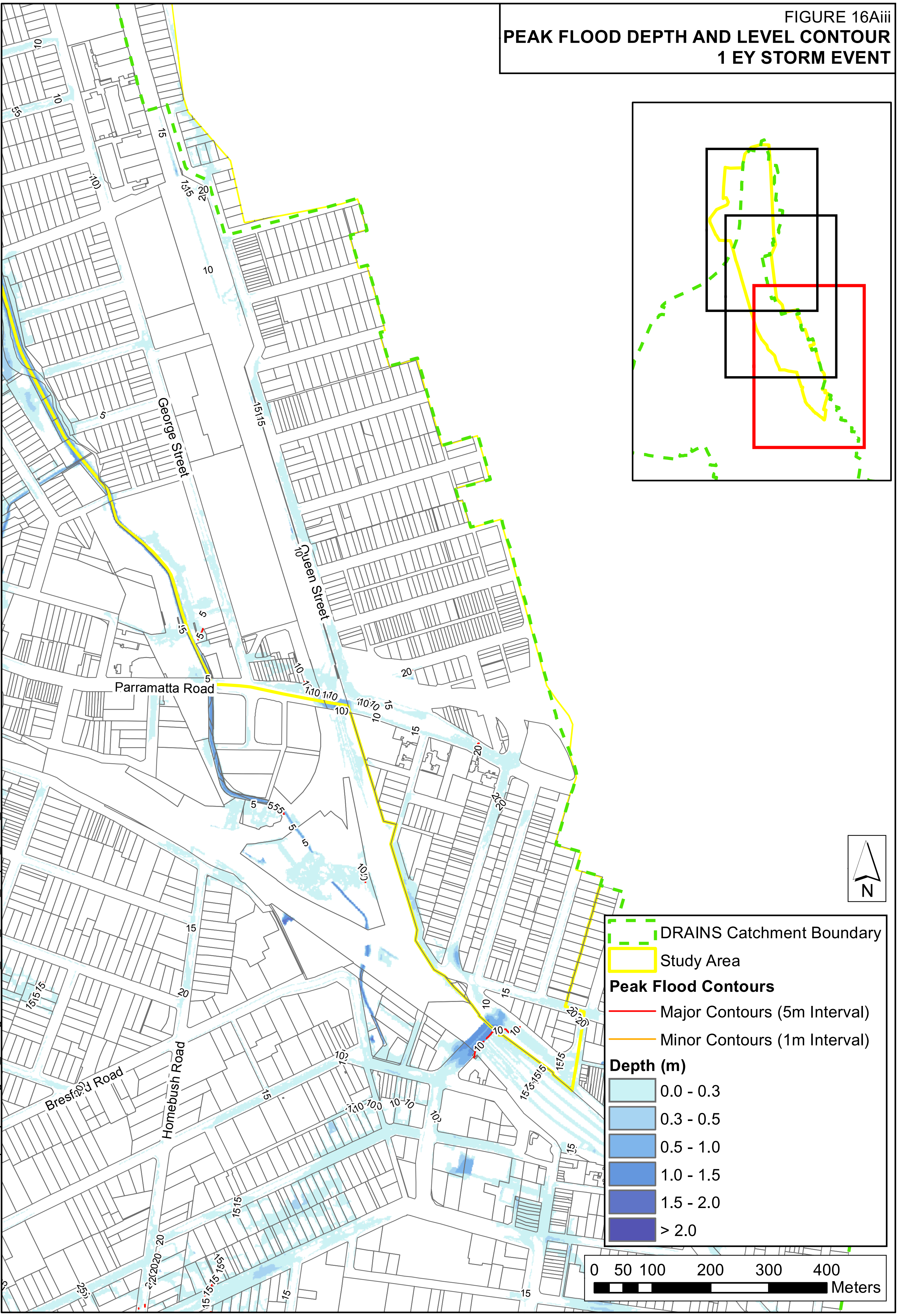


FIGURE 16Aiii
PEAK FLOOD DEPTH AND LEVEL CONTOUR
1 EY STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure_16\Figure16Aiii_1EY_Flood_Depth_level_contour.mxd

FIGURE 16Bi

PEAK FLOOD DEPTH AND LEVEL CONTOUR 0.2 EY STORM EVENT

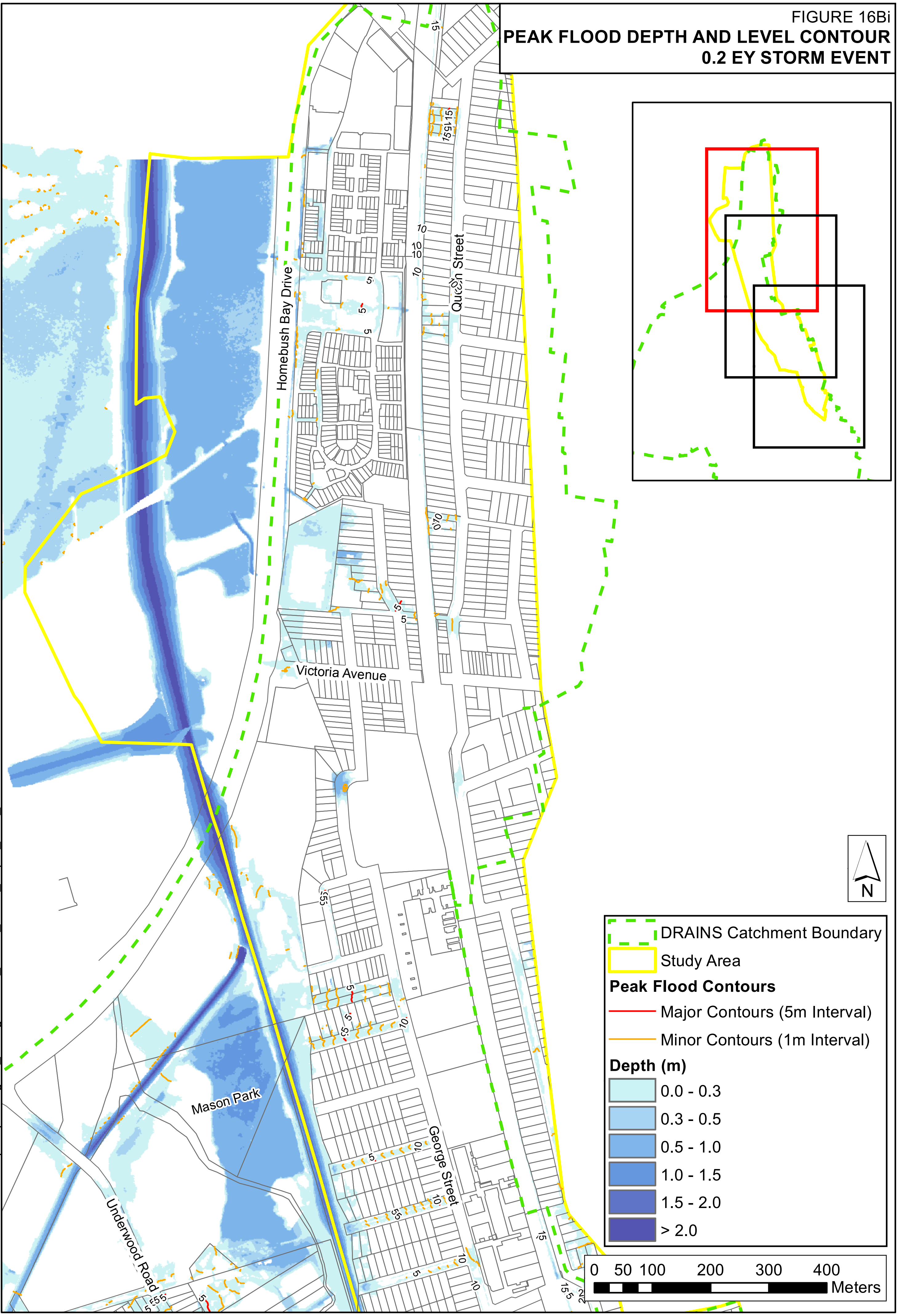


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FIGURE 16Bii

PEAK FLOOD DEPTH AND LEVEL CONTOUR 0.2 EY STORM EVENT

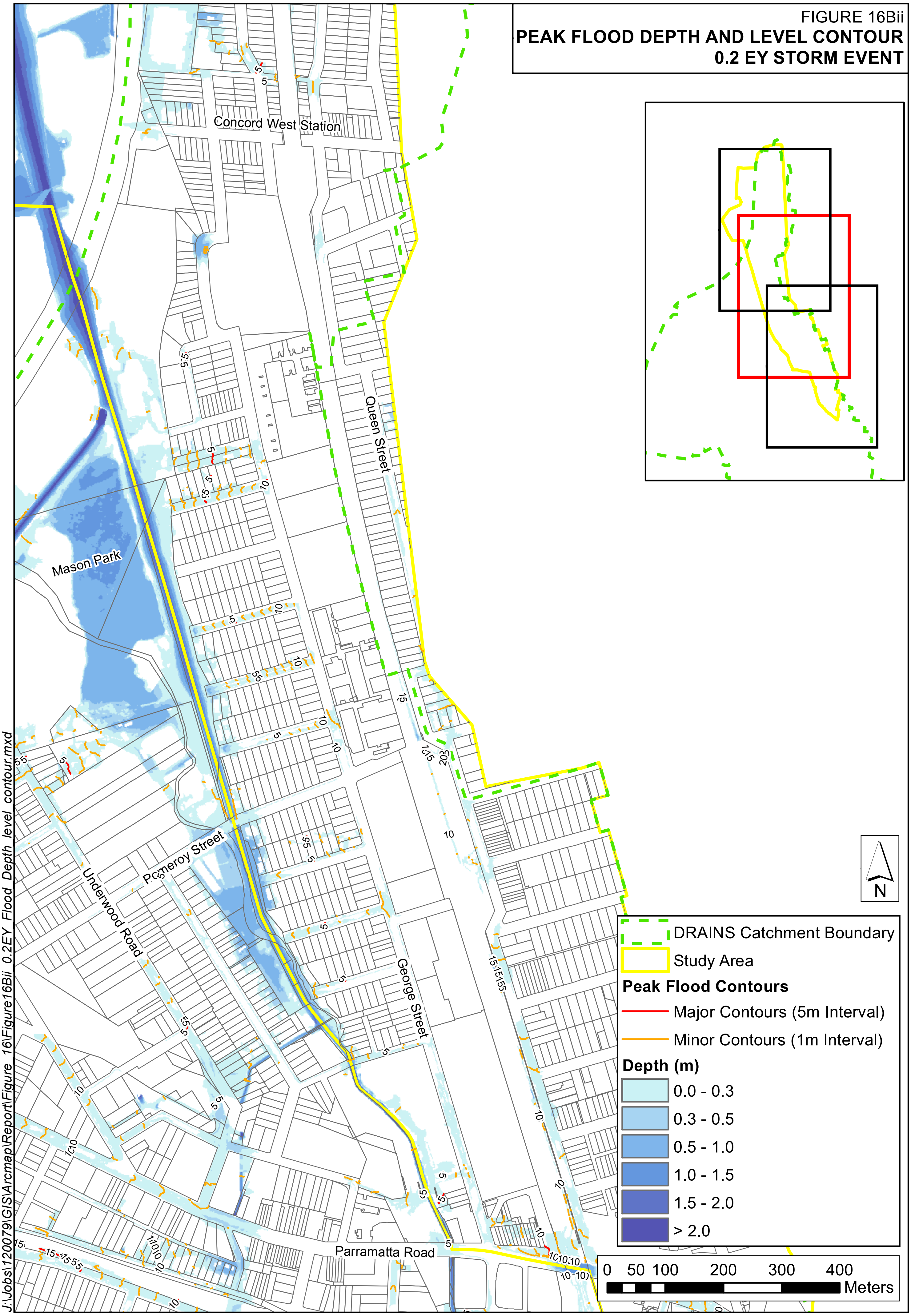
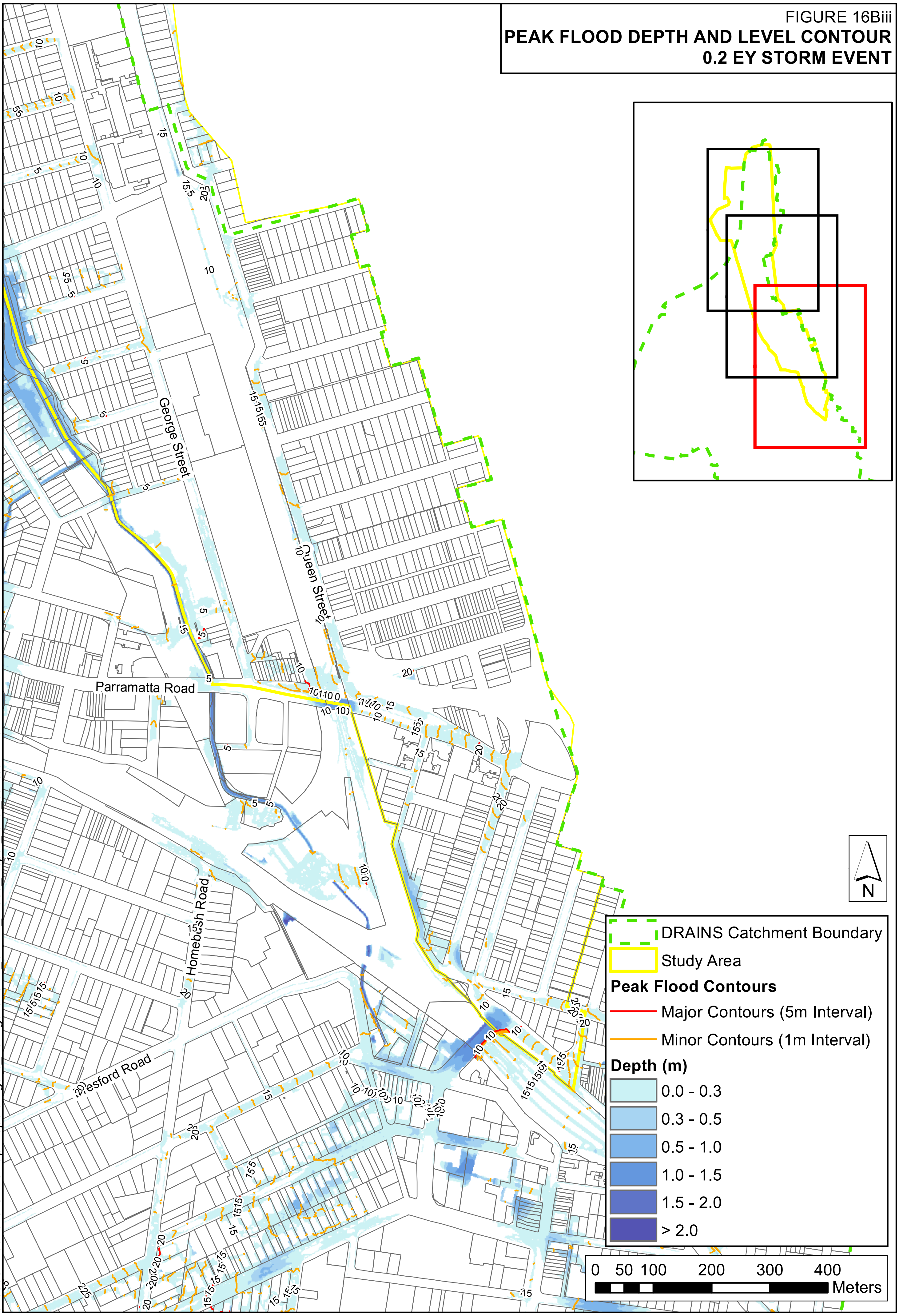


FIGURE 16Biii

PEAK FLOOD DEPTH AND LEVEL CONTOUR
0.2 EY STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure 16\Figure16Biii 0.2EY Flood Depth level contour.mxd

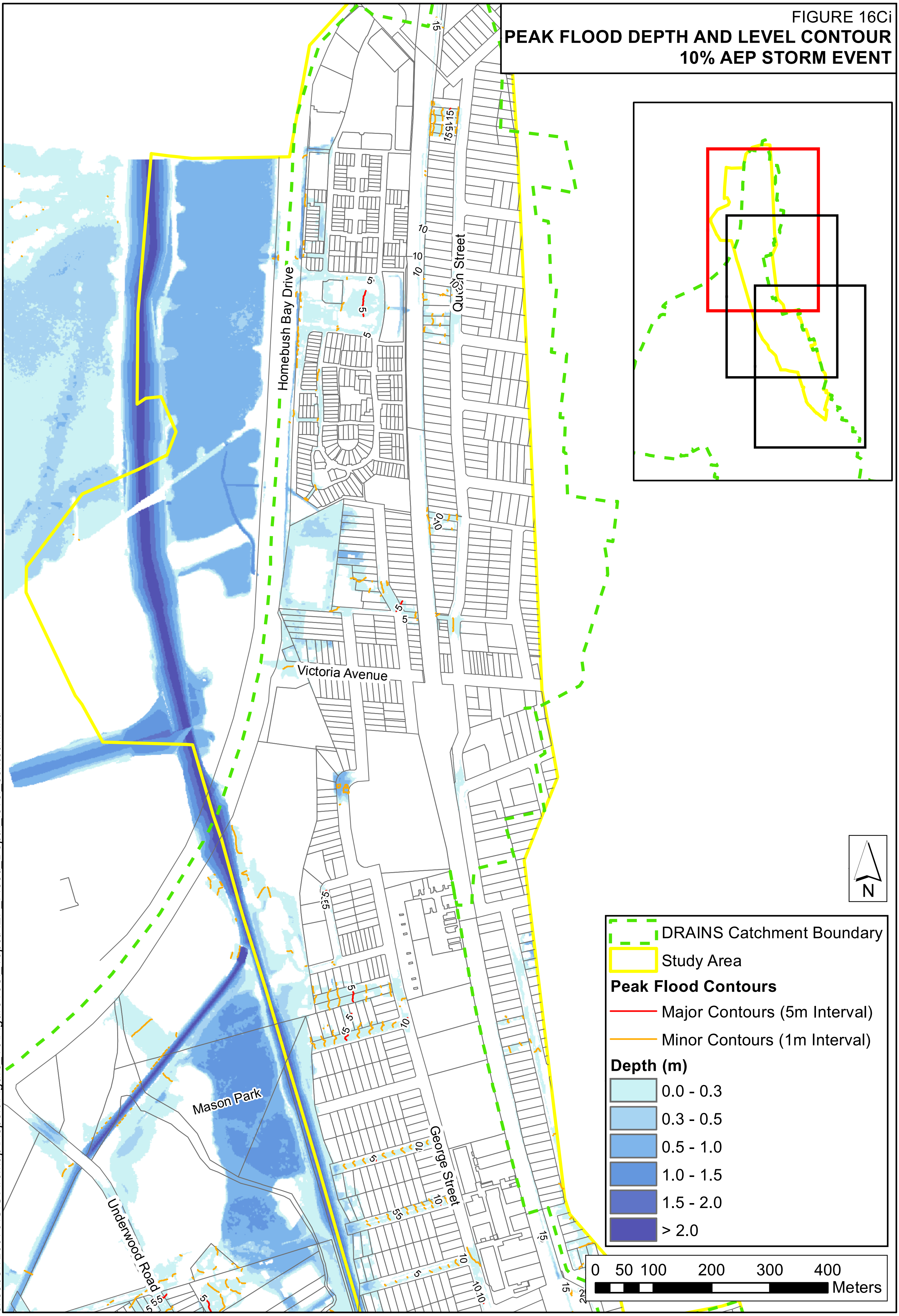
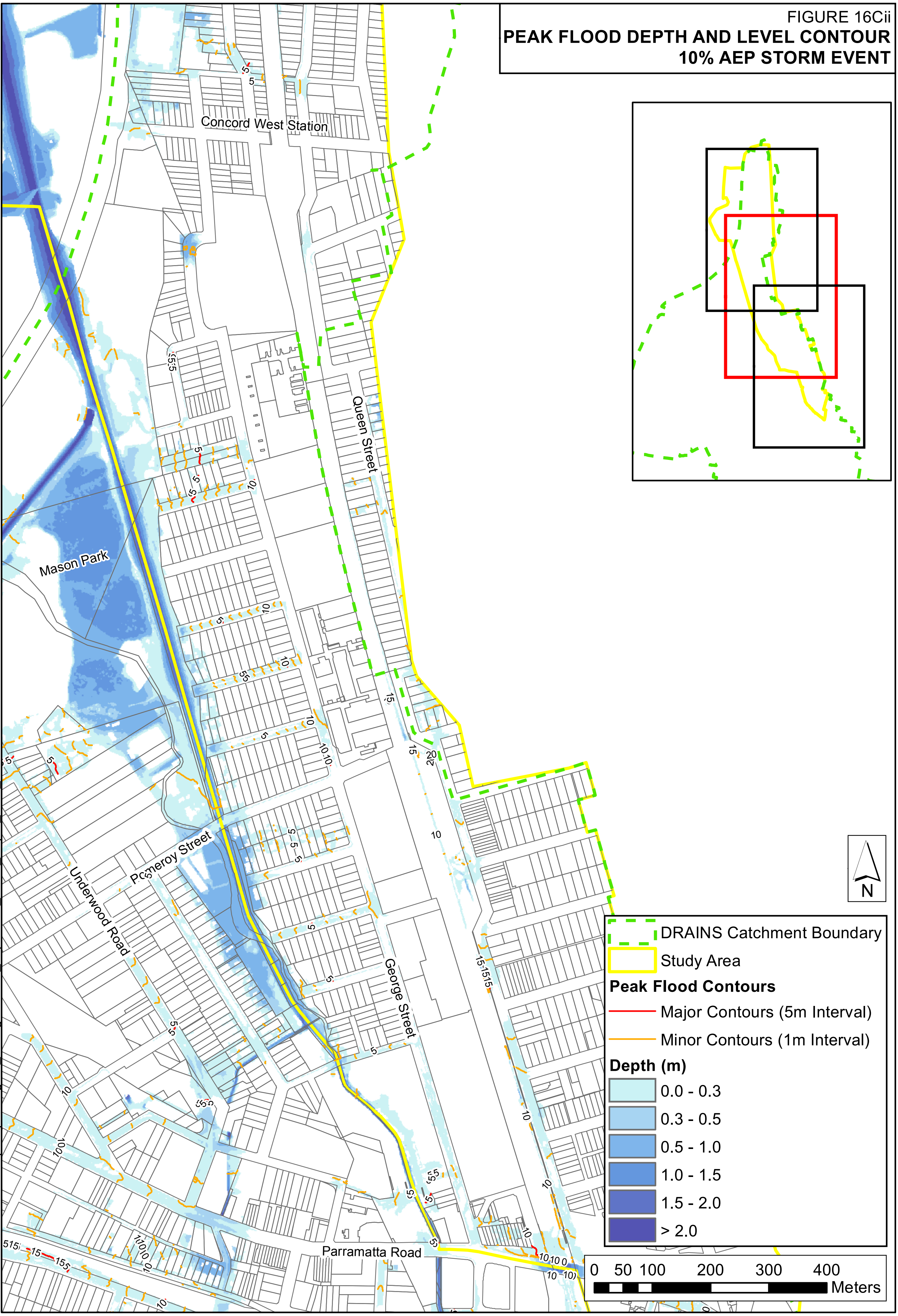


FIGURE 16Ci
PEAK FLOOD DEPTH AND LEVEL CONTOUR
10% AEP STORM EVENT
Homebush Bay Drive
Queen Street
Victoria Avenue
Mason Park
Underwood Road
George Street
N
DRAINS Catchment Boundary
Study Area
Peak Flood Contours
Major Contours (5m Interval)
Minor Contours (1m Interval)
Depth (m)
0.0 - 0.3
0.3 - 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
0 50 100 200 300 400
Meters
J:\Jobs\120079\GIS\Arcmap\Report\Figure_16\Figure16Ci_10pctAEP_Flood_Depth_level_contour.mxd

FIGURE 16Cii

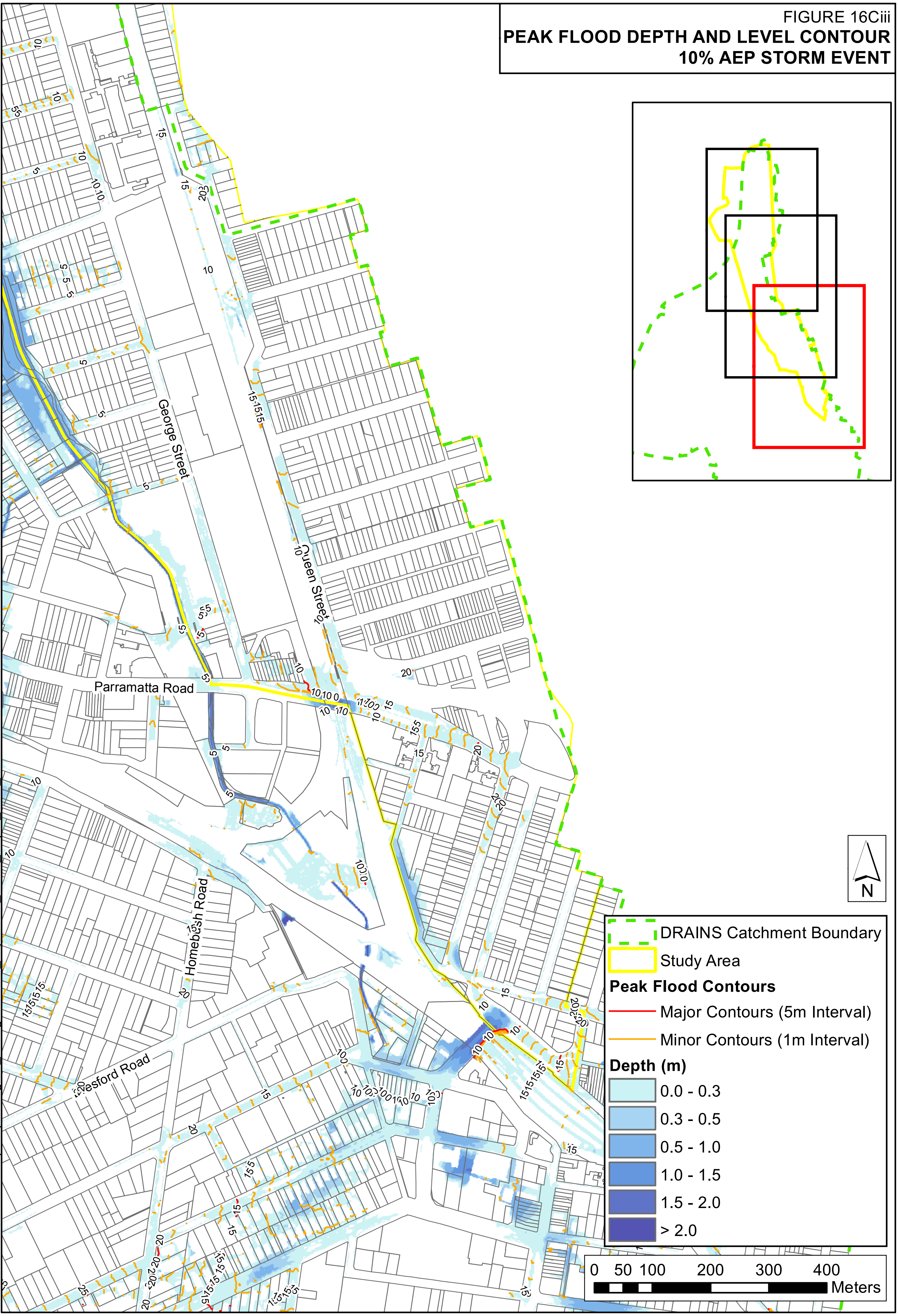
PEAK FLOOD DEPTH AND LEVEL CONTOUR
10% AEP STORM EVENT



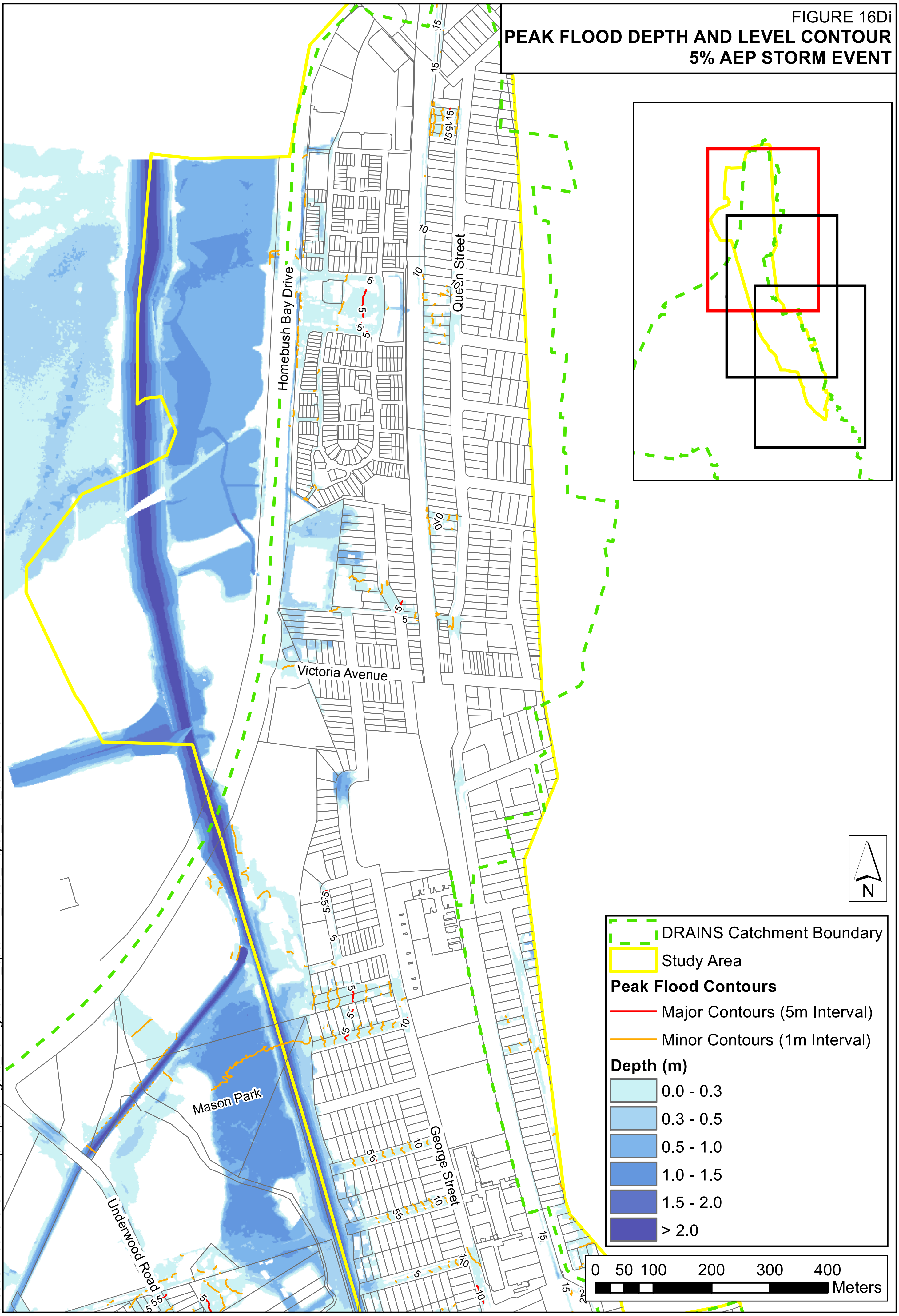
J:\Jobs\120079\GIS\Arcmap\Report\Figure 16\Figure16Cii_10pctAEP_Flood_Depth_level_contour.mxd

FIGURE 16Ciii

PEAK FLOOD DEPTH AND LEVEL CONTOUR 10% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure_16\Figure16Ciii_10pctAEP_Flood_Depth_level_contour.mxd



J:\Jobs\120079\GIS\Arcmap\Report\Figure_16\Figure16Di_5pctAEP_Flood_Depth_level_contour.mxd

FIGURE 16Dii

PEAK FLOOD DEPTH AND LEVEL CONTOUR

5% AEP STORM EVENT

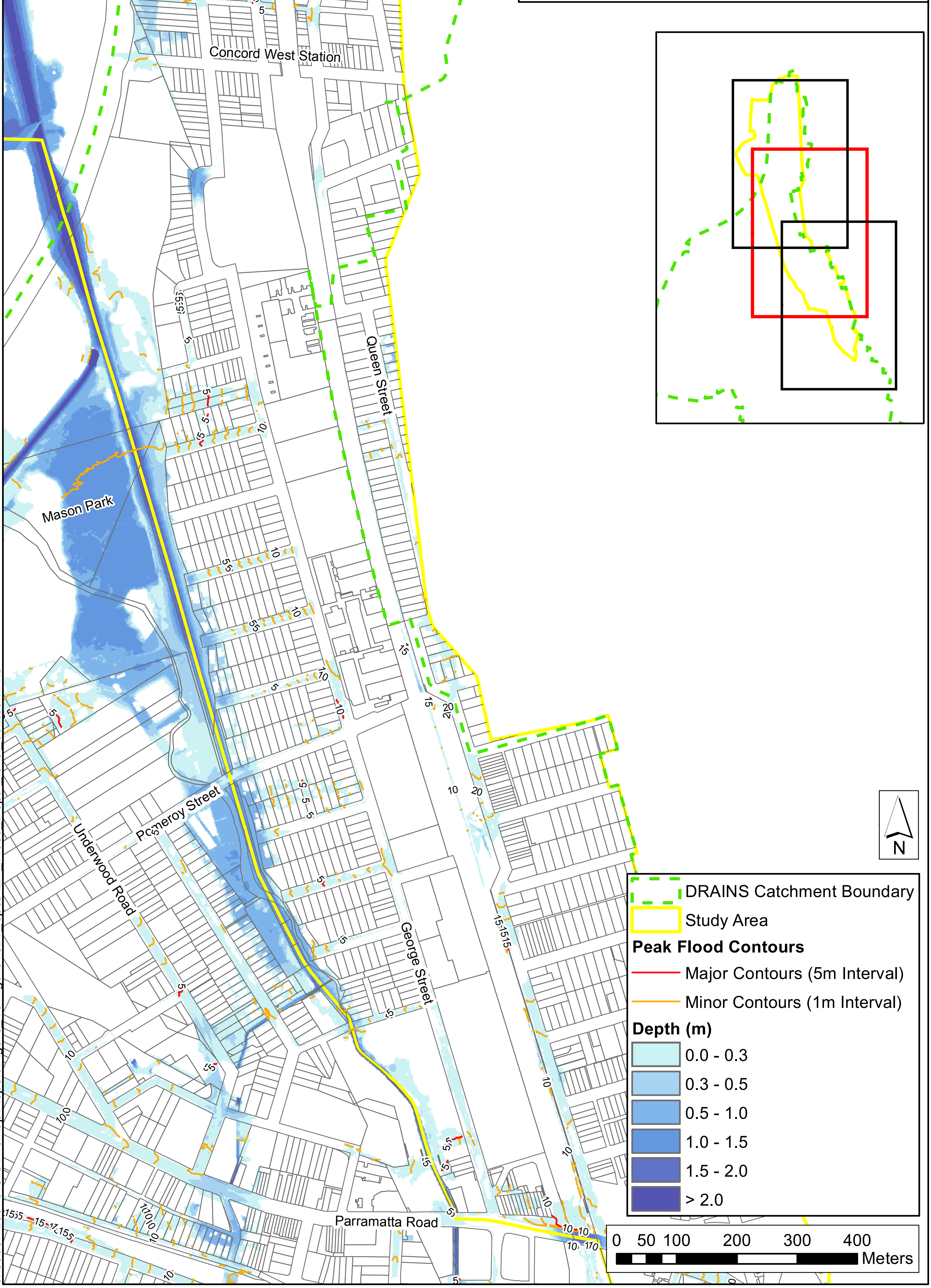
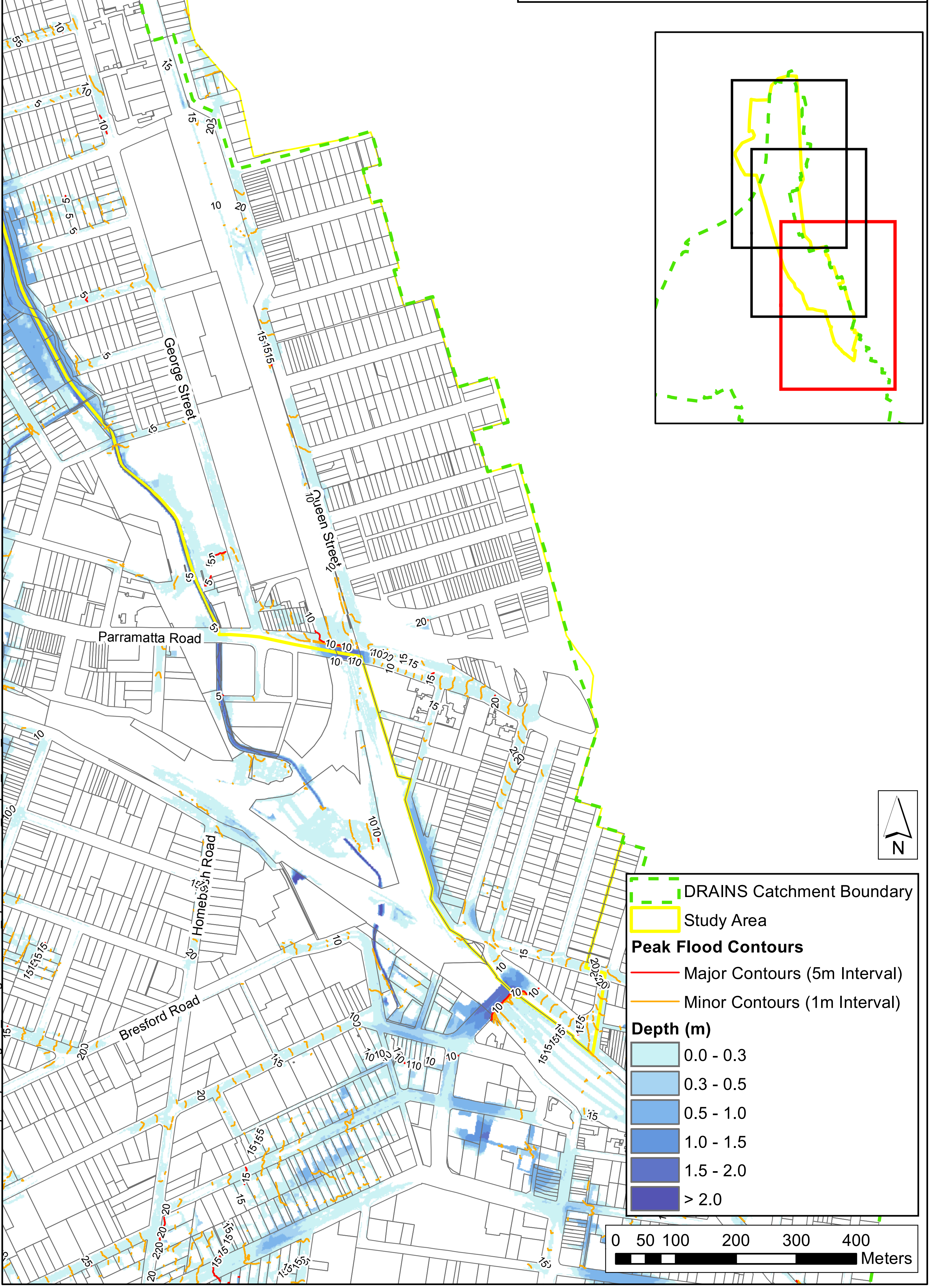


FIGURE 16Diii

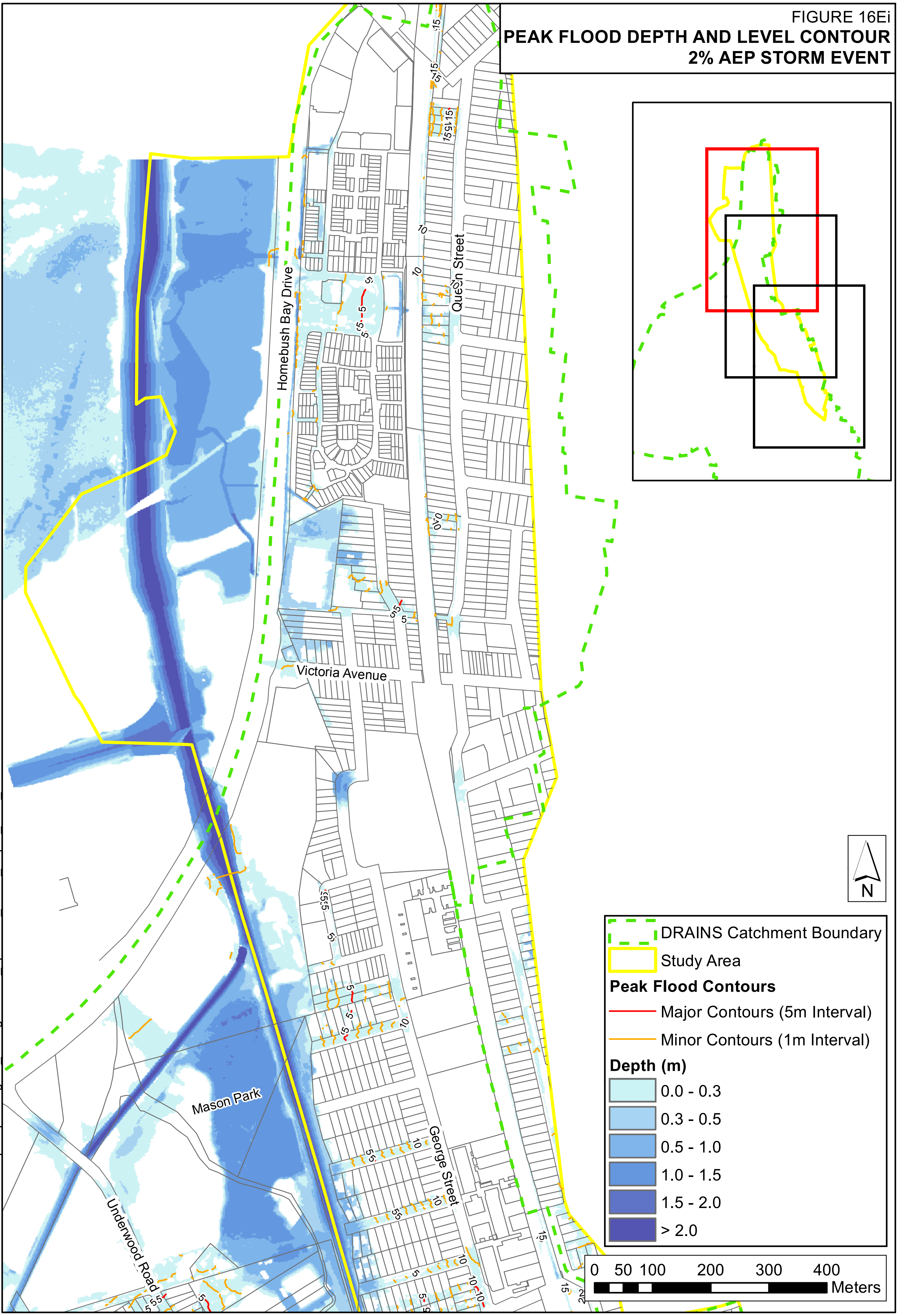
PEAK FLOOD DEPTH AND LEVEL CONTOUR
5% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure 16\Figure16Diii_5pctAEP_Flood_Depth_level_contour.mxd

FIGURE 16Ei

PEAK FLOOD DEPTH AND LEVEL CONTOUR 2% AEP STORM EVENT

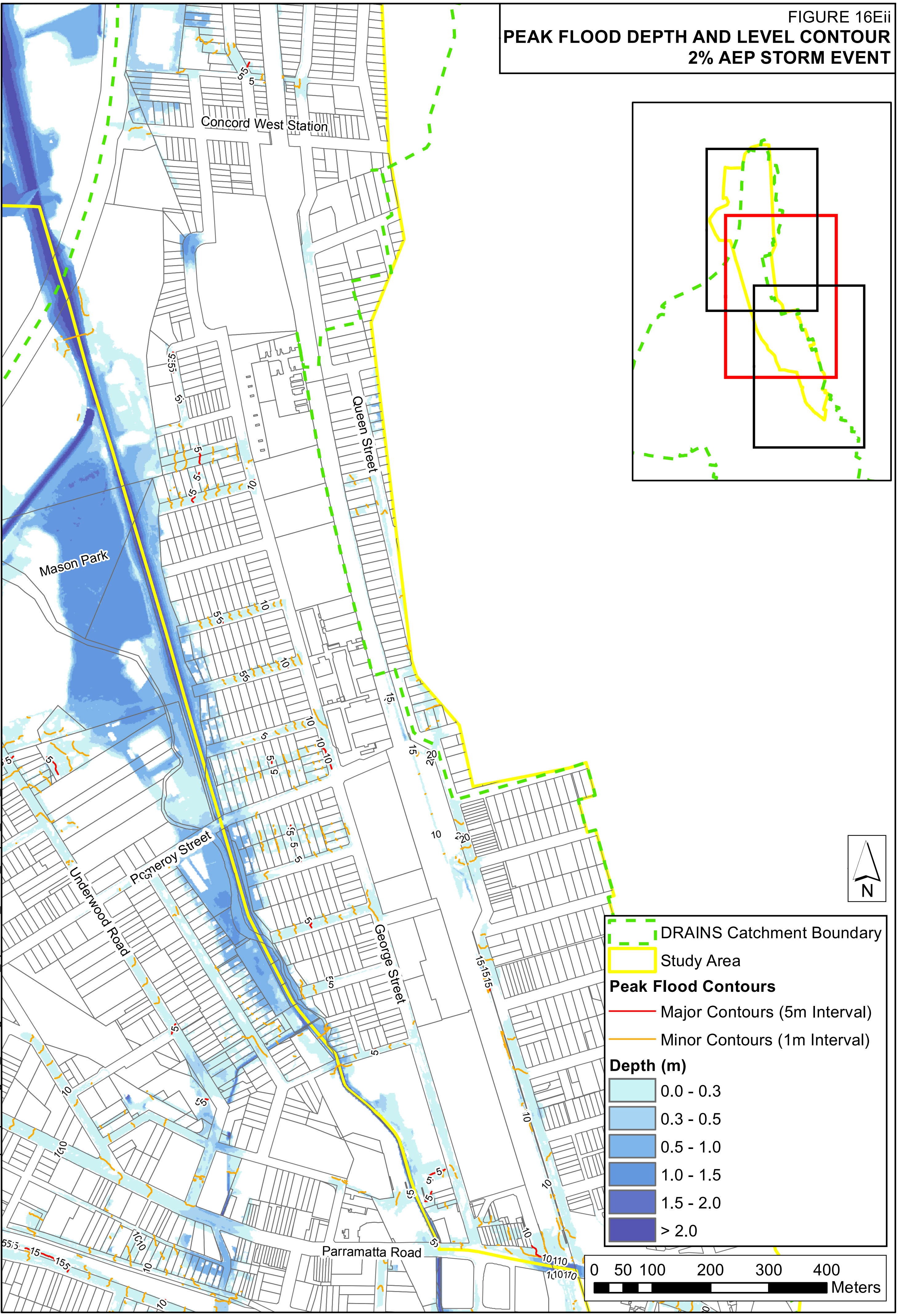


J:\Jobs\120079\GIS\Arcmap\Report\Figure 16\Figure16Ei_2pctAEP_Flood_Depth_level_contour.mxd

FIGURE 16Eii

PEAK FLOOD DEPTH AND LEVEL CONTOUR

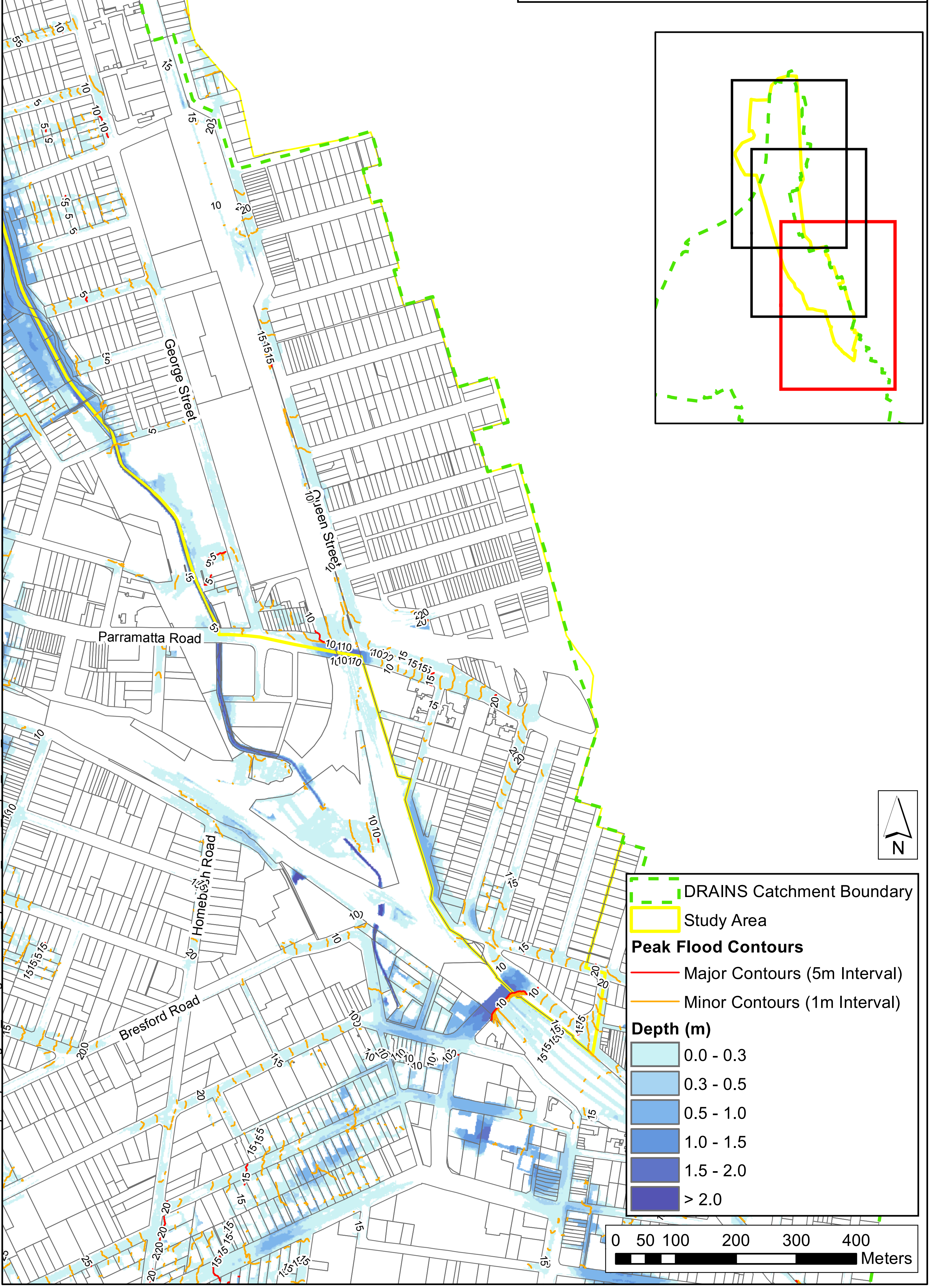
2% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure 16\Figure16Eii_2pctAEP_Flood_Depth_level_contour.mxd

FIGURE 16Eiii

PEAK FLOOD DEPTH AND LEVEL CONTOUR 2% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure 16\Figure16Eiii_2pctAEP_Flood_Depth_level_contour.mxd

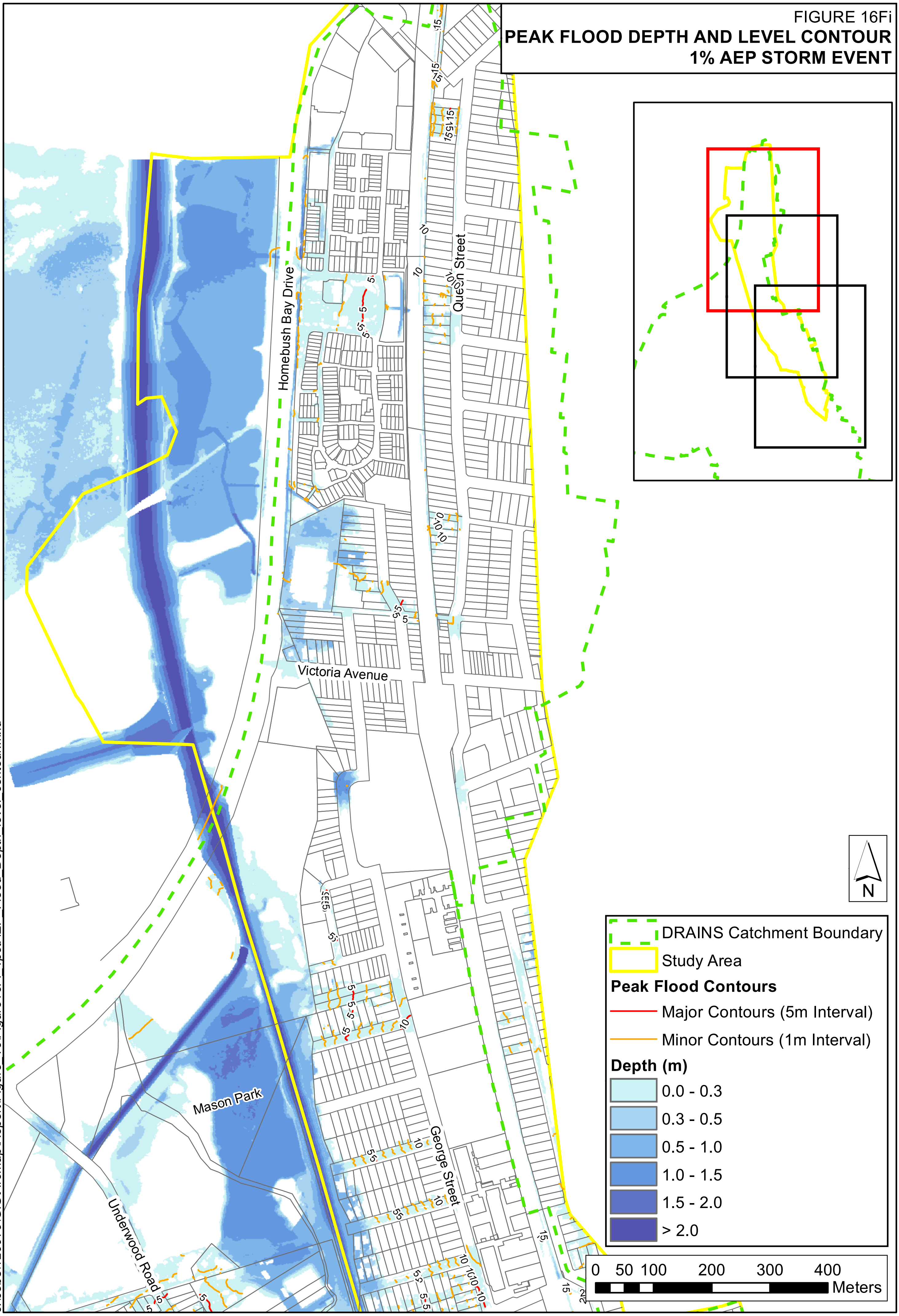
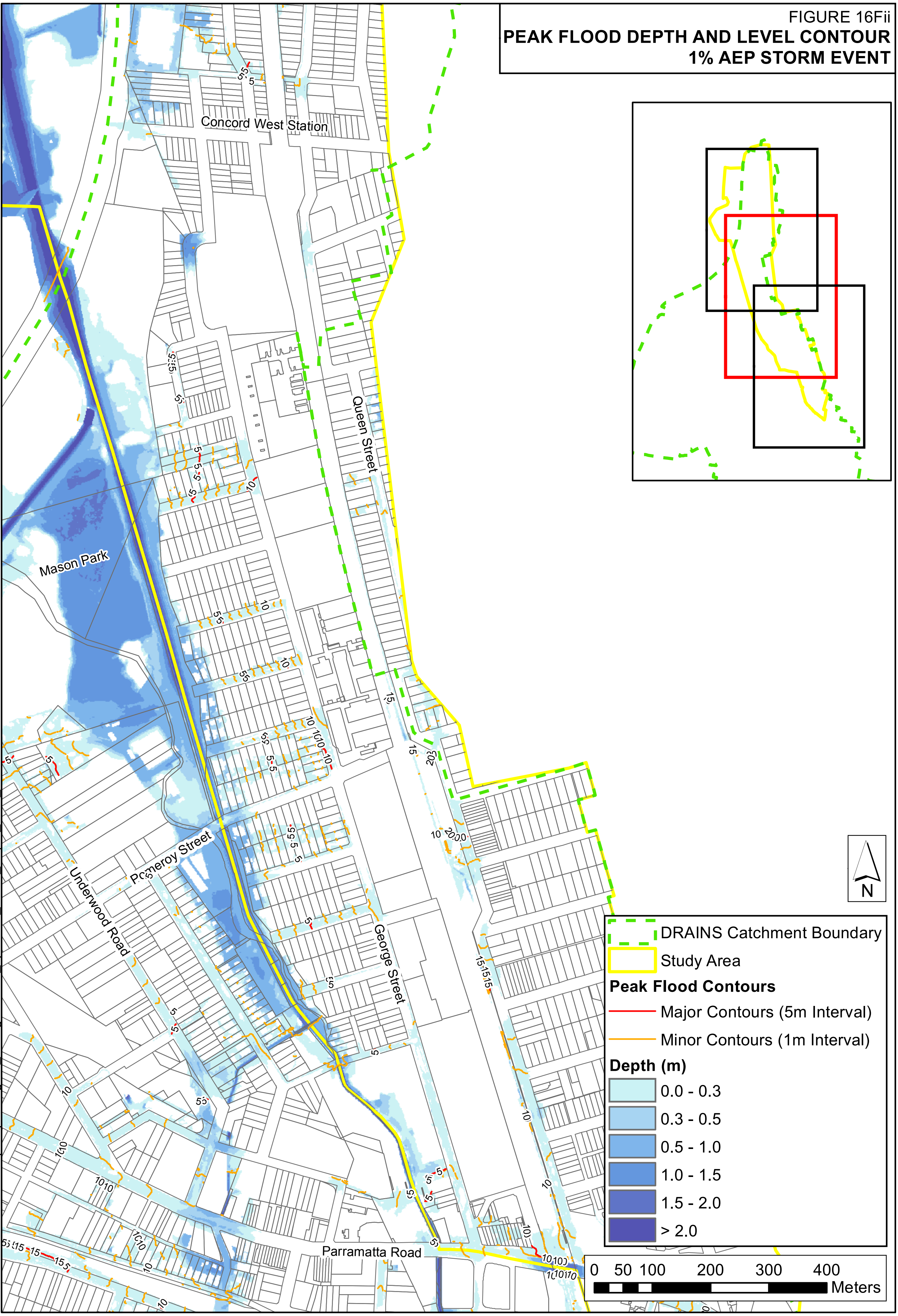


FIGURE 16Fi
PEAK FLOOD DEPTH AND LEVEL CONTOUR
1% AEP STORM EVENT

J:\Jobs\120079\GIS\Arcmap\Report\Figure_16\Figure16Fi_1pctAEP_Flood_Depth_level_contour.mxd

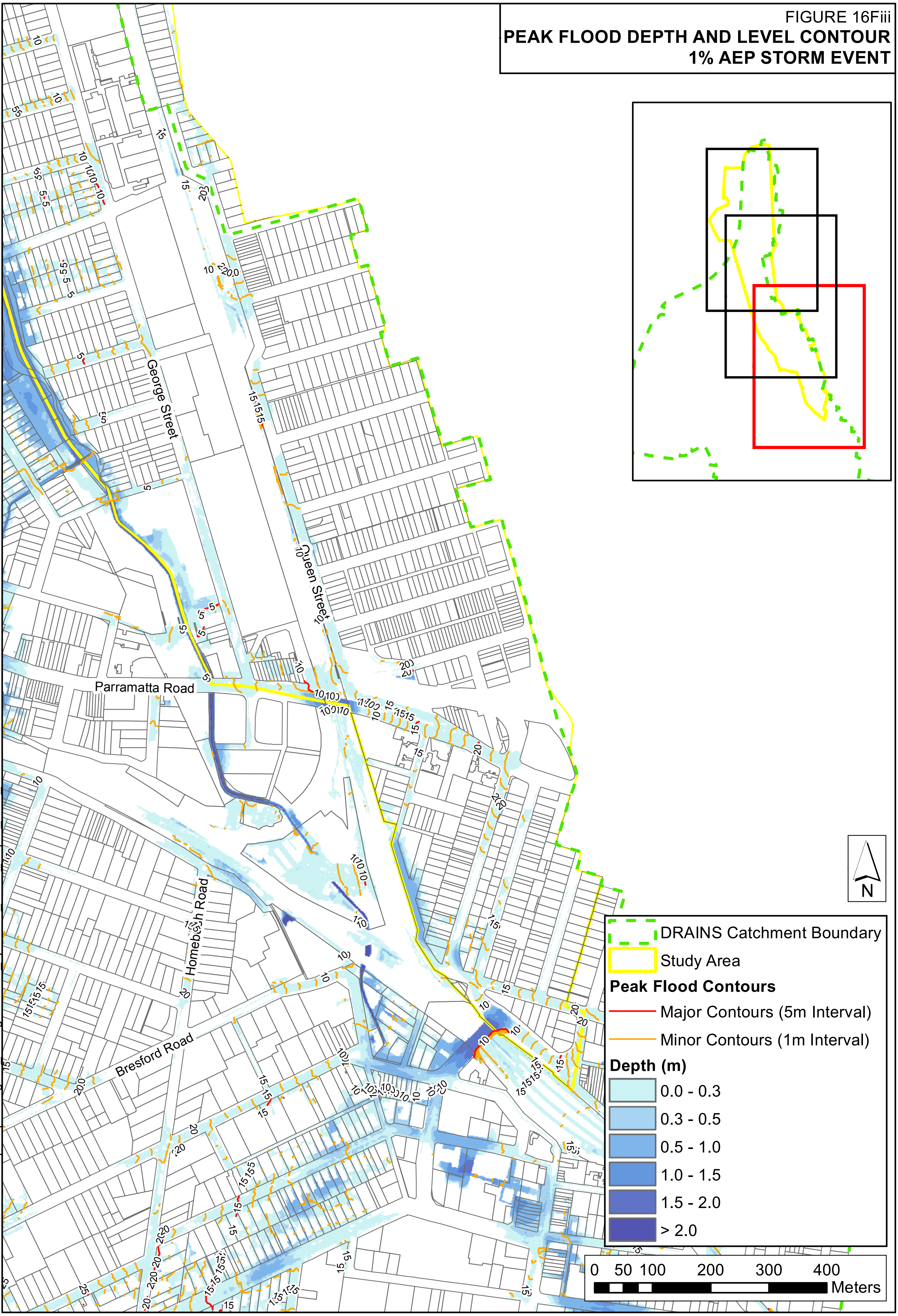
FIGURE 16Fii

PEAK FLOOD DEPTH AND LEVEL CONTOUR 1% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure_16\Figure16Fii_1pctAEP_Flood_Depth_level_contour.mxd

FIGURE 16Fiii
PEAK FLOOD DEPTH AND LEVEL CONTOUR
1% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure 16\Figure16Fiii 1pctAEP Flood Depth level contour.mxd

FIGURE 16Gi

PEAK FLOOD DEPTH AND LEVEL CONTOUR 0.5% AEP STORM EVENT

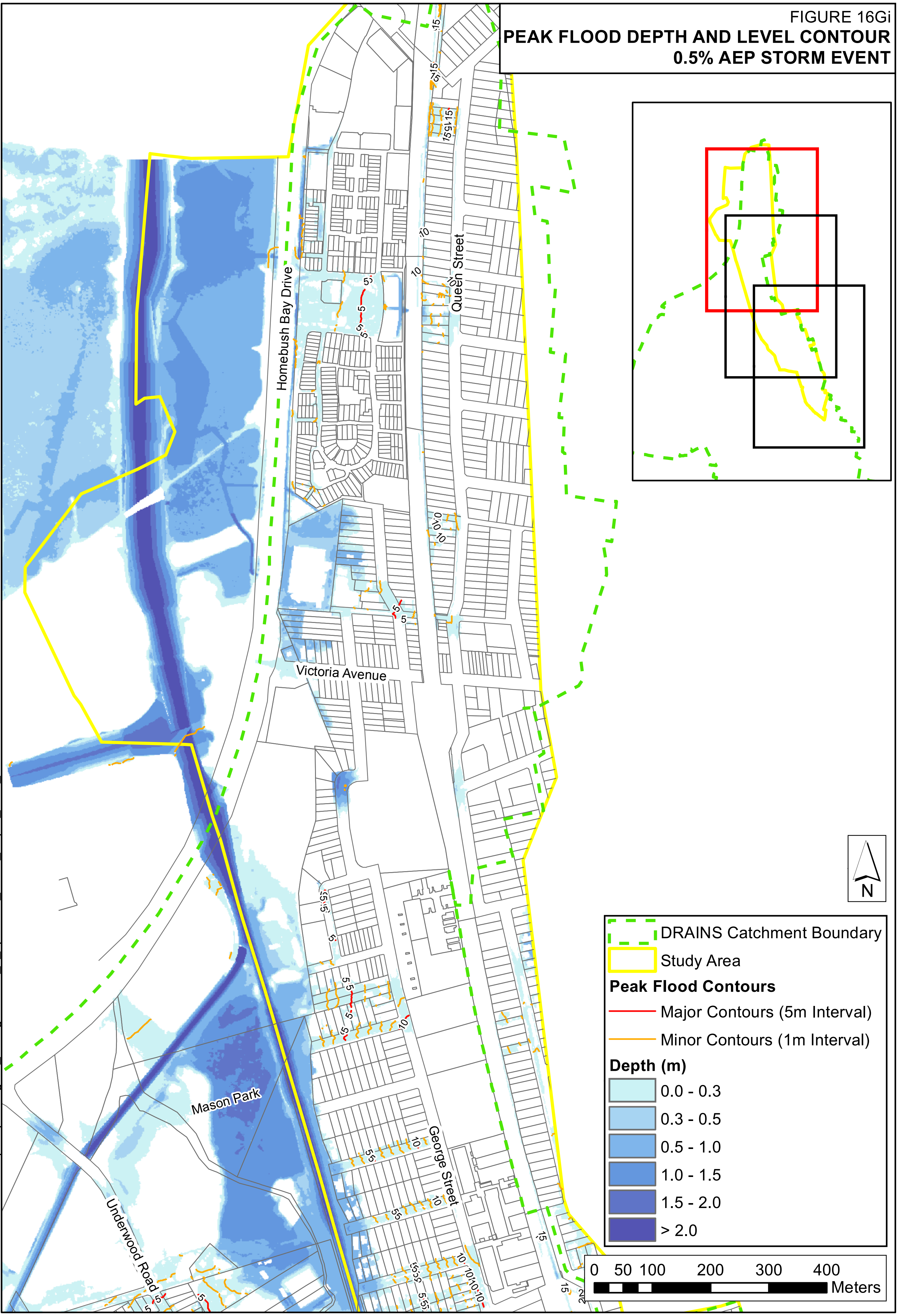
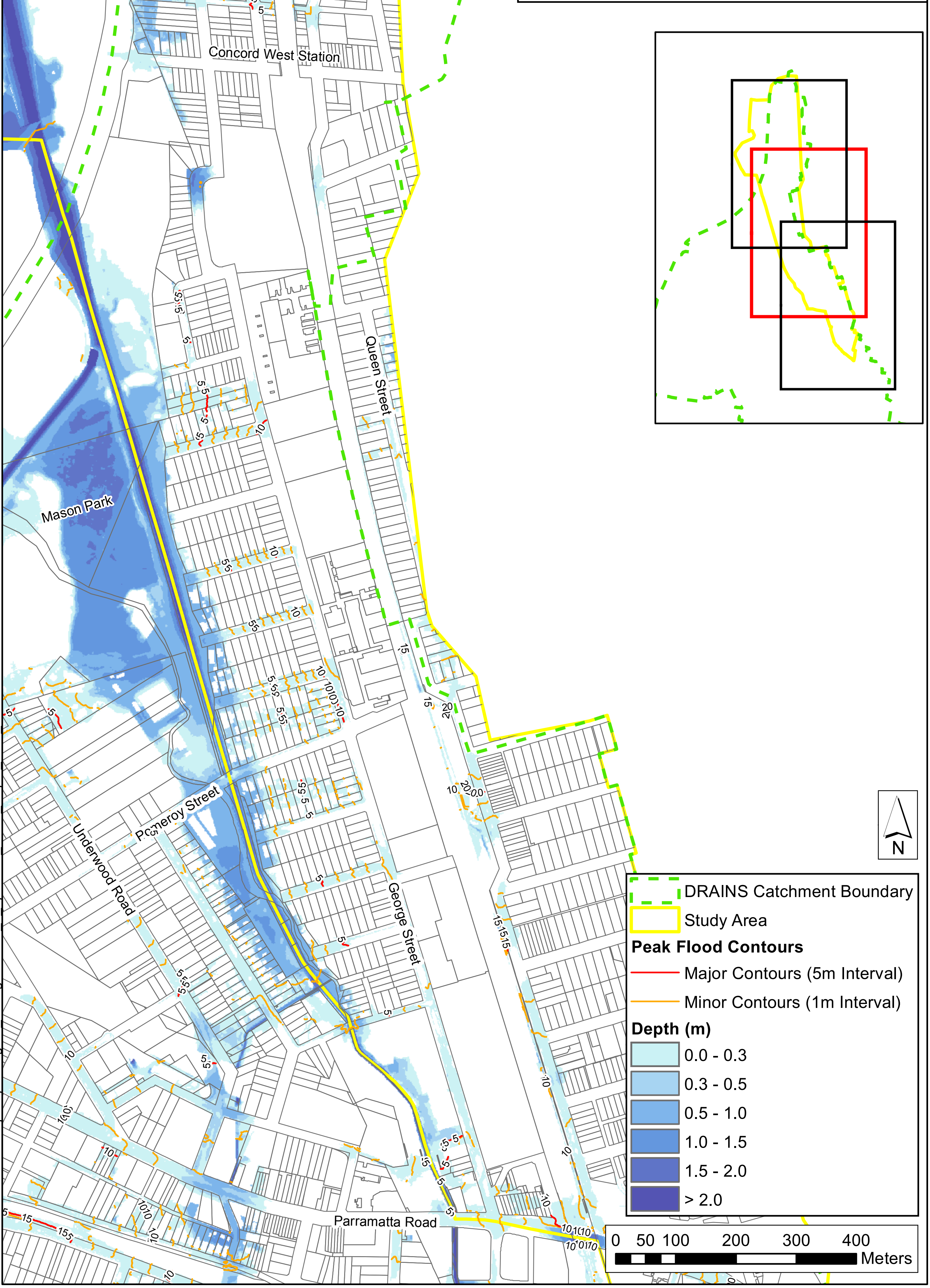


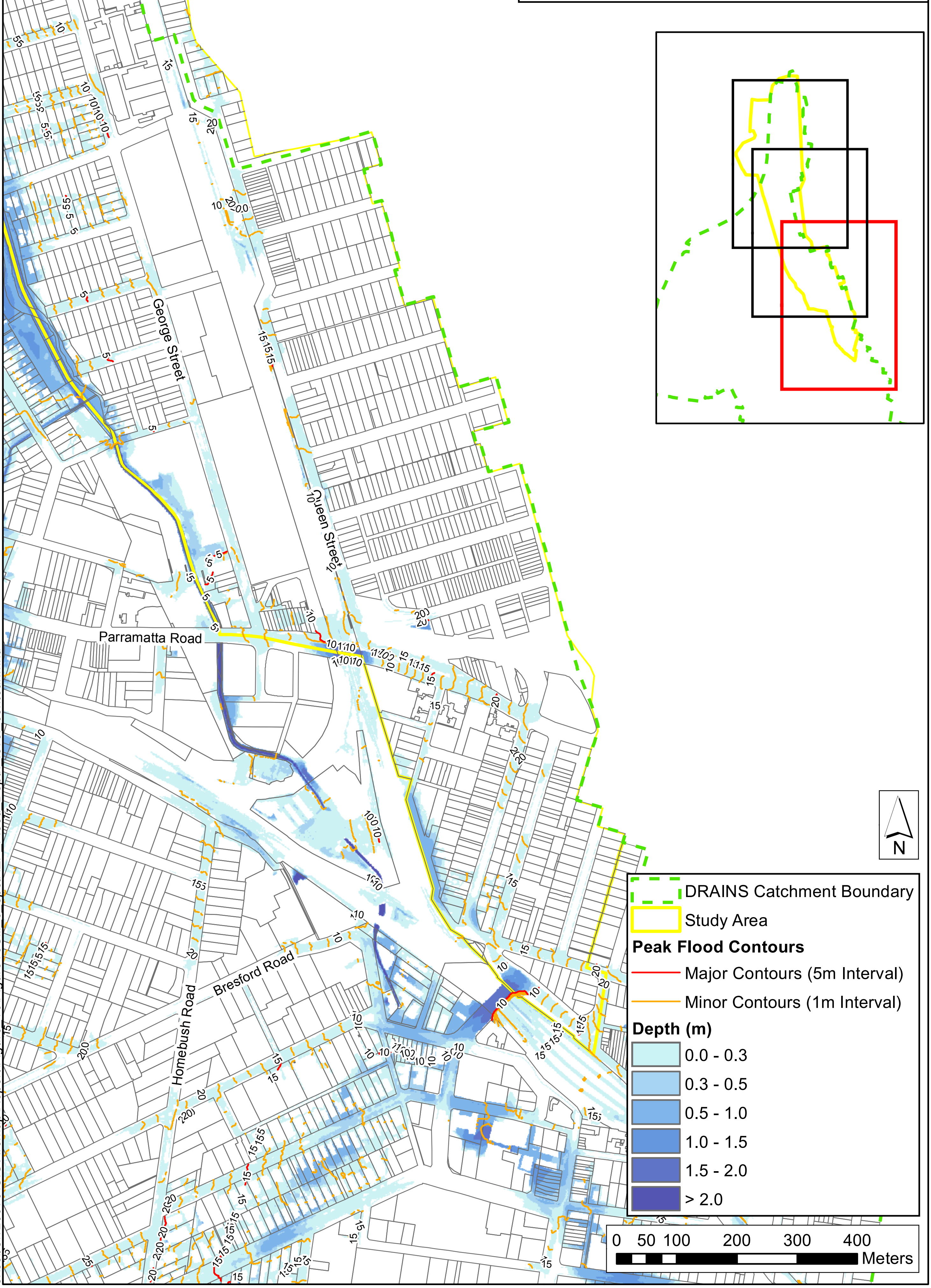
FIGURE 16Gii
PEAK FLOOD DEPTH AND LEVEL CONTOUR
0.5% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure 16\Figure16Gii_0_5pctAEP_Flood_Depth_level_contour.mxd

FIGURE 16Giii

PEAK FLOOD DEPTH AND LEVEL CONTOUR
0.5% AEP STORM EVENT

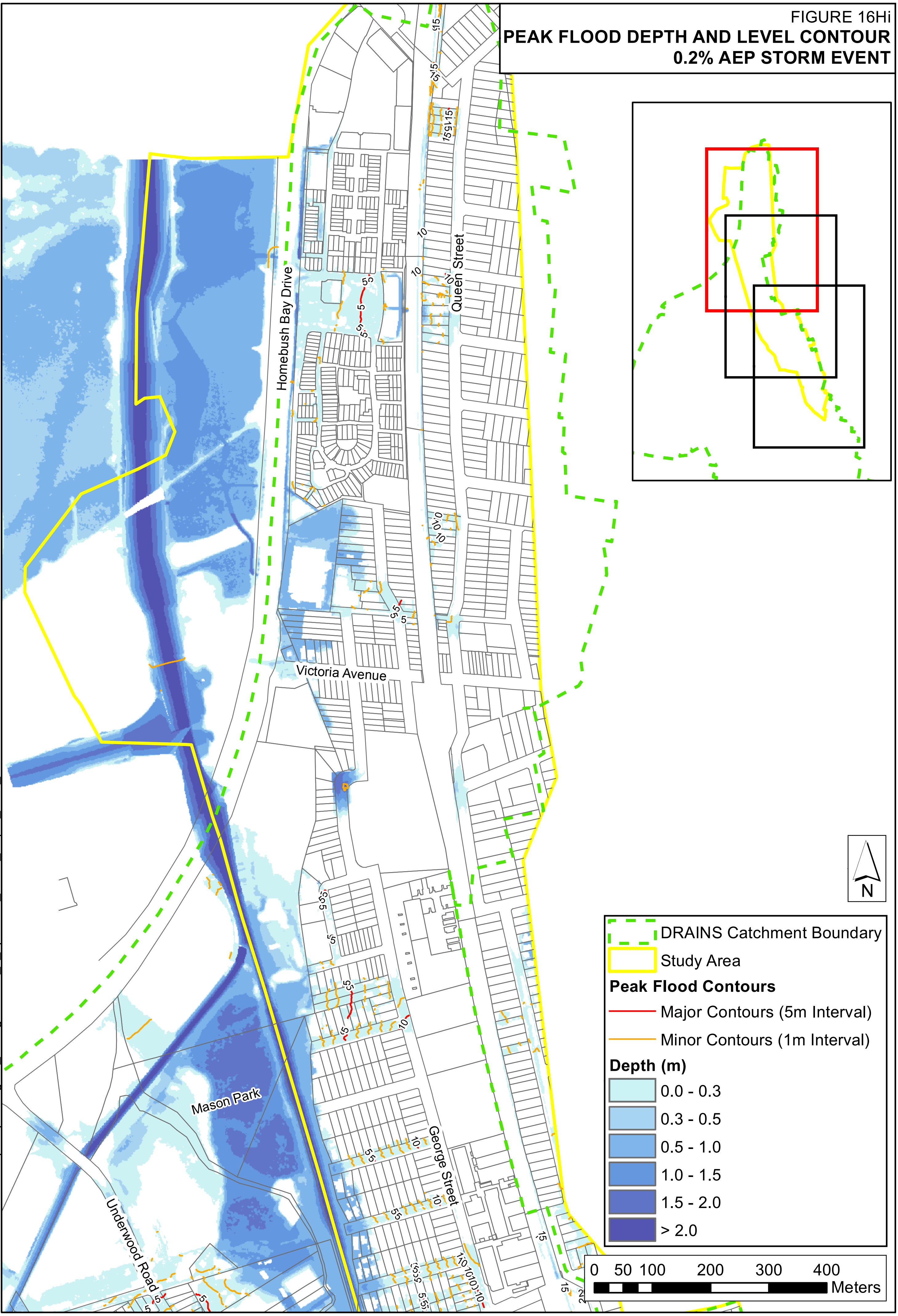


J:\Jobs\120079\GIS\Arcmap\Report\Figure 16\Figure16Giii 0 5pctAEP Flood Depth level contour.mxd

FIGURE 16Hi

PEAK FLOOD DEPTH AND LEVEL CONTOUR

0.2% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure_16\Figure16Hi_0_2pctAEP_Flood_Depth_level_contour.mxd

FIGURE 16Hii

PEAK FLOOD DEPTH AND LEVEL CONTOUR 0.2% AEP STORM EVENT

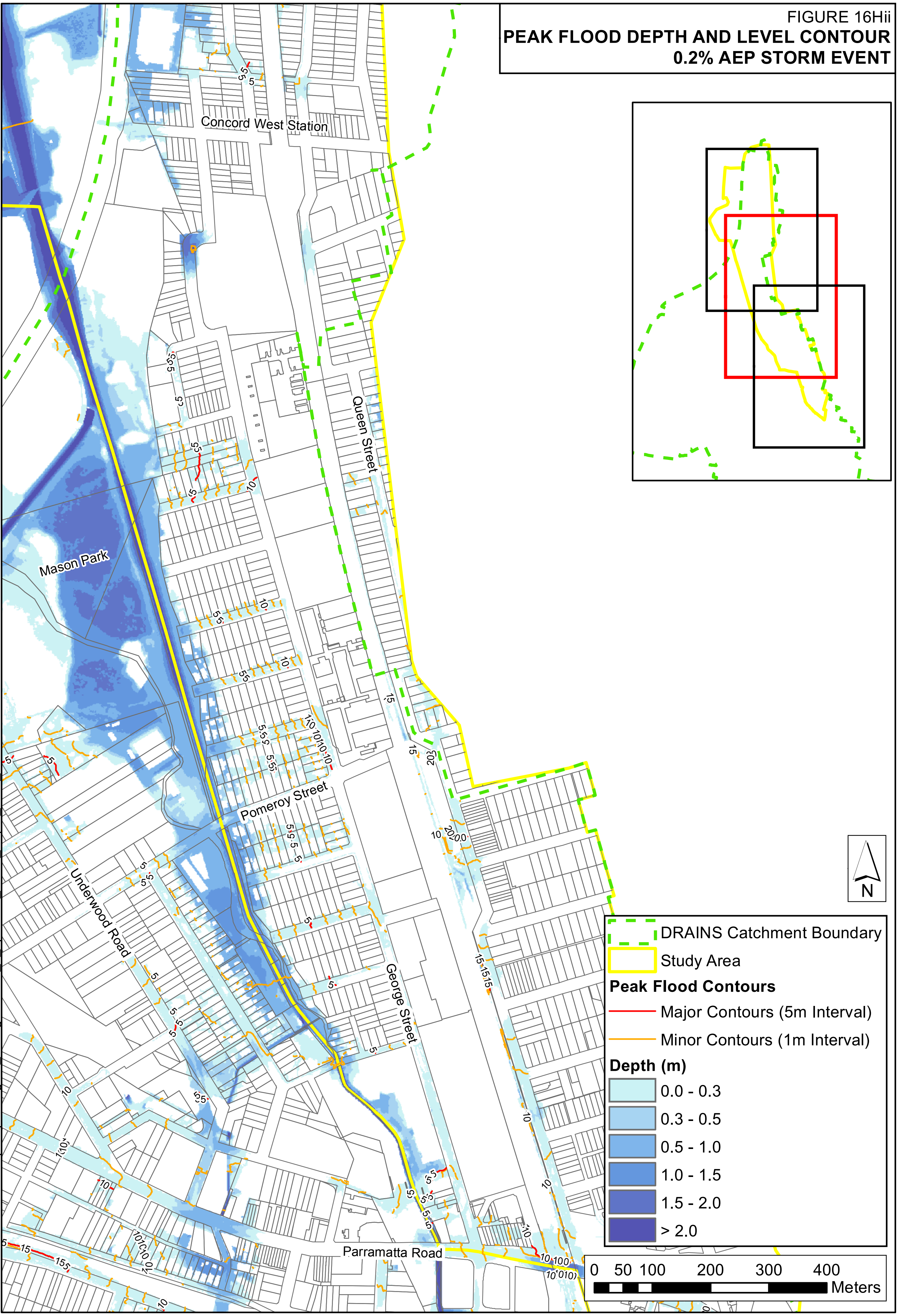


FIGURE 16Hiii

PEAK FLOOD DEPTH AND LEVEL CONTOUR
0.2% AEP STORM EVENT

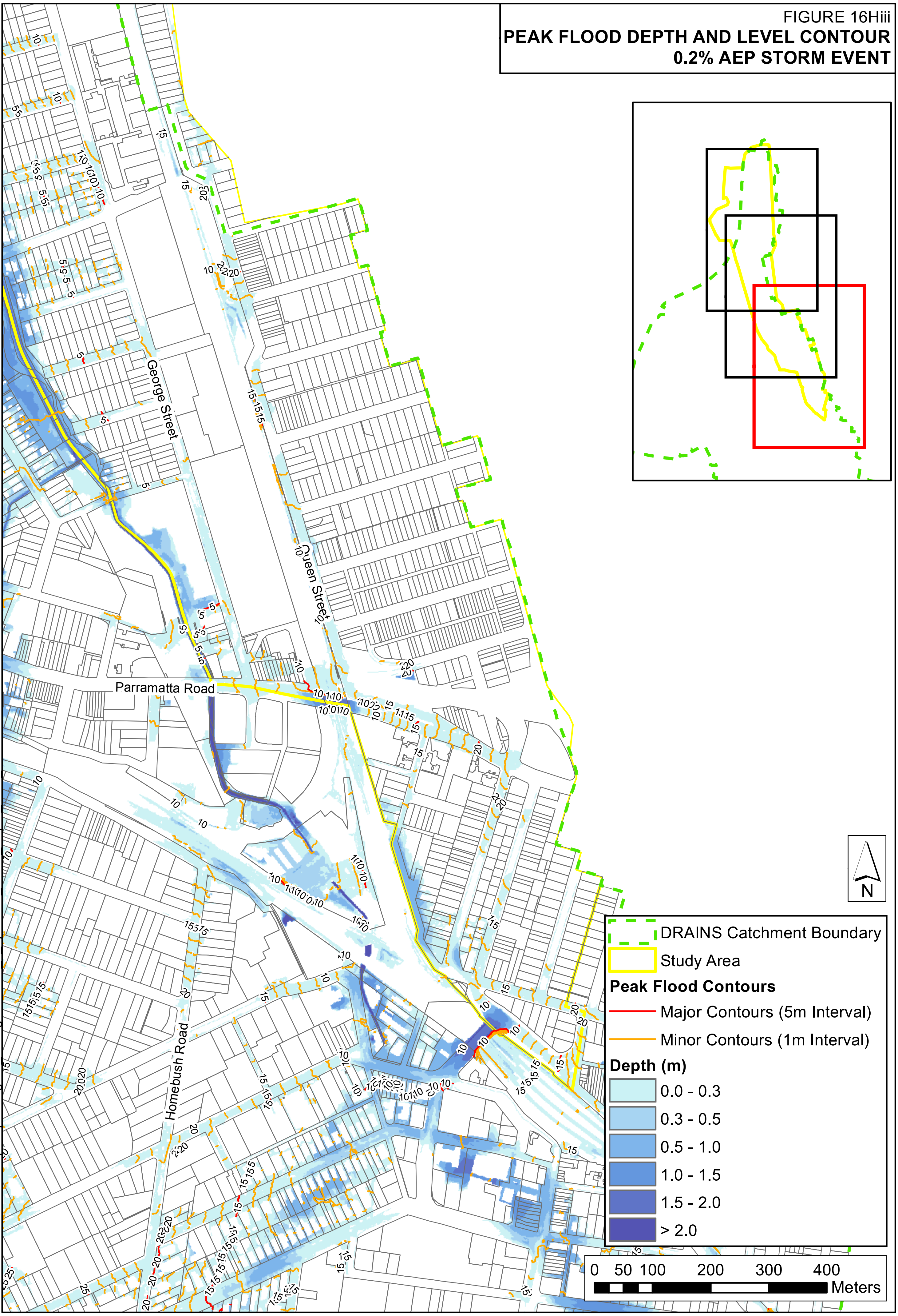
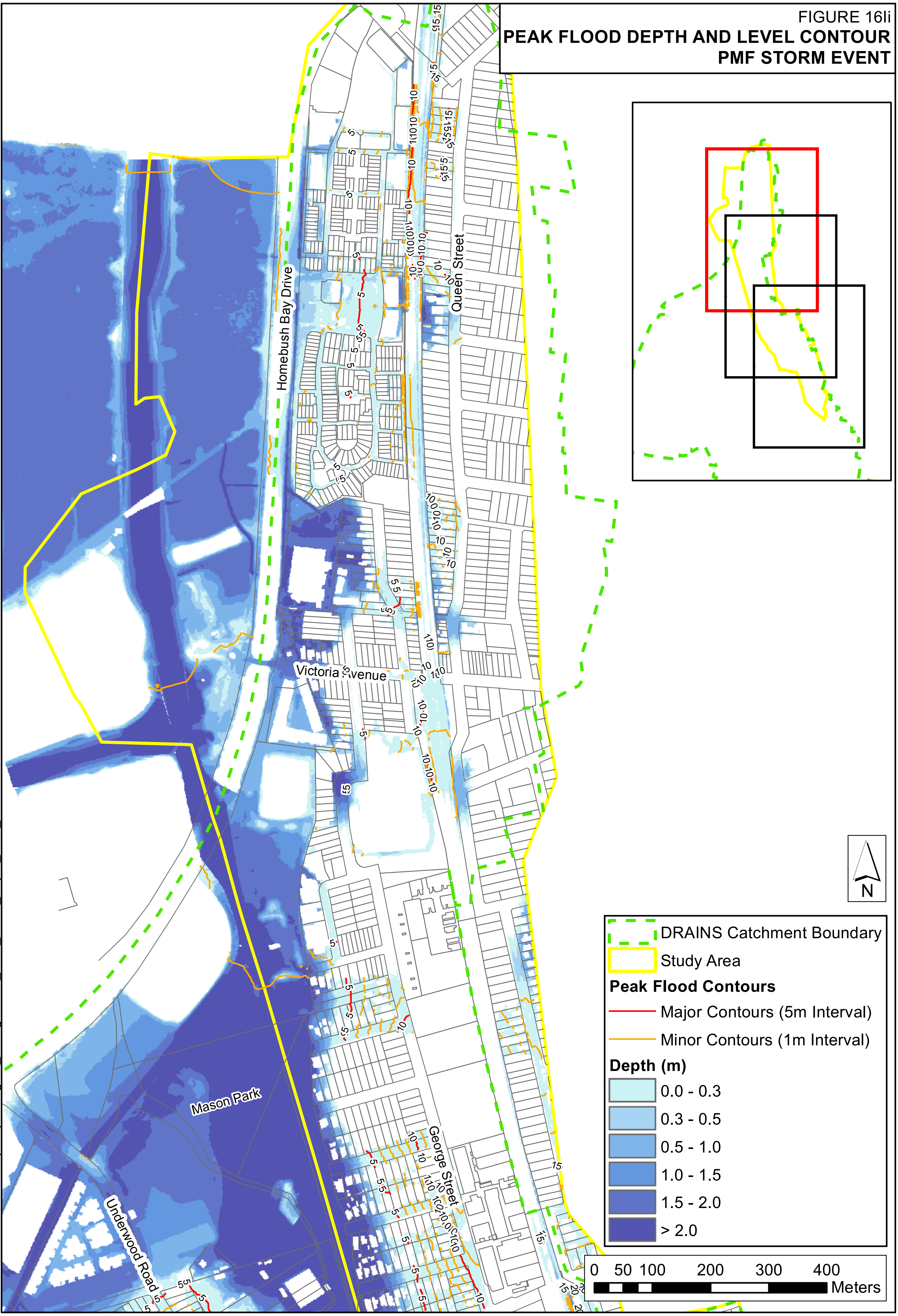


FIGURE 16li

PEAK FLOOD DEPTH AND LEVEL CONTOUR PMF STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure 16\Figure16li_PMF_Flood_Depth_level_contour.mxd

FIGURE 16Iii

PEAK FLOOD DEPTH AND LEVEL CONTOUR PMF STORM EVENT

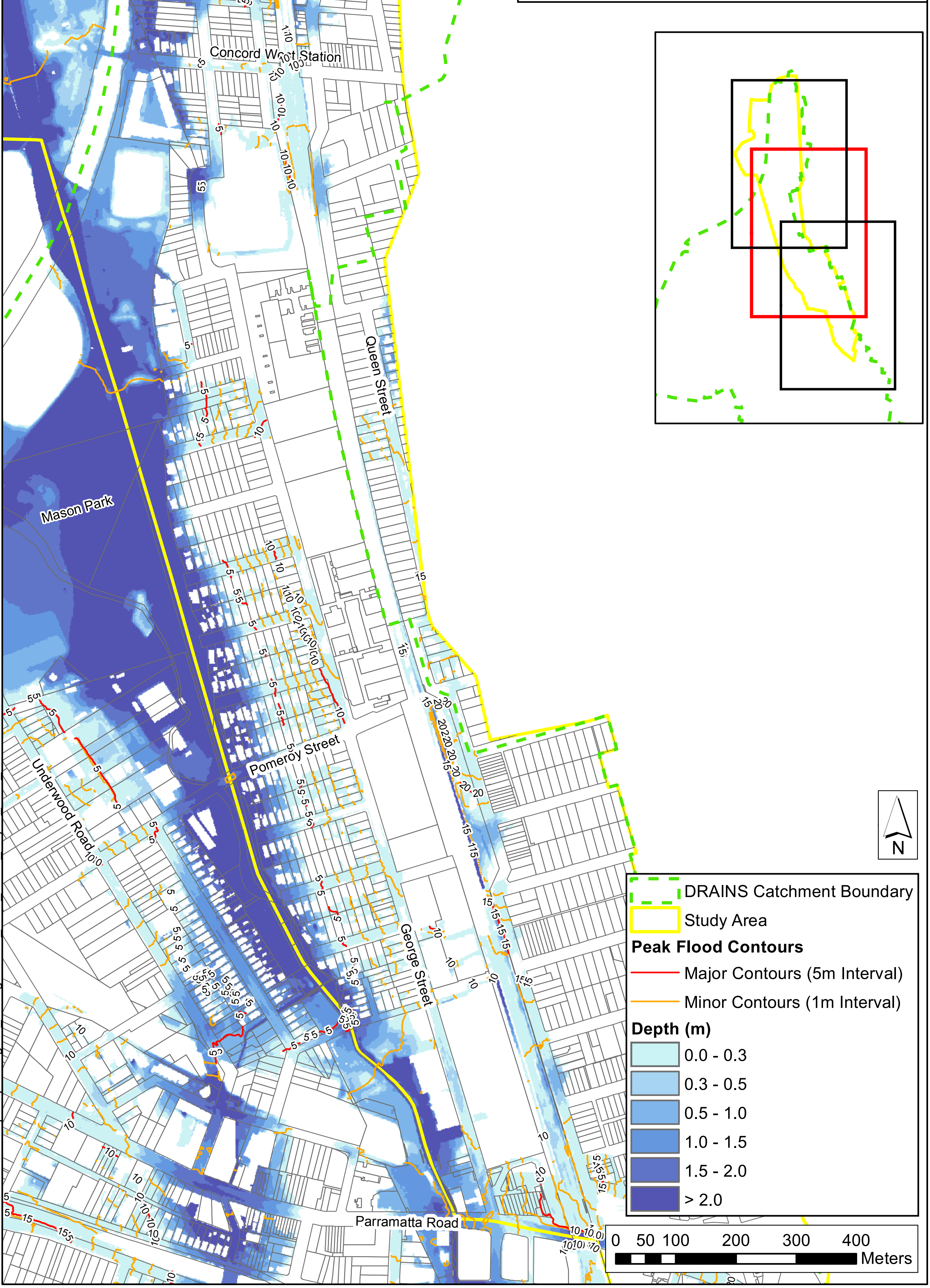
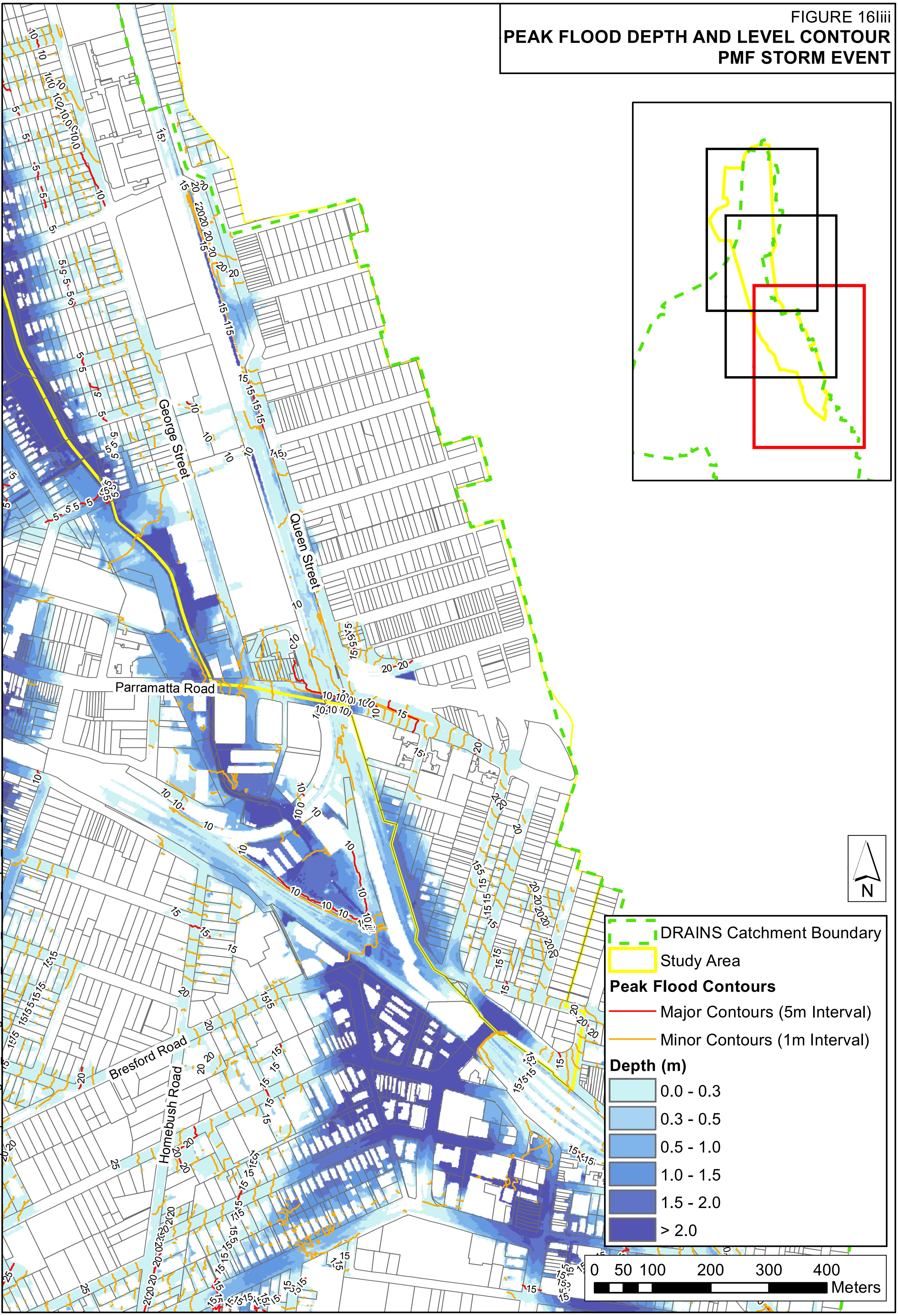


FIGURE 16liii

PEAK FLOOD DEPTH AND LEVEL CONTOUR
PMF STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure 16\Figure16liii PMF Flood Depth level contour.mxd

FIGURE 17Ai

PEAK FLOOD VELOCITY
1 EY STORM EVENT

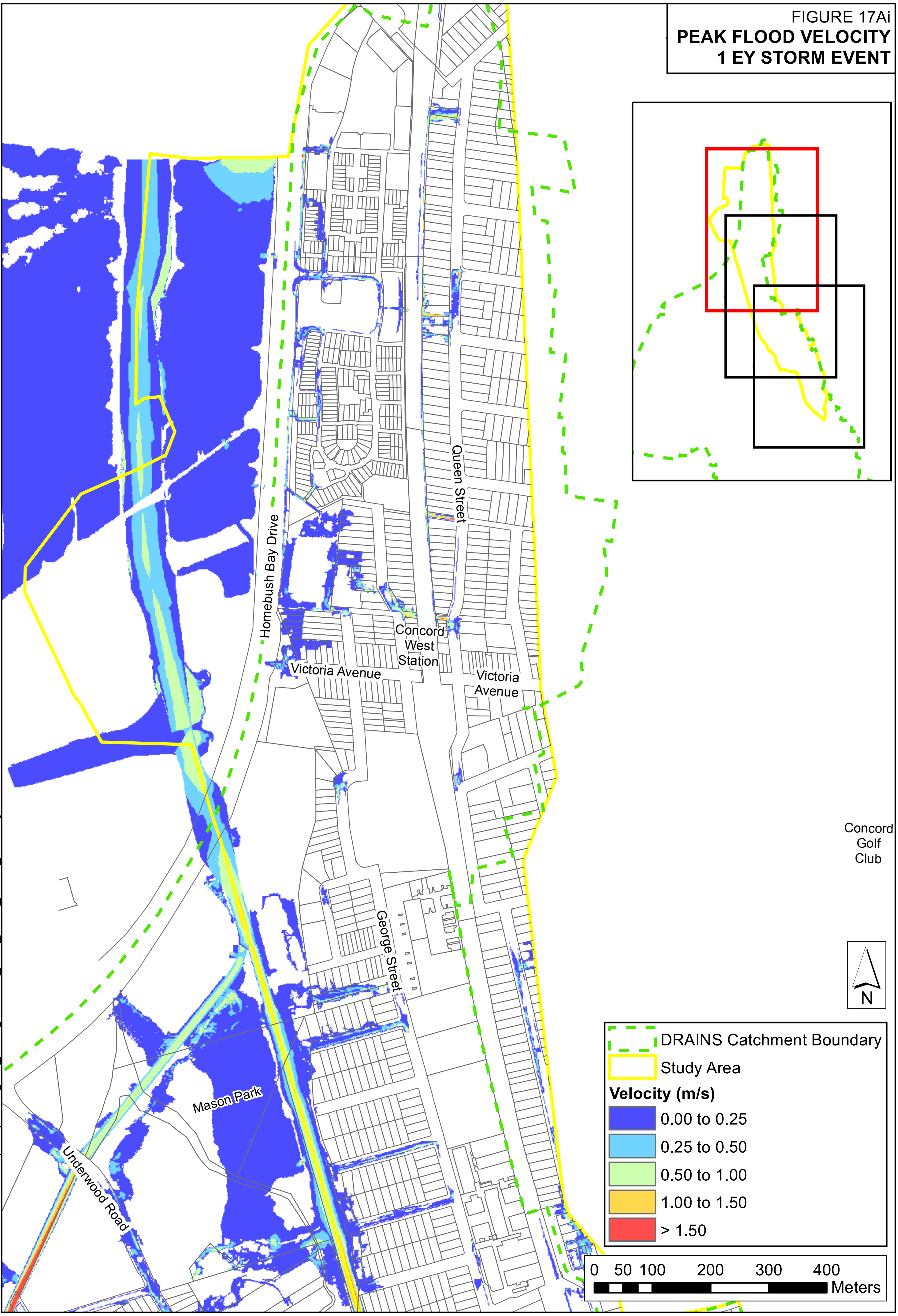


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FIGURE 17Aii
PEAK FLOOD VELOCITY
1 EY STORM EVENT

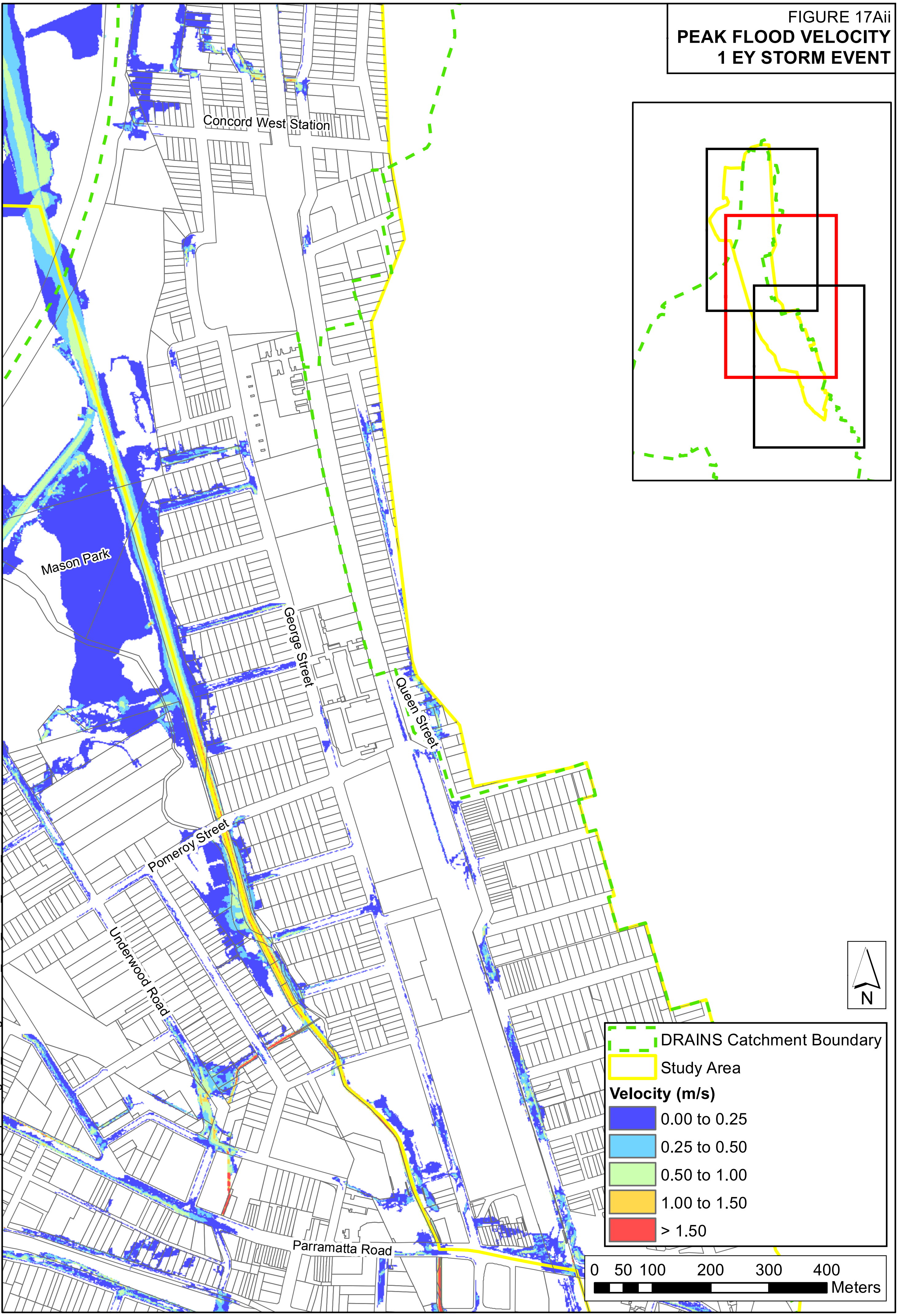

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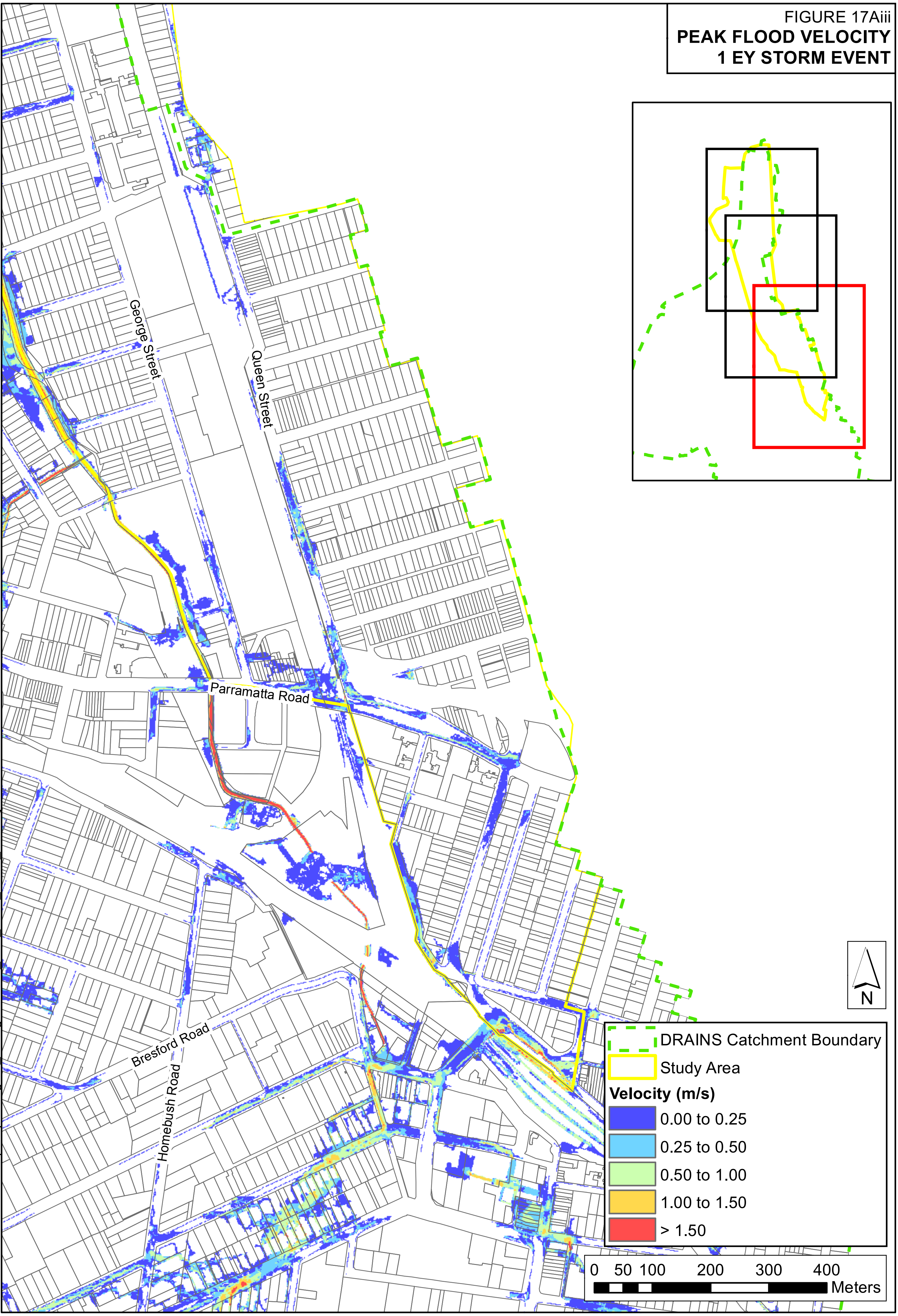
FIGURE 17Aiii

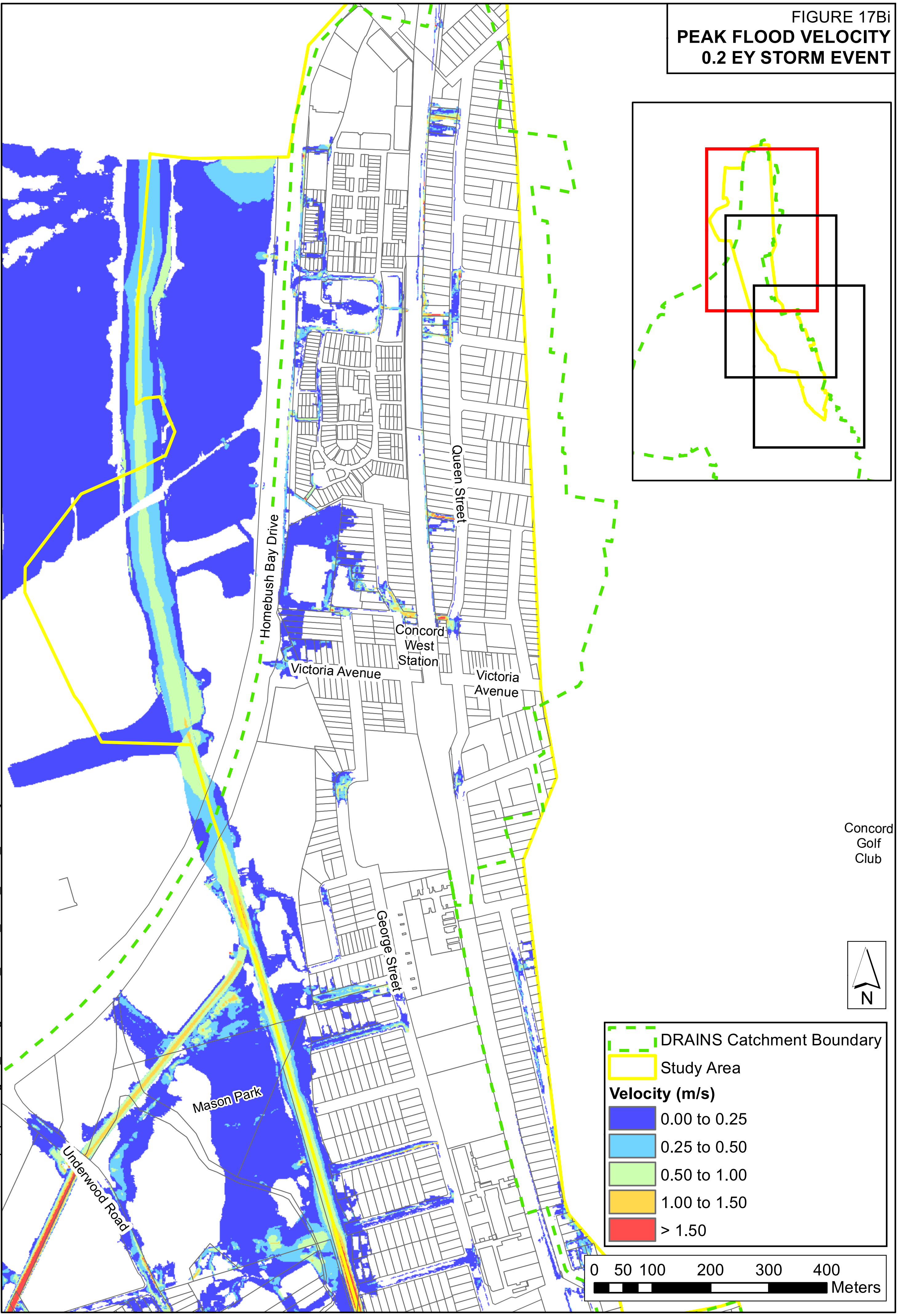
PEAK FLOOD VELOCITY
1 EY STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure 17\Figure17Aiii 1EY Peak Flood Velocity.mxd

FIGURE 17Bi

PEAK FLOOD VELOCITY
0.2 EY STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure_17\Figure17Bi_0.2EY_Peak_Flood_Velocity.mxd

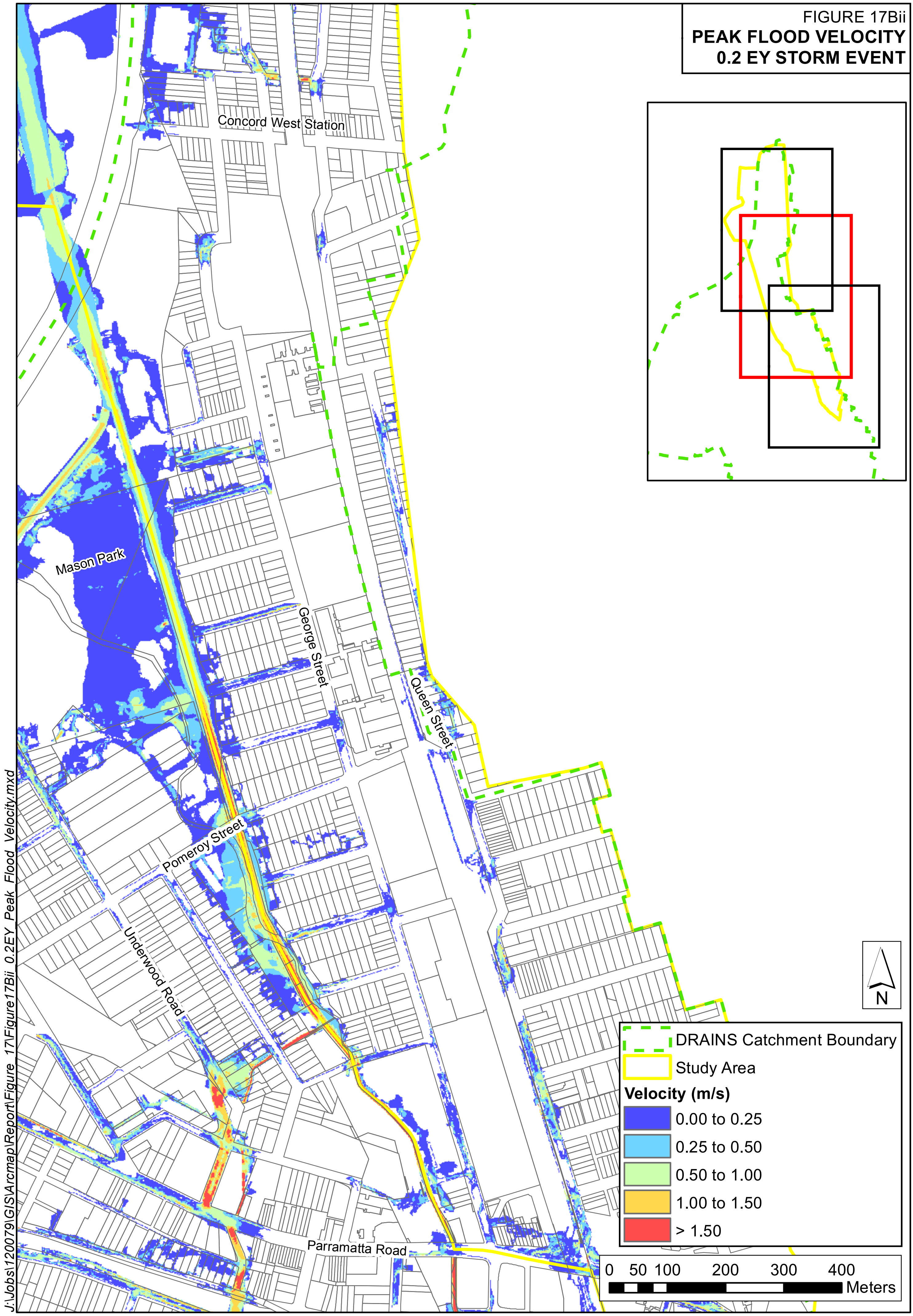
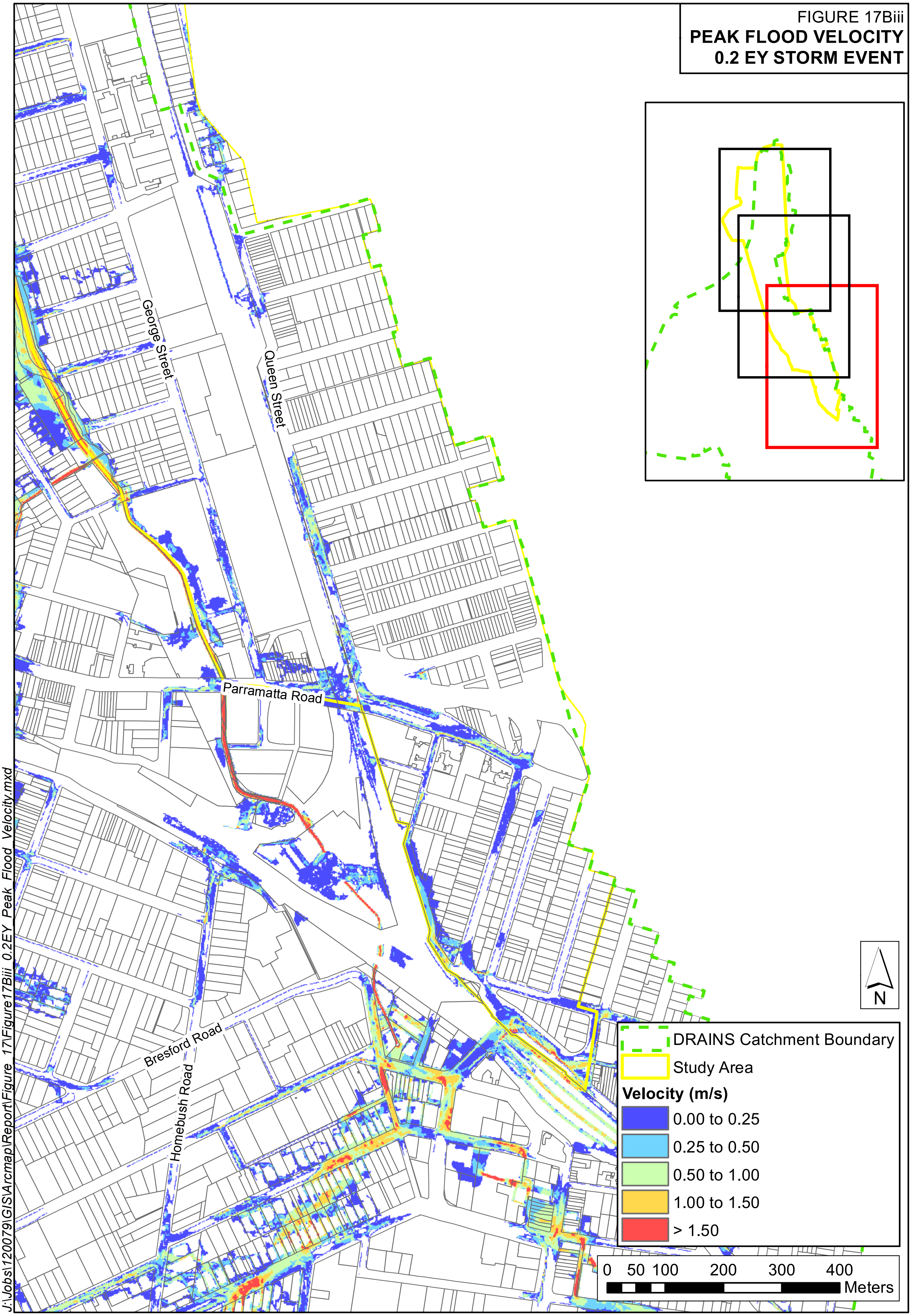


FIGURE 17Bii
PEAK FLOOD VELOCITY
0.2 EY STORM EVENT
Concord West Station
Mason Park
George Street
Queen Street
Pomeroy Street
Underwood Road
Parramatta Road
DRAINS Catchment Boundary
Study Area
Velocity (m/s)
0.00 to 0.25
0.25 to 0.50
0.50 to 1.00
1.00 to 1.50
> 1.50
N
0 50 100 200 300 400
Meters
J:\Jobs\120079\GIS\Arcmap\Report\Figure 17\Figure17Bii 0.2EY Peak Flood Velocity.mxd

FIGURE 17Biii

PEAK FLOOD VELOCITY
0.2 EY STORM EVENT



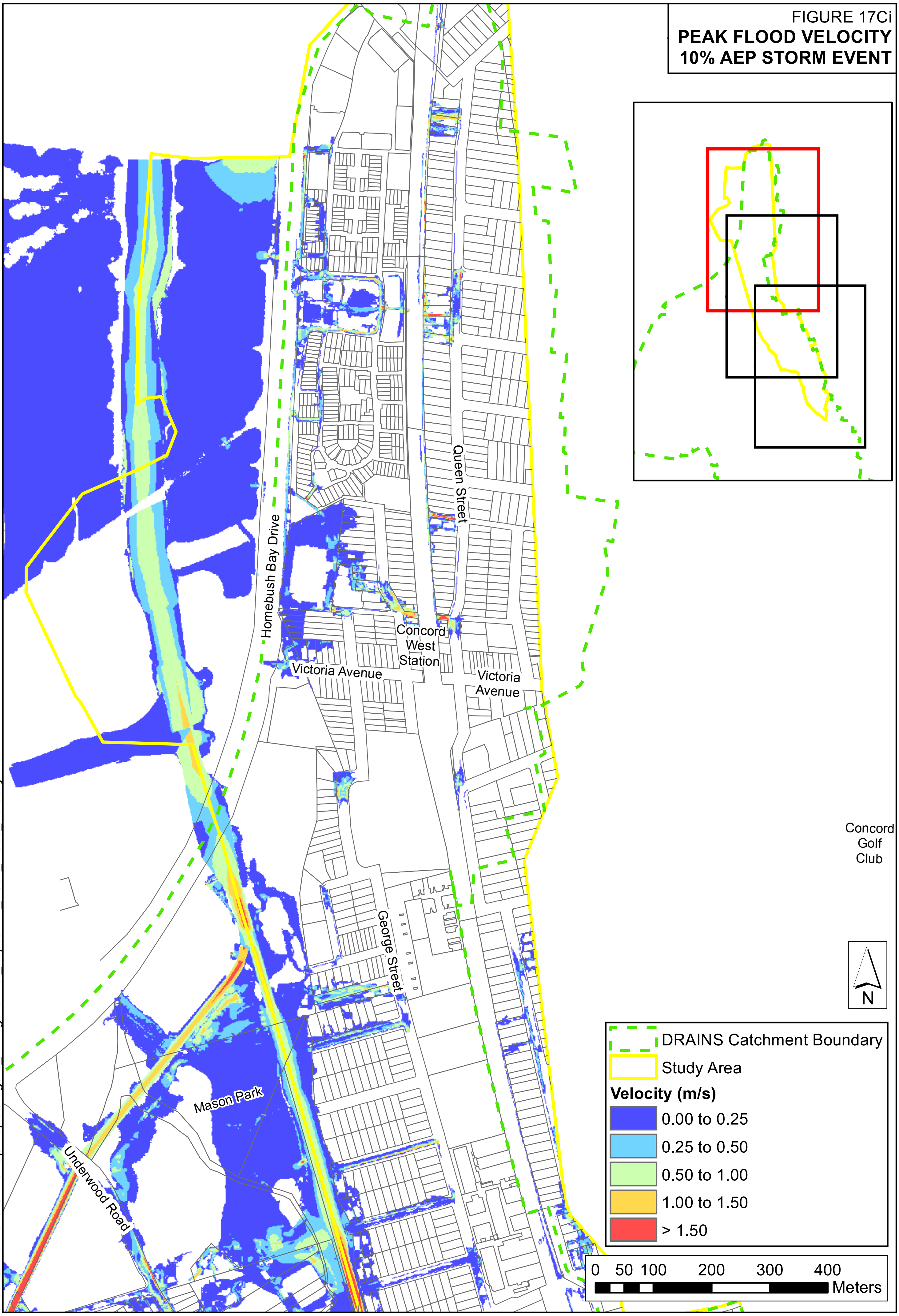
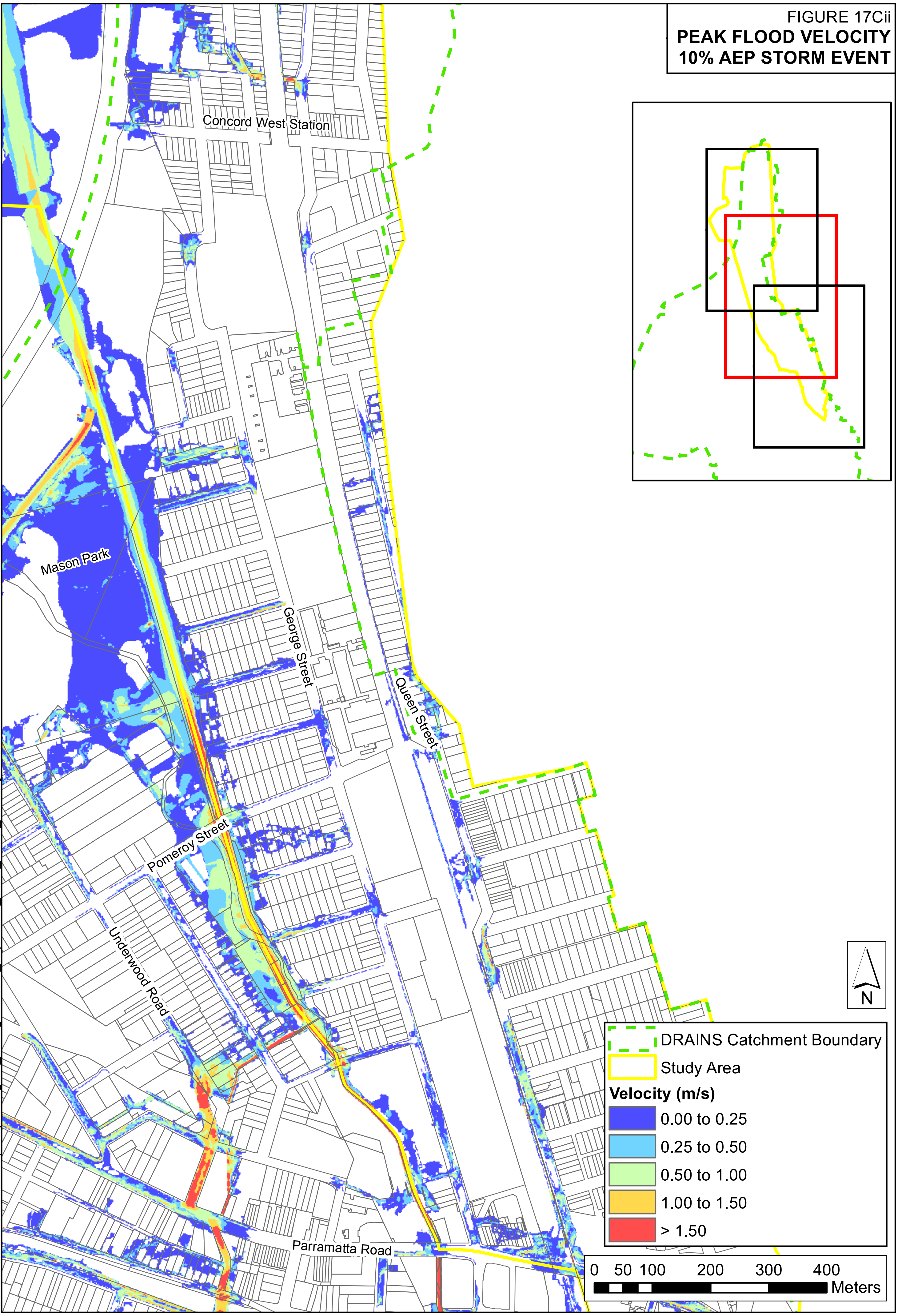


FIGURE 17Ci
PEAK FLOOD VELOCITY
10% AEP STORM EVENT
Queen Street
Homebush Bay Drive
Concord West Station
Victoria Avenue
Victoria Avenue
Concord Golf Club
George Street
Mason Park
Underwood Road
N
DRAINS Catchment Boundary
Study Area
Velocity (m/s)
0.00 to 0.25
0.25 to 0.50
0.50 to 1.00
1.00 to 1.50
> 1.50
0 50 100 200 300 400
Meters
J:\Jobs\120079\GIS\Arcmap\Report\Figure_17\Figure17Ci_10pctAEP_Peak_Flood_Velocity.mxd

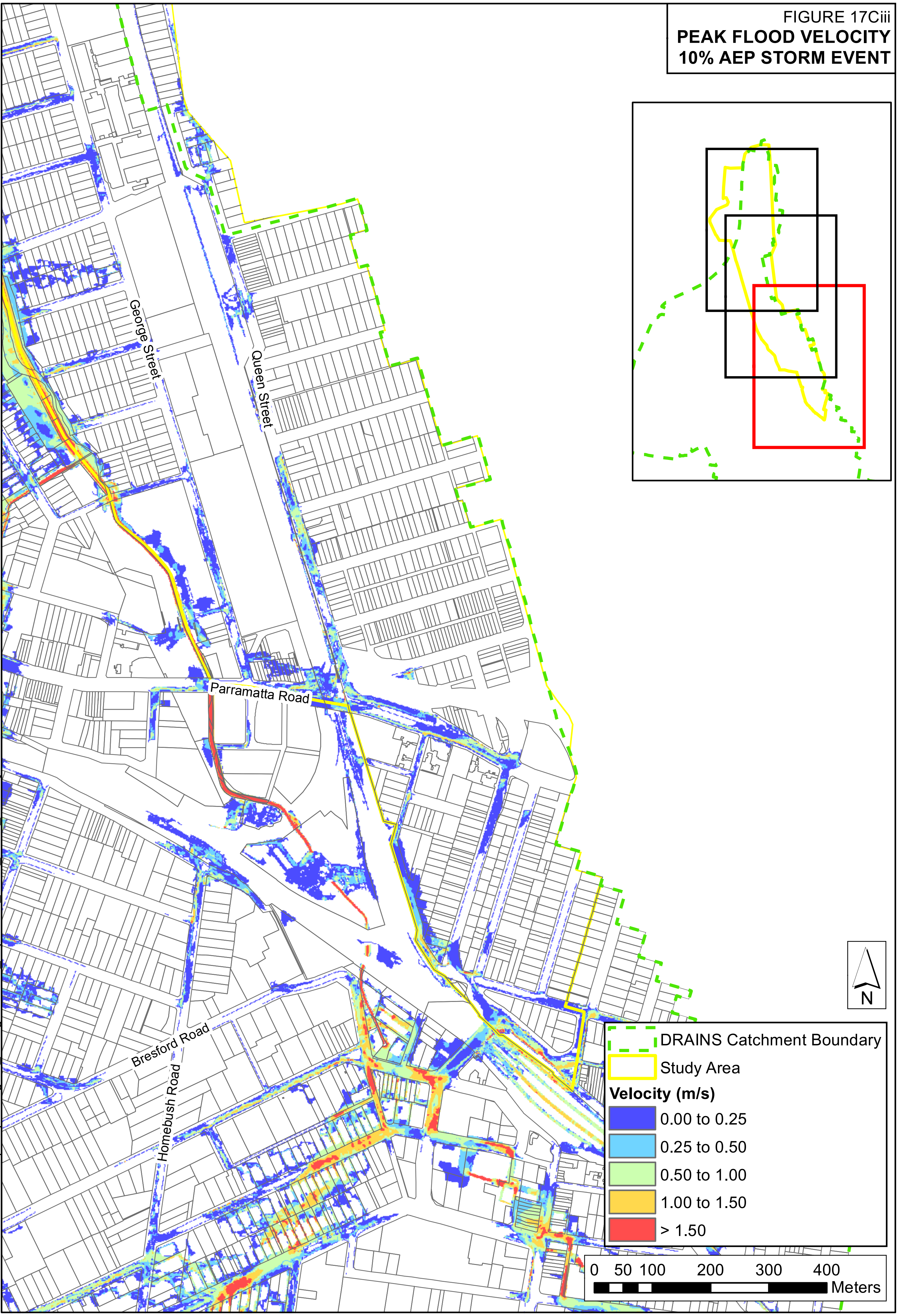
FIGURE 17Cii
PEAK FLOOD VELOCITY
10% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure_17\Figure17Cii_10pctAEP_Peak_Flood_Velocity.mxd

FIGURE 17Ciii

PEAK FLOOD VELOCITY
10% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure 17\Figure17Ciii 10pctAEP Peak Flood Velocity.mxd

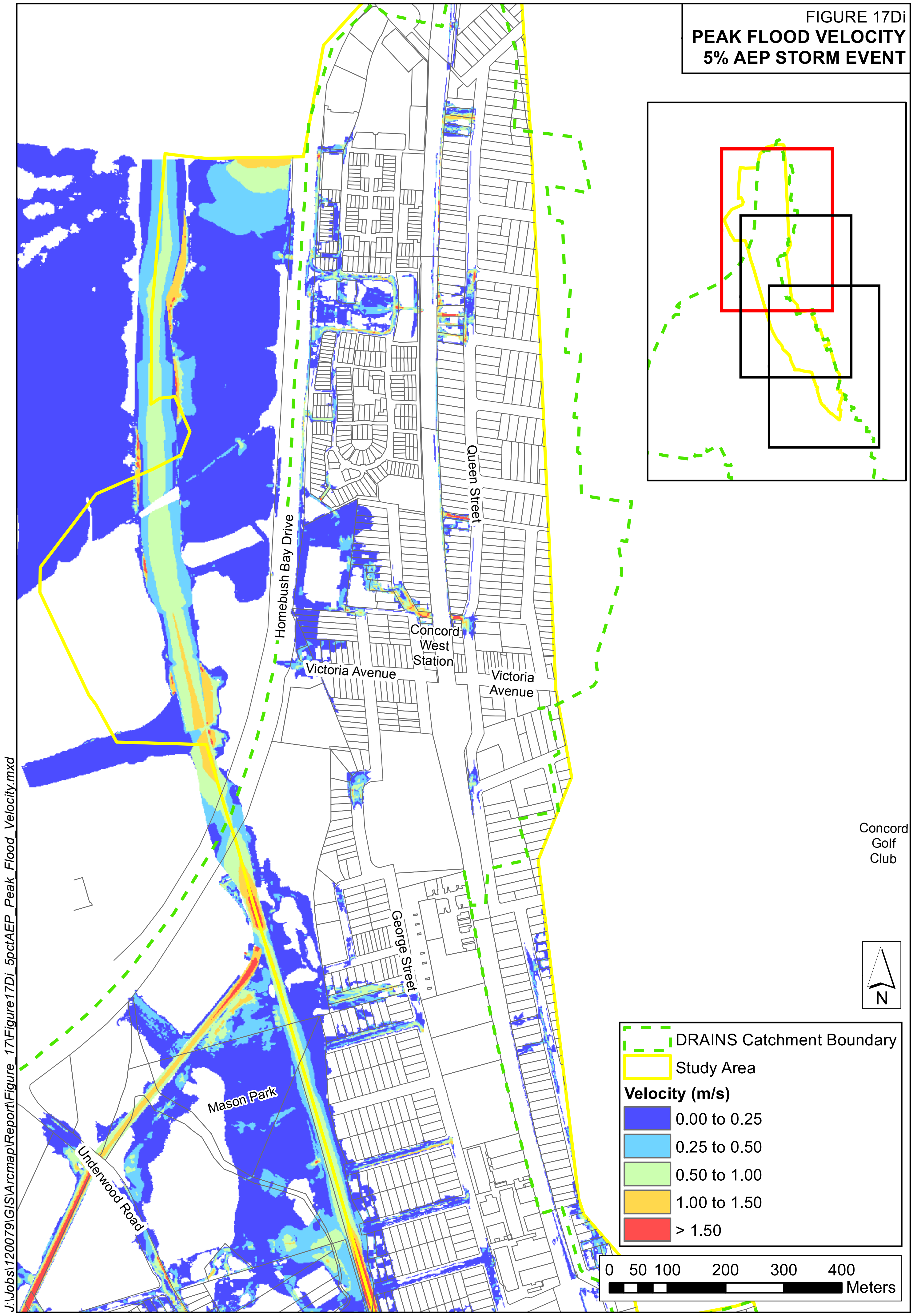
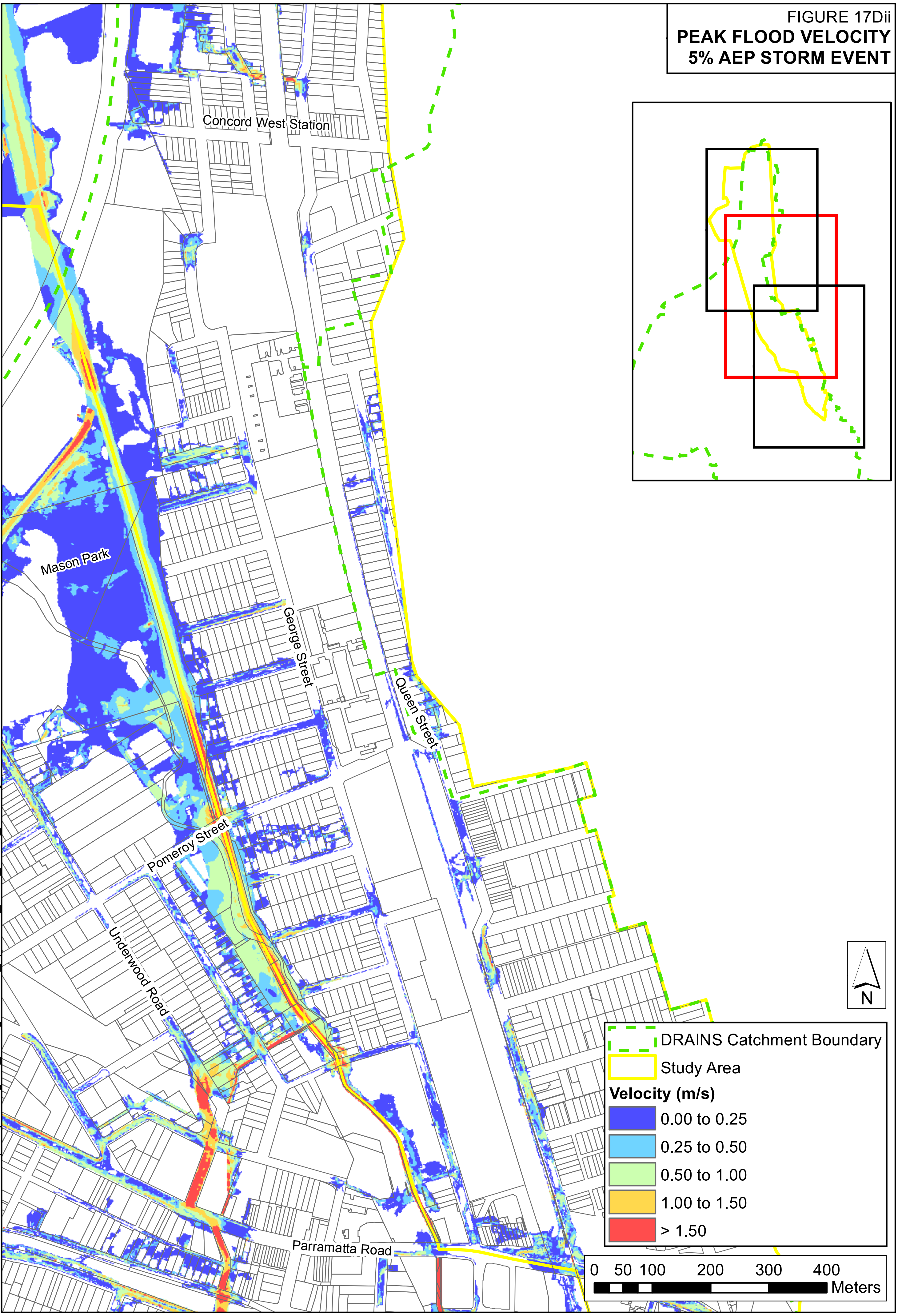


FIGURE 17Di
PEAK FLOOD VELOCITY
5% AEP STORM EVENT
Homebush Bay Drive
Queen Street
Concord
West
Station
Victoria Avenue
Victoria
Avenue
Concord
Golf
Club
George Street
Mason Park
Underwood Road
N
DRAINS Catchment Boundary
Study Area
Velocity (m/s)
0.00 to 0.25
0.25 to 0.50
0.50 to 1.00
1.00 to 1.50
> 1.50
0 50 100 200 300 400
Meters
J:\Jobs\120079\GIS\Arcmap\Report\Figure 17\Figure17Di_5pctAEP_Peak_Flood_Velocity.mxd

FIGURE 17Dii

PEAK FLOOD VELOCITY

5% AEP STORM EVENT

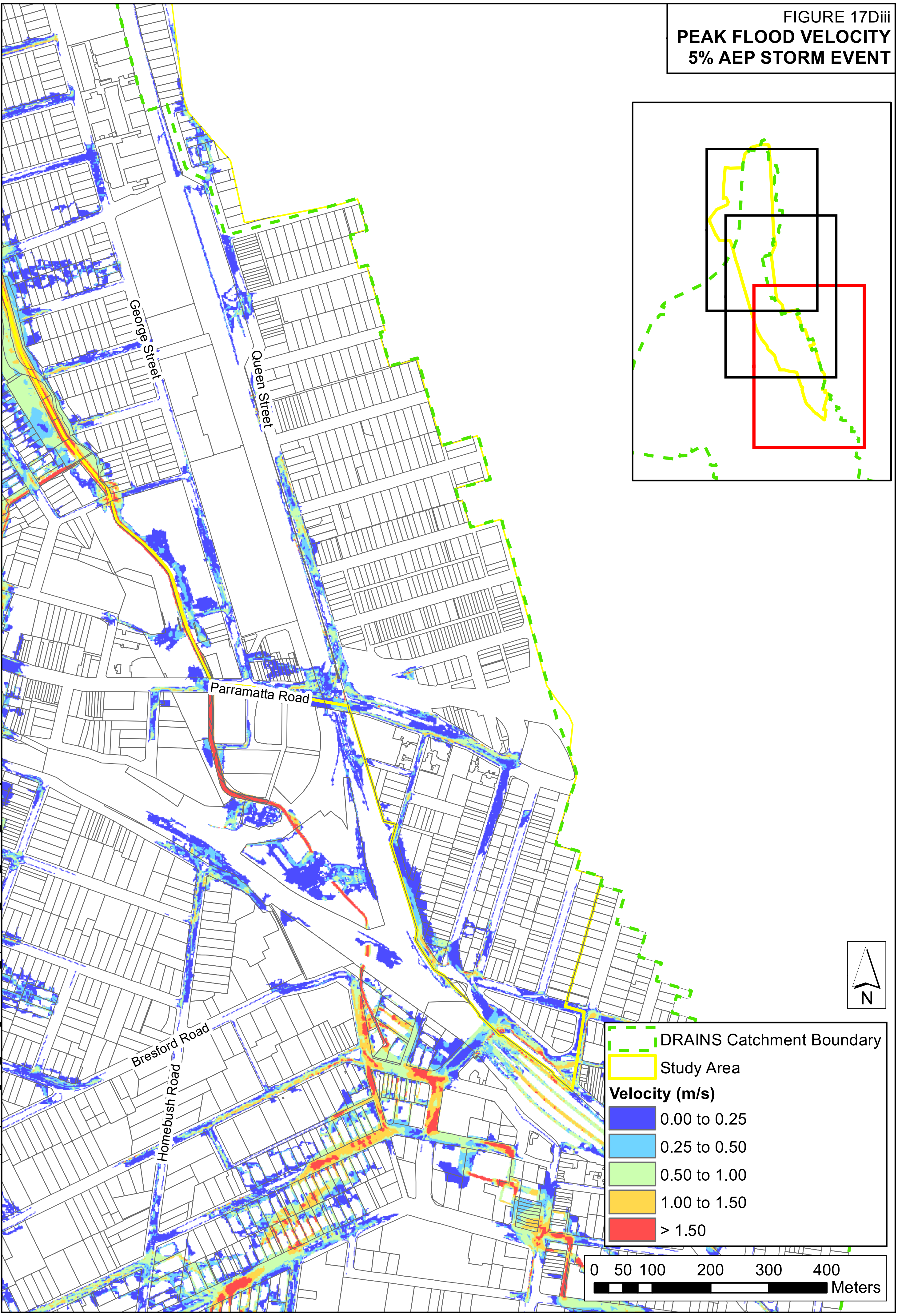


J:\Jobs\120079\GIS\Arcmap\Report\Figure_17\Figure17Dii_5pctAEP_Peak_Flood_Velocity.mxd

FIGURE 17Diii

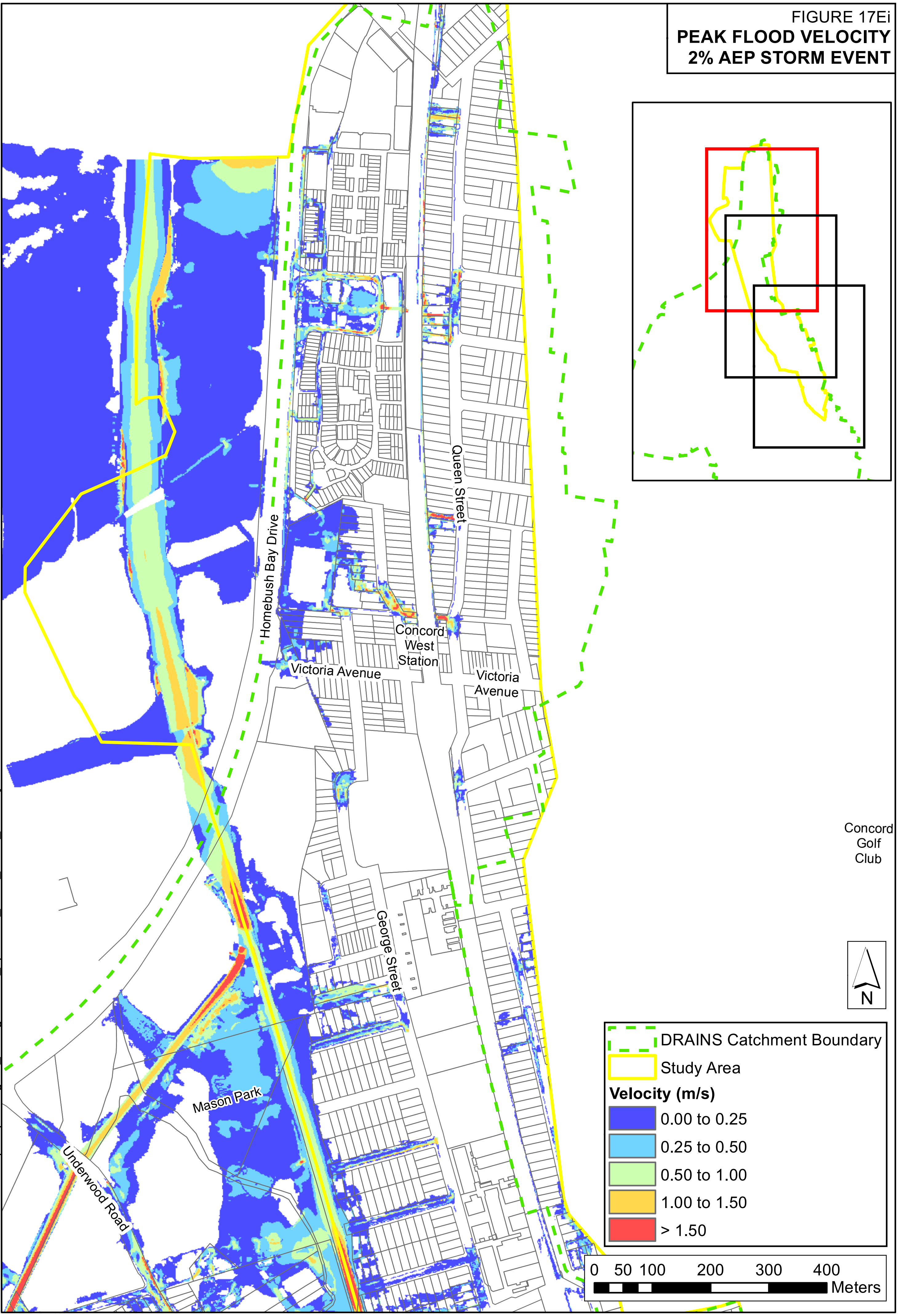
PEAK FLOOD VELOCITY

5% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure_17\Figure17Diii_5pctAEP_Peak_Flood_Velocity.mxd

FIGURE 17Ei
PEAK FLOOD VELOCITY
2% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure_17\Figure17Ei_2pctAEP_Peak_Flood_Velocity.mxd

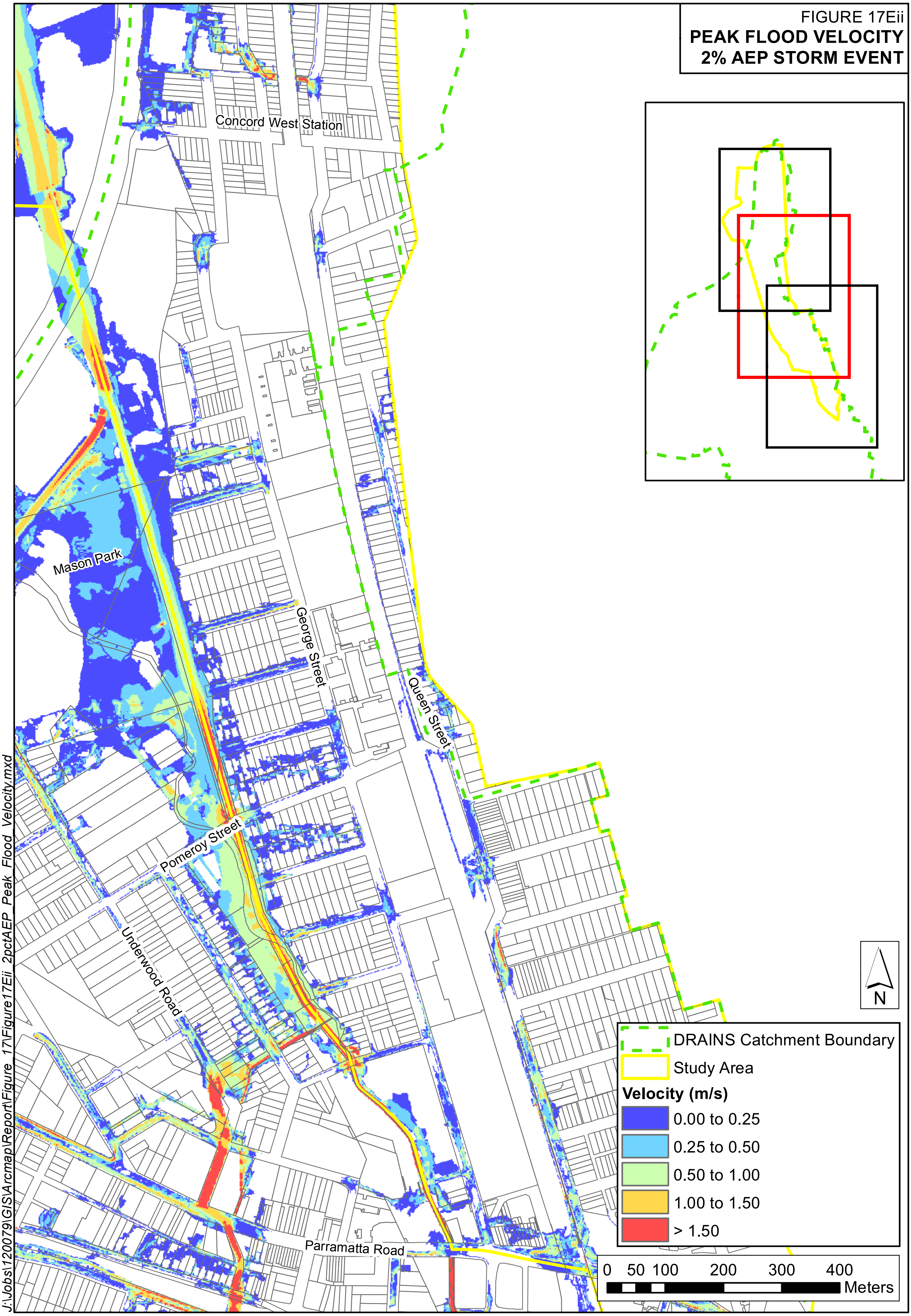
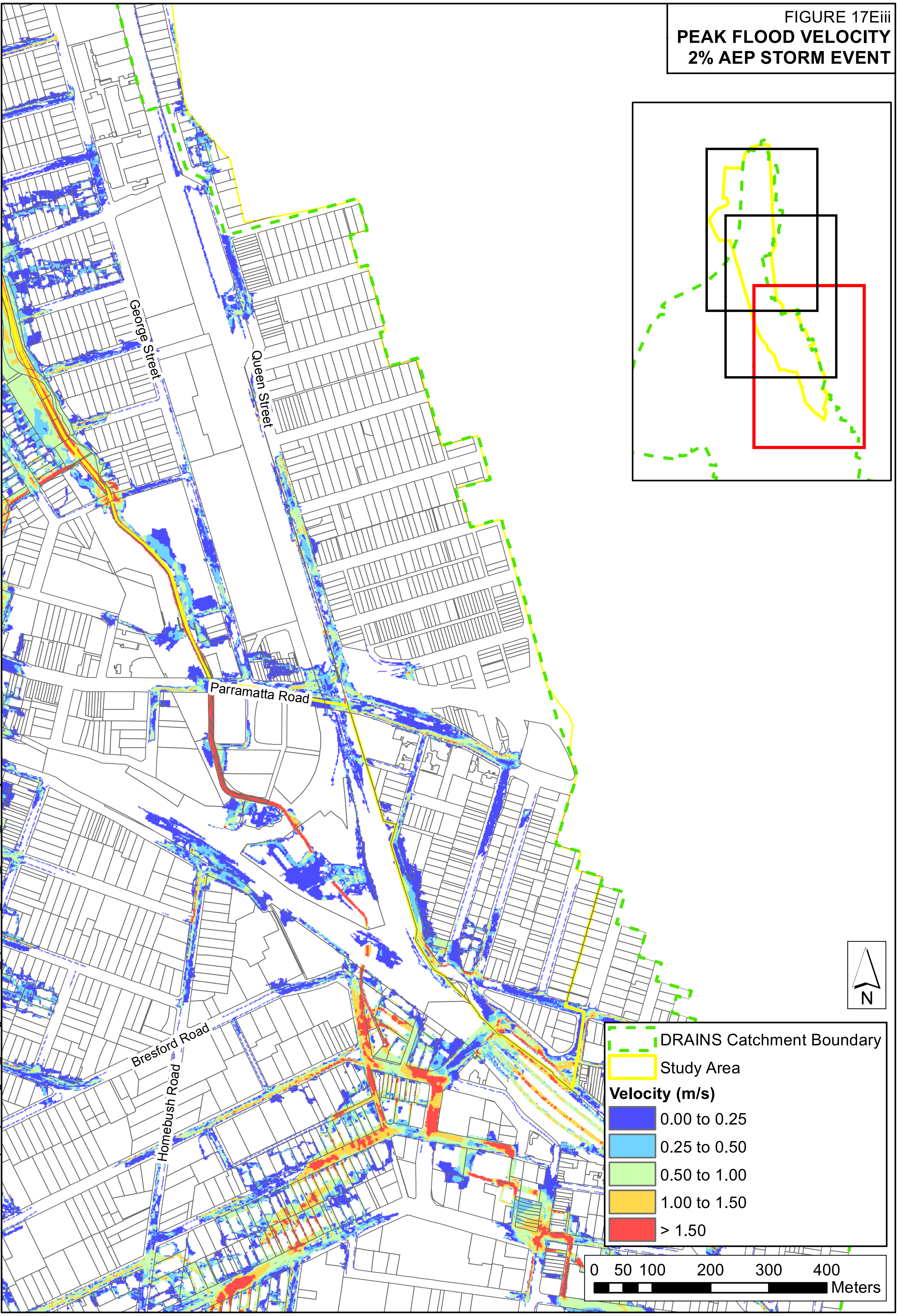


FIGURE 17Eii
PEAK FLOOD VELOCITY
2% AEP STORM EVENT
Concord West Station
Mason Park
George Street
Queen Street
Pomeroy Street
Underwood Road
Parramatta Road
N
DRAINS Catchment Boundary
Study Area
Velocity (m/s)
0.00 to 0.25
0.25 to 0.50
0.50 to 1.00
1.00 to 1.50
> 1.50
0 50 100 200 300 400
Meters
J:\Jobs\120079\GIS\Arcmap\Report\Figure 17\Figure17Eii_2pctAEP_Peak_Flood_Velocity.mxd

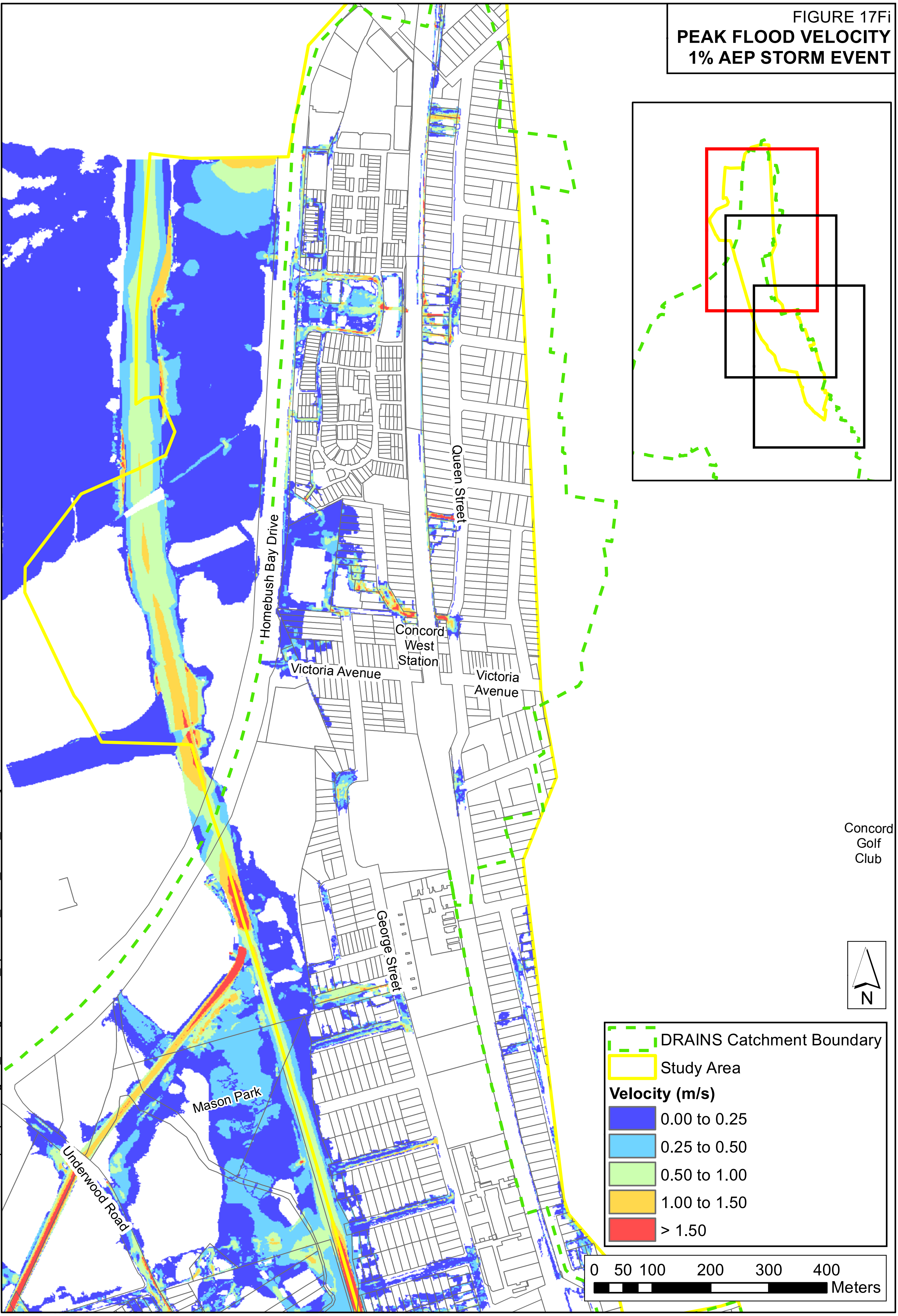
FIGURE 17Eiii
PEAK FLOOD VELOCITY
2% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure_17\Figure17Eiii_2pctAEP_Peak_Flood_Velocity.mxd

FIGURE 17Fi

PEAK FLOOD VELOCITY
1% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure_17\Figure17Fi_1pctAEP_Peak_Flood_Velocity.mxd

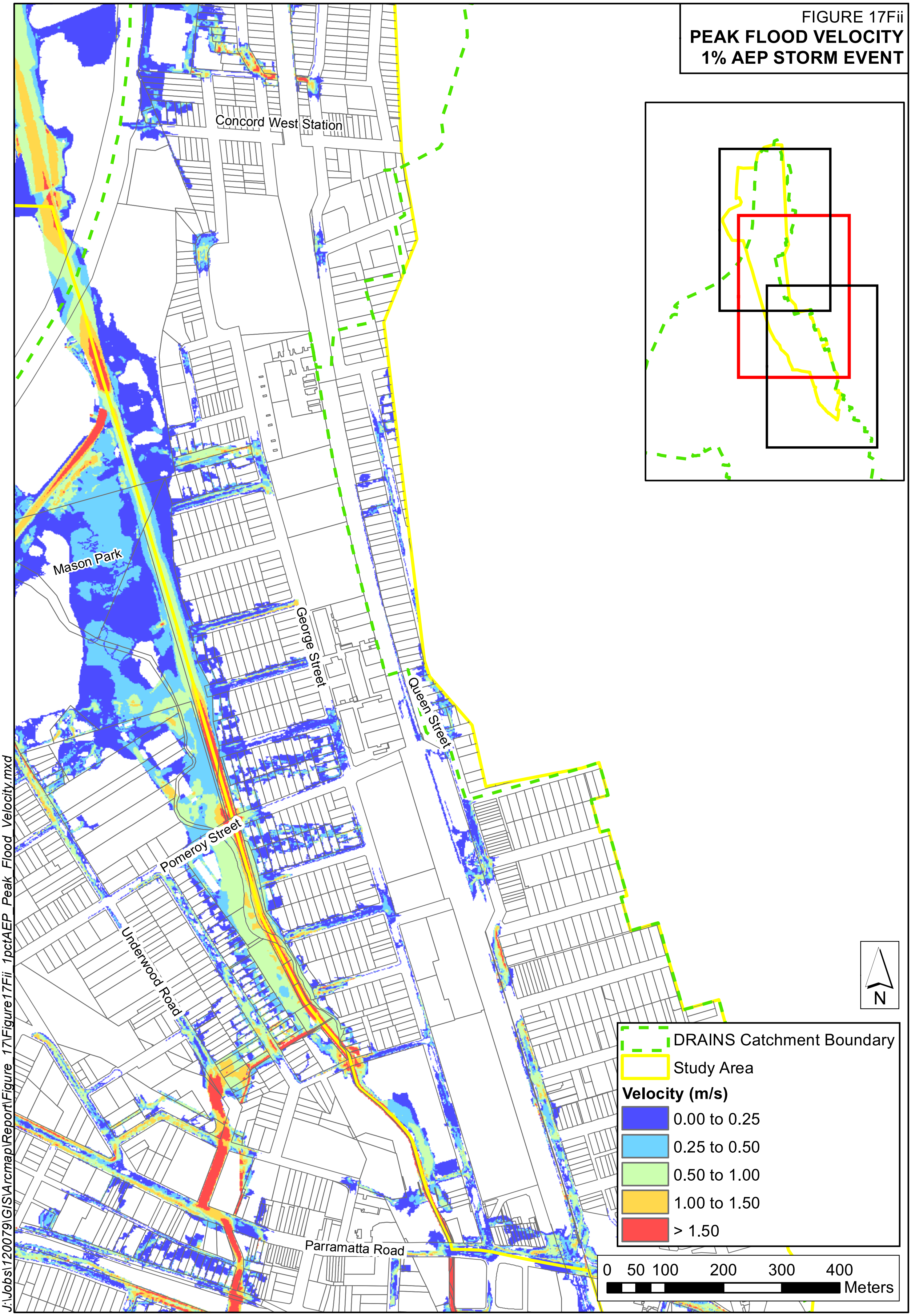
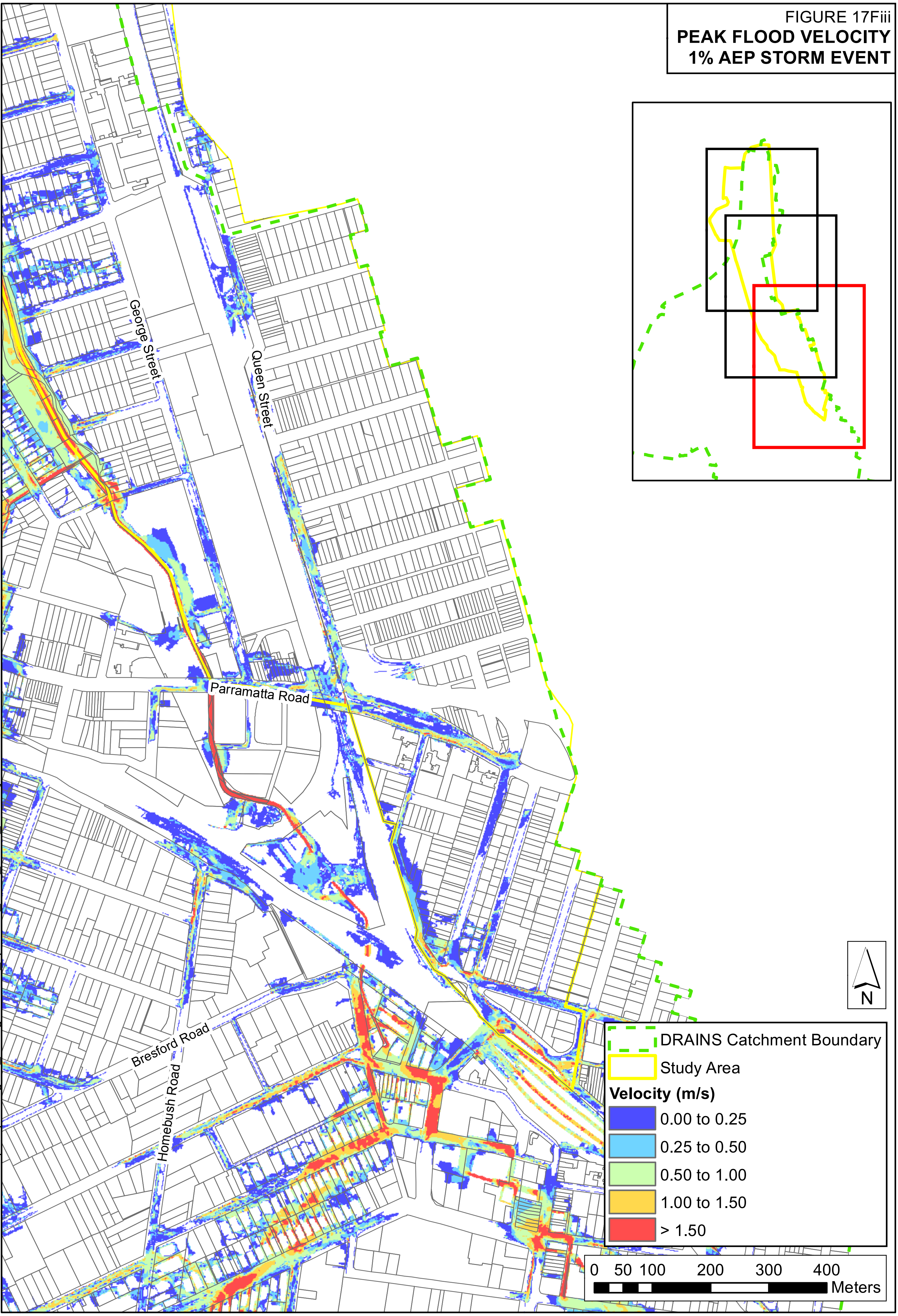


FIGURE 17Fii
PEAK FLOOD VELOCITY
1% AEP STORM EVENT
Concord West Station
Mason Park
George Street
Queen Street
Pomeroy Street
Underwood Road
Parramatta Road
DRAINS Catchment Boundary
Study Area
Velocity (m/s)
0.00 to 0.25
0.25 to 0.50
0.50 to 1.00
1.00 to 1.50
> 1.50
0 50 100 200 300 400
Meters
N
J:\Jobs\120079\GIS\Arcmap\Report\Figure 17\Figure17Fii_1pctAEP_Peak_Flood_Velocity.mxd

FIGURE 17Fiii

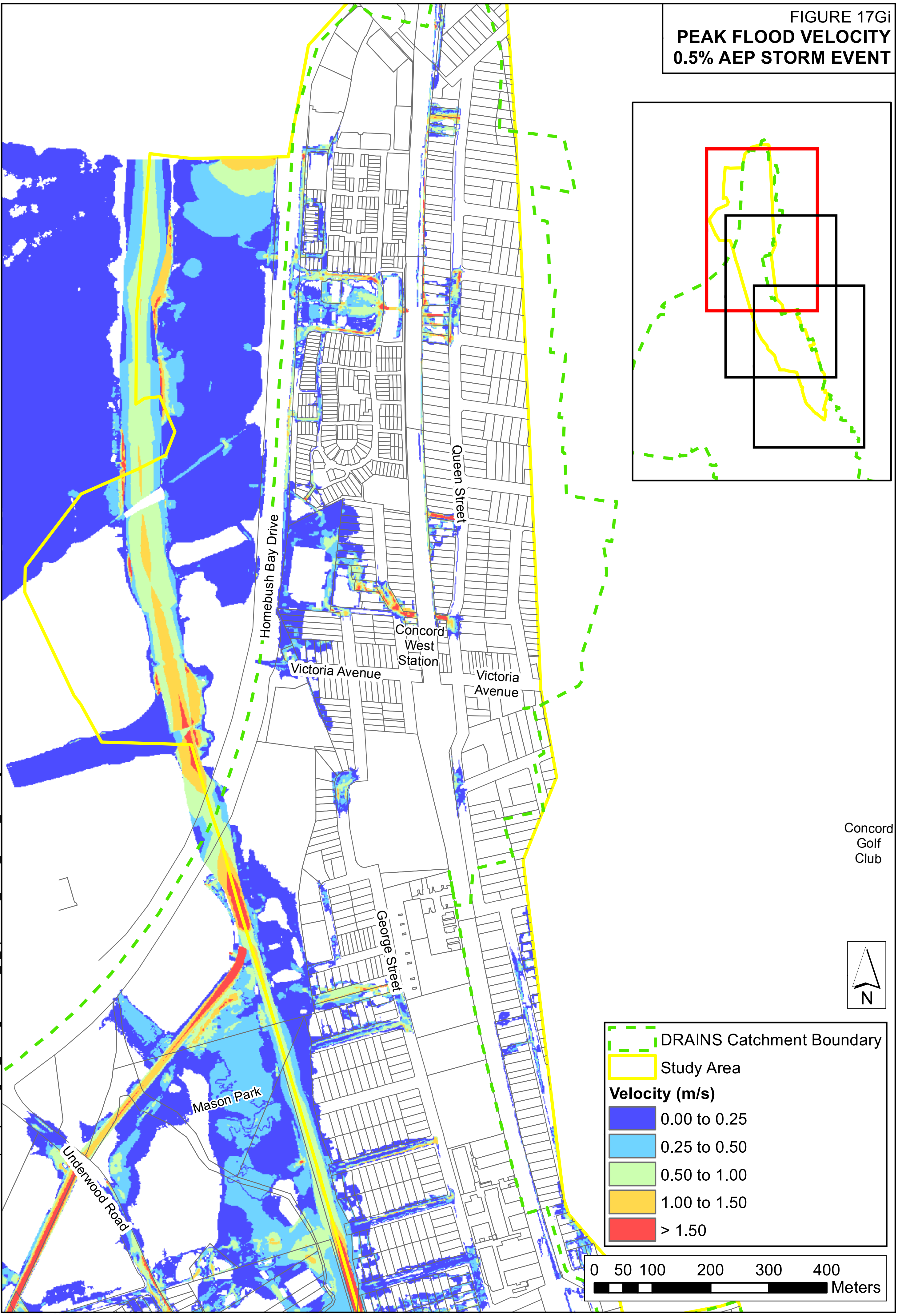
PEAK FLOOD VELOCITY
1% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure_17\Figure17Fiii_1pctAEP_Peak_Flood_Velocity.mxd

FIGURE 17Gi

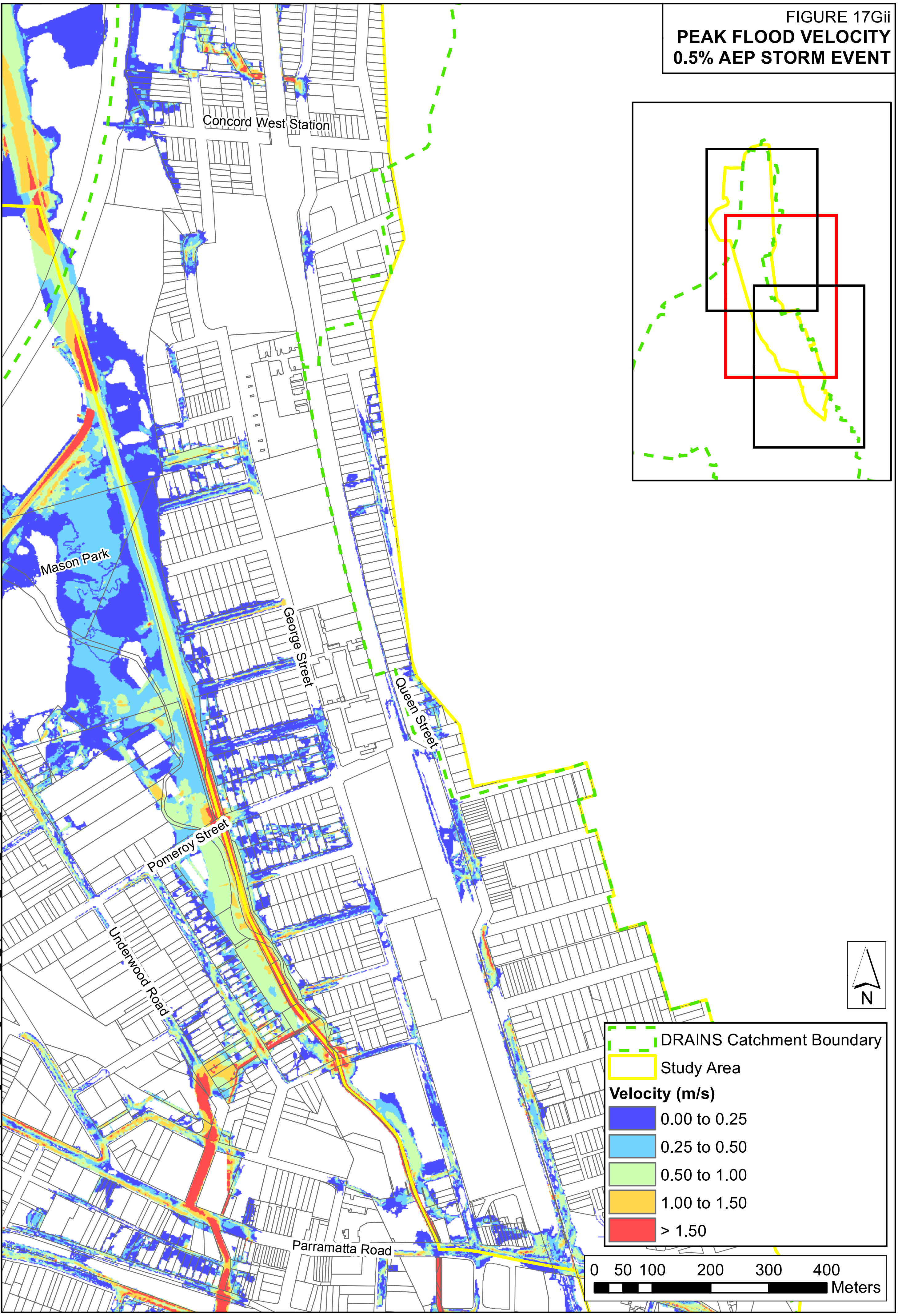
PEAK FLOOD VELOCITY
0.5% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure_17\Figure17Gi_0_5pctAEP_Peak_Flood_Velocity.mxd

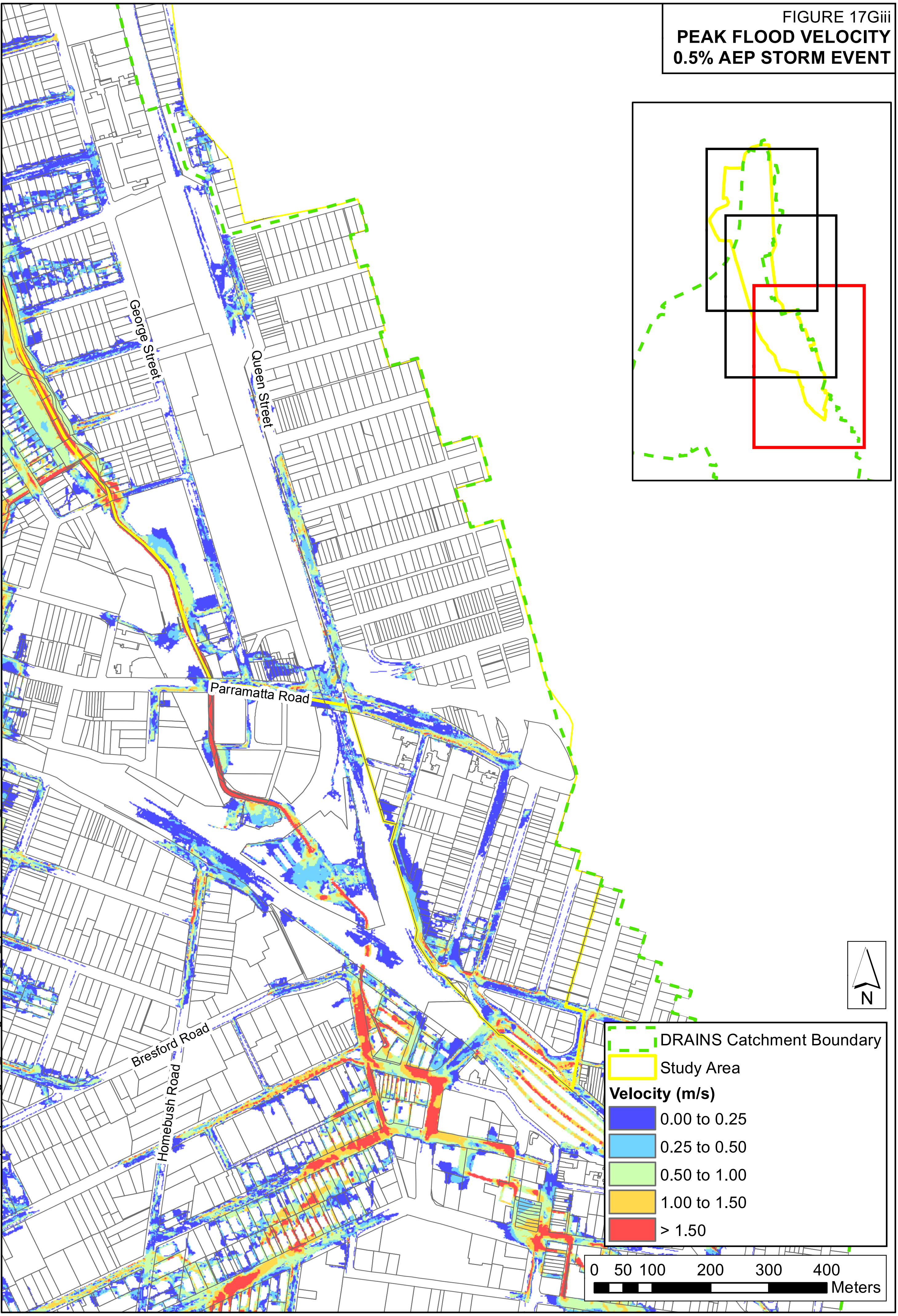
FIGURE 17Gii

PEAK FLOOD VELOCITY
0.5% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure 17\Figure17Gii 0 5pctAEP Peak Flood Velocity.mxd

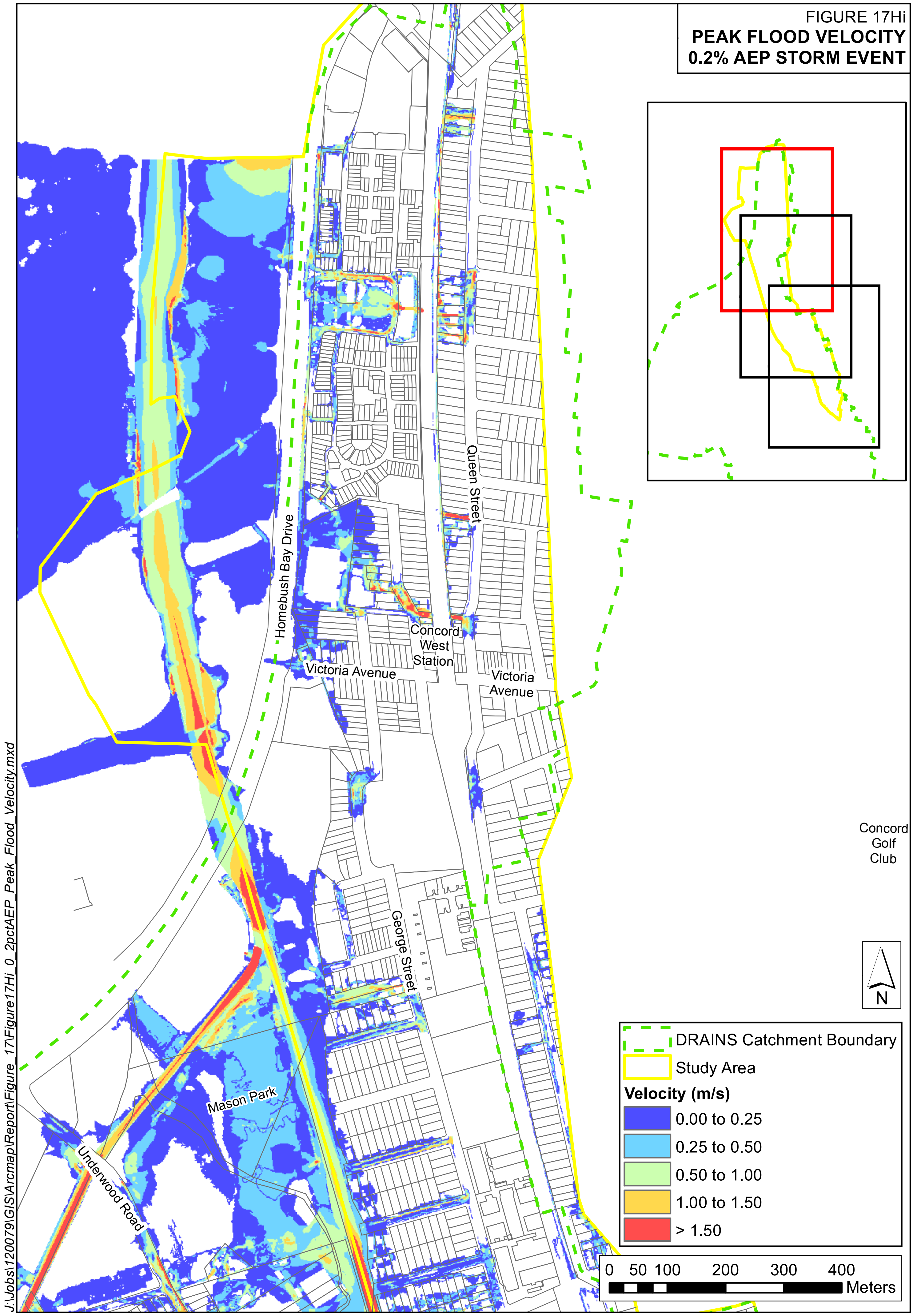
FIGURE 17Giii
PEAK FLOOD VELOCITY
0.5% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure_17\Figure17Giii_0_5pctAEP_Peak_Flood_Velocity.mxd

FIGURE 17Hi

PEAK FLOOD VELOCITY 0.2% AEP STORM EVENT



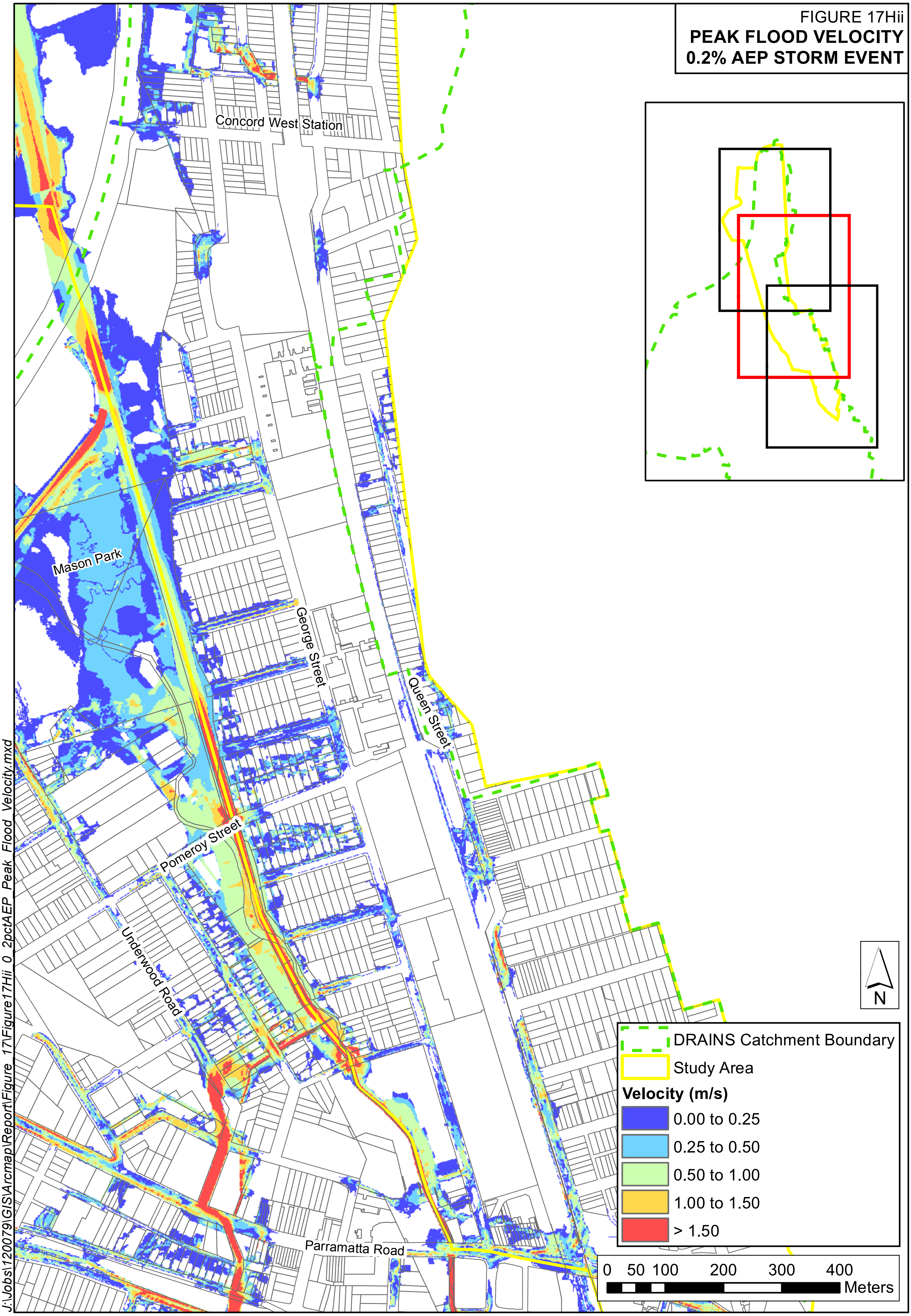
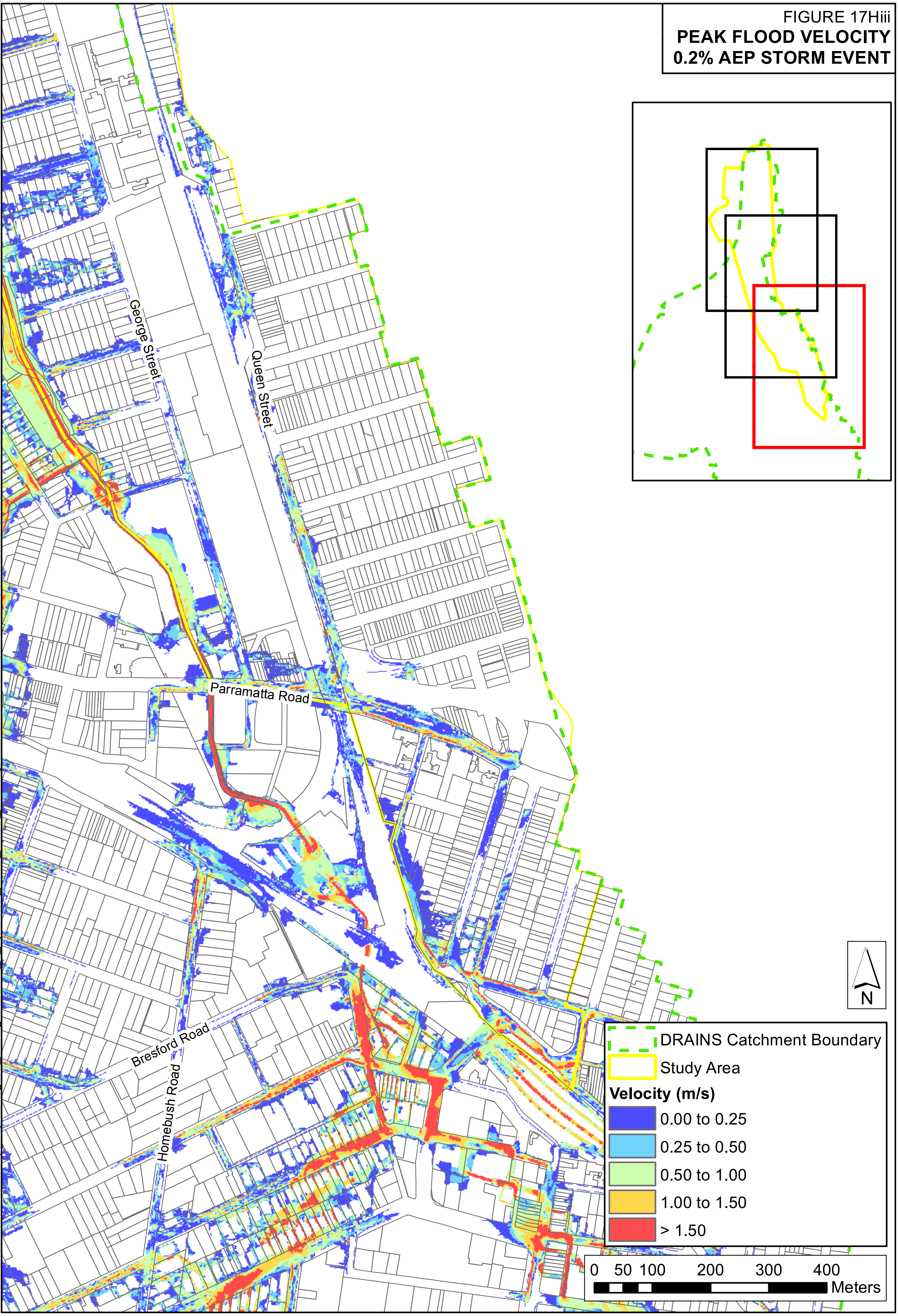


FIGURE 17Hii
PEAK FLOOD VELOCITY
0.2% AEP STORM EVENT
Concord West Station
Mason Park
George Street
Queen Street
Pomeroy Street
Underwood Road
Parramatta Road
N
DRAINS Catchment Boundary
Study Area
Velocity (m/s)
0.00 to 0.25
0.25 to 0.50
0.50 to 1.00
1.00 to 1.50
> 1.50
0 50 100 200 300 400
Meters
J:\Jobs\120079\GIS\Arcmap\Report\Figure_17\Figure17Hii_0_2pctAEP_Peak_Flood_Velocity.mxd

FIGURE 17Hiii
PEAK FLOOD VELOCITY
0.2% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure 17\Figure17Hiii 0 2pctAEP Peak Flood Velocity.mxd

FIGURE 17Ii
PEAK FLOOD VELOCITY
PMF STORM EVENT

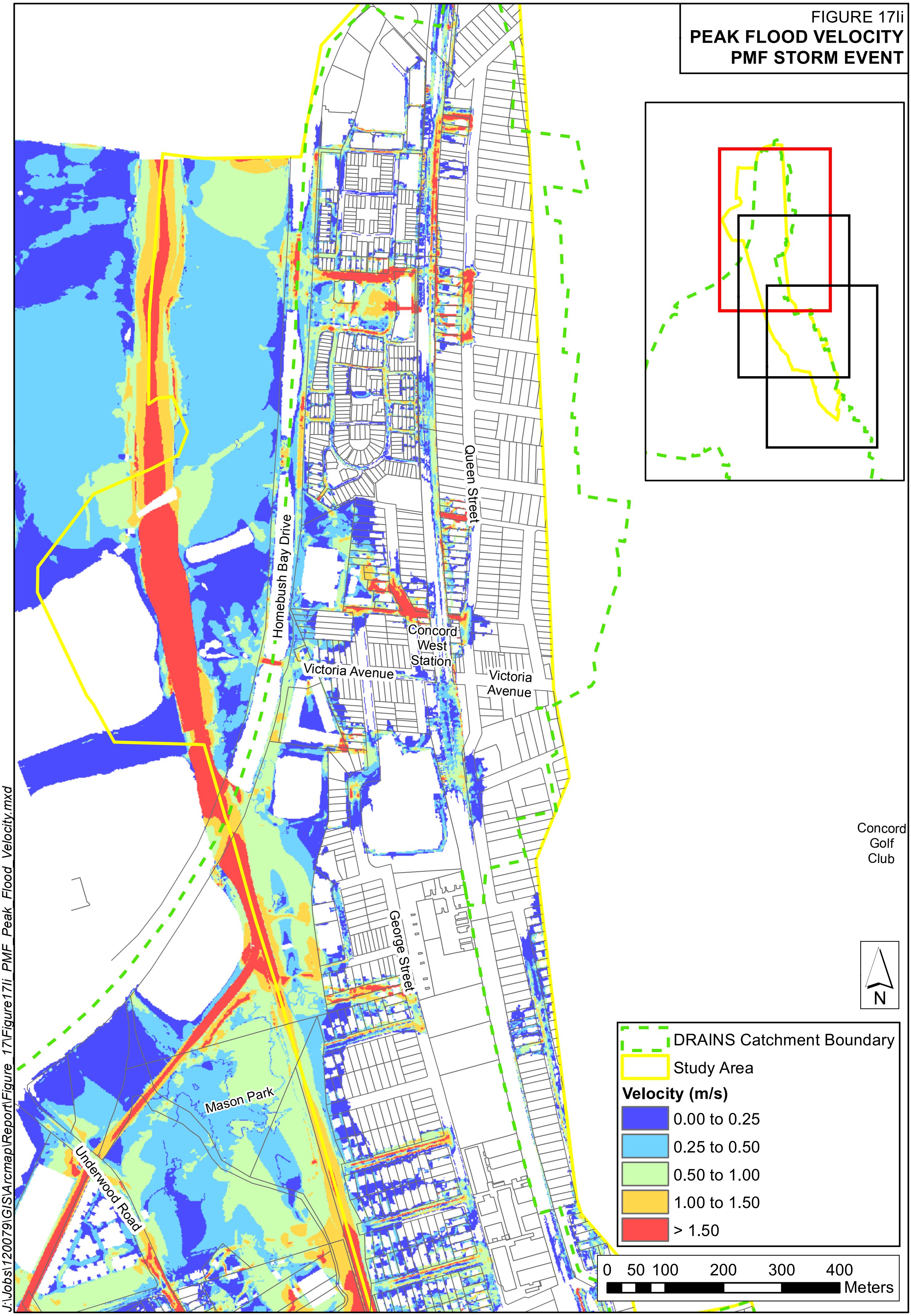
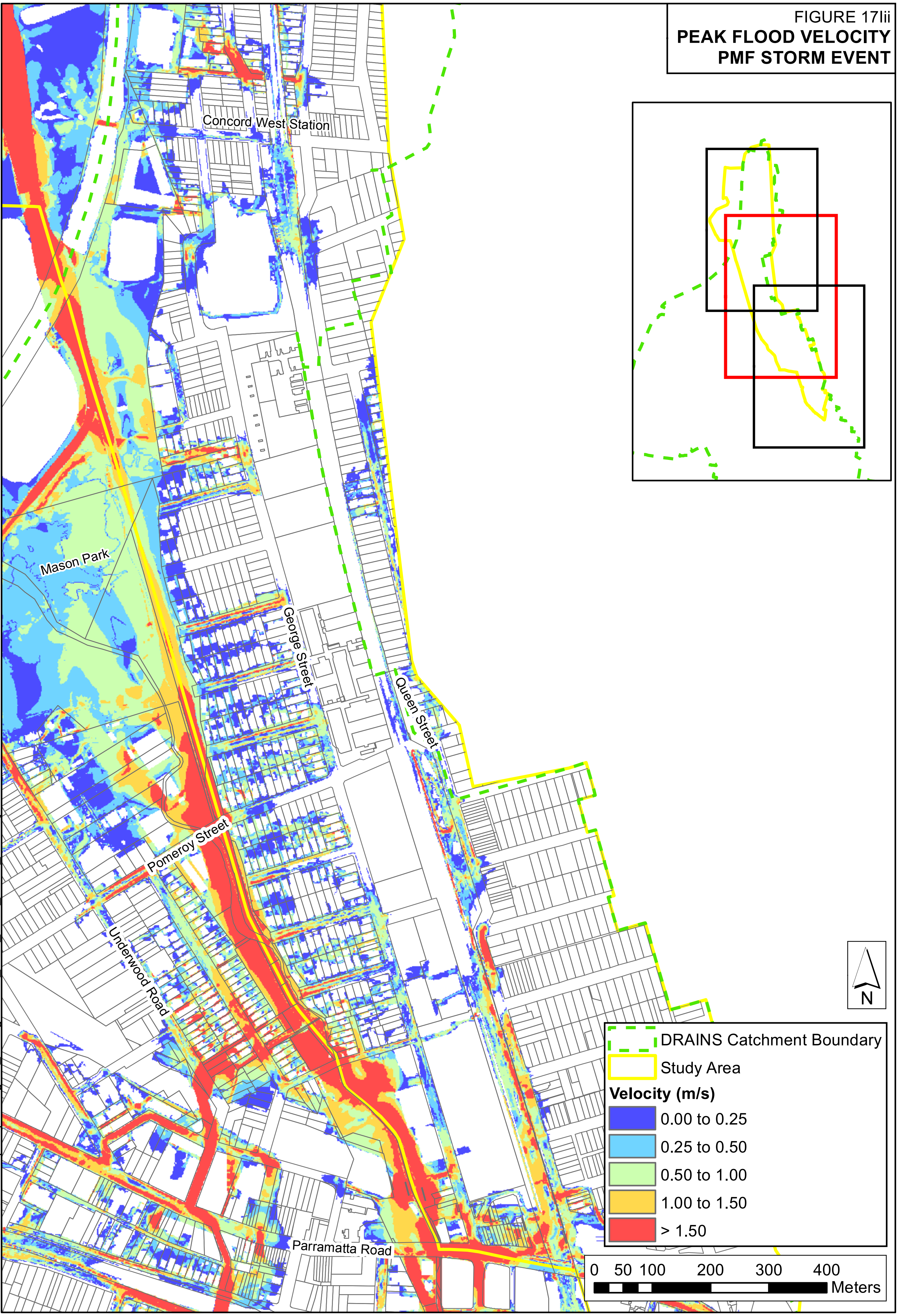


FIGURE 17lii

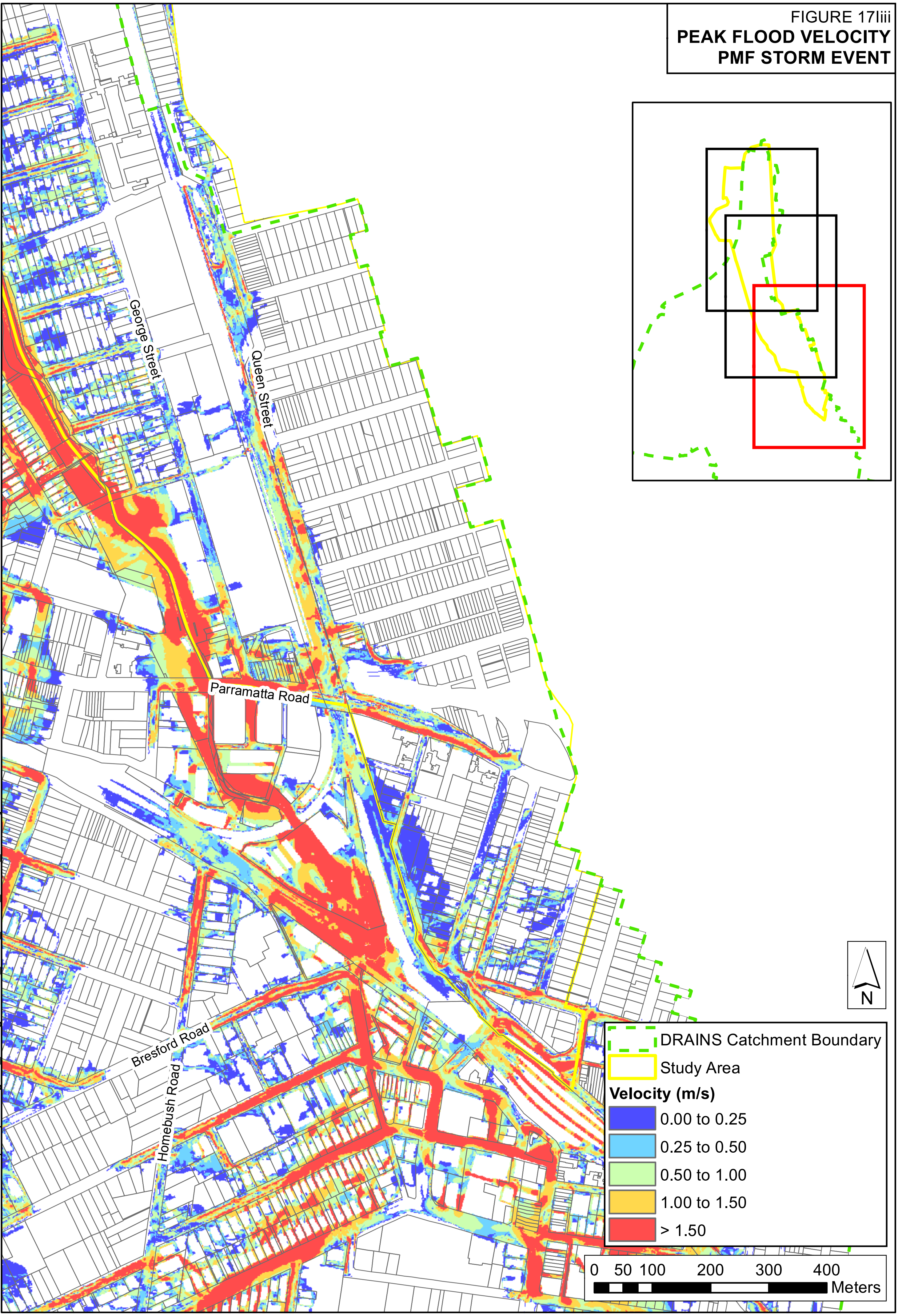
PEAK FLOOD VELOCITY

PMF STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure_17\Figure17lii_PMF_Peak_Flood_Velocity.mxd

FIGURE 17Iiii
PEAK FLOOD VELOCITY
PMF STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure 17\Figure17Iiii PMF Peak Flood Velocity.mxd

FIGURE 18Ai

PEAK FLOOD HAZARD
1 EY STORM EVENT

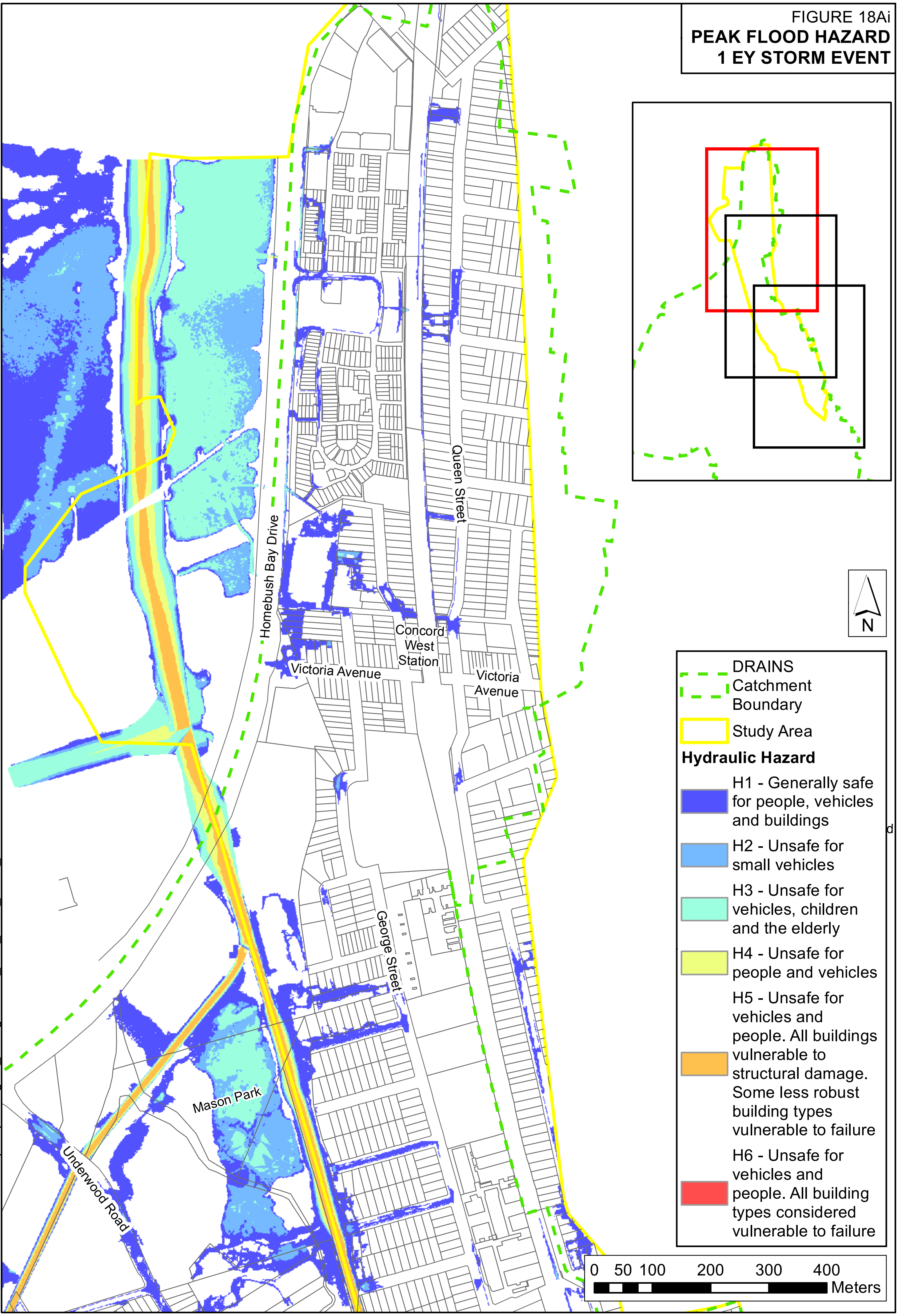


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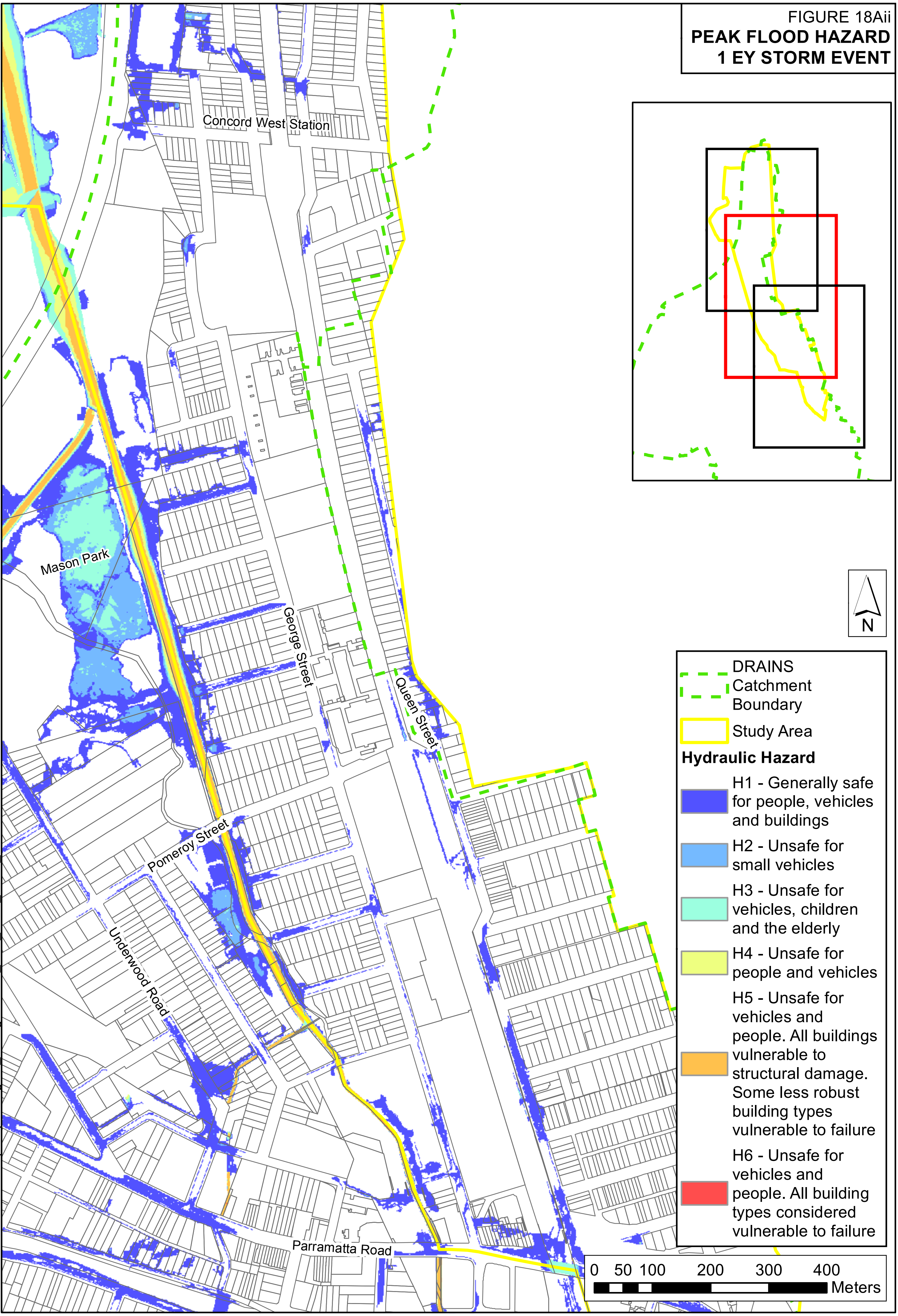
FIGURE 18Aii

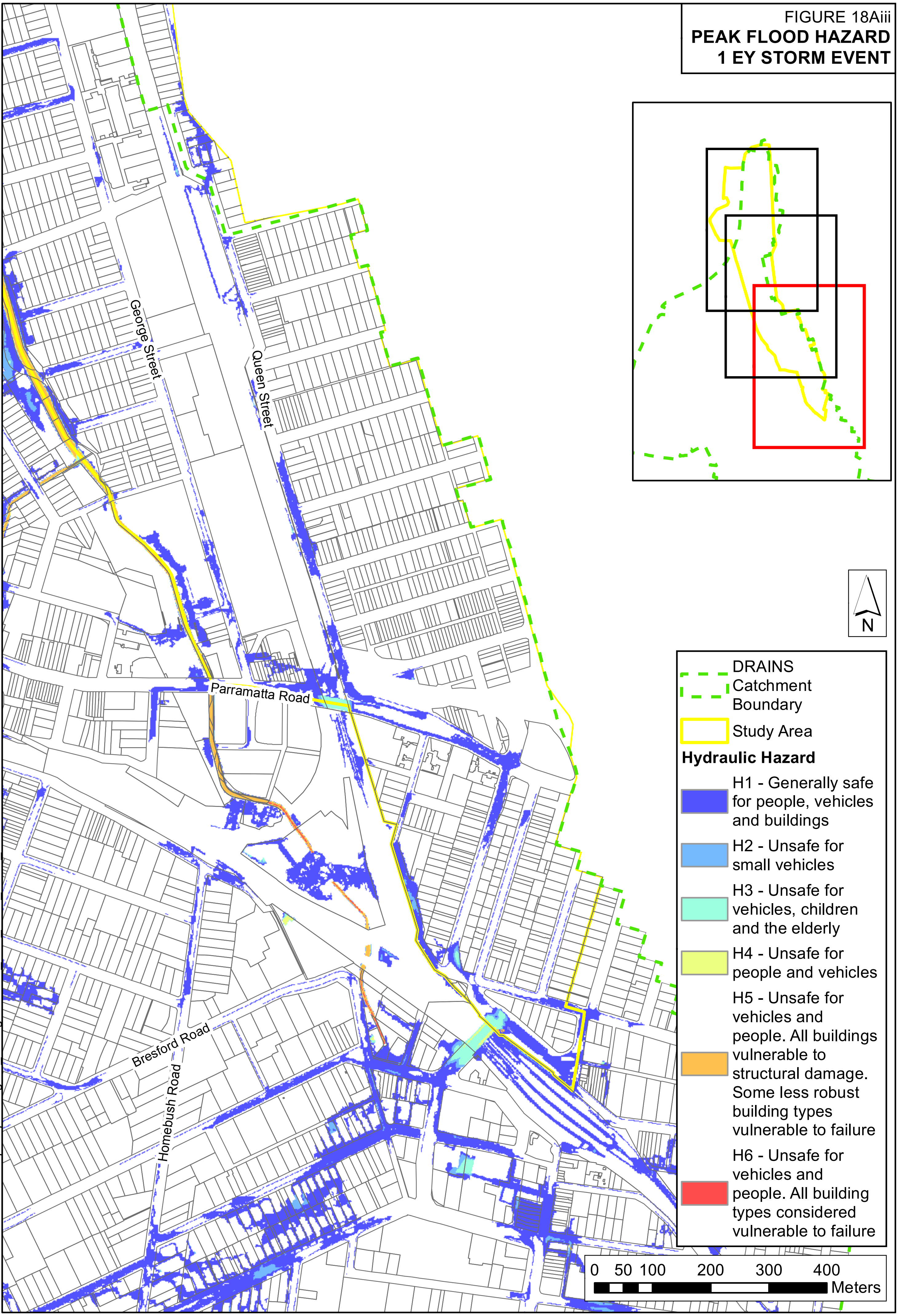
PEAK FLOOD HAZARD
1 EY STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure_18\Figure18Aii_1EY_Peak_Flood_Hazard.mxd

FIGURE 18Aiii

PEAK FLOOD HAZARD
1 EY STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure_18\Figure18Aiii_1EY_Peak_Flood_Hazard.mxd

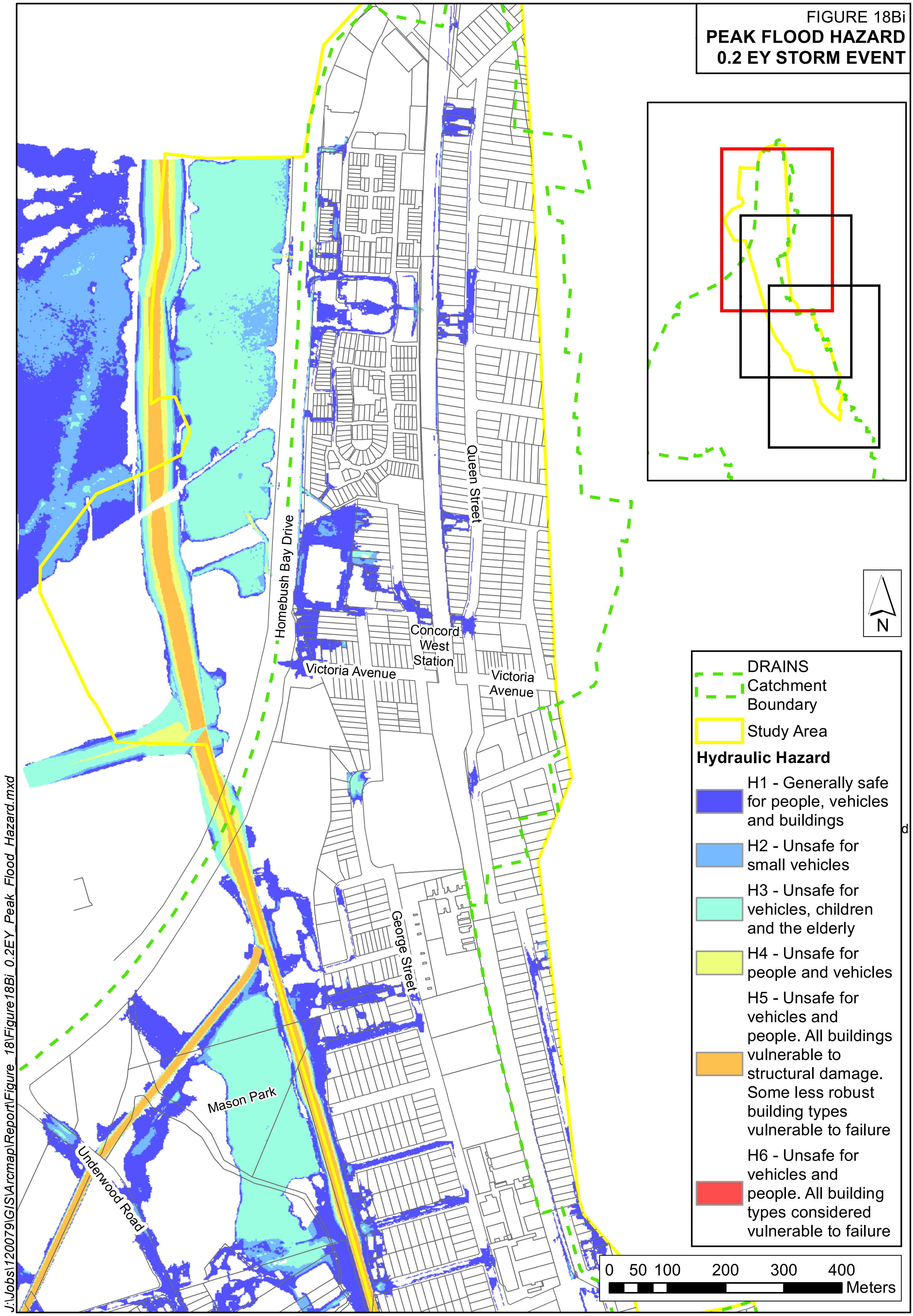


FIGURE 18Bi
PEAK FLOOD HAZARD
0.2 EY STORM EVENT
Homebush Bay Drive
Queen Street
Concord West Station
Victoria Avenue
Victoria Avenue
George Street
Mason Park
Underwood Road
N
DRAINS Catchment Boundary
Study Area
Hydraulic Hazard
H1 - Generally safe for people, vehicles and buildings
H2 - Unsafe for small vehicles
H3 - Unsafe for vehicles, children and the elderly
H4 - Unsafe for people and vehicles
H5 - Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust building types vulnerable to failure
H6 - Unsafe for vehicles and people. All building types considered vulnerable to failure
0 50 100 200 300 400
Meters
J:\Jobs\120079\GIS\Arcmap\Report\Figure_18\Figure18Bi_0.2EY_Peak_Flood_Hazard.mxd

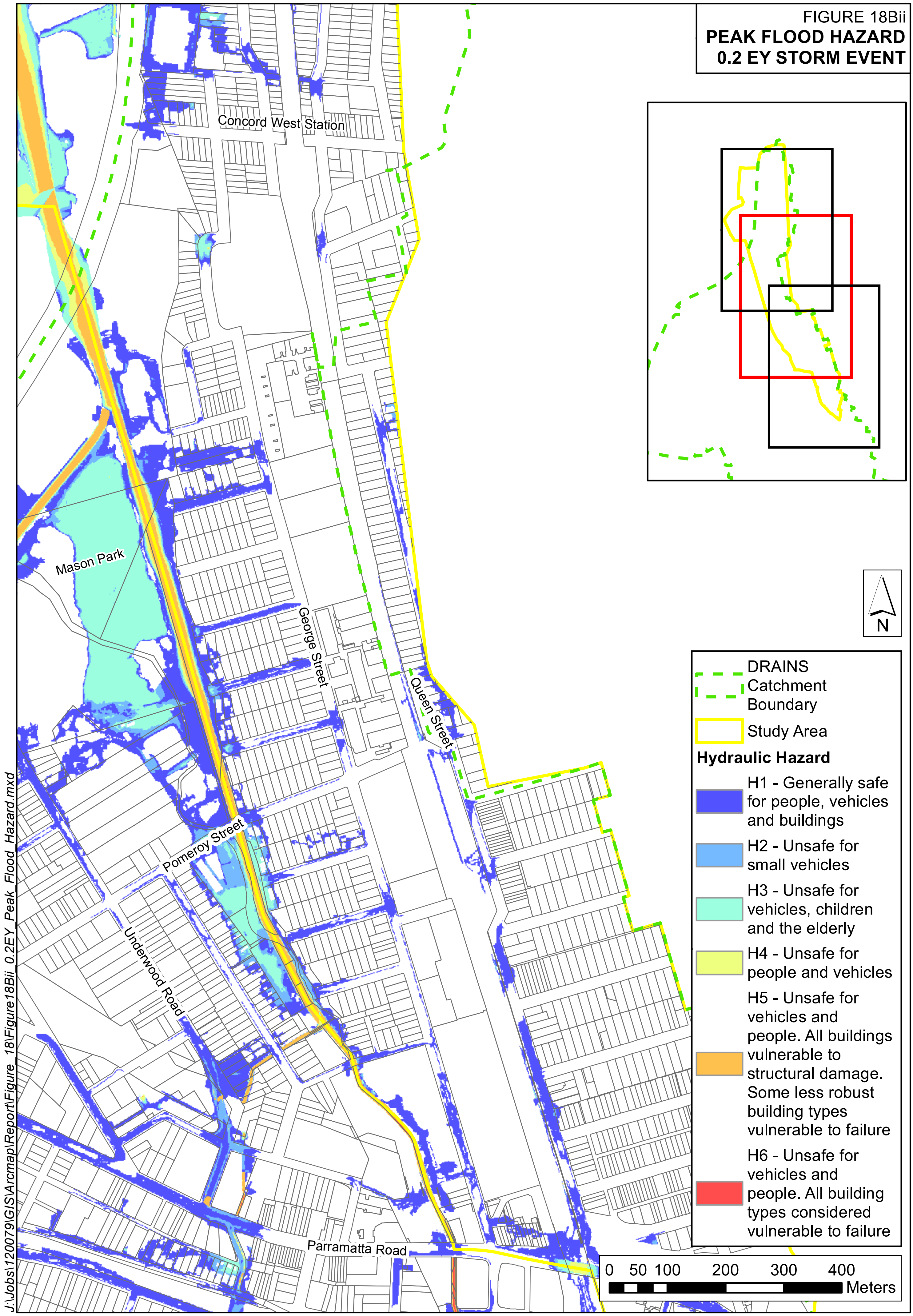


FIGURE 18Bii
PEAK FLOOD HAZARD
0.2 EY STORM EVENT
Concord West Station
Mason Park
George Street
Queen Street
Pomeroy Street
Underwood Road
Parramatta Road
N
DRAINS Catchment Boundary
Study Area
Hydraulic Hazard
H1 - Generally safe for people, vehicles and buildings
H2 - Unsafe for small vehicles
H3 - Unsafe for vehicles, children and the elderly
H4 - Unsafe for people and vehicles
H5 - Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust building types vulnerable to failure
H6 - Unsafe for vehicles and people. All building types considered vulnerable to failure
0 50 100 200 300 400
Meters
J:\Jobs\120079\GIS\Arcmap\Report\Figure 18\Figure18Bii 0.2EY Peak Flood Hazard.mxd

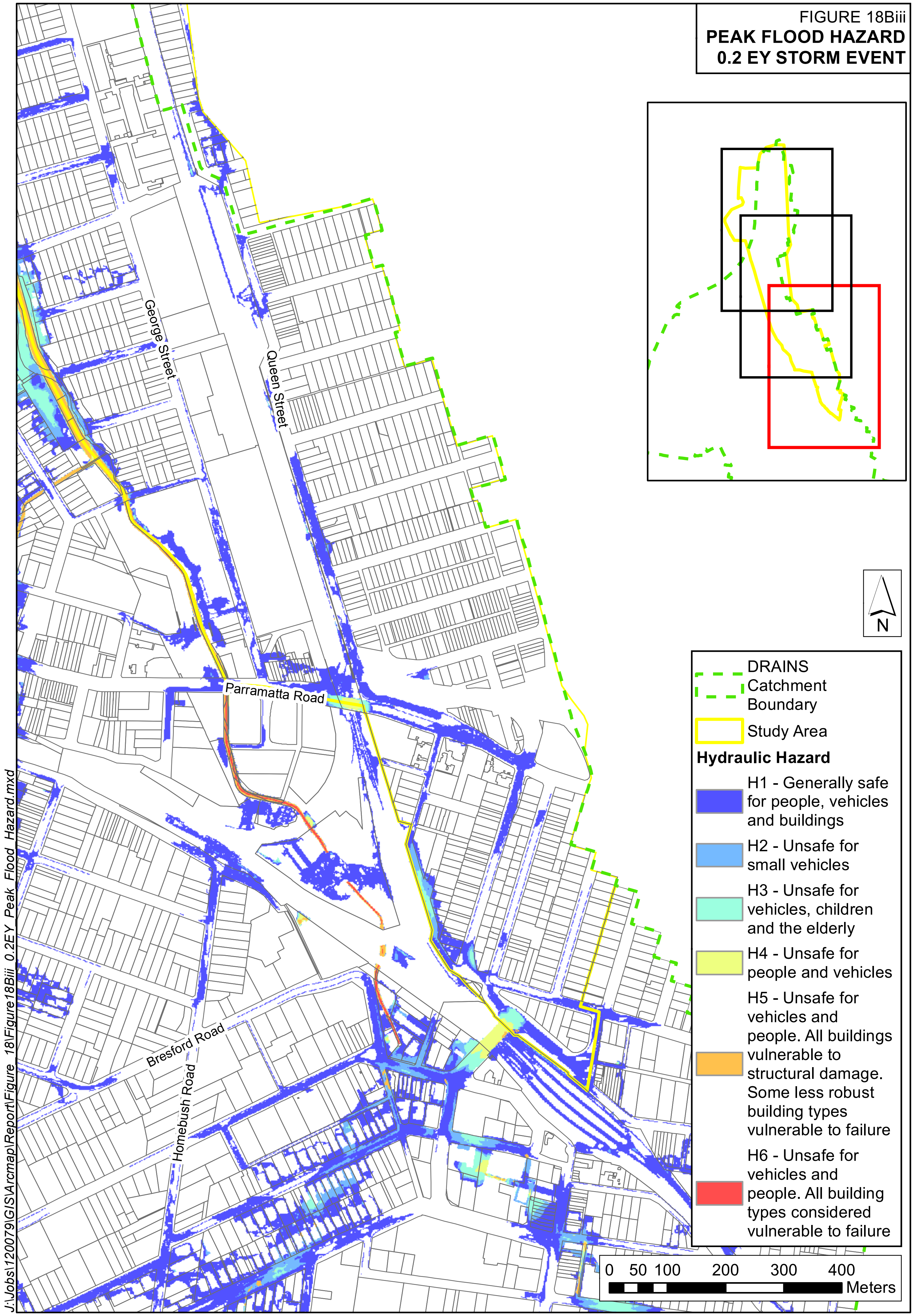


FIGURE 18Biii
PEAK FLOOD HAZARD
0.2 EY STORM EVENT
George Street
Queen Street
Parramatta Road
Bresford Road
Homebush Road
N
DRAINS Catchment Boundary
Study Area
Hydraulic Hazard
H1 - Generally safe for people, vehicles and buildings
H2 - Unsafe for small vehicles
H3 - Unsafe for vehicles, children and the elderly
H4 - Unsafe for people and vehicles
H5 - Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust building types vulnerable to failure
H6 - Unsafe for vehicles and people. All building types considered vulnerable to failure
0 50 100 200 300 400
Meters
J:\Jobs\120079\GIS\Arcmap\Report\Figure_18\Figure18Biii_0.2EY_Peak_Flood_Hazard.mxd

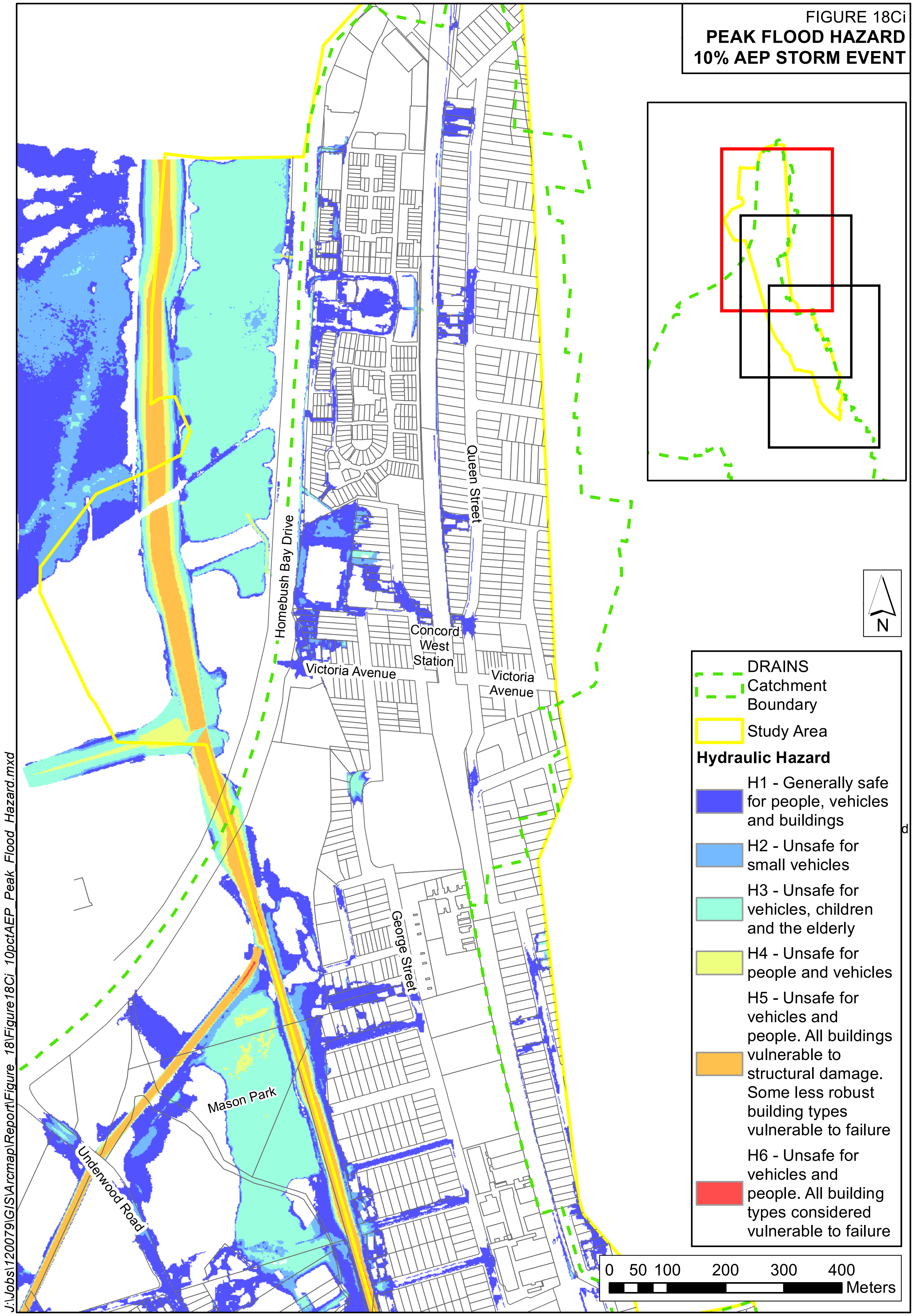


FIGURE 18Ci
PEAK FLOOD HAZARD
10% AEP STORM EVENT
Homebush Bay Drive
Queen Street
Concord West Station
Victoria Avenue
Victoria Avenue
George Street
Mason Park
Underwood Road
DRAINS Catchment Boundary
Study Area
Hydraulic Hazard
H1 - Generally safe for people, vehicles and buildings
H2 - Unsafe for small vehicles
H3 - Unsafe for vehicles, children and the elderly
H4 - Unsafe for people and vehicles
H5 - Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust building types vulnerable to failure
H6 - Unsafe for vehicles and people. All building types considered vulnerable to failure
N
0 50 100 200 300 400
Meters
J:\Jobs\120079\GIS\Arcmap\Report\Figure_18\Figure18Ci_10pctAEP_Peak_Flood_Hazard.mxd

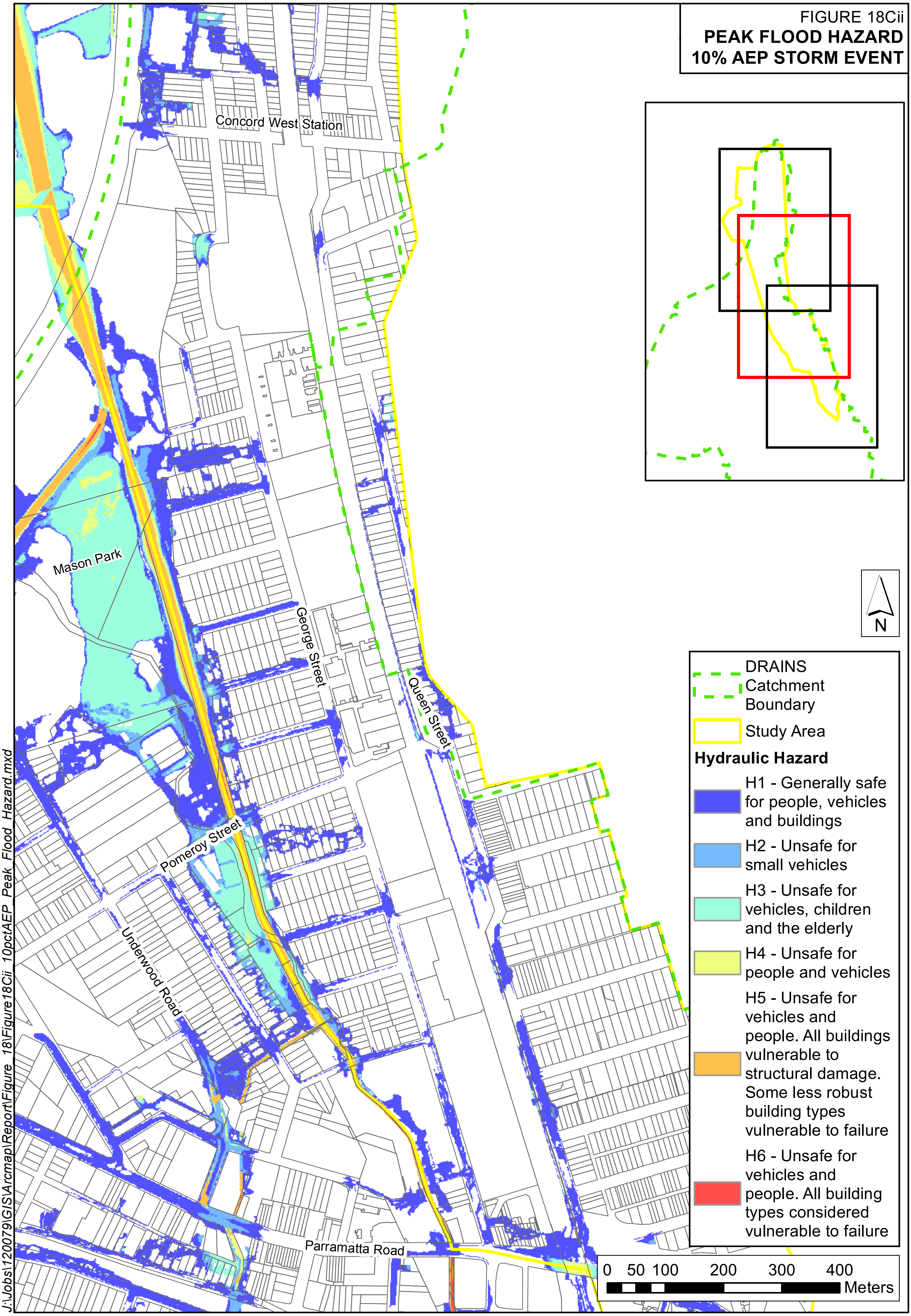


FIGURE 18Cii
PEAK FLOOD HAZARD
10% AEP STORM EVENT
Concord West Station
Mason Park
George Street
Queen Street
Pomeroy Street
Underwood Road
Parramatta Road
N
DRAINS Catchment Boundary
Study Area
Hydraulic Hazard
H1 - Generally safe for people, vehicles and buildings
H2 - Unsafe for small vehicles
H3 - Unsafe for vehicles, children and the elderly
H4 - Unsafe for people and vehicles
H5 - Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust building types vulnerable to failure
H6 - Unsafe for vehicles and people. All building types considered vulnerable to failure
0 50 100 200 300 400 Meters
J:\Jobs\120079\GIS\Arcmap\Report\Figure_18\Figure18Cii_10pctAEP_Peak_Flood_Hazard.mxd

FIGURE 18Ciii

PEAK FLOOD HAZARD
10% AEP STORM EVENT

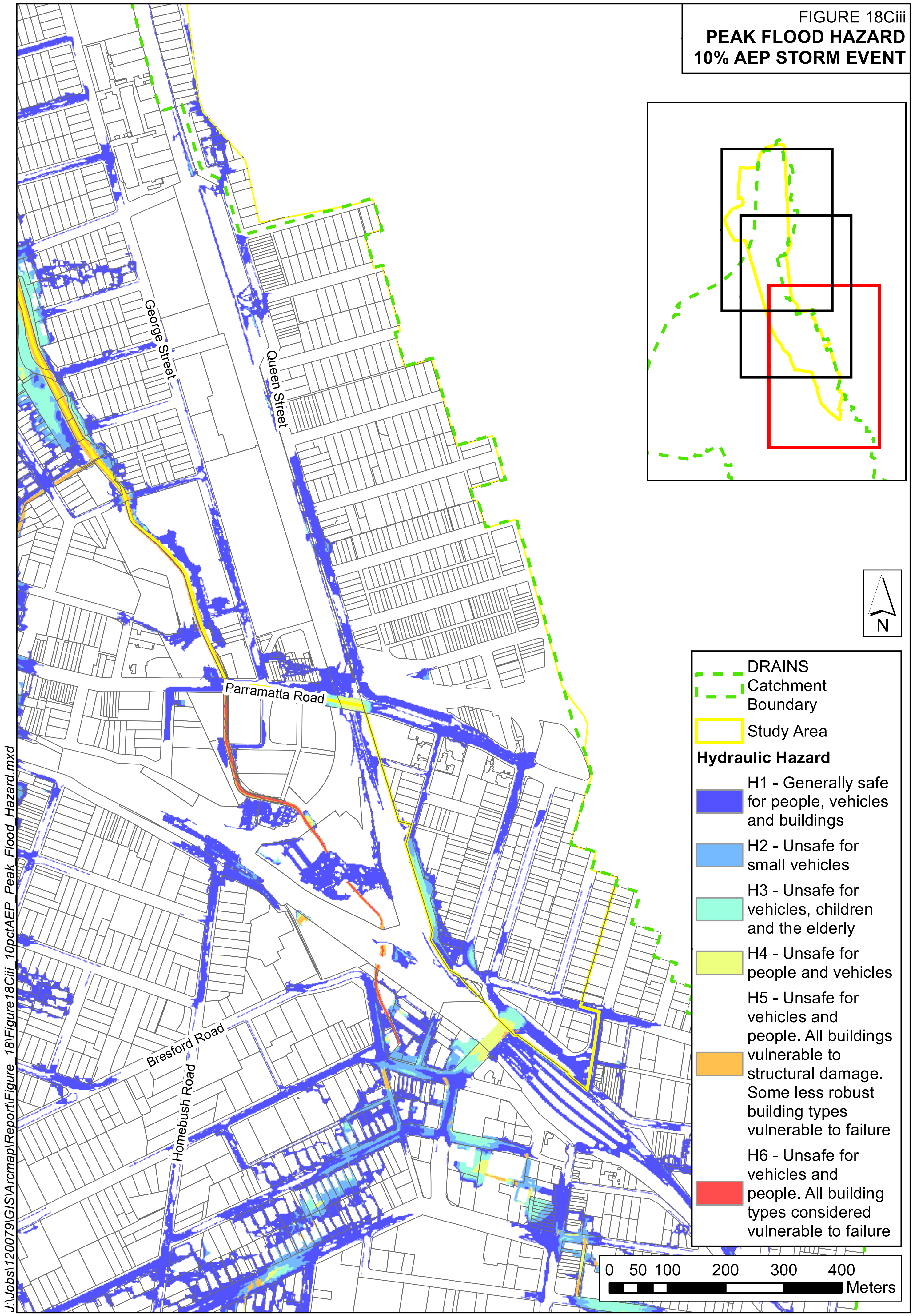


FIGURE 18Di
PEAK FLOOD HAZARD
5% AEP STORM EVENT

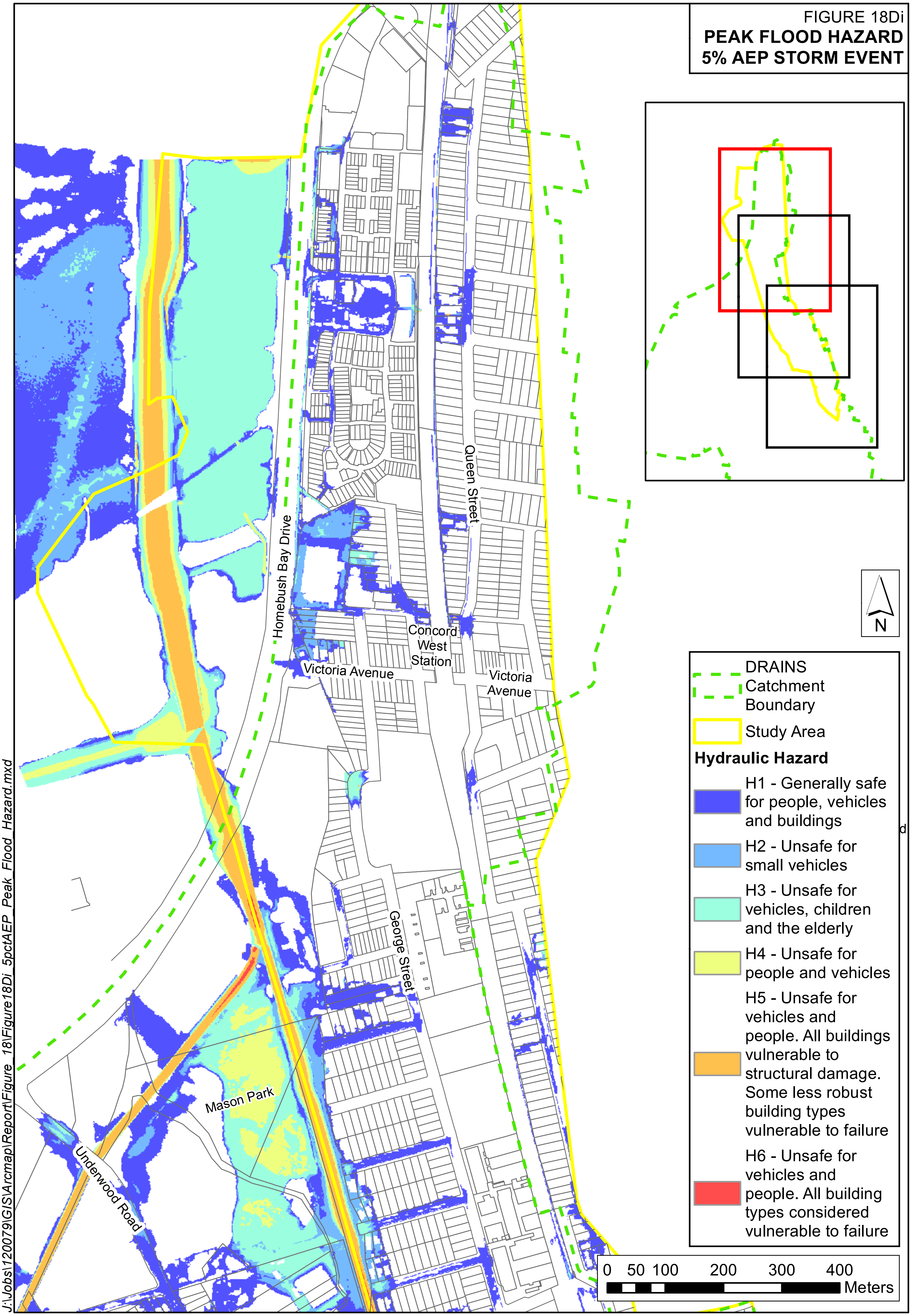
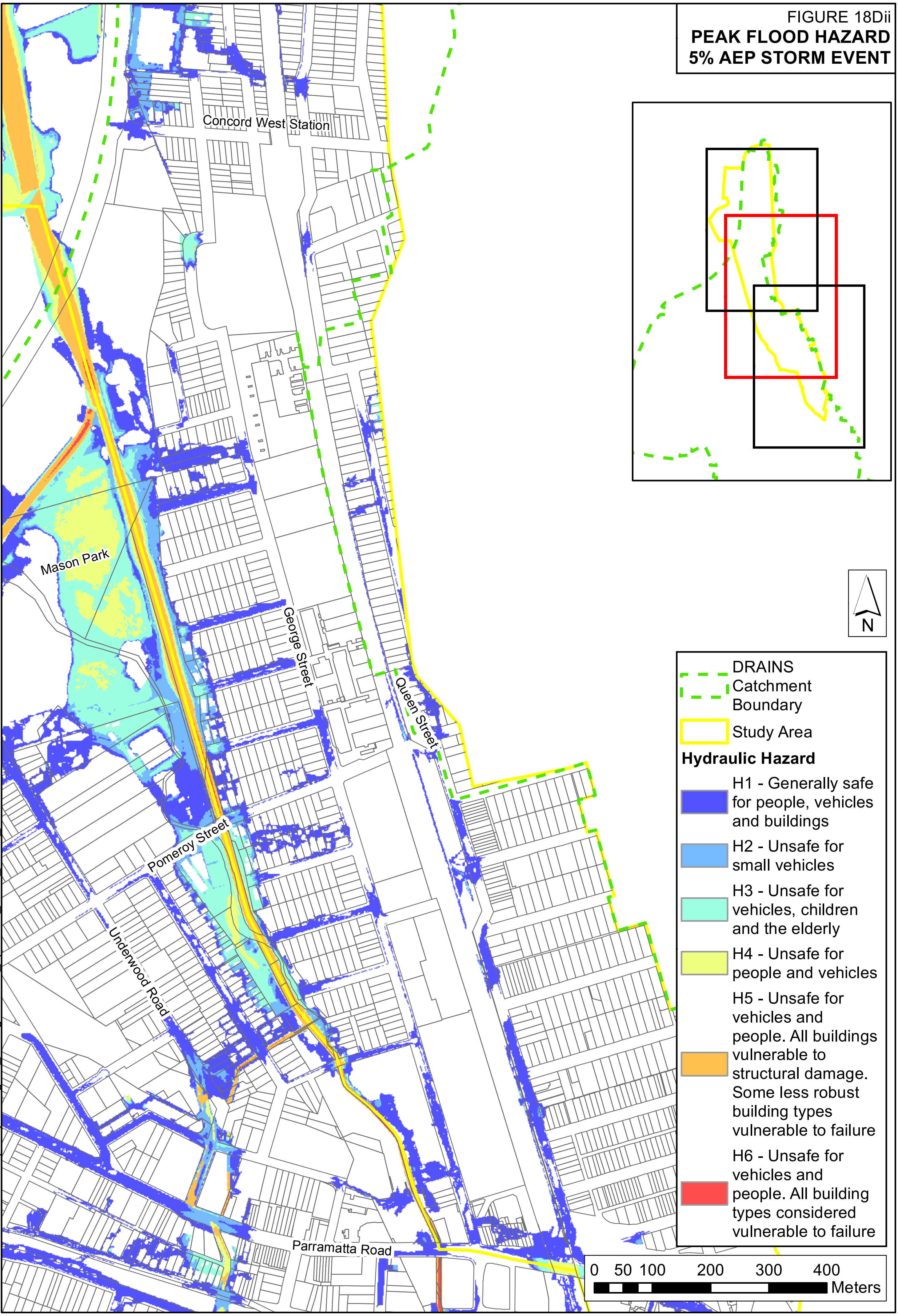


FIGURE 18Dii

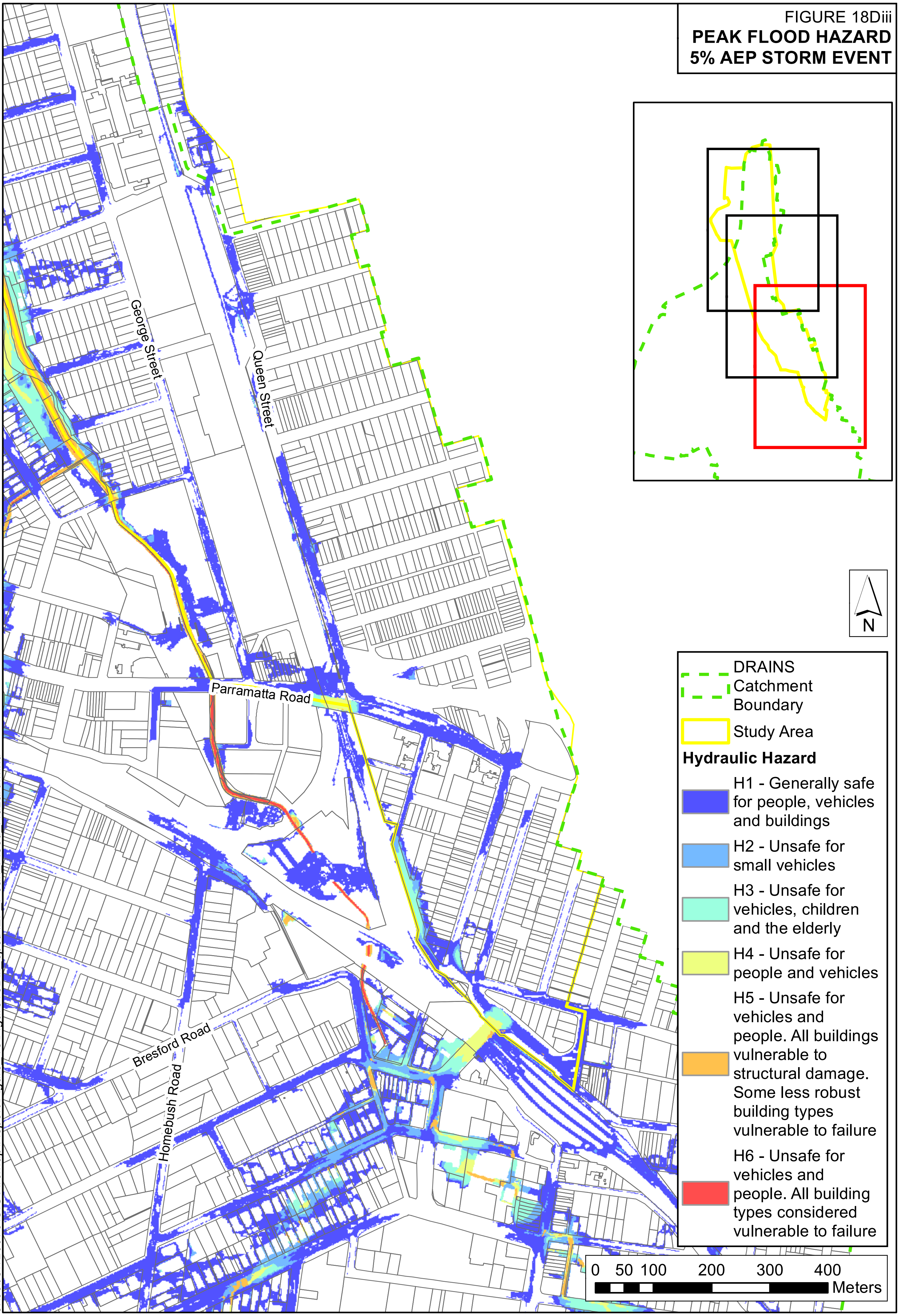
PEAK FLOOD HAZARD 5% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure_18\Figure18Dii_5pctAEP_Peak_Flood_Hazard.mxd

FIGURE 18Diii

PEAK FLOOD HAZARD
5% AEP STORM EVENT



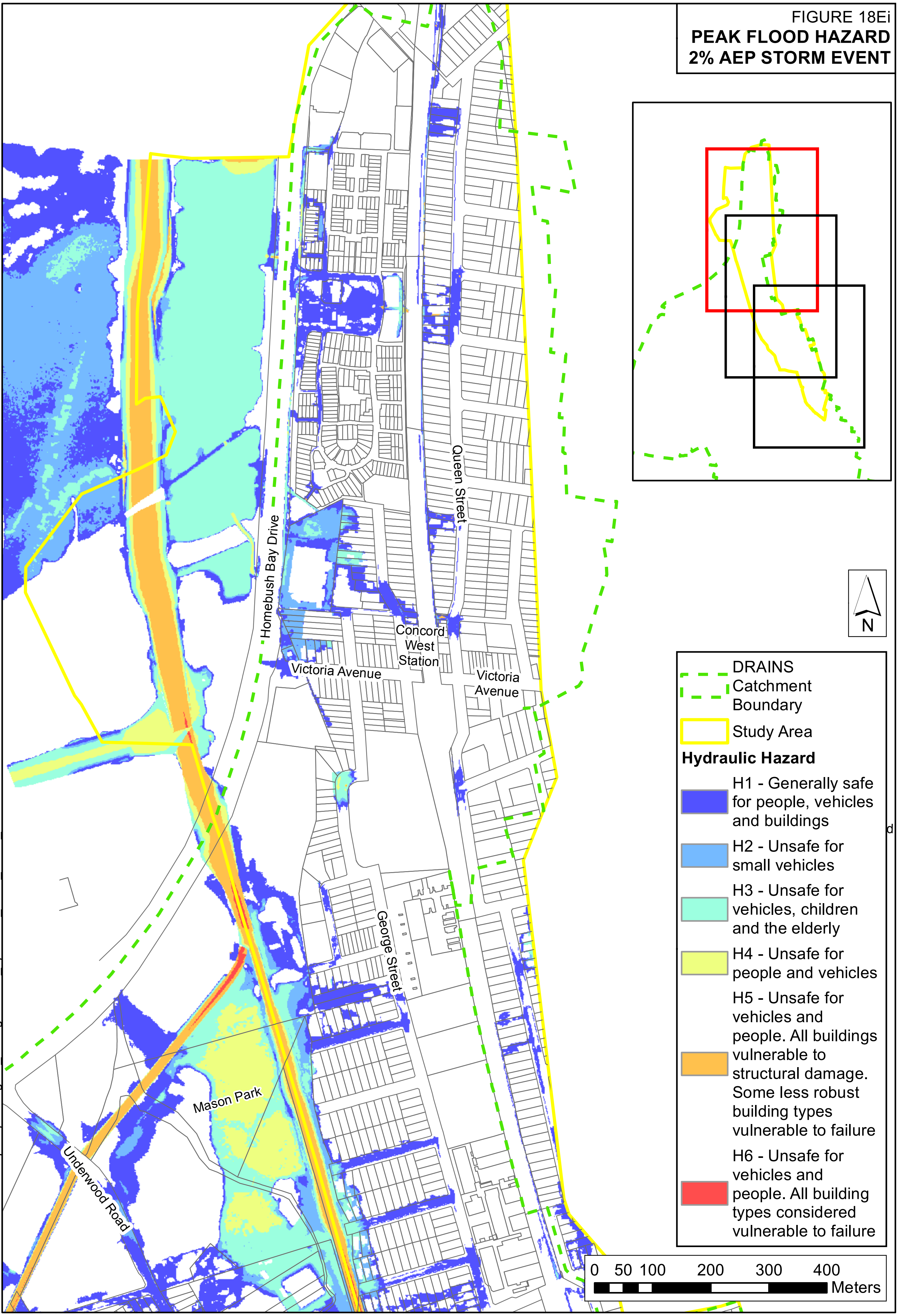
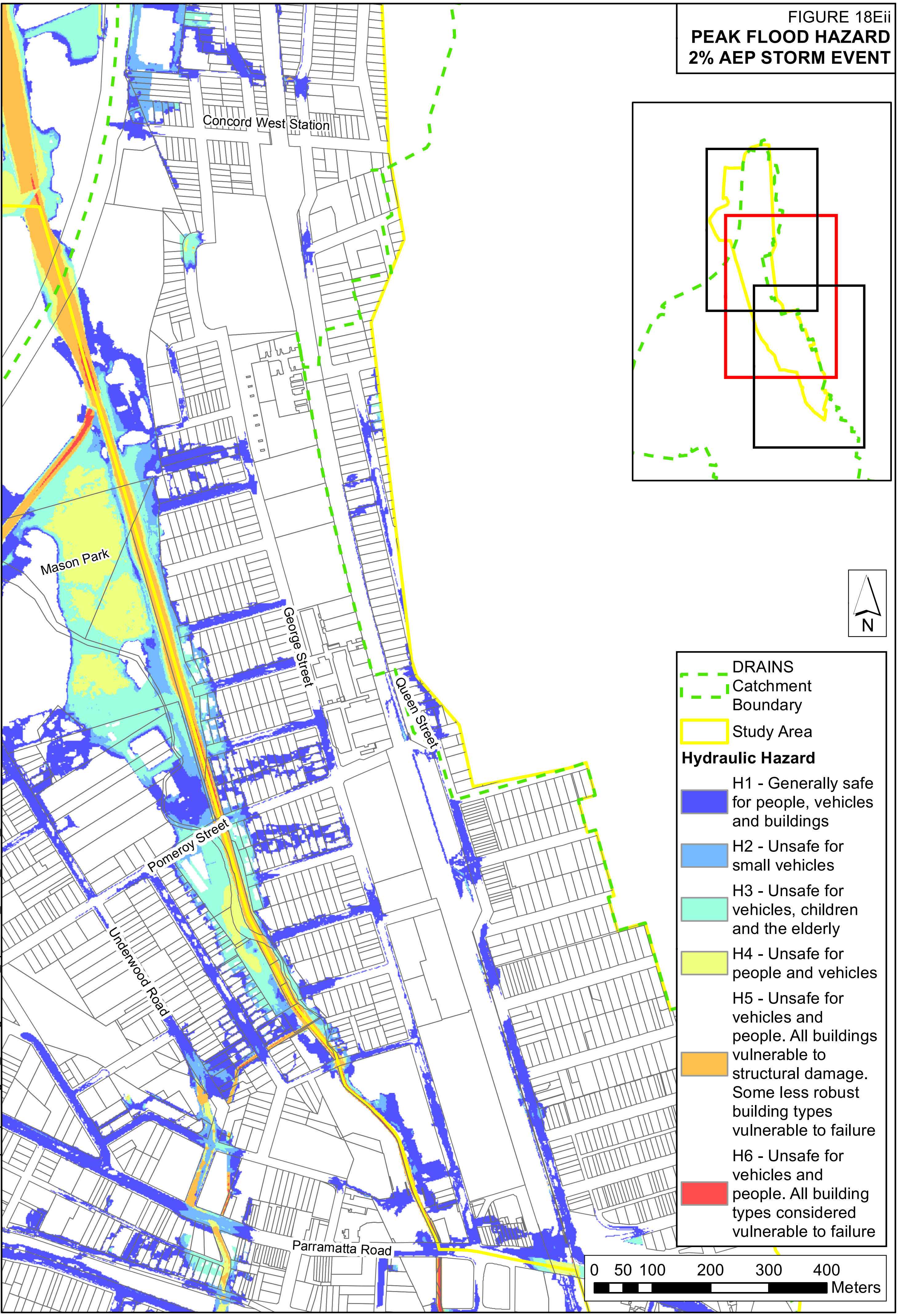


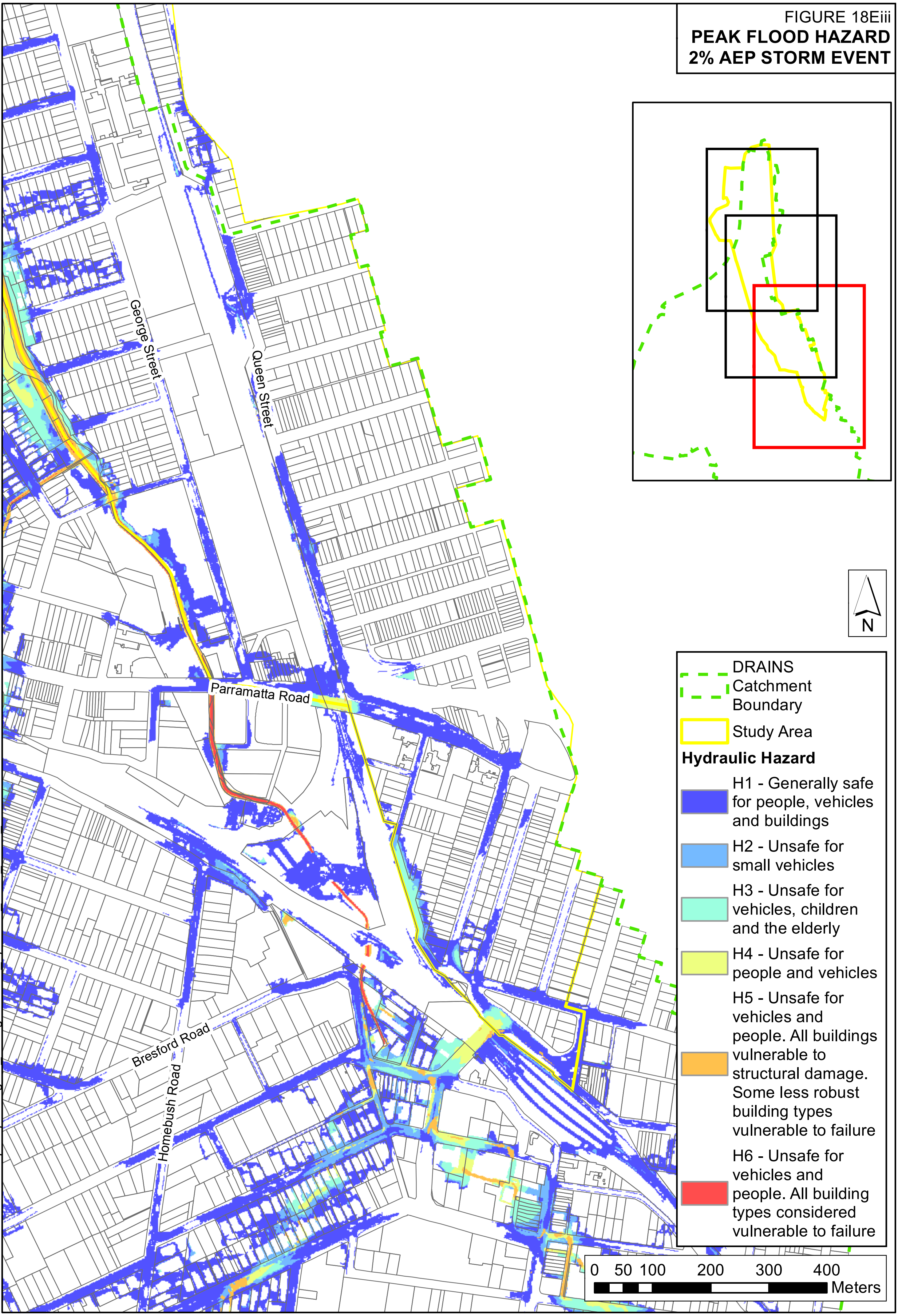
FIGURE 18Ei
PEAK FLOOD HAZARD
2% AEP STORM EVENT

J:\Jobs\120079\GIS\Arcmap\Report\Figure_18\Figure18Ei_2pctAEP_Peak_Flood_Hazard.mxd

FIGURE 18Eii
PEAK FLOOD HAZARD
2% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure_18\Figure18Eii_2pctAEP_Peak_Flood_Hazard.mxd



J:\Jobs\120079\GIS\Arcmap\Report\Figure 18\Figure18Eiii 2pctAEP Peak Flood Hazard.mxd

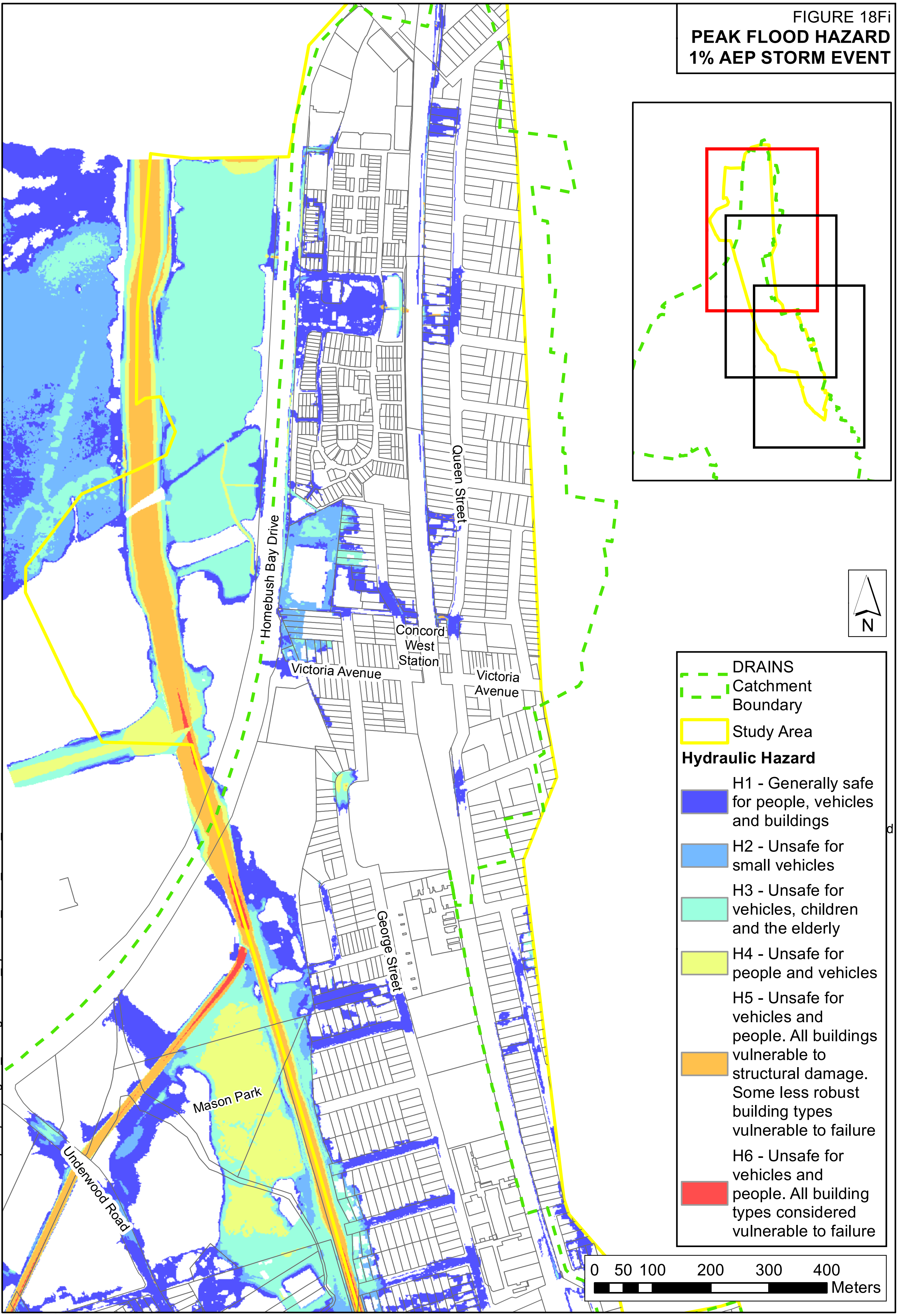


FIGURE 18Fi
PEAK FLOOD HAZARD
1% AEP STORM EVENT

J:\Jobs\120079\GIS\Arcmap\Report\Figure_18\Figure18Fi_1pctAEP_Peak_Flood_Hazard.mxd

FIGURE 18Fii

PEAK FLOOD HAZARD 1% AEP STORM EVENT

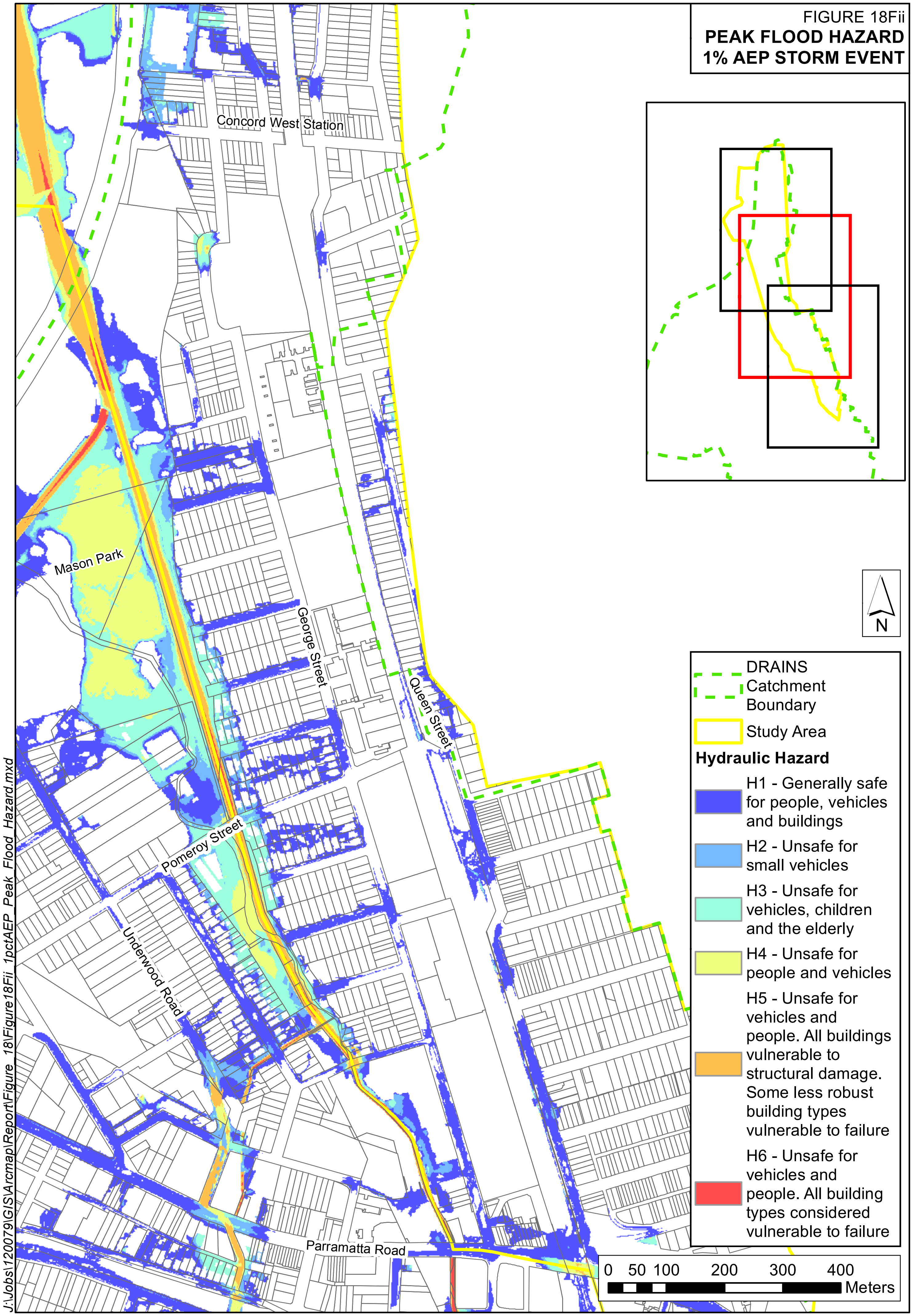
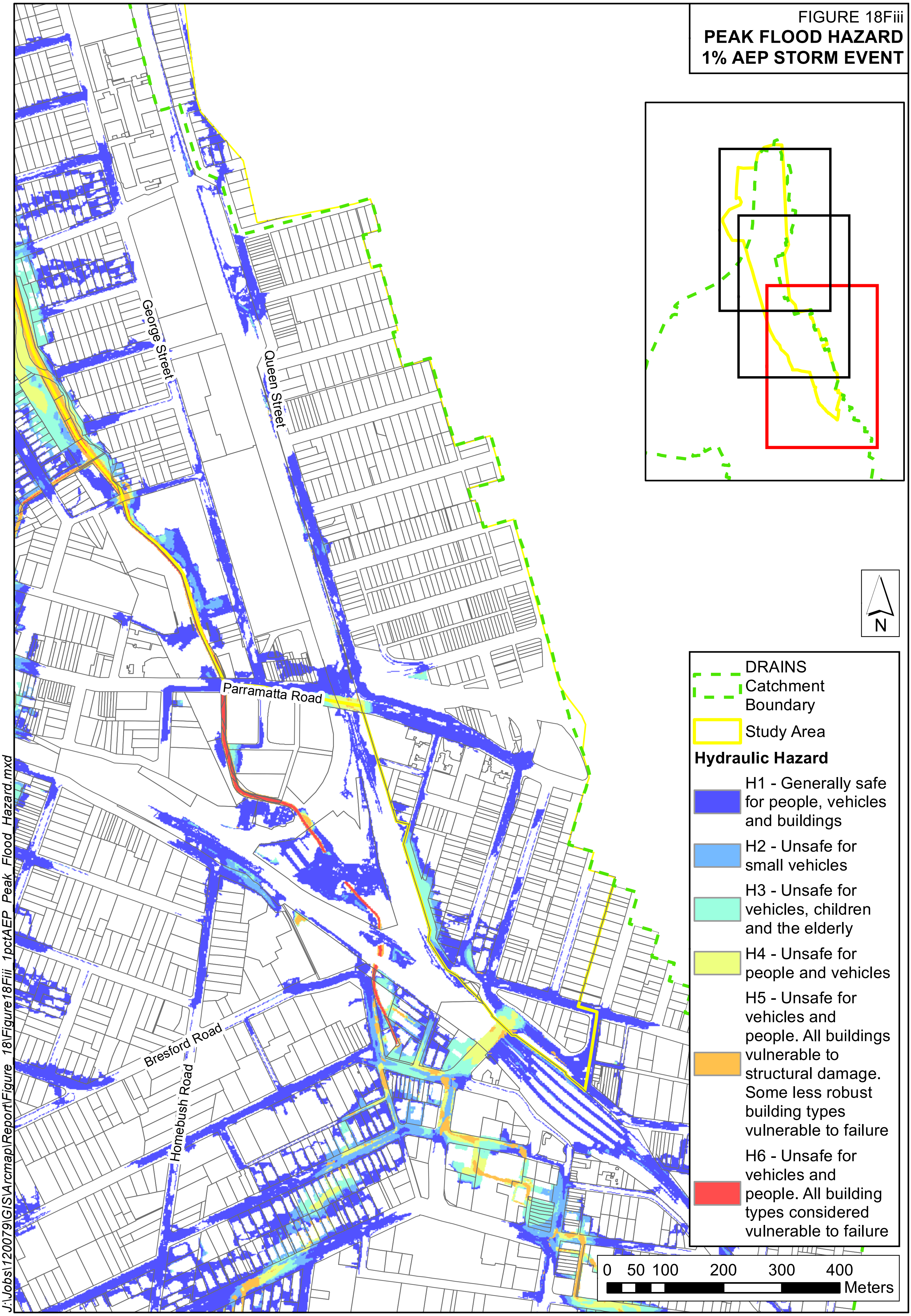


FIGURE 18Fiii
PEAK FLOOD HAZARD
1% AEP STORM EVENT



DRAINS Catchment Boundary

Study Area

Hydraulic Hazard

H1 - Generally safe for people, vehicles and buildings

H2 - Unsafe for small vehicles

H3 - Unsafe for vehicles, children and the elderly

H4 - Unsafe for people and vehicles

H5 - Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust building types vulnerable to failure

H6 - Unsafe for vehicles and people. All building types considered vulnerable to failure

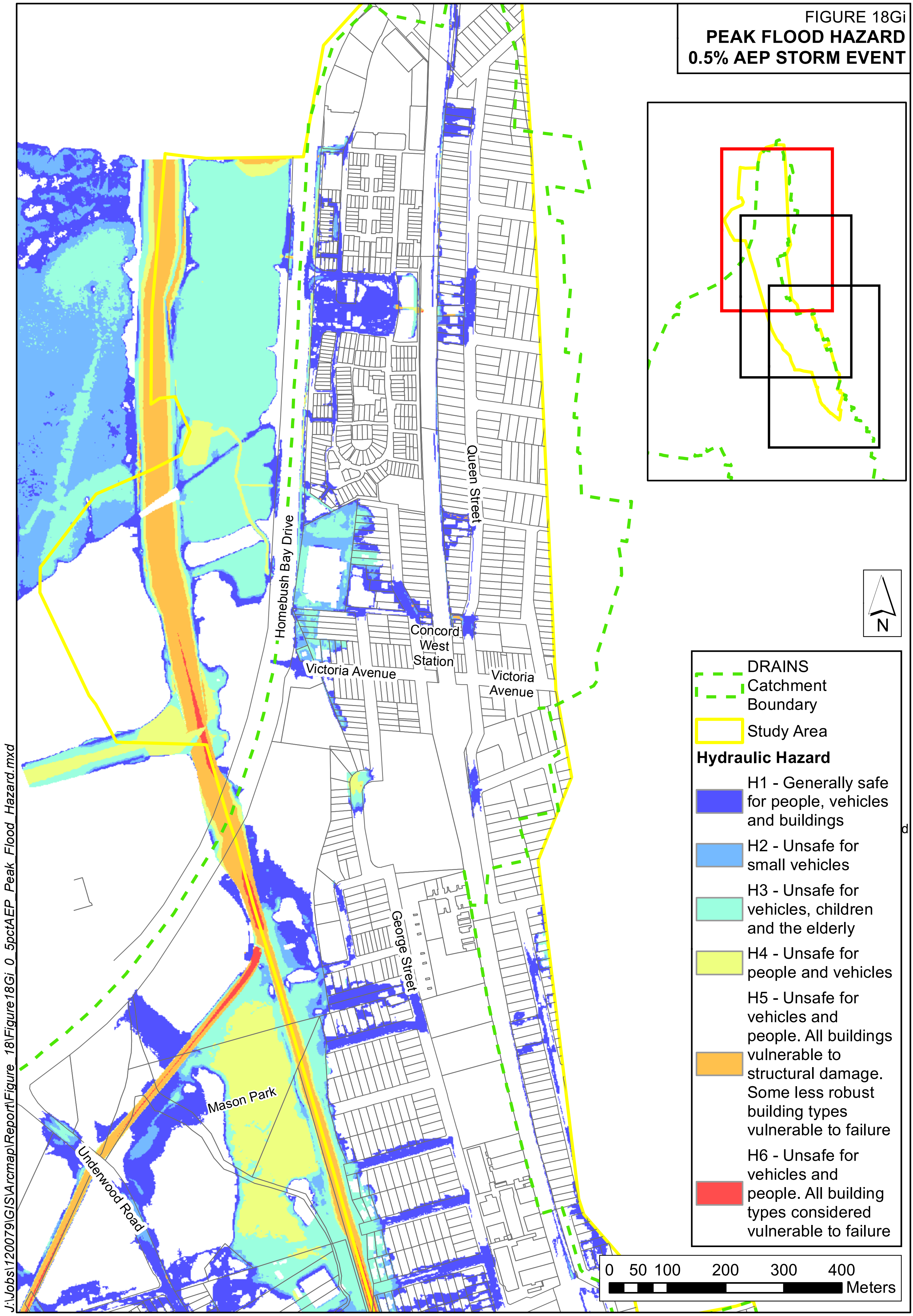
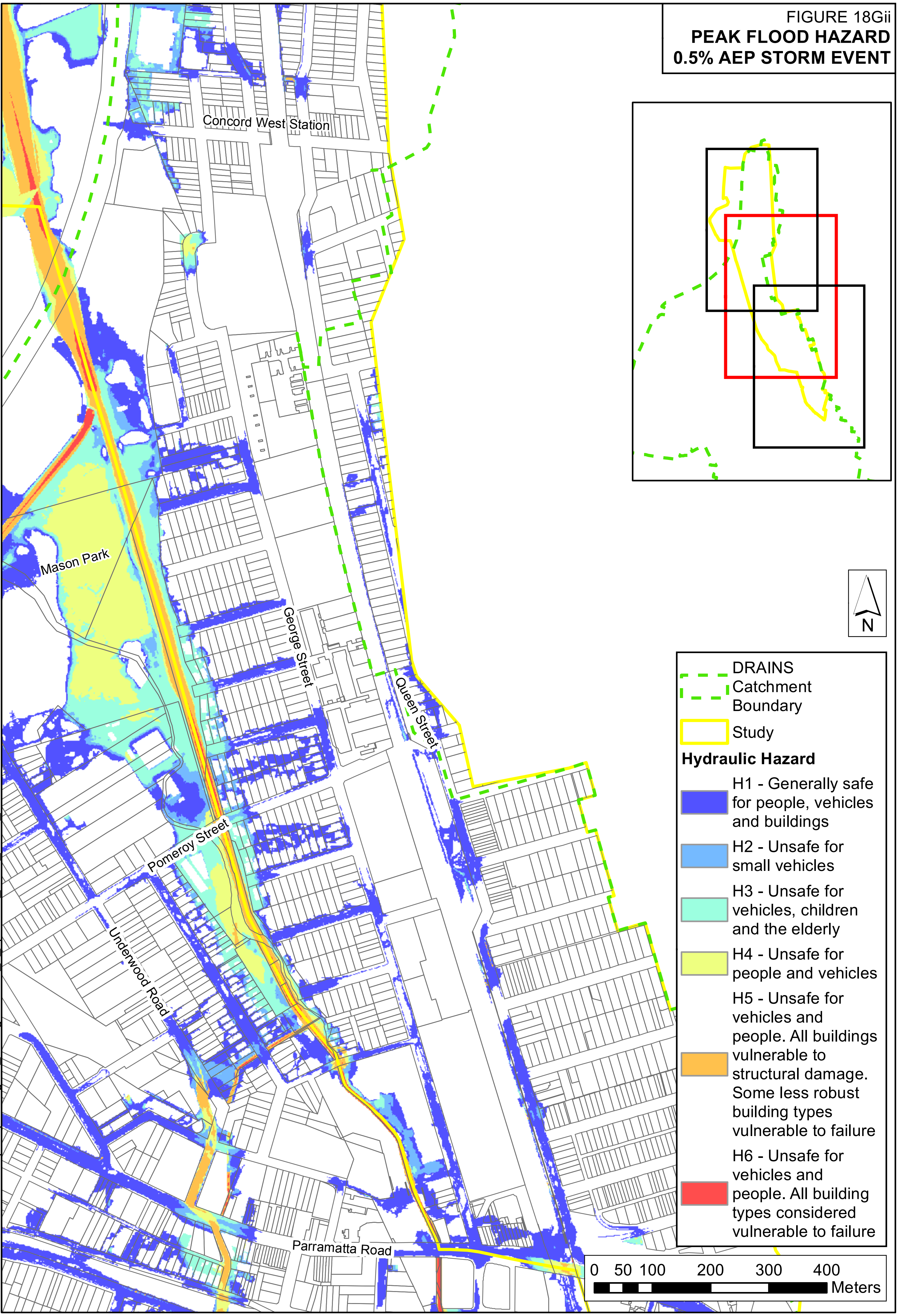


FIGURE 18Gi
PEAK FLOOD HAZARD
0.5% AEP STORM EVENT
Homebush Bay Drive
Queen Street
Concord West Station
Victoria Avenue
Victoria Avenue
George Street
Mason Park
Underwood Road
N
DRAINS Catchment Boundary
Study Area
Hydraulic Hazard
H1 - Generally safe for people, vehicles and buildings
H2 - Unsafe for small vehicles
H3 - Unsafe for vehicles, children and the elderly
H4 - Unsafe for people and vehicles
H5 - Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust building types vulnerable to failure
H6 - Unsafe for vehicles and people. All building types considered vulnerable to failure
0 50 100 200 300 400
Meters
J:\Jobs\120079\GIS\Arcmap\Report\Figure_18\Figure18Gi_0_5pctAEP_Peak_Flood_Hazard.mxd

FIGURE 18Gii
PEAK FLOOD HAZARD
0.5% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure_18\Figure18Gii_0_5pctAEP_Peak_Flood_Hazard.mxd

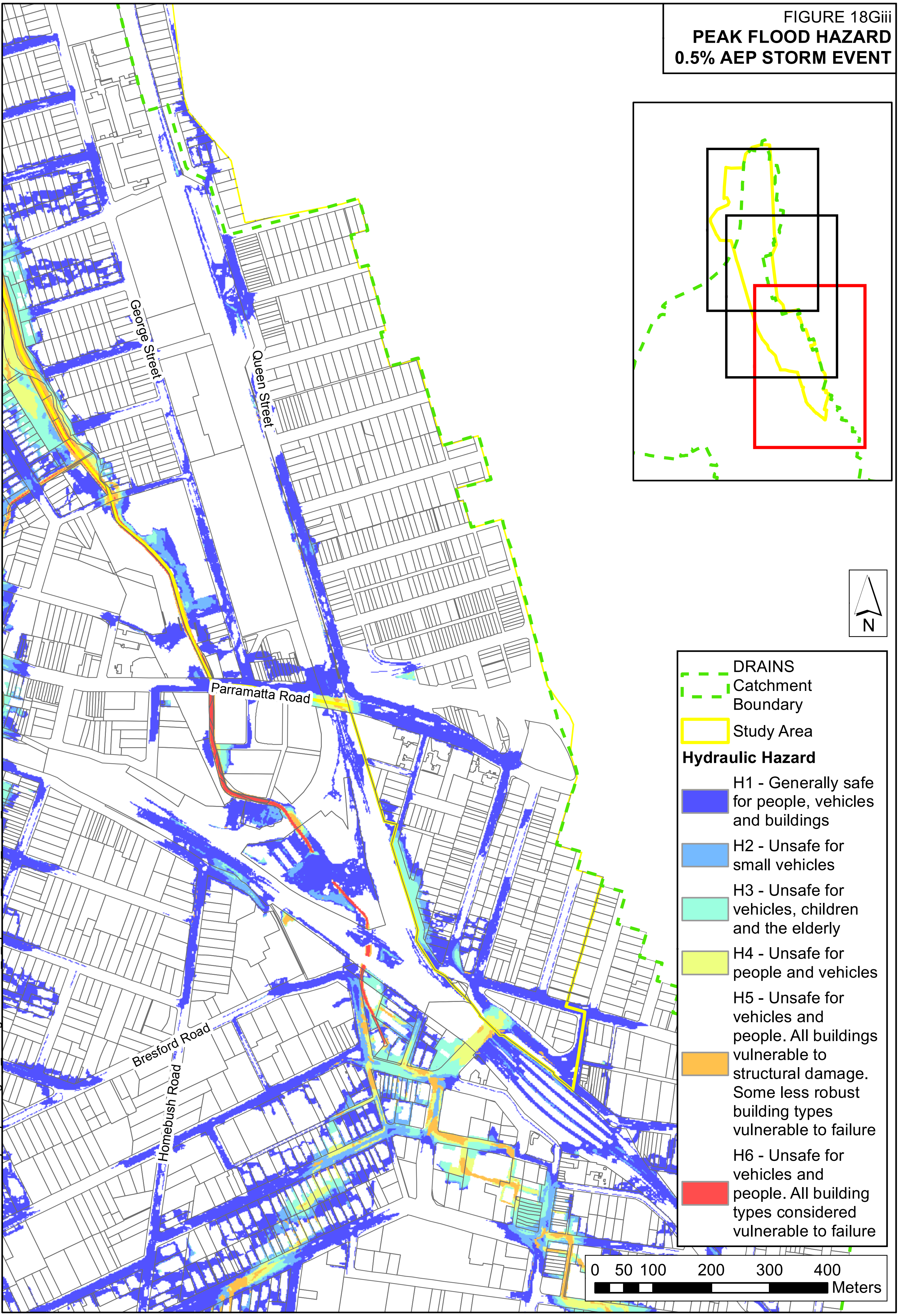


FIGURE 18Giii
PEAK FLOOD HAZARD
0.5% AEP STORM EVENT

J:\Jobs\120079\GIS\Arcmap\Report\Figure 18\Figure18Giii 0 5pctAEP Peak Flood Hazard.mxd

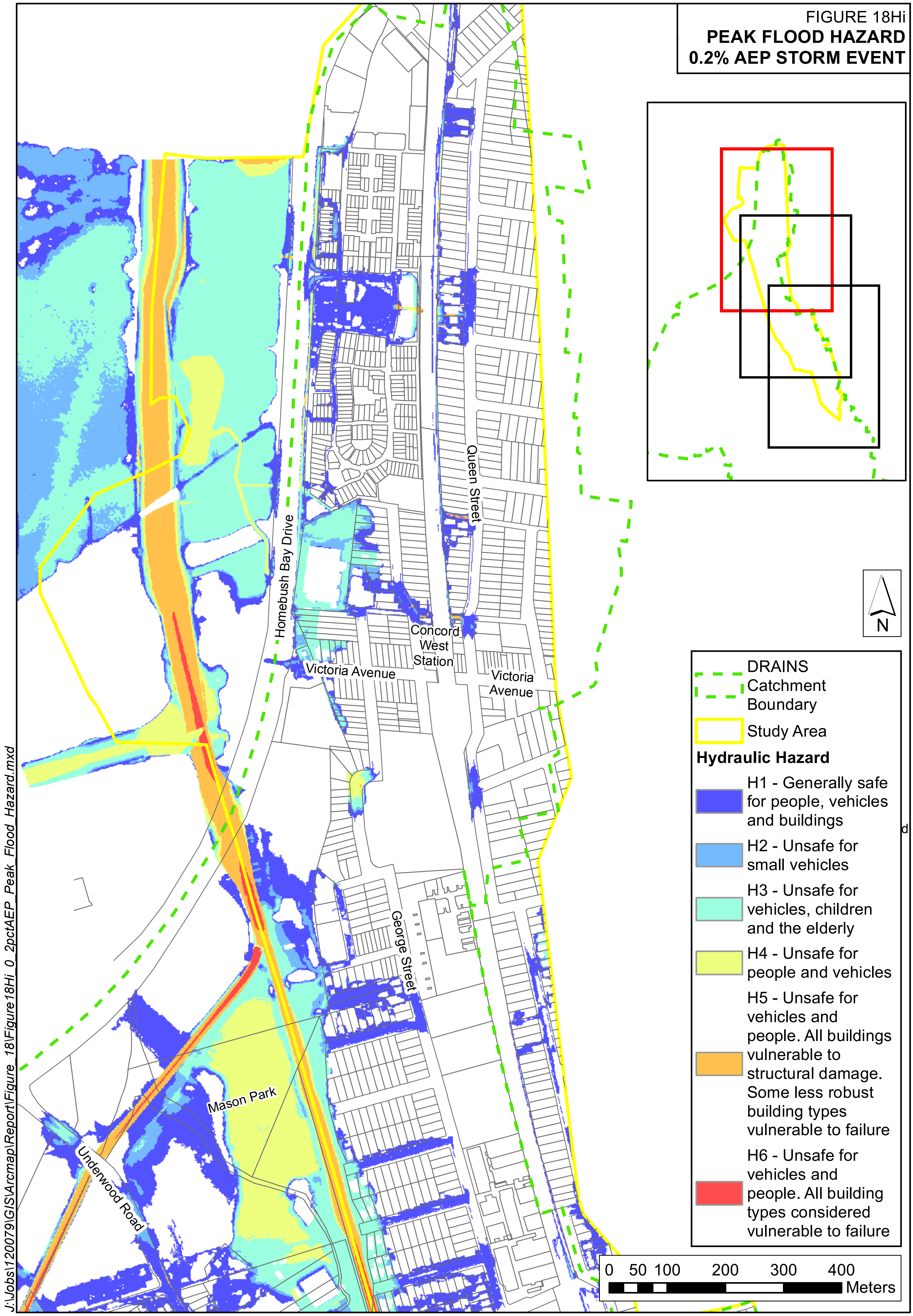


FIGURE 18Hi
PEAK FLOOD HAZARD
0.2% AEP STORM EVENT
Homebush Bay Drive
Queen Street
Concord West Station
Victoria Avenue
Victoria Avenue
George Street
Mason Park
Underwood Road
N
DRAINS Catchment Boundary
Study Area
Hydraulic Hazard
H1 - Generally safe for people, vehicles and buildings
H2 - Unsafe for small vehicles
H3 - Unsafe for vehicles, children and the elderly
H4 - Unsafe for people and vehicles
H5 - Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust building types vulnerable to failure
H6 - Unsafe for vehicles and people. All building types considered vulnerable to failure
0 50 100 200 300 400
Meters
J:\Jobs\120079\GIS\Arcmap\Report\Figure_18\Figure18Hi_0_2pctAEP_Peak_Flood_Hazard.mxd

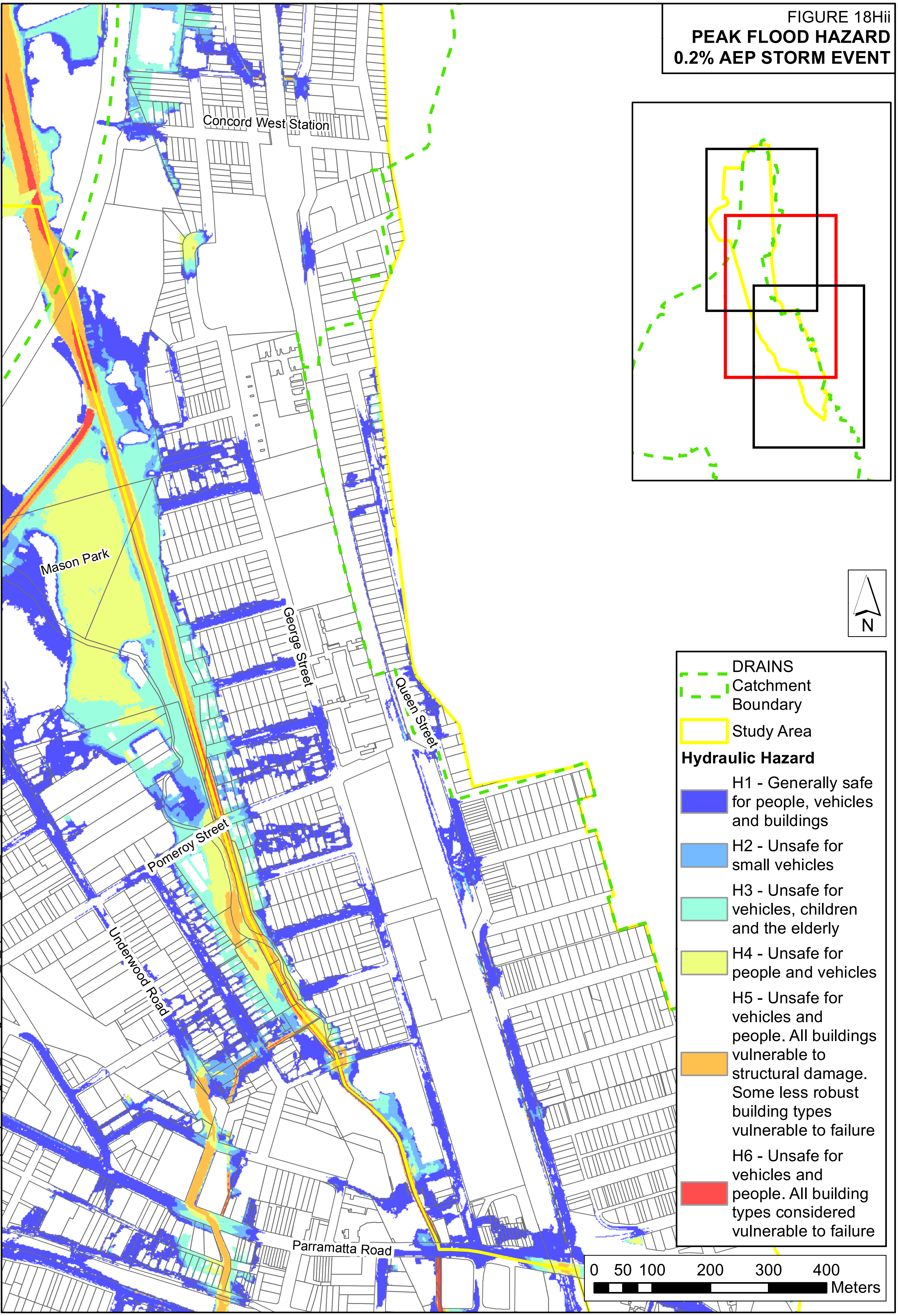
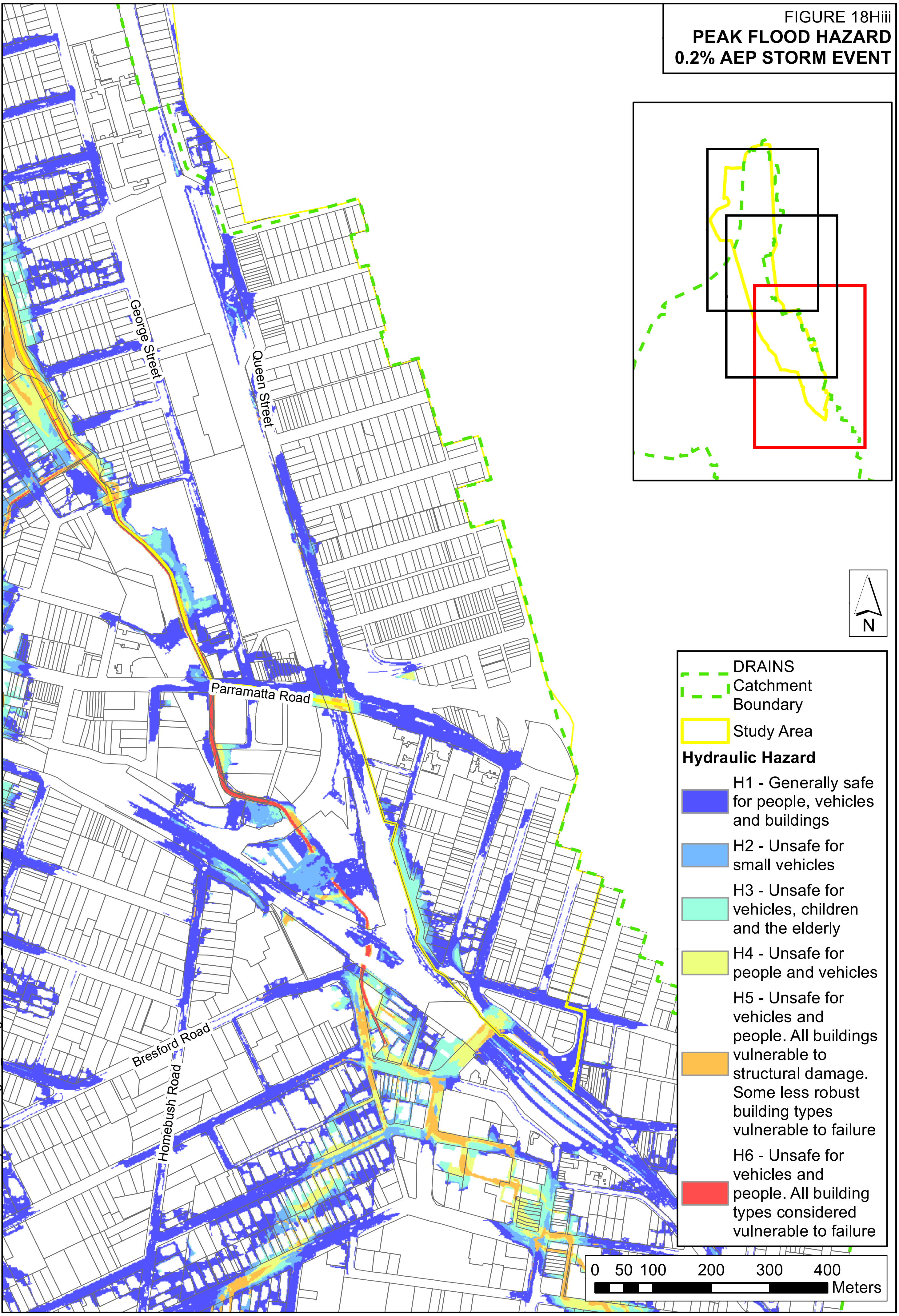


FIGURE 18Hii
PEAK FLOOD HAZARD
0.2% AEP STORM EVENT

J:\Jobs\120079\GIS\Arcmap\Report\Figure 18\Figure18Hii 0_2pctAEP Peak Flood Hazard.mxd

FIGURE 18Hiii

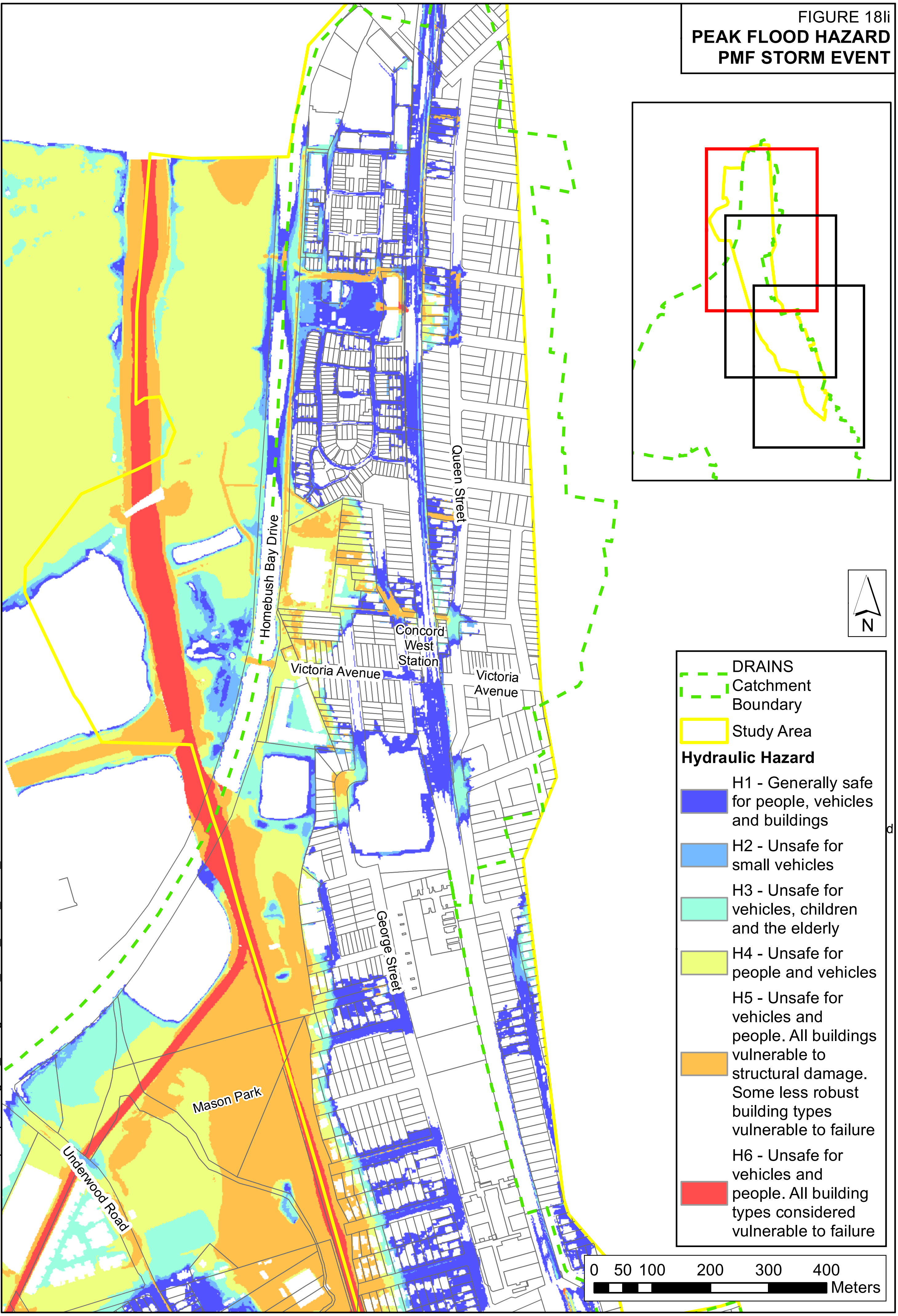
PEAK FLOOD HAZARD
0.2% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure 18\Figure18Hiii_0_2pctAEP_Peak_Flood_Hazard.mxd

FIGURE 18li

PEAK FLOOD HAZARD PMF STORM EVENT



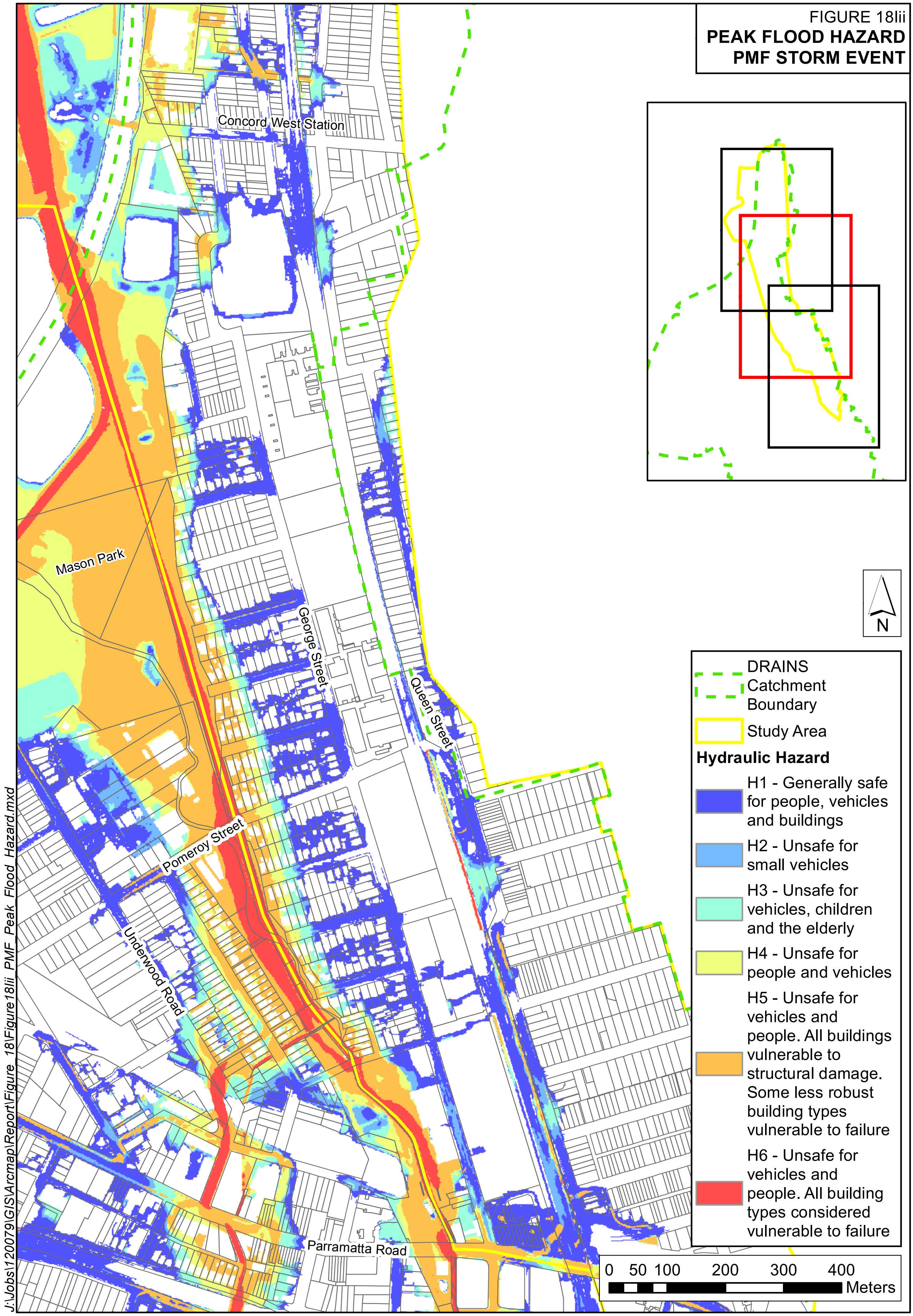


FIGURE 18lii
PEAK FLOOD HAZARD
PMF STORM EVENT
Concord West Station
Mason Park
George Street
Queen Street
Pomeroy Street
Underwood Road
Parramatta Road
N
DRAINS Catchment Boundary
Study Area
Hydraulic Hazard
H1 - Generally safe for people, vehicles and buildings
H2 - Unsafe for small vehicles
H3 - Unsafe for vehicles, children and the elderly
H4 - Unsafe for people and vehicles
H5 - Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust building types vulnerable to failure
H6 - Unsafe for vehicles and people. All building types considered vulnerable to failure
0 50 100 200 300 400
Meters
J:\Jobs\120079\GIS\Arcmap\Report\Figure 18\Figure18lii_PMF_Peak_Flood_Hazard.mxd

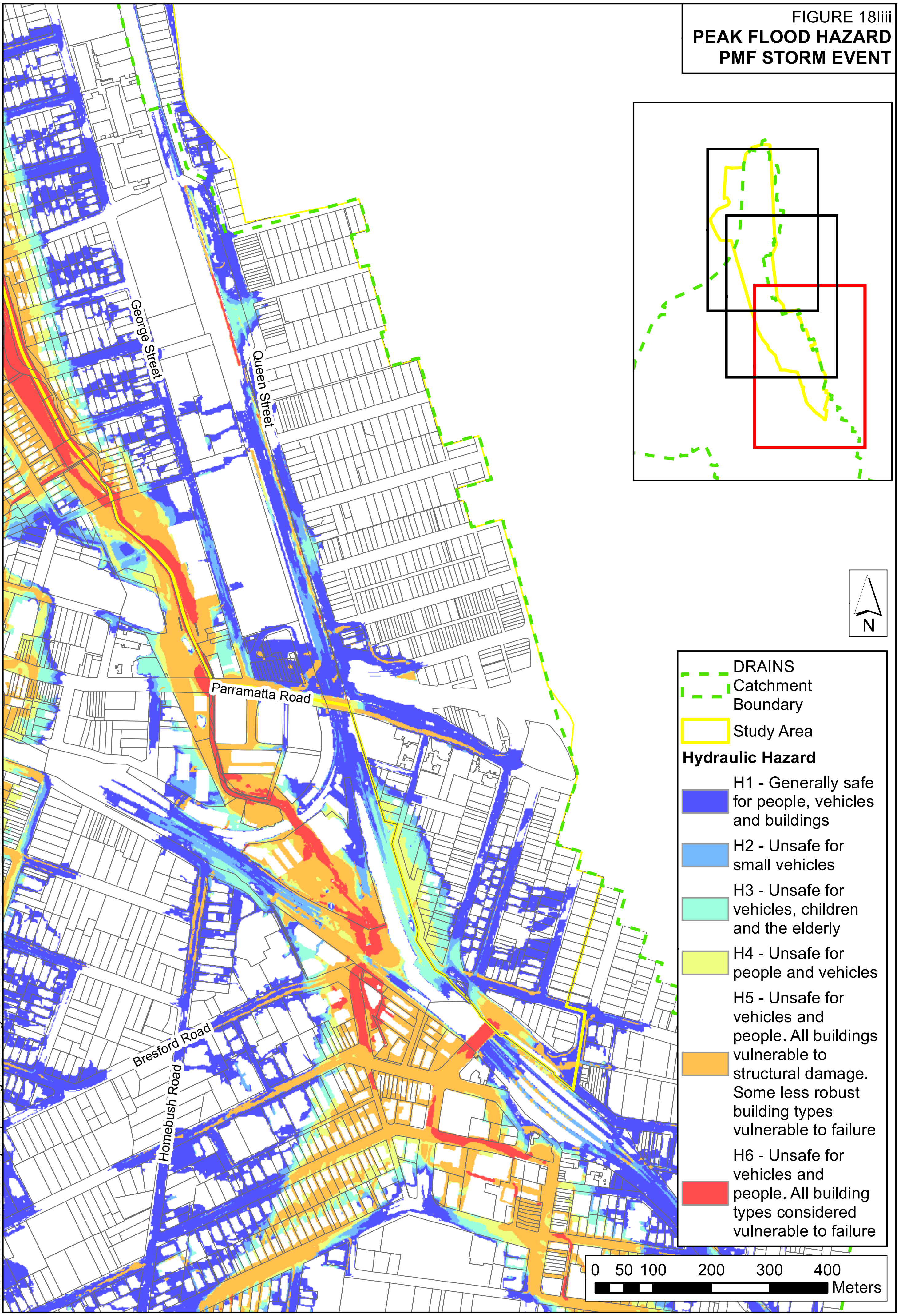
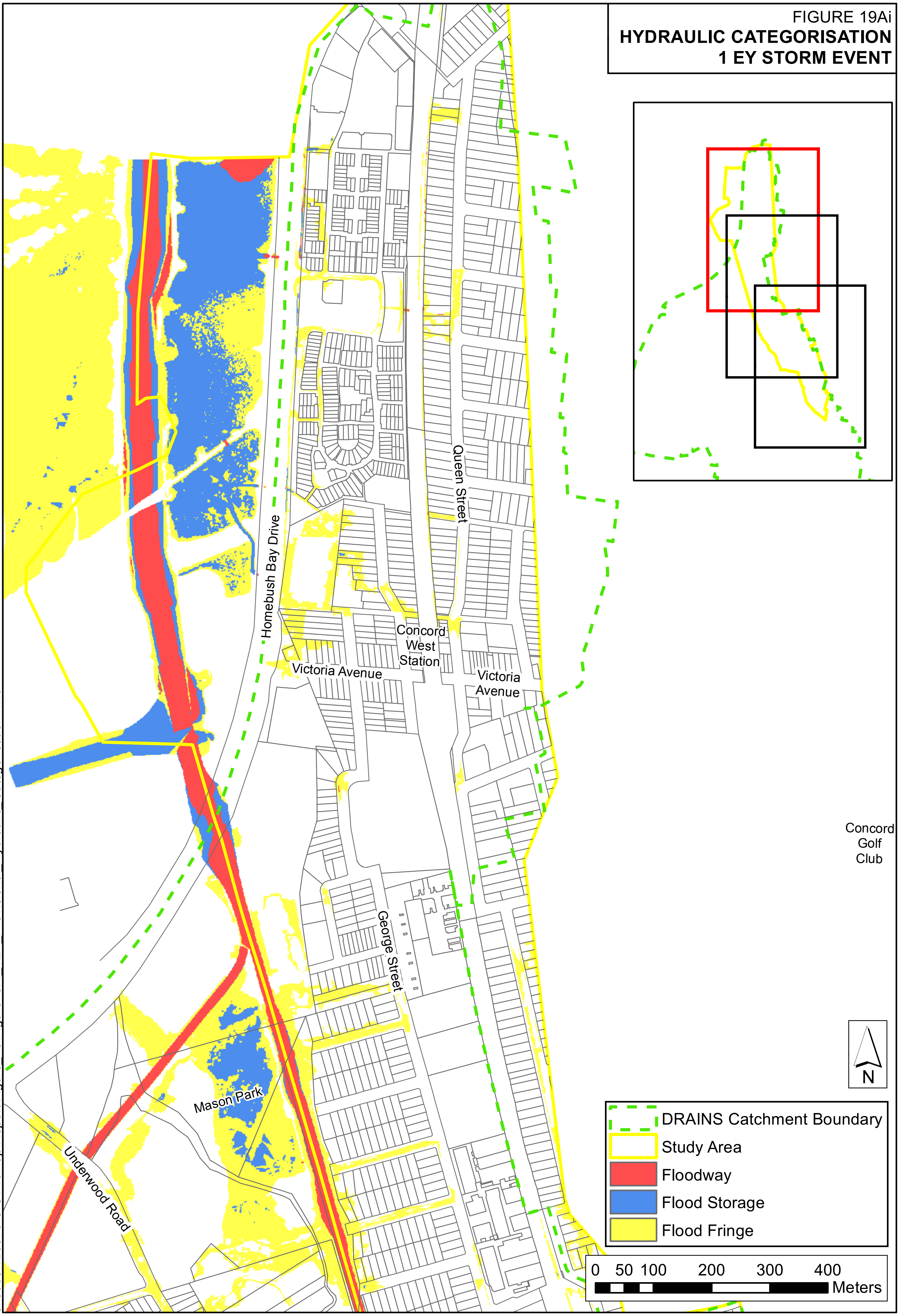


FIGURE 18liii
PEAK FLOOD HAZARD
PMF STORM EVENT
George Street
Queen Street
Parramatta Road
Bresford Road
Homebush Road
N
DRAINS Catchment Boundary
Study Area
Hydraulic Hazard
H1 - Generally safe for people, vehicles and buildings
H2 - Unsafe for small vehicles
H3 - Unsafe for vehicles, children and the elderly
H4 - Unsafe for people and vehicles
H5 - Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust building types vulnerable to failure
H6 - Unsafe for vehicles and people. All building types considered vulnerable to failure
0 50 100 200 300 400
Meters
J:\Jobs\120079\GIS\Arcmap\Report\Figure 18\Figure18liii PMF Peak Flood Hazard.mxd

FIGURE 19Ai
HYDRAULIC CATEGORISATION
1 EY STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure_19\Figure19Ai_1EY_Provisional_Hydraulic_Categorisation.mxd

FIGURE 19Aii
HYDRAULIC CATEGORISATION
1 EY STORM EVENT

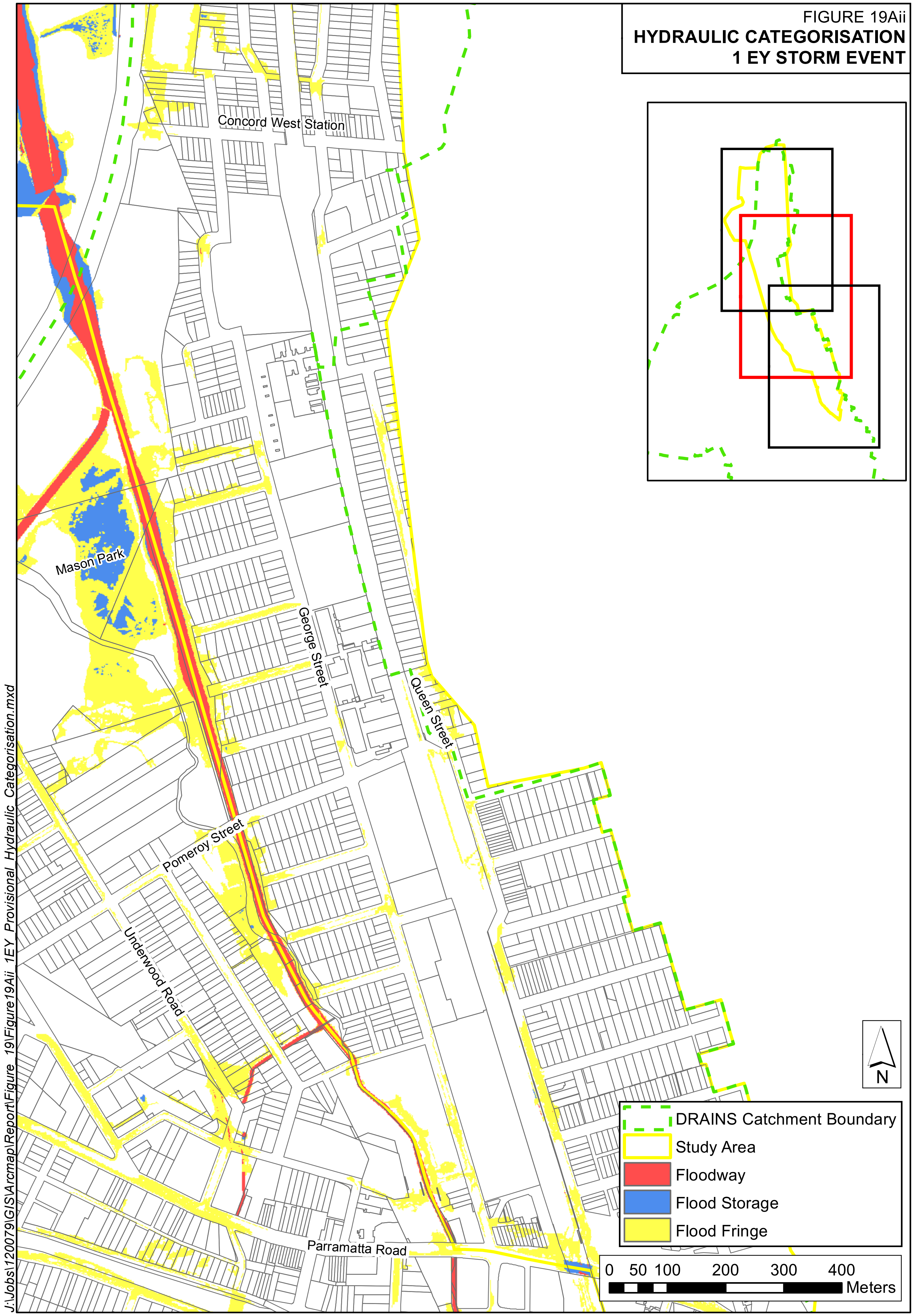
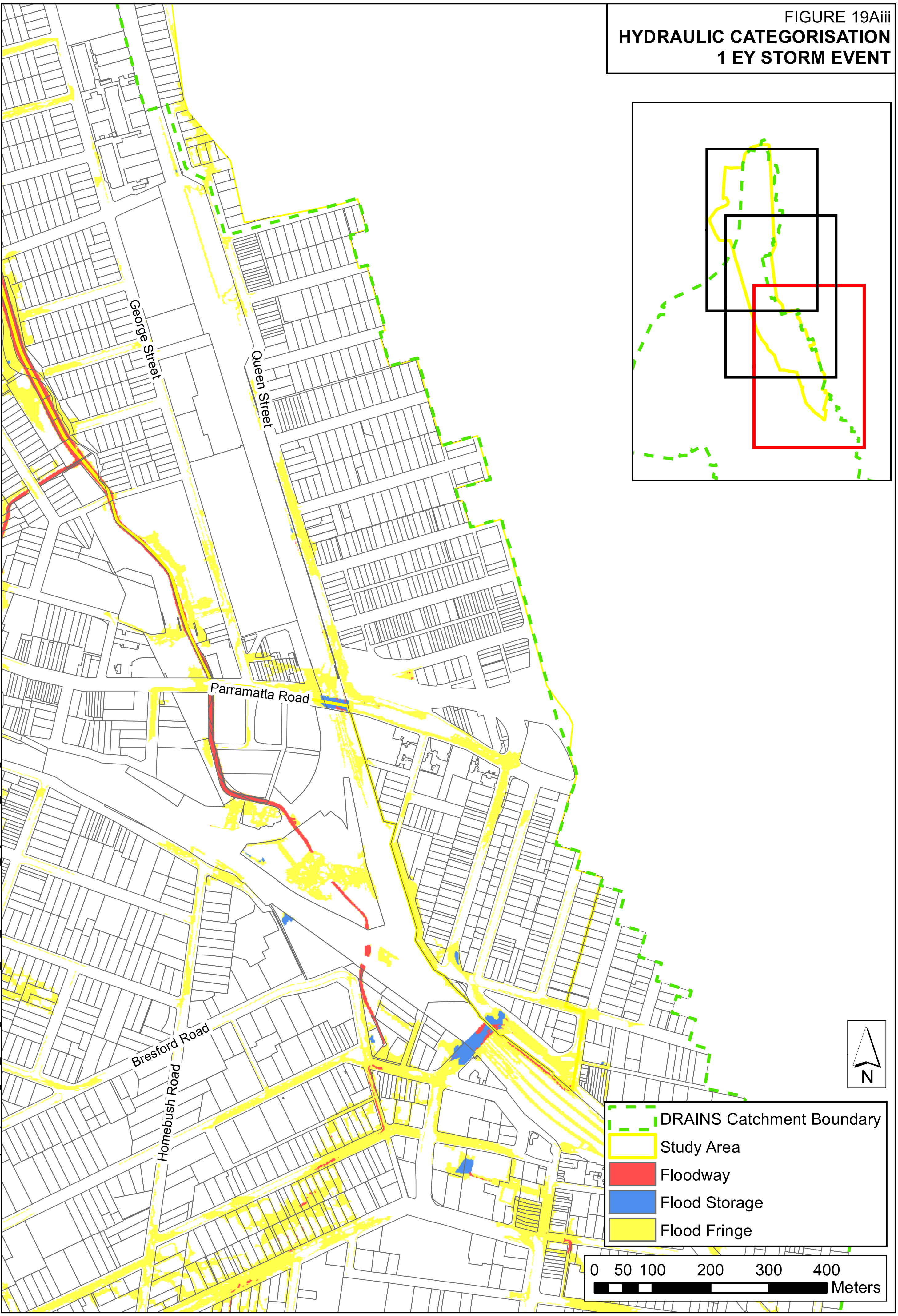
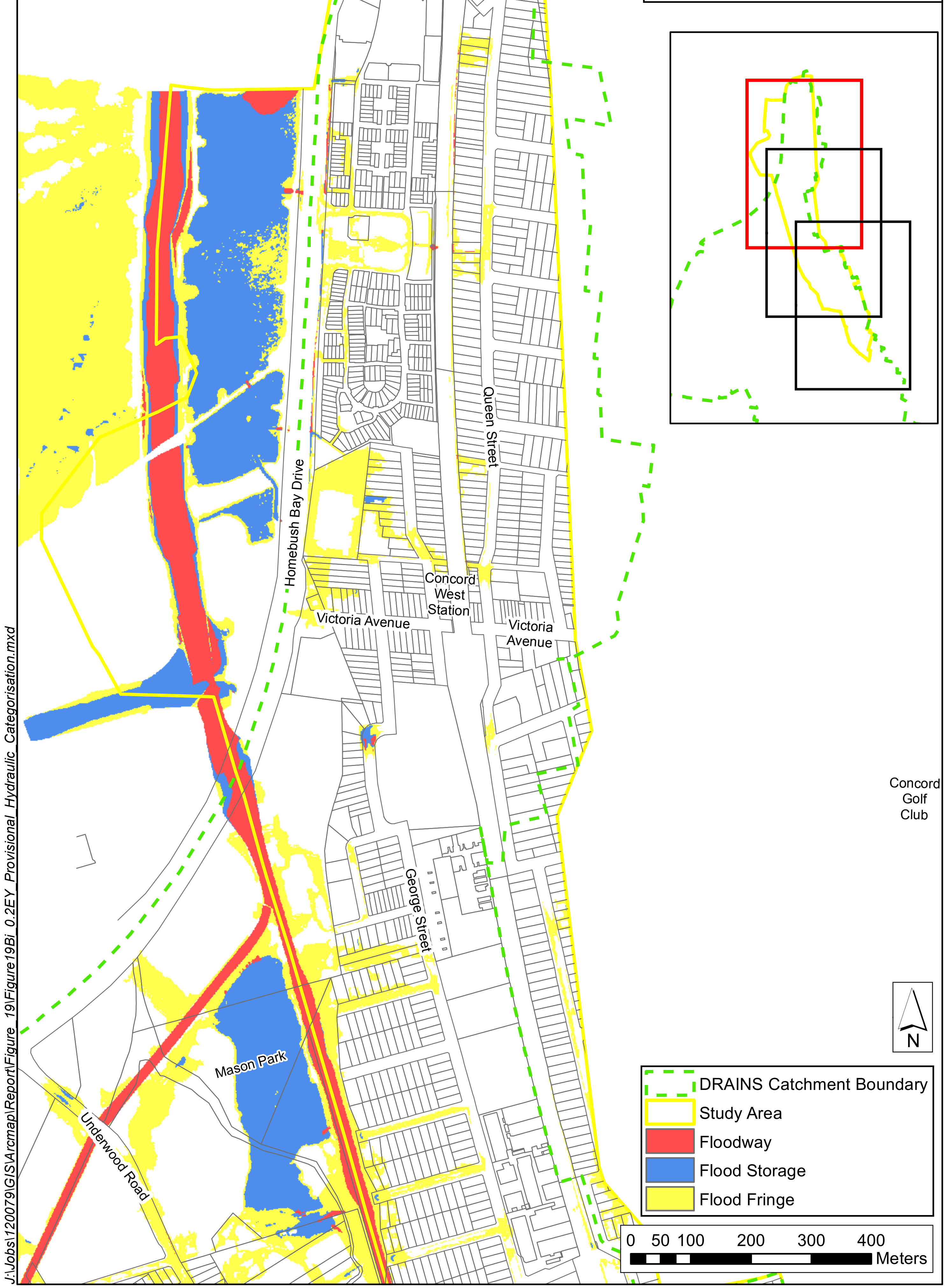


FIGURE 19Aiii
HYDRAULIC CATEGORISATION
1 EY STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure 19\Figure19Aiii 1EY Provisional Hydraulic Categorisation.mxd

FIGURE 19Bi
HYDRAULIC CATEGORISATION
0.2 EY STORM EVENT



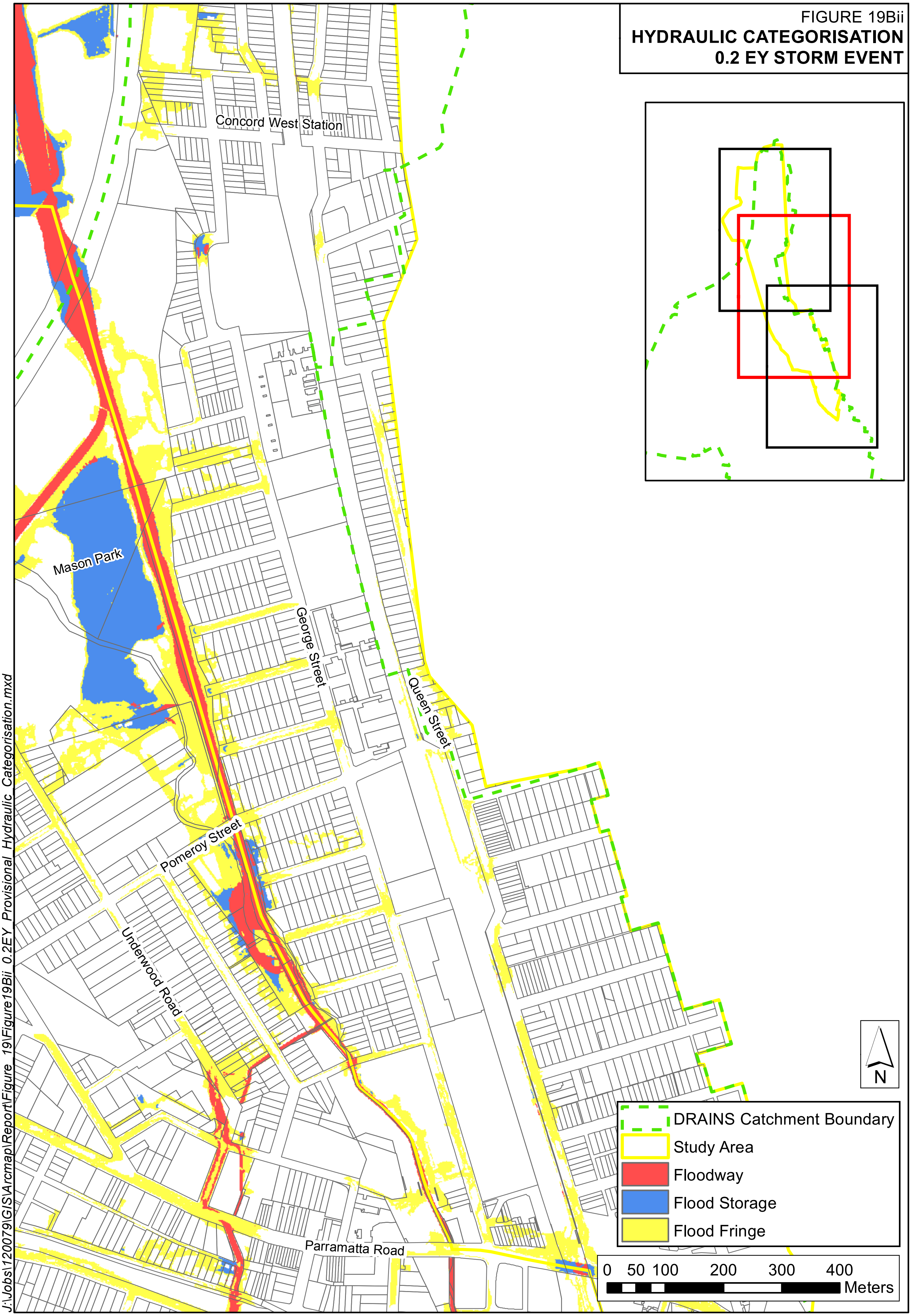
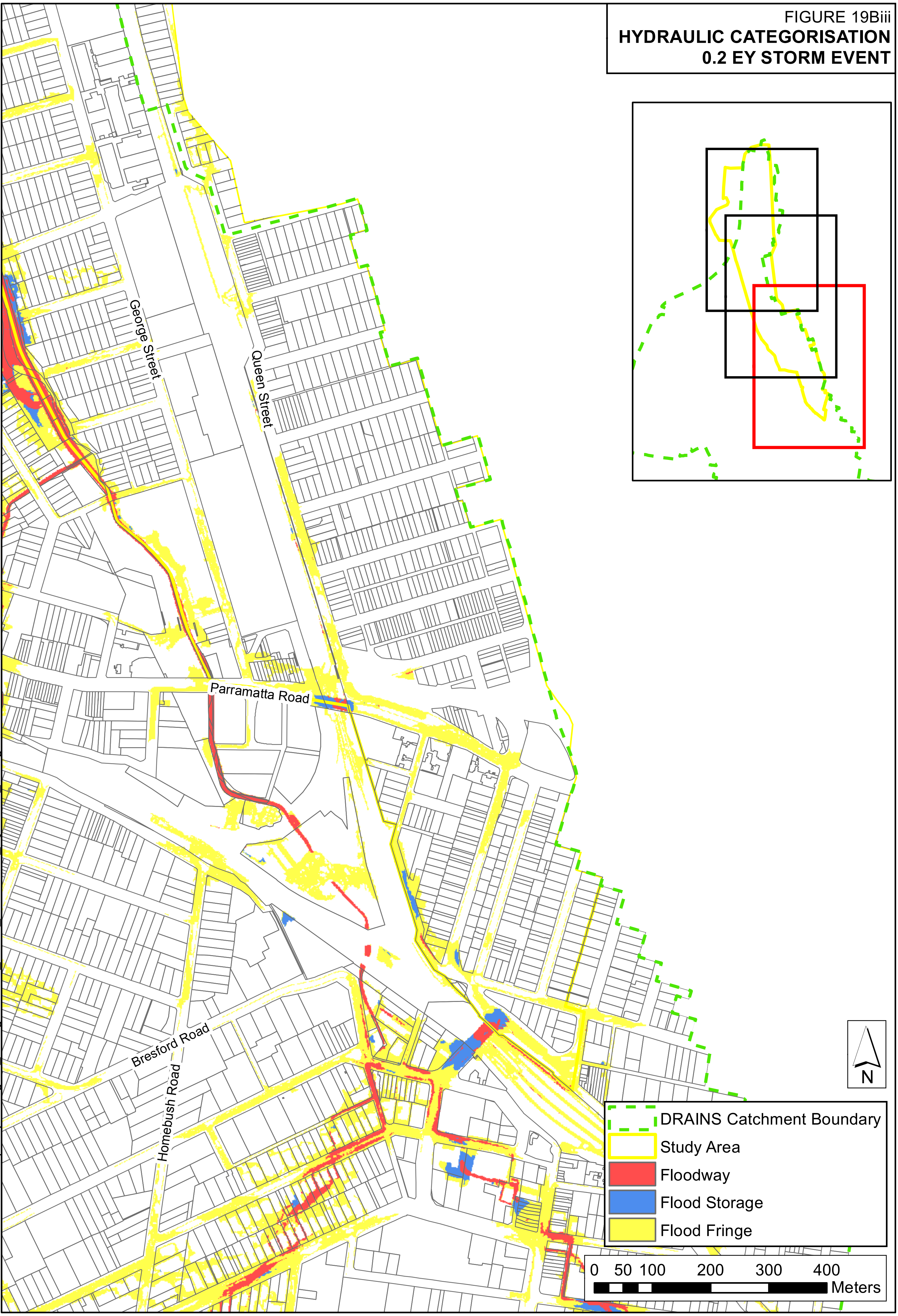


FIGURE 19Bii
HYDRAULIC CATEGORISATION
0.2 EY STORM EVENT
Concord West Station
Mason Park
George Street
Queen Street
Pomeroy Street
Underwood Road
Parramatta Road
N
DRAINS Catchment Boundary
Study Area
Floodway
Flood Storage
Flood Fringe
0 50 100 200 300 400
Meters
J:\Jobs\120079\GIS\Arcmap\Report\Figure 19\Figure19Bii 0.2EY Provisional Hydraulic Categorisation.mxd

FIGURE 19Biii

HYDRAULIC CATEGORISATION

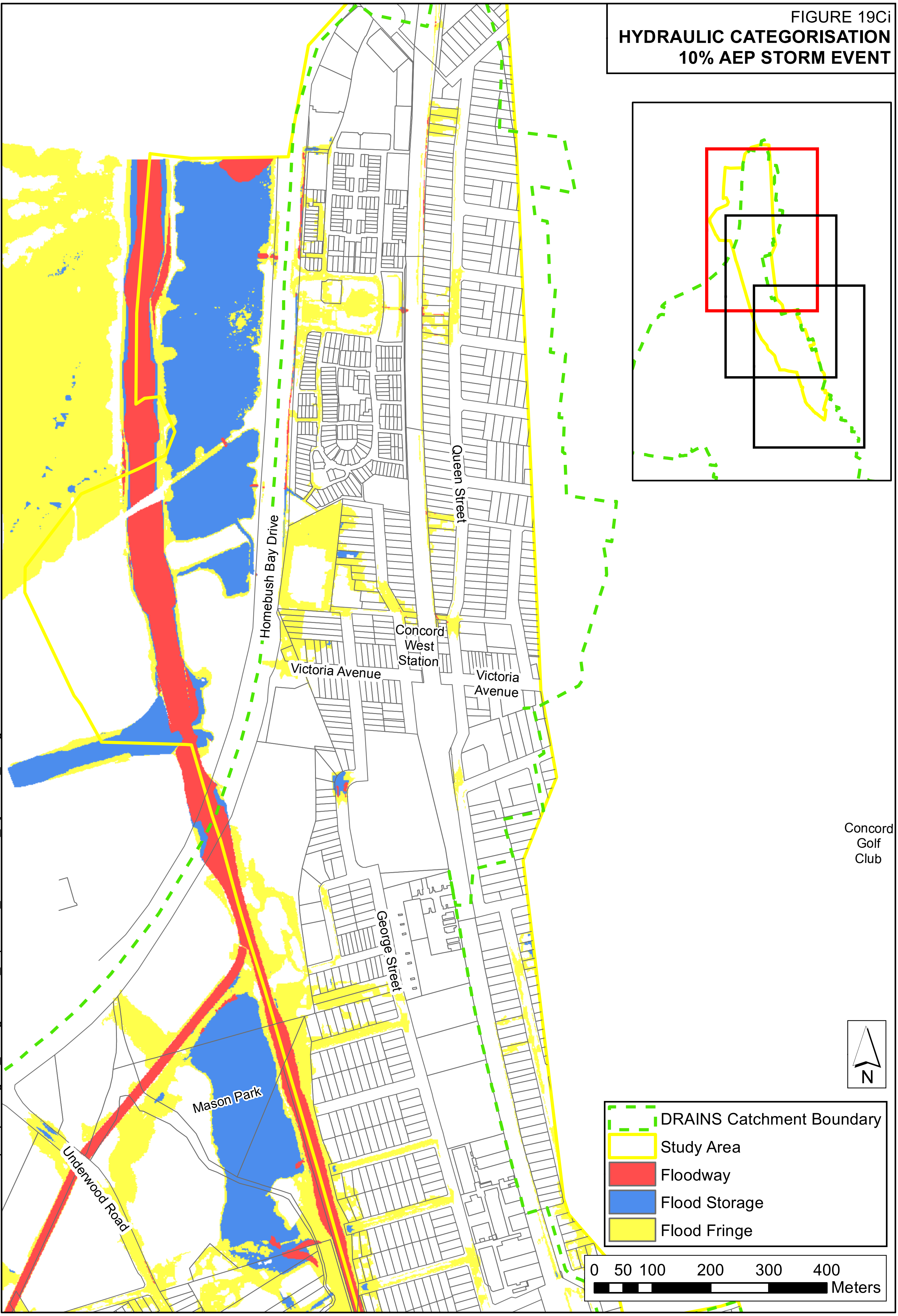
0.2 EY STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure 19\Figure19Biii 0.2EY Provisional Hydraulic Categorisation.mxd

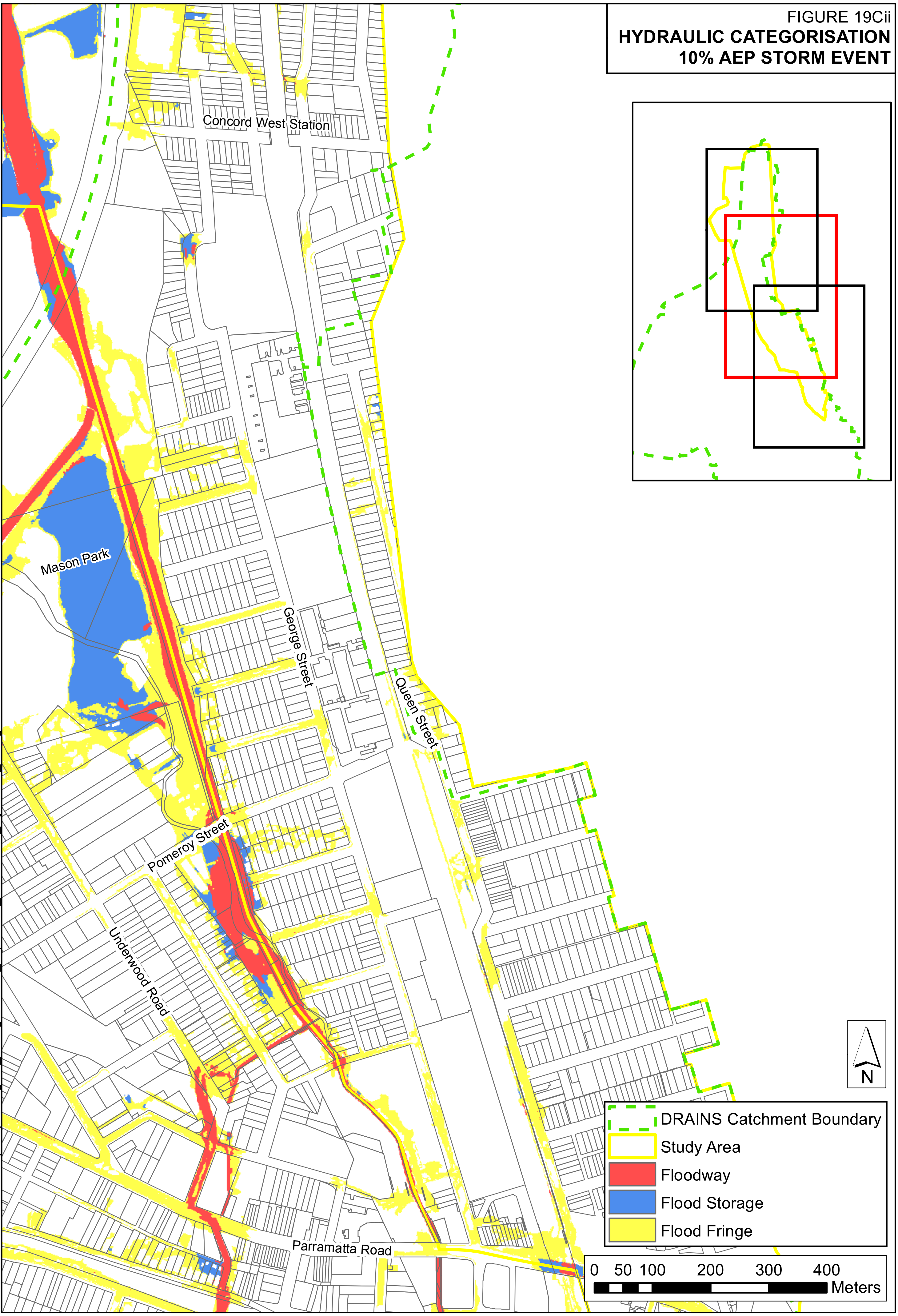
FIGURE 19Ci

HYDRAULIC CATEGORISATION
10% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure_19\Figure19Ci_10pctAEP_Provisional_Hydraulic_Categorisation.mxd

FIGURE 19Cii
HYDRAULIC CATEGORISATION
10% AEP STORM EVENT



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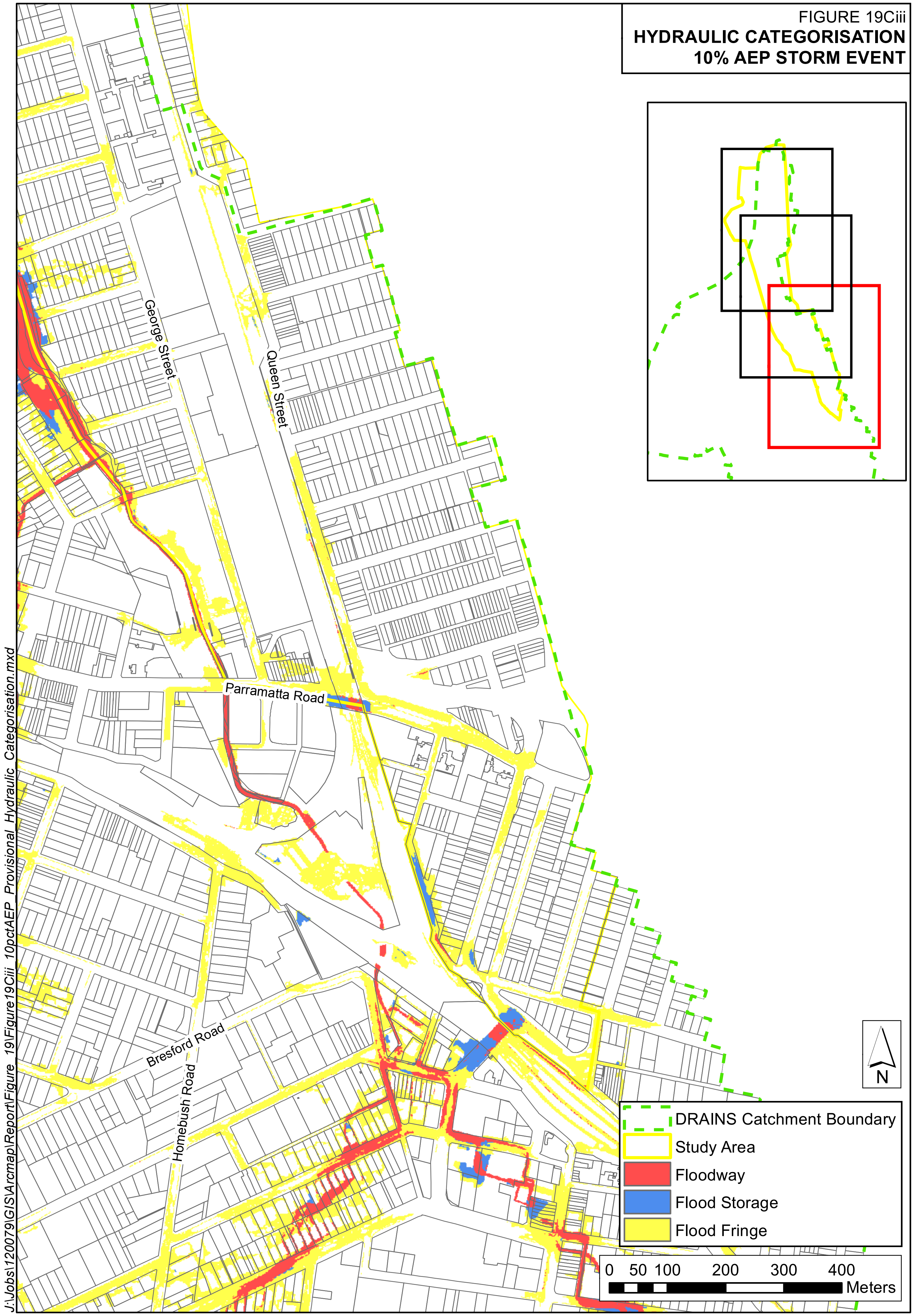


FIGURE 19Ciii
HYDRAULIC CATEGORISATION
10% AEP STORM EVENT
George Street
Queen Street
Parramatta Road
Bresford Road
Homebush Road
N
DRAINS Catchment Boundary
Study Area
Floodway
Flood Storage
Flood Fringe
0 50 100 200 300 400
Meters
J:\Jobs\120079\GIS\Arcmap\Report\Figure 19\Figure19Ciii 10pctAEP Provisional Hydraulic Categorisation.mxd

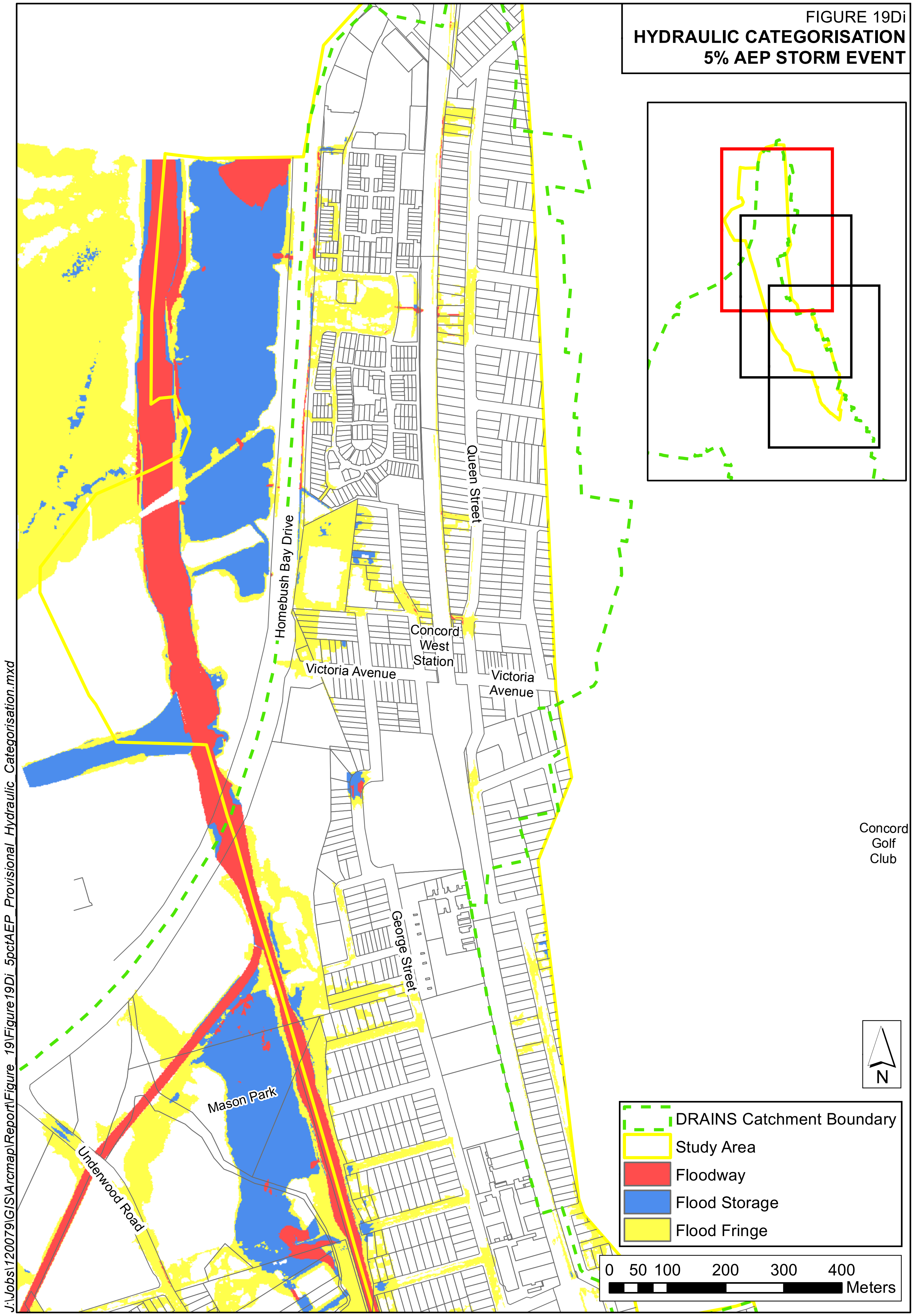


FIGURE 19Di
HYDRAULIC CATEGORISATION
5% AEP STORM EVENT
Homebush Bay Drive
Queen Street
Concord West Station
Victoria Avenue
Victoria Avenue
George Street
Mason Park
Underwood Road
Concord Golf Club
N
DRAINS Catchment Boundary
Study Area
Floodway
Flood Storage
Flood Fringe
0 50 100 200 300 400
Meters
J:\Jobs\120079\GIS\Arcmap\Report\Figure_19\Figure19Di_5pctAEP_Provisional_Hydraulic_Categorisation.mxd

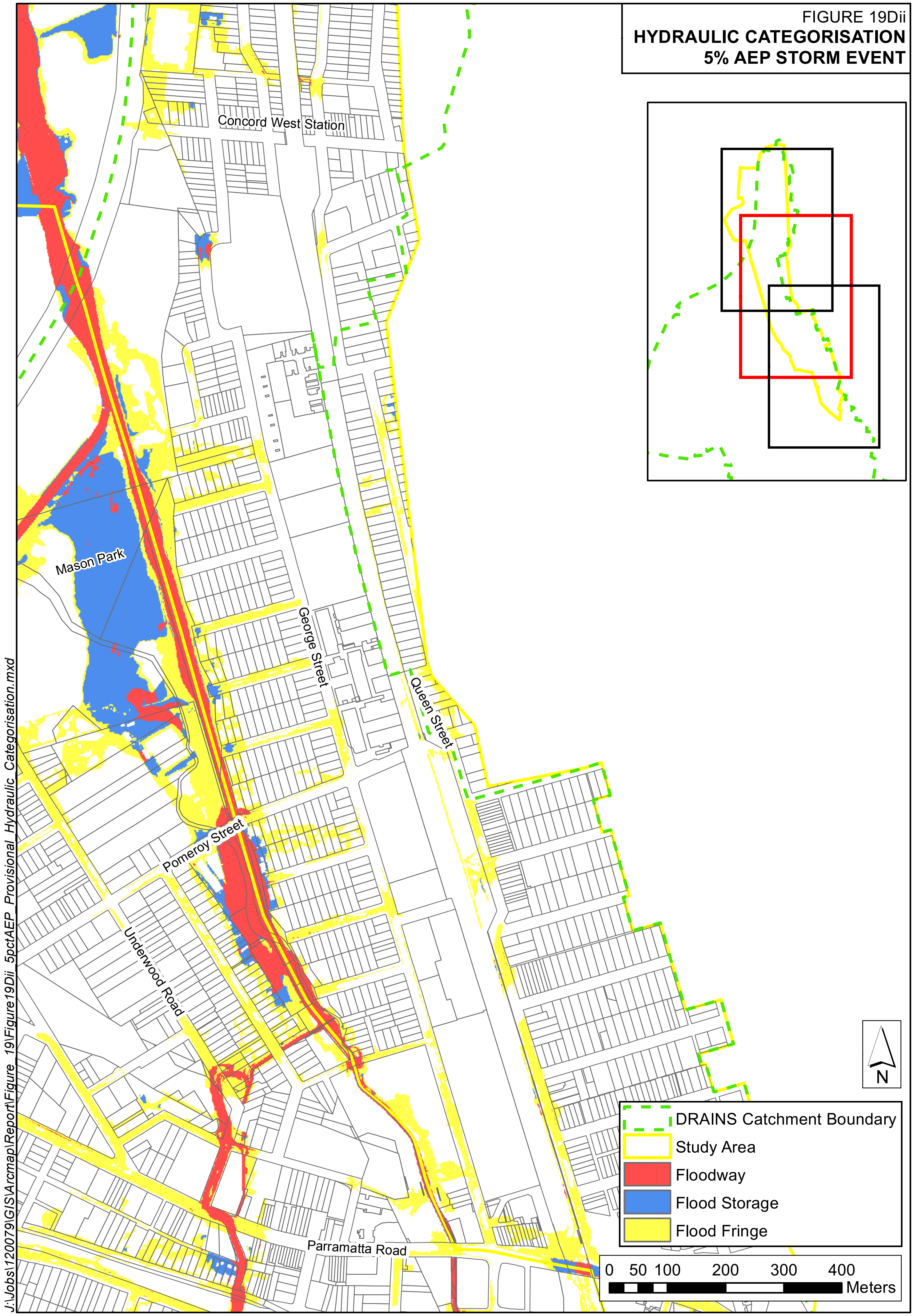
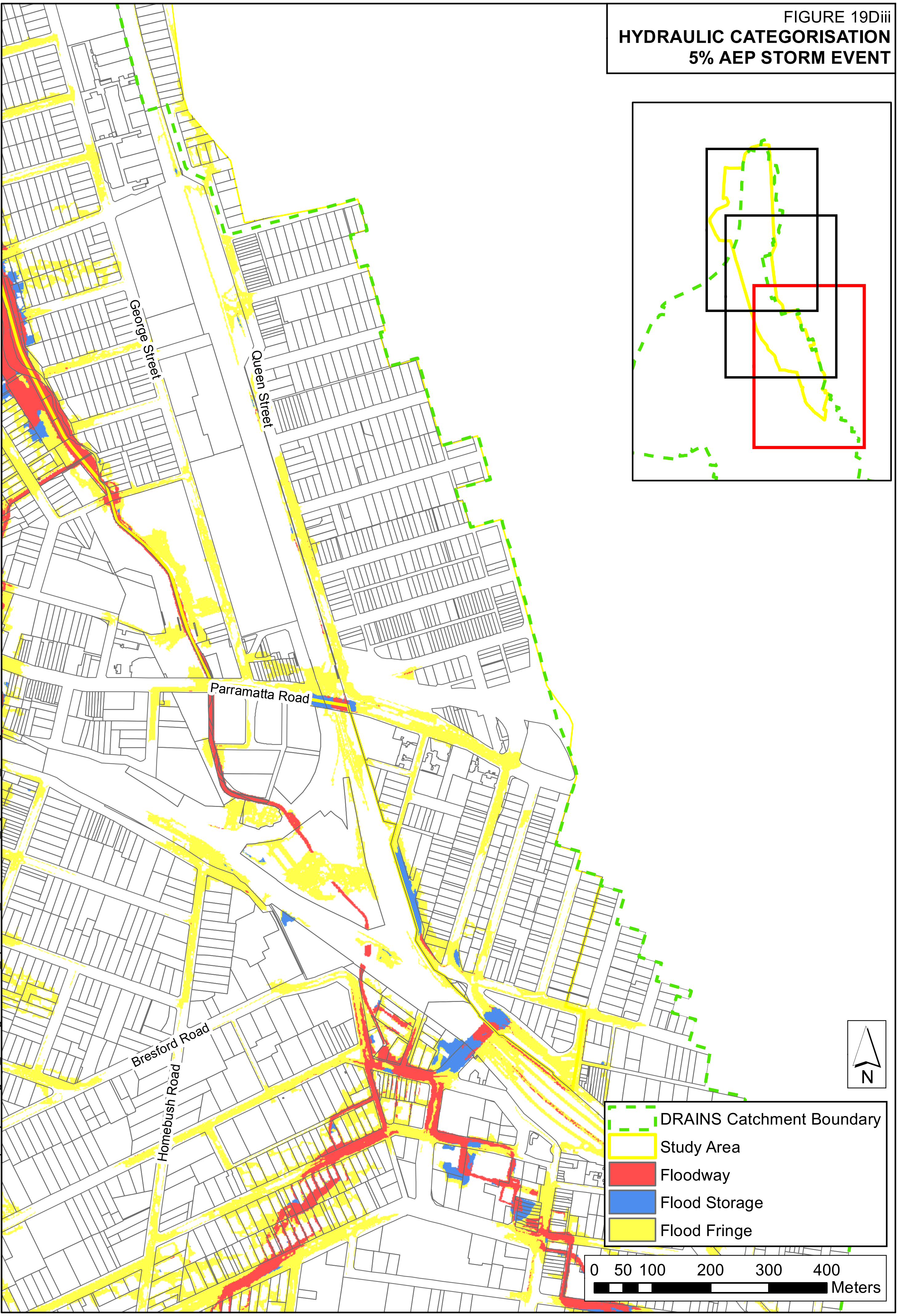


FIGURE 19Dii
HYDRAULIC CATEGORISATION
5% AEP STORM EVENT
Concord West Station
Mason Park
George Street
Queen Street
Pomeroy Street
Underwood Road
Parramatta Road
DRAINS Catchment Boundary
Study Area
Floodway
Flood Storage
Flood Fringe
0 50 100 200 300 400
Meters
N
J:\Jobs\120079\GIS\Arcmap\Report\Figure 19\Figure19Dii 5pctAEP Provisional Hydraulic Categorisation.mxd

FIGURE 19Diii

HYDRAULIC CATEGORISATION
5% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure 19\Figure19Diii 5pctAEP Provisional Hydraulic Categorisation.mxd

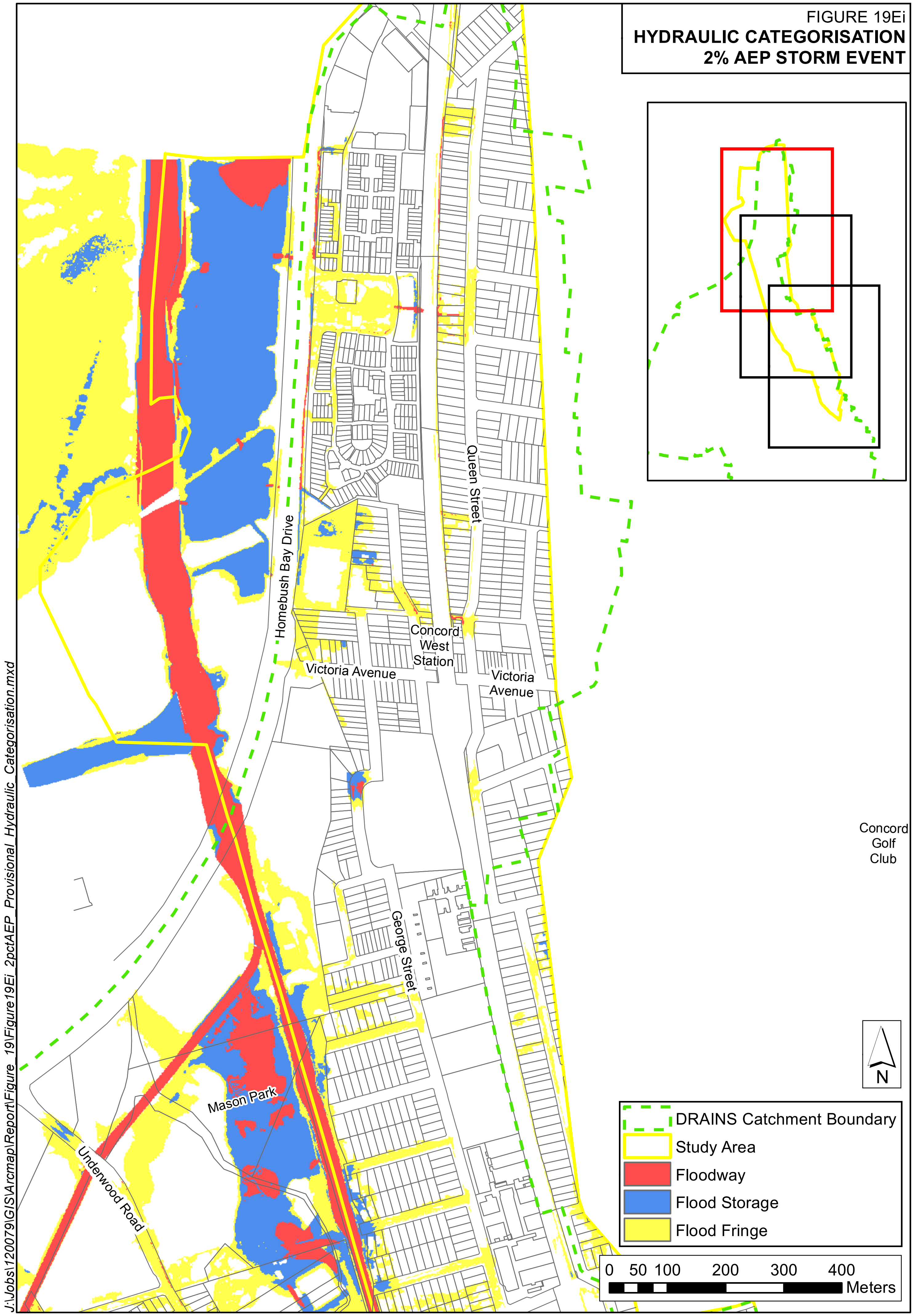
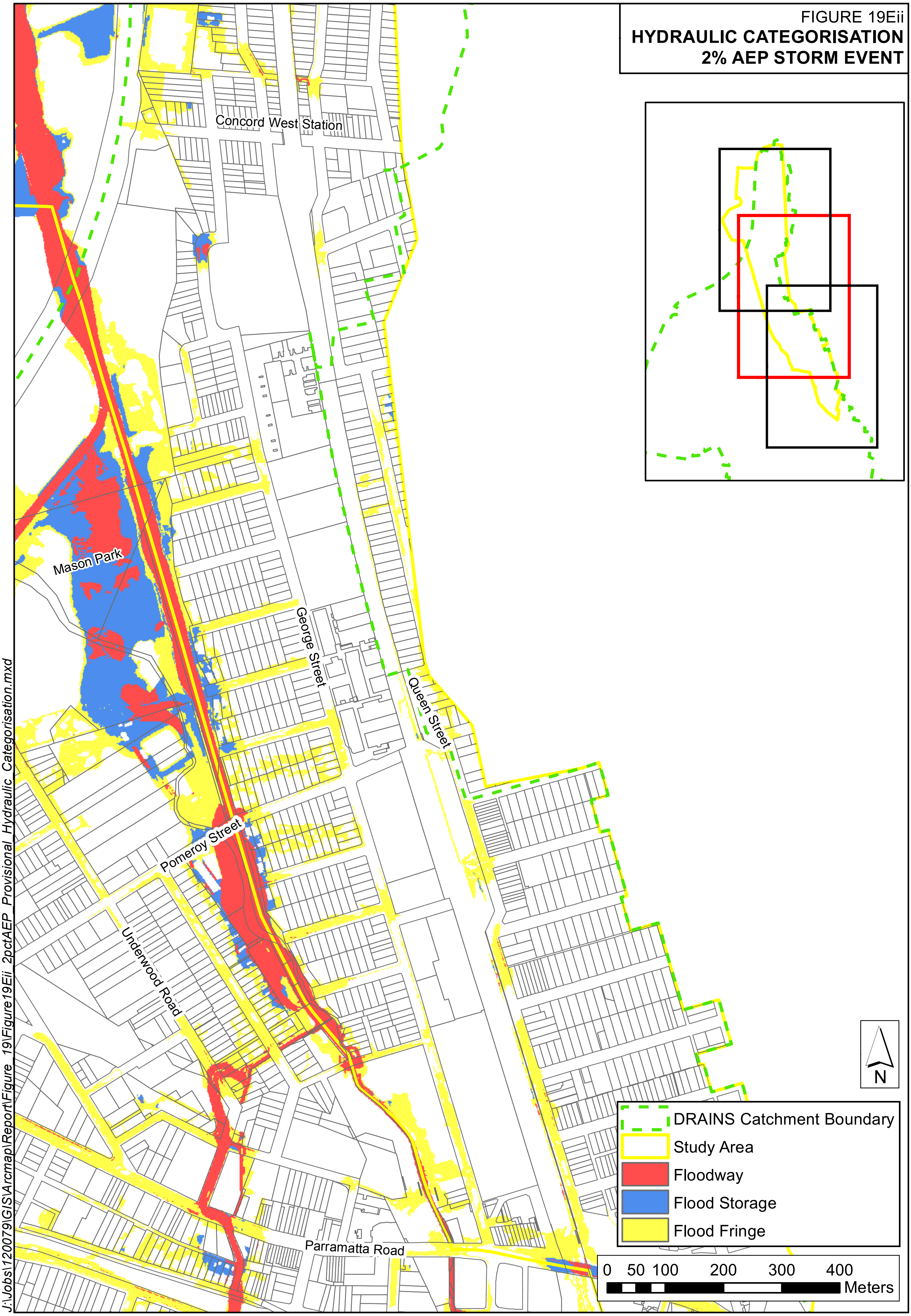


FIGURE 19Ei
HYDRAULIC CATEGORISATION
2% AEP STORM EVENT
Homebush Bay Drive
Queen Street
Concord
West
Station
Victoria Avenue
Victoria
Avenue
George Street
Mason Park
Underwood Road
Concord
Golf
Club
N
DRAINS Catchment Boundary
Study Area
Floodway
Flood Storage
Flood Fringe
0 50 100 200 300 400
Meters
J:\Jobs\120079\GIS\Arcmap\Report\Figure_19\Figure19Ei_2pctAEP_Provisional_Hydraulic_Categorisation.mxd

FIGURE 19Eii

HYDRAULIC CATEGORISATION
2% AEP STORM EVENT



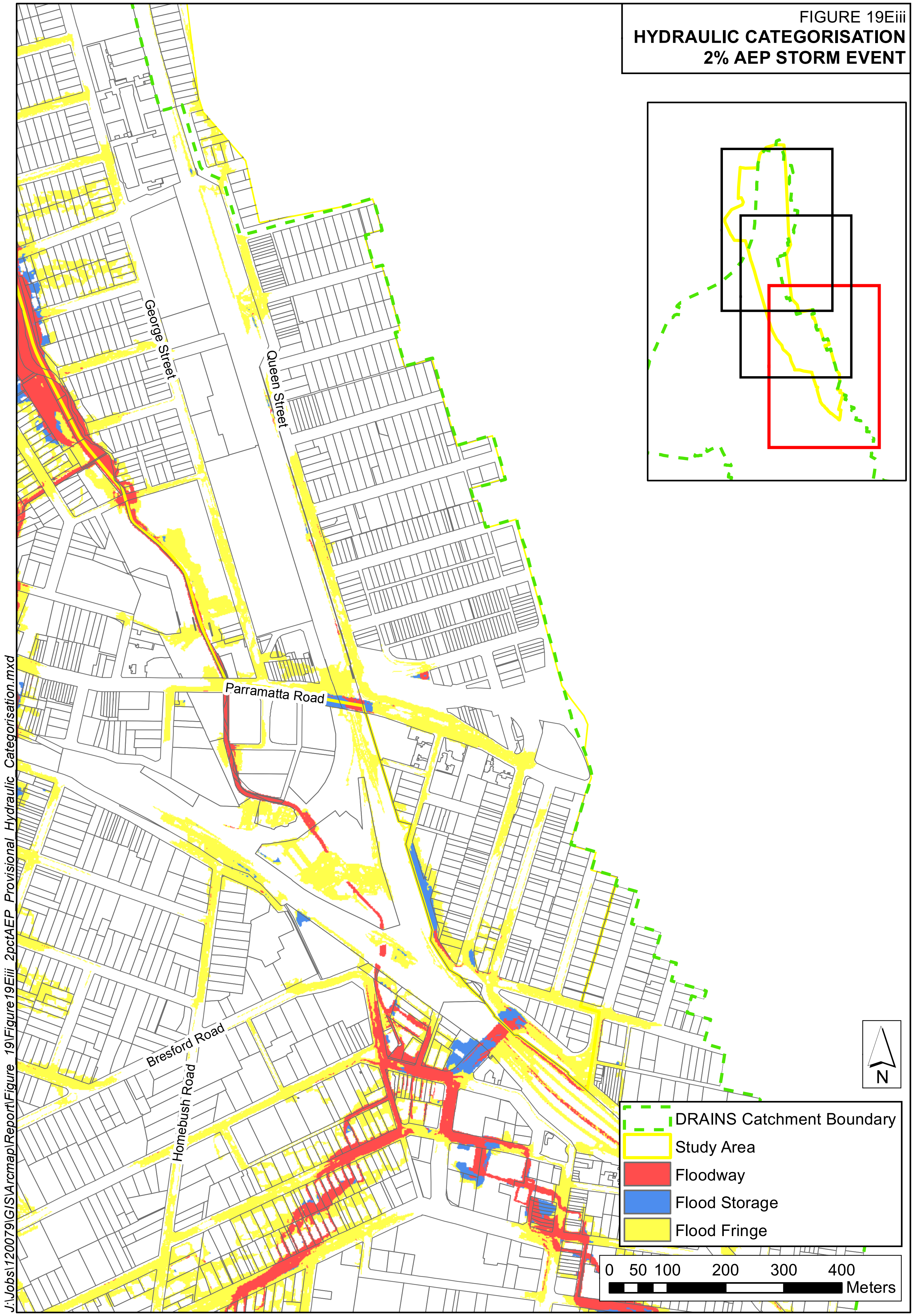


FIGURE 19Eiii
HYDRAULIC CATEGORISATION
2% AEP STORM EVENT
George Street
Queen Street
Parramatta Road
Bresford Road
Homebush Road
N
DRAINS Catchment Boundary
Study Area
Floodway
Flood Storage
Flood Fringe
0 50 100 200 300 400
Meters
J:\Jobs\120079\GIS\Arcmap\Report\Figure 19\Figure19Eiii 2pctAEP Provisional Hydraulic Categorisation.mxd

FIGURE 19Fi
HYDRAULIC CATEGORISATION
1% AEP STORM EVENT

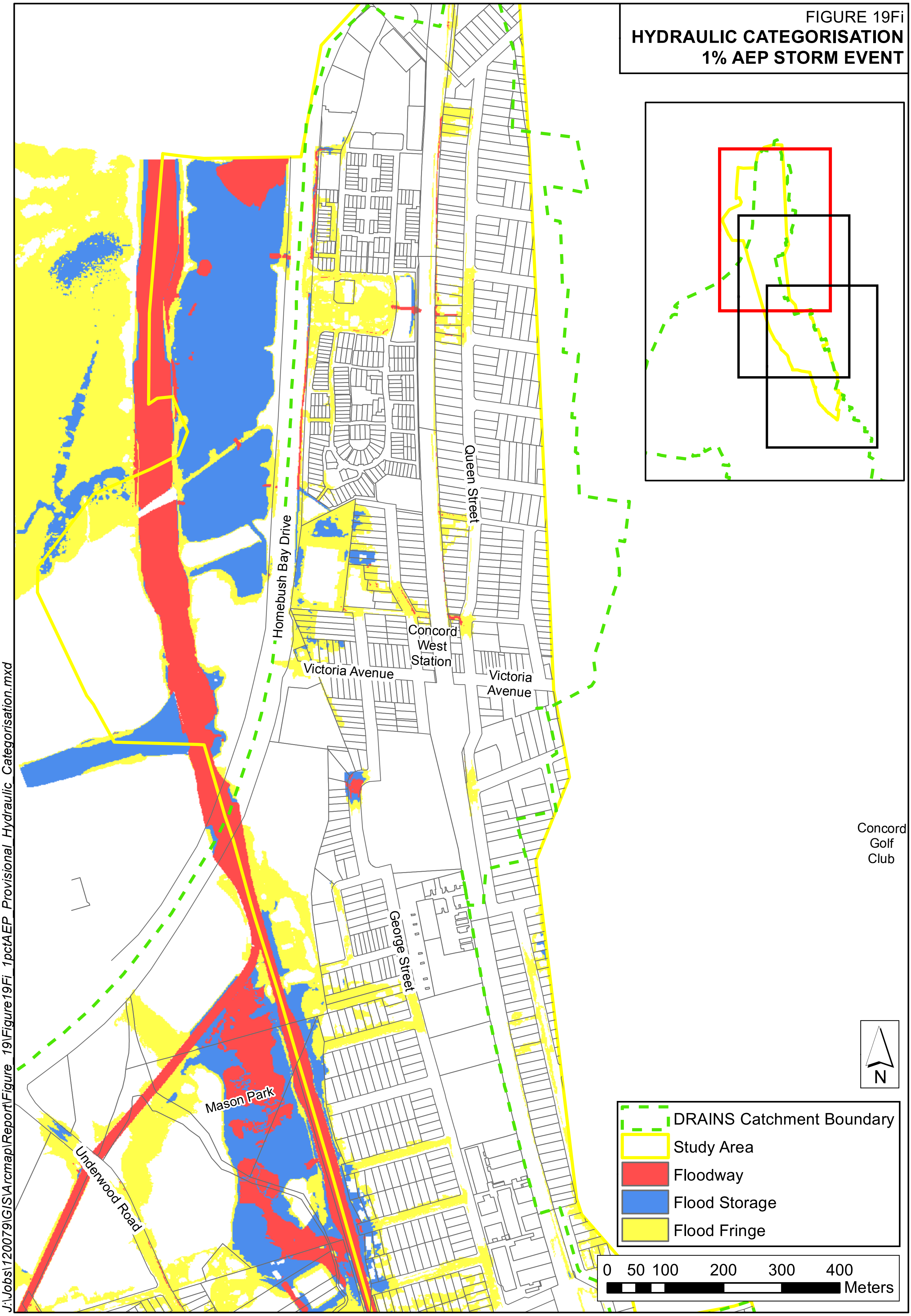


FIGURE 19Fii
HYDRAULIC CATEGORISATION
1% AEP STORM EVENT

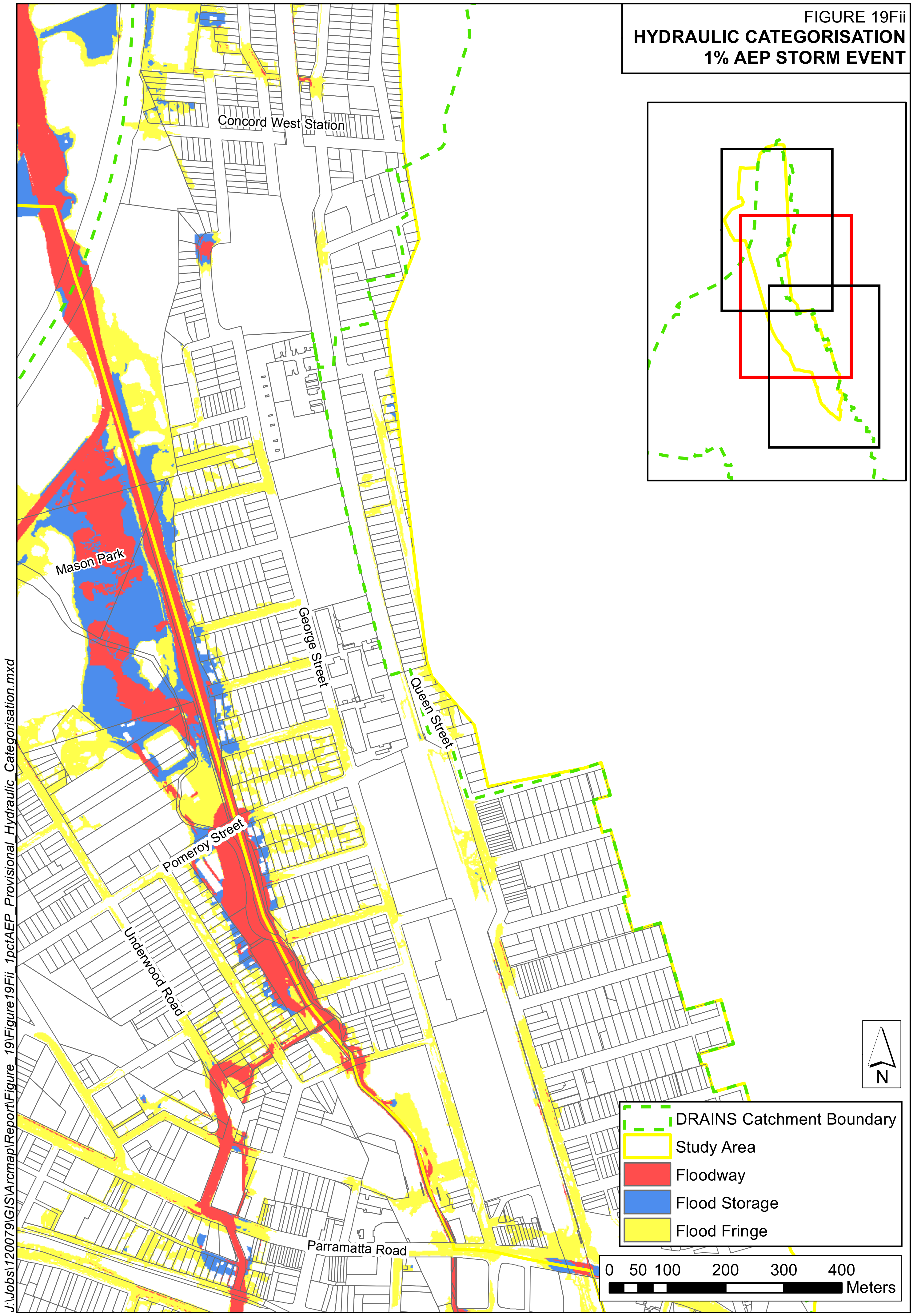
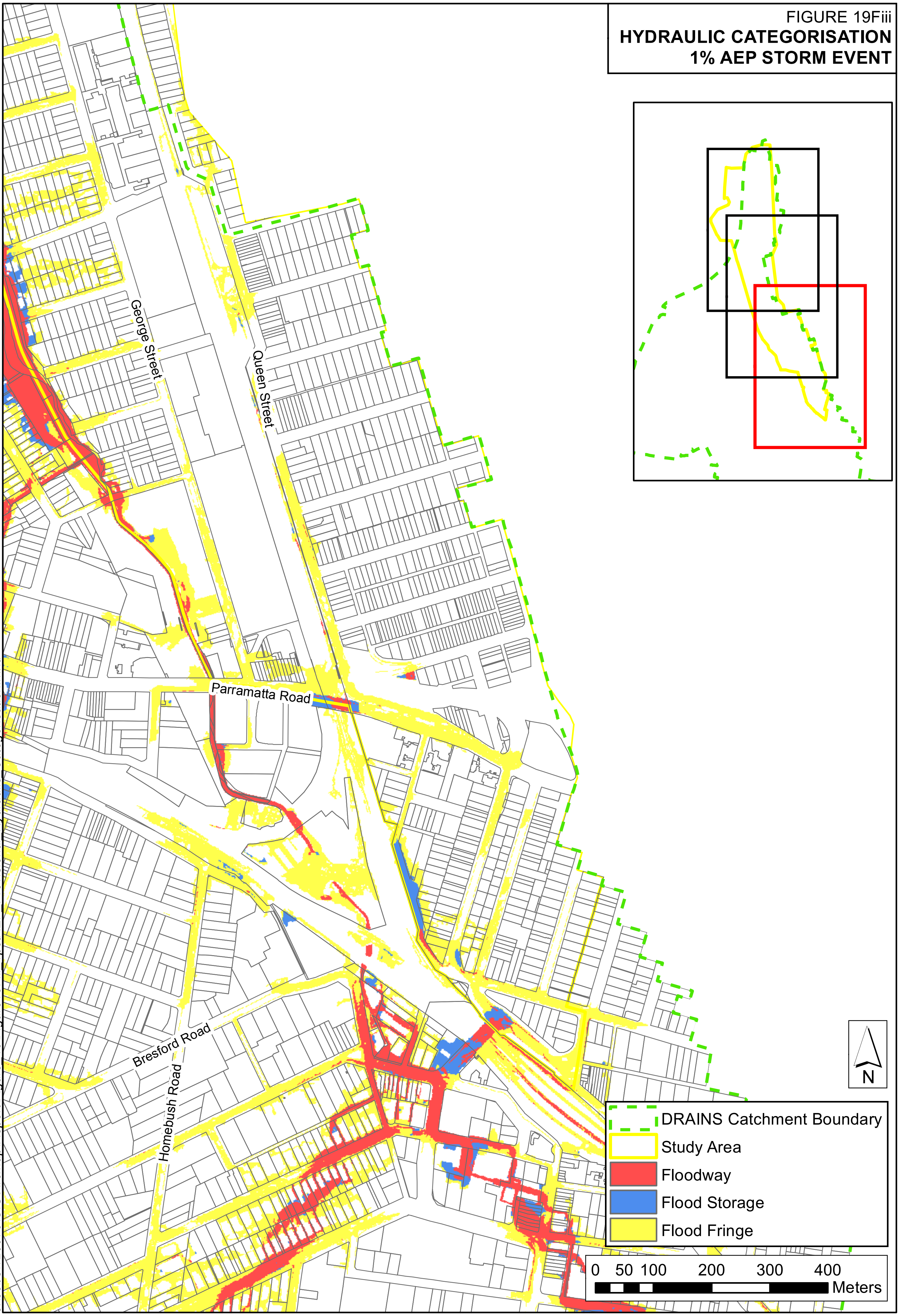


FIGURE 19Fiii

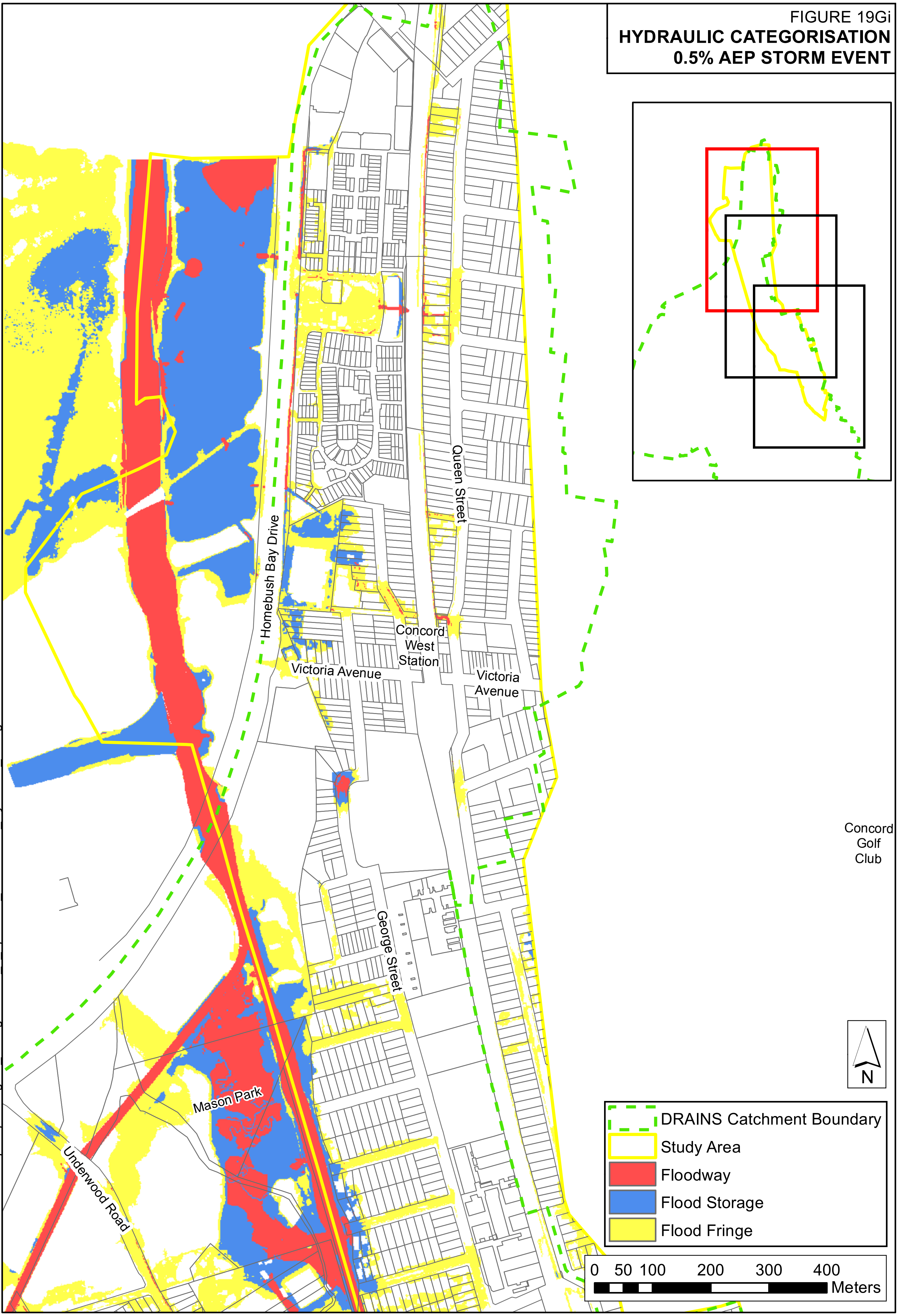
HYDRAULIC CATEGORISATION
1% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure 19\Figure19Fiii 1pctAEP Provisional Hydraulic Categorisation.mxd

FIGURE 19Gi

HYDRAULIC CATEGORISATION
0.5% AEP STORM EVENT

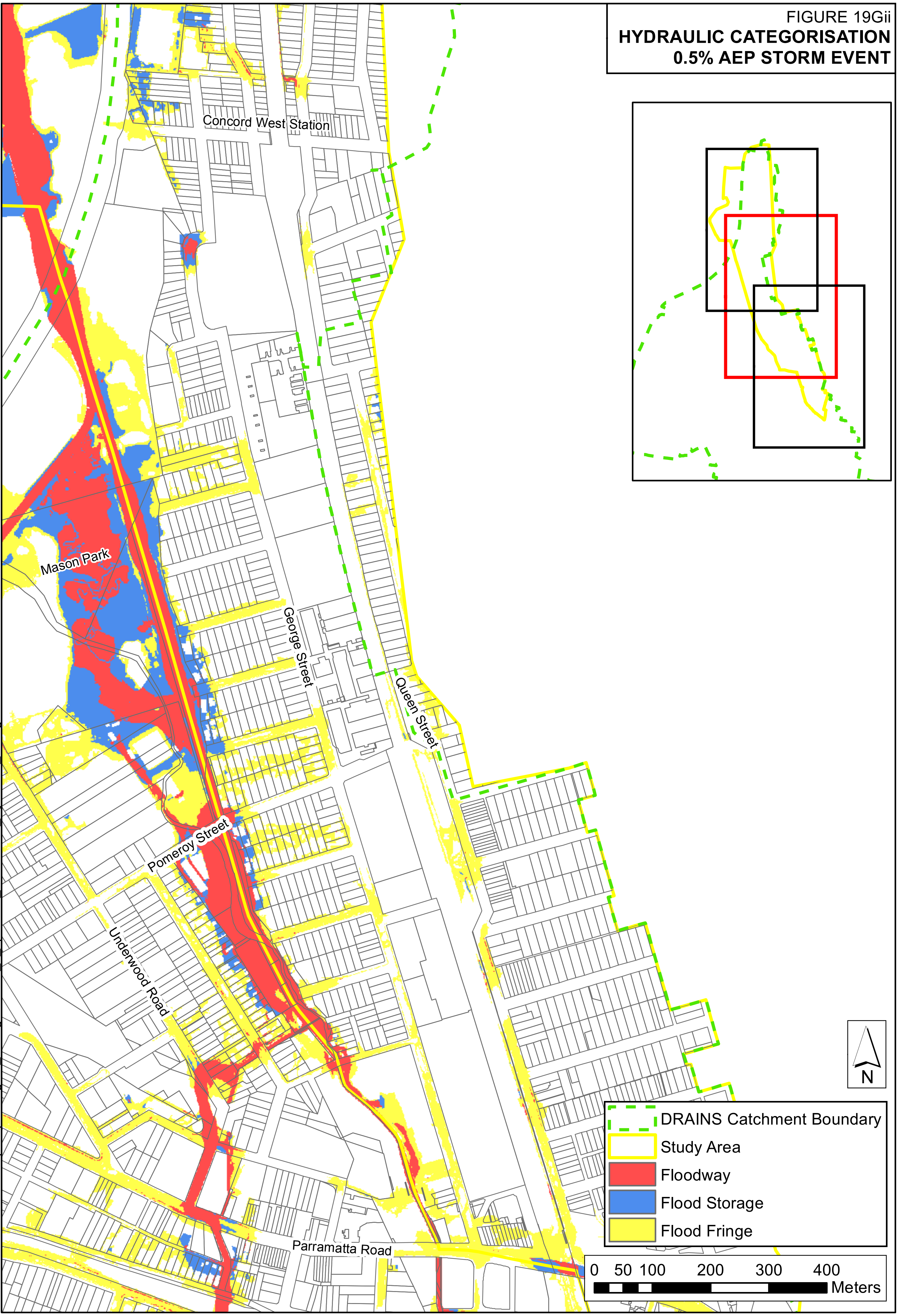


J:\Jobs\120079\GIS\Arcmap\Report\Figure_19\Figure19Gi_0_5pctAEP_Provisional_Hydraulic_Categorisation.mxd

FIGURE 19Gii

HYDRAULIC CATEGORISATION

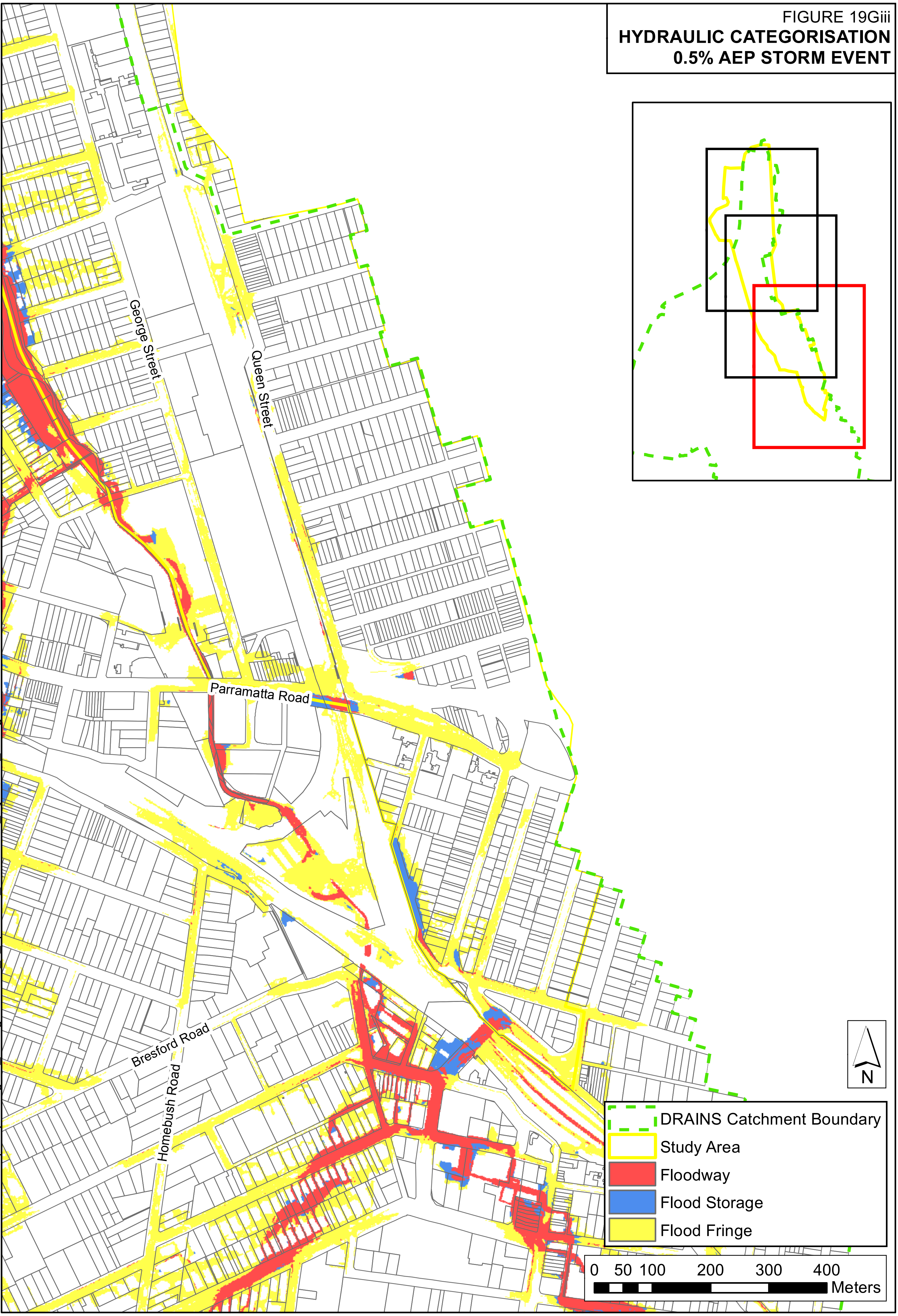
0.5% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure 19\Figure19Gii 0 5pctAEP Provisional Hydraulic Categorisation.mxd

FIGURE 19Giii

HYDRAULIC CATEGORISATION 0.5% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure 19\Figure19Giii 0 5pctAEP Provisional Hydraulic Categorisation.mxd

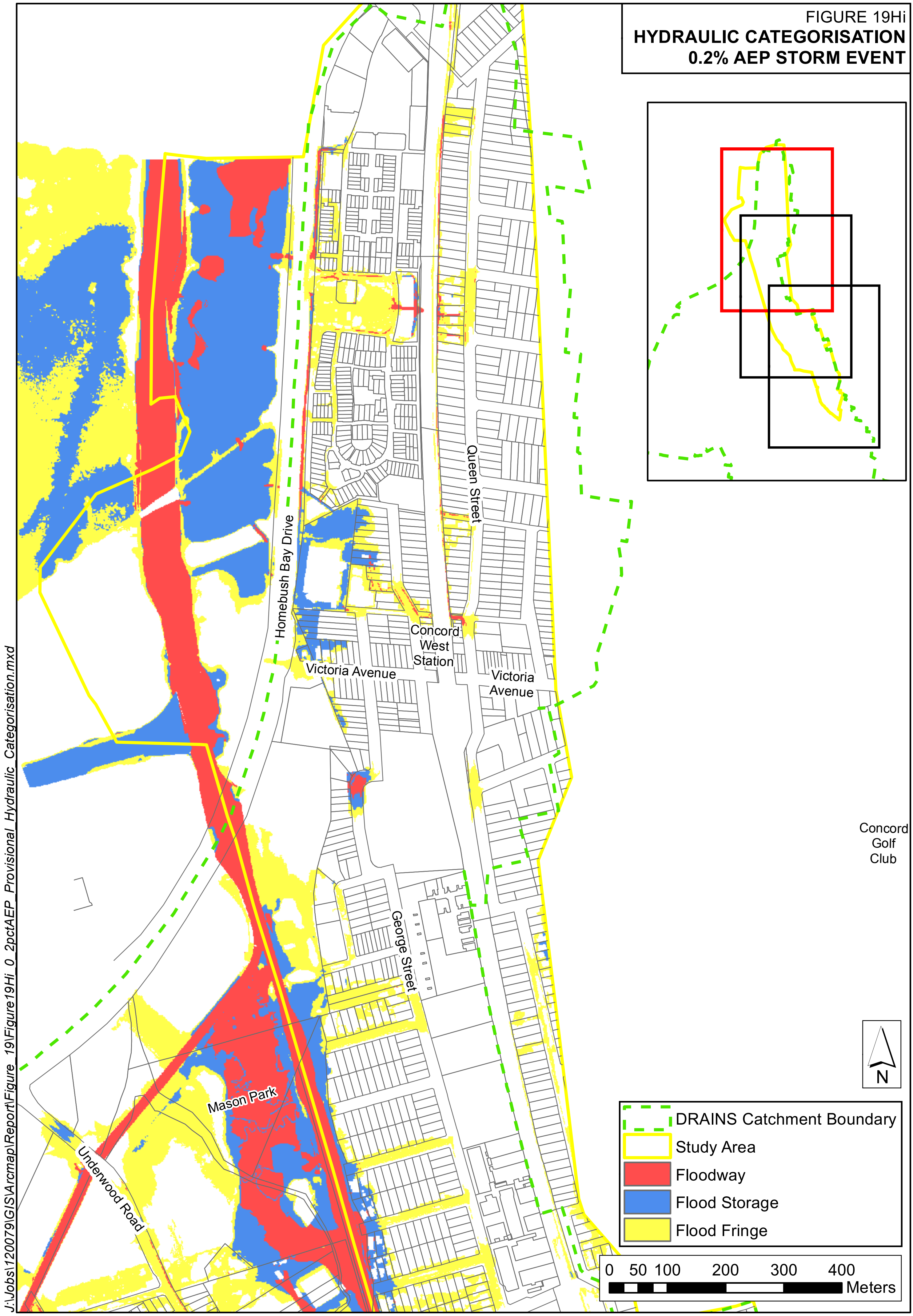
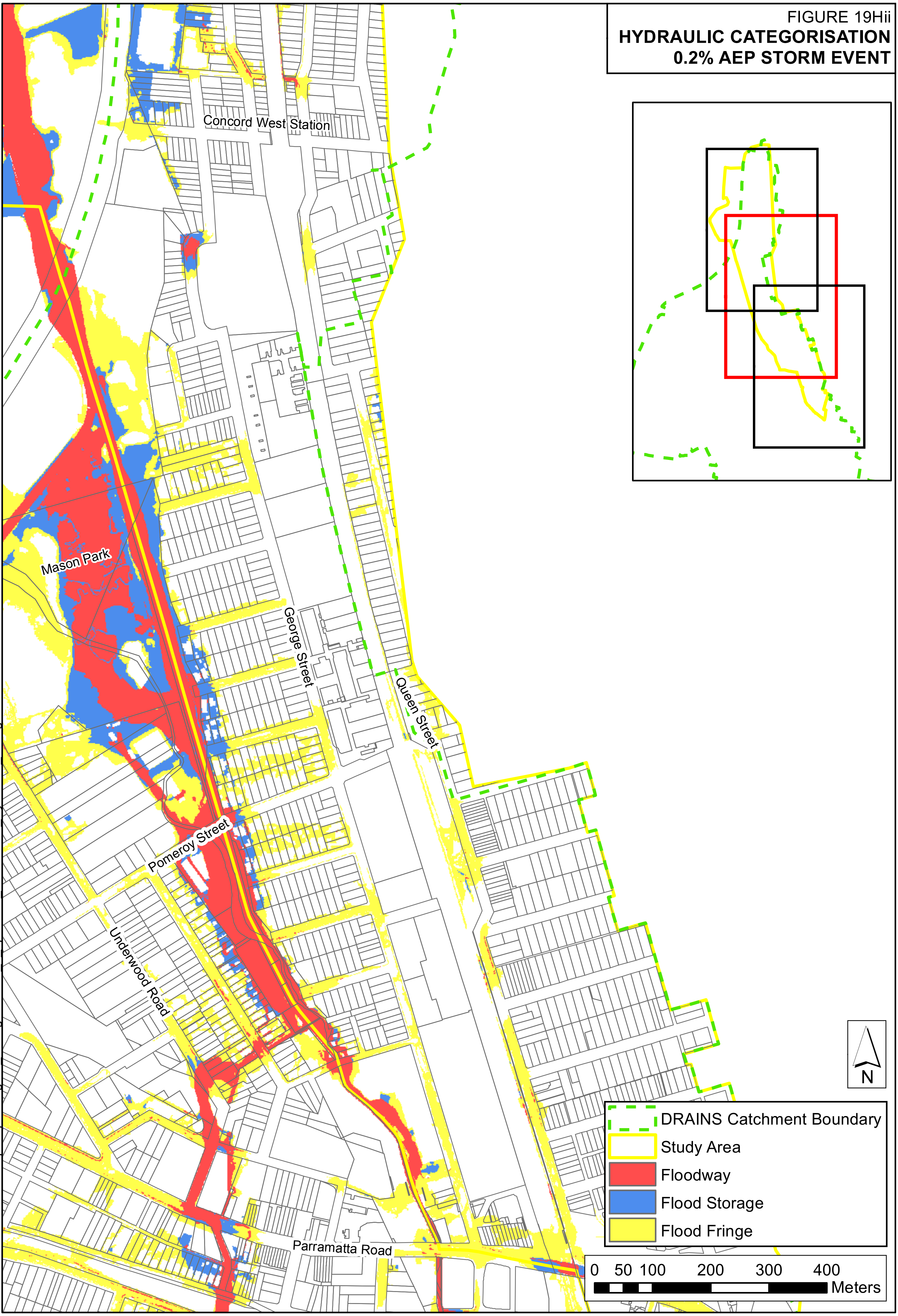


FIGURE 19Hi
HYDRAULIC CATEGORISATION
0.2% AEP STORM EVENT
Homebush Bay Drive
Queen Street
Concord West Station
Victoria Avenue
Victoria Avenue
George Street
Mason Park
Underwood Road
Concord Golf Club
N
DRAINS Catchment Boundary
Study Area
Floodway
Flood Storage
Flood Fringe
0 50 100 200 300 400
Meters
J:\Jobs\120079\GIS\Arcmap\Report\Figure_19\Figure19Hi_0_2pctAEP_Provisional_Hydraulic_Categorisation.mxd

FIGURE 19Hii

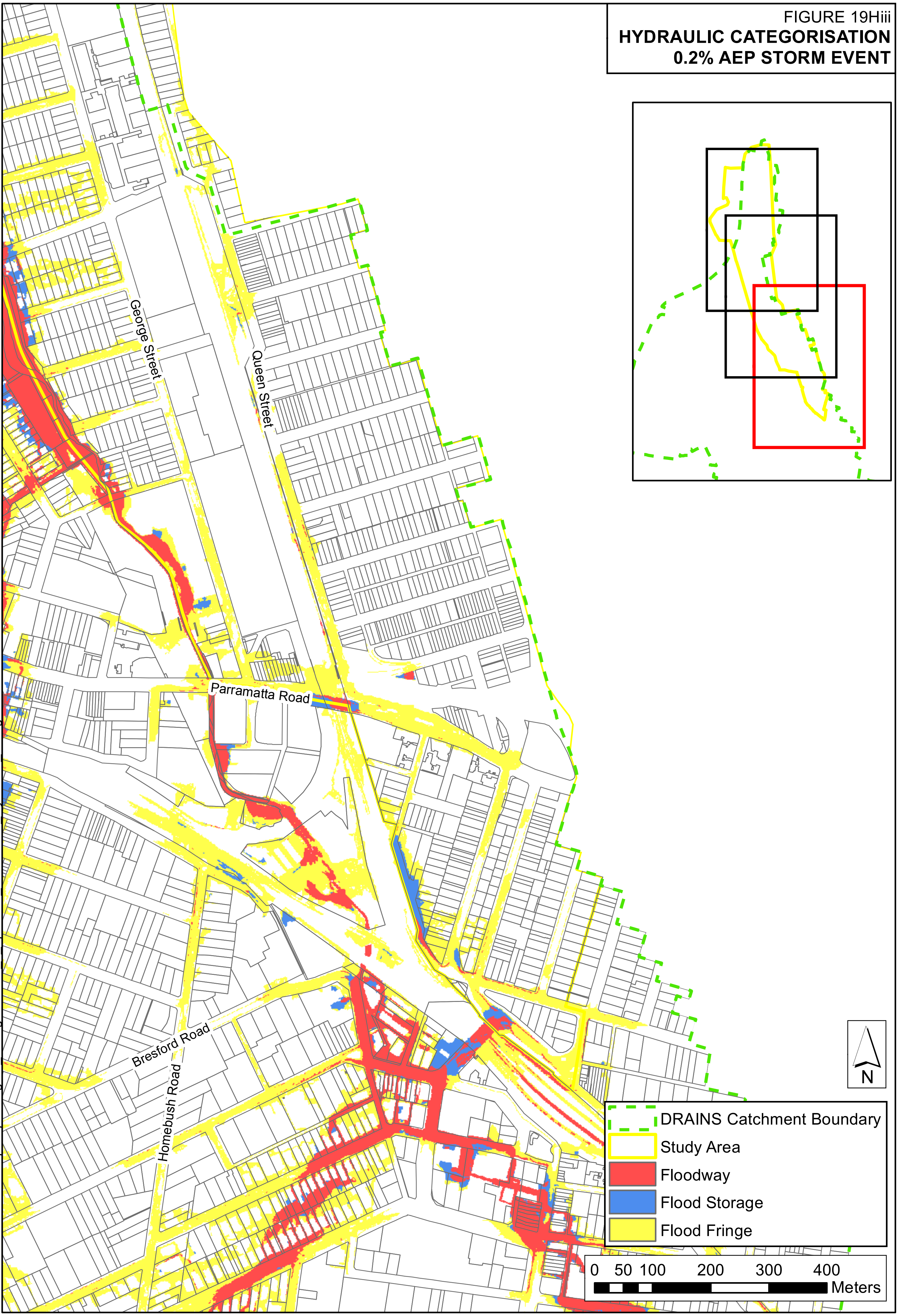
HYDRAULIC CATEGORISATION
0.2% AEP STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure 19\Figure19Hii 0 2pctAEP Provisional Hydraulic Categorisation.mxd

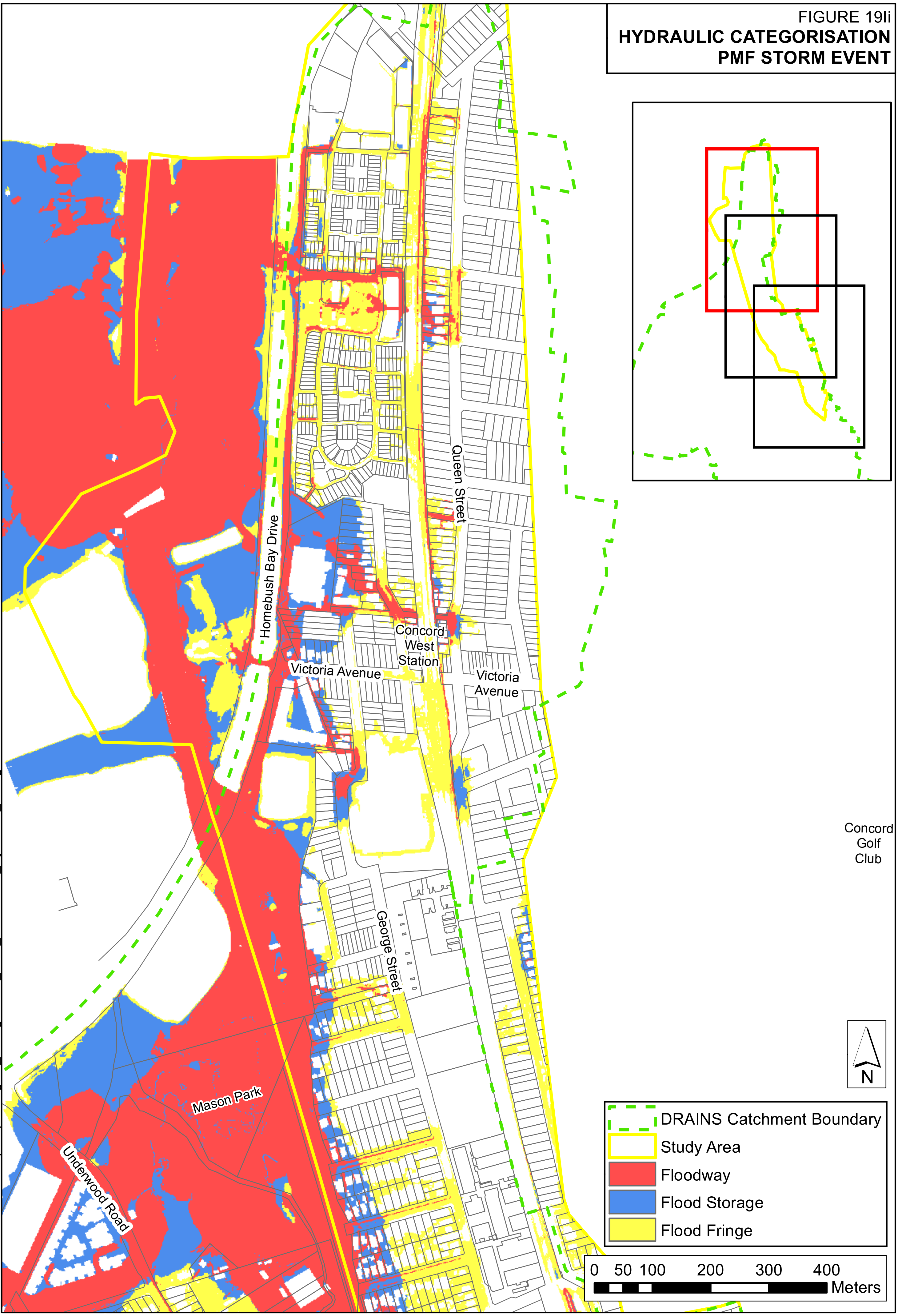
FIGURE 19Hiii

HYDRAULIC CATEGORISATION
0.2% AEP STORM EVENT



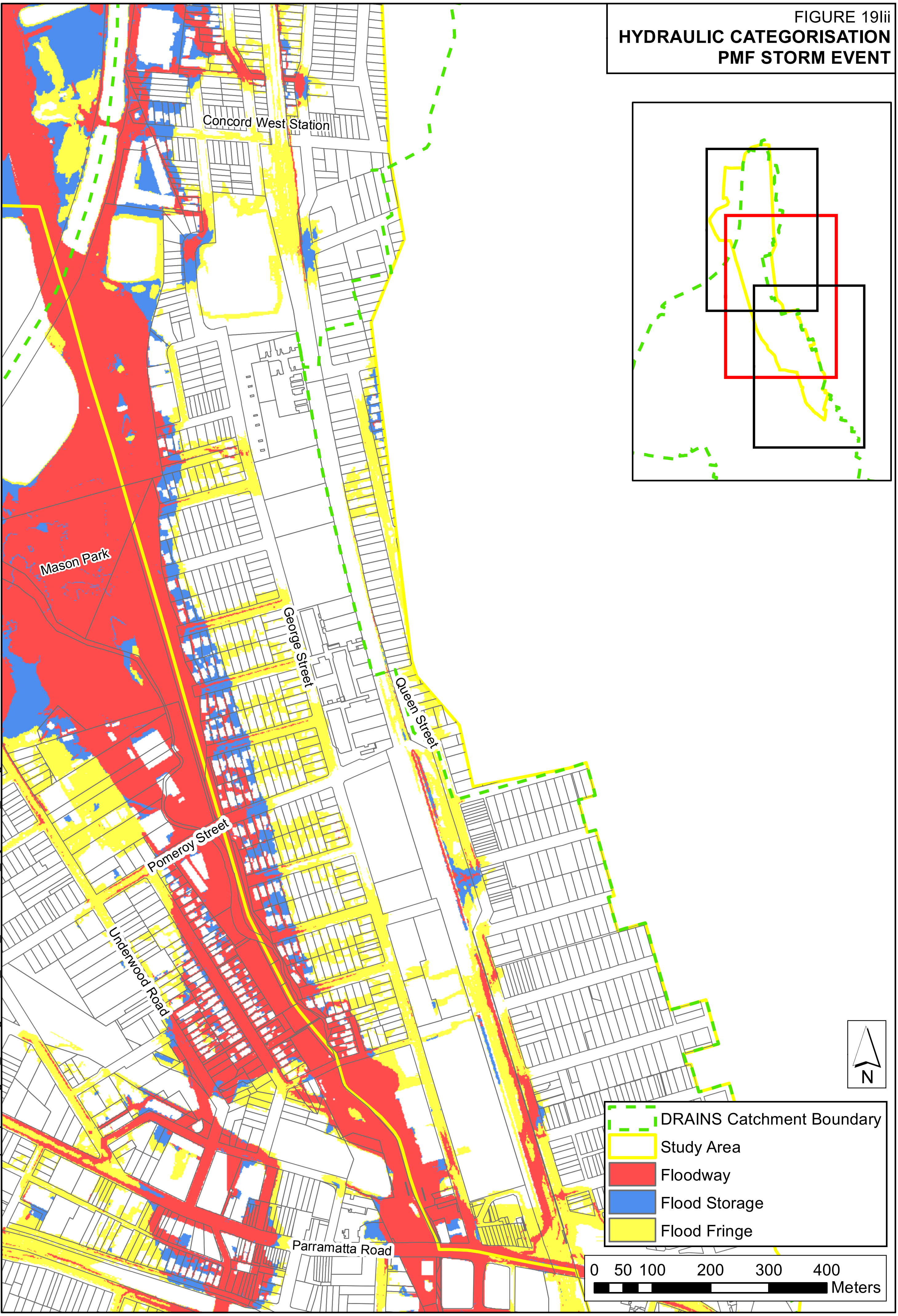
J:\Jobs\120079\GIS\Arcmap\Report\Figure 19\Figure19Hiii 0 2pctAEP Provisional Hydraulic Categorisation.mxd

FIGURE 19li
HYDRAULIC CATEGORISATION
PMF STORM EVENT



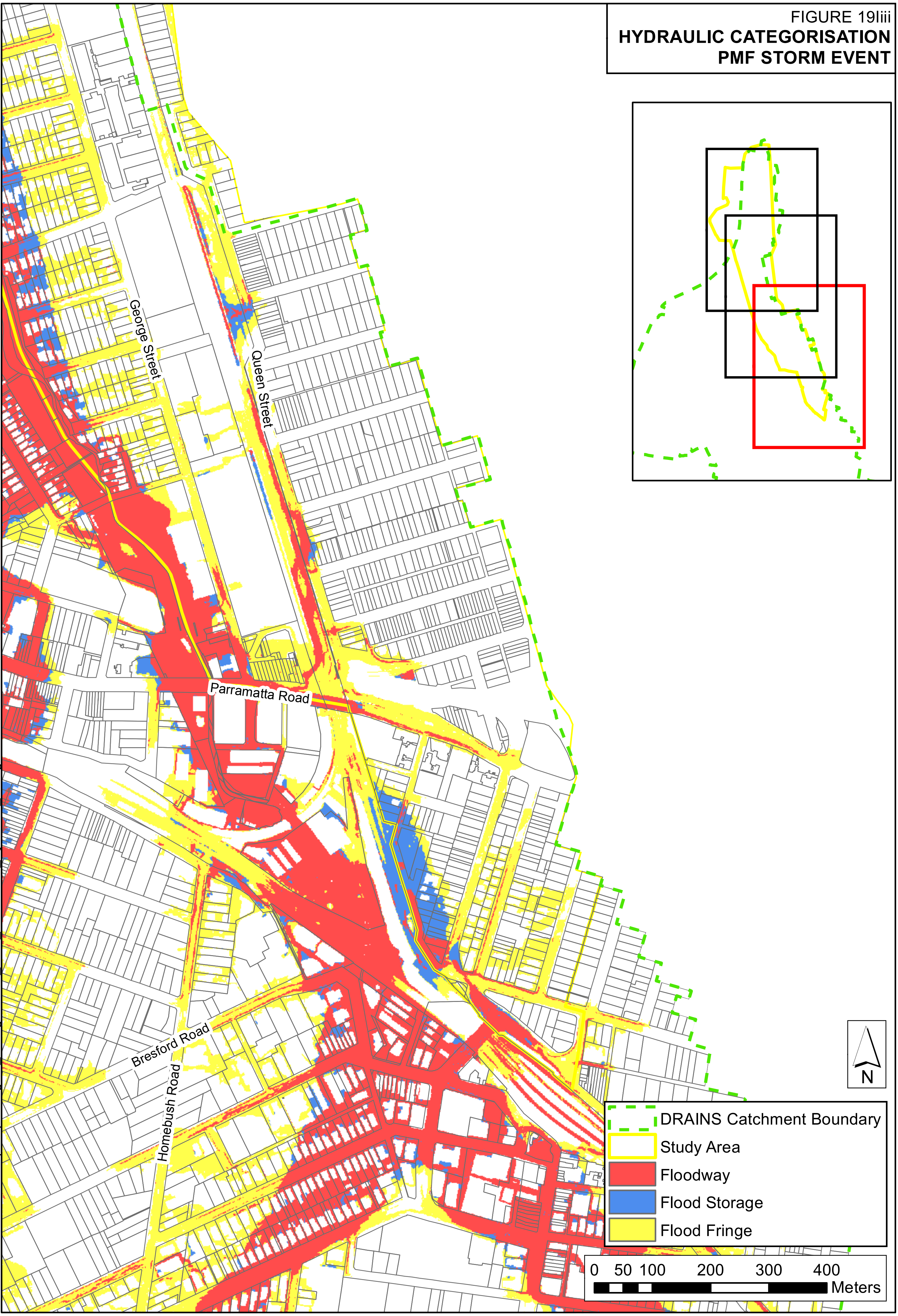
J:\Jobs\120079\GIS\Arcmap\Report\Figure_19\Figure19li_PMF_Provisional_Hydraulic_Categorisation.mxd

FIGURE 19Iii
HYDRAULIC CATEGORISATION
PMF STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure_19\Figure19Iii_PMF_Provisional_Hydraulic_Categorisation.mxd

FIGURE 19Iiii
HYDRAULIC CATEGORISATION PMF STORM EVENT



J:\Jobs\120079\GIS\Arcmap\Report\Figure 19\Figure19Iiii PMF Provisional Hydraulic Categorisation.mxd

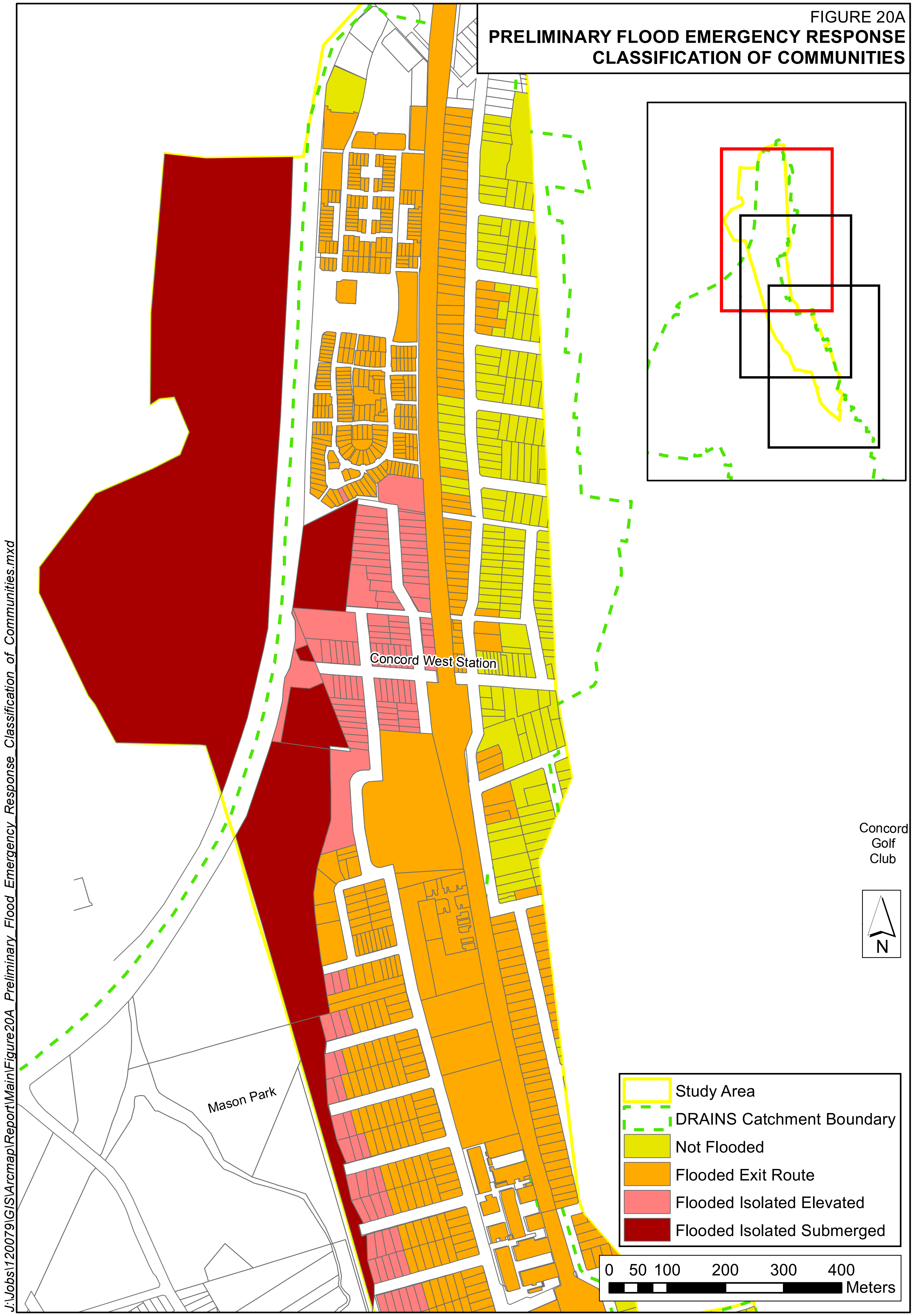
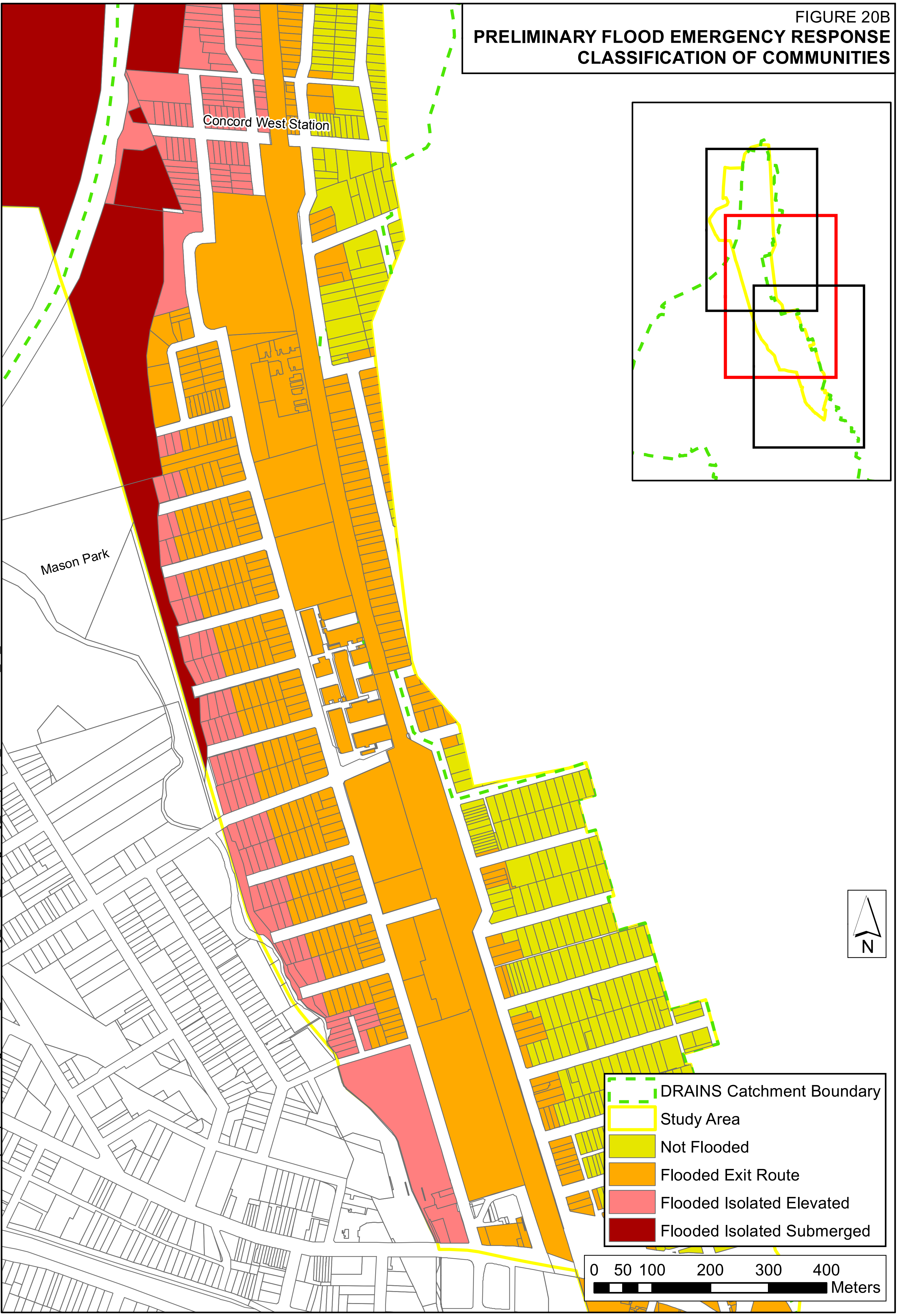


FIGURE 20A
PRELIMINARY FLOOD EMERGENCY RESPONSE CLASSIFICATION OF COMMUNITIES
Concord West Station
Concord Golf Club
Mason Park
N
Study Area
DRAINS Catchment Boundary
Not Flooded
Flooded Exit Route
Flooded Isolated Elevated
Flooded Isolated Submerged
0 50 100 200 300 400
Meters
J:\Jobs\120079\GIS\Arcmap\Report\Main\Figure20A_Preliminary_Flood_Emergency_Response_Classification_of_Communities.mxd

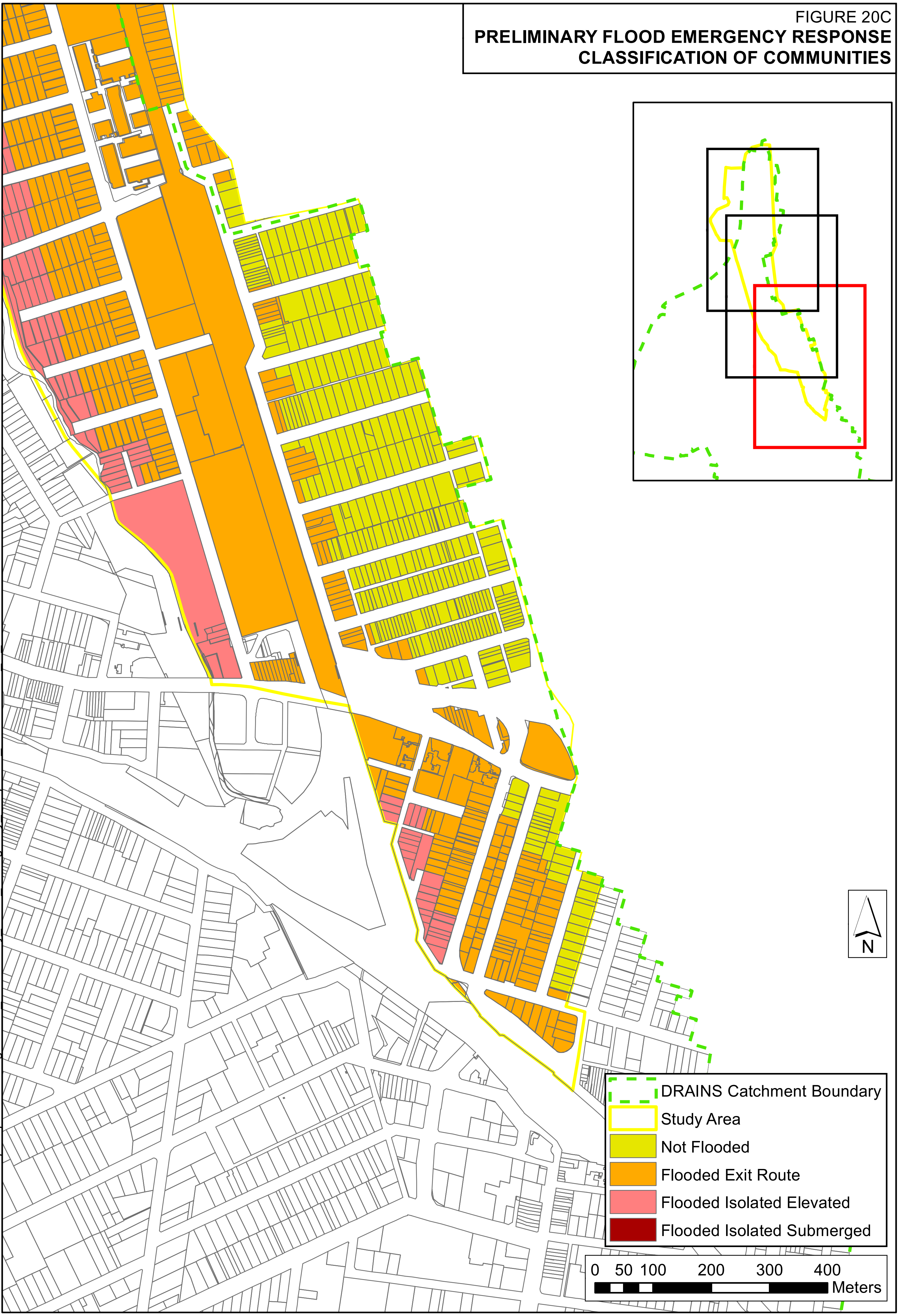
FIGURE 20B
PRELIMINARY FLOOD EMERGENCY RESPONSE CLASSIFICATION OF COMMUNITIES



J:\Jobs\120079\GIS\Arcmap\Report\Main\Figure20B_Preliminary_Flood_Emergency_Response_Classification_of_Communities.mxd

FIGURE 20C

PRELIMINARY FLOOD EMERGENCY RESPONSE CLASSIFICATION OF COMMUNITIES



J:\Jobs\120079\GIS\Arcmap\Report\Main\Figure20C_Preliminary_Flood_Emergency_Response_Classification_of_Communities.mxd

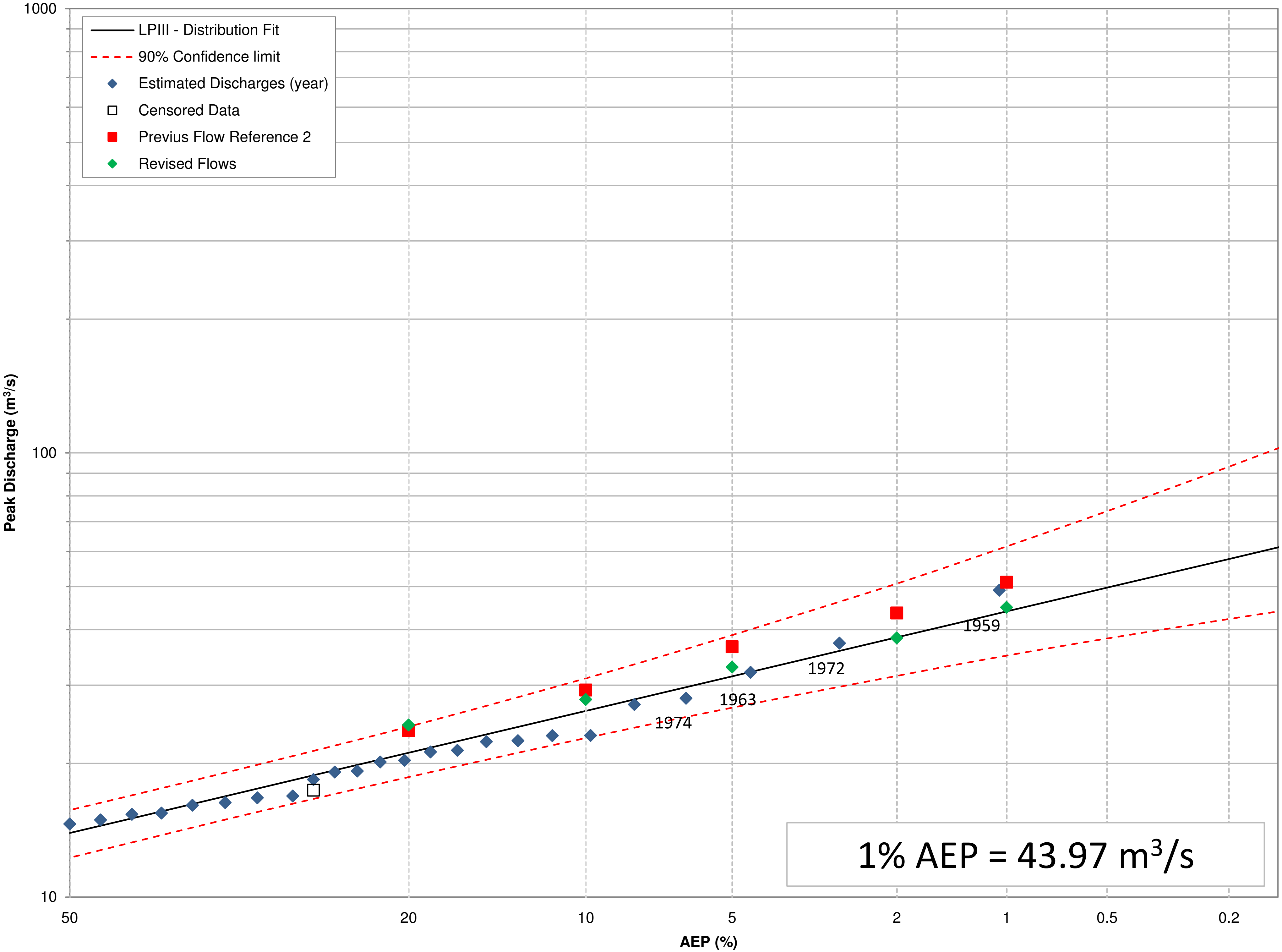


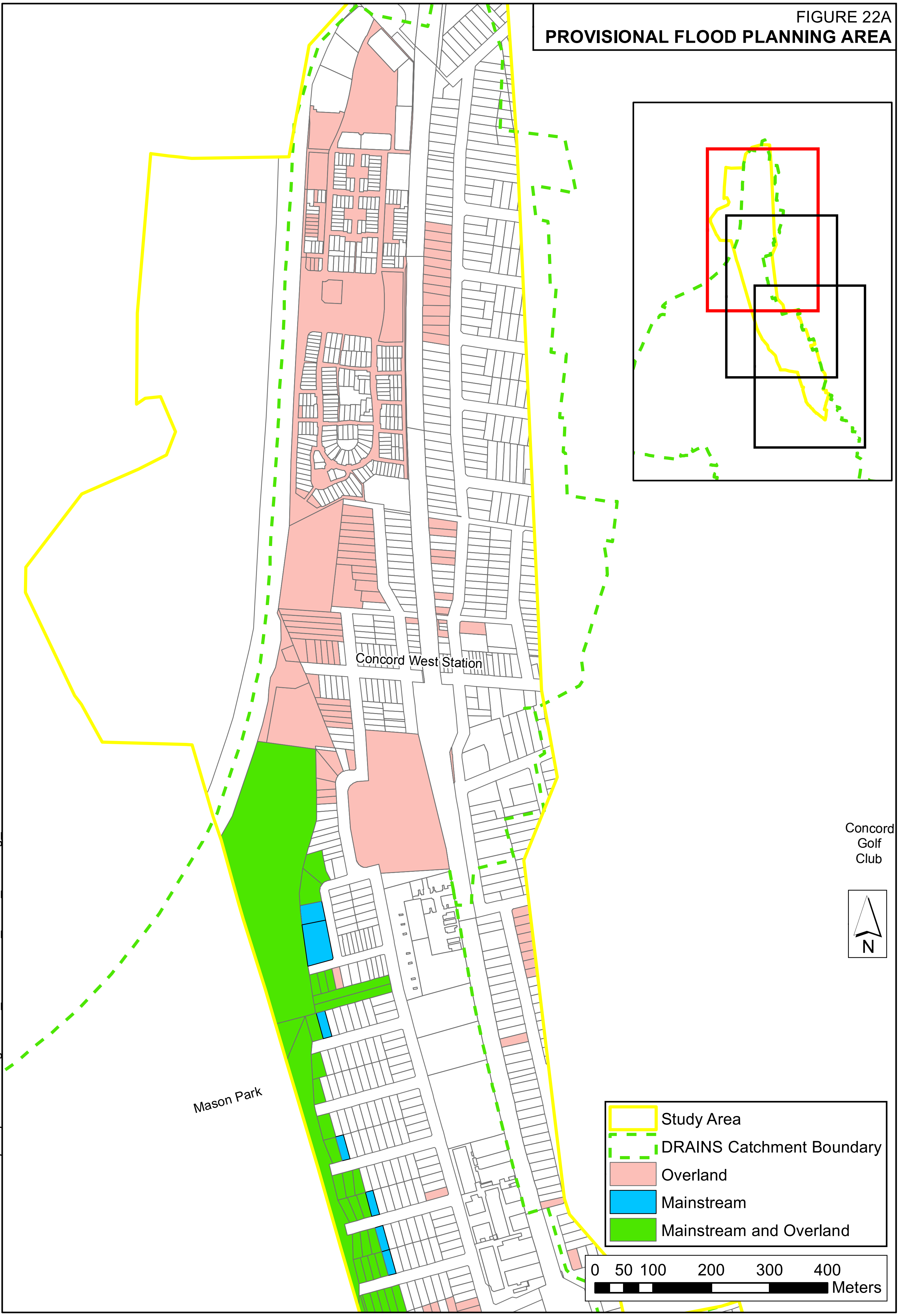
FIGURE 21

POWELLS CREEK - FLOOD FREQUENCY ANALYSIS

DATA SET #2

LP3 ANALYSIS - BAYESIAN

FIGURE 22A
PROVISIONAL FLOOD PLANNING AREA



J:\Jobs\120079\GIS\Arcmap\Report\Main\Figure22A_Provisional_Flood_Planning_Area.mxd

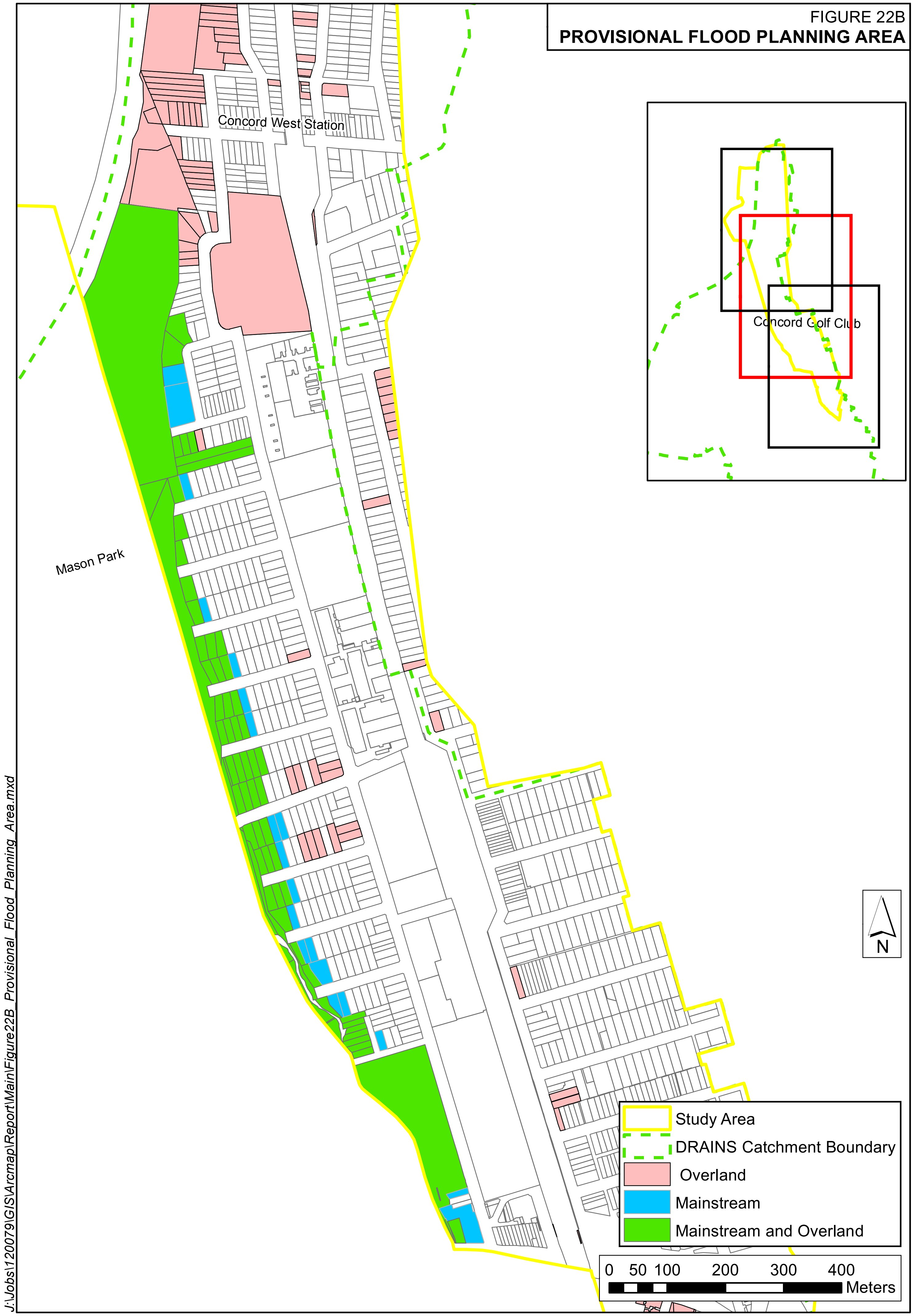
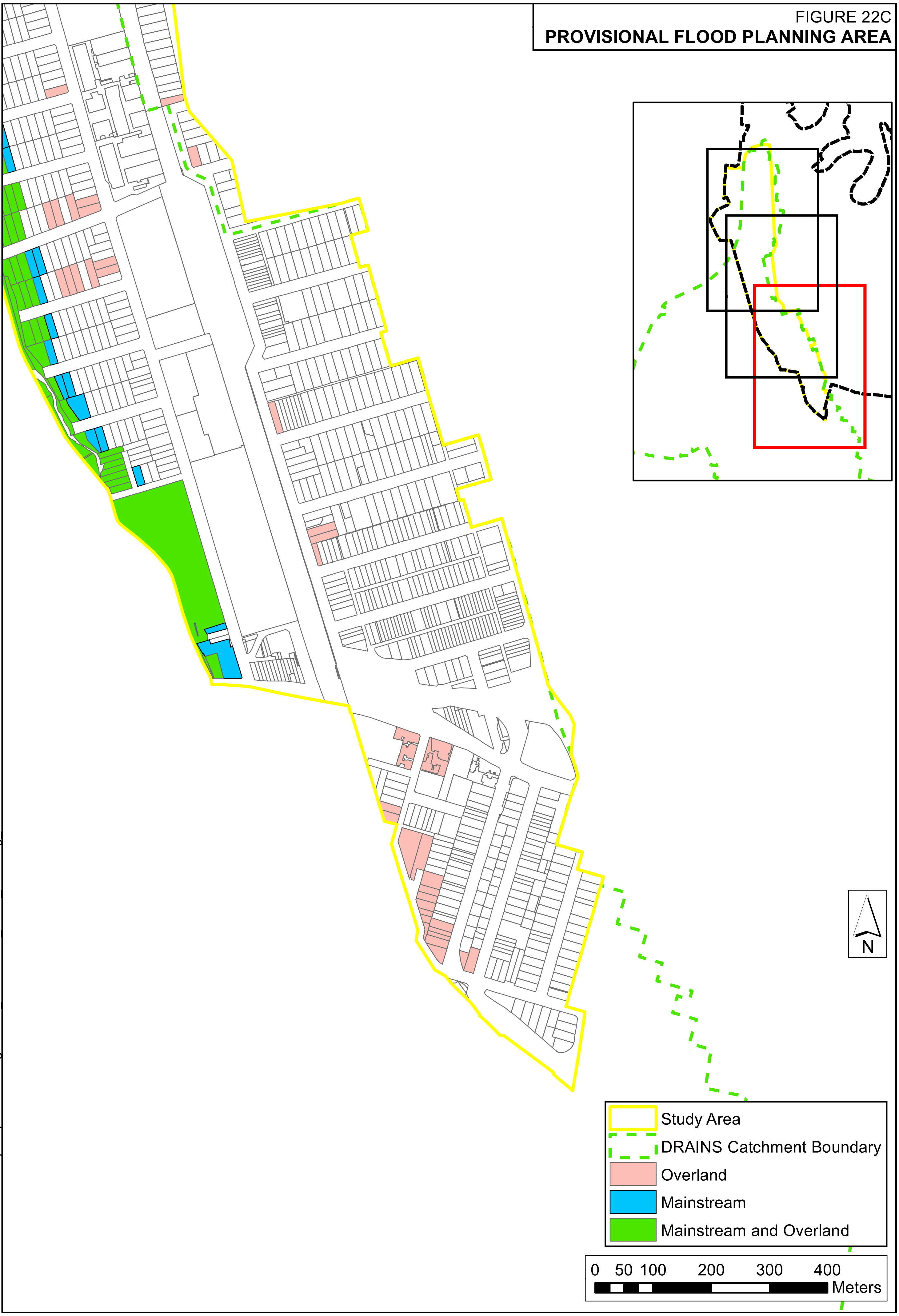


FIGURE 22B
PROVISIONAL FLOOD PLANNING AREA
Concord West Station
Mason Park
Concord Golf Club
Study Area
DRAINS Catchment Boundary
Overland
Mainstream
Mainstream and Overland
N
0 50 100 200 300 400
Meters
J:\Jobs\120079\GIS\Arcmap\Report\Main\Figure22B_Provisional_Flood_Planning_Area.mxd

FIGURE 22C
PROVISIONAL FLOOD PLANNING AREA



J:\Jobs\120079\GIS\Arcmap\Report\Main\Figure22C_Provisional_Flood_Planning_Area.mxd

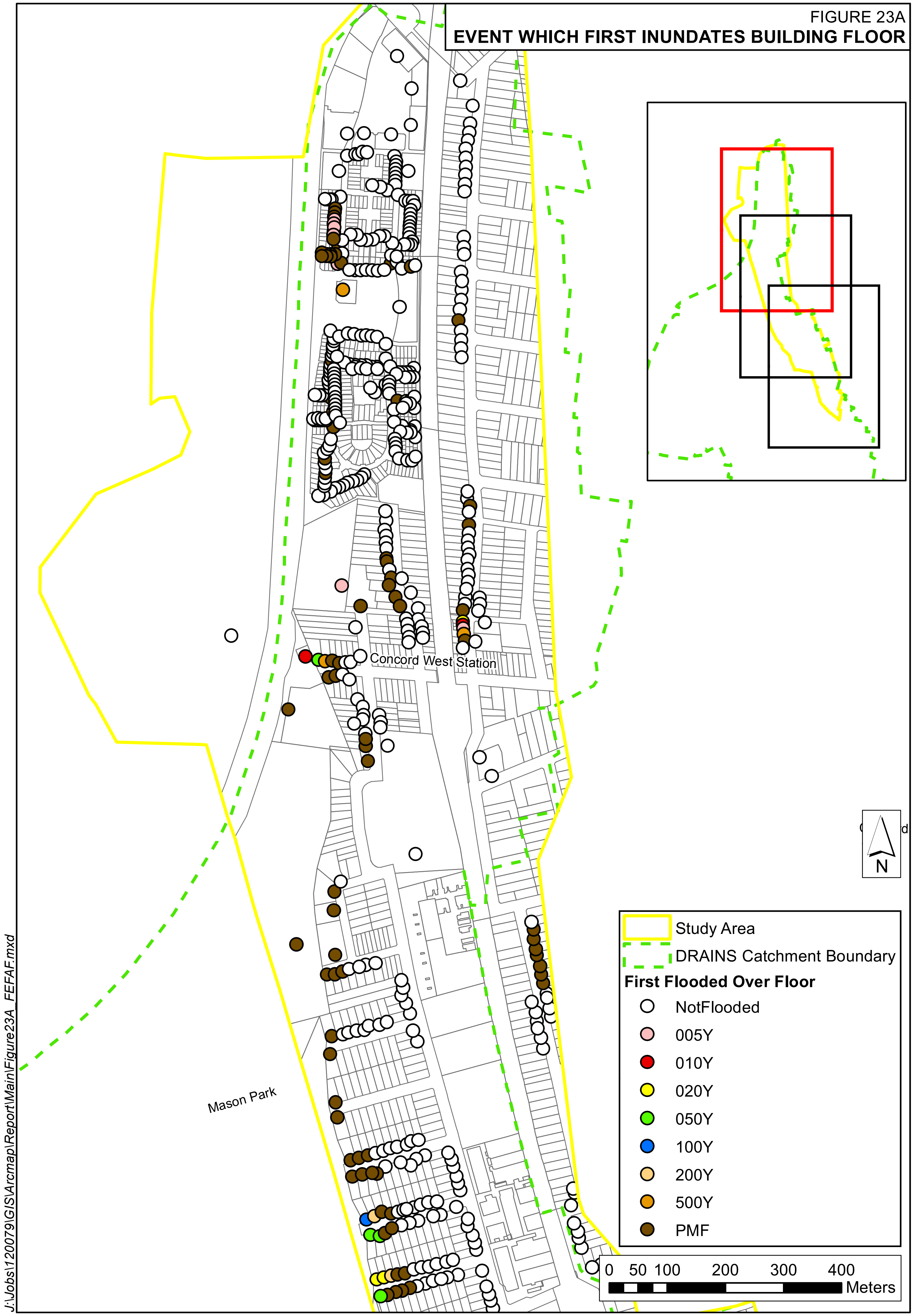
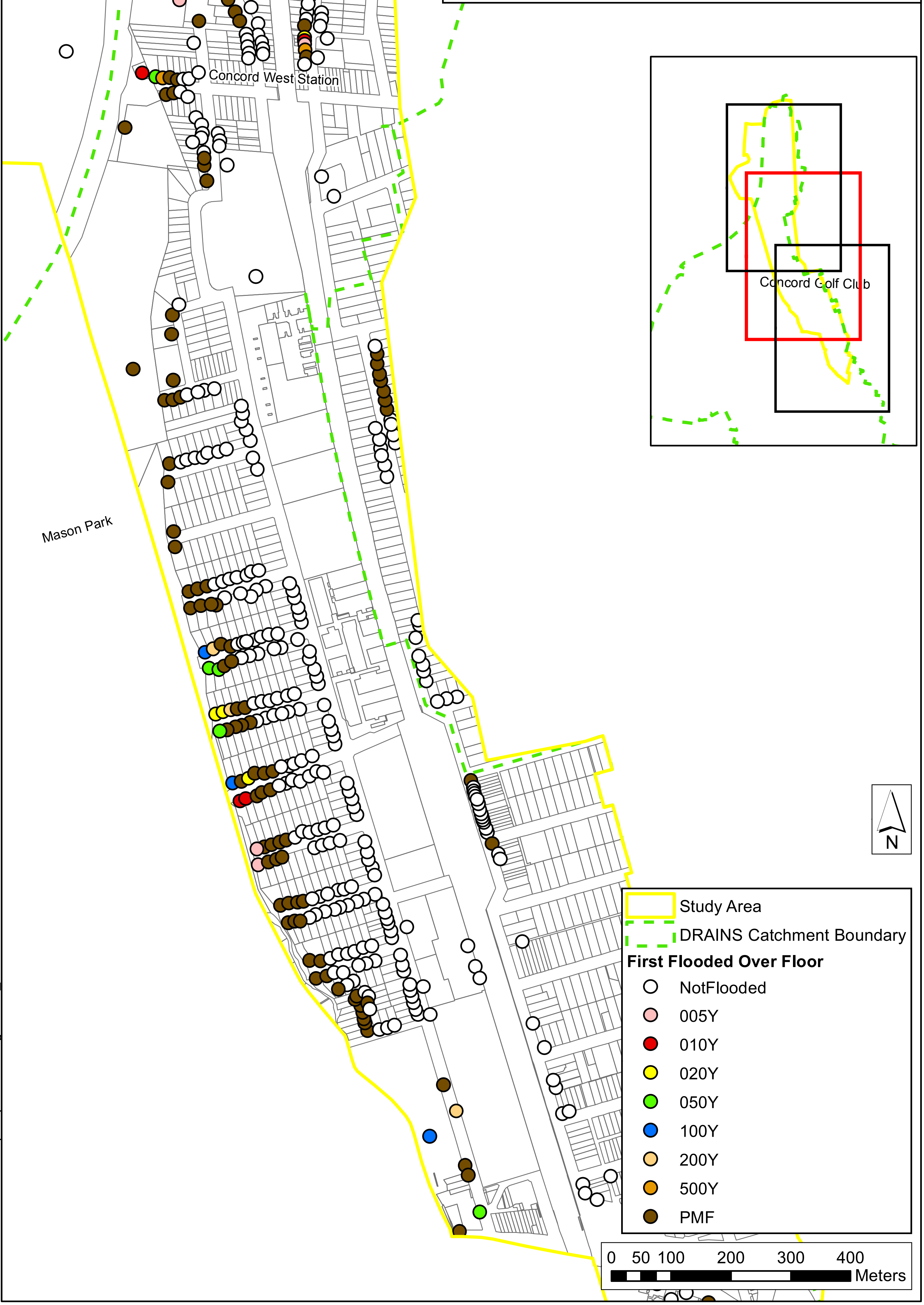


FIGURE 23A
EVENT WHICH FIRST INUNDATES BUILDING FLOOR
Concord West Station
Mason Park
Study Area
DRAINS Catchment Boundary
First Flooded Over Floor
NotFlooded
005Y
010Y
020Y
050Y
100Y
200Y
500Y
PMF
N
0 50 100 200 300 400
Meters
J:\Jobs\120079\GIS\Arcmap\Report\Main\Figure23A_FEFAF.mxd

FIGURE 23B

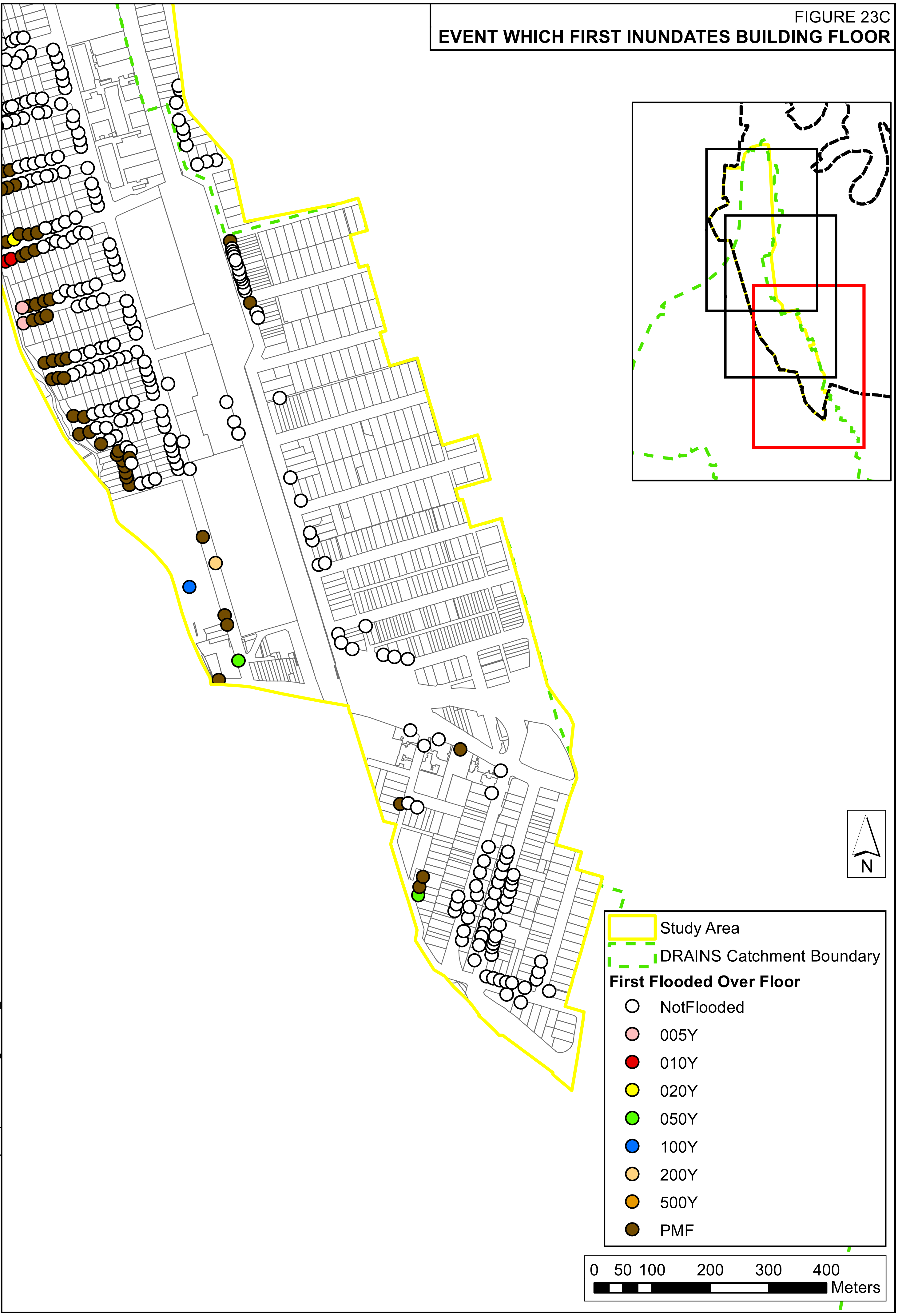
EVENT WHICH FIRST INUNDATES BUILDING FLOOR



J:\Jobs\120079\GIS\Arcmap\Report\Main\Figure23B_FEFAF.mxd

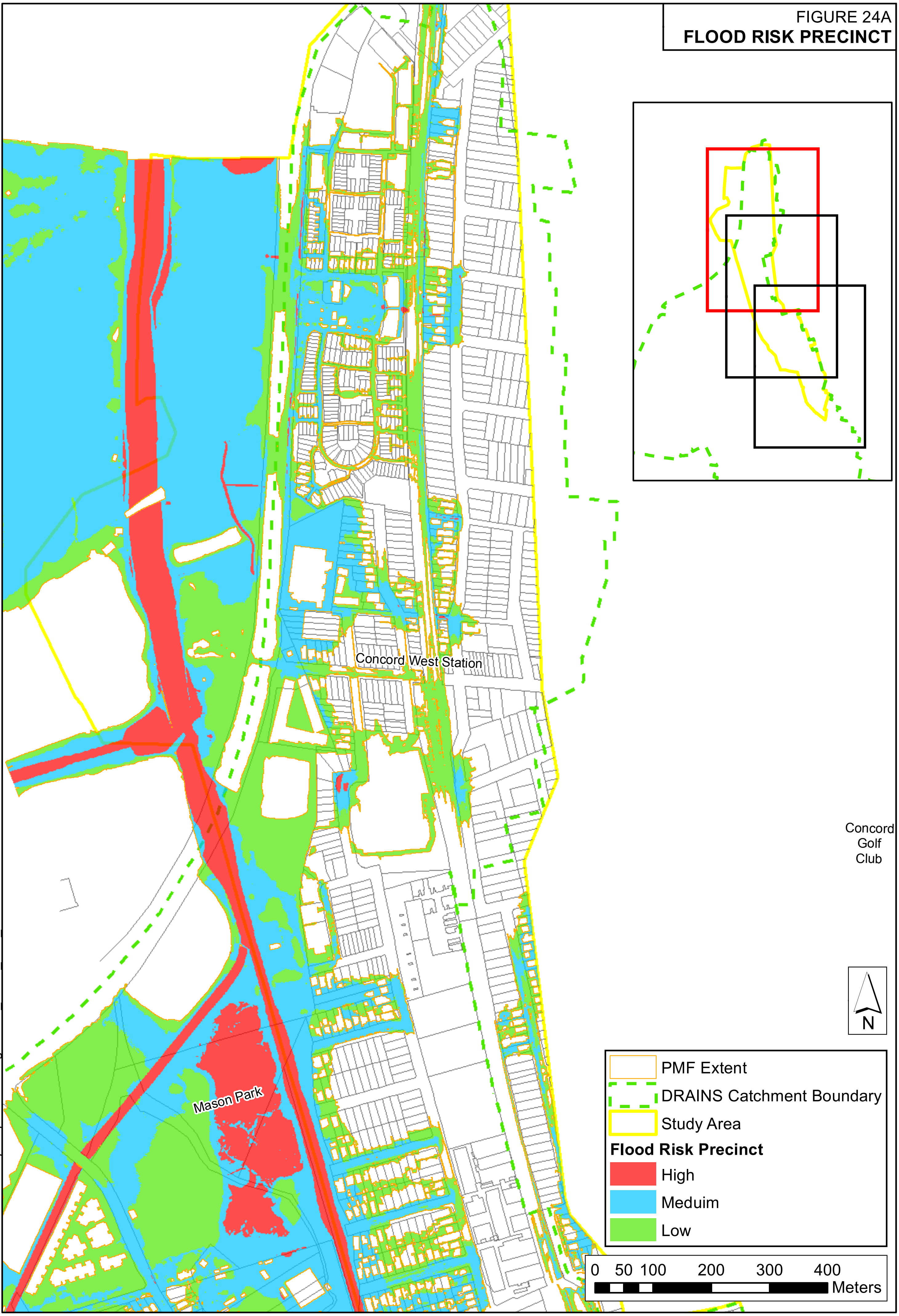
FIGURE 23C

EVENT WHICH FIRST INUNDATES BUILDING FLOOR



J:\Jobs\120079\GIS\Arcmap\Report\Main\Figure23C_FEFAF.mxd

FIGURE 24A
FLOOD RISK PRECINCT



J:\Jobs\120079\GIS\Arcmap\Report\Main\Figure24A_Flood_Risk_Precincts.mxd

FIGURE 24B
FLOOD RISK PRECINCT

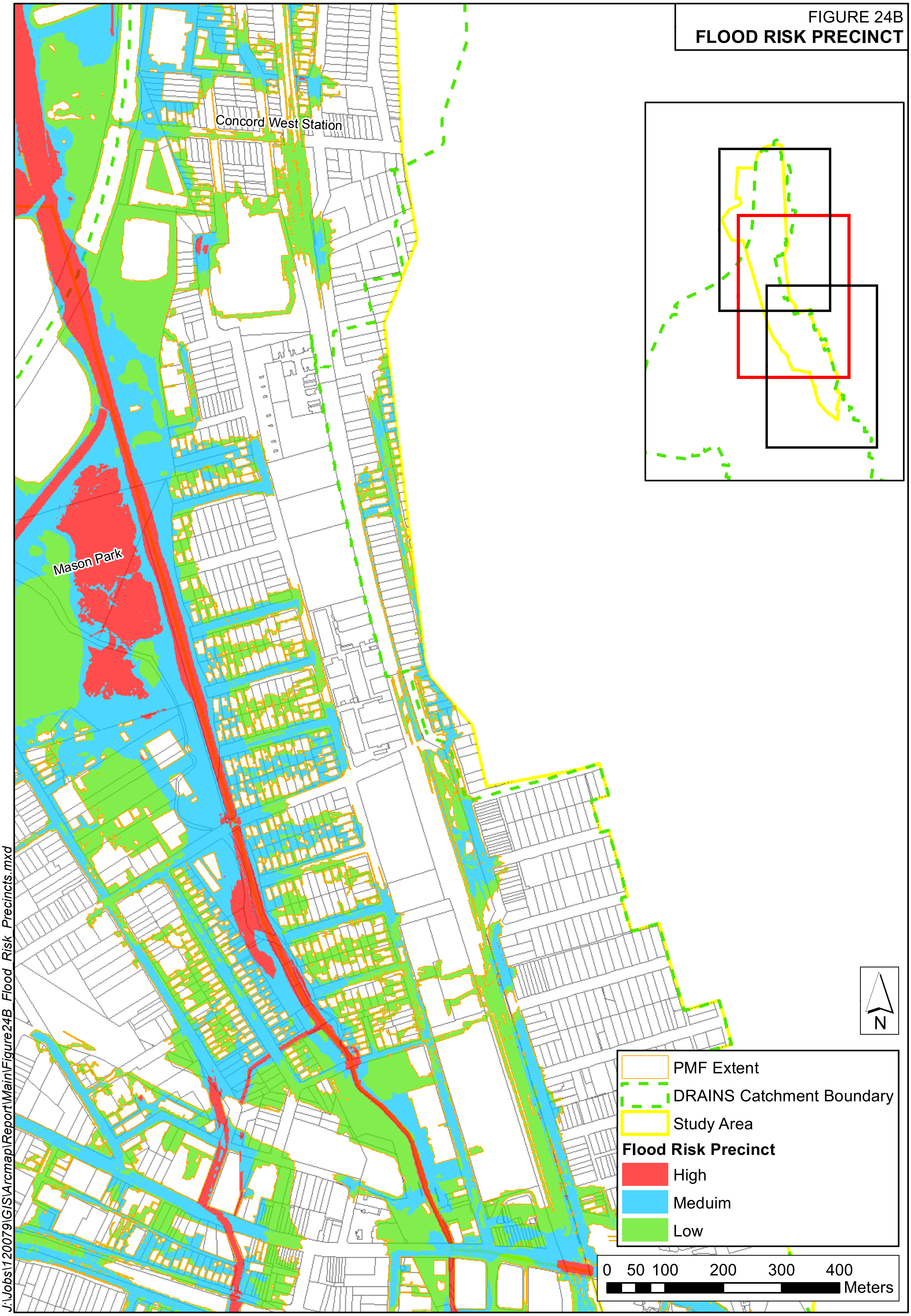
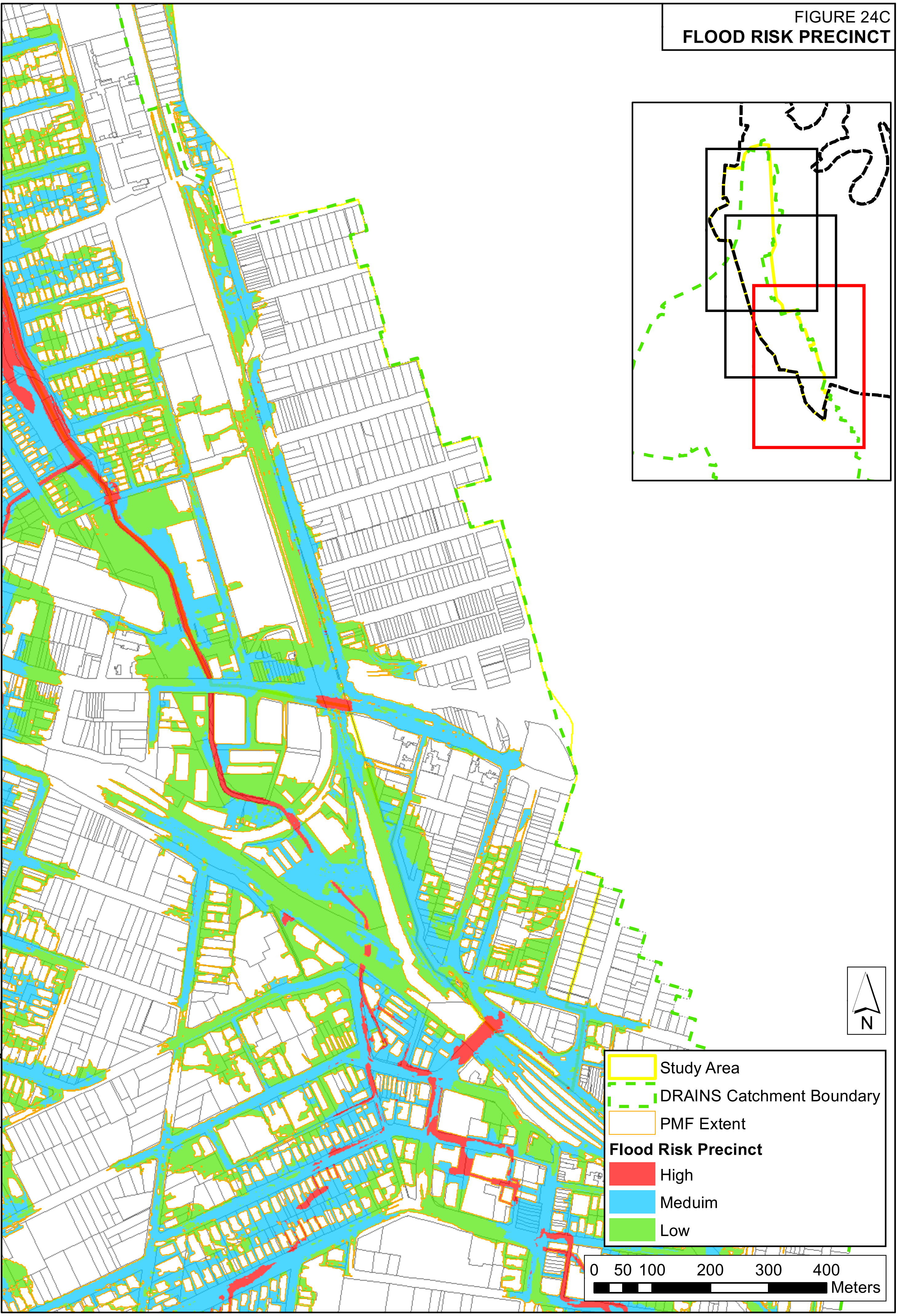


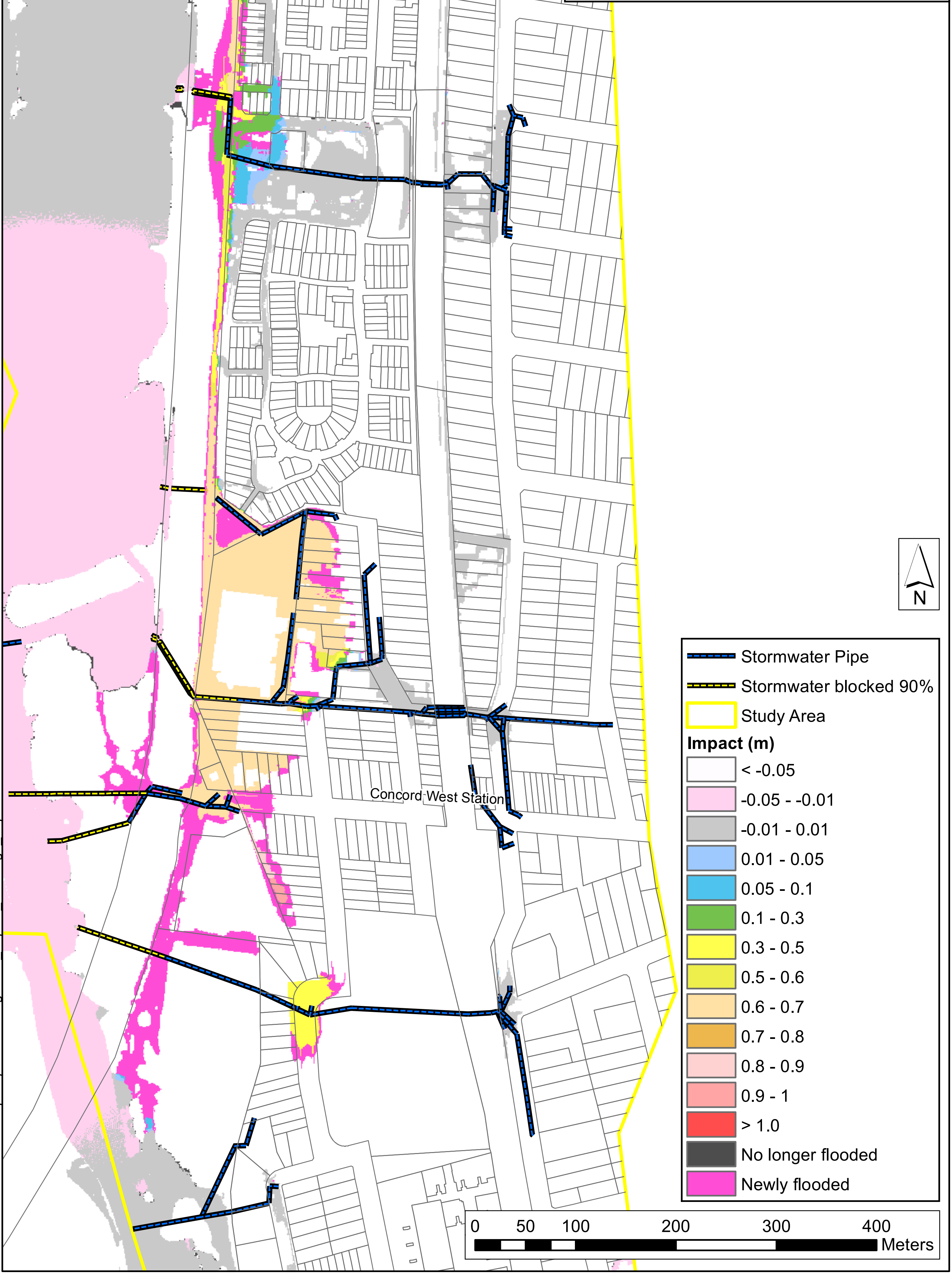
FIGURE 24C
FLOOD RISK PRECINCT



J:\Jobs\120079\GIS\Arcmap\Report\Main\Figure24C_Flood_Risk_Precincts.mxd

FIGURE 25

CHANGE IN PEAK FLOOD LEVEL EFFECTS OF BLOCKAGE OF CULVERTS UNDER HOMEBUSH BAY DRIVE 1% AEP EVENT



Appendix A

APPENDIX A: GLOSSARY of TERMS

Taken from the Floodplain Development Manual (April 2005 edition)

acid sulfate soils	Are sediments which contain sulfidic mineral pyrite which may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual published by Acid Sulfate Soil Management Advisory Committee.
Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Annual Damage (AAD)	Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
Average Recurrence Interval (ARI)	The long term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
caravan and moveable home parks	Caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the LG Act.
catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
consent authority	The Council, Government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the Council, however legislation or an EPI may specify a Minister or public authority (other than a Council), or the Director General of DIPNR, as having the function to determine an application.
development	Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act). **infill development:** refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development. **new development:** refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power. **redevelopment:** refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services.
disaster plan (DISPLAN)	A step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of

	connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.
discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
ecologically sustainable development (ESD)	Using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act 1993. The use of sustainability and sustainable in this manual relate to ESD.
effective warning time	The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.
emergency management	A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.
flash flooding	Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
flood awareness	Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.
flood education	Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves an their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.
flood fringe areas	The remaining area of flood prone land after floodway and flood storage areas have been defined.
flood liable land	Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).
flood mitigation standard	The average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.
floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
floodplain risk management options	The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
floodplain risk management plan	A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and 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)	FPL's are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the "standard flood event" in the 1986 manual.
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.
flood readiness	Flood readiness is an ability to react within the effective warning time.
flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. **existing flood risk:** the risk a community is exposed to as a result of its location on the floodplain. **future flood risk:** the risk a community may be exposed to as a result of new development on the floodplain. **continuing flood risk:** the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.
flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.
freeboard	Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
habitable room	**in a residential situation:** a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom. **in an industrial or commercial situation:** an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.
hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to

	the community. Definitions of high and low hazard categories are provided in the Manual.
hydraulics	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
hydrograph	A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
hydrology	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
local drainage	Are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.
mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
major drainage	Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purpose of this manual major drainage involves: • the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or • water depths generally in excess of 0.3 m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or • major overland flow paths through developed areas outside of defined drainage reserves; and/or • the potential to affect a number of buildings along the major flow path.
mathematical/computer models	The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
merit approach	The merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well being of the State's rivers and floodplains. The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into Council plans, policy and EPIs. At a site specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local floodplain risk management policy and EPIs.
minor, moderate and major flooding	Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood: **minor flooding:** causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded.

	moderate flooding: low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered. **major flooding:** appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.
modification measures	Measures that modify either the flood, the property or the response to flooding. Examples are indicated in Table 2.1 with further discussion in the Manual.
peak discharge	The maximum discharge occurring during a flood event.
Probable Maximum Flood (PMF)	The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.
Probable Maximum Precipitation (PMP)	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
probability	A statistical measure of the expected chance of flooding (see AEP).
risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	Equivalent to “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.