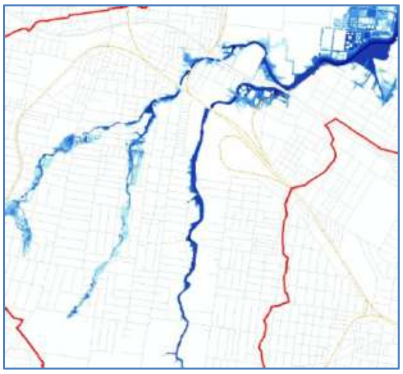
DUCK RIVER AND DUCK CREEK
FLOOD STUDY REVIEW



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wma water

Level 2, 160 Clarence Street
Sydney, NSW, 2000

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

DUCK RIVER AND DUCK CREEK FLOOD STUDY REVIEW

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Client Parramatta City Council	**Client's Representative** Paul Hackney
Authors R Dewar M Chadwick	**Prepared by**
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AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ARI	Average Recurrence Interval
ALS	Airborne Laser Scanning
BoM	Bureau of Meteorology
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DECC	Department of Environment and Climate Change (now Office of Environment and Heritage)
FPL	Flood Planning Level
GIS	Geographic Information System
IFD	Intensity-Frequency-Duration of design rainfall
IPCC	Intergovernmental Panel on Climate Change
LEP	Local Environmental Plan
LGA	Local Government Area
m	metre
m^3/s	cubic metres per second
mAHD	metres above Australian Height Datum
PMF	Probable Maximum Flood
SMCMA	Sydney Metro Catchment Management Authority
SWP	Sydney Water Pipeline
TUFLOW	one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software program (hydraulic computer model)
WBNM	Watershed Bounded Network Model (hydrologic computer model)
1D	One dimensional hydraulic computer model
2D	Two dimensional hydraulic computer model

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FOREWORD

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

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

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

1. ***Flood Study -*** determine the nature and extent of the flood problem.
2. ***Floodplain Risk Management Study -*** evaluates management options for the floodplain in respect of both existing and proposed development.
3. ***Floodplain Risk Management Plan -*** involves formal adoption by Council of a plan of management for the floodplain.
4. ***Implementation of the Plan -*** construction of flood mitigation works to protect existing development, use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

The Flood Study constitutes the first stage of the management process for the areas adjacent to the main creek/river channel of the Duck River catchment which includes Duck River, Duck Creek and Little Duck Creek. These areas have had flood studies conducted in previous years but as part of the Duck River and Duck Creek Floodplain Risk Management Study a review of the Flood Studies has been undertaken. The principal reason for this review was to ensure:

- consistency in the approach within the Parramatta City Council and Auburn Council local government areas (LGA); and
- that the results are compatible with the approach adopted within the upstream Bankstown City Council LGA.

This Flood Study Review supersedes the previous flood studies and provides the basis for the future management of flood liable lands along the main channel of Duck River and Duck Creek within the Parramatta and Auburn City Council LGAs. This study considers inundation from overtopping of the main channel of Duck River and Duck Creek only (i.e. mainstream flooding) and does not consider inundation within the local catchments which contribute to the main channel system.

EXECUTIVE SUMMARY

The NSW Government's Flood Policy provides for:

- a framework to ensure the sustainable use of floodplain environments,
- solutions to flooding problems,
- a means of ensuring new development is compatible with the flood hazard.

Implementation of the Policy requires a four stage approach, the first of which is preparation of a Flood Study (this document) to determine the nature and extent of the flood problem.

Duck River has a catchment area of approximately 41km^2 to its confluence with the Parramatta River with the main creeks comprising:

- the upper Duck River catchment (8 km^2) within Bankstown City Council LGA,
- the lower Duck River catchment (17 km^2) within Parramatta and Auburn City Council LGAs,
- the Duck Creek and Little Duck Creek catchments (9 km^2) within Parramatta and Holroyd City Council LGAs,
- the A'Becketts Creek catchment (7 km^2) within Parramatta and Holroyd City Councils LGAs.

The specific aims of this review of the Duck River and Duck Creek Flood Study are to:

- define mainstream flood behavior in the Duck River and Duck Creek catchment within the Parramatta and Auburn Council LGA that is compatible with the recently completed Upper Duck River Flood Study completed for Bankstown City Council,
- prepare flood hazard and flood extent mapping based on airborne laser scanning survey,
- prepare suitable models of the catchment and floodplain for use in a subsequent Floodplain Risk Management Study.

Description of Creek System: The study area for this review includes only the Duck River, Duck Creek and Little Duck Creek catchments within Parramatta and Auburn City Council local government areas (LGA). The remainder of the Duck River catchment is included within the upper Duck River catchment Flood Study prepared for Bankstown City Council (completed in 2009) and the A'Becketts Creek catchment Flood Study prepared for Parramatta City Council (currently in draft form).

The study area largely consists of residential developments with conglomerations of industrial and commercial developments and large areas of open space (parks, golf courses) adjacent to the main creek channel.

Available Data: Airborne Laser Scanning (ALS) survey (obtained for Parramatta in 2001 and Auburn in 2006) was available for the entire study area and was used to define the overbank topography for the hydraulic models. ALS data for the Parramatta LGA dated 2006 was not used due to the low quality of accuracy.

Previous reports were available to describe the past history of flooding in the catchment. The main historical flood events occurred in April 1974, April 1969 and April 1988, however only a very limited amount of peak height data and no flow data are available.

Approach: The XP-RAFTS hydrologic model established for the previous Flood Studies was used to provide inflow hydrographs to a TUFLOW 2D hydraulic model which was used to determine design flood levels and extents. As the upper Duck River catchment enters into the Parramatta City LGA study area at the Sydney Water pipeline, flows from the Bankstown City Council upper Duck River catchment Flood Study were adopted as the upstream inflows on Duck River. This approach ensures compatibility between the upper and lower Duck River Flood Studies and a verification process was undertaken to confirm the validity of these flows.

Validation against Historical Flood Levels: Due to the lack of available data a rigorous calibration of the TUFLOW model could not be undertaken. However a limited calibration was undertaken based on recorded flood levels. This generally indicates that the results from TUFLOW are similar to historical data.

Determination of Design Flood Flows and Levels: Design rainfall data and design rainfall patterns from Australian Rainfall and Runoff were obtained and input to XP-RAFTS to determine design inflows. The lower parts of the TUFLOW model are influenced by high water levels in the Parramatta River and these were accounted for in the modeling approach.

Sensitivity analyses were undertaken of both the XP-RAFTS and TUFLOW model results. Due to the limited quantity and quality of the calibration data available and in view of the sensitivity analyses, it is estimated that the "average" order of accuracy of the design flood levels is up to ±0.5m but in places may be up to 1m (in localized areas where blockage occurs or there is a localized hydraulic gradient). This ±0.5m order of accuracy is typical of such studies and can only be improved upon with additional observed flood data to refine the model calibration. With high quality calibration data this can be reduced to ±0.3m.

Outcomes: The main outcomes of this study are:

- full documentation of the methodology and results,
- preparation of flood contour, hazard and extent maps for the study area,
- a modeling platform that will form the basis for a subsequent Floodplain Risk Management Study and Plan.

A key recommendation from this study is to highlight the importance of collecting and maintaining a rigorous database of historical rainfall and flood height data. It is vital that information from future flood events are collected within 24 hours and the magnitude and direction of flow paths accurately recorded.

1. INTRODUCTION

1.1. General

The study area (Figures 1 and 2) includes the Duck River and Duck Creek catchments within the Parramatta City, Bankstown City and Auburn Council local government areas (LGA). The study area drains the suburbs of Rosehill, Silverwater, Granville, South Granville, Auburn, Chester Hill, Guildford, Merrylands, Sefton, Birrong and Regents Park. The land usage within the study area comprises of a mix of residential, industrial and commercial developments together with significant amounts of open space (parks, Auburn and Woodville golf courses). A large part of the floodplain comprises areas of open space.

Flooding problems have been experienced at a number of locations within the study area during periods of heavy rainfall in the past, particularly in April 1969, April 1974 and April 1988. This flooding was described in the Duck River Flood Study (Reference 1 – completed in 2006) and the Duck Creek Sub-catchment Management Plan (Reference 2 – completed in 2003). The Upper Duck River catchment within the Bankstown City Council LGA has been investigated in the Duck River Stormwater Catchment Study (References 3 and 4 – completed in 2007 and 2010). The A'Becketts Creek catchment which joins Duck River downstream of the Great Western Highway has been investigated in Reference 5 (October 2009) and the Parramatta River has been investigated in Reference 6 (completed in 1986) and Reference 7 (completed in 2005). In addition there have been many other studies of the catchment and these reports are referenced in the above studies.

For the present flood study review, the study area comprises the lined and natural open channel systems but does not include the pit/pipe and overland flow systems except where large pipes have been considered under roadways or as part of major hydraulic structures such as the Granville Park detention basin upstream of Woodville Road.

1.2. Objectives

Parramatta City Council engaged WMAwater to undertake a review of the existing Duck River and Duck Creek Flood Studies to:

- undertake design flood analysis for the 20%, 5%, 2% and 1% average exceedance probability (AEP) events and the Probable Maximum Flood (PMF),
- ensure consistency in flood modelling approach for both catchments,
- ensure consistency in flood modelling approach within Auburn and Parramatta LGAs along Duck River,
- ensure compatibility with the outflows from the upper Duck River catchment Flood Study (References 3 and 4). The previous Duck River Flood Study (Reference 1) indicates peak flows significantly higher than those provided in the current upper Duck River Stormwater Catchment Study for Bankstown City Council (Reference 4),
- assess the possible effects of climate change (increase in design rainfalls) in accordance with the Department of Environment, Climate Change and Water's current guidelines (Reference 8). Subsequent advice from NSW Government Departments does not

update this advice regarding rainfall increases due to climate change,
- update the flood extent and hazard mapping to incorporate the most up to date and reliable ALS. Parramatta City Council has ALS from 2001 and 2006 but it was determined that the 2006 ALS was of lesser accuracy than the 2001 dataset and for this reason the 2001 ALS was used. ALS was available for Auburn for 2006. This combined dataset (Parramatta 2001 and Auburn 2006) was provided by the Upper Parramatta River Catchment Trust (as part of the study this dataset was verified using available survey from Reference 1),
- resolve anomalies with the historical flood height data adopted in the previous studies,
- undertake sensitivity analyses,
- assume consideration of blockage at each culvert,
- identify properties inundated and assign design flood levels,
- adopt downstream water levels consistent with those in the Lower Parramatta River Flood Study Review of May 2005 (Reference 7).

This report details the results and findings of the investigations. The key elements include:
- description of study area,
- review of previous reports,
- a summary of available historical flood related data,
- calibration of the hydrologic and hydraulic models,
- definition of the design flood behaviour for existing conditions through the analysis and interpretation of model results.

This review has relied upon information provided in References 1 to 7 and these references should be viewed for further background information.

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

2. BACKGROUND

2.1. Study Area

Duck River has a catchment area of approximately 41km^2 to its confluence with the Parramatta River with the main creeks comprising:

- the upper Duck River catchment (8 km^2) within Bankstown City Council LGA,
- the lower Duck River catchment (17 km^2) within Parramatta and Auburn City Council LGAs,
- the Duck Creek and Little Duck Creek catchments (9 km^2) within Parramatta and Holroyd City Council LGAs,
- the A'Becketts Creek catchment (7 km^2) within Parramatta and Holroyd City Councils LGAs.

The study area comprises the Duck River and Duck Creek (including Little Duck Creek) catchments within the Auburn and Parramatta City Council LGAs (Figures 1 and 2) and the lower parts of A'Becketts Creek within the Parramatta City Council LGA.

2.1.1. Duck River Catchment

The Duck River catchment commences in the Yagoona West suburb and the drainage travels in a northerly direction through the suburbs of Birrong and Sefton before crossing under the Sydney Water pipeline which forms the divide between the Bankstown and Parramatta City Council LGAs.

Within the Bankstown City Council LGA the open channel is almost entirely concrete lined with the upper parts draining by overland flow and a pit and pipe network. There are approximately five kilometres of open channel system (trapezoidal or rectangular section) with wider sections as the upstream catchment increases. There are closed channels under roads and railways.

Downstream of the Sydney Water pipeline the channel is in a semi natural state (unlined) and is crossed by several bridges and pipelines. In places the channel is deeply incised and anecdotal evidence suggests that in places the floodplain has been filled or landscaped for sporting fields or areas of open space. The main channel is vegetated to varying extents and in places extensive bank re-vegetation has occurred. In the lower parts the channel is lined by mangroves.

The floodplain largely consists of parks (Norford, Hislop, Everley, Rosnay Golf Course, Progress, Marshall Reserve, Auburn Botanic Gardens, Oriole, Mona) from the Sydney Water pipeline to Mona Street. Further downstream the residential areas encroach on the fringes of the floodplain with industrial developments fronting the channel from upstream of the main Southern Railway to its junction with the Parramatta River upstream of Silverwater Road.

The catchment is predominately occupied by detached residential developments with higher density villa and unit developments in parts. There is considerable industrial development in the lower parts and scattered commercial development throughout.

2.1.2. Duck Creek and Little Duck Creek

West of the main Southern Railway the catchment is within the Holroyd City Council LGA. Duck Creek and Little Duck Creek have similar sized catchments to their confluence upstream of the main Southern Railway. Both catchments are largely occupied by medium to high density residential areas (Reference 2) and drained by lined open channels. The channel only becomes non concrete lined downstream of the M4 Western Motorway.

2.1.3. A'Becketts Creek

A'Becketts Creek is within the Parramatta City Council LGA downstream of the Western rail line as it passes under the M4 Western Motorway. The land to the north of the creek is largely medium to high density residential with the land to the south medium density residential with commercial developments along Parramatta Road. The creek is lined upstream of the Carlingford railway line. The creek is crossed by several bridges between the two rail tracks.

Downstream of the Carlingford railway the creek joins with Duck Creek and further downstream with Duck River.

2.2. Causes of Flooding

Based on the available information, observations from the site and experience in similar catchments, flooding within the study area occurs as a result of three main mechanisms:

- due to flow in excess of the pit and pipe networks being conveyed along roads and overland flowpaths to natural low points, ultimately this flow reaches the open channels of Duck River and Duck Creek (termed **Overland** flooding in this report). Flooding may be exacerbated by inadequate or blocked local drainage systems and restrictions in overland flow paths such as buildings or fences,
- due to Duck River and Duck Creek overtopping their main channels and spreading into the overbank areas (termed **Mainstream** flooding in this report), this may be exacerbated by blockage of hydraulic structures (bridges, culverts) along the main channel.
- due to elevated water levels in the Parramatta River.

The focus of the present study is flooding due to overtopping of the main channels (**Mainstream** flooding) caused by intense rain over the catchment and elevated water levels in the Parramatta River. **Overland** flooding is not considered in this study.

2.3. Review of Previous Flood Studies

This review of previous studies has only been undertaken for those references relevant to each part of the catchment. Other reports are described in each of these references.

2.3.1. Duck River Flood Study, September 2006 (Reference 1)

This study used a 1D Mike-11 hydraulic model to establish design flood levels but used a 2D TUFLOW model for floodplain mapping. ALS was used (presumably the 2001 version) as well as surveyed cross sections. A XP-RAFTS hydrologic model (23 sub catchments) was established to determine inflows from the various tributaries. This study was completed after Reference 7 and thus the hydrologic and hydraulic models included data from Reference 7.

Key features of the results were:

- The 90 minute duration was adopted as the critical storm duration,
- The peak flows from XP-RAFTS (not routed through Mike-11) and for Mike-11 at key locations are provided in Table 1,

Table 1: Duck River – XP-RAFTS and Mike-11 Peak Flow Estimates

	Peak flow for design AEP event (m^3/s)							
Location	**1%**		**2%**		**5%**		**20%**	
Model	**Rafts**	**Mike-11**	**Rafts**	**Mike-11**	**Rafts**	**Mike-11**	**Rafts**	**Mike-11**
Upstream Pipeline (boundary of Parramatta/Bankstown LGAs)	193	178	171	152	151	134	112	100
Downstream Pipeline		156		139		127		103
Wellington Road	277	240	245	211	214	180	158	146
Mona Street	329	246	290	221	250	193	183	149
Upstream Parramatta Road	348	222	306	203	262	175	192	134
Downstream Parramatta Road		195		191		174		135

NOTES: Information for the above table sourced from Reference 1

In a comparison of RAFTS and MIKE-11 flows it should be noted that different methods of storage routing are applied in each model and this may affect the resulting peak flows. Thus the above peak flows are not necessarily directly comparable.

- The comparison of the XP-RAFTS and MIKE-11 model results indicates a significant difference in peak flows. Most notably this occurs for the larger design events and at Mona Street and Parramatta Road,
- The study noted that the 1% AEP peak flow estimates (from XP-RAFTS) were practically identical to those in a 1986 Lower Parramatta River Flood Study (Reference 6) and the current 2005 Lower Parramatta River Flood Study (Reference 7). Overall the estimates were considered "*reasonable and acceptable*",
- The hydraulic model was calibrated/verified using data from the April 1969, April 1974 and April 1988 events and assumed some blockage at the bridge railings at Parramatta, Mona and Wellington Roads. The report noted that changes to catchment conditions (urbanisation, riparian vegetation) may have affected the peak flows obtained for the various historical events used in calibration/verification. The results are shown in Table 2 (scanned from the report),

Table 2: Duck River Flood Study (2006) Historical and Modelled Flood Levels

Locations	Apr-69 Observed mAHD (a)	Estimated mAHD (b)	diff. (m) (b)-(a)	Apr-74 Observed mAHD (c)	Estimated mAHD (d)	diff. (m) (d)-(c)
Confluence of Duck River and Parramatta River	2.47	2.50	0.03	-	2.42	-
Parramatta Road	4.10	4.90	0.80	3.60	3.25	-0.35
Upstream of Mona Street Bridge	6.57	6.69	0.12	6.06	5.47	-0.59

Locations	Apr-88 Observed mAHD (e)	Estimated mAHD (f)	diff. (m) (f)-(e)
Confluence of Duck River and Parramatta River	2.40	2.40	0.00
Parramatta Road	4.20	3.70	-0.50
Upstream of Mona Street Bridge	-	5.67	-

Note: Based on 50% blockage on Parramatta Road bridge railing, and 30% on Mona Road and Wellington Road bridge railings.

As shown in the above table, there is considerable variation between observed and modelled flood levels, particularly at Parramatta Road. This inconsistency was noted in Reference 1 and attributed to the limited amount of reliable rainfall data and uncertainties in the location and magnitude of the historical flood levels.

2.3.2. Duck Creek Sub-Catchment Management Plan, December 2003 (Reference 2)

This study was undertaken by the same consultants as the Duck River Flood Study and incorporated both a Flood Study and a stormwater management strategy. Whilst a DRAINS hydrologic model was setup it was considered that XP-RAFTS (62 sub catchments) be adopted for the overall hydrology of the catchment. Flows were only derived for the 10%, 5% and 1% AEP design events. Mike-11 was used to determine the design flood levels.

Key features of the results were:

- The Mike-11 model was taken from a previous Duck Creek Catchment Management Study (Reference 9) where the August 1986 flood was used for model calibration. Reference 2 provides very limited details on the model calibration except in Appendix C where it is stated that the flood levels were only in the tidal reaches downstream of the A'Becketts Creek junction. No comparison of levels is provided,
- RAFTS was used as the hydrologic model as opposed to RORB which was used in Reference 9,

- The 90 minute duration was adopted as the critical storm duration,
- Blockage was considered at many of the road crossings,
- The design peak flows (from Mike-11) are indicated in Table 3.

Table 3: Duck Creek - Design Peak Flows (Mike-11) from Reference 2

Location	Chainage	Design Flow (m^3/s)	
	(km)	1% AEP	5% AEP
Duck Creek			
Main southern railway	8.245	46.2	35.6
Guildford Park	8.621	51.0	41.4
u/s Baker Street	9.226	58.1	45.9
d/s Woodville Road	10.000	57.5	47.6
Memorial Drive	11.598	106.1	82.9
Parramatta Road	12.058	100.9	81.0
Shirley Street	13.236	116.1	91.0
Little Duck Creek			
u/s Lavinia Street	0.640	39.1	31.3
Guildford Road Branch			
Guildford Rd		14.1	10.7

2.3.3. Duck River Stormwater Catchment Study (References 3 and 4)

In this study a TUFLOW 2D hydraulic model (5m by 5m grid) was established over the entire 8 km^2 catchment with channels and pipes included as 1D elements. Hydrologic inputs were not obtained from a separate hydrologic model such as RORB, XP-RAFTS or WBNM but rather what is commonly termed "*rainfall on the grid or direct rainfall*". In this approach the hydraulic model is used to estimate the flow routing across the catchment. The 2 hour storm duration was determined as the critical storm duration based on the results from the 1% AEP event. No spatial reduction factor was applied to the rainfall and variable rates of initial loss (10mm or nil) and continuing loss (2.5mm/h or nil) were applied, depending upon the terrain.

The report states that there were *"no sufficient flood records to allow a conventional calibration of the TUFLOW model. Model parameters were based on industry standards and those adopted for other catchment studies".* Blockage was assumed at pits, bridges and culverts.

The downstream boundary levels at the Sydney Water pipeline was determined based on the results from Reference 1, with some adjustments. The following levels were adopted:

50% AEP	18.5 m AHD,
5% AEP	19.0 m AHD,
1% AEP	19.5 m AHD,
PMF	20.5 m AHD.

Provisional flood mapping was undertaken according to the following criteria.

Flood Risk Category	Description
High	Land below the 100 year ARI flood level that is subject to a high hydraulic hazard (i.e provisional hazard in accordance with the Floodplain Development Manual).
Medium	Land below the 100 year ARI flood level that is NOT subject to a high hydraulic hazard.
Low	Land inundated by the PMF event but not identified as either high flood risk or medium flood risk.

Reference 4 extended the hydraulic modelling work undertaken in Reference 3 to include TUFLOW modelling software upgrades, updated design assumptions (particularly Manning's "n") and changed blockage assumptions. The revised results are indicated in Table 4 for the three design scenarios (blocked, unblocked apart from at the pipeline, fully unblocked).

Table 4: Peak Flows and Levels at Sydney Water Pipeline (Reference 4)

	1% AEP	PMF
Peak Outflow m^3/s (downstream of pipeline)		
Blocked (Council's blockage policy to all pits and structures)	121	247
Unblocked (no blockage apart from at the pipeline)	128	251
Fully unblocked (no blockage at all)	129	285
Peak Flood Level mAHD (upstream of pipeline)		
Blocked (Council's blockage policy to all pits and structures)	19.75	21.08
Unblocked (no blockage apart from at the pipeline)	19.85	21.14
Fully unblocked (no blockage at all)	19.70	21.05

2.3.4. A'Becketts Creek (Reference 5)

This report was prepared for that part of 6.9 km^2 A'Becketts Creek catchment within the Parramatta City Council LGA (approximately 80 hectares). A XP-RAFTS hydrologic model prepared for an earlier 2006 Upper A'Becketts Creek Flood Study (Reference 10) was adopted for use with some minor modifications. A MIKE-11 1D hydraulic model was used to determine design flood levels and velocities. A channel geometry survey from an earlier study together with ALS was used to generate a digital elevation model and this was then used to generate cross sections for use in MIKE-11. Point source inflows were taken from a DRAINS model.

Tailwater levels were obtained from Reference 2.

3. AVAILABLE DATA

3.1. Overview

The first stage in the investigation of flooding matters is to establish the nature, size and frequency of the problem. On large river systems such as the Hawkesbury River there are generally stream height and historical records dating back to the early 1900's, or in some cases even further. However, in small urban catchments such as for Duck River and Duck Creek there are no stream gauges or official historical records available. A picture of flooding must therefore be obtained from an examination of rainfall records and local knowledge. Hence, a comprehensive data collection and review exercise was undertaken with much of the data coming from a number of previous studies.

3.2. Topographic Data

3.2.1. Aerial Laser (ALS) Scanning Survey Data

Ground level survey was available based on Airborne Laser Scanning (ALS) spot levels provided by the Sydney Metro Catchment Management Authority (SMCMA) (Figure 3). This survey comprised ground levels located at approximately 1 m to 2 m intervals throughout the study area. The dataset provided was derived from 2001 ALS data within the Parramatta City Council LGA and 2006 ALS data of the Auburn Council LGA.

During the initial stages of the study, Parramatta City Council provided a more recent (2006) ALS dataset of the LGA. However, a detailed review found the 2006 dataset to be of poor quality and it was not considered suitable for use in the present study. Hence the SMCMA dataset described above was used instead to define the topography of the overbank and floodplain areas and for obtaining ground levels within properties. The ALS data has an assumed vertical order of accuracy of the order of ±0.15 m to within one standard deviation on clear, hard ground. 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 survey. A limited amount (where checks could be made) of checking was undertaken to verify the accuracy of the ALS.

3.2.2. Cross-section Data

Within the study area there is dense vegetation within the stream channel and open water near the junction with the Parramatta River. For these areas the in-bank definition was based on cross sections obtained from the MIKE11 hydraulic models established in the previous Duck River Flood Study (Reference 1) and Duck Creek Sub-catchment Management Plan (Reference 2).

3.3. Rainfall Data

3.3.1. Overview

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

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

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

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

3.3.2. Historical Rainfall Data

There two BoM "operational" gauges rain gauges located within the Duck River study area (Guildford - Woodville Golf Club and Auburn - Rosnay Golf Club) but as they were only established in 1999 they are of no value for use calibration of pre-1990 events. There was another gauge at the Shell Oil refinery at Clyde but this has been discontinued. There are also several BoM gauges in adjacent catchments (refer to Figure 4). For this study the original historical rainfall data from the relevant stations has not been collected as it was already available from the previous studies and there has been no significant flood since.

3.3.3. Design Rainfall

Design Intensity-Frequency-Duration (IFD) information for the study area was obtained from Australian Rainfall and Runoff 1987 (Reference 11). Table 5 shows the corresponding IFD data including the estimated duration and intensities for design storms of various AEPs. Probable Maximum Precipitation estimates were obtained in accordance with current BoM guidelines (Reference 12). Further details regarding the estimation of design floods for this study is presented in Section 7.

Table 5: Duck River Study Area IFD data (Average Rainfall Intensities in mm/hr)

Duration	Average Recurrence Interval (ARI)						
	1 year	2 year	5 year	10 year	20 year	50 year	100 year
5 min	87	111	140	156	178	207	229
10 min	67	85	108	120	137	160	176
15 min	56	71	90	101	115	134	148
20 min	48.5	62	79	88	101	117	129
25 min	43.4	56	70	79	90	105	116
30 min	39.4	51	64	72	82	95	106
45 min	31.6	40.5	51	58	66	77	85
1 hr	26.9	34.5	43.8	49.1	56	66	72
1.5 hr	20.8	26.7	34.2	38.5	44.2	52	57
2 hr	17.3	22.3	28.6	32.3	37.1	43.5	48.3
3 hr	13.3	17.1	22.2	25.1	28.9	34	37.8
4.5 hr	10.2	13.2	17.2	19.5	22.5	26.6	29.6
6 hr	8.45	10.9	14.3	16.3	18.9	22.3	24.9
9 hr	6.49	8.42	11.1	12.7	14.7	17.4	19.5
12 hr	5.38	7	9.26	10.6	12.3	14.6	16.4
18 hr	4.2	5.47	7.26	8.33	9.72	11.6	13
24 hr	3.52	4.59	6.1	7.01	8.19	9.75	10.9
30 hr	3.06	3.99	5.32	6.12	7.15	8.52	9.57
36 hr	2.72	3.55	4.74	5.46	6.38	7.61	8.56
48 hr	2.24	2.93	3.93	4.53	5.3	6.33	7.13
72 hr	1.68	2.2	2.96	3.42	4.01	4.8	5.41

3.4. Historical Flood Information

3.4.1. Overview

There is extensive documentation of past flooding within the catchment contained within previous studies of the Duck River catchment. The key sources of information include the 1986 Lower Parramatta River Study (Reference 6) and the 1991 Duck Creek SWC No. 35 Catchment Management Study (Reference 9).

A summary of available historical flood levels sourced from these reports is provided in Table 6 and Figures 5a and 5b.

Table 6: Summary of Historical Flood Levels

Flood Event	Branch	Location	Observed Flood Level (mAHD)	Documented Comments	Source
April 1969	Duck Creek	South side just north of George St	3.95	Noted reliable	Ref. 6
April 1969	Duck Creek	West of Duck Creek/River confluence, Hill Street	2.47	Noted reliable	Ref. 6
April 1969	Duck River	West side just south of Parramatta Rd	4.10	Noted reliable	Ref. 6
April 1969	Duck River	West side just u/s Mona St Bridge	6.57	Noted reliable	Ref. 6
April 1974	Duck Creek	South side just north of George St	5.12	Noted reliable	Ref. 6
April 1974	Duck River	West side just south of Parramatta Rd	3.60	Noted reliable	Ref. 6
April 1974	Duck Creek	West side just south of Parramatta Rd	3.82	Noted reliable	Ref. 6
April 1974	Duck River	under Mona St Bridge	6.06	Noted reliable	Ref. 6
April 1974	Duck Creek	East side just u/s Memorial Dr	6.41	Noted reliable	Ref. 6
April 1974	Duck Creek	James Ruse Drive	5.15	(refer note 1)	Ref. 9
April 1974	Duck Creek	Carlingford Railway line	5.3	(refer note 1)	Ref. 9
April 1974	Duck Creek	d/s adjacent East Street	5.75	(refer note 1)	Ref. 9
April 1974	Duck Creek	20m d/s main railway line	6.45	(refer note 1)	Ref. 9
April 1974	Duck Creek	80m d/s main railway line	6.5	(refer note 1)	Ref. 9
April 1974	Duck Creek	140m d/s main railway line	6.4	(refer note 1)	Ref. 9
April 1974	Duck Creek	80m u/s William St	6.45	(refer note 1)	Ref. 9
April 1974	Duck Creek	u/s William St	6.45	(refer note 1)	Ref. 9
April 1974	Duck Creek	d/s William St	6.45	(refer note 1)	Ref. 9
April 1974	Duck Creek	30m d/s William St	6.7	(refer note 1)	Ref. 9
April 1974	Duck Creek	d/s The Avenue	9.4	(refer note 1)	Ref. 9
April 1974	Duck Creek	150m u/s Louis St	10.15	(refer note 1)	Ref. 9
April 1974	Duck Creek	70m u/s Louis St	10.45	(refer note 1)	Ref. 9
April 1974	Duck Creek	u/s Claremont St	13.2	(refer note 1)	Ref. 9
April 1974	Duck Creek	50m u/s Claremont St	13.4	(refer note 1)	Ref. 9
April 1974	Duck Creek	u/s Patten Av	15	(refer note 1)	Ref. 9
April 1974	Duck Creek	10m u/s Patten Av	15.2	(refer note 1)	Ref. 9
April 1974	Duck Creek	Baker St	15.2	(refer note 1)	Ref. 9
April 1974	Duck Creek	60m u/s Baker St	15.4	(refer note 1)	Ref. 9
April 1974	Duck Creek	100m u/s Baker St	15.7	(refer note 1)	Ref. 9
April 1974	Duck Creek	110m u/s Baker St	15.9	(refer note 1)	Ref. 9
April 1974	Duck Creek	10m u/s Landsdowne St	17.1	(refer note 1)	Ref. 9
April 1974	Duck Creek	20m u/s Landsdowne St	17.4	(refer note 1)	Ref. 9
April 1974	Duck Creek	100m d/s Oxford St	18.35	(refer note 1)	Ref. 9
April 1974	Duck Creek	d/s Oxford St	19.0	(refer note 1)	Ref. 9

Flood Event	Branch	Location	Observed Flood Level (mAHD)	Documented Comments	Source
April 1974	Duck Creek	u/s Oxford St	19.2	(refer note 1)	Ref. 9
April 1974	Guildford Rd Branch	u/s Woodstock St	21.2	(refer note 1)	Ref. 9
April 1974	Guildford Rd Branch	Bursill St	22.1	(refer note 1)	Ref. 9
April 1974	Guildford Rd Branch	20m d/s Mountford Av	24.1	(refer note 1)	Ref. 9
April 1974	Guildford Rd Branch	d/s Mountford Av	24.45	(refer note 1)	Ref. 9
April 1974	Guildford Rd Branch	d/s Guildford Rd	26.5	(refer note 1)	Ref. 9
April 1974	Little Duck Creek	u/s Elizabeth St	7.5	(refer note 1)	Ref. 9
April 1974	Little Duck Creek	10m u/s Elizabeth St	7.75	(refer note 1)	Ref. 9
April 1974	Little Duck Creek	John St	7.7	(refer note 1)	Ref. 9
April 1974	Little Duck Creek	Louis St	8.0	(refer note 1)	Ref. 9
April 1974	Little Duck Creek	u/s Louis St	8.5	(refer note 1)	Ref. 9
April 1974	Little Duck Creek	Thomas St	9.65	(refer note 1)	Ref. 9
April 1974	Little Duck Creek	u/s Farnell St	11.0	(refer note 1)	Ref. 9
April 1974	Little Duck Creek	Lisgar St	12.45	(refer note 1)	Ref. 9
April 1974	Little Duck Creek	Lackey St	13.35	(refer note 1)	Ref. 9
April 1974	Little Duck Creek	140m u/s Lackey St	14.0	(refer note 1)	Ref. 9
April 1974	Little Duck Creek	Lavinia St	14.6	(refer note 1)	Ref. 9
April 1974	Little Duck Creek	Willoughby St	23.85	(refer note 1)	Ref. 9
April 1974	Little Duck Creek	Caroline St	24.5	(refer note 1)	Ref. 9
April 1974	Little Duck Creek	Rawson Rd	31.2	(refer note 1)	Ref. 9
August 1986	Duck Creek	South side u/s Wentworth St	4.63	Noted reliable	Ref. 9
August 1986	Duck Creek	North side u/s Shirley St	3.65	Noted reliable	Ref. 9
August 1986	Duck Creek	South side d/s Deniehy St	3.19	Noted reliable	Ref. 9
August 1986	Duck Creek	South side d/s Deniehy St	3.2	Noted reliable	Ref. 9
August 1986	Duck Creek	South side near Tennyson St (mid Deniehy and Hill St)	3.14	Noted reliable	Ref. 9
August 1986	Duck Creek	South Side u/s Hill St	2.52	Noted reliable	Ref. 9
unknown	Duck River	East side near confluence with Duck Creek	1.7	unknown	Ref. 9

NOTE 1: The quoted flood levels have been manually estimated (approximately to within ±0.1m) from hard copies of longitudinal profiles presented in Reference 9.

3.4.2. Review of April 1988 Flood Levels, Duck River at Parramatta Road

Based on the hydraulic model validation presented in the 2006 Duck River Flood Study (Reference 1), there was considerable variation between observed and modelled flood levels for different events particularly at Parramatta Road (as noted earlier in Section 2.3.1).

As part of the initial review undertaken for the present study it was also noted that the April 1988 flood level on Duck River at Parramatta Road of 4.2 mAHD quoted in the 2006 Duck River Flood Study (Reference 1) differed from the level of 4.6 mAHD quoted in the 2005 Lower Parramatta River Flood Study (Reference 7) at this location.

To clarify the apparent discrepancy as part of this study:

- enquiries were made to both Parramatta City Council and to the consultants responsible for the preparation of the 2006 Duck River Flood Study (Reference 1),

- a field inspection of the site adjacent to Duck River was undertaken (refer Photo 1 to Photo 3), and
- the recorded information from the April 1988 event as documented in Reference **7** was reviewed in conjunction with available topographic survey of the site (both ALS and hydraulic model cross-sections). A copy of the original April 1988 flood mark and data record is shown in Photo 4 and Figure 6.

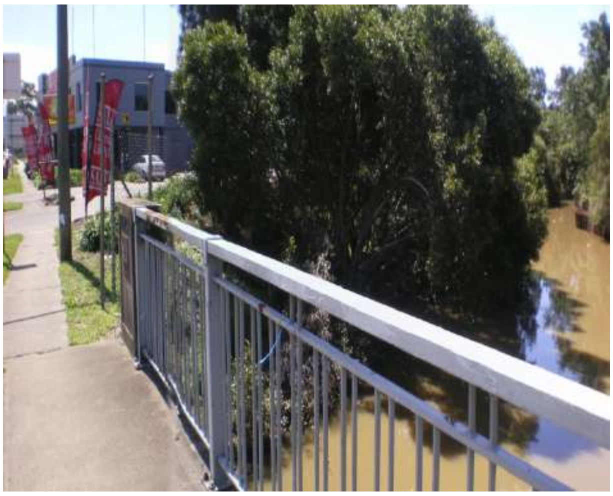

Photo 1: View from Duck River at Parramatta Road looking downstream. Subject site where April 1988 flood level was recorded is to the left of the photo.

Photo 2: Similar location to Photo 1 showing overbank area between Duck River and the subject site.

Photo 3: View from subject site looking downstream adjacent to Duck River (to right of photo). The site has been re-developed since the April 1988 event (refer to Photo 4).

Photo 4: Photo record of April 1988 flood mark approximately 0.4m-0.5m above ground level (Source: Ref. 7).

From a visual inspection of the site in comparison to the available cross-section and ALS data, it does not appear that the ground levels within the site have changed significantly since 2001 (i.e. the date at which the ALS data was obtained). Ground levels along the eastern edge of the site are typically around 3.9 mAHD to 4.0 mAHD grading up towards the building edge (to around 4.1 mAHD to 4.3 mAHD). Unfortunately there is no available survey of the site and surrounding area prior to this date and hence the ground levels on the site as it existed in April 1988 could not be reliably determined. However, it does not appear that any significant off-site works have been undertaken in the overbank area immediately adjacent to the river channel (i.e. it is consistent with the cross-section survey based on the available ALS data). In view of this it is difficult to conclusively identify the magnitude of any filling that may have occurred although it is unlikely that any filling would have been more than 0.3m (based a relative comparison of site and overbank levels).

From information in the 2005 Lower Parramatta River Study (Reference 7) it is estimated that the depth of flooding above the site level for the April 1988 event was in the order of 0.4m. Based on typical levels of the current site this would correspond to an observed flood height of around 4.5 mAHD to 4.6 mAHD (i.e. consistent with that documented in Reference 7). If filling of the site has occurred (estimated to be no more than 0.3m), the observed flood height would be in the order of 4.2 mAHD to 4.3 mAHD (consistent with that documented in Reference 1).

Unfortunately no further information regarding the reliability of this level (as used in Reference 1) could be provided by Parramatta City Council due to staff turnover since the study was undertaken. Whilst subsequent enquiries with the original consultants did not resolve anything further, WMAwater were advised that concerns were held regarding the reliability of the flood level data at this location (Yu/Chadwick *pers.comms. 2010*).

Hence in view of these outcomes it is can only be concluded that the flood level at this location may have been somewhere between 4.2mAHD to 4.6mAHD based on the information available at the time of this study.

When flooding occurs within the catchment in future, it is recommended that Council undertake to collect any available information (photographs, rainfall data, flood heights, depth/extent of inundation and damages to private property etc.) as soon as practicable after the event including after smaller, more frequent flooding such as would be expected in the 50% AEP event.

4. APPROACH ADOPTED

A diagrammatic representation of the Flood Study process is shown in Diagram 1. The urbanised nature of the study area with its mix of pervious and impervious surfaces, and existing piped and overland flow drainage systems has created a complex hydrologic and hydraulic flow regime. Inflow hydrographs for the sub-catchments were used to define inflow boundary conditions to the TUFLOW 1D/2D unsteady flow hydraulic model. The TUFLOW hydraulic model assessed the runoff passing through the stormwater network and floodplain by using the channel survey details, ALS ground height data and various inflow boundaries.

With the limited amount of flood height data available and given the lack of any stream gaugings, the parameters adopted in the model were based on engineering judgement and experience. A limited model validation was undertaken although the outcomes of are limited value due to a number of factors. However, an extensive sensitivity analysis was undertaken to assess the impacts of different modelling assumptions in terms of the adopted 1% AEP design event. Historical information was also compared to design flood estimates as a further check on the validity of the modelled behaviour.

The adopted TUFLOW model was then used to quantify the design flood behaviour for a range of design storm events up to and including the Probable Maximum Flood (PMF). The methodology and outcomes of this component of the study are described in the following sections.

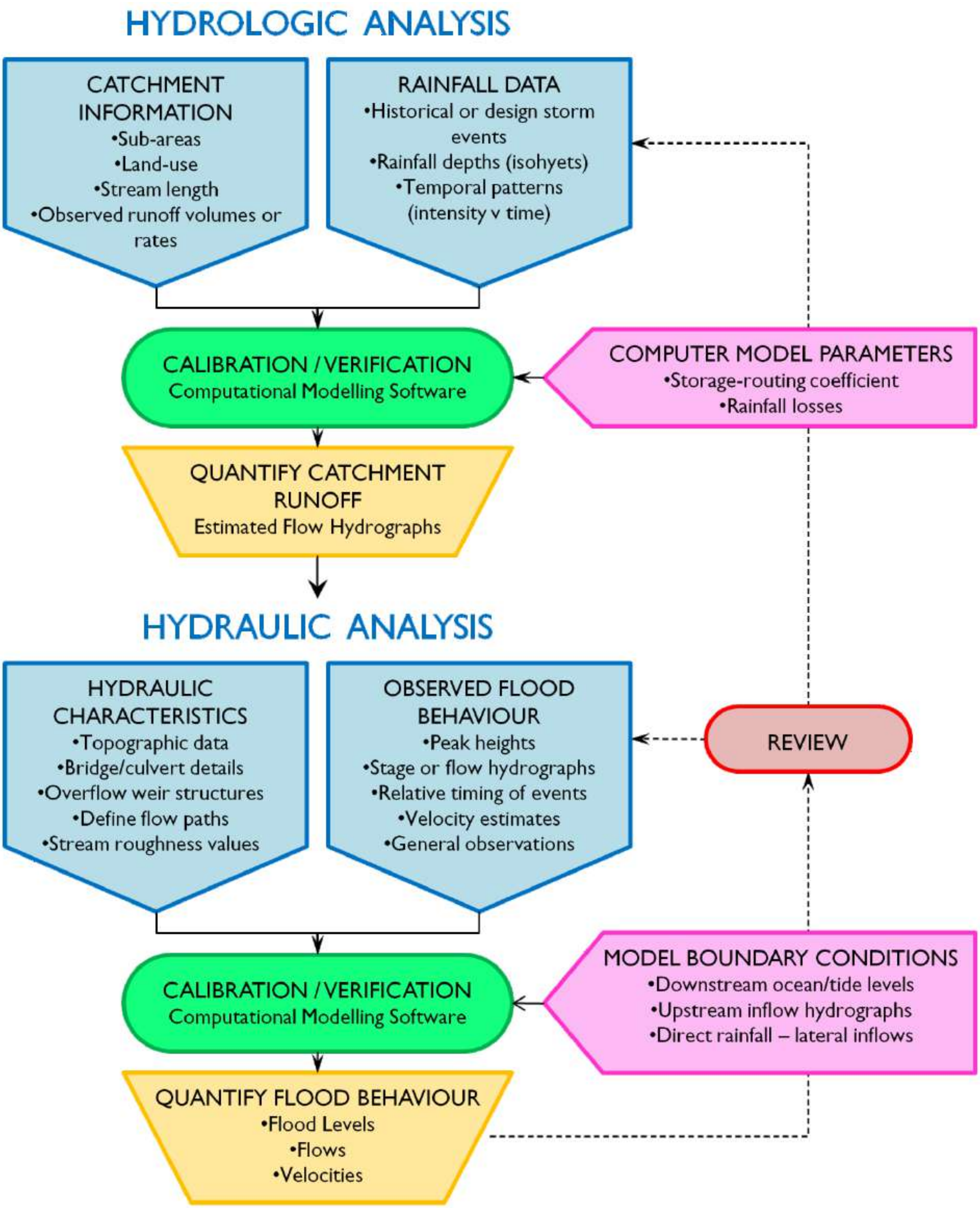

Diagram 1 Flood Study Process

5. HYDROLOGIC MODEL

5.1. Background

Techniques suitable for design flood estimation in an urban environment are described in ARR87 (Reference 11). These techniques range from simple procedures to estimate peak flows (e.g. Probabilistic Rational Method calculations), to more complex rainfall-runoff routing models that estimate complete flow hydrographs and can be calibrated to recorded flow data.

The rainfall-runoff routing model XP-RAFTS was used to estimate the hydrologic response of the catchment. The software was previously adopted for the Lower Parramatta River study (Reference 7), as well as for most of the tributaries. The model was used to generate flow hydrographs for the historical floods using the limited amount of available rainfall data. The model was also used to generate discharge hydrographs for the design and PMF events.

For the present study the catchment hydrology has been determined making use of existing models prepared as part of previous flood studies. Inflows from the Upper Duck River catchment within the Bankstown City Council LGA were based on model results from the 2010 Bankstown Duck River Flood Modelling Study (Reference 4). For the A'Becketts Creek catchment, design flow hydrographs were estimated using an existing XP-RAFTS model provided by Parramatta City Council (Reference 5). An existing XP-RAFTS hydrologic model of the entire catchment (established as part of the previous Duck River and Duck Creek studies – References 1 and 2) was used to estimate runoff hydrographs for the remaining portion of the catchment. The model layouts are shown in Figure 7.

5.2. XP-RAFTS Model Parameters

All XP-RAFTS model parameters (including Bx factors) were maintained as per existing studies with the exception of rainfall loss assumptions. For this study, the design rainfall losses were adjusted to ensure consistent losses were applied across all XP-RAFTS models. The losses were adopted in accordance with recommended values in Australian Rainfall and Runoff (Reference 11). The adopted parameters are shown in Table 7.

Table 7: XP-RAFTS Model Parameters

Parameter	Pervious Areas	Impervious Areas
Manning's 'n'	0.025	0.015
Initial Loss (mm)	10	5
Continuing Loss (mm)	2.5	0
BX Factor (Duck River, A'Becketts Ck)	1.0	
BX Factor (Duck Creek)	1.1	

Further details regarding the existing XP-RAFTS models used for this study can be found in References 1, 2, 5 and 6.

6. HYDRAULIC MODEL

6.1. TUFLOW Background

The TUFLOW modelling package includes a finite difference numerical model for the solution of the depth averaged shallow water flow equations in two dimensions (2D). The TUFLOW software has been widely used for a range of similar floodplain projects both internationally and within Australia. 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 TUFLOW model build used in this study is 2010-10-AA-iSP-64, further details regarding TUFLOW software can be found in Reference 12.

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

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

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

6.2. Model Topography and Extents

6.2.1. Model Domain

Given the study objectives and the availability of both ALS and cross-section data, an integrated one-dimensional/two-dimensional 1D/2D hydrodynamic model is the most suitable approach to assess hydraulic behaviour. The floodplain and overbank areas were defined as part of the 2D model domain whilst in-bank features (e.g. constructed stormwater channels, waterway crossing and Duck River waterway area) were represented in 1D. The 1D components of the model were dynamically linked to the 2D model domain. 1D cross-sections for in-bank features were based directly on the existing MIKE11 cross-sections for the Duck Creek/Duck River systems.

The TUFLOW hydraulic model of the study area was divided into three separate models (Duck River, Duck Creek and the Confluence) for ease of use and to ensure computational runtimes were kept to practical limits (refer to Figure 8). The results from each model are then combined to produce a single integrated set of results for the study area. For each design event, the upper models were first run using preliminary tailwater conditions - the corresponding outflows from these models were then used as input into the lower confluence model. The results from the confluence model were then used to provide refined dynamic tailwater estimates for use as downstream boundary conditions for the upper model. The considerable overlap between models and the presence of well-defined hydraulic controls in these areas ensures that any boundary condition assumptions did not influence the combined set of model results ultimately used for interpretation and mapping.

For all models, a 2m by 2m 2D grid was generated from the ALS data (refer to Section 3.2.1). The in-channel cross-sections and definition of waterway crossings were based on the existing Parramatta City Council MIKE11 models of Duck River and Duck Creek (References 1 and 2).

6.2.2. Hydraulic Model for PMF

The TUFLOW model was predominantly established to simulate floods up to and including the 1% AEP event. For larger events such as the PMF floodwaters are likely to significantly damage property, fences and other structures and in this way cause flow to "take a different route". The high flows also tend to cause instability issues and thus for the PMF event all 1D channels in the Duck Creek and lower Duck River areas were converted to 2D channels. The 2D channels were simplified and a box channel was assumed to William Street in Duck Creek. ALS data was used to define the flow paths but at some locations this is of limited accuracy. It is likely there are other openings under the M4 motorway that have not been accurately identified in the available survey which may affect PMF results.

6.2.3. Buildings

All buildings within approximately the 1% AEP floodplain were assumed to act as flow obstructions with the outlines determined from aerial photography. For this study it has been considered that properties immediately adjacent to the main drainage channels would not be part of the effective flow path due to the presence of fences and buildings. However inundation into these properties has been allowed in the model where this is likely to occur as a result of road overtopping or flows entering the site via an overland flowpath. For these situations:

- high Manning's "n" coefficients were defined within property boundaries (n = 0.15 to 0.20),
- the flow capacity of property fences aligned normal to the general flow direction was reduced to 10%.

6.2.4. Waterway Crossings

Waterway crossings were generally defined in the model as composite control structures with capacity for both culvert/bridge throughflow in combination with road overtopping. Each crossing was defined using details from the existing MIKE11 models of Duck Creek and Duck River. In some locations these datasets were supplemented with additional information obtained from field inspections.

All structures having a waterway opening less than 6.1m (as measured in the diagonal and based on a review of the blockage in the August 1998 flood at North Wollongong by Wollongong City Council) were assumed to be 50% blocked for the base case design event modelling. The impact of different blockage assumptions at these structures was examined as part of the sensitivity analyses. (for the no blockage and 100% blockage scenarios).

6.3. Boundary Conditions

6.3.1. Design Inflows

Upper Duck River Catchment within Bankstown City Council LGA

The upstream boundary of the Parramatta City Council Duck River hydraulic model is located just downstream of the Sydney Water pipeline near the LGA boundary. For each design event the corresponding inflow hydrograph at this location was taken directly from model results documented in References 3 and 4. The inflows from the upper Duck River catchment were based on the 2 hour storm duration for each design event up to the 1% AEP (100 year ARI) event.

As part of the review of existing datasets undertaken for the present study it became apparent that the most recent estimate of the 1% AEP (1 in 100 year) flow as determined from References 3 and 4 was significantly different from corresponding estimates reported in earlier studies (refer to Table 8).

Table 8: Flow Estimates for upper Duck River catchment within Bankstown LGA

Study	1% AEP (100 year ARI) Flow at Sydney Water Pipeline	Comments
Duck River Flood Study (2006) – Reference 1	201 m^3/s	Based on results from XP-RAFTS hydrological model
C14 Duck River TUFLOW Flood Model **Update Report Addendum (2010) – Reference 4**	121 m^3/s	Based on direct "rainfall on grid" approach (2D hydrologic/hydraulic modelling)

As can be seen from Table 8 the flow estimates have been derived using very different hydrological modelling methods. However, when comparing the modelling approaches, the 2010 study can better represent the effects of hydraulic storage within the catchment in comparison to the XP-RAFTS model used in the 2006 study. A review of the upper catchment and TUFLOW modelling results from within the Bankstown area indicated that there are several flood storage features that were not accounted for in the 2006 XP-RAFTS model including:

- flood storage in large open space areas including Maluga Passive Park and Jim Ring Reserve.
- features likely to act as hydraulic controls (e.g. Sydney Water pipeline and Carlingford Road).

It is considered that the hydraulic control and flood storage provided by these features could account for the difference in flow estimates between the two modelling approaches.

To confirm this, the 2006 XP-RAFTS model was modified to allow for the above features and re-run for the 2 hour duration 1% AEP event. The subsequent XP-RAFTS estimates were found to be within 20% of the 2010 estimates from the Bankstown TUFLOW model for reasonable storage assumptions in the XP-RAFTS model. Given the simplistic hydraulic modelling approach used in the XP-RAFTS model (as compared to the more detailed 2D TUFLOW hydraulic model) it is considered that the flow discrepancies noted in Table 8 can be attributed to effects of flood storage within the Bankstown portion of the catchment. On this basis, design inflows from the upper Duck River catchment used for the present study were based on the TUFLOW results reported in References 3 and 4.

A'Becketts Creek Catchment
Design inflow hydrographs at the downstream end of the A'Becketts Creek catchment were obtained from the existing XP-RAFTS model used for the recent A'Becketts Creek Flood Study (Reference 5).

Remaining Catchments
For the remaining portions of the Duck River and Duck Creek catchments, design inflow hydrographs were obtained using existing XP-RAFTS models prepared as part of previous studies (References 1 and 2 Duck River Flood Study and Duck Creek Study). Inflows from these local sub-catchments were defined as point source flow boundaries suitably located along the Duck Creek and Duck River systems.

6.3.2. Tailwater Conditions

The external tailwater boundary at the confluence of Duck River and Parramatta River was defined using:

- observed levels for historical events (as reported in Reference 1 –Duck River Flood Study) and
- reported design flood levels from the 2005 Lower Parramatta River Floodplain Risk Management Study – Flood Study Review (Reference 7).

In each case, the boundary condition was specified as a constant tailwater level (refer Table 9).

Table 9: Adopted Parramatta River Tailwater Levels

Event	Tailwater Level (mAHD)	Source
April 1969	2.57	2006 Duck River F.S. (Ref. 1)
April 1974	2.31	2006 Duck River F.S. (Ref. 1)
April 1988	2.40	2006 Duck River F.S. (Ref. 1)
20% AEP (1 in 5 year)	2.22	2005 LPR F.S (Ref 7)
5% AEP (1 in 20 year)	2.66	2005 LPR F.S. (Ref 7)

2% AEP (1 in 50 year)	2.96	2005 LPR F.S. (Ref 7)
1% AEP (1 in 100 year)	3.18	2005 LPR F.S. (Ref 7)
PMF	5.52	2005 LPR F.S. (Ref 7)

6.4. Model Parameters

6.4.1. Manning's 'n' 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'. This factor describes the net influence of bed roughness and incorporates the effects of vegetation and other features which may affect the hydraulic performance of the particular flow path.

The Manning's 'n' values adopted for flowpaths (overland, pipe and in-channel) are shown in Table 10. These values have been adopted based on several site inspections and past experience in similar floodplain environments.

Table 10: TUFLOW Hydraulic model Roughness Coefficients

Surface	Manning's 'n' Adopted
Roads, car parks	0.02
Railway	0.06
Residential within property	0.15 to 0.20
Commercial/industrial	0.15
Recreation/parks	0.05
Light vegetation	0.04
Medium vegetation	0.08
Heavy vegetation	0.15

The sensitivity of the model results to these assumed values is examined as part of an overall sensitivity analysis, the outcomes of which are documented in Section 7.4.

6.4.2. Eddy Viscosity

The 2D numerical scheme for the TUFLOW model includes an allowance for sub-grid scale turbulence and eddies, features that are too small to be modelled directly. These physical processes result in energy loss and can affect the flow behaviour. Within the TUFLOW model the effects of these sub-grid processes are modelled by the introduction of an eddy viscosity formulation, where energy losses are applied either as a constant term or according to the Smagorinsky formulation, in proportion to the flow velocity and the 2D cell edge length. For this assessment, a combination of the constant and Smagorinsky eddy viscosity formulations were used, with coefficients of 0.1 and 0.2 respectively as recommended in the TUFLOW manual (Reference 13).

6.5. Model Calibration and Verification

Ideally the TUFLOW hydraulic model should be calibrated to one historical event and verified using another historical event. There should also be sufficient historical flood height data (preferably for both historical events) to define the flood gradient within the modelling extent. However, as identified in previous studies (e.g. refer to Appendix C of Reference 1):

- there is only a limited amount of historical flood information available for the study area. For example, in Sydney (east of Parramatta) there are only two water level recorders in urban catchments similar to that of the study area,
- rainfall records for past floods are limited and there is a lack of temporal information describing historical rainfall patterns within the catchment (the April 1974 event is a good example of this where pluviometer records are only available well outside the catchment), and
- there appears to be some uncertainty regarding some of the observed flood levels for Duck River, particularly when comparing observations at the same location for different events.

In view of these issues is was not possible to undertake a rigorous calibration/validation for the present study. This is typical of the majority of urban catchments. However, the Duck River models were used to estimate the flooding from past flooding observed in April 1969, April 1974 and April 1988. The results are shown in Table 11 and Figure 9.

Table 11: Comparison of Observed and Modelled flood levels in Duck River

Location	April 1969			April 1974			April 1988		
	Obs. (mAHD)	Modelled (mAHD)	Diff. (m)	Obs. (mAHD)	Modelled (mAHD)	Diff. (m)	Obs. (mAHD)	Modelled (mAHD)	Diff. (m)
Parramatta Road	4.10	4.61	0.51	3.60	2.93	-0.67	4.2/4.6	3.91	-0.39/ -0.79
Upstream of Mona Street Bridge	6.57	6.78	0.21	6.06	5.13	-0.93	-	5.72	-

As can be seen from the results in Table 11, the models were not able to closely reproduce the historical flood behaviour based on the existing rainfall information and default blockage assumptions adopted in the hydraulic model. However, drawing definitive conclusions from these outcomes is difficult as the estimated levels for the April 1969 event are consistently over-estimated, whilst the corresponding behaviour for the April 1974 and April 1988 events appears to be under-estimated. This type of result typically indicates problems with the historical rainfall patterns (i.e. not enough or too much runoff volume). Further, given most of the observed levels are taken at crossings (albeit large crossings) there is also the potential that these may be affected by blockage. Unfortunately, further details regarding the nature of most of the original flood level observations are not available.

In view of the above, the design flood results for a range of events are compared to all historical information to provide an additional measure of validation. Sensitivity analyses on key model assumptions were also undertaken.

A key outcome of this comparison of the model results with the historical data is the importance of accurately collecting historical flood data immediately (within 1 day) after the next flood. This can readily be obtained by visiting the affected area and digitally photographing the various flood levels (some from of debris mark), which can later be accurately surveyed. Unfortunately flood debris marks are quickly destroyed in the clean up or washed away by further rain.

7. DESIGN FLOOD RESULTS

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 homogeneous record of flood levels and flows over a number of decades to give satisfactory results. No such records were available within the catchment. For this reason a *rainfall and runoff routing* approach using the combination of existing model inflows from References 3 and 4 (upper Duck River within Bankstown LGA) and XP-RAFTS model results was adopted for this study to derive inflow hydrographs for input to the TUFLOW hydraulic model, which determines design flood levels, flows and velocities. This approach reflects current engineering practice and is consistent with the quality and quantity of available data.

7.2. Boundary Conditions

7.2.1. Inflow Hydrographs

Inflows from the Upper Duck River catchment within the Bankstown City Council LGA were derived from References 3 and 4.

For local sub-catchments draining with the TUFLOW model domain, local runoff hydrographs were extracted from the XP-RAFTS model and specified as point source inflow boundaries defined at the corresponding 1D section in the TUFLOW model.

7.2.2. Downstream Boundaries

A constant tailwater boundary was used at the downstream limit of the TUFLOW model representing the peak water level in Parramatta River during historical and design storm events.

7.3. Design Events

The 2 hour design storm duration was adopted for all design modelling as this was the critical storm duration adopted in the Bankstown Duck River Stormwater Catchment Study (References 3 and 4). Sensitivity of this adopted duration was examined in the sensitivity analyses (Section 7.4).

The results from the design event modelling provide a description of the design flood behaviour within the study area. Information such as peak flood levels; flows and depths were extracted and have been documented as part of this report. In addition, the model results have also been produced in a digital format that can be readily imported into Council's GIS systems. Tables 12 and 13 provide a summary of design flood levels and flows at key locations for each event.

Peak height profiles for design events are provided on Figure 10. Design flood extents and depths are provided on Figures 11 to 15 for the 20%, 5%, 2% and 1% AEP events and the PMF. Maps indicating flood velocity, hazard (as defined in NSW Floodplain Development Manual – Reference 14) are provided on Figure 16 to 19.

Hydraulic categorisations for the 5%, 1% AEP and PMF events are provided on Figures 20 to 22. There is no technical definition of hydraulic categorisation and different approaches are used by different consultants and authorities. For this study hydraulic categorisation was defined as:

- Floodway = Velocity * Depth > 0.25 m^2/s AND velocity > 0.25 m/s OR Velocity > 1 m/s. The remainder of the floodplain outside the Floodway becomes either Flood Storage or Flood Fringe,
- Flood Storage is defined where the depth is greater than 1.0 m outside the Floodway,
- Flood Fringe where the depth is less than 1.0 m outside the Floodway.

Table 12: Summary of Peak Design Flood Levels at Key Locations

		Level (mAHD)				
Branch	**Location**	**20% AEP**	**5% AEP**	**2% AEP**	**1% AEP**	**PMF**
Duck River	u/s Mona Street	8.5	8.9	9.2	9.3	11.9
Duck River	u/s Wellington Road	5.5	6.1	6.4	6.6	9.1
Duck River	u/s Railway	4.4	5.0	5.4	5.6	8.4
Duck River	u/s Railway footbridge	3.8	4.5	4.8	5.0	8.0
Duck River	Footbridge (u/s Parramatta Rd)	3.7	4.3	4.6	4.8	7.4
Duck River	u/s Parra Road	3.6	4.2	4.5	4.7	7.4
Duck River	u/s Footbridge (u/s M4)	3.3	3.7	4.0	4.2	7.0
Duck River	u/s M4	3.3	3.7	4.0	4.2	6.9
Duck River	Confluence Duck Creek & Duck River	3.2	3.7	4.0	4.2	6.8
Duck River	Parramatta River	3.2	3.2	3.2	3.2	5.5
Duck Creek	u/s Mountford Ave	24.2	24.3	24.3	24.4	24.4
Duck Creek	u/s Bursill Street	21.8	21.9	21.9	21.9	22.2
Duck Creek	u/s Woodstock Street	20.8	20.9	20.9	20.9	21.2
Duck Creek	Railway Terrace	20.3	20.4	20.4	20.5	20.7
Duck Creek	Guildford Park	19.5	19.6	19.7	19.7	20.4
Duck Creek	u/s Oxford Street	18.5	18.9	19.0	19.1	20.3
Duck Creek	u/s Lansdowne Street	15.4	16.0	16.2	16.4	17.8
Duck Creek	u/s Bertha Street	14.3	14.9	15.1	15.4	16.9
Duck Creek	u/s Baker Street	14.2	14.8	15.0	15.2	16.3
Duck Creek	u/s Patten Street	13.3	13.7	13.9	14.1	16.1
Duck Creek	u/s Claremont Street	13.1	13.3	13.4	13.4	13.9
Duck Creek	Granville Park basin	12.7	12.9	13.0	13.0	13.5
Duck Creek	u/s Woodville Road	11.7	12.1	12.2	12.2	13.4
Duck Creek	d/s Woodville Road	9.4	10.0	10.3	10.5	13.4
Duck Creek	u/s Louis Street	9.2	9.9	10.2	10.4	12.5
Duck Creek	Adjacent Brunswick Street	7.7	8.1	8.3	8.5	11.6

		Level (mAHD)				
Branch	**Location**	**20% AEP**	**5% AEP**	**2% AEP**	**1% AEP**	**PMF**
Duck Creek	u/s The Avenue	6.6	7.2	7.6	8.0	10.3
Duck Creek	u/s Elizabeth Street	5.8	6.5	7.0	7.3	9.4
Duck Creek	"Dog Park"	5.4	6.3	6.8	7.2	9.3
Duck Creek	Confluence Duck and Little Duck Creek (u/s SWP)	5.3	6.3	6.8	7.1	9.2
Duck Creek	u/s William Street	4.9	6.0	6.5	6.8	9.1
Duck Creek	u/s Memorial Park Drive	4.4	5.1	5.6	6.0	8.7
Duck Creek	u/s Parra Rd	4.2	4.7	5.1	5.4	7.8
Duck Creek	u/s James-Russ	4.1	4.6	4.9	5.1	7.5
Duck Creek	u/s M4	4.1	4.6	4.8	5.0	7.3
Duck Creek	u/s Kay Street	4.1	4.5	4.8	5.0	7.0
Duck Creek	u/s SWP	3.6	4.1	4.5	4.7	6.8
Little Duck Creek	u/s Rawson Road	30.9	31.0	31.0	31.0	31.5
Little Duck Creek	Rawson Road	30.8	30.9	30.9	30.9	31.5
Little Duck Creek	Excelsior Street (u/s channel)	27.9	28.0	28.0	28.0	28.2
Little Duck Creek	u/s Brazier Place	26.8	26.9	27.0	27.0	27.0
Little Duck Creek	Willoughby Street	22.9	23.0	23.0	23.0	23.3
Little Duck Creek	u/s Guildford Road	22.5	22.6	22.6	22.6	23.0
Little Duck Creek	u/s Eve Street	18.9	19.3	19.4	19.5	19.7
Little Duck Creek	u/s Adam Street	16.5	16.7	16.8	16.9	17.4
Little Duck Creek	Lavinia Street	13.9	13.9	14.0	14.0	14.9
Little Duck Creek	u/s Lackey Street	12.1	12.2	12.3	12.3	13.8
Little Duck Creek	u/s Lisgar Street	12.1	12.2	12.2	12.2	13.1
Little Duck Creek	u/s Farnell Street	10.6	10.7	10.8	10.8	11.5
Little Duck Creek	u/s Thomas Street	9.4	9.7	9.9	10.1	10.8
Little Duck Creek	u/s Louis Street	8.3	8.7	8.8	8.9	10.1
Little Duck Creek	u/s John Street	6.6	7.0	7.3	7.6	9.8
Little Duck Creek	u/s Elizabeth Street	6.0	6.8	7.2	7.5	9.4

Table 13: Summary of Peak Design Flow Estimates at Key Locations

		Flow (m^3/s)				
Branch	**Location**	**20% AEP**	**5% AEP**	**2% AEP**	**1% AEP**	**PMF**
Duck River	u/s Mona Street	103	135	154	164	508
Duck River	u/s Wellington Road	91	119	135	141	403
Duck River	u/s Railway	99	132	153	164	231
Duck River	u/s Railway footbridge	99	132	154	165	213
Duck River	u/s Parra Road	100	133	159	168	225
Duck River	u/s M4	100	127	149	156	318
Duck Creek	u/s Mountford Ave	7.9	11	12	14	19
Duck Creek	u/s Bursill Street	10	15	17	19	29
Duck Creek	Railway Terrace	20	25	28	31	34
Duck Creek	Guildford Park	20	27	32	36	120
Duck Creek	u/s Oxford Street	21	30	36	42	128
Duck Creek	u/s Lansdowne Street	29	41	46	53	133
Duck Creek	u/s Bertha Street	29	40	45	51	132
Duck Creek	u/s Baker Street	29	40	44	50	134
Duck Creek	u/s Patten Street	31	41	46	52	149
Duck Creek	u/s Claremont Street	29	41	47	52	135
Duck Creek	d/s Woodville Road	28	43	51	60	153
Duck Creek	u/s Louis Street	28	40	46	53	154

		Flow (m³/s)				
Branch	**Location**	**20% AEP**	**5% AEP**	**2% AEP**	**1% AEP**	**PMF**
Duck Creek	u/s The Avenue	29	39	48	49	175
Duck Creek	u/s Elizabeth Street	31	42	53	53	176
Duck Creek	Confluence (u/s SWP)	48	62	71	79	298
Duck Creek	u/s William Street	48	62	73	85	285
Duck Creek	u/s Memorial Park Drive	49	63	73	80	259
Duck Creek	u/s Parramatta Road	48	62	73	82	203
Duck Creek	u/s James-Russ	51	64	72	83	217
Duck Creek	u/s SWP	92	110	121	130	100
Little Duck Creek	Rawson Road	4.6	7.1	8.4	10	19
Little Duck Creek	Excelsior Street (u/s channel)	1.6	2.4	3.3	4.4	23
Little Duck Creek	u/s Brazier Place	5.4	8.1	10	12	36
Little Duck Creek	Willoughby Street	6.2	9.6	11	13	44
Little Duck Creek	u/s Guildford Road	5.6	8.8	11	12	56
Little Duck Creek	u/s Eve Street	7.1	11	14	16	60
Little Duck Creek	u/s Adam Street	7.6	13	17	19	76
Little Duck Creek	Lavinia Street	10	14	16	19	92
Little Duck Creek	u/s Lackey Street	16	21	24	26	115
Little Duck Creek	u/s Lisgar Street	21	31	37	42	115
Little Duck Creek	u/s Farnell Street	16	25	29	34	132
Little Duck Creek	u/s Thomas Street	18	25	28	31	142
Little Duck Creek	u/s Louis Street	22	31	41	49	147
Little Duck Creek	u/s John Street	21	35	44	52	132
Little Duck Creek	u/s Elizabeth Street	18	25	28	30	128

7.4. Sensitivity Analyses

7.4.1. Overview

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

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

- -10% and +10% change in rainfall,
- varying the lag parameter used in the XP-RAFTS hydrologic model by ± 20% (Bx factor),
- -15% and +20% change in Manning's 'n' values,
- varying the blockage assumptions at structures with a diagonal opening width of less than 6.1m. Analyses were undertaken for the case of no blockage and 100% blockage (note: the base case assumed 50% blockage).

The outcomes are presented and discussed in the following sections.

7.4.2. Climate Change Assessment

The 2005 Floodplain Development Manual (Reference 14) requires that Flood Studies and Floodplain Risk Management Studies consider the impacts of climate change on flood behaviour. Hence the sensitivity of the model results to various climate change scenarios was also assessed as part of this study.

Within the last three years current best practice for considering the impacts of climate change (in terms of ocean level rise and rainfall increase) has been evolving rapidly. Key developments have included:

- the release of the Fourth Assessment Report by the Inter-governmental Panel on Climate Change (IPCC) in February 2007, which updated the Third IPCC Assessment Report of 2001;
- the preparation of Climate Change Adaptation Actions for Local Government for the Australian Greenhouse Office in mid 2007;
- the preparation of Climate Change in Australia by CSIRO in late 2007, which provides an Australian focus on Climate Change 2007;
- the release of the Floodplain Risk Management Guideline Practical Consideration of Climate Change by the NSW Department of Environment and Climate Change in October 2007 (referred to herein as the DECC Guideline 2007 – Reference 8).

In accordance with the DECC Guideline 2007, the following climate change scenarios involving an increase (by the year 2100) in the peak rainfall and storm volume are considered:

- low level rainfall increase = +10%
- medium level rainfall increase = +20%
- high level rainfall increase = +30%

To assess the effects of an increase in peak rainfall and storm volume each ordinate design rainfall hyetograph was increased by the nominated DECC 2007 value. External catchment inflows were similarly increased by the nominated DECC 2007 value.

A high degree of uncertainty surrounds the likely impact of climate change upon rainfall. Hence, a range of increased rainfalls have been assessed for this study. It is understood that work currently being undertaken by CSIRO and the Sydney Catchment Authority should provide better direction on the possible impacts to rainfall.

In order to asses the impact of ocean level rise a conservative approach (the impact of a 0.9m sea level rise will equate to a smaller increase the further upstream from the ocean) was adopted by increasing tailwater levels in the Parramatta River by + 0.9 m.

Since the modelling work for this report was carried out, NSW State Government Policy about sea level rise has changed. On 8th September 2012 the NSW Government announced its Stage One Coastal Management Reforms. As part of these reforms, the NSW Government no longer recommends state-wide sea level rise benchmarks for use by local councils, with councils having the flexibility to consider local conditions when determining local future hazards.

Accordingly councils should consider information on historical and projected future sea level rise that is widely accepted by competent scientific opinion. This may include information in the NSW Chief Scientist and Engineer's Report entitled 'Assessment of the Science behind the NSW Government's Sea Level Rise Planning Benchmarks' (April 2012), available at www.chiefscientist.nsw.gov.au/Home/Reports.aspx. The NSW Chief Scientist and Engineer's Report noted the evolving nature of the science, which will provide a clearer picture of the changing sea levels into the future. The report identified that:

- the science behind sea level rise benchmarks from the NSW Sea Level Rise Policy Statement (October 2009) was adequate;
- historically, sea levels have been rising since the early 1880s;
- there is considerable variability in the projections for future sea level rise;
- the science behind future sea level rise projections is continually evolving and improving.

The potential impacts of sea level rise on flooding in the Duck River catchment described in this report have been based on sea level rise projections from the 2009 NSW Sea Level Rise Policy Statement. Given that the Chief Scientist and Engineer's Report identifies the science behind these sea level rise projections is adequate, the three Councils are satisfied that the potential impacts of sea level rise for flooding in the Duck River catchment have been based on the best available information at the time of preparation of this report

7.4.3. Results

The models were run for the 1% AEP 2 hour duration design storm for each of the sensitivity and climate change scenarios described previously. A relative comparison of the peak flows and flood heights at various locations is provided in Tables 14 and 15. These results have been determined relative to the existing conditions (base case) model (which adopts the assumptions as outlined in previous sections).

Impacts of Changes to XP-RAFTS Bx Factor

For Duck Creek and Little Duck Creek the impacts of varying the assumed Bx factor are as expected:

- A decrease in the Bx factor (producing 'peakier' hydrographs) results in slightly increased peak flows (in the order of 5% to 10%) and increases in peak flood level within 0.1m. There are a limited number of locations where the increase in peak flood level was slightly higher but are still less than 0.15m. The greatest relative increase (+0.21m) was found to occur upstream of The Avenue where there is a limited amount of storage available due to the relatively narrow and confined channel in this location.
- Increasing the Bx factor by 10% (which acts to attenuate the estimated local runoff hydrographs) was found to produce converse trends and the peak flood levels and flows were found to decrease. The magnitude of these impacts is comparable to those noted above for the increased Bx factor scenario.
- For Duck River, the majority of inflow is from the Bankstown catchment, which is taken from Reference **4**. As such the sensitivity results do not show the influence

of the Bx factor on flood levels and flows.

Impacts of Blockage Assumptions of 0% and 100% blockage

The channel structures underneath Wellington Road, Mona Street and all other structures along Duck River have a diagonal opening with of greater than 6.1m and as such are not considered for blockage. The impact of changing blockage assumptions is therefore minimal along Duck River.

Flood levels downstream of the railway and upstream of the confluence of Duck River and Duck Creek are lower for both the 0% and 100% blockage scenarios. For the 100% blockage scenario, flood levels in Duck Creek are decreased due to attenuation of flow and this has an impact of as much as -0.07m in Duck River downstream of the railway, for the 0% blockage case the impact is up to -0.05m.

For Duck Creek the 100% blockage scenario results in increased flood levels in the upper reaches and the no blockage scenario results in lower flood levels, as expected due to increased efficiency of hydraulic structures with lower losses in momentum.

For the lower reaches this has the effect of increasing flood levels for the no blockage case due to increased flow. The 100% blockage case decreases flood levels in the lower reaches due to the attenuation of flow from storage in the upper reaches.

Little Duck Creek has similar trends with flood levels increasing upstream of Elizabeth Street due to storage and decreasing downstream of Elizabeth Street. The greatest impact is seen upstream of Thomas Street with levels varying by +/- 0.6m. For the 1% AEP design scenario a large proportion of flow is overland and hence subject to higher losses and low hydraulic efficiency. Assuming blockage to be 100% forces the majority of flow to travel overland, hence increasing storage and flood levels significantly.

Table 14: Sensitivity Analyses –1% AEP Peak Flood Levels (in m)

Location		Base Case	Variations in Rainfall				Variations in Manning's 'n'		Assumed Blockage		BX Factor	
Branch	Description	Peak Flood Level (m AHD)	-10%	+10%	+20%	+30%	-15%	+20%	0%	100%	-20%	+20%
Duck River	u/s Wellington Road	9.32	-0.29	0.24	0.42	0.57	-0.32	0.32	-	-	-0.03	-
Duck River	u/s Mona Street	6.58	-0.23	0.22	0.43	0.60	-0.17	0.18	-	-	-0.02	-
Duck River	u/s Railway	5.55	-0.21	0.21	0.40	0.59	-0.03	0.04	-	-	-	-
Duck River	u/s Railway Footbridge	5.01	-0.22	0.07	0.19	0.28	-0.21	0.07	-0.06	-0.08	-0.07	-0.08
Duck River	Footbridge (u/s Parramatta Rd)	4.79	-0.18	0.06	0.16	0.22	-0.16	0.05	-0.05	-0.06	-0.05	-0.07
Duck River	u/s Parramatta Road	4.66	-0.16	0.06	0.16	0.20	-0.15	0.06	-0.04	-0.06	-0.04	-0.06
Duck River	u/s Footbridge (u/s M4)	4.25	-0.14	0.08	0.18	0.19	-0.13	0.08	-0.01	-0.05	-0.01	-0.05
Duck River	u/s M4 Motorway	4.23	-0.14	0.08	0.17	0.18	-0.13	0.08	-	-0.05	-0.01	-0.05
Duck River	Duck Creek confluence	4.16	-0.13	0.08	0.17	0.17	-0.12	0.08	-	-0.05	-	-0.04
Duck Creek	u/s Mountford Avenue	24.39	-0.04	0.03	0.06	0.09	-0.04	0.05	-0.07	0.06	0.02	-0.02
Duck Creek	u/s Bursill Street	21.94	-0.03	0.03	0.06	0.07	-	-	-0.07	0.06	0.02	-
Duck Creek	u/s Woodstock Street	20.91	-0.02	0.01	0.03	0.05	-	-	-0.02	-	-	-
Duck Creek	Railway Terrace	20.46	-0.03	0.03	0.06	0.11	-0.02	0.12	-0.06	0.02	-	-
Duck Creek	Guildford Park	19.70	-0.04	0.04	0.08	0.11	-0.03	0.03	-0.06	0.05	0.02	-
Duck Creek	u/s Oxford Street	19.13	-0.12	0.08	0.19	0.31	-	-0.05	-	0.02	0.07	-0.05
Duck Creek	u/s Lansdowne Street	16.38	-0.14	0.13	0.22	0.31	-	-	-0.01	0.02	0.07	-0.06
Duck Creek	u/s Bertha Street	15.37	-0.23	0.19	0.32	0.46	-	0.02	-0.01	0.03	0.13	-0.12
Duck Creek	u/s Baker Street	15.25	-0.23	0.19	0.32	0.45	0.02	-0.02	-	0.03	0.13	-0.12
Duck Creek	u/s Patten Street	14.06	-0.16	0.18	0.34	0.53	0.03	0.14	0.02	0.08	0.12	-0.08
Duck Creek	u/s Claremont Street	13.41	-0.05	0.06	0.12	0.17	-0.03	0.06	-0.14	0.11	0.04	-0.02
Duck Creek	Granville Park Basin	12.98	-0.02	0.02	0.05	0.08	-	0.02	-0.06	0.05	0.02	-
Duck Creek	u/s Woodville Road	12.24	-0.07	0.09	0.18	0.23	-	0.06	-0.14	0.16	0.07	-0.02
Duck Creek	d/s Woodville Road	10.46	-0.05	0.12	0.22	0.31	-0.02	0.02	0.07	-0.01	0.07	-0.06
Duck Creek	u/s Louis Street	10.35	-0.06	0.13	0.22	0.31	-	-	0.07	-0.02	0.08	-0.08
Duck Creek	Adjacent Brunswick Street	8.51	-0.23	0.27	0.53	0.78	-0.15	0.15	0.08	-	0.13	-0.09
Duck Creek	u/s The Avenue	7.96	-0.39	0.44	0.82	1.12	-0.10	0.08	0.18	-0.12	0.21	-0.22
Duck Creek	u/s Elizabeth Street	7.29	-0.28	0.25	0.45	0.58	-0.08	0.08	0.14	-0.15	0.10	-0.11
Duck Creek	Park u/s of Little Duck Creek confluence	7.16	-0.28	0.25	0.45	0.57	-0.09	0.09	0.14	-0.15	0.10	-0.10

Location		Base Case	Variations in Rainfall				Variations in Manning's 'n'		Assumed Blockage		BX Factor	
Duck Creek	Little Duck Creek confluence (u/s of pipeline)	7.13	-0.28	0.25	0.44	0.57	-0.09	0.09	0.14	-0.15	0.10	-0.10
Duck Creek	u/s William Street	6.85	-0.27	0.23	0.42	0.52	-0.10	0.11	0.13	-0.14	0.09	-0.10
Duck Creek	u/s Memorial Park Drive	6.00	-0.32	0.31	0.57	0.67	-0.09	0.07	0.16	-0.17	0.11	-0.11
Duck Creek	u/s Parramatta Road	5.39	-0.19	0.18	0.31	0.29	-0.08	0.06	0.08	-0.10	0.06	-0.07
Duck Creek	u/s James Ruse Drive	5.08	-0.16	0.10	0.19	0.12	-0.08	0.08	0.04	-0.06	-	-0.08
Duck Creek	u/s M4 Motorway	5.04	-0.15	0.09	0.18	0.09	-0.09	0.08	0.04	-0.05	-	-0.07
Duck Creek	u/s Kay Street	5.02	-0.14	0.09	0.18	0.09	-0.09	0.08	0.04	-0.05	0.02	-0.06
Duck Creek	u/s Lower Sydney Water pipe	4.67	-0.13	0.10	0.18	0.12	-0.07	0.04	0.02	-0.05	0.02	-0.04
Little Duck Creek	u/s Rawson Road	31.04	-0.02	0.02	0.04	0.06	-	-	-0.04	0.02	0.02	-0.02
Little Duck Creek	Rawson Road	30.92	-0.02	-	0.02	0.04	-0.02	-	-0.04	-	-	-0.02
Little Duck Creek	Excelsior Street (u/s channel)	28.05	-0.03	0.03	0.05	0.07	-	-	-0.07	0.03	0.02	-0.02
Little Duck Creek	u/s Brazier Place	27.04	-0.05	0.05	0.09	0.14	-0.02	0.03	-0.11	0.10	0.03	-0.03
Little Duck Creek	Willoughby Street	23.04	-0.02	0.01	0.03	0.05	-0.02	-	-0.05	0.04	-	-
Little Duck Creek	u/s Guildford Road	22.63	-0.02	0.02	0.05	0.07	-	0.02	-0.07	0.05	-	-
Little Duck Creek	u/s Eve Street	19.46	-0.06	0.03	0.06	0.08	-	-0.03	-0.30	0.17	-	-0.03
Little Duck Creek	u/s Adam Street	16.86	-0.05	0.05	0.09	0.13	-	0.03	-0.10	0.20	0.02	-0.02
Little Duck Creek	Lavinia Street	14.05	-0.05	0.05	0.09	0.15	0.03	-	0.03	-	0.01	-
Little Duck Creek	u/s Lackey Street	12.28	-	0.06	0.09	0.12	0.02	0.06	-0.02	0.07	0.04	-
Little Duck Creek	u/s Lisgar Street	12.23	-	0.05	0.07	0.10	0.03	0.05	-0.05	0.07	0.03	-
Little Duck Creek	u/s Farnell Street	10.83	-0.05	0.05	0.10	0.14	-0.02	0.02	-0.19	0.08	0.03	-0.03
Little Duck Creek	u/s Thomas Street	10.06	-0.14	0.14	0.27	0.39	-	0.02	-0.59	0.50	0.06	-0.06
Little Duck Creek	u/s Louis Street	8.94	-0.17	0.18	0.29	0.36	0.04	-0.03	-0.55	0.33	0.06	-0.08
Little Duck Creek	u/s John Street	7.57	-0.25	0.23	0.44	0.58	-0.08	0.09	-0.03	0.33	0.09	-0.10
Little Duck Creek	u/s Elizabeth Street	7.48	-0.28	0.25	0.47	0.61	-0.07	0.07	-0.02	0.34	0.09	-0.10

Table 15: Sensitivity Analyses –1% AEP Peak Flows (% change)

Location		Base Case	Variations in Rainfall				Variations in Manning's 'n'		Assumed Blockage		BX Factor	
Branch	Description	Peak Flow (m^3/s)	-10%	+10%	+20%	+30%	-15%	+20%	0%	100%	-20%	+20%
Duck River	u/s Wellington Road	164	-9%	10%	18%	26%	3%	-5%	-	-	-	-1%
Duck River	u/s Mona Street	141	-9%	8%	16%	23%	2%	-4%	-	-	-1%	1%
Duck River	u/s Railway	164	-9%	9%	17%	26%	4%	-6%	-	-	-	-
Duck River	u/s Railway footbridge	165	-9%	10%	18%	27%	5%	-6%	-	-	-	-
Duck River	u/s Parramatta Road	168	-10%	10%	18%	27%	4%	-7%	-	-1%	-	-
Duck River	u/s M4 Motorway	156	-9%	8%	16%	24%	6%	-8%	-	-	-1%	-
Duck Creek	u/s Mountford Ave	14	-13%	8%	23%	37%	-	-1%	-	-	8%	-6%
Duck Creek	u/s Bursill Street	19	-13%	13%	29%	40%	2%	0%	-10%	12%	9%	-6%
Duck Creek	Railway Terrace	31	-11%	8%	17%	26%	-4%	-4%	6%	-20%	2%	-4%
Duck Creek	Guildford Park	36	-11%	13%	26%	40%	1%	-2%	1%	-7%	7%	-3%
Duck Creek	u/s Oxford Street	42	-14%	15%	30%	47%	3%	-4%	11%	-7%	8%	-6%
Duck Creek	u/s Lansdowne Street	53	-13%	14%	22%	34%	1%	-2%	-2%	2%	8%	-6%
Duck Creek	u/s Bertha Street	51	-13%	16%	27%	40%	2%	-1%	-1%	3%	10%	-7%
Duck Creek	u/s Baker Street	50	-12%	15%	26%	42%	2%	-2%	-1%	3%	10%	-6%
Duck Creek	u/s Patten Street	52	-11%	13%	23%	35%	2%	-2%	-1%	2%	8%	-6%
Duck Creek	u/s Claremont Street	52	-10%	11%	23%	35%	4%	-1%	3%	-2%	7%	-3%
Duck Creek	d/s Woodville Road	60	-2%	9%	18%	27%	-	-	-6%	6%	7%	-2%
Duck Creek	u/s Louis Street	53	-1%	12%	26%	42%	2%	-2%	1%	3%	8%	-3%
Duck Creek	u/s The Avenue	49	-	12%	21%	30%	3%	-2%	-	10%	7%	-4%
Duck Creek	u/s Elizabeth Street	53	1%	10%	19%	26%	6%	-4%	-	9%	5%	1%
Duck Creek	Confluence (u/s SWP)	79	-11%	10%	20%	30%	3%	-5%	6%	-6%	4%	-4%
Duck Creek	u/s William Street	85	-13%	13%	26%	36%	3%	-4%	8%	-7%	5%	-5%
Duck Creek	u/s Memorial Park Drive	80	-10%	8%	15%	22%	4%	-5%	5%	-6%	3%	-4%
Duck Creek	u/s Parramatta Road	82	-9%	7%	16%	23%	3%	-6%	4%	-7%	3%	-9%
Duck Creek	u/s James Ruse Drive	83	5%	20%	33%	39%	3%	-5%	4%	-8%	14%	6%
Duck Creek	u/s of Lower Sydney Water pipeline	130	-6%	9%	16%	2%	6%	-7%	4%	-4%	3%	-1%

Location		Base Case	Variations in Rainfall				Variations in Manning's 'n'		Assumed Blockage		BX Factor	
Branch	Description	Peak Flow (m^3/s)	-10%	+10%	+20%	+30%	-15%	+20%	0%	100%	-20%	+20%
Little Duck Creek	Rawson Road	10	-13%	13%	27%	44%	1%	1%	-1%	1%	13%	-12%
Little Duck Creek	Excelsior Street (u/s channel)	4	-25%	24%	48%	77%	-1%	-1%	20%	-14%	19%	-18%
Little Duck Creek	u/s Brazier Place	12	-15%	15%	30%	48%	1%	-1%	-8%	20%	10%	-9%
Little Duck Creek	Willoughby Street	13	-13%	12%	25%	39%	2%	-4%	-2%	-6%	6%	-7%
Little Duck Creek	u/s Guildford Road	12	-14%	15%	34%	51%	3%	-4%	-4%	15%	6%	-6%
Little Duck Creek	u/s Eve Street	16	-17%	15%	30%	55%	6%	-7%	-5%	24%	6%	-8%
Little Duck Creek	u/s Adam Street	19	-15%	17%	30%	48%	10%	-6%	-11%	42%	7%	-6%
Little Duck Creek	Lavinia Street	19	-13%	13%	26%	43%	12%	-4%	8%	3%	4%	-2%
Little Duck Creek	u/s Lackey Street	26	-9%	12%	21%	33%	7%	-9%	11%	-8%	4%	-3%
Little Duck Creek	u/s Lisgar Street	42	-13%	16%	29%	44%	7%	-8%	-5%	12%	9%	-7%
Little Duck Creek	u/s Farnell Street	34	-12%	15%	28%	42%	4%	-2%	-3%	-1%	9%	-7%
Little Duck Creek	u/s Thomas Street	31	-9%	13%	24%	35%	4%	-5%	14%	-	8%	-6%
Little Duck Creek	u/s Louis Street	49	-18%	20%	32%	32%	8%	-14%	-22%	10%	10%	-13%
Little Duck Creek	u/s John Street	52	-14%	15%	28%	41%	7%	-7%	2%	6%	4%	-5%
Little Duck Creek	u/s Elizabeth Street	30	-9%	12%	21%	32%	4%	-5%	11%	-3%	2%	-3%

Impacts of Changes to Manning's 'n' Roughness Factors
Higher Manning's 'n' values produced increased flood levels along each waterway.

For Duck River, the estimated peak flood levels were found to be more sensitive in the heavily vegetated upper reaches (including reaches in the vicinity of Mona Street and Wellington Road). In these locations the nominated changes to the Manning's 'n' resulted in corresponding changes in flood levels in the order of 0.2m – 0.3m. Similar variations were also noted downstream of the railway bridge although the impacts were lower typically being within ±0.15m.

Consistent trends were also noted for Duck Creek and Little Duck Creek with variations in peak flood levels typically between ±0.1m.

Impacts of ±10% Variations in Rainfall
For Duck River, a 10% reduction in design rainfall reduced peak flood levels by between 0.1m to 0.3m. For the case where the design rainfalls were increased by 10%, peak flood levels were increased by up to 0.25m in reaches upstream of the railway bridge. The corresponding increase for downstream reaches was generally 0.1m or less.

For Duck Creek, the impacts of variations in design rainfall were generally found to be greater in the lower reaches as compared to the upper parts of the catchment (as expected). There were some localised exceptions where the model results were found to be more sensitive to changes in assumed rainfall. For example for the reach of Duck Creek between Brunswick Street through to Memorial Park Drive ±10% variations in rainfall produced corresponding changes in peak floods levels in the order of ±0.3m respectively. Further downstream of Memorial Park Drive the magnitude of the impacts was smaller, typically being within ±0.15m.

For Little Duck Creek, the impacts within the upper reaches (upstream of Farnell Street) were within ±0.1m. Larger impacts in the order of ±0.3m were noted to occur in the downstream reaches.

Impacts of Climate Change: +10%, +20% and +30% Increase in Rainfall
For Duck River the flood level increases by up to 0.22m, 0.4m and 0.6 m for increases in rainfall of +10%, +20% and +30% respectively. The impact of rainfall increases on flood level decreases further down the catchment due to the effect of storage attenuating the increase.

For Duck Creek the largest variation in flood levels due to assumed rainfall occurred between Brunswick Street and Memorial Park Drive. Peak flood levels upstream of The Avenue were found to be very sensitive, with rainfalls of +30% increasing flood levels by up to +1.12m.

For Little Duck Creek the change in peak flood level increase for increased rainfalls are as expected. For the reaches downstream of Farnell Street the proportion of overland flow to channel flow is high and the +30% rainfall scenario increases levels by up to 0.58m upstream of John Street. Elsewhere, further upstream, the levels only increase by up to 0.15m with a 30% increase in rainfall.

Impacts of Climate Change: Tailwater level increase of + 0.9 m

In order to assess the potential impact of ocean level rise, the peak tailwater level in the Parramatta River was increased by 0.9 m. This provides a conservative estimate of the extent of impact of an ocean level rise on the Duck River catchment.

In Duck River, upstream of the railway, water levels were increased by 0.1 m. For Duck Creek water levels were increased by 0.2 m upstream of the railway and Memorial Park Drive. Table 16 shows impacts at several locations in the catchment.

Table 16: Impact of Increasing Tailwater Level by + 0.9m.

Branch	Location	Change in Peak Water Level (m)
Duck Creek	u/s Memorial Park Drive	0.22
Duck Creek	u/s Parramatta Road	0.17
Duck Creek	d/s A'Becketts Creek	0.19
Duck Creek	u/s of Lower Sydney Water Pipeline	0.23
Duck River	u/s Railway	0.11
Duck River	u/s Parramatta Road	0.27
Duck River	confluence of Duck Creek with Duck River	0.43
Duck River	u/s Parramatta River	0.90

7.5. Comparison With Other Historical Flood Level Information

All available historical flood levels have been compared to the estimated design event profiles throughout the study area (refer to Figures 10a, 10b and 10c). In general, observed levels from past events are within the range of design events analysed for the present study.

Of particular interest is the comparison with observed levels for the April 1974 event which exceeded the corresponding 1% AEP (1 in 100 year) levels estimated as part of this study along many reaches of Duck Creek and Little Duck Creek (refer to Figures 10b and 10c).

There is reference from previous studies that the rainfall recorded during the 26th April 1974 event was centred on the catchment (refer Chester Hill record) and may have been comparable to a 1% AEP event (Reference 1). A list of the 26th April 1974 daily rainfalls taken from BoM records is shown on Table 17.

Table 17: Daily Rainfalls – 26th April 1974

Station Number	Location	Daily Total (mm)
66013	Concord Golf Club	2
66020	Epping - Chester Street	13
66050	Potts Hill Pumping Station	21
66057	Ryde Pumping Station	7
66082	Concord West - Plaster Mills	4
66085	Auburn - Wagon Works	76
66121	Chester Hill	97
66124	Parramatta North	62
66134	Granville - Shell Refinery	36

66164	Strathfield Council	4
67019	Prospect Dam	9
67026	Seven Hills Experimental Farm	2
67059	Blacktown - Kildare Road	32
67070	Merrylands - Wellsford Street	39
67080	Winston Hills	39
67089	Pennant Hills C.F.S	44

Unfortunately for the 26th April 1974 event there are no pluviometers available within the catchment, with the closest station being located at Liverpool. Comparison with the IFD indicates that the storm recorded at the Liverpool gauge was less then a 20% AEP event. A review of daily rainfall records within and adjacent to the study catchment indicates that the 26th April 1974 event was comparable to a 50% AEP event (for a 24 hour duration storm, depending on the station location). It is certainly possible that the equivalent magnitude of the rainfall event may have been of a higher magnitude if the storm burst occurred for a smaller duration – the Liverpool records indicate that the bulk of the rainfall fell within a 1 hour period, supporting this view.

Taking the above into account, it is feasible that the 26th April 1974 storm was a significant event. Along Duck Creek and Little Duck Creek, the observed levels often exceed those estimates from this study for the 1% AEP (1in 100y year) event. However, a desktop review of modelled versus observed behaviour at road crossings indicated that most of the 1974 levels could be achieved should 100% blockage be assumed for the 1% AEP event. However, there were still some locations along Little Duck Creek where the indicated 1974 levels could not be reasonably accounted for with the information currently available including areas upstream of Willoughby Street and Lisgar Street.

In conclusion the available rainfall data (pluviometer and daily read) indicates that the 26th April 1974 event was less than a 1 in 5 year event. However the recorded flood levels within Duck Creek contradict this finding. It is noted (taken from Reference 9) that all previous references generally have the 26th April 1974 event recorded levels above the calculated design 1% AEP event. It would appear that the only explanation in the past was that the 26th April 1974 levels resulted from debris (Reference 9). The previous references provided no source for the 26th April 1974 levels or a description (debris, tide mark) of the actual level. The investigations undertaken as part of this present study can provide no further explanation for the magnitude of the 26th April 1974 levels compared to the recorded rainfalls.

7.6. Comparison with Previous Studies

Table 18 compares the peak design 1% AEP flood levels and flows estimated in this study with those presented in References 1 and 2 for a number of locations throughout the catchment.

The peak flows are generally lower in the current study for both the Duck River and Duck Creek catchments. The peak flows for Duck River are lower as the revised inflows from the Bankstown City Council portion of the catchment are lower than previously estimated. For example, the 1% AEP (1 in 100 year) peak inflow for Duck River near the Sydney Water Pipeline (near the LGA boundary) was estimated as being 201m^3/s in Reference 1. By comparison, the most recent study (based on more sophisticated modelling approaches) estimated a corresponding inflow of 121 m^3/s (refer to Section 6.3.1 previous).

Within Duck Creek, peak flows are typically 5 to 15% lower than previous estimates. This can be attributed to the use of a 2D model that includes a more detailed representation of floodplain storage and overland flow through properties (compared to the 1D hydraulic model used in previous studies). In certain locations, relatively larger discrepancies were noted when comparing flood level estimates. However, these are due to localised features and/or differences in modelling assumptions. For example, the peak water level upstream of The Avenue was 0.5m higher than that estimated previously. However, this increase is due to differences in representation of the culvert structure between models (e.g. blockage and roughness assumptions).

In Little Duck Creek, the relative discrepancies between peak flow estimates are greater than those found in Duck Creek, being between 20% to 50% lower than previous estimates. However, these differences are a result of the more detailed hydraulic modelling approach adopted for this study and can be attributed to the better representation of a number of features including:

- available storage upstream of Brazier Street,
- the formation of alternative flow paths down roads in key reaches and
- flow through properties from downstream of Eve Street.

For example, 1% AEP peak flood levels within the main stormwater channel at Patten Street are 0.8m lower in the current study compared to those in Reference 2. This is due to additional flow paths that form in this area extending along from Baker Street to Claremont Street down roads and through properties.

Table 18: Comparison of 1% AEP results from Previous and Current Studies

Branch	Location	1% AEP Peak Flow (m^3/s)			1% AEP Peak Level (mAHD)		
		Previous	Current	Difference	Previous	Current	Difference
Duck River	u/s Wellington Road	240	164	-32%	9.9	9.5	-0.4
Duck River	u/s Mona Street	246	141	-43%	7.1	6.6	-0.5
Duck River	u/s Railway	218	164	-25%	5.8	5.6	-0.2
Duck River	u/s Railway footbridge	221	165	-26%	5.6	5	-0.6
Duck River	u/s Parramatta Road	226	168	-26%	5.2	4.7	-0.5
Duck River	u/s M4	232	156	-33%	4.4	4.2	-0.2
Duck Creek	u/s Mountford Avenue	14	14	-1%	24.5	24.5	0
Duck Creek	u/s Bursill Street	18	19	7%	22.3	22	-0.3
Duck Creek	Railway Terrace	46	31	-32%	20.6	20.7	0.1
Duck Creek	u/s Oxford Street	52	42	-19%	19.5	19.2	-0.3
Duck Creek	u/s Lansdowne Street	55	53	-3%	16.9	16.5	-0.4
Duck Creek	u/s Bertha Street	55	51	-7%	15.9	15.4	-0.5
Duck Creek	u/s Baker Street	58	50	-14%	15.6	15.3	-0.3
Duck Creek	u/s Patten Street	58	52	-11%	14.9	14.1	-0.8
Duck Creek	u/s Claremont Street	58	52	-10%	13.5	13.5	0
Duck Creek	d/s Woodville Road	58	60	3%	10.9	10.5	-0.4
Duck Creek	u/s Louis Street	58	53	-8%	10.8	10.4	-0.4
Duck Creek	u/s The Avenue	61	49	-20%	7.6	8.1	0.5
Duck Creek	u/s William Street	113	85	-24%	7	6.9	-0.1
Duck Creek	u/s Elizabeth Street	61	53	-14%	7	7.3	0.3
Duck Creek	u/s Memorial Park Drive	106	80	-24%	5.9	6	0.1
Duck Creek	u/s Parra Rd	101	82	-19%	5.8	5.4	-0.4
Duck Creek	u/s James-Russ	100	83	-17%	5.5	5.1	-0.4
Little Duck Creek	Rawson Road	10	10	-3%	31.5	31	-0.5
Little Duck Creek	u/s Brazier Place	14	12	-16%	26.9	27.1	0.2
Little Duck Creek	Willoughby Street	20	13	-34%	23.1	23	-0.1
Little Duck Creek	u/s Guildford Road	22	12	-44%	23	22.7	-0.3
Little Duck Creek	u/s Eve Street	23	16	-29%	19.5	19.5	0
Little Duck Creek	u/s Adam Street	25	19	-22%	17.6	16.9	-0.7
Little Duck Creek	Lavinia Street	39	19	-52%	15.4	14.1	-1.3
Little Duck Creek	u/s Lackey Street	41	26	-36%	13	12.4	-0.6
Little Duck Creek	u/s Lisgar Street	38	42	11%	12.9	12.3	-0.6
Little Duck Creek	u/s Farnell Street	38	34	-11%	11.2	10.9	-0.3
Little Duck Creek	u/s Thomas Street	41	31	-25%	9.5	10.2	0.7
Little Duck Creek	u/s Louis Street	43	49	14%	8.3	8.9	0.6
Little Duck Creek	u/s John Street	42	52	25%	7.3	7.6	0.3
Little Duck Creek	u/s Elizabeth Street	43	30	-29%	7.1	7.5	0.4

8. ACKNOWLEDGEMENTS

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- Bankstown City Council,
- Auburn City Council,
- NSW State Government,
- Residents of the Duck River and Duck Creek catchments.

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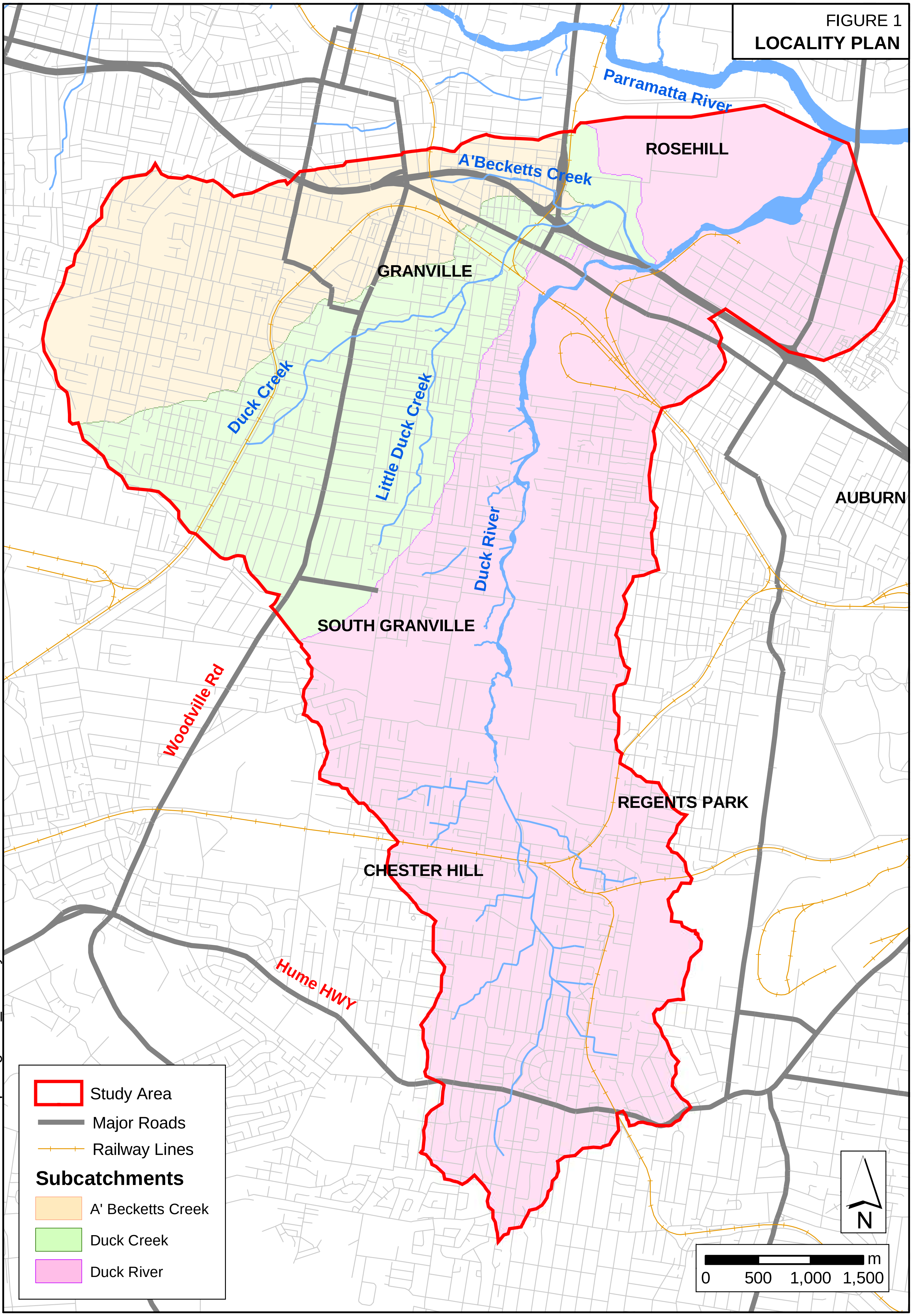
Figures



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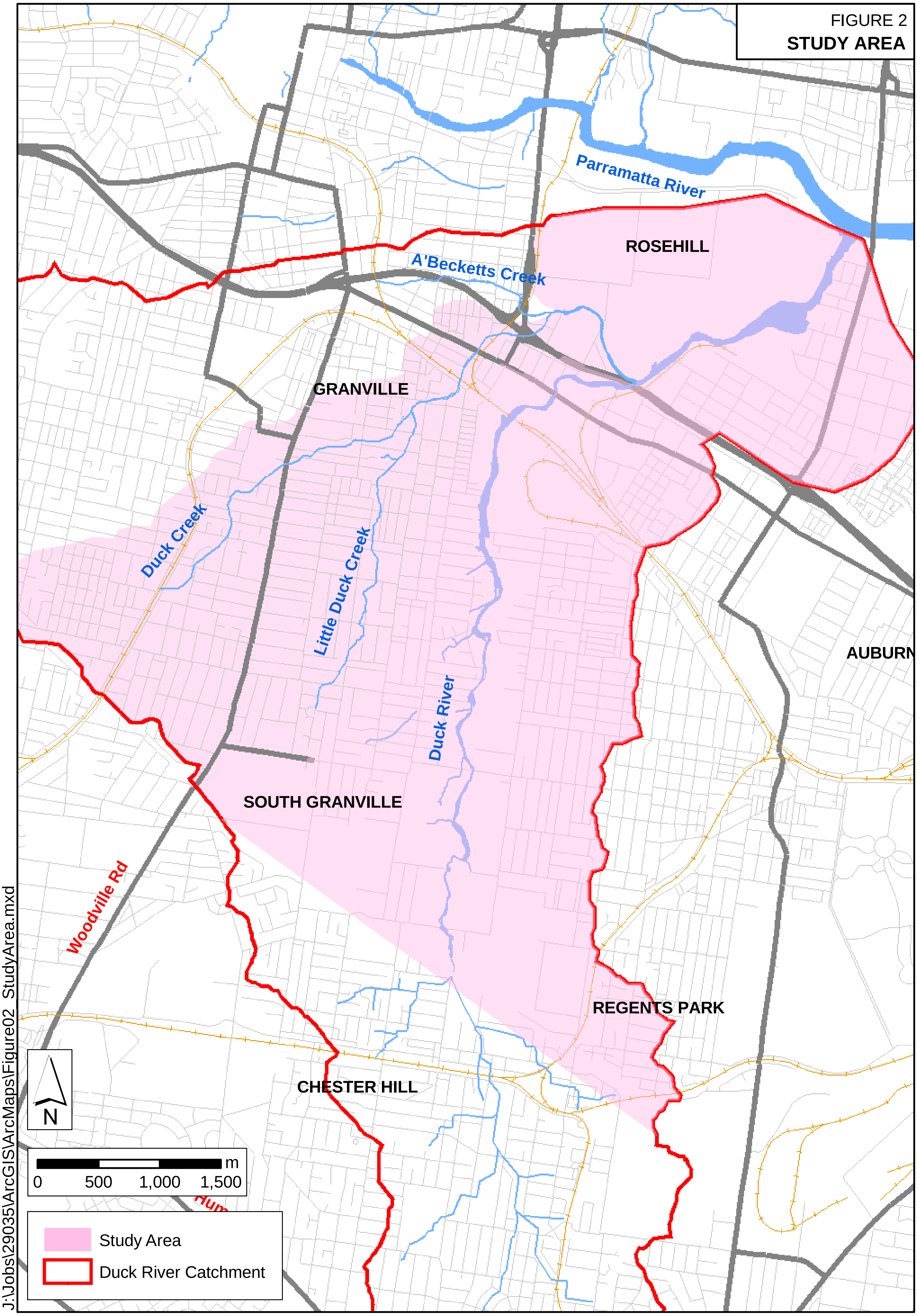
FIGURE 2
STUDY AREA
Parramatta River
ROSEHILL
A'Becketts Creek
GRANVILLE
Duck Creek
Little Duck Creek
Duck River
AUBURN
SOUTH GRANVILLE
Woodville Rd
REGENTS PARK
CHESTER HILL
N
m
0
500
1,000
1,500
Study Area
Duck River Catchment
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FIGURE 3
ALS GROUND SURFACE

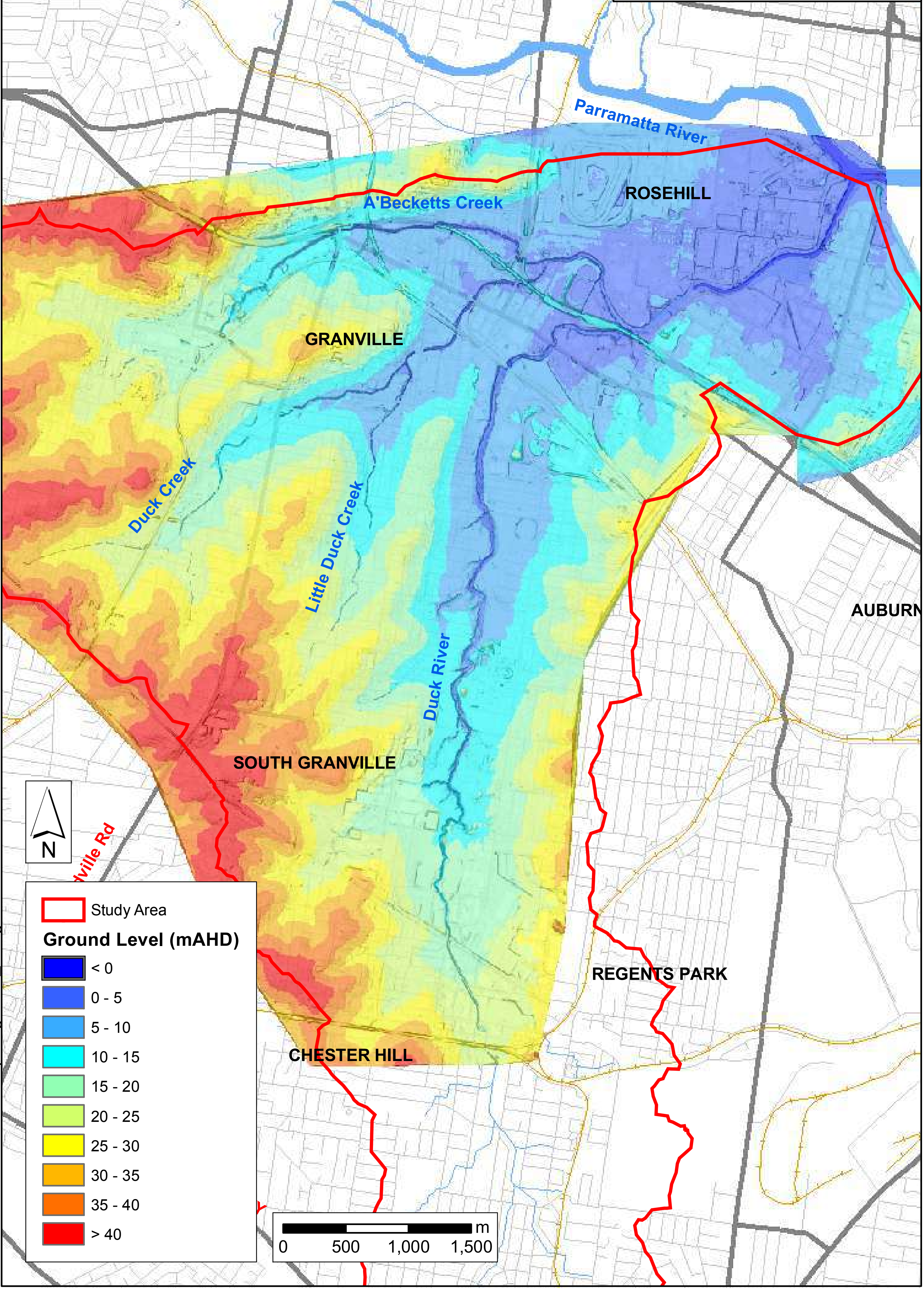

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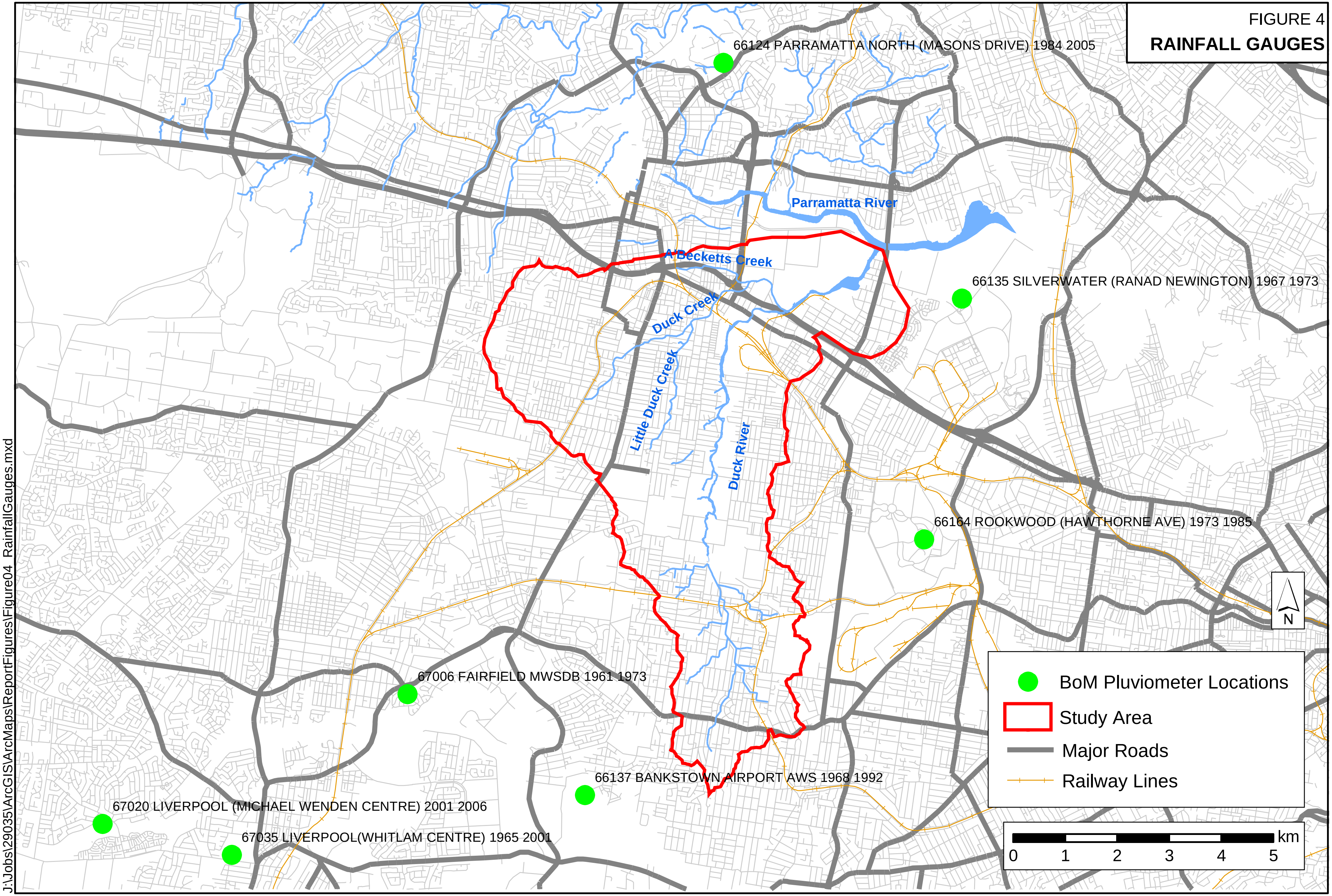
FIGURE 4
RAINFALL GAUGES



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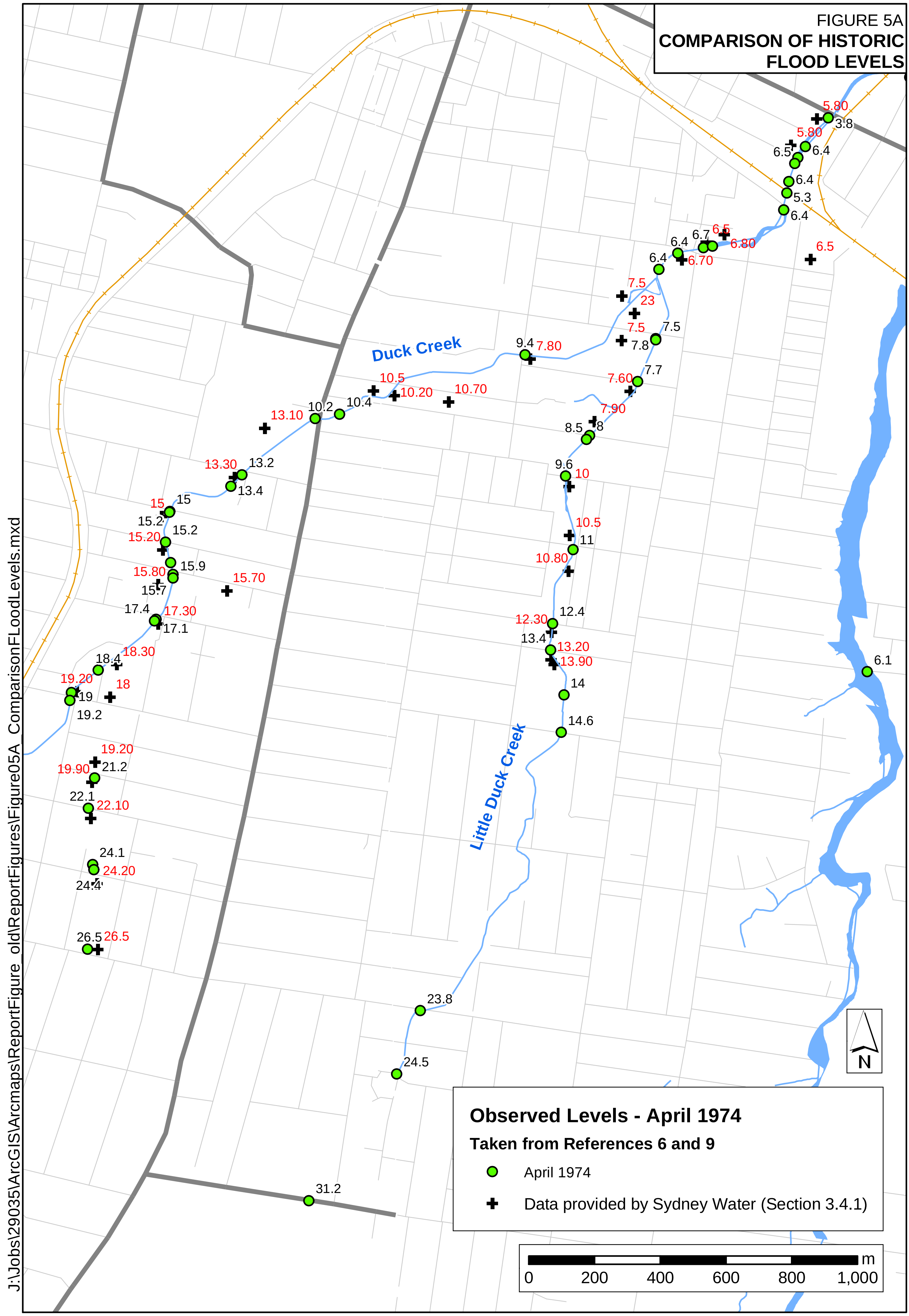

FIGURE 5A
COMPARISON OF HISTORIC FLOOD LEVELS
Duck Creek
Little Duck Creek
Observed Levels - April 1974
Taken from References 6 and 9
April 1974
Data provided by Sydney Water (Section 3.4.1)
0
200
400
600
800
1,000
m
N
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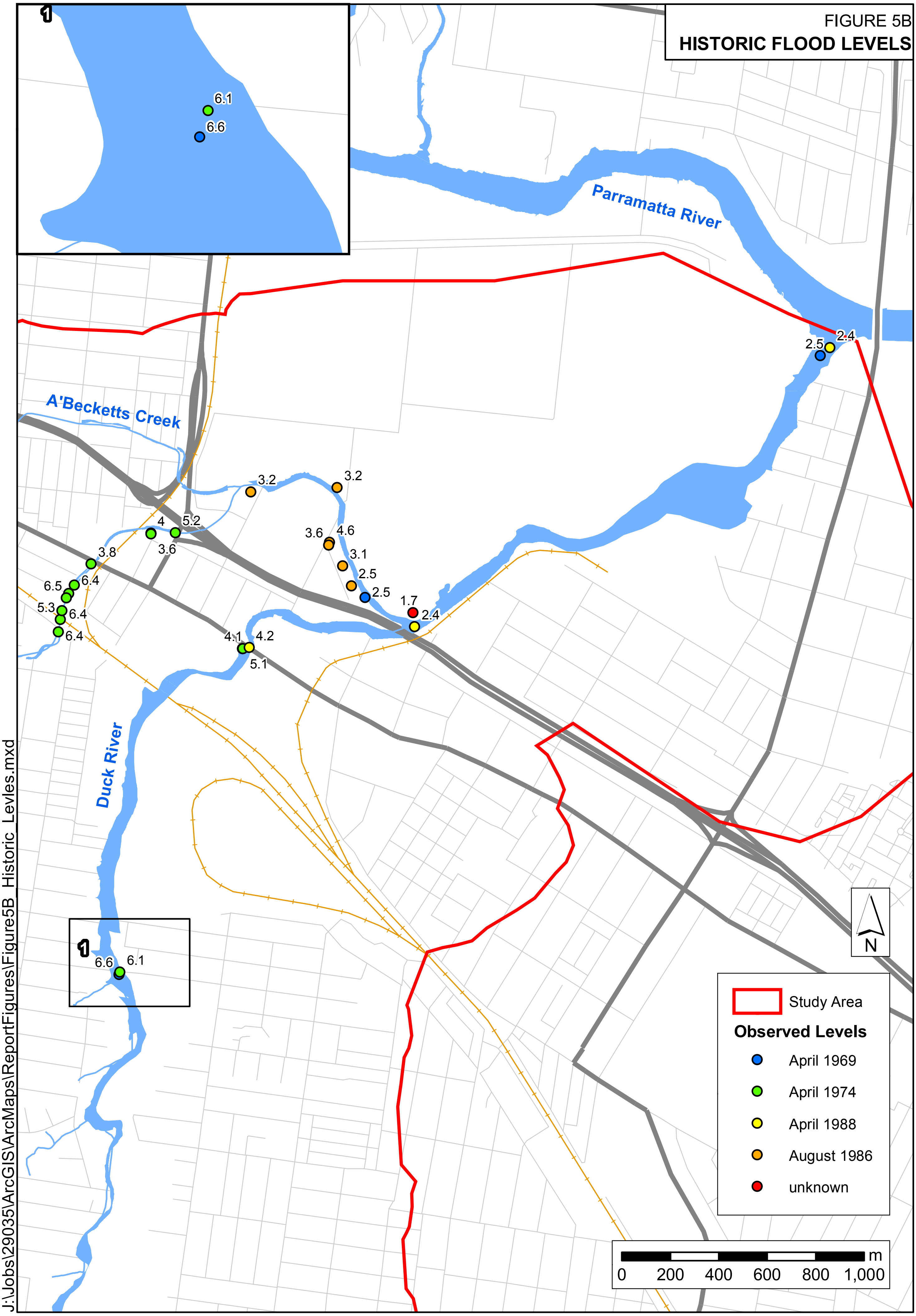


FIGURE 5B
HISTORIC FLOOD LEVELS
Parramatta River
A'Becketts Creek
Duck River
6.1
6.6
2.5
2.4
3.2
3.2
4
5.2
3.6
3.8
3.6
4.6
3.1
2.5
2.5
1.7
2.4
6.5
6.4
5.3
6.4
6.4
4.1
4.2
5.1
6.6
6.1
1
N
Study Area
Observed Levels
April 1969
April 1974
April 1988
August 1986
unknown
m
0 200 400 600 800 1,000
J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures\Figure5B_Historic_Levles.mxd

FIGURE 6
APRIL 1988 FLOOD LEVEL RECORD
DUCK RIVER AT PARRAMATTA ROAD

FLOOD MARKING DATA SHEET

RIVER: Duck.

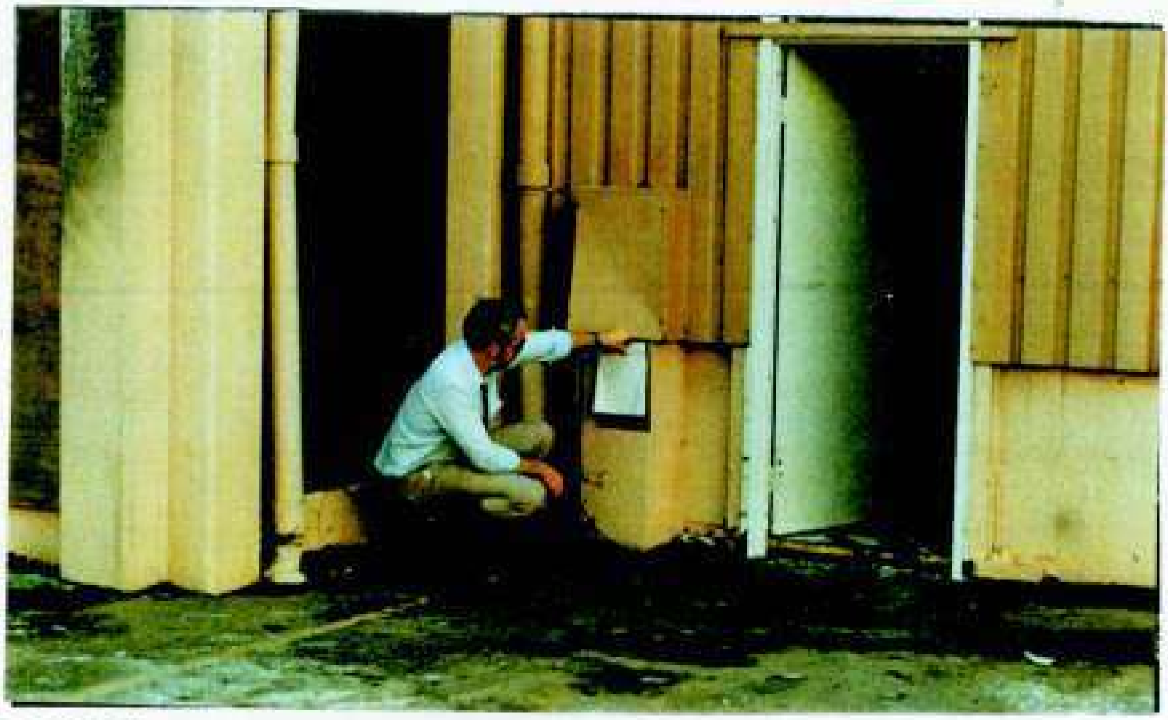
DATE: 30/4/88 TIME:

REMARKS: Flood levels.
- burned out building in industrial complex off Parramatta Rd. (Northside)

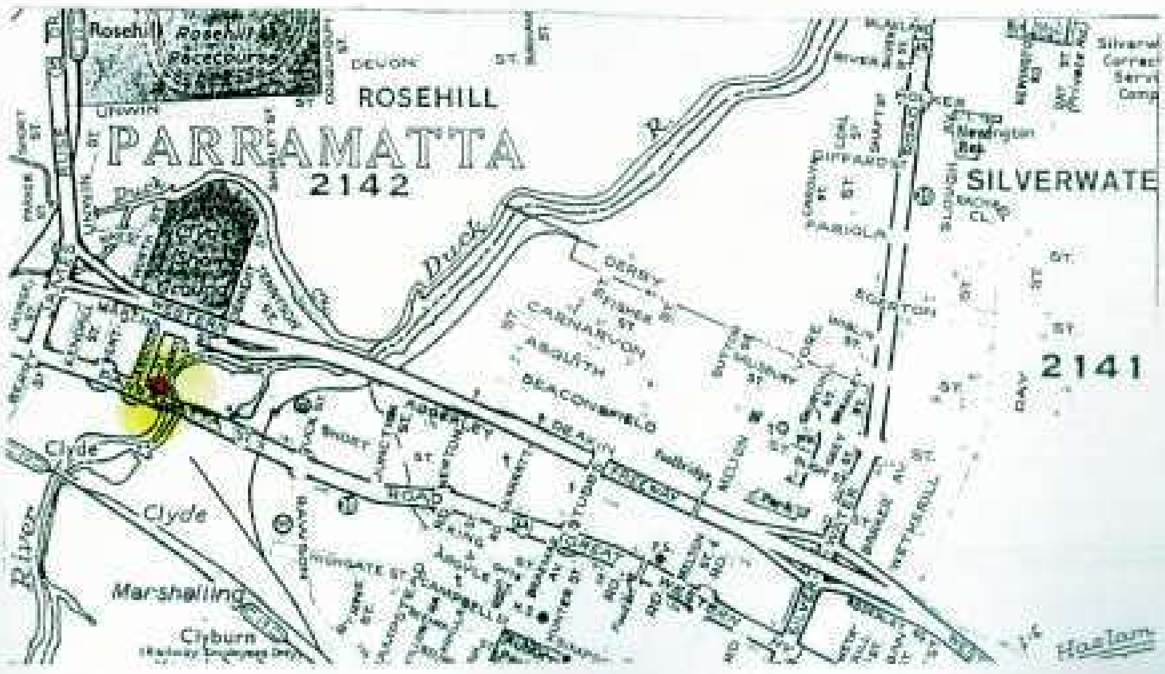
Comments assumed to be added by SKM as part of 2005 Lower Parramatta River Flood Study Review

FROM ALS – G.L. ≈ 4.2 – AHD
FLOOD LEVEL ≈ 4.6m AHD

PHOTOGRAPH:

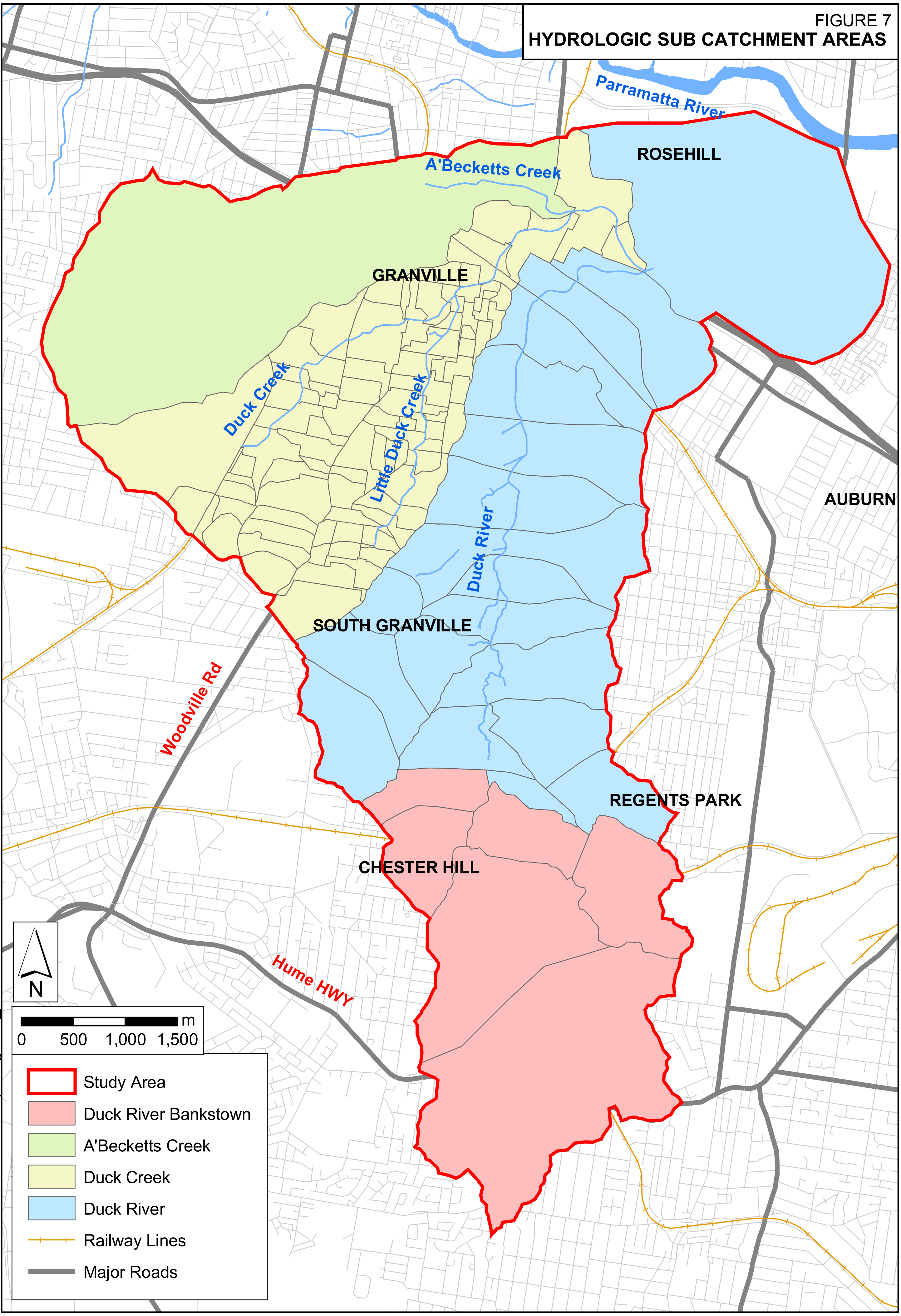


SITE SKETCH:



Source: Lower Parramatta River Floodplain Risk Management Study - Flood Study Review Final May 2005
J:\Jobs\29035\Admin\Report\AdditionalFigures\Figure6_April1988FloodMark_DuckRiver_ParramattaRoad.cdr

FIGURE 7
HYDROLOGIC SUB CATCHMENT AREAS



J:\Jobs\129035\ArcGIS\ArcMaps\Figure7_SubCatchmentAreas.mxd

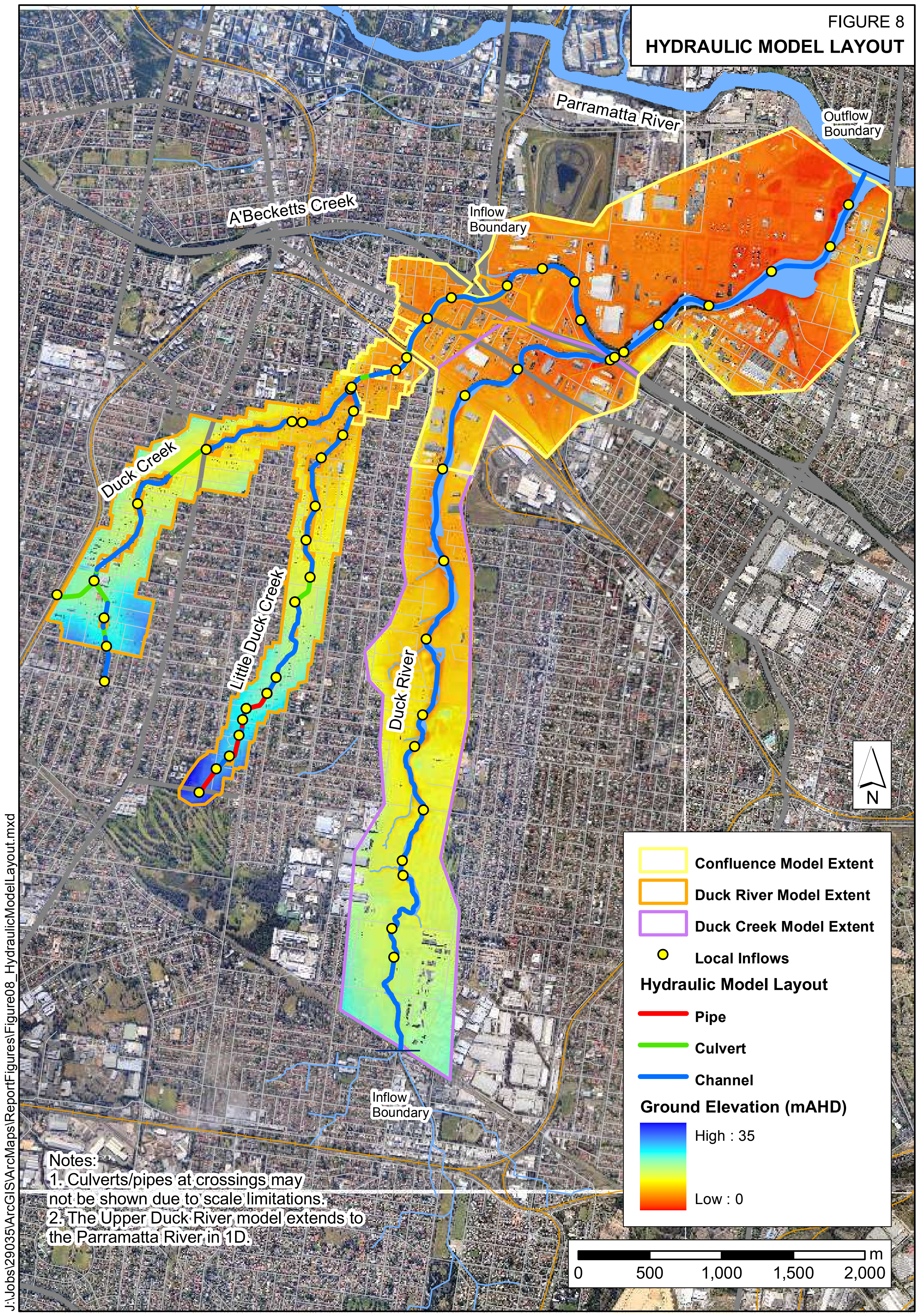


FIGURE 8
HYDRAULIC MODEL LAYOUT
Parramatta River
Outflow Boundary
Inflow Boundary
A'Becketts Creek
Duck Creek
Little Duck Creek
Duck River
Inflow Boundary
N
Confluence Model Extent
Duck River Model Extent
Duck Creek Model Extent
Local Inflows
Hydraulic Model Layout
Pipe
Culvert
Channel
Ground Elevation (mAHD)
High : 35
Low : 0
m
0
500
1,000
1,500
2,000
Notes:
1. Culverts/pipes at crossings may not be shown due to scale limitations.
2. The Upper Duck River model extends to the Parramatta River in 1D.
J:\Jobs\29035\ArcMaps\ReportFigures\Figure08_HydraulicModelLayout.mxd

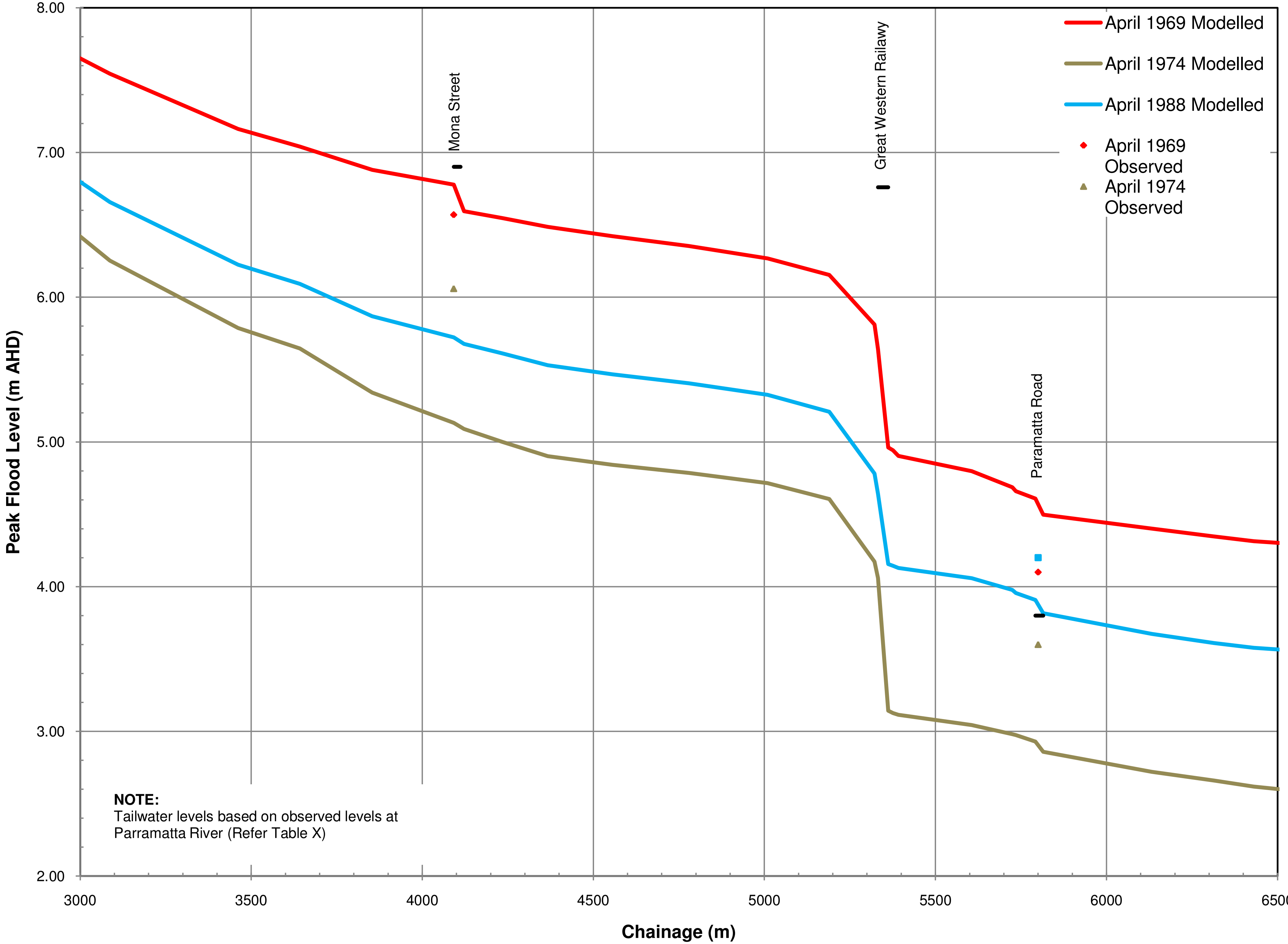


FIGURE 9
HISTORIC FLOOD PROFILES
DUCK RIVER

FIGURE 10A

DESIGN FLOOD PROFILES

DUCK RIVER

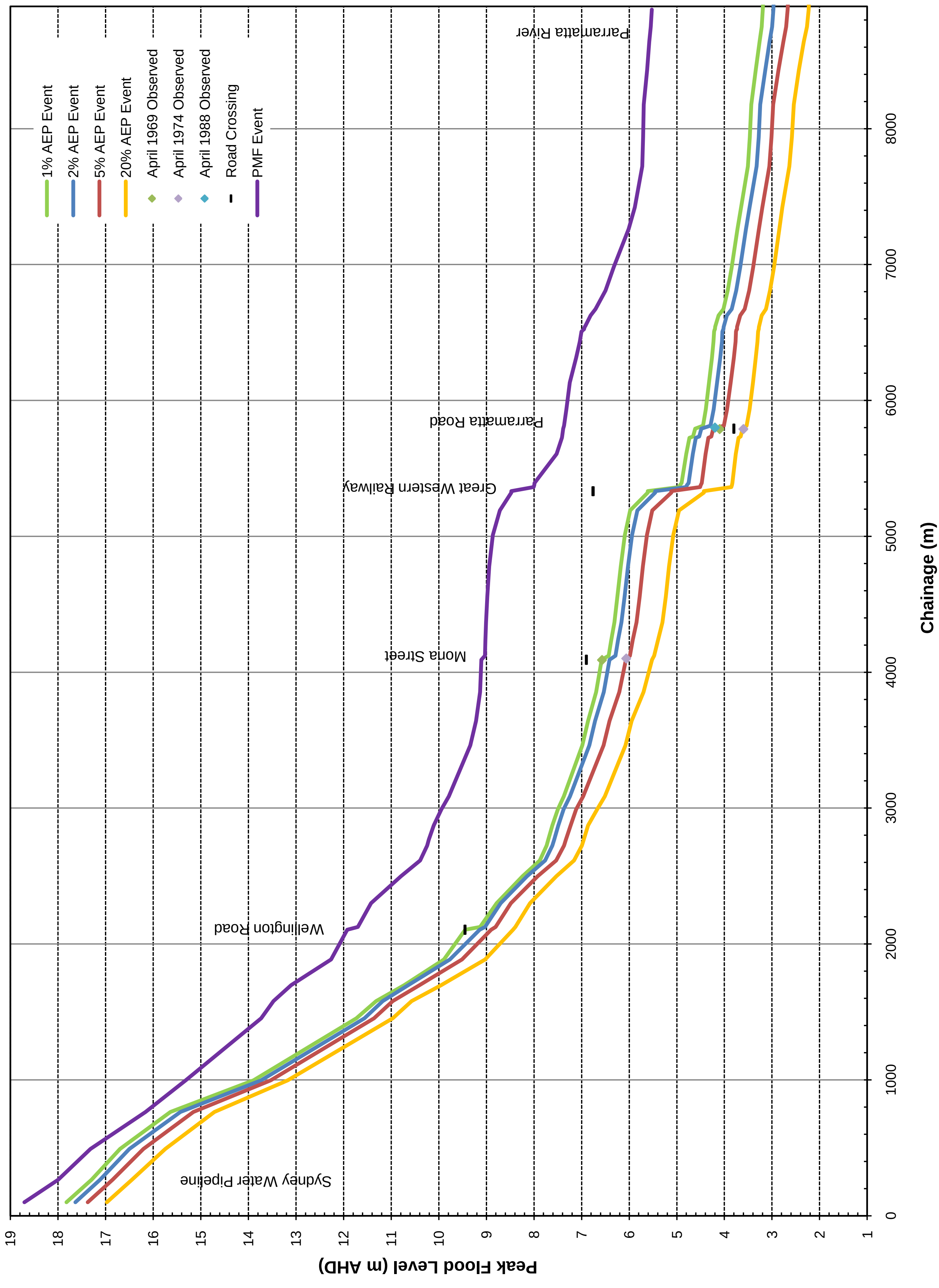


FIGURE 10B
DESIGN FLOOD PROFILES
DUCK CREEK

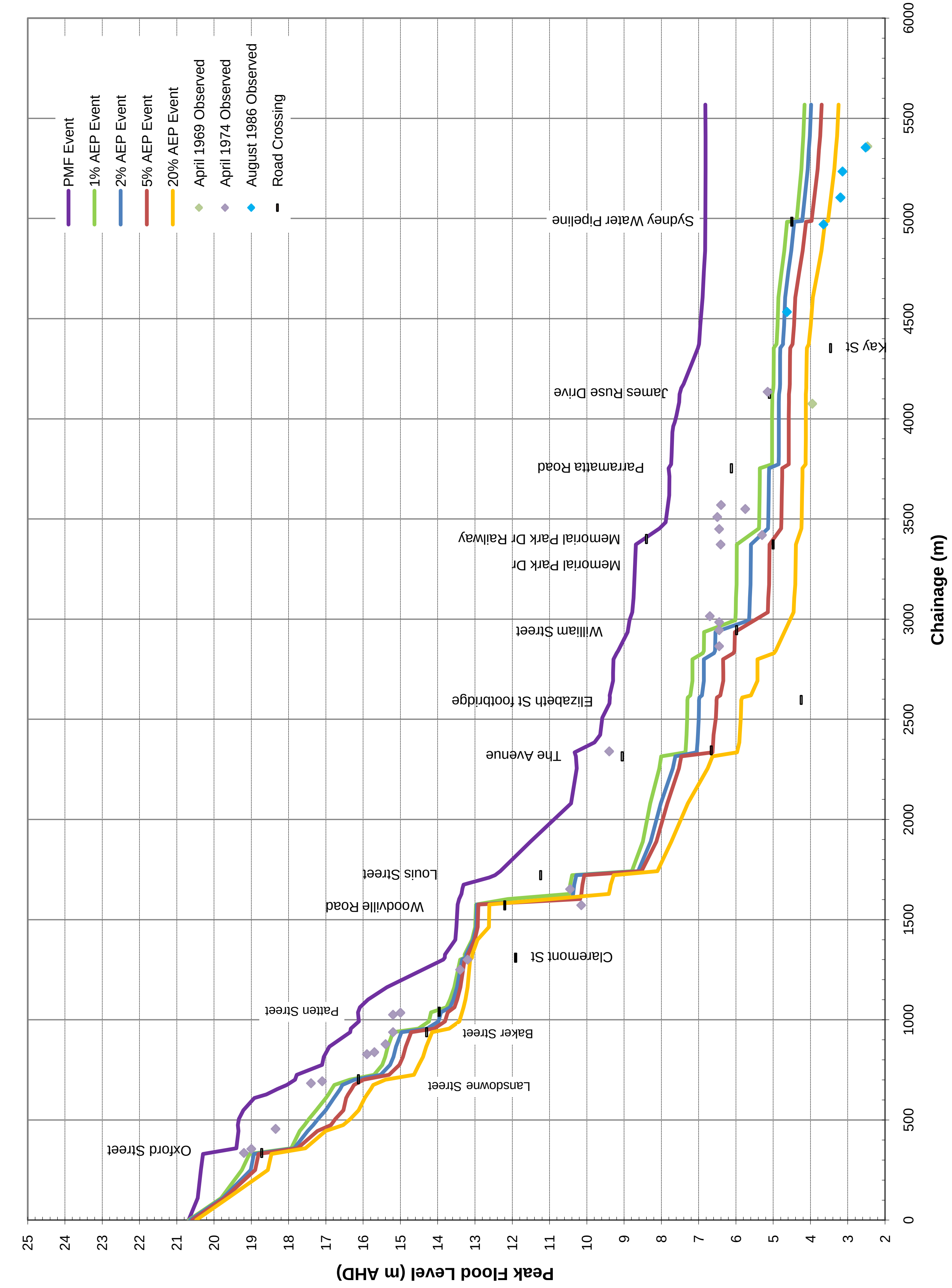


FIGURE 10C
DESIGN FLOOD PROFILES
LITTLE DUCK CREEK

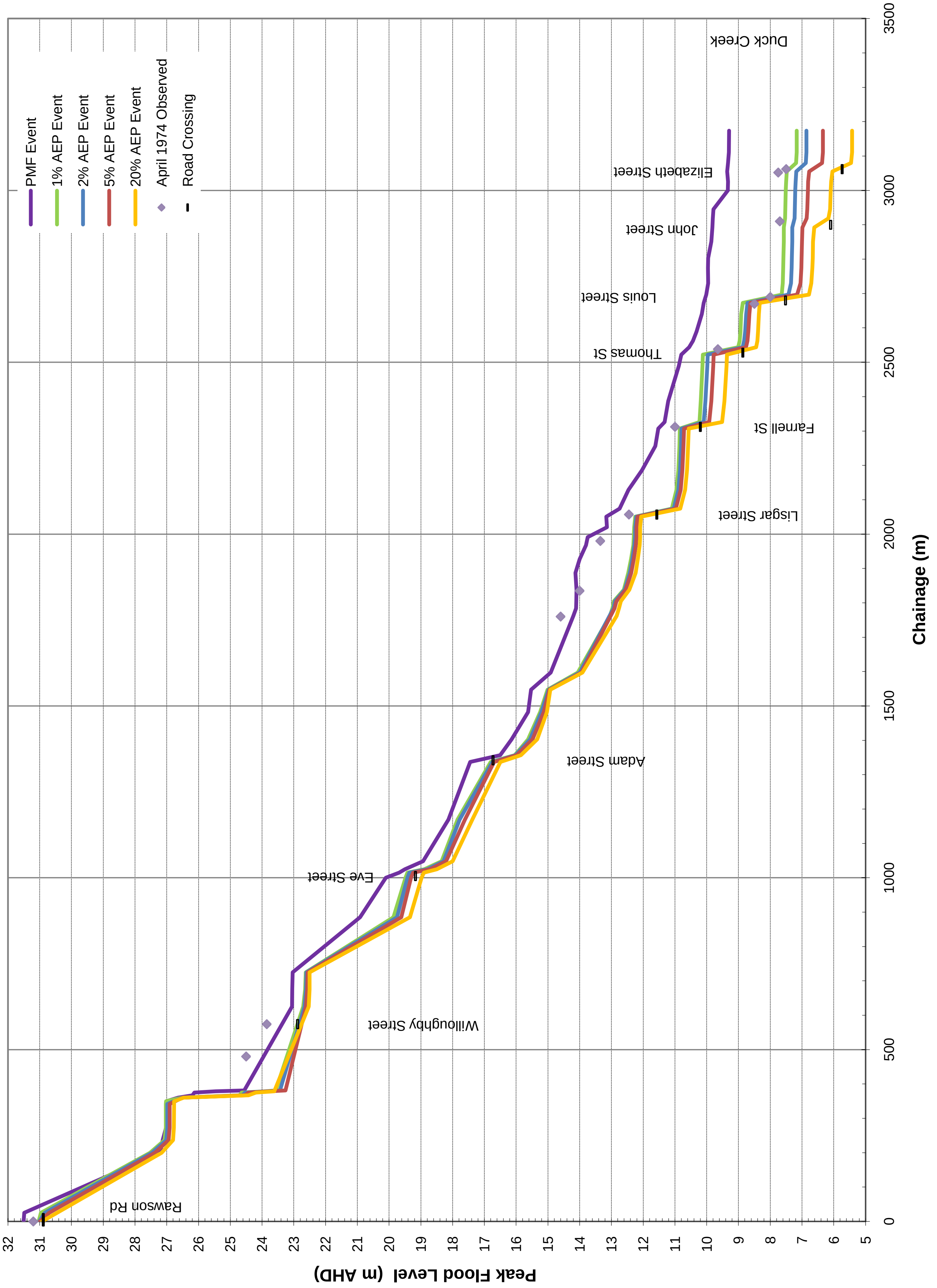


FIGURE 11A

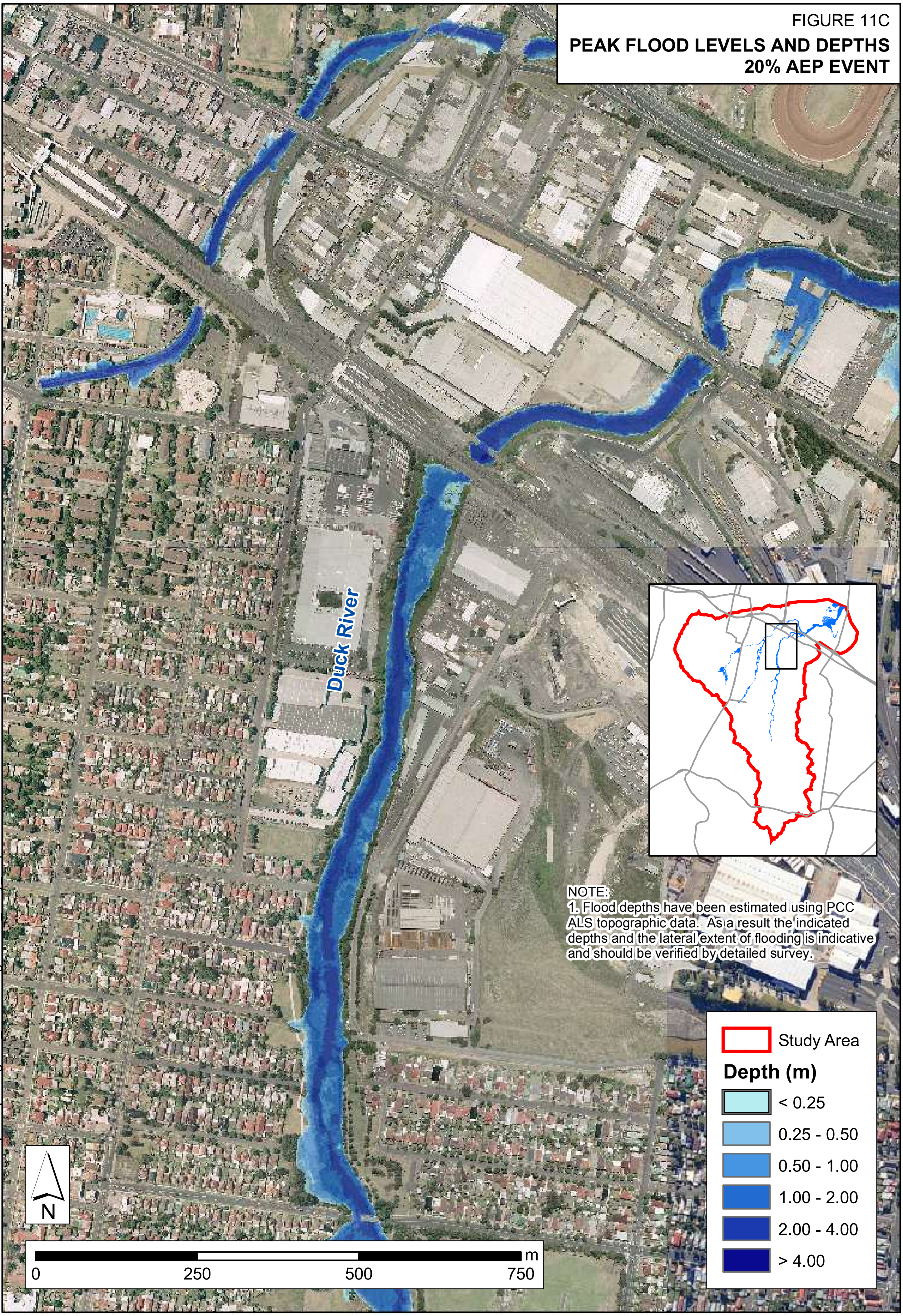
PEAK FLOOD LEVELS AND DEPTHS 20% AEP EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures 110119\Figure11A 005y Map1.mxd

J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures\Figure11B_005y_Map2.mxd

FIGURE 11C

PEAK FLOOD LEVELS AND DEPTHS 20% AEP EVENT



J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure11C_005y_Map3.mxd

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

J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure11D_005y_Map4.mxd

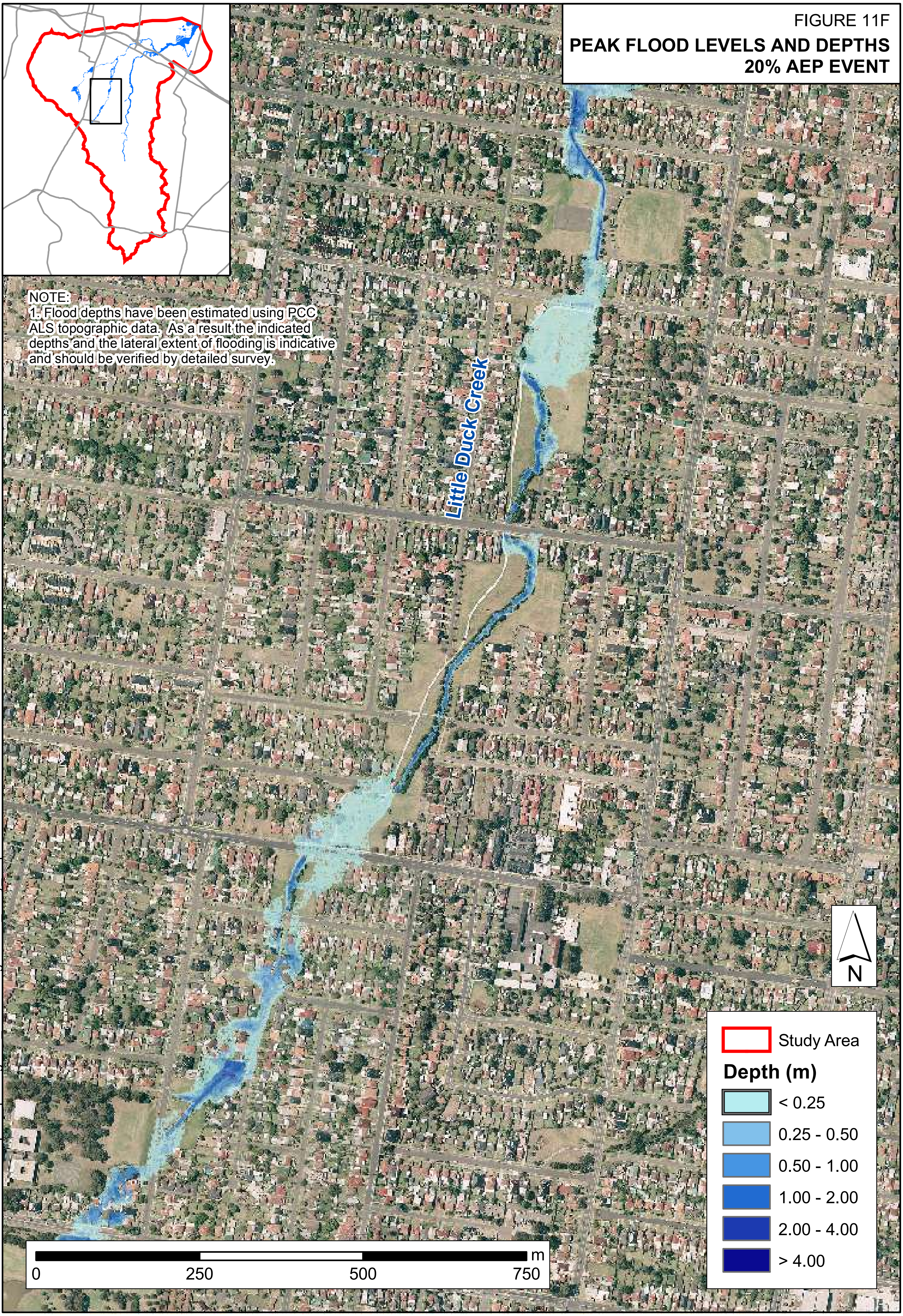
FIGURE 11E

PEAK FLOOD LEVELS AND DEPTHS 20% AEP EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure11E_005y_Map5.mxd

FIGURE 11F

PEAK FLOOD LEVELS AND DEPTHS 20% AEP EVENT



J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure11F_005y_Map6.mxd

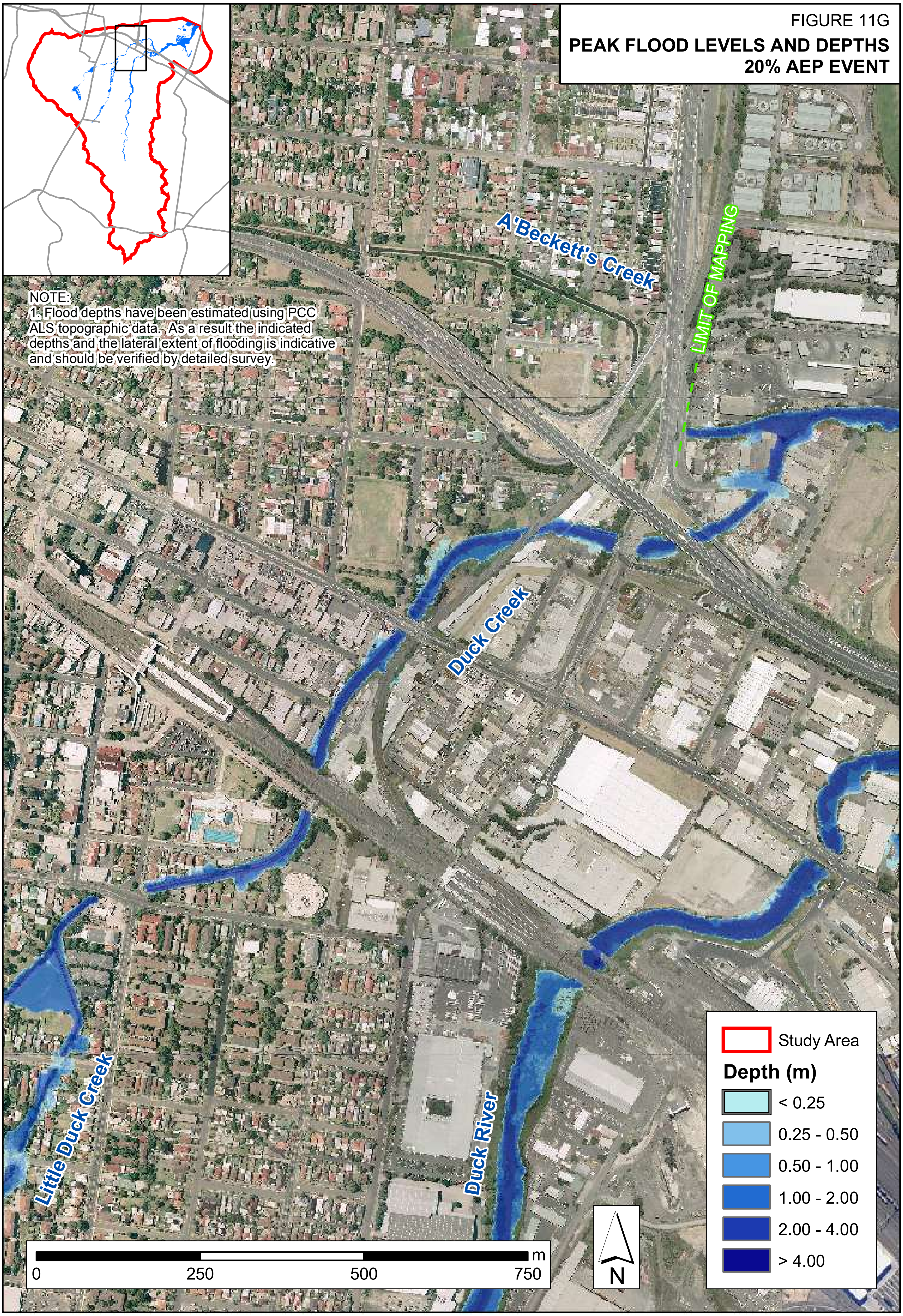


FIGURE 11G
PEAK FLOOD LEVELS AND DEPTHS
20% AEP EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure11G_005y_Map6.mxd

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

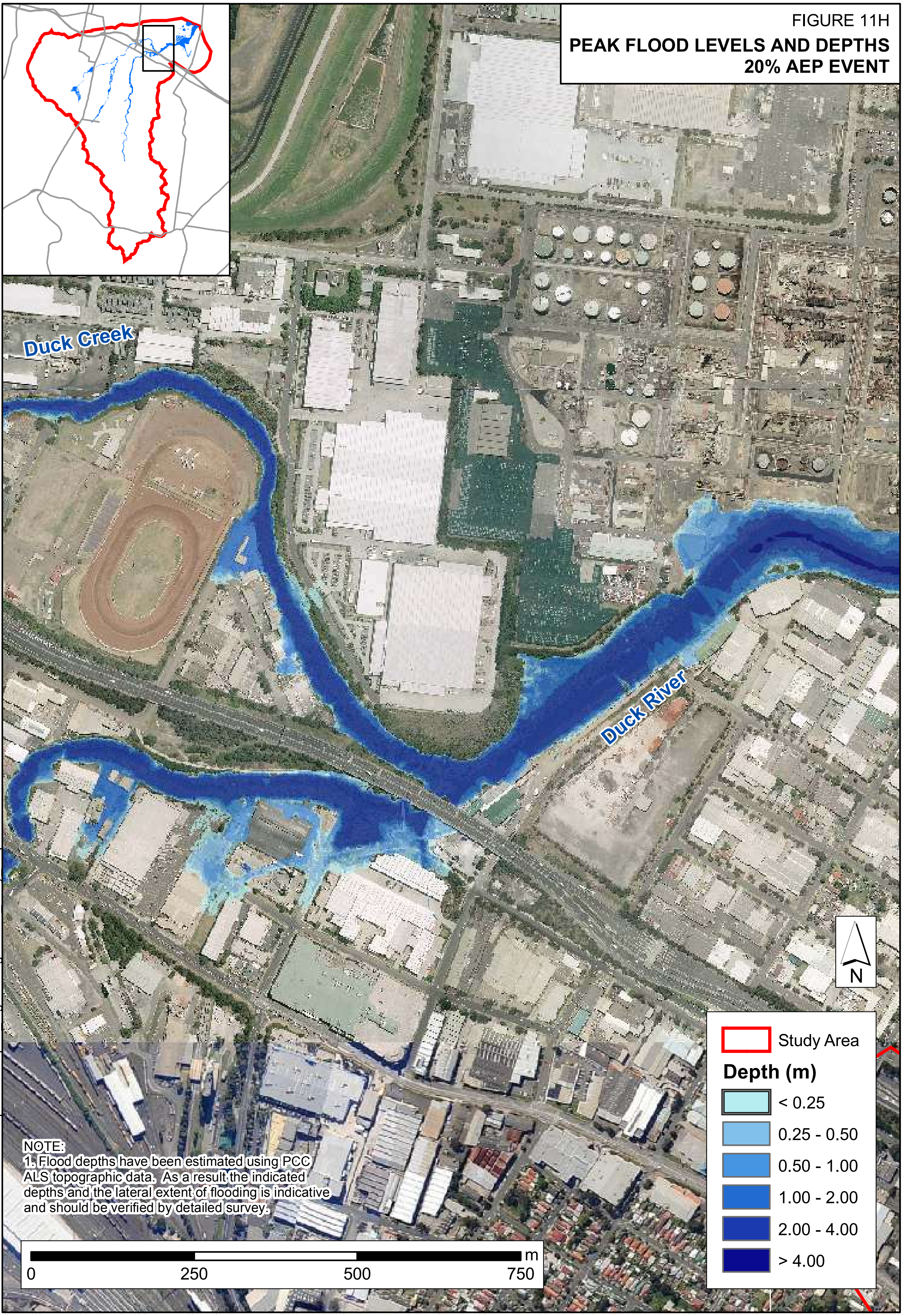
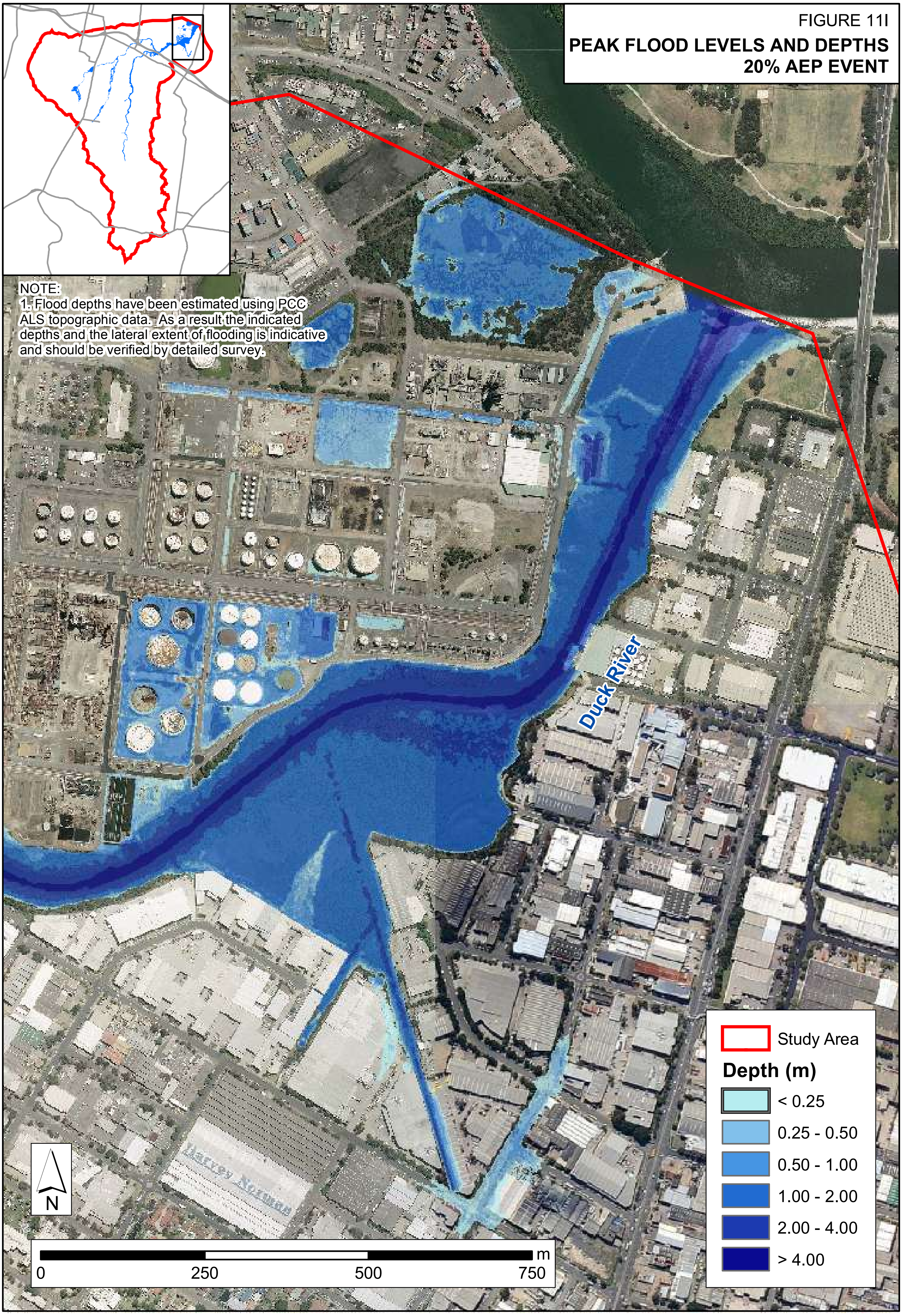


FIGURE 11I

PEAK FLOOD LEVELS AND DEPTHS 20% AEP EVENT



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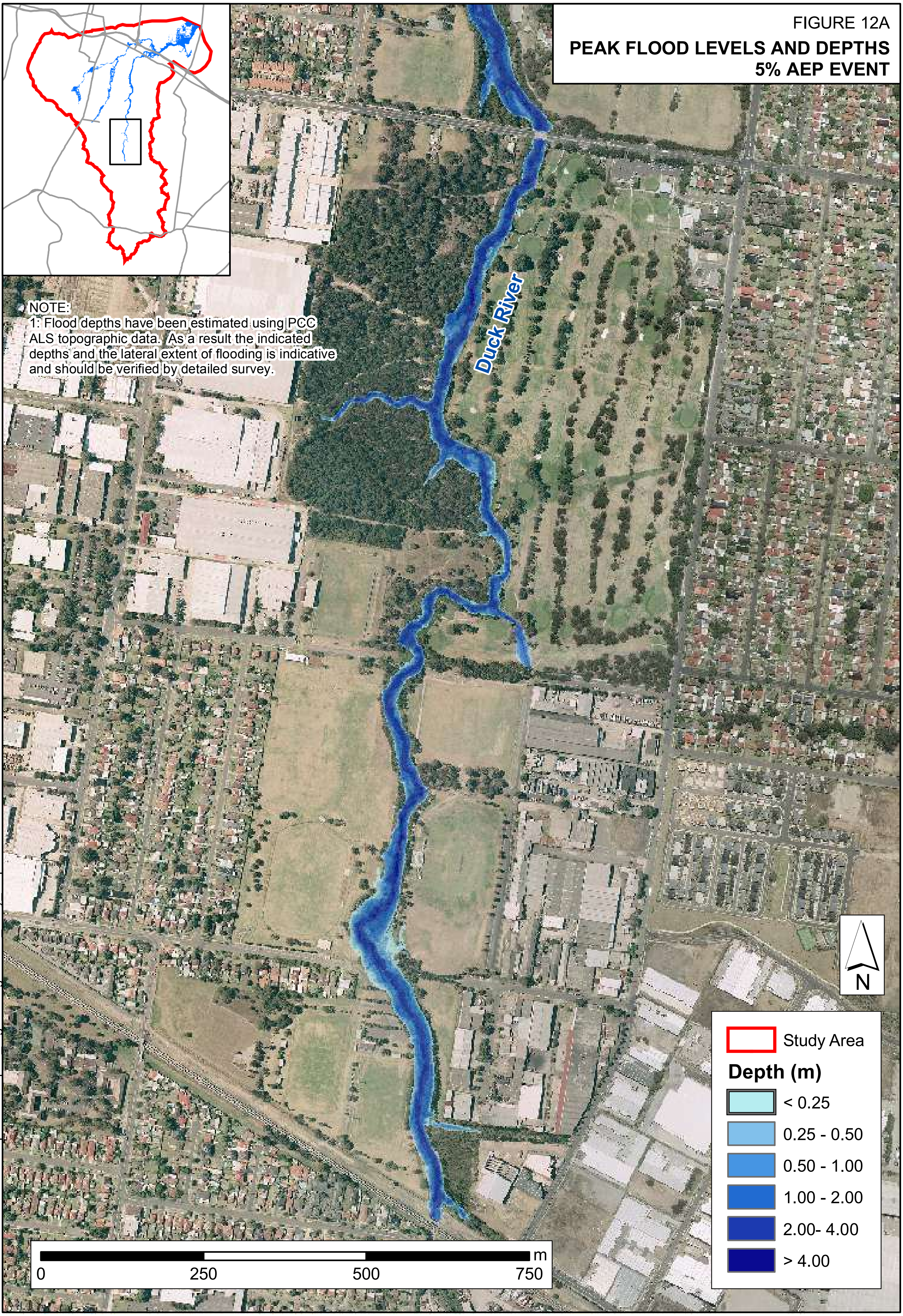
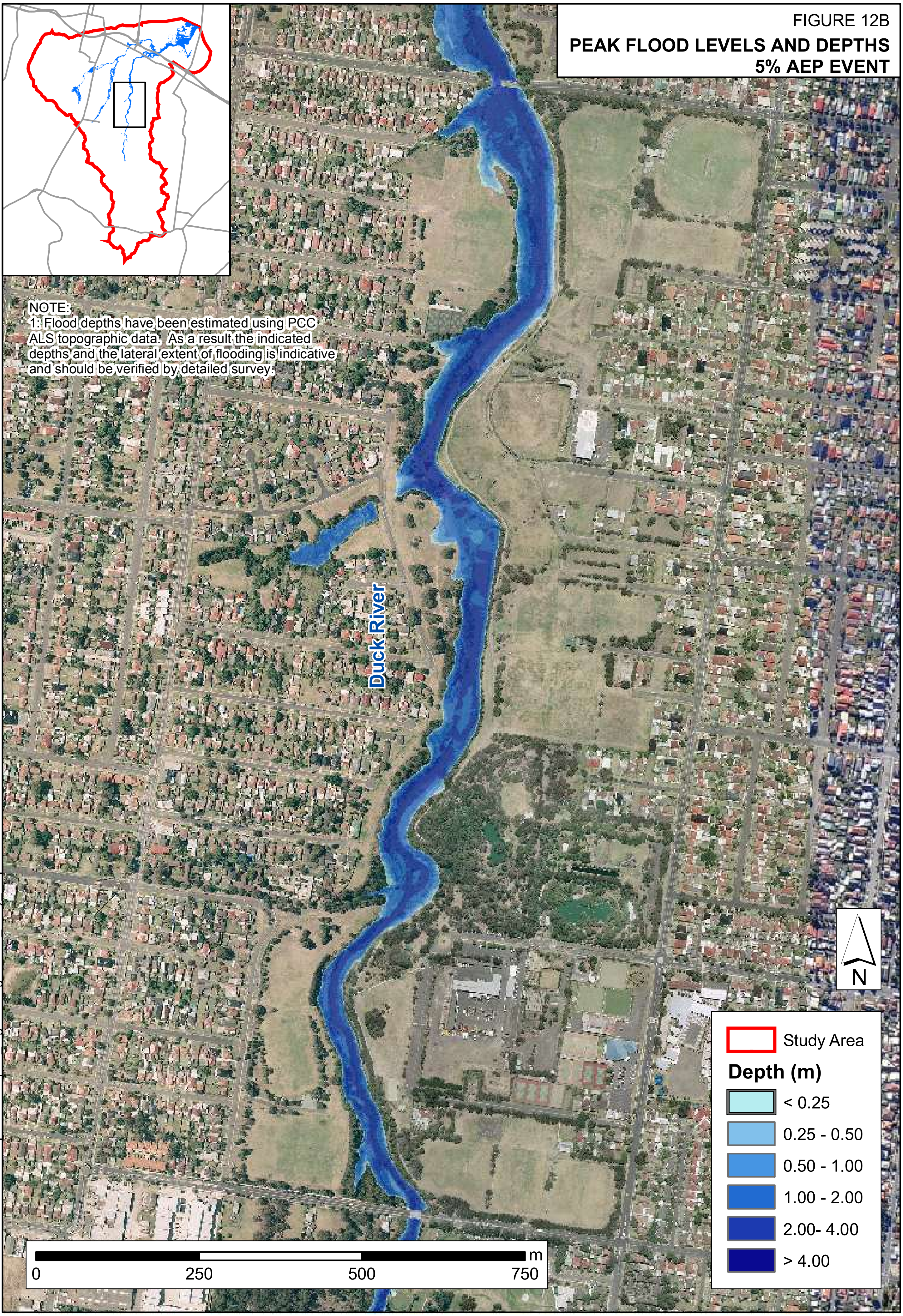


FIGURE 12A
PEAK FLOOD LEVELS AND DEPTHS 5% AEP EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure12A_020y_Map1.mxd



J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure12B_020y_Map2.mxd

FIGURE 12C
PEAK FLOOD LEVELS AND DEPTHS
5% AEP EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure12C_020y_Map3.mxd

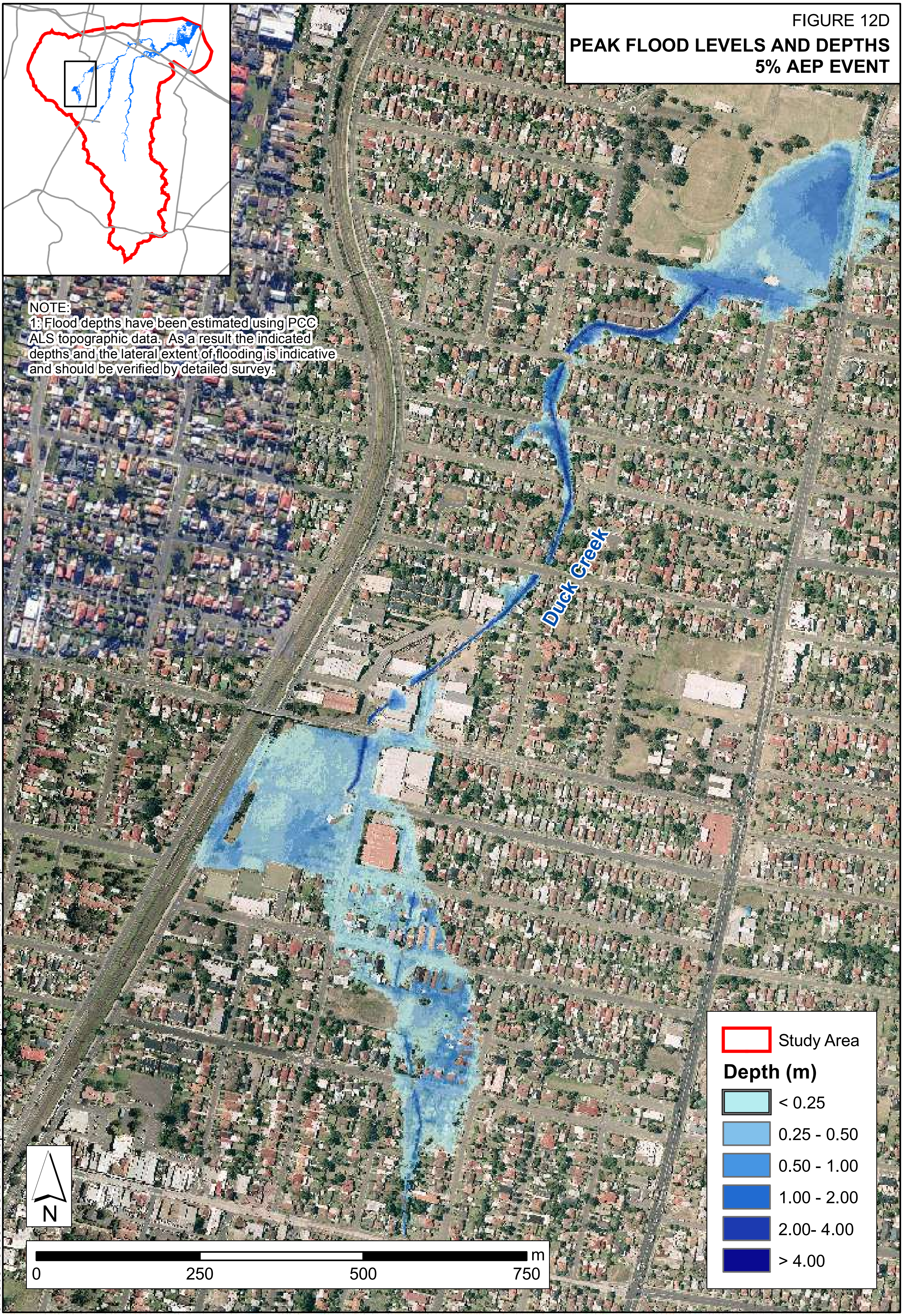
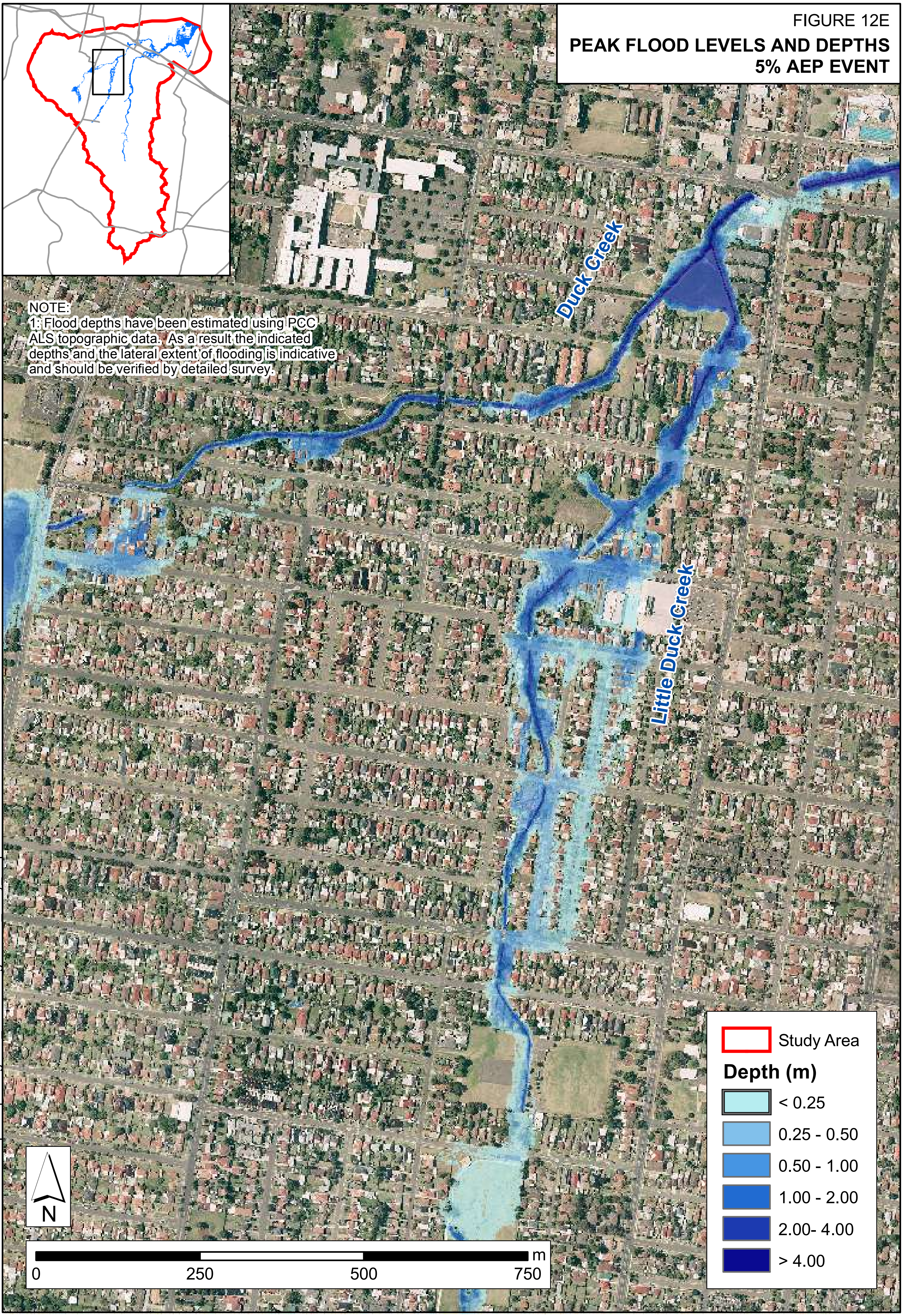


FIGURE 12D
PEAK FLOOD LEVELS AND DEPTHS 5% AEP EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure12D_020y_Map4.mxd

FIGURE 12E

**PEAK FLOOD LEVELS AND DEPTHS
5% AEP EVENT**



J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures 110119\Figure12E 020y Map5.mxd

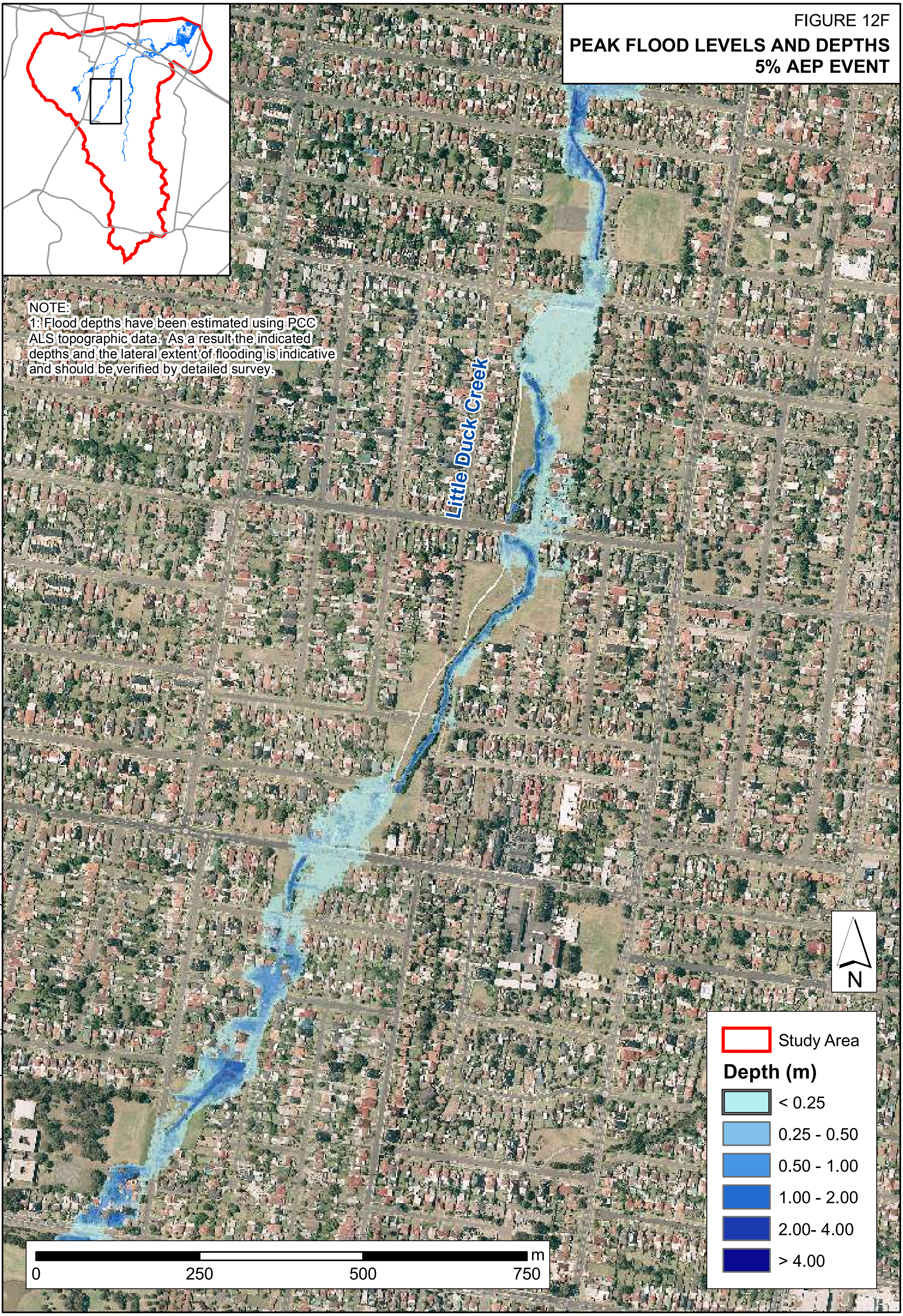
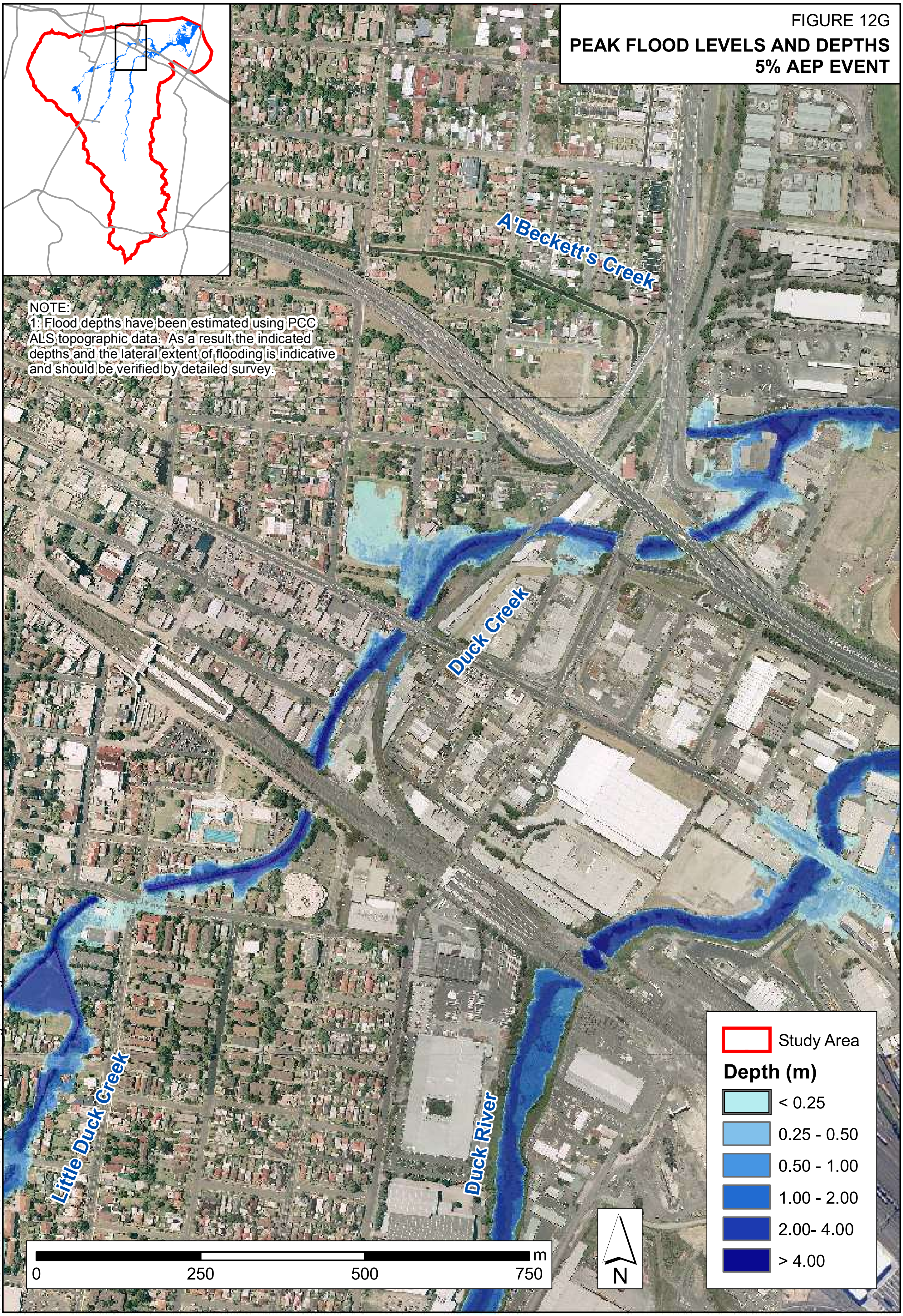


FIGURE 12F
PEAK FLOOD LEVELS AND DEPTHS
5% AEP EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure12F_020y_Map6.mxd

FIGURE 12G

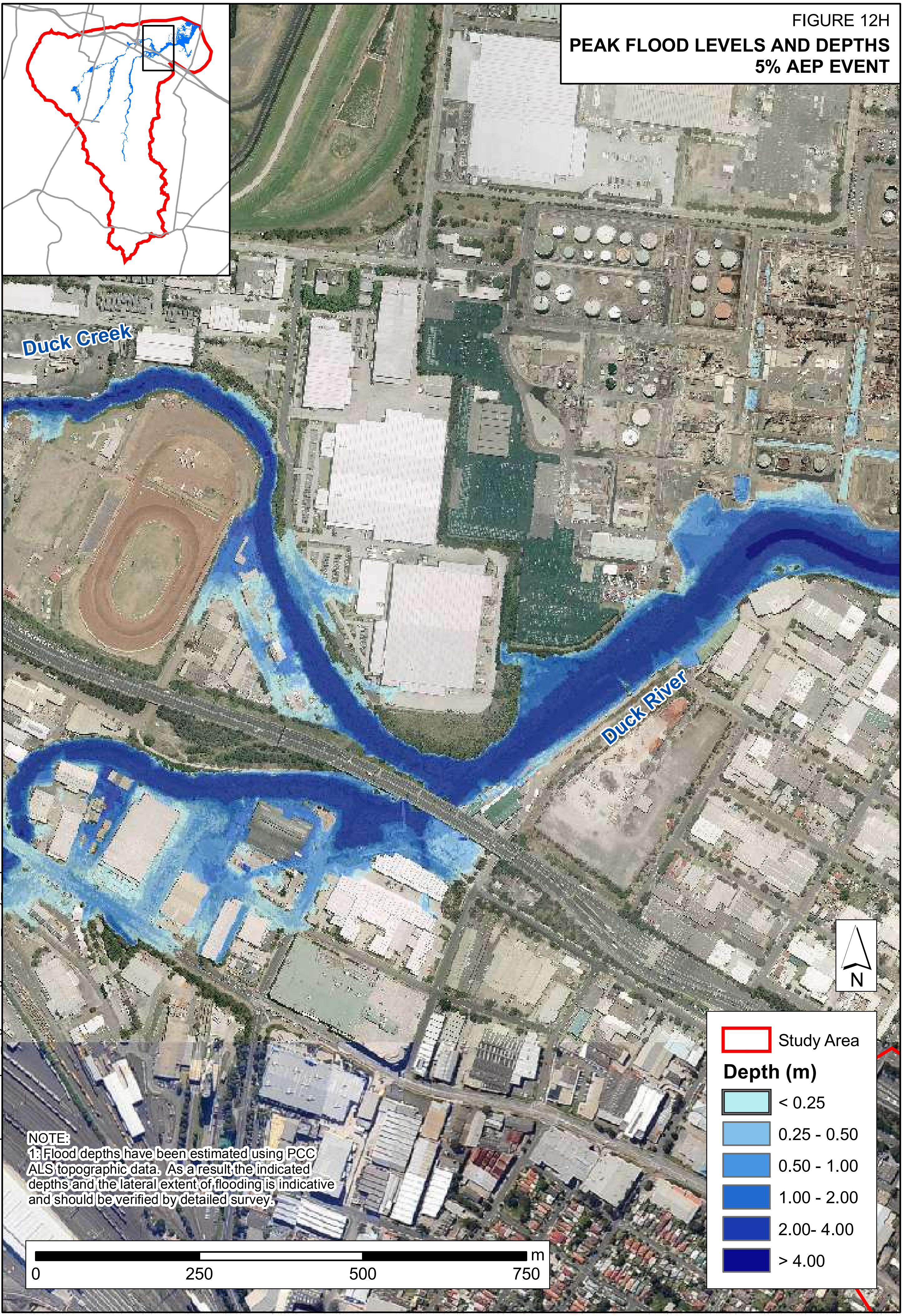
PEAK FLOOD LEVELS AND DEPTHS 5% AEP EVENT



J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure12G_020y_Map7.mxd

FIGURE 12H

PEAK FLOOD LEVELS AND DEPTHS
5% AEP EVENT



NOTE:
1: Flood depths have been estimated using PCC ALS topographic data. As a result the indicated depths and the lateral extent of flooding is indicative and should be verified by detailed survey.

J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure12H_020y_Map8.mxd

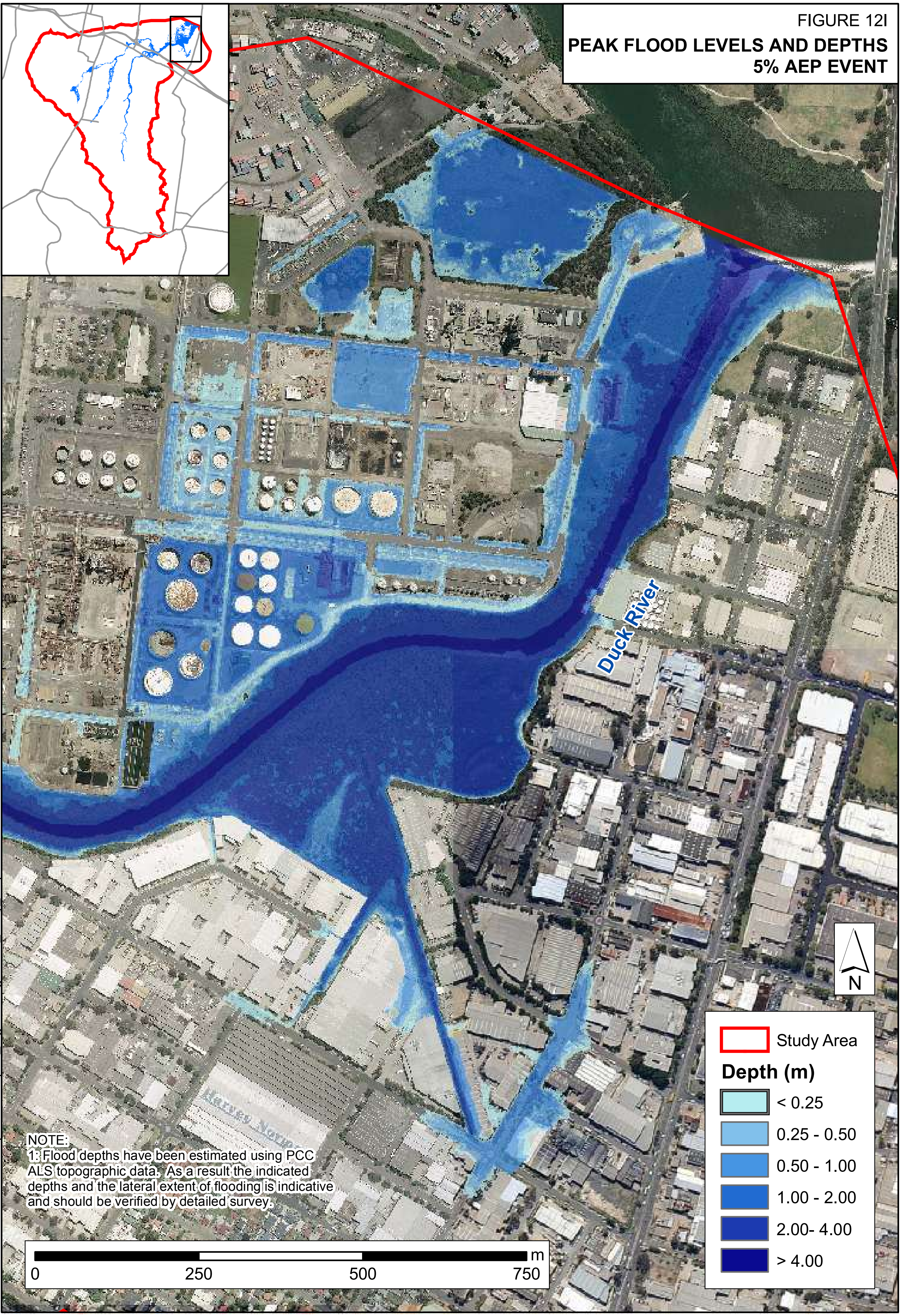


FIGURE 12I
PEAK FLOOD LEVELS AND DEPTHS
5% AEP EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure12I_020y_Map9.mxd

FIGURE 13A

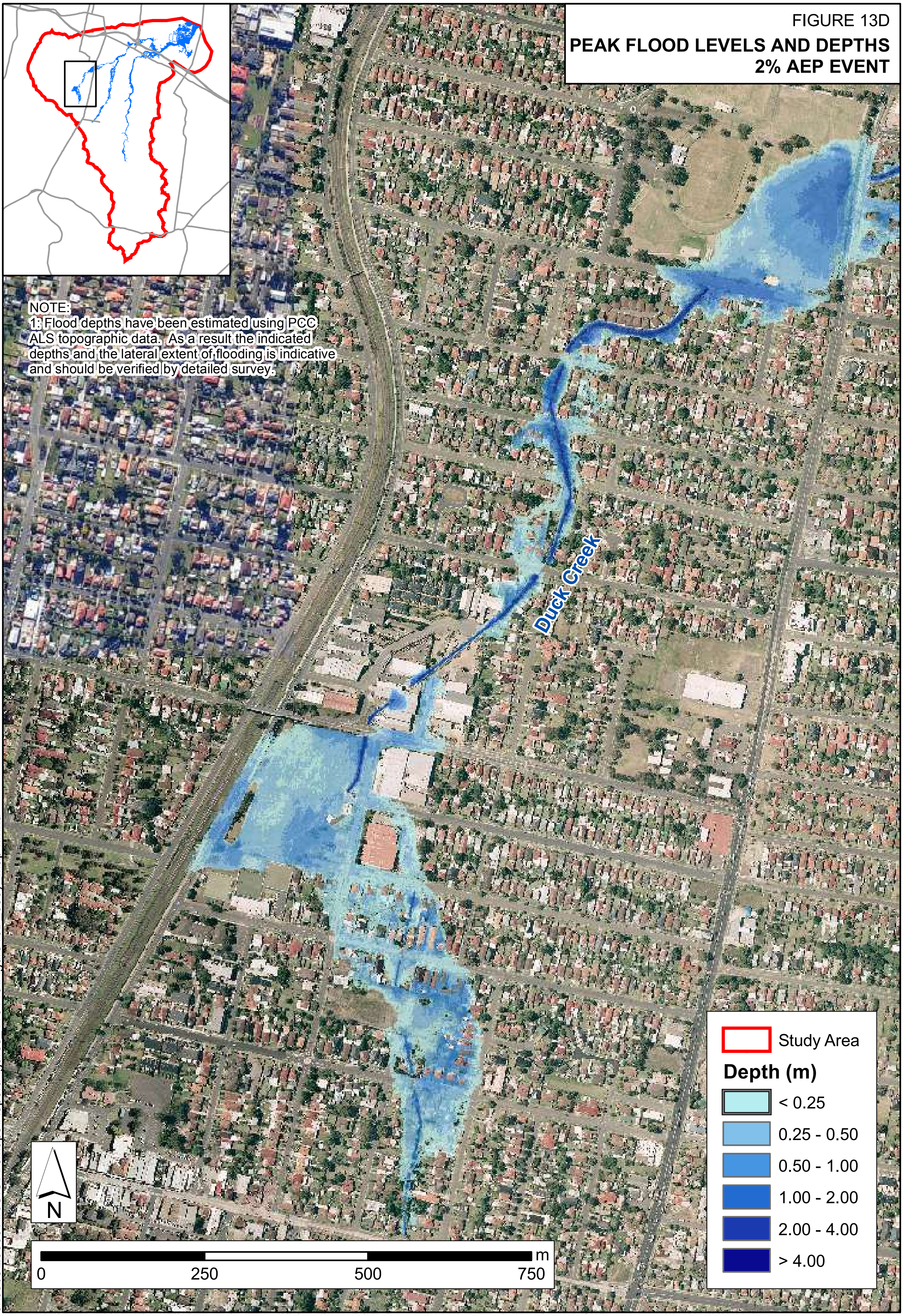
PEAK FLOOD LEVELS AND DEPTHS 2% AEP EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure13A_050y_Map1.mxd

FIGURE 13B
PEAK FLOOD LEVELS AND DEPTHS
2% AEP EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures\Figure13B_050y_Map2.mxd


FIGURE 13C
PEAK FLOOD LEVELS AND DEPTHS
2% AEP EVENT
Duck River
NOTE:
1: Flood depths have been estimated using PCC ALS topographic data. As a result the indicated depths and the lateral extent of flooding is indicative and should be verified by detailed survey.
Study Area
Depth (m)
< 0.25
0.25 - 0.50
0.50 - 1.00
1.00 - 2.00
2.00 - 4.00
> 4.00
N
0
250
500
750
m
J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure13C_050y_Map3.mxd



J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure13D_050y_Map4.mxd

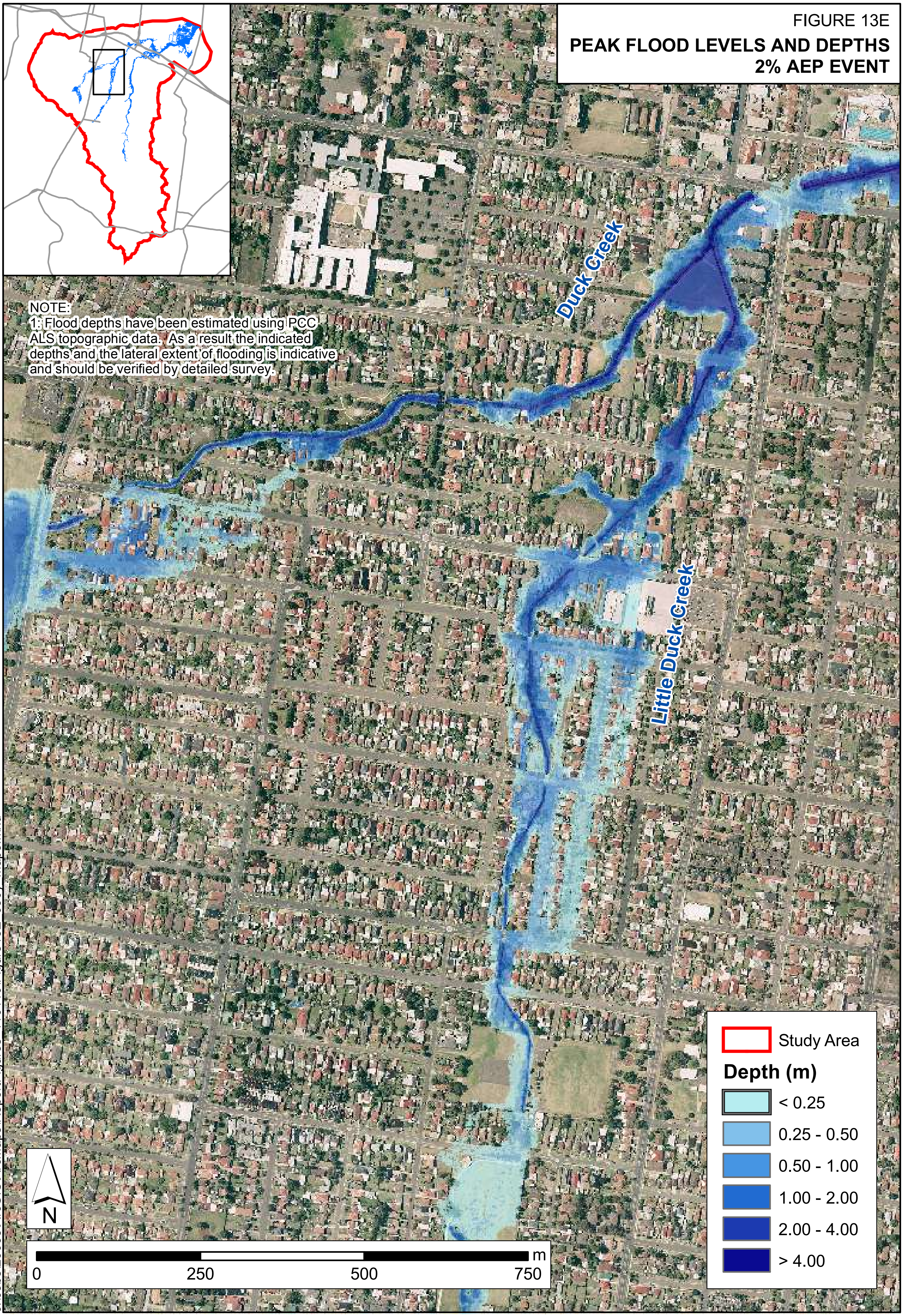


FIGURE 13E
PEAK FLOOD LEVELS AND DEPTHS
2% AEP EVENT
NOTE:
1. Flood depths have been estimated using PCC ALS topographic data. As a result the indicated depths and the lateral extent of flooding is indicative and should be verified by detailed survey.
Duck Creek
Little Duck Creek
Study Area
Depth (m)
< 0.25
0.25 - 0.50
0.50 - 1.00
1.00 - 2.00
2.00 - 4.00
> 4.00
N
0
250
500
750
m
J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure13E_050y_Map5.mxd

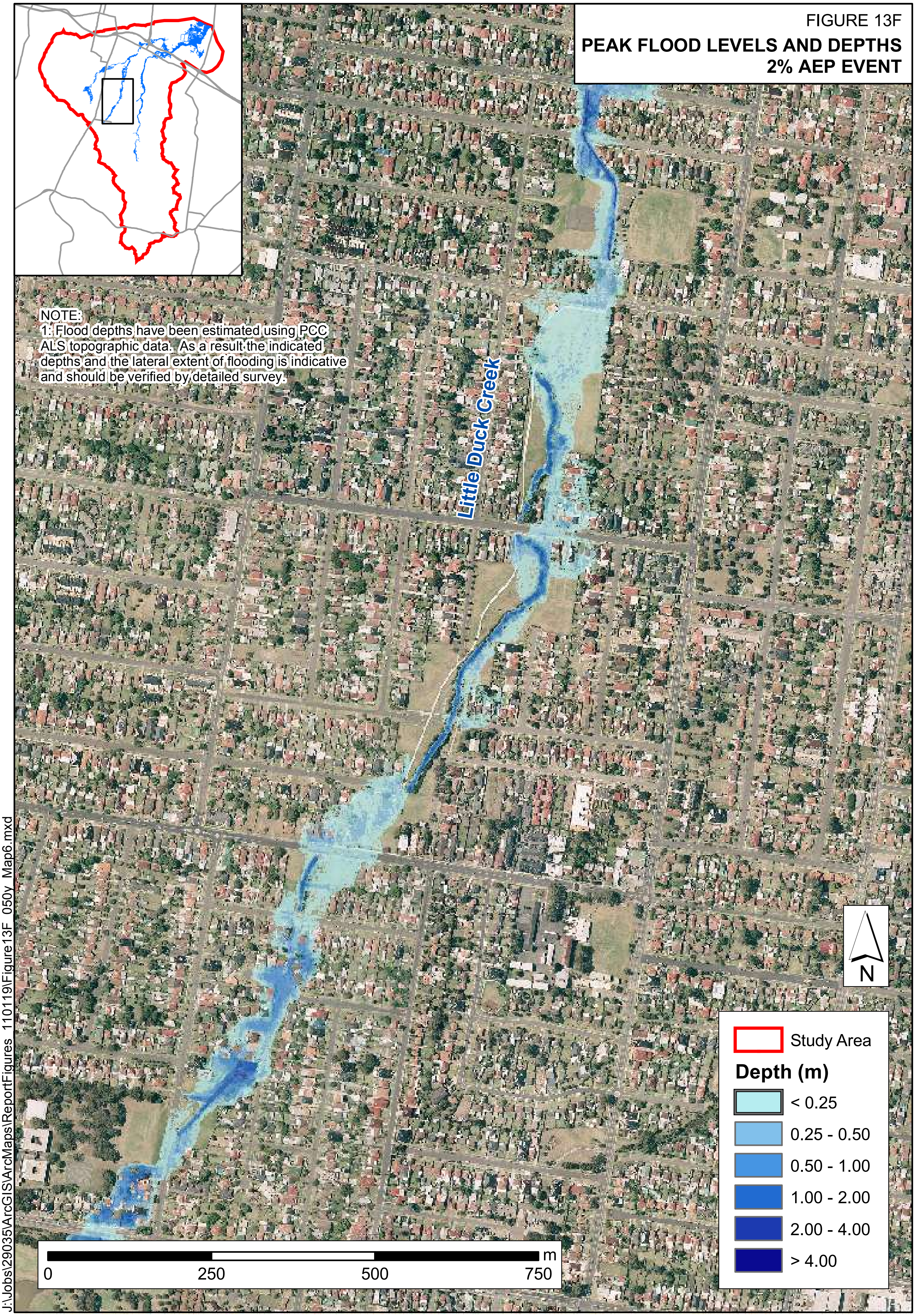


FIGURE 13F
PEAK FLOOD LEVELS AND DEPTHS
2% AEP EVENT
NOTE:
1. Flood depths have been estimated using PCC ALS topographic data. As a result the indicated depths and the lateral extent of flooding is indicative and should be verified by detailed survey.
Little Duck Creek
N
Study Area
Depth (m)
< 0.25
0.25 - 0.50
0.50 - 1.00
1.00 - 2.00
2.00 - 4.00
> 4.00
0
250
500
750
m
J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure13F_050y_Map6.mxd

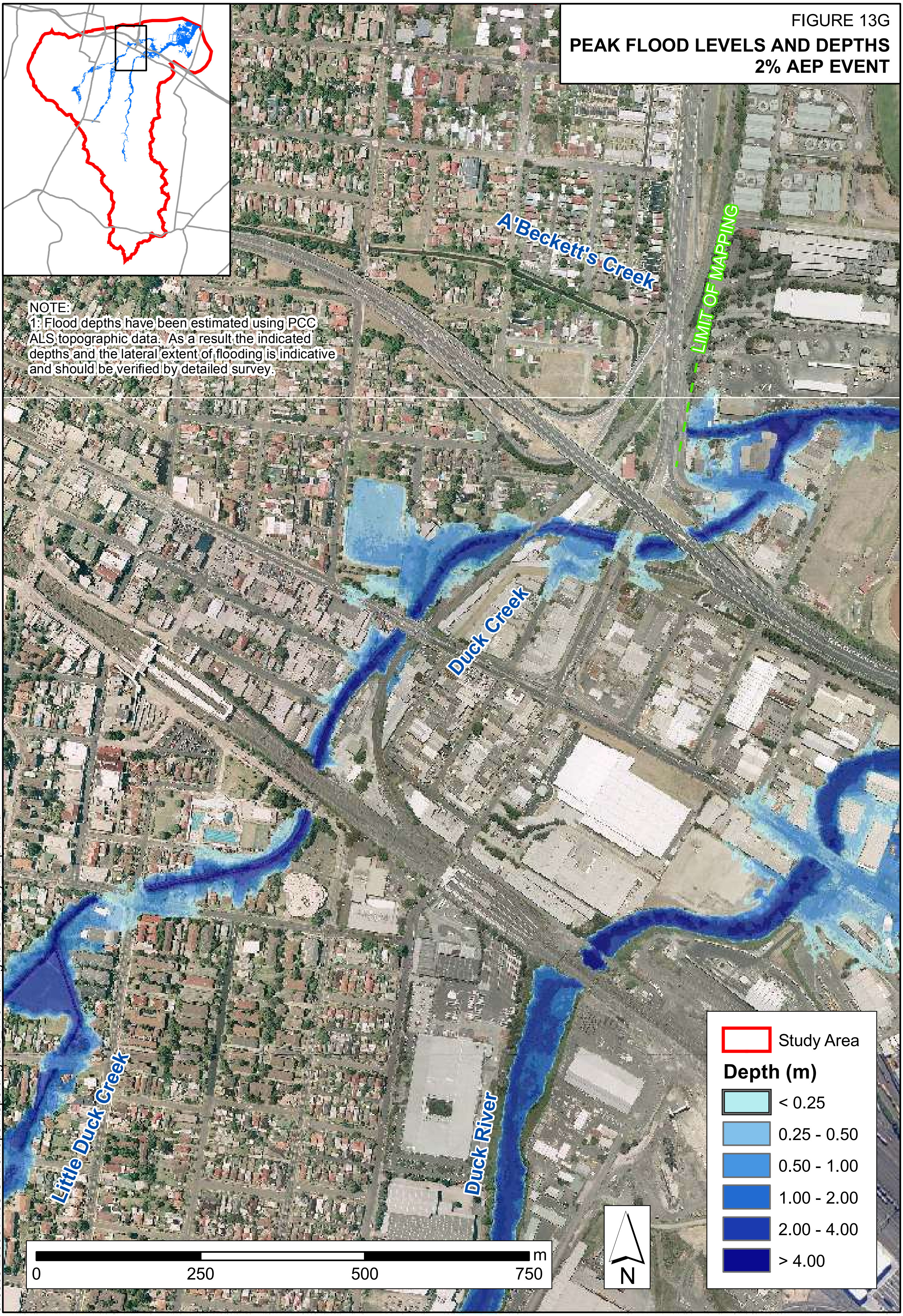
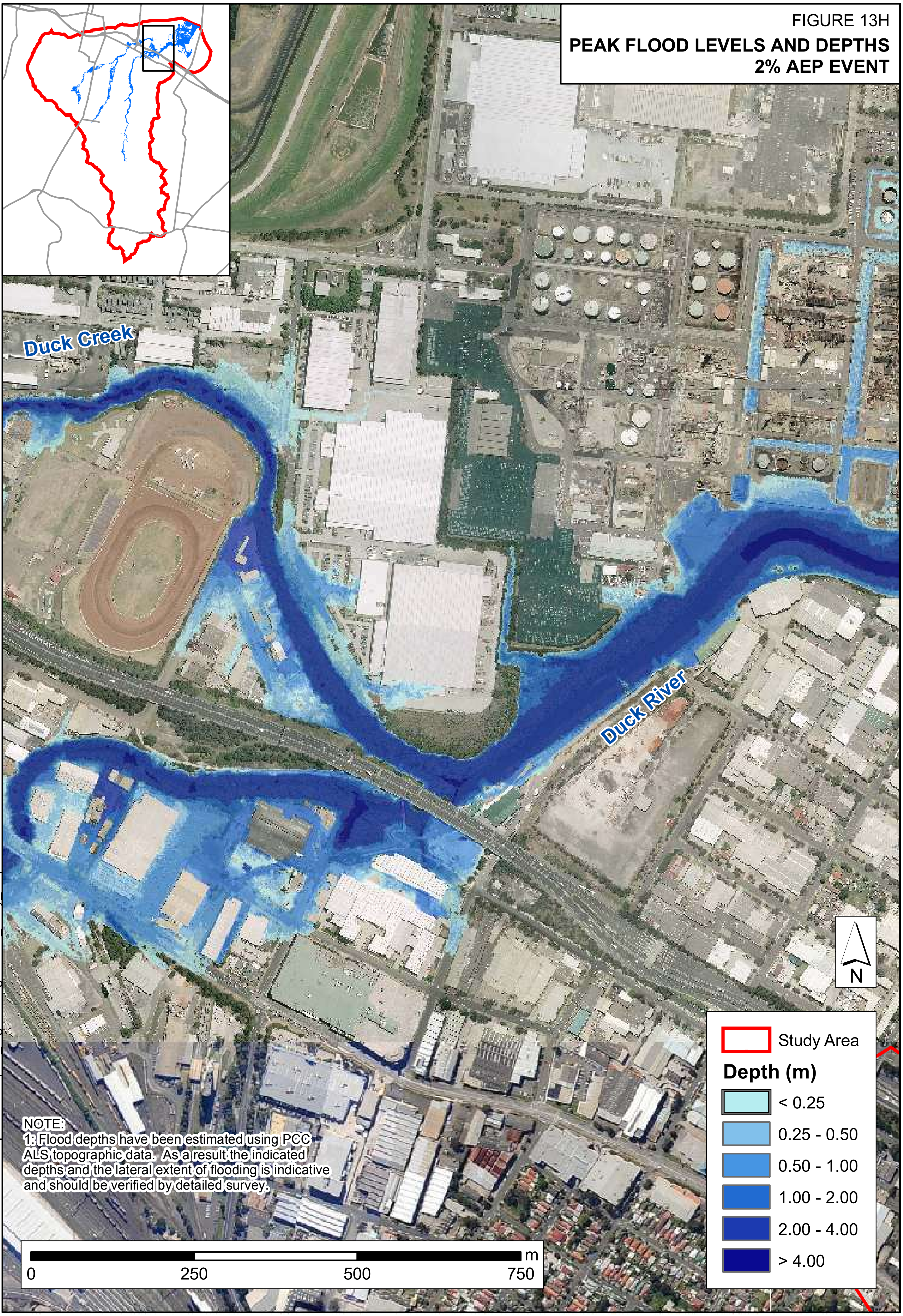


FIGURE 13G
PEAK FLOOD LEVELS AND DEPTHS
2% AEP EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures 110119\Figure13G 050y Map6.mxd

FIGURE 13H

PEAK FLOOD LEVELS AND DEPTHS
2% AEP EVENT

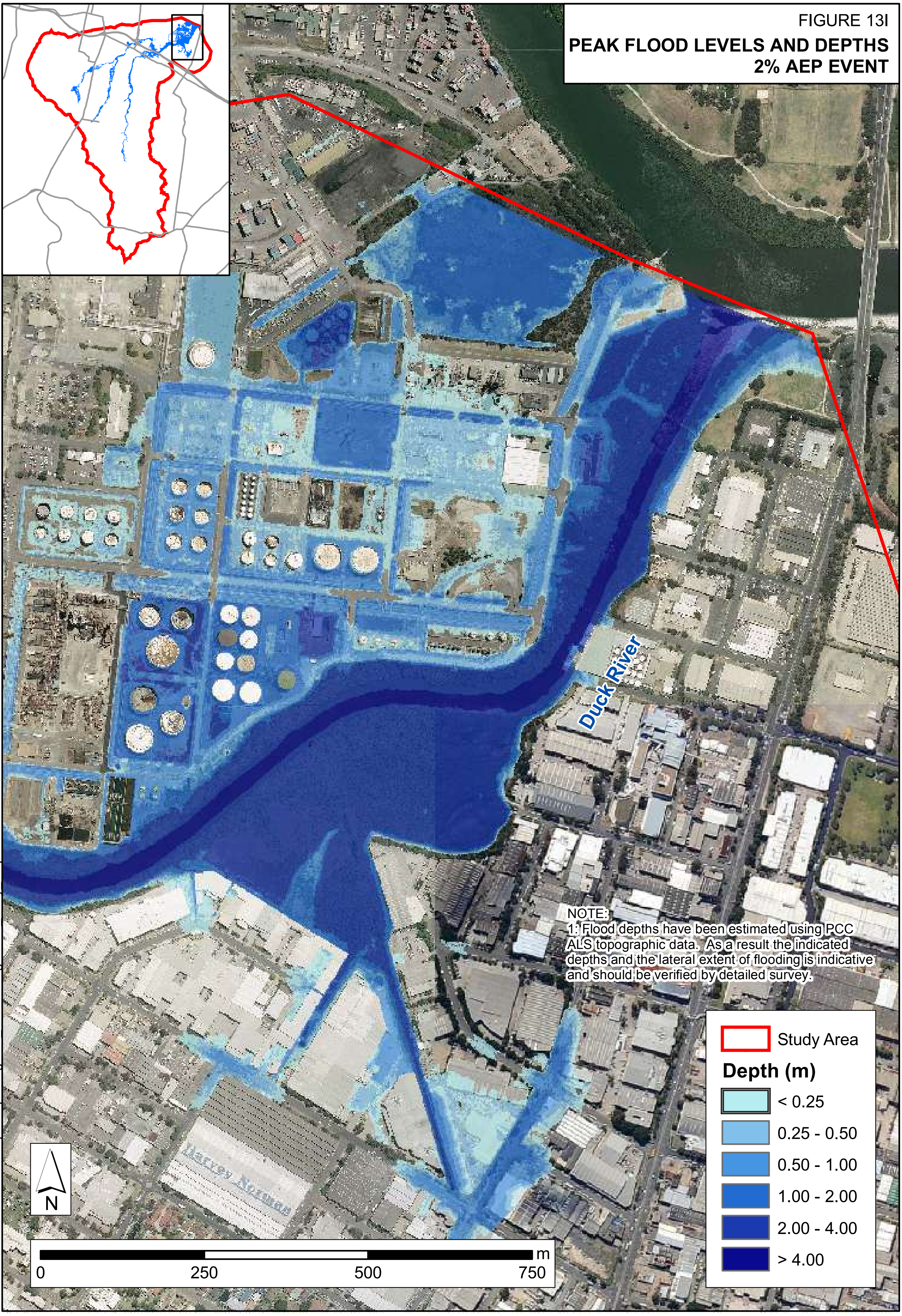


NOTE:
1. Flood depths have been estimated using PCC ALS topographic data. As a result the indicated depths and the lateral extent of flooding is indicative and should be verified by detailed survey.

J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport Figures\Figure13H 050y Map8.mxd

FIGURE 13I

PEAK FLOOD LEVELS AND DEPTHS 2% AEP EVENT



J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures 110119\Figure13I 050y Map9.mxd

J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure14A_100y_Map1.mxd

FIGURE 14B

PEAK FLOOD LEVELS AND DEPTHS 1% AEP EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure14B_100y_Map2.mxd

FIGURE 14C
PEAK FLOOD LEVELS AND DEPTHS 1% AEP EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure14C_100y_Map3.mxd

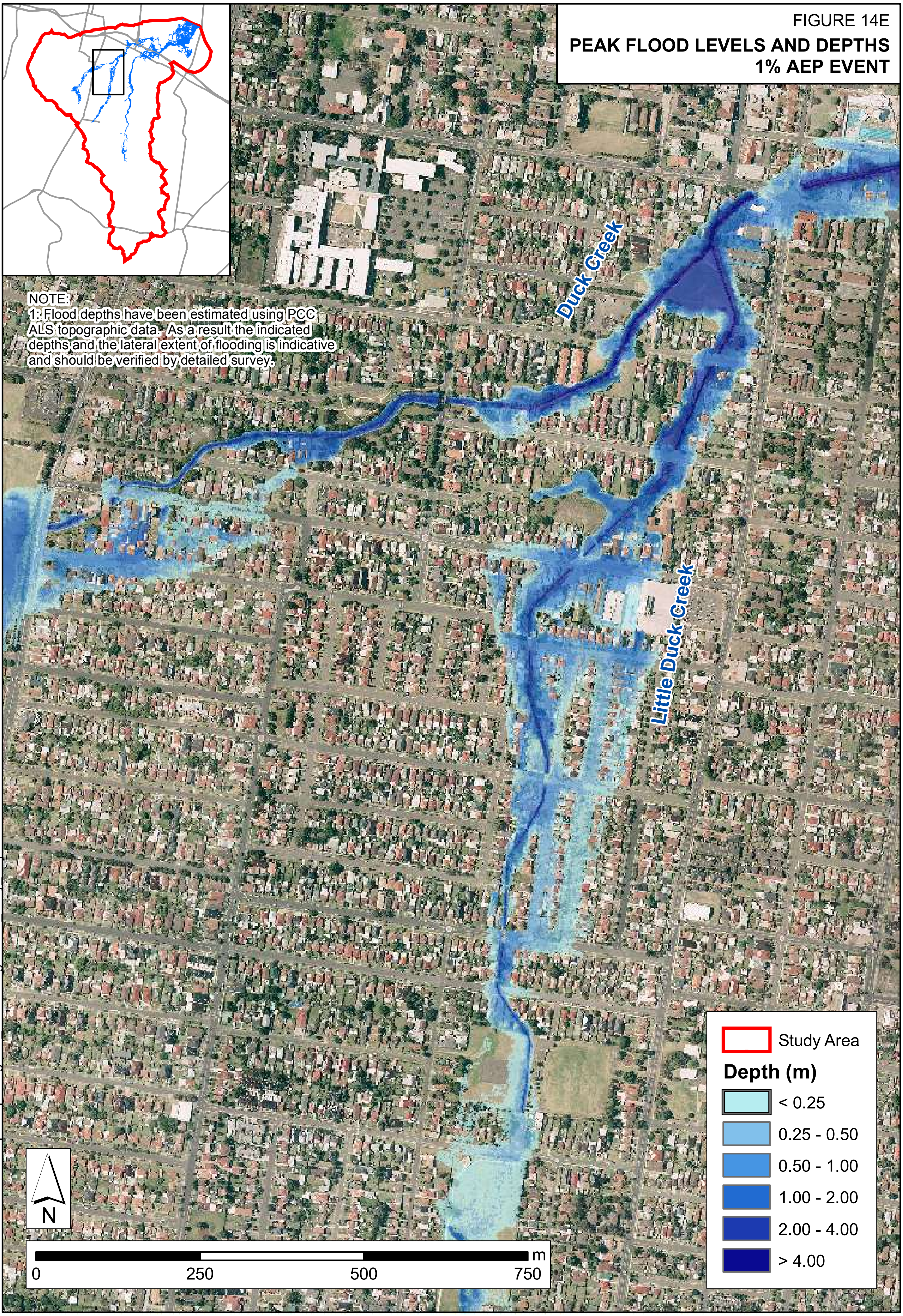
FIGURE 14D

PEAK FLOOD LEVELS AND DEPTHS
1% AEP EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure14D_100y_Map4.mxd

FIGURE 14E

PEAK FLOOD LEVELS AND DEPTHS
1% AEP EVENT



J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure14E_100y_Map5.mxd

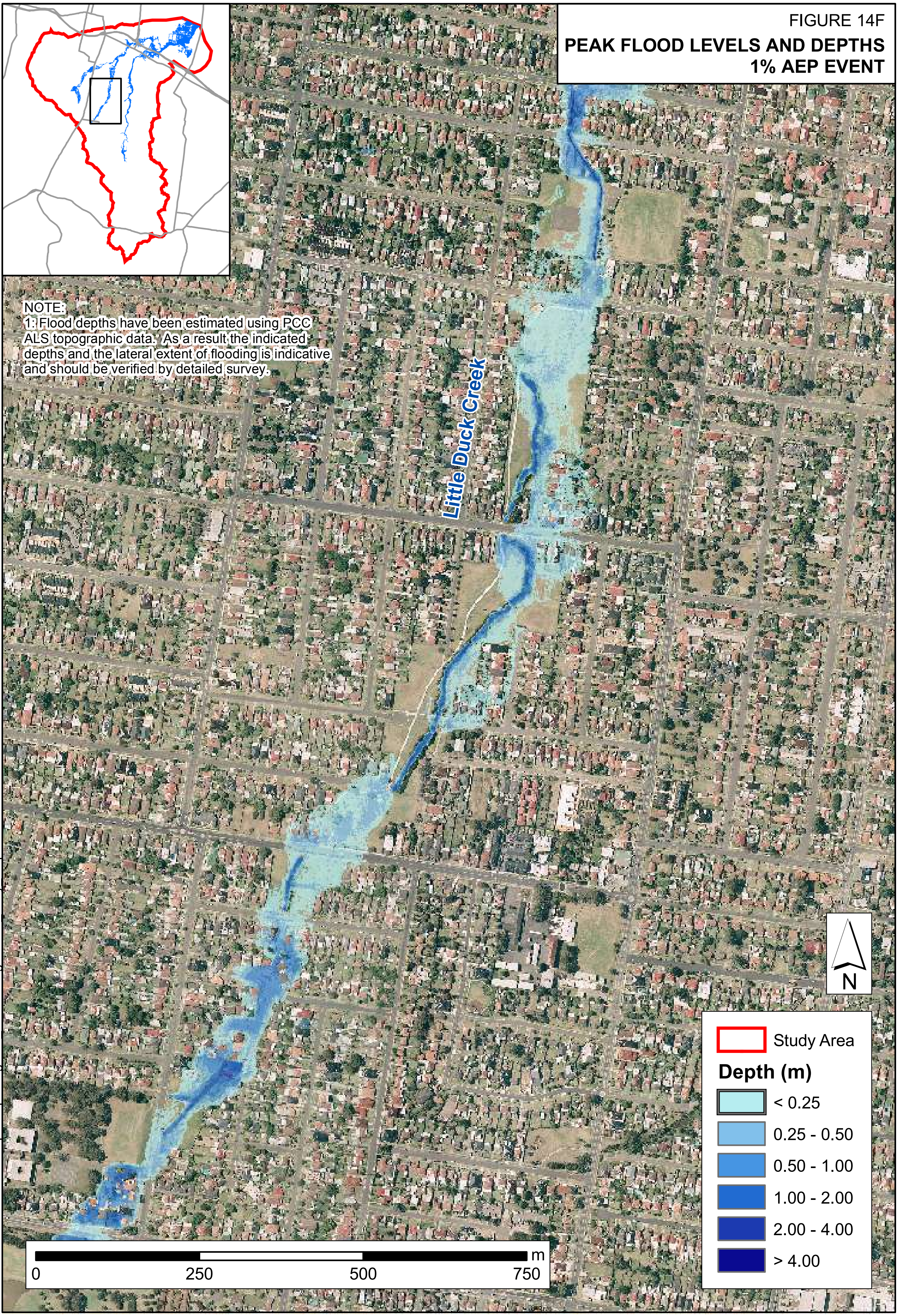
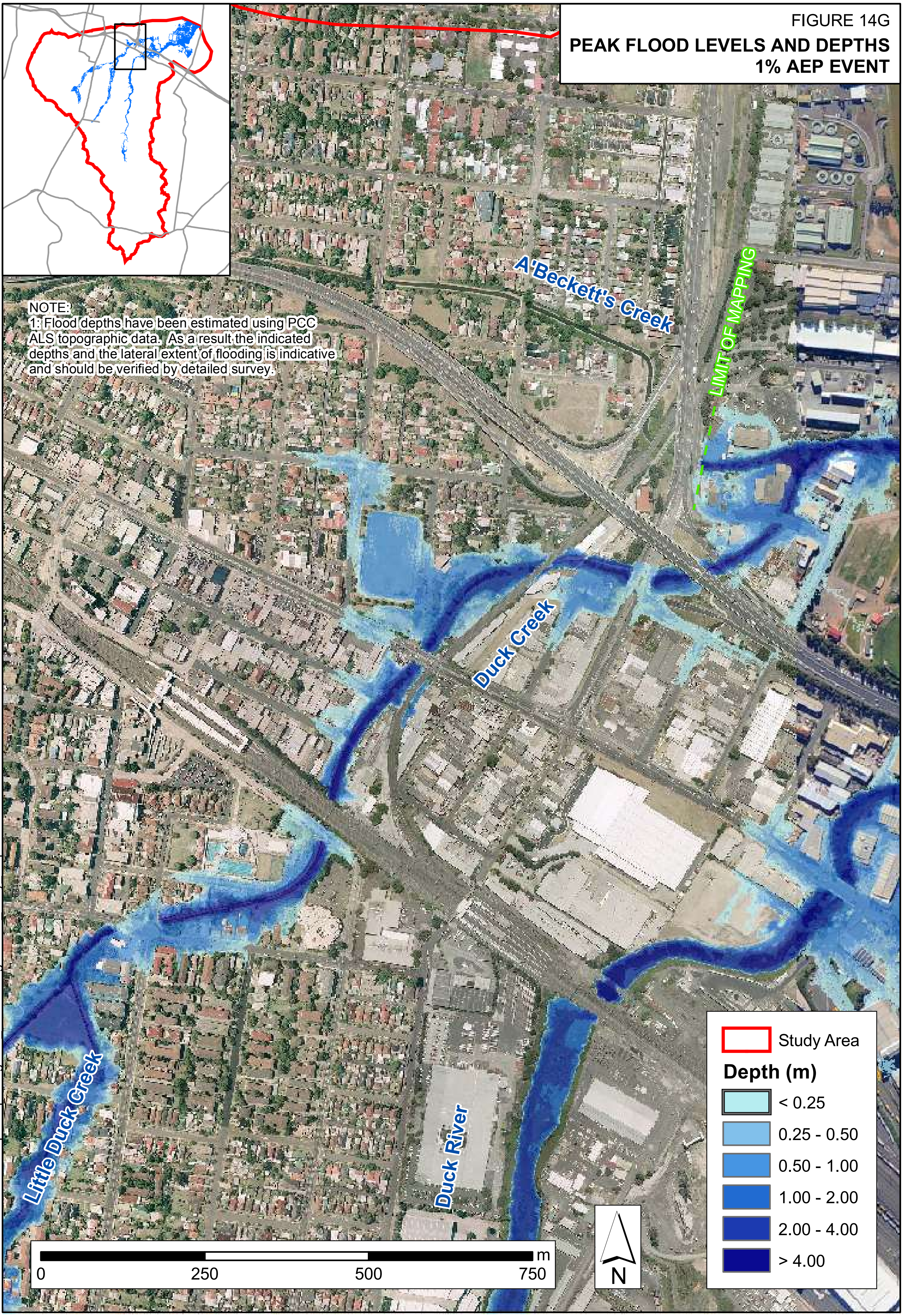


FIGURE 14F
PEAK FLOOD LEVELS AND DEPTHS
1% AEP EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures 110119\Figure14F 100y Map6.mxd

FIGURE 14G

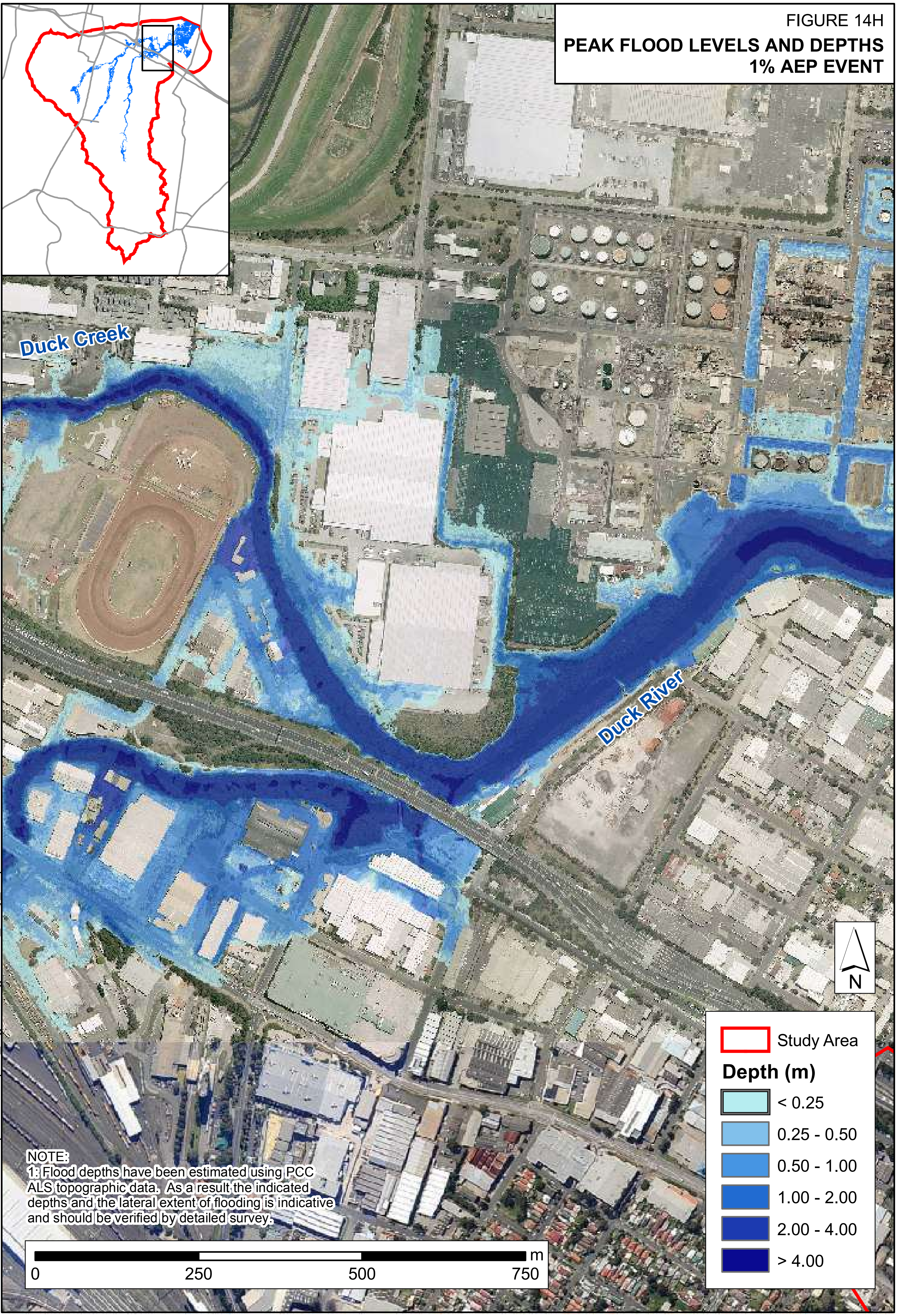
PEAK FLOOD LEVELS AND DEPTHS
1% AEP EVENT



J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure14G_100y_Map6.mxd

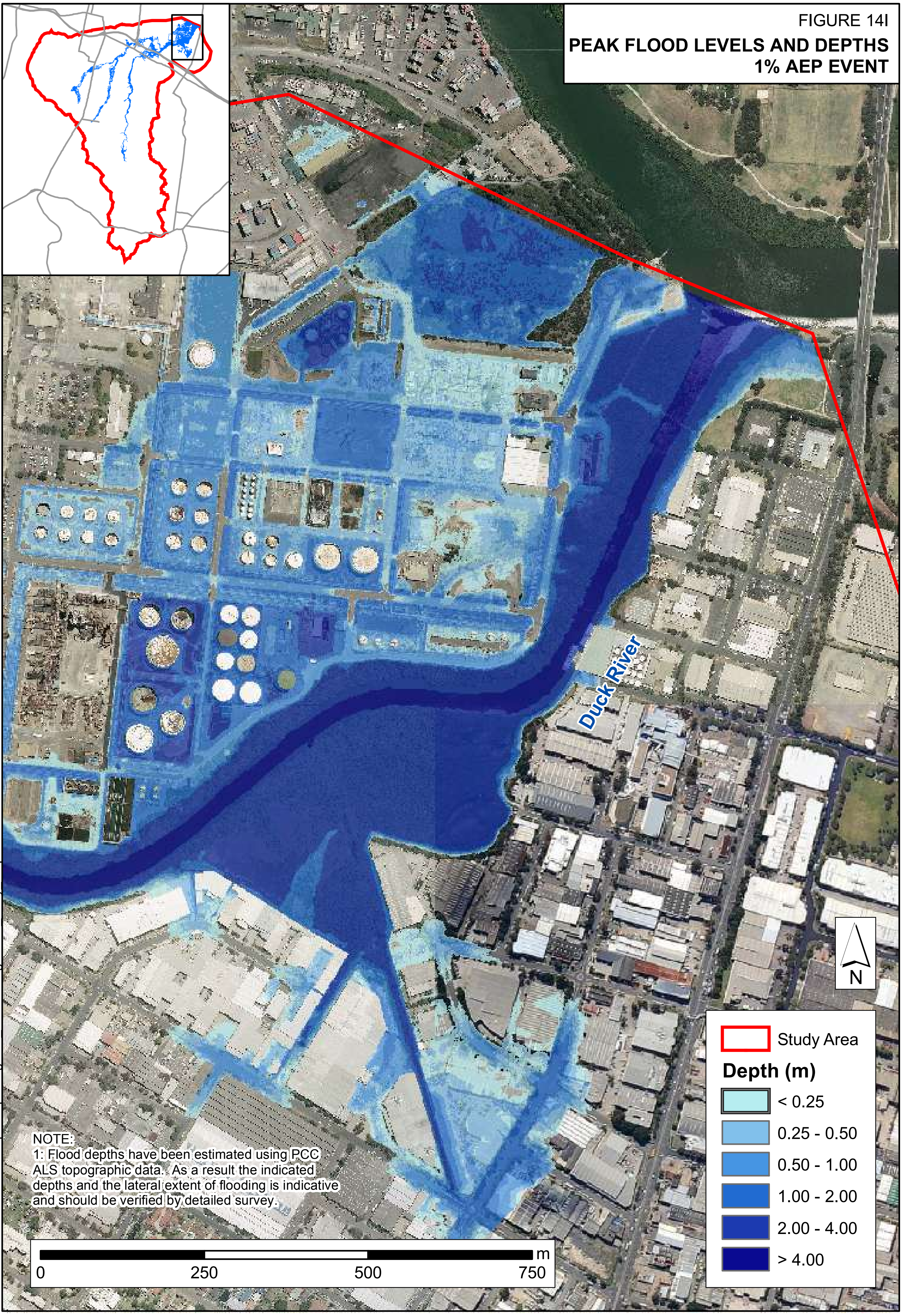
FIGURE 14H

PEAK FLOOD LEVELS AND DEPTHS
1% AEP EVENT



NOTE:
1: Flood depths have been estimated using PCC ALS topographic data. As a result the indicated depths and the lateral extent of flooding is indicative and should be verified by detailed survey.

J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport Figures\Figure14H 100y Map8.mxd



J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure14I_100y_Map9.mxd

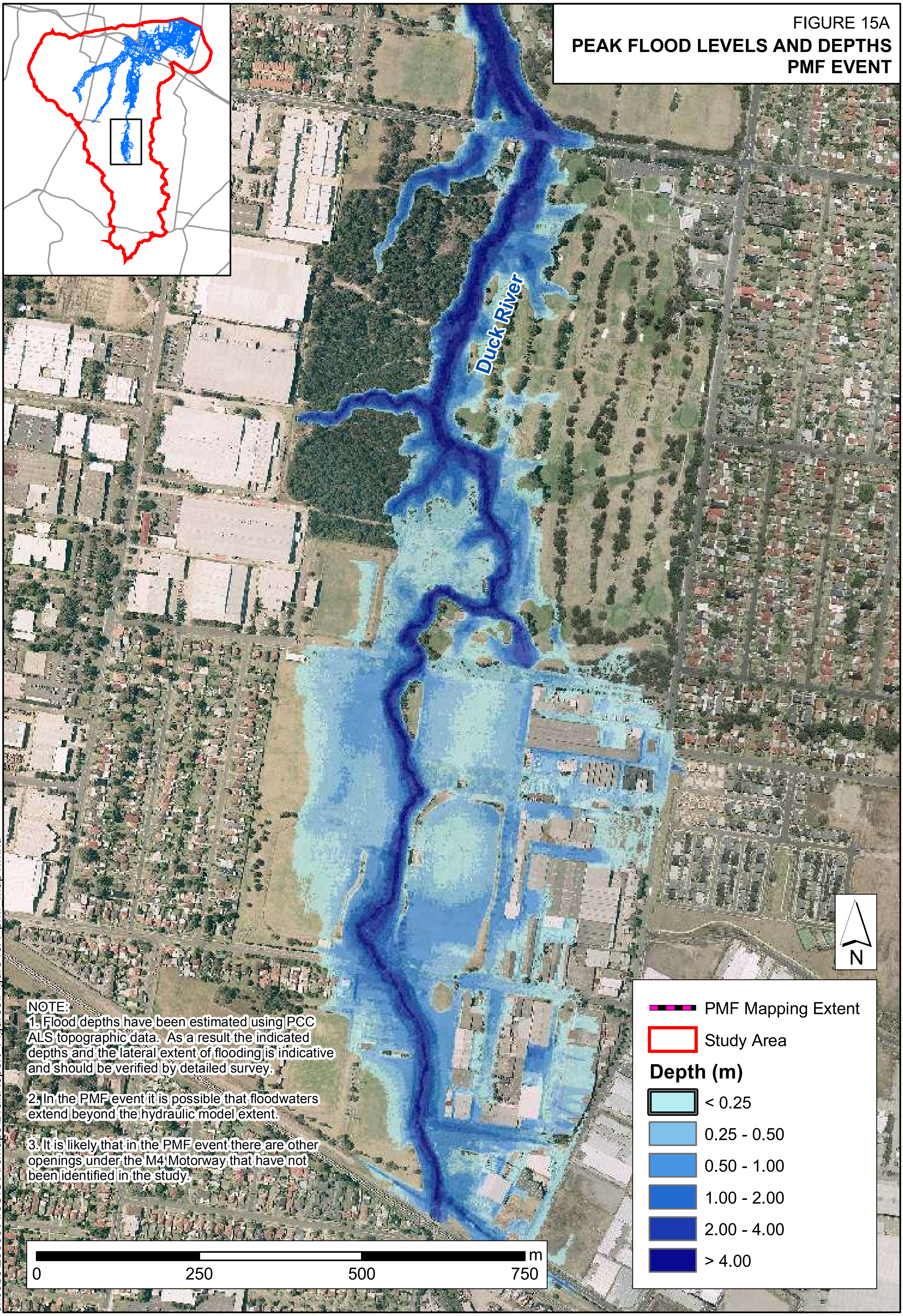


FIGURE 15A
PEAK FLOOD LEVELS AND DEPTHS
PMF EVENT
Duck River
N
NOTE:
1. Flood depths have been estimated using PCC ALS topographic data. As a result the indicated depths and the lateral extent of flooding is indicative and should be verified by detailed survey.
2. In the PMF event it is possible that floodwaters extend beyond the hydraulic model extent.
3. It is likely that in the PMF event there are other openings under the M4 Motorway that have not been identified in the study.
PMF Mapping Extent
Study Area
Depth (m)
< 0.25
0.25 - 0.50
0.50 - 1.00
1.00 - 2.00
2.00 - 4.00
> 4.00
m
0
250
500
750
J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure15A_pmf_Map1.mxd

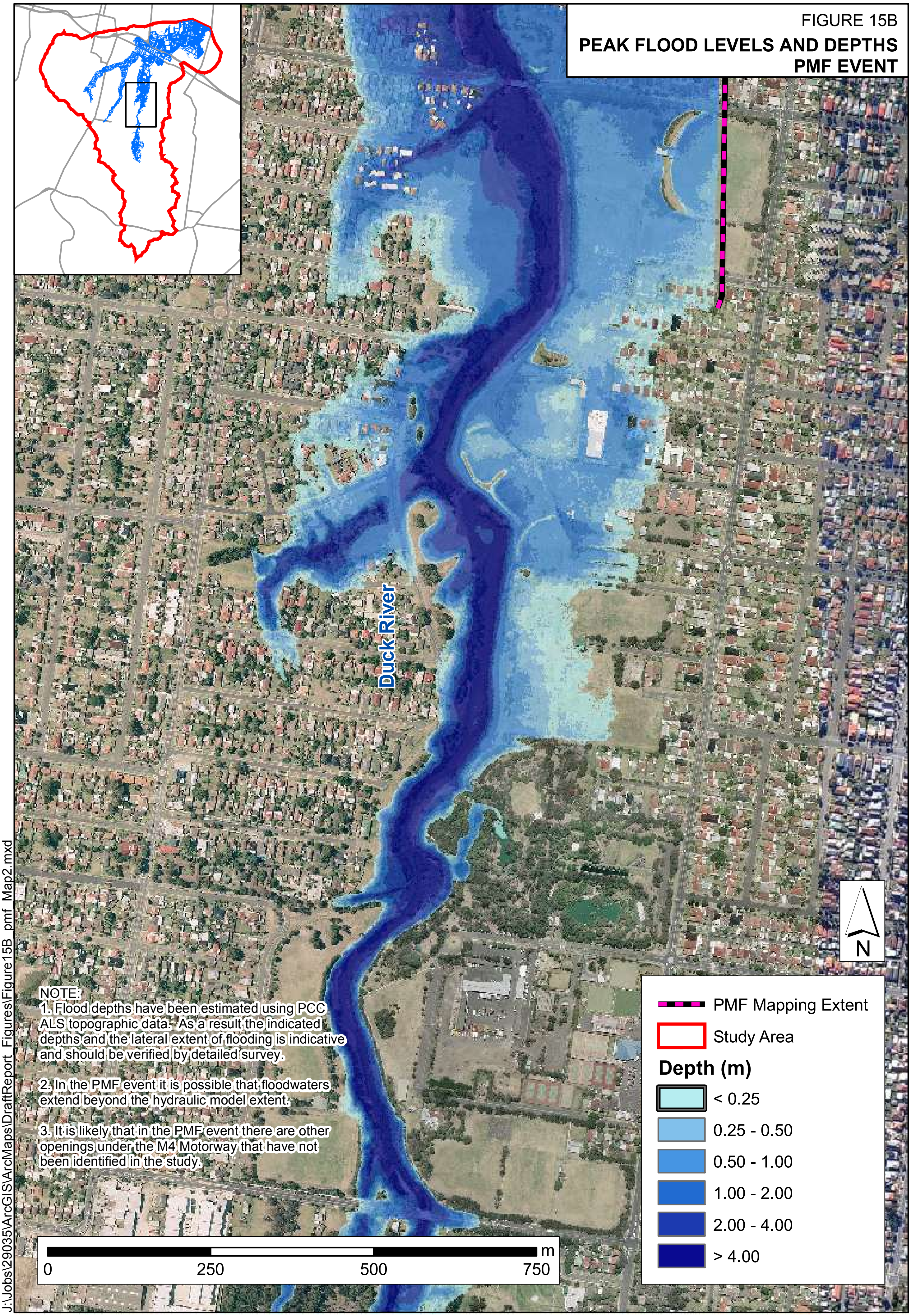


FIGURE 15B
PEAK FLOOD LEVELS AND DEPTHS
PMF EVENT
Duck River
NOTE:
1. Flood depths have been estimated using PCC ALS topographic data. As a result the indicated depths and the lateral extent of flooding is indicative and should be verified by detailed survey.
2. In the PMF event it is possible that floodwaters extend beyond the hydraulic model extent.
3. It is likely that in the PMF event there are other openings under the M4 Motorway that have not been identified in the study.
0
250
500
750
m
N
PMF Mapping Extent
Study Area
Depth (m)
< 0.25
0.25 - 0.50
0.50 - 1.00
1.00 - 2.00
2.00 - 4.00
> 4.00
J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure15B_pmf_Map2.mxd

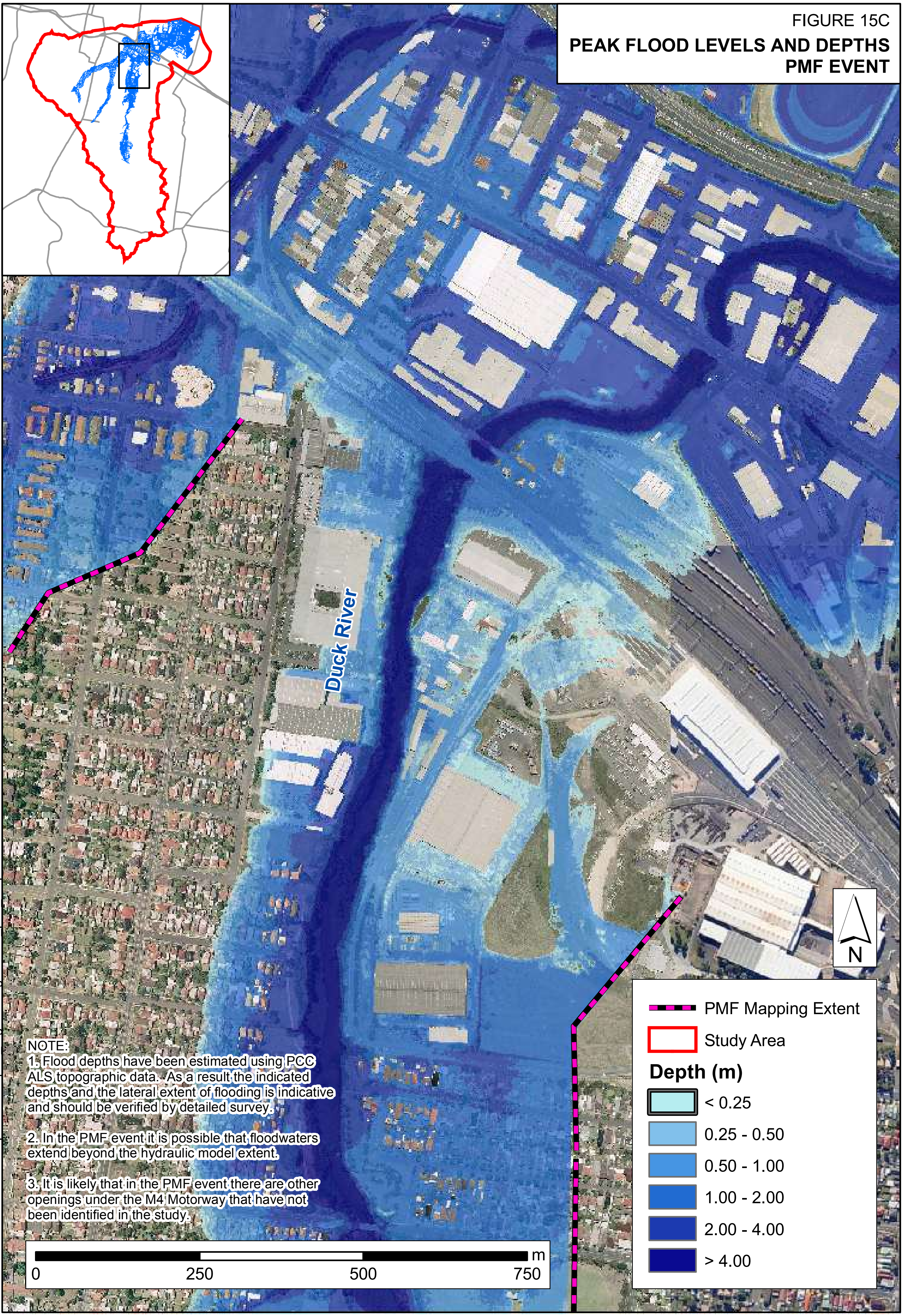
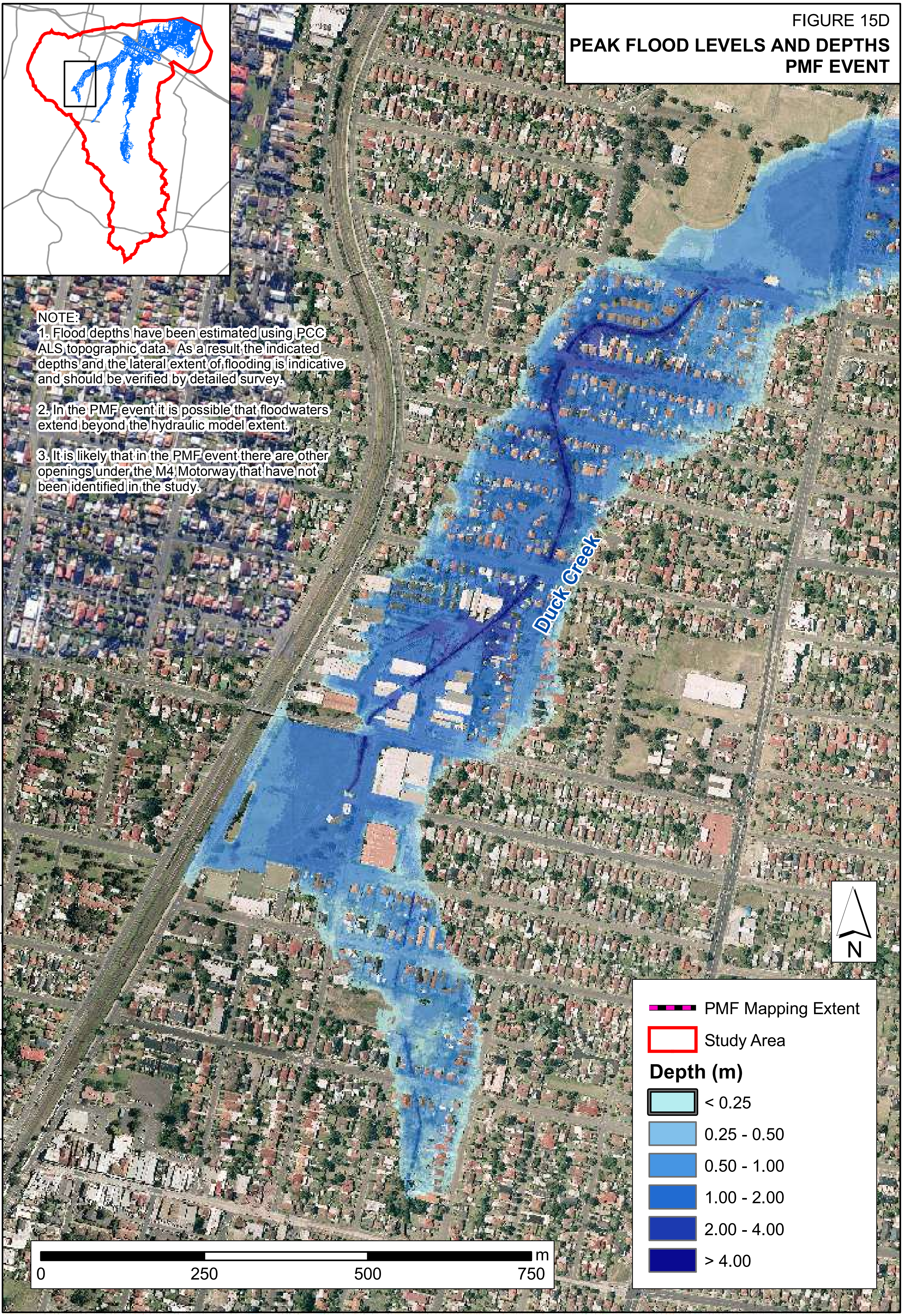


FIGURE 15C
PEAK FLOOD LEVELS AND DEPTHS PMF EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure15C_pmf_Map3.mxd

FIGURE 15D

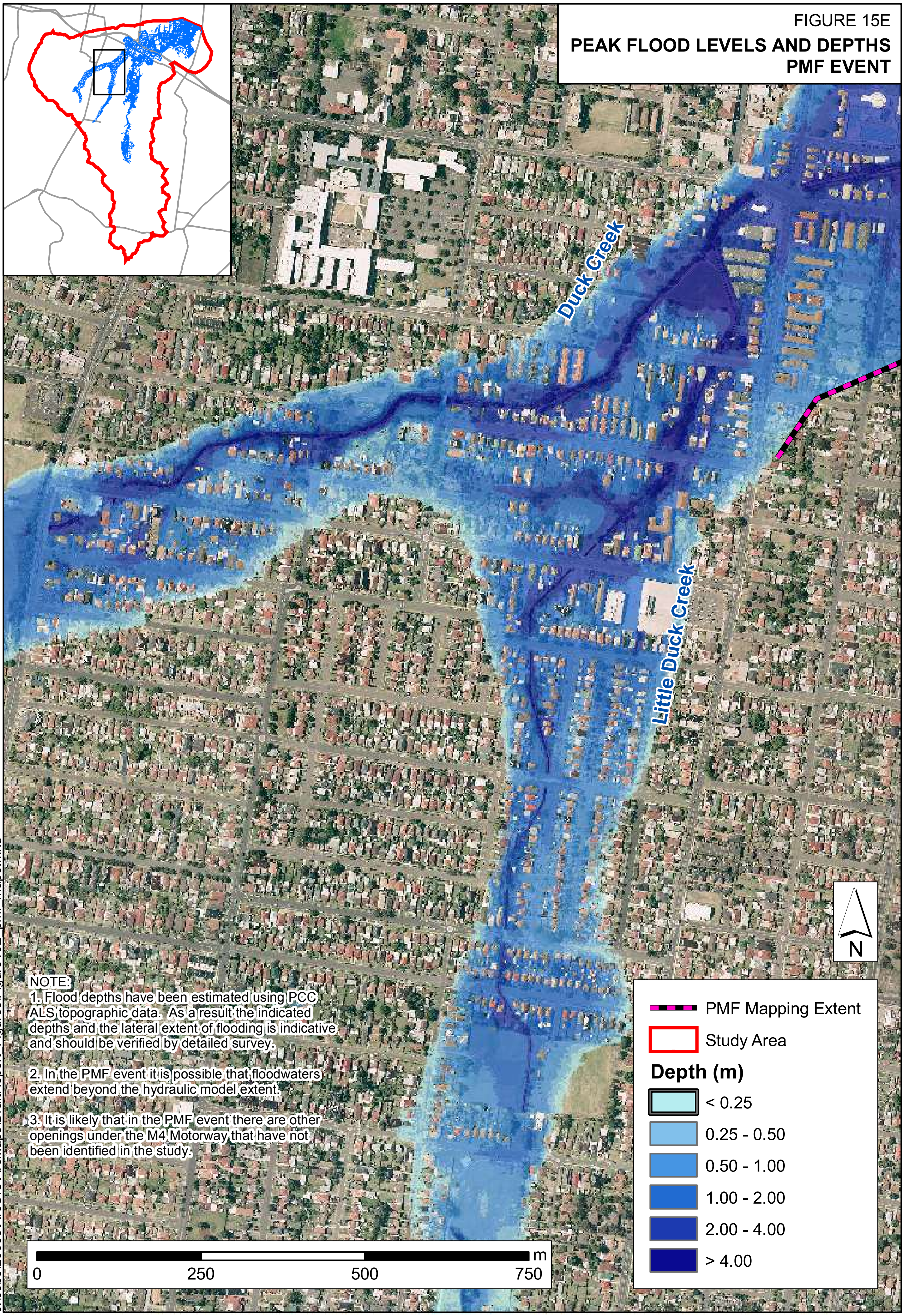
PEAK FLOOD LEVELS AND DEPTHS
PMF EVENT



J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport Figures\FigureXD pmf Map4.mxd

FIGURE 15E

PEAK FLOOD LEVELS AND DEPTHS PMF EVENT



NOTE:

1. Flood depths have been estimated using PCC ALS topographic data. As a result the indicated depths and the lateral extent of flooding is indicative and should be verified by detailed survey.

2. In the PMF event it is possible that floodwaters extend beyond the hydraulic model extent.

3. It is likely that in the PMF event there are other openings under the M4 Motorway that have not been identified in the study.

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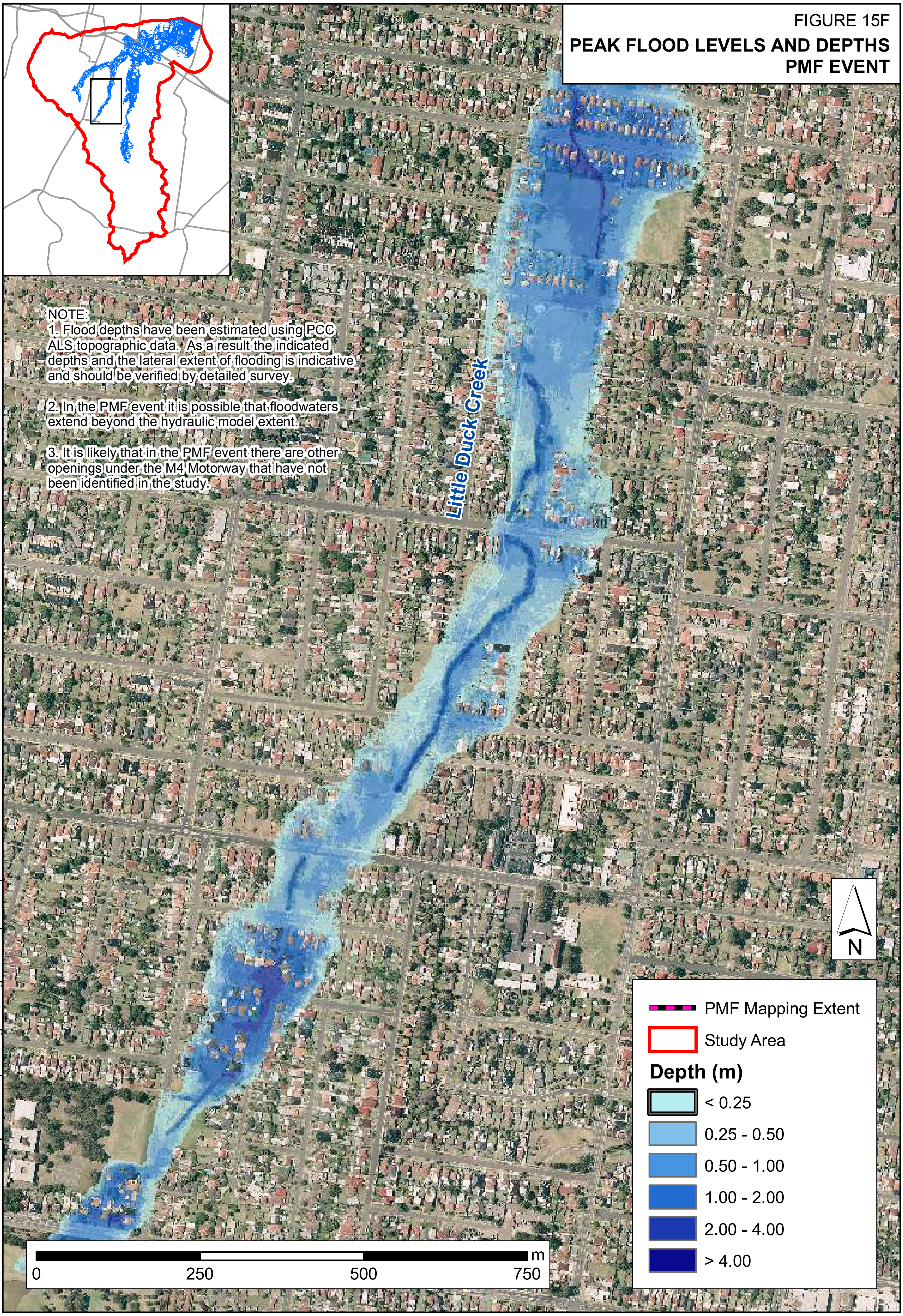
FIGURE 15F

PEAK FLOOD LEVELS AND DEPTHS PMF EVENT



J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport Figures\Figure15F pmf Map6.mxd

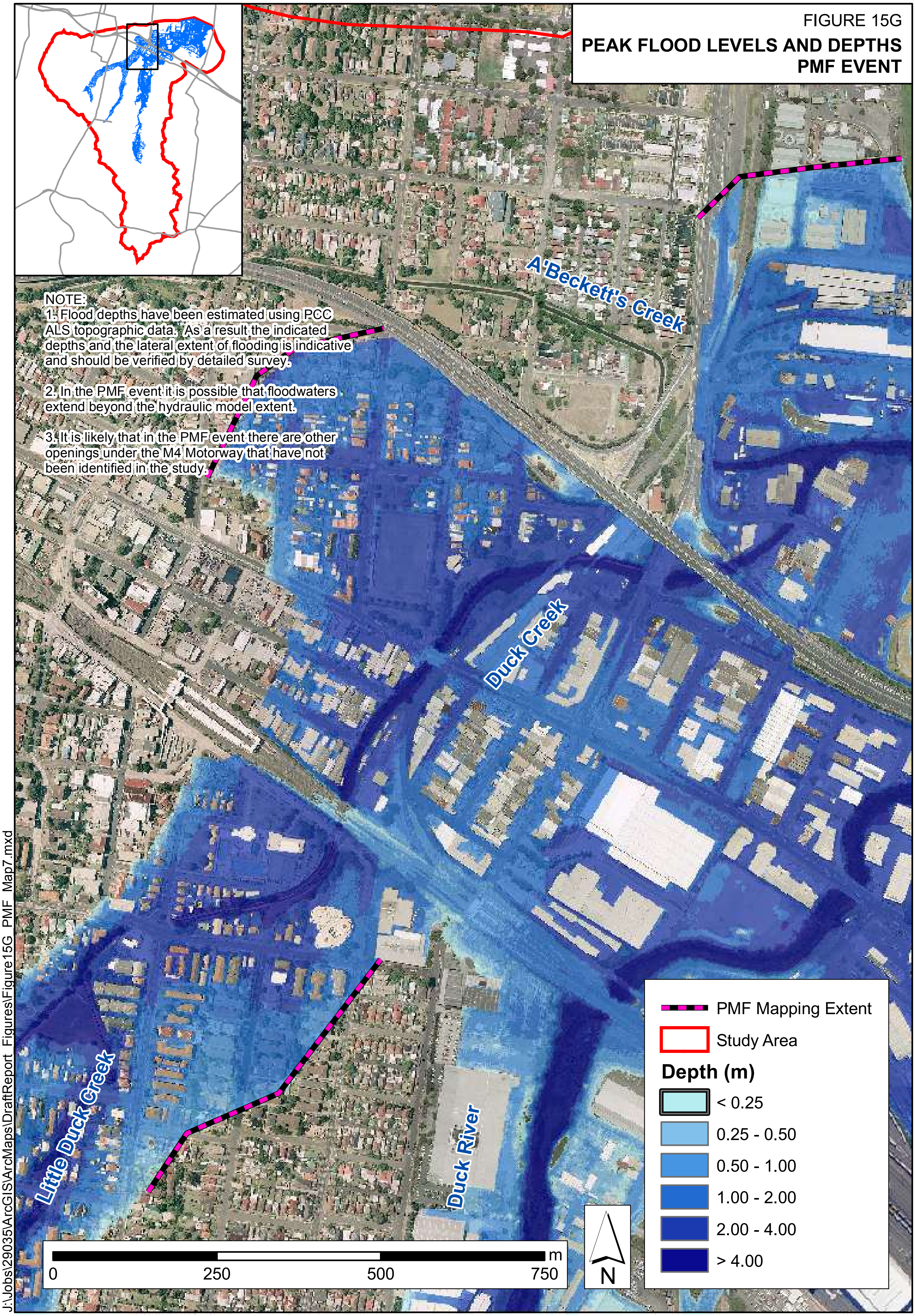
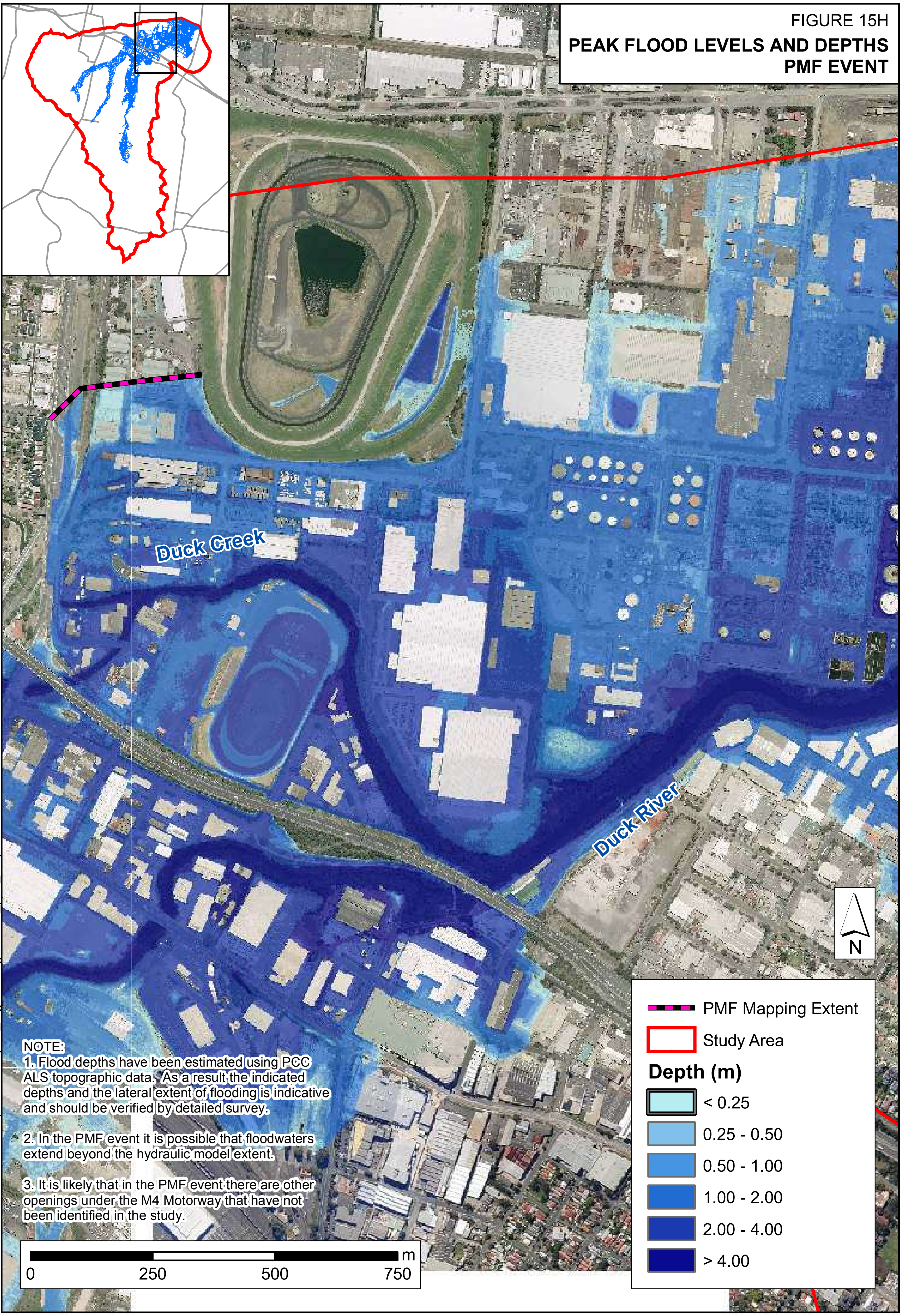


FIGURE 15G
PEAK FLOOD LEVELS AND DEPTHS
PMF EVENT
NOTE:
1. Flood depths have been estimated using PCC ALS topographic data. As a result the indicated depths and the lateral extent of flooding is indicative and should be verified by detailed survey.
2. In the PMF event it is possible that floodwaters extend beyond the hydraulic model extent.
3. It is likely that in the PMF event there are other openings under the M4 Motorway that have not been identified in the study.
A'Beckett's Creek
Duck Creek
Little Duck Creek
Duck River
PMF Mapping Extent
Study Area
Depth (m)
< 0.25
0.25 - 0.50
0.50 - 1.00
1.00 - 2.00
2.00 - 4.00
> 4.00
0
250
500
750
m
N
J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure15G_PMF_Map7.mxd

FIGURE 15H

PEAK FLOOD LEVELS AND DEPTHS PMF EVENT



NOTE:
1. Flood depths have been estimated using PCC ALS topographic data. As a result the indicated depths and the lateral extent of flooding is indicative and should be verified by detailed survey.

2. In the PMF event it is possible that floodwaters extend beyond the hydraulic model extent.

3. It is likely that in the PMF event there are other openings under the M4 Motorway that have not been identified in the study.

PMF Mapping Extent
Study Area

Depth (m)
- < 0.25
- 0.25 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 4.00
- > 4.00

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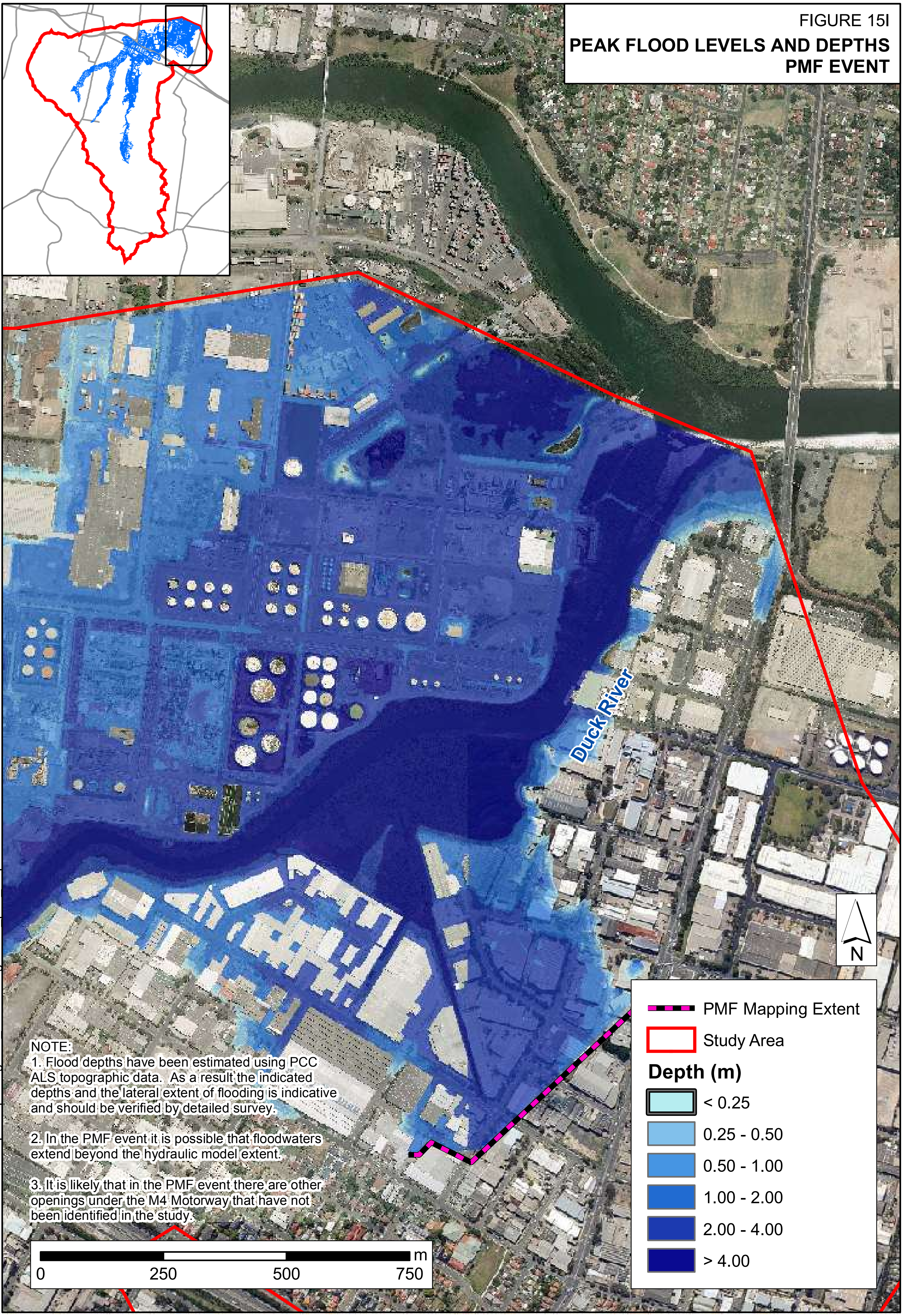
FIGURE 15I

PEAK FLOOD LEVELS AND DEPTHS PMF EVENT



NOTE:
1. Flood depths have been estimated using PCC ALS topographic data. As a result the indicated depths and the lateral extent of flooding is indicative and should be verified by detailed survey.

2. In the PMF event it is possible that floodwaters extend beyond the hydraulic model extent.

3. It is likely that in the PMF event there are other openings under the M4 Motorway that have not been identified in the study.

J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure15I_pmf_Map9.mxd

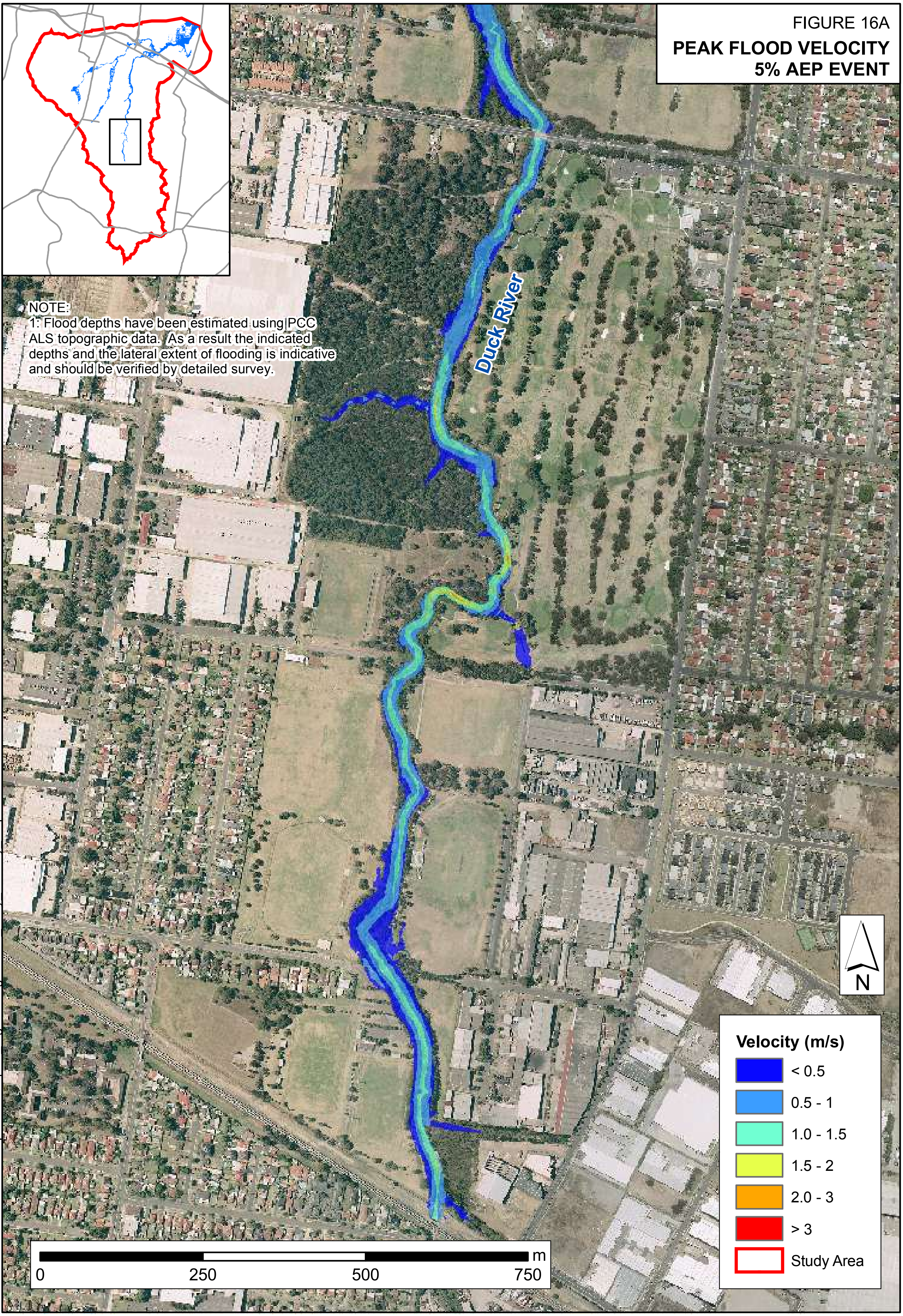


FIGURE 16A
PEAK FLOOD VELOCITY 5% AEP EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure16A_020y_velocity_Map1.mxd

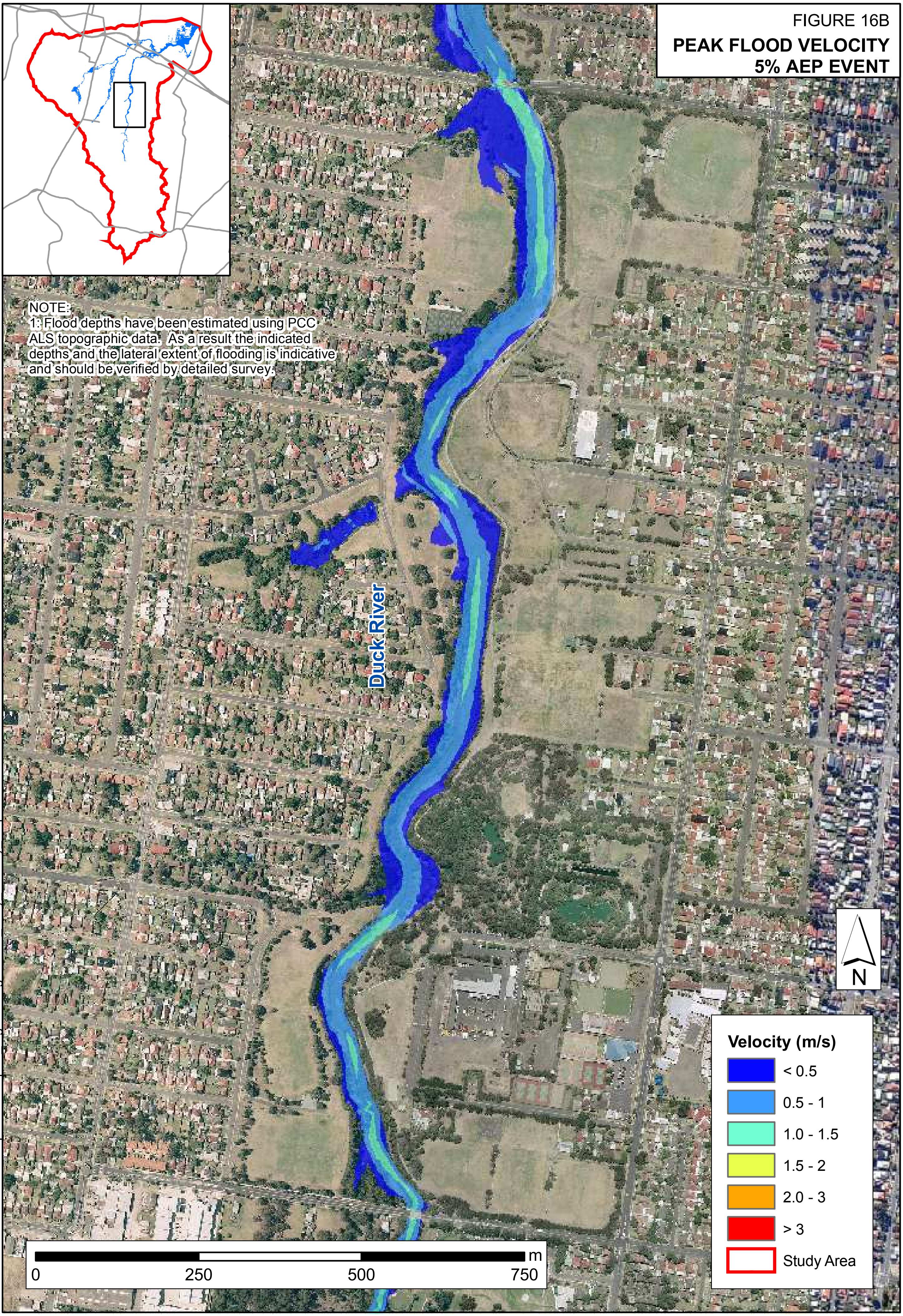


FIGURE 16B
PEAK FLOOD VELOCITY
5% AEP EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure16B_020y_velocity_Map2.mxd

J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure16C_020y_velocity_Map3.mxd

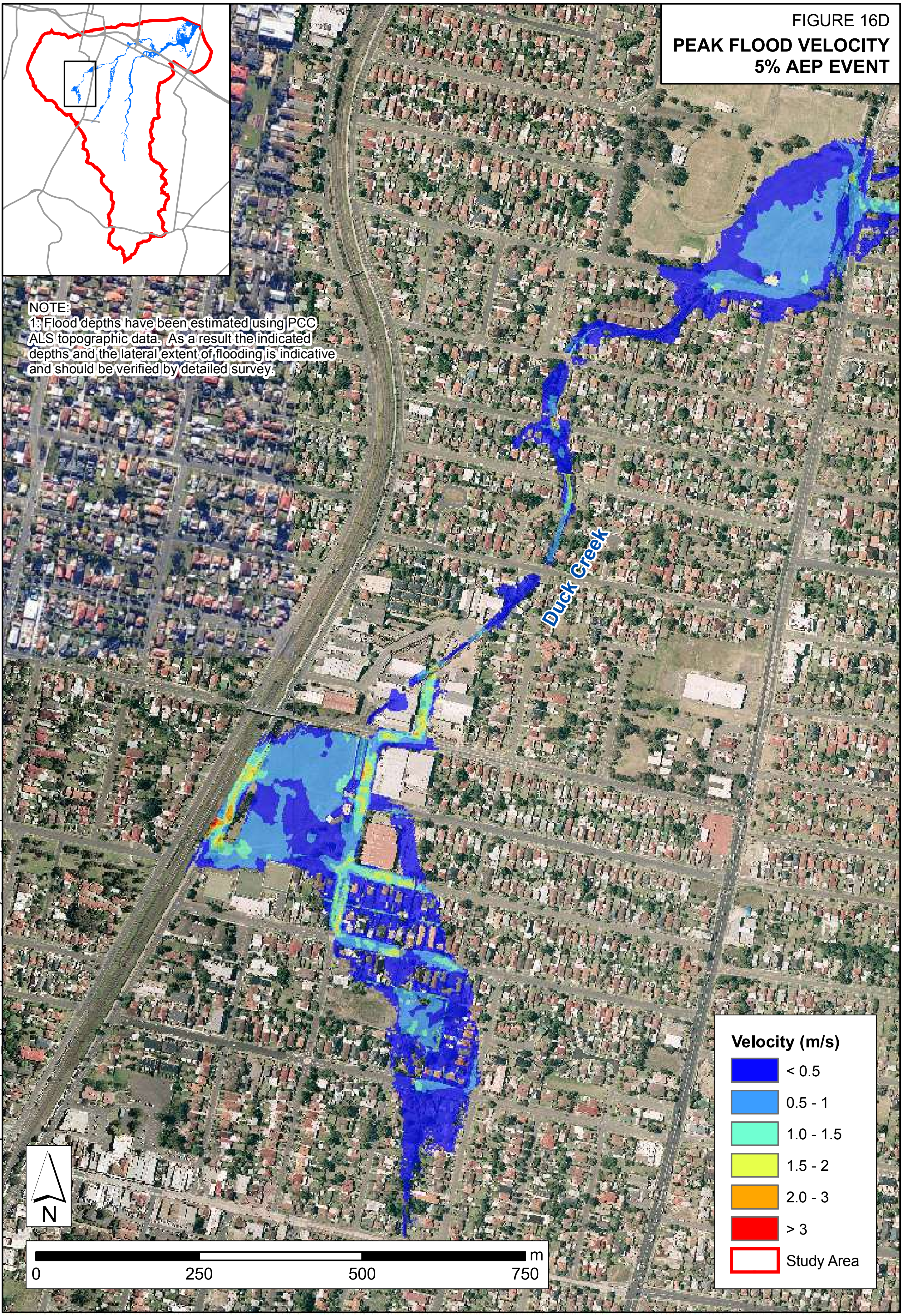
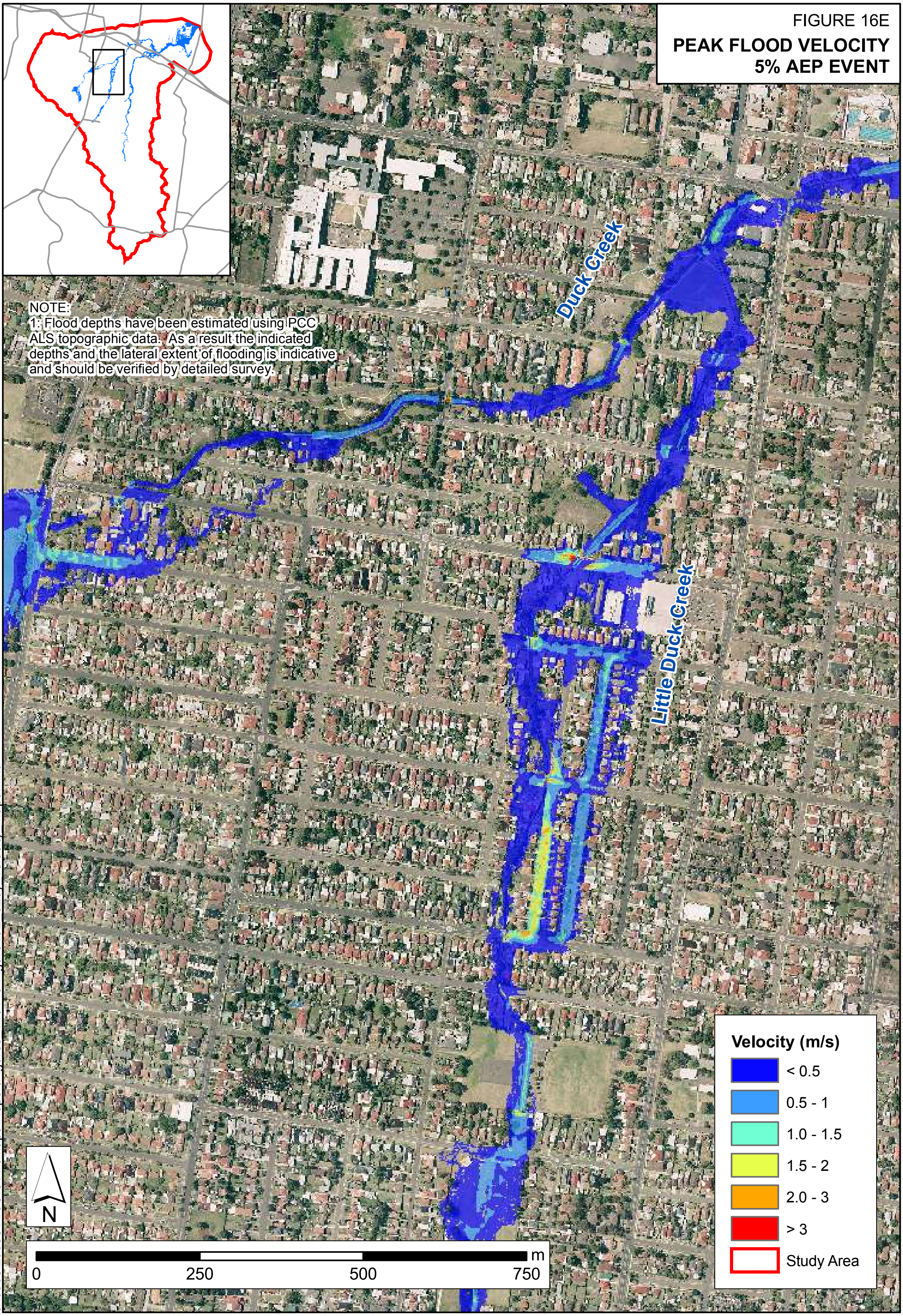


FIGURE 16D
PEAK FLOOD VELOCITY
5% AEP EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure16D_020y_velocity_Map4.mxd

FIGURE 16E

PEAK FLOOD VELOCITY 5% AEP EVENT



J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure16E_020y_velocity_Map5.mxd

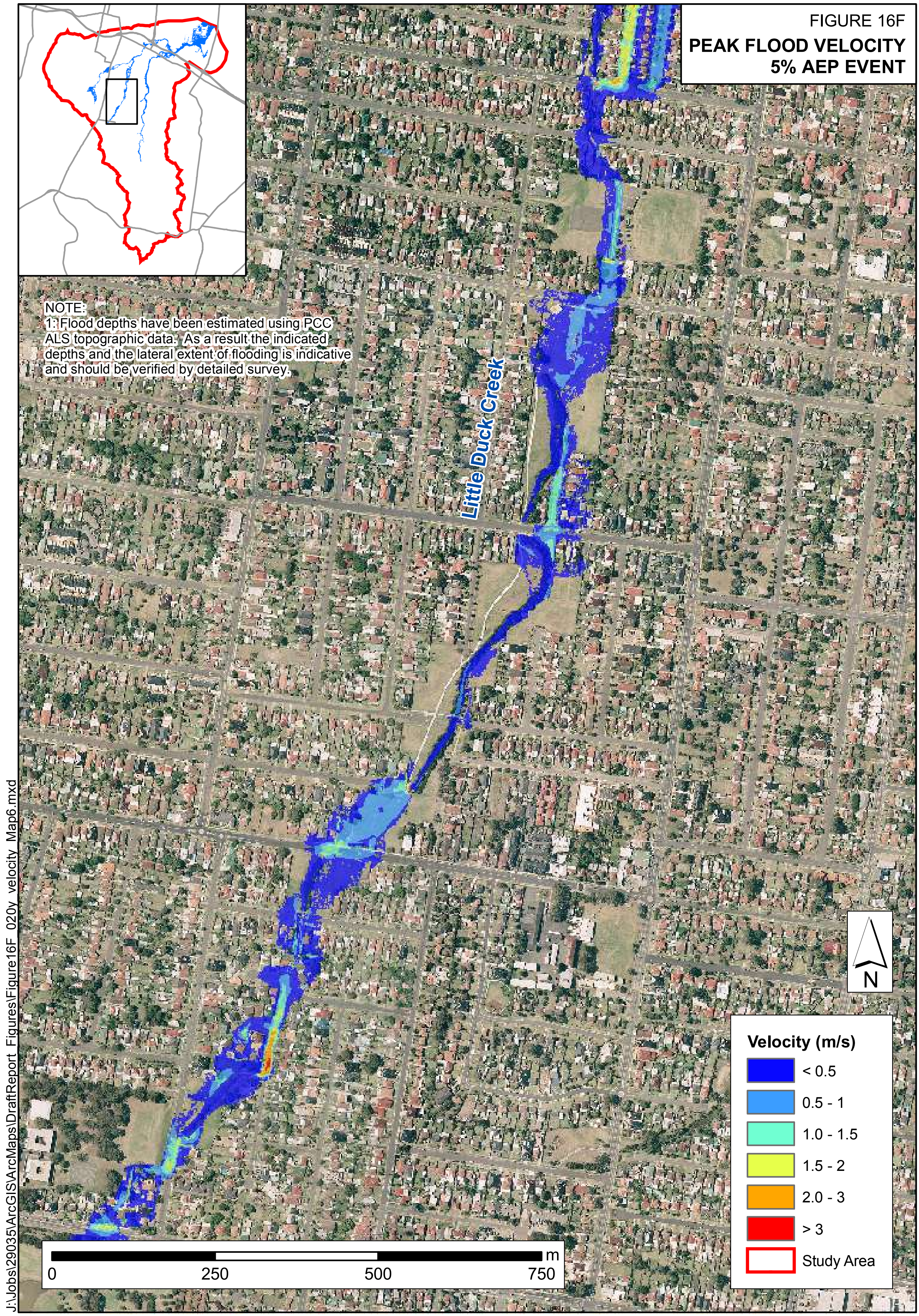
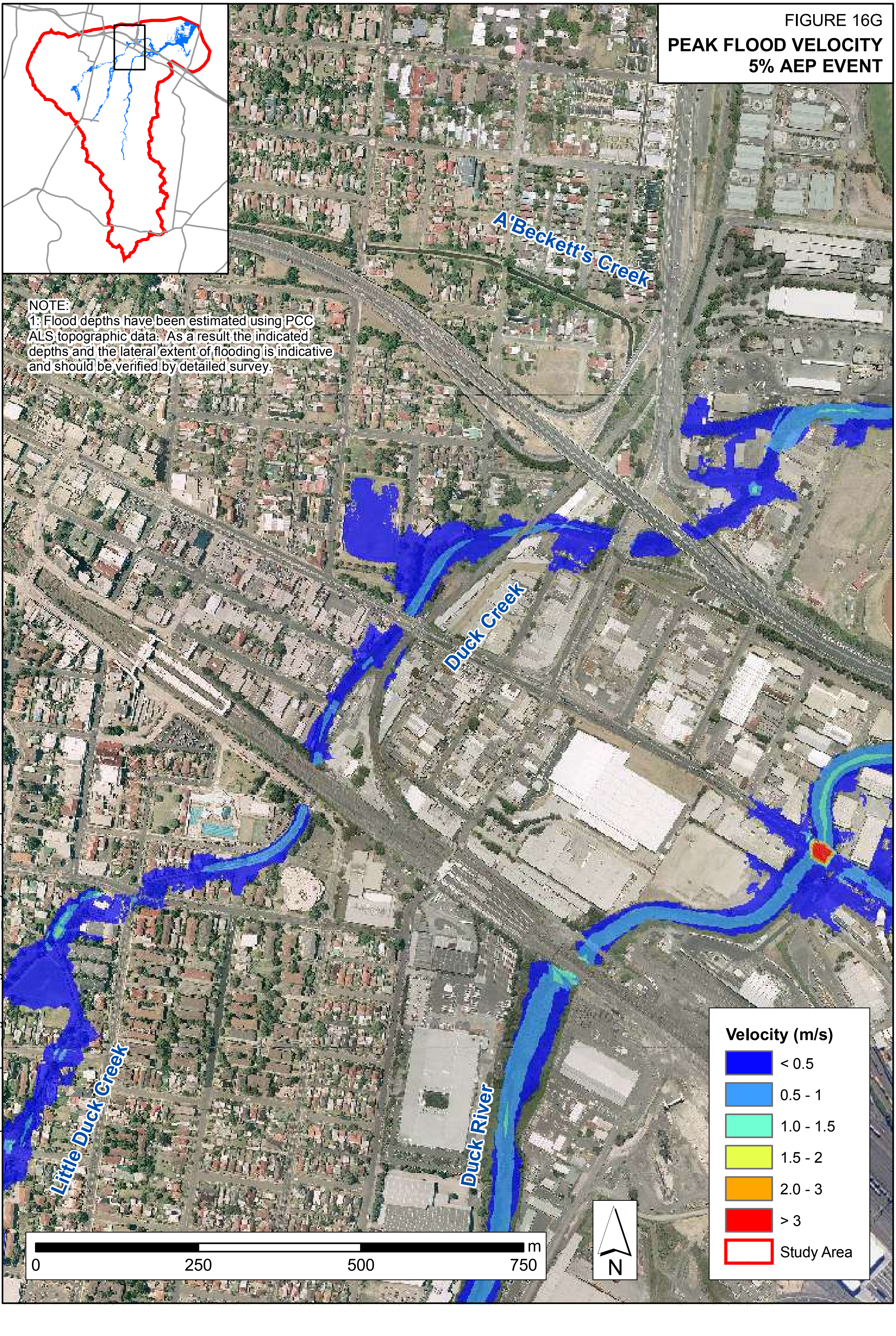
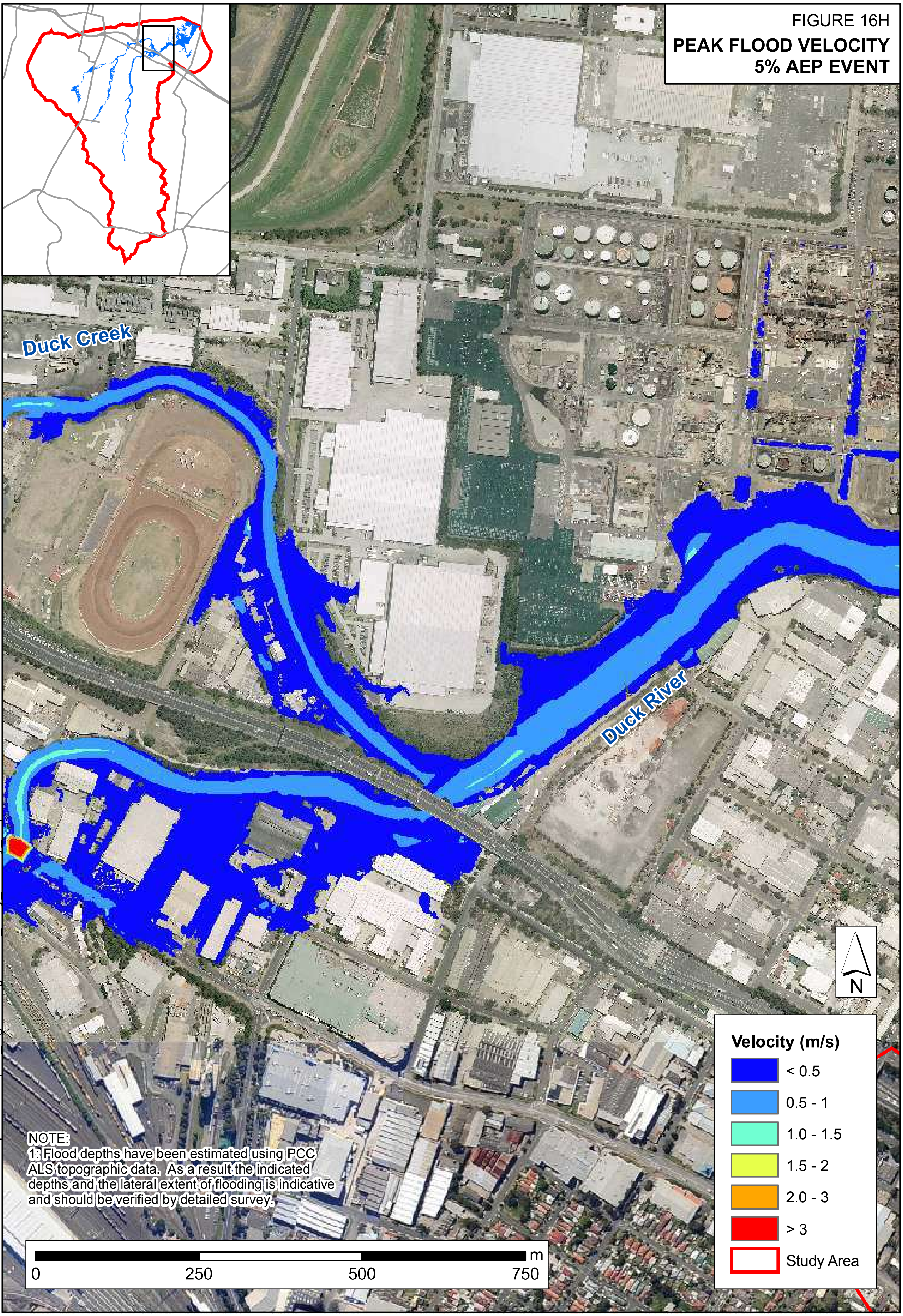


FIGURE 16F
PEAK FLOOD VELOCITY
5% AEP EVENT
NOTE:
1. Flood depths have been estimated using PCC ALS topographic data. As a result the indicated depths and the lateral extent of flooding is indicative and should be verified by detailed survey.
Little Duck Creek
N
Velocity (m/s)
< 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 3
> 3
Study Area
0
250
500
750
m
J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure16F_020y_velocity_Map6.mxd



J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure16G_020y_velocity_Map7.mxd

FIGURE 16H
PEAK FLOOD VELOCITY
5% AEP EVENT



J:\Jobs\29035\ArcMaps\DraftReport_Figures\Figure16H_020y_velocity_Map8.mxd

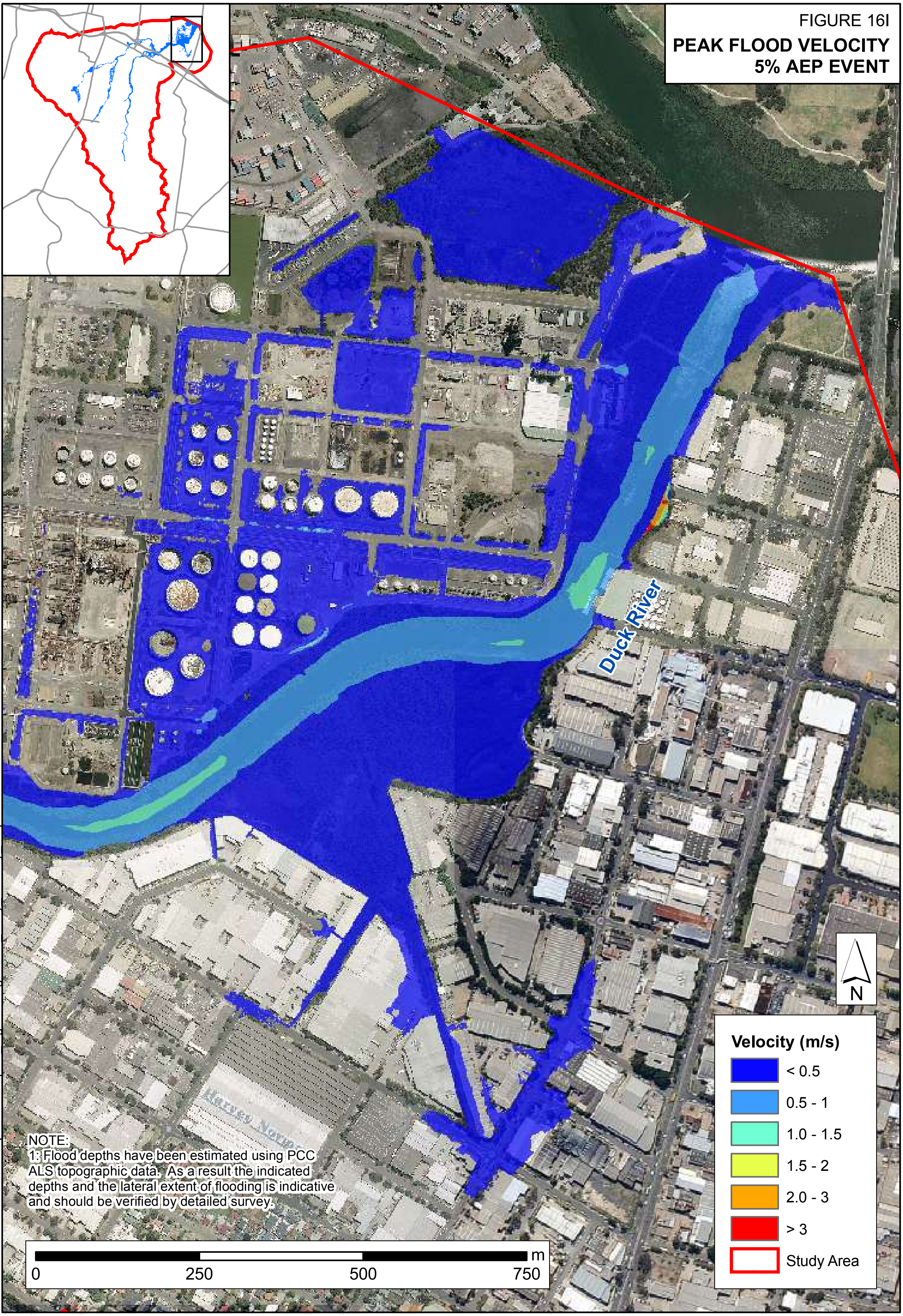


FIGURE 16I
PEAK FLOOD VELOCITY 5% AEP EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport Figures\Figure16I 020y velocity Map9.mxd

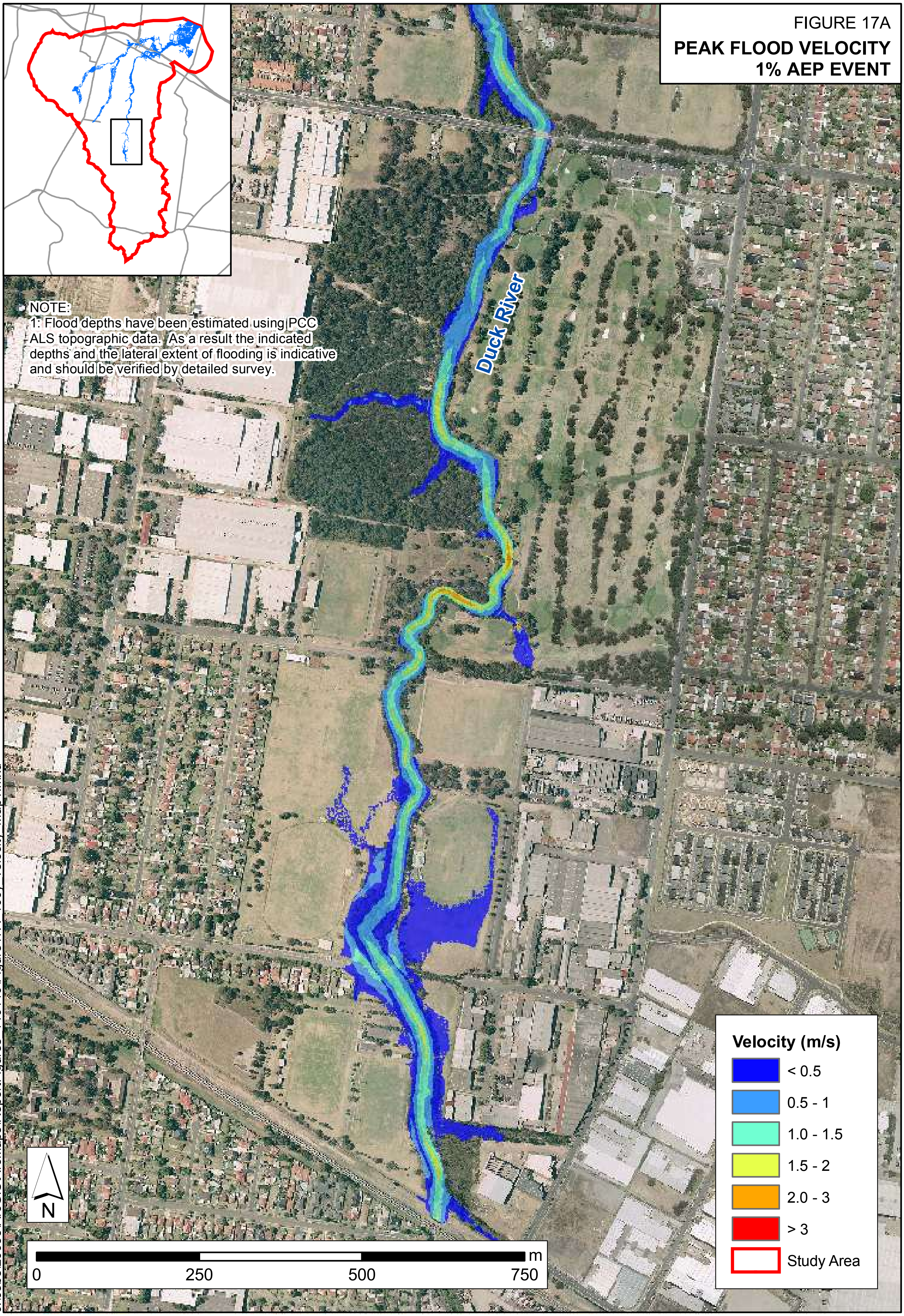


FIGURE 17A
PEAK FLOOD VELOCITY 1% AEP EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure17A_100y_velocity_Map1.mxd

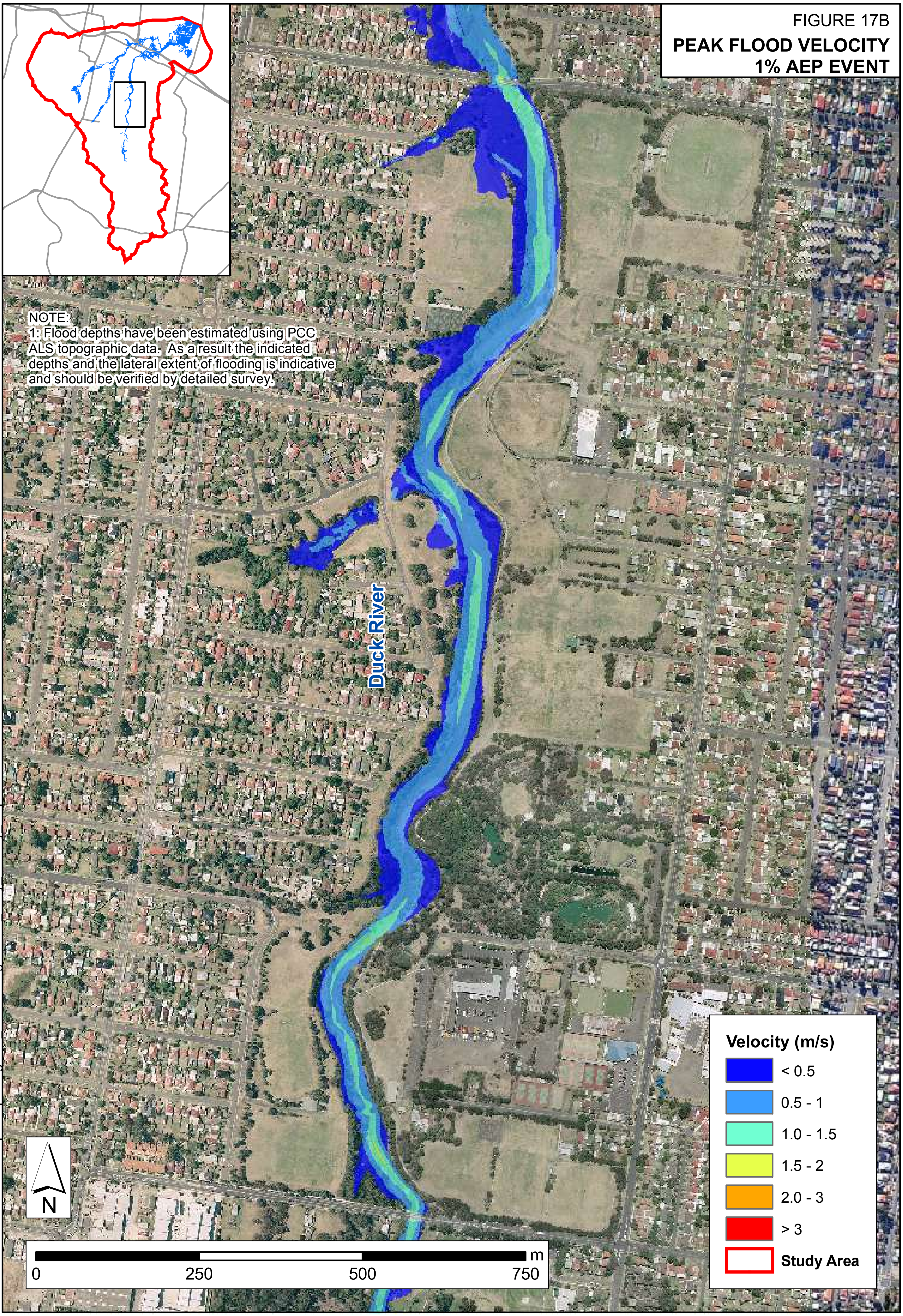
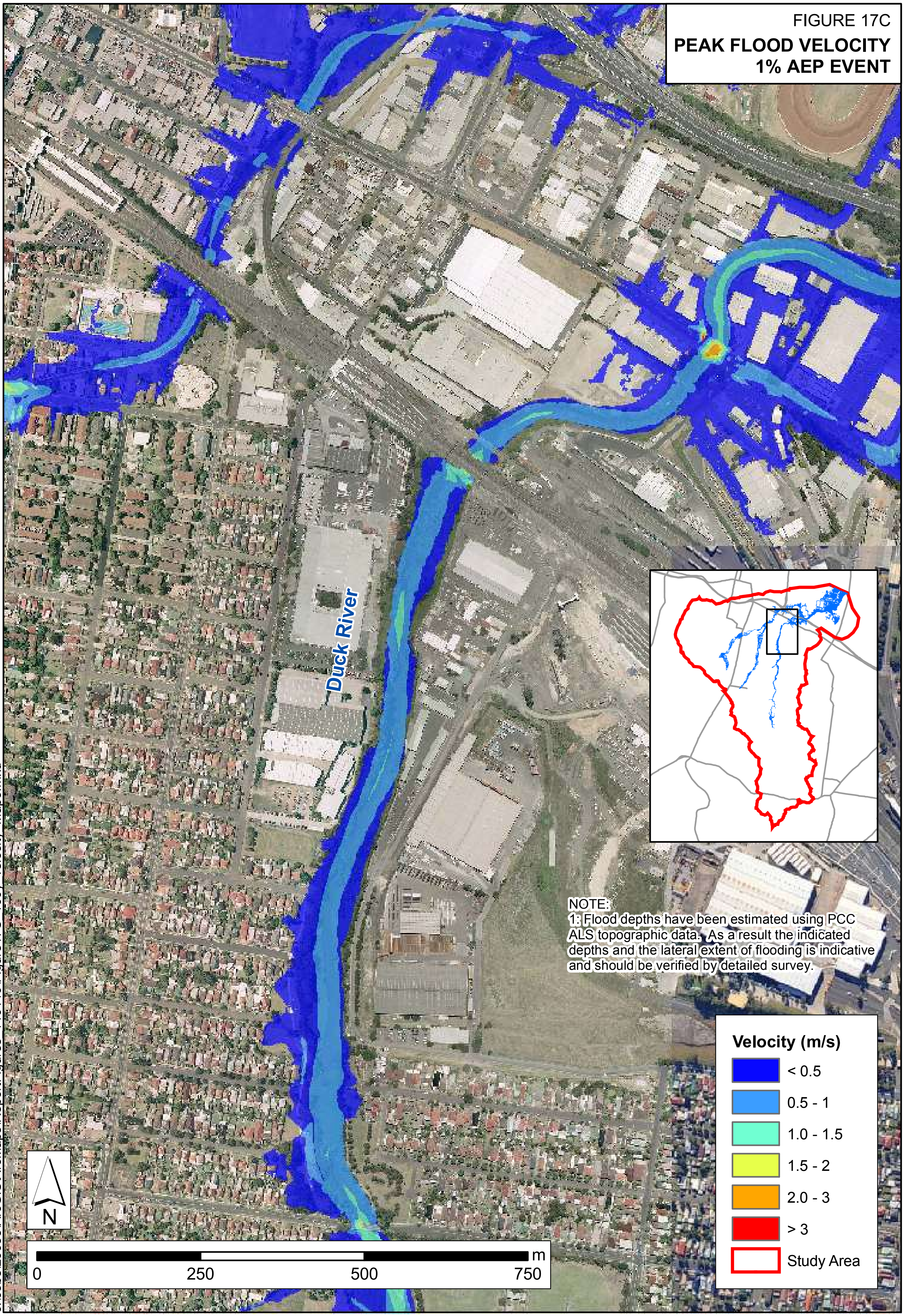


FIGURE 17B
PEAK FLOOD VELOCITY 1% AEP EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures 110119\Figure17B 100y velocity Map2.mxd

FIGURE 17C

PEAK FLOOD VELOCITY 1% AEP EVENT



J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure17C_100y_velocity_Map3.mxd

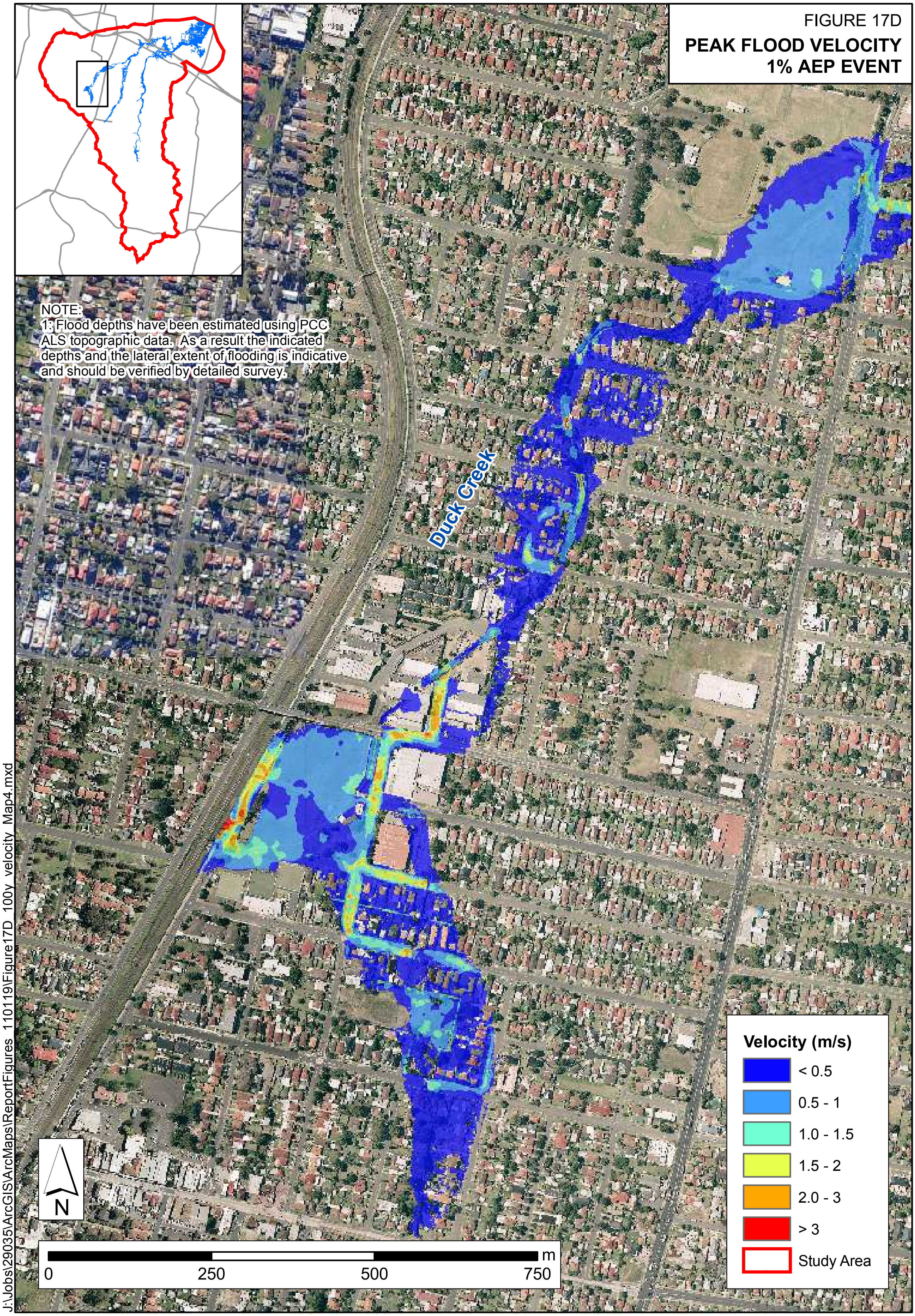
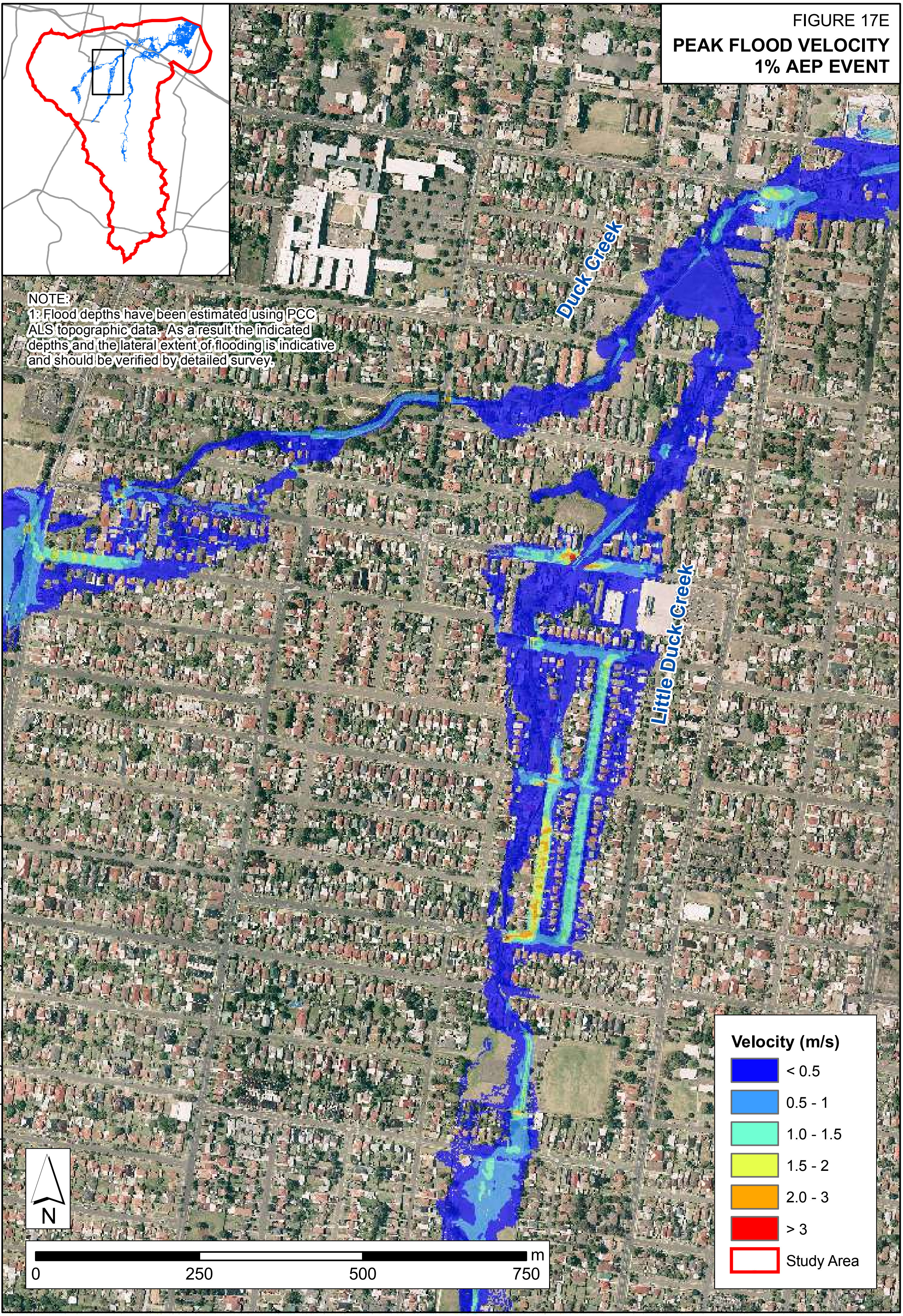


FIGURE 17D
PEAK FLOOD VELOCITY
1% AEP EVENT
NOTE:
1. Flood depths have been estimated using PCC ALS topographic data. As a result the indicated depths and the lateral extent of flooding is indicative and should be verified by detailed survey.
Duck Creek
Velocity (m/s)
< 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 3
> 3
Study Area
N
0
250
500
750
m
J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure17D_100y_velocity_Map4.mxd

FIGURE 17E

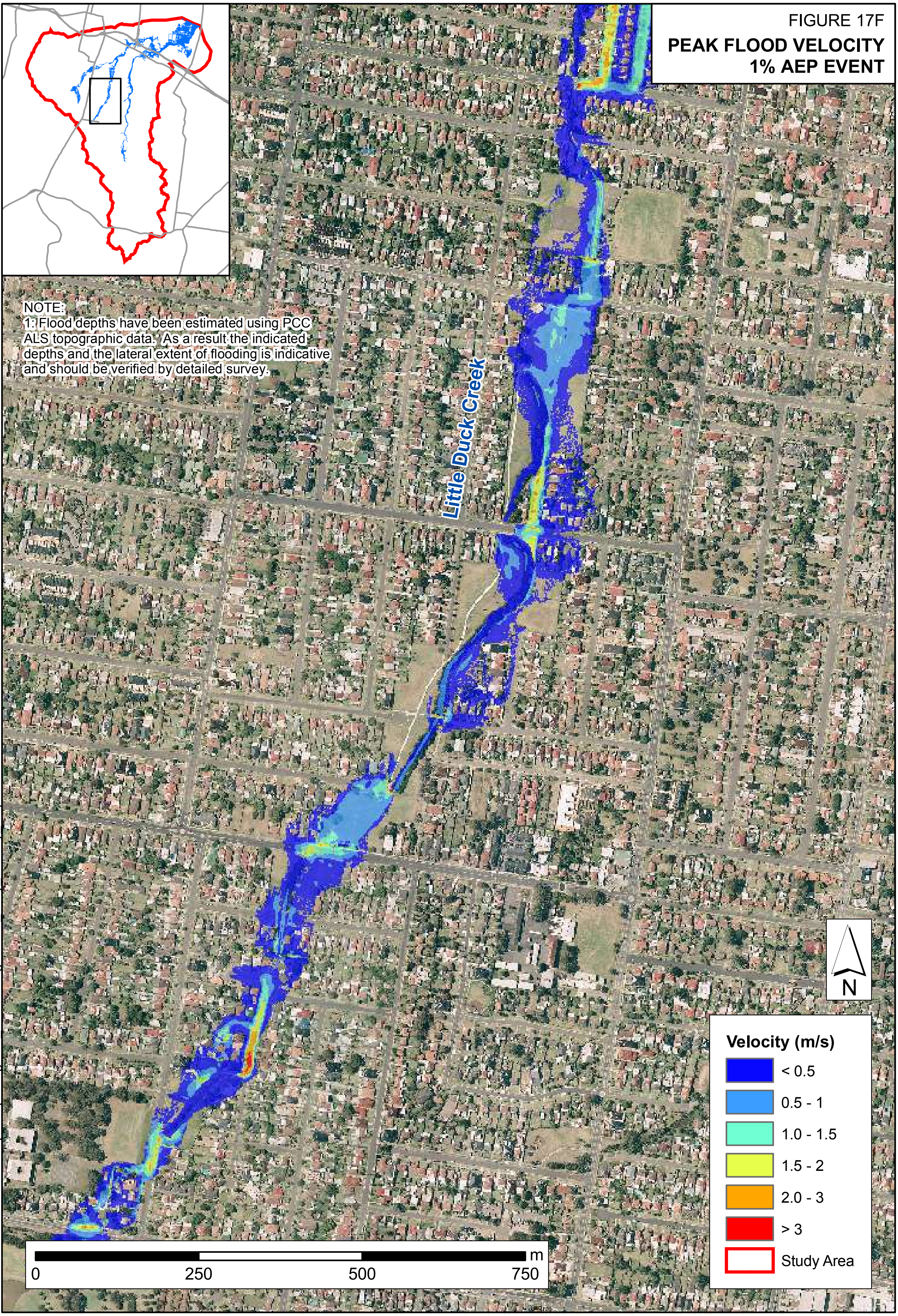
PEAK FLOOD VELOCITY 1% AEP EVENT



J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures 110119\Figure17E 100y velocity Map5.mxd

FIGURE 17F

PEAK FLOOD VELOCITY 1% AEP EVENT



J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure17F_100y_velocity_Map6.mxd

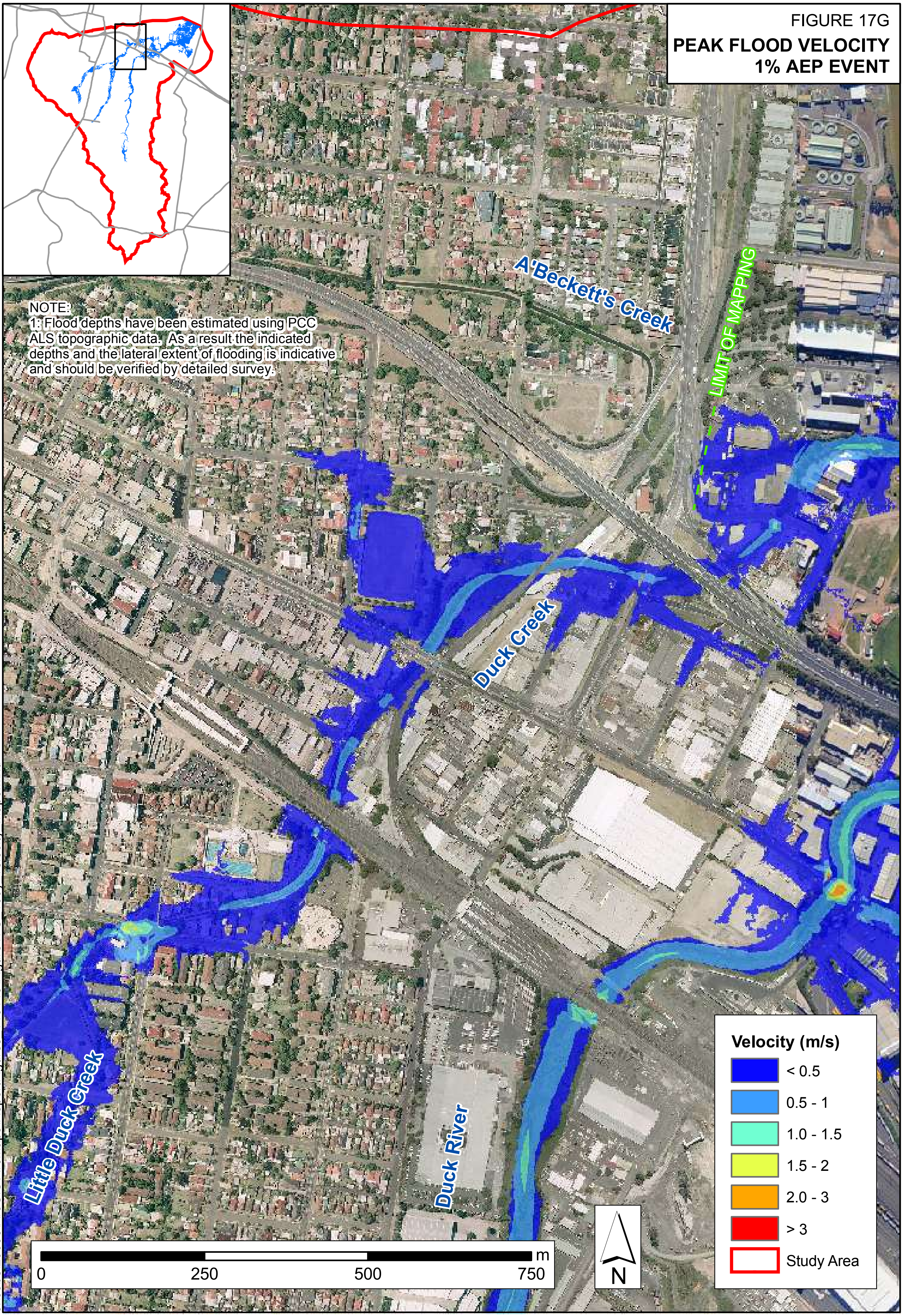
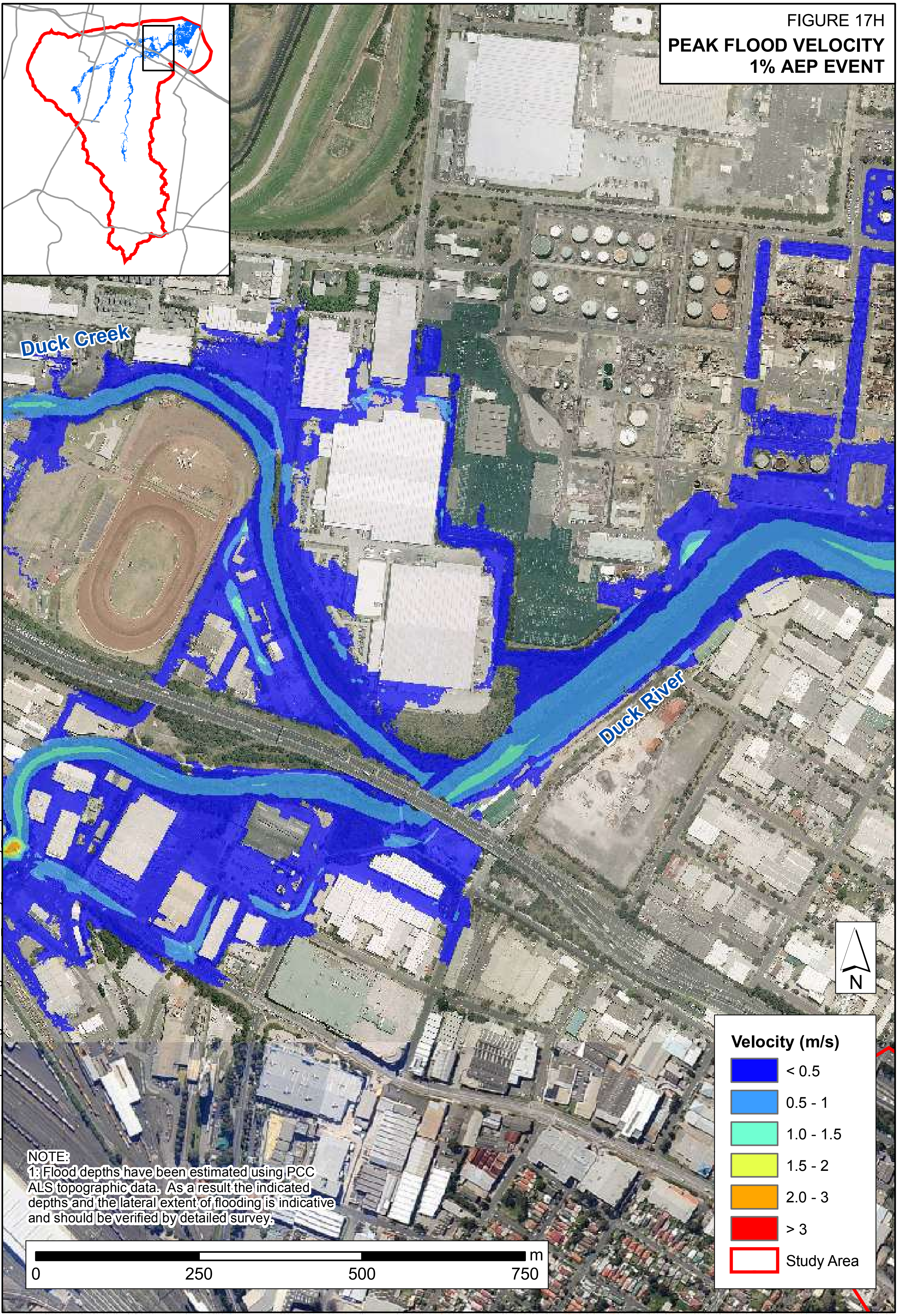


FIGURE 17G
PEAK FLOOD VELOCITY
1% AEP EVENT

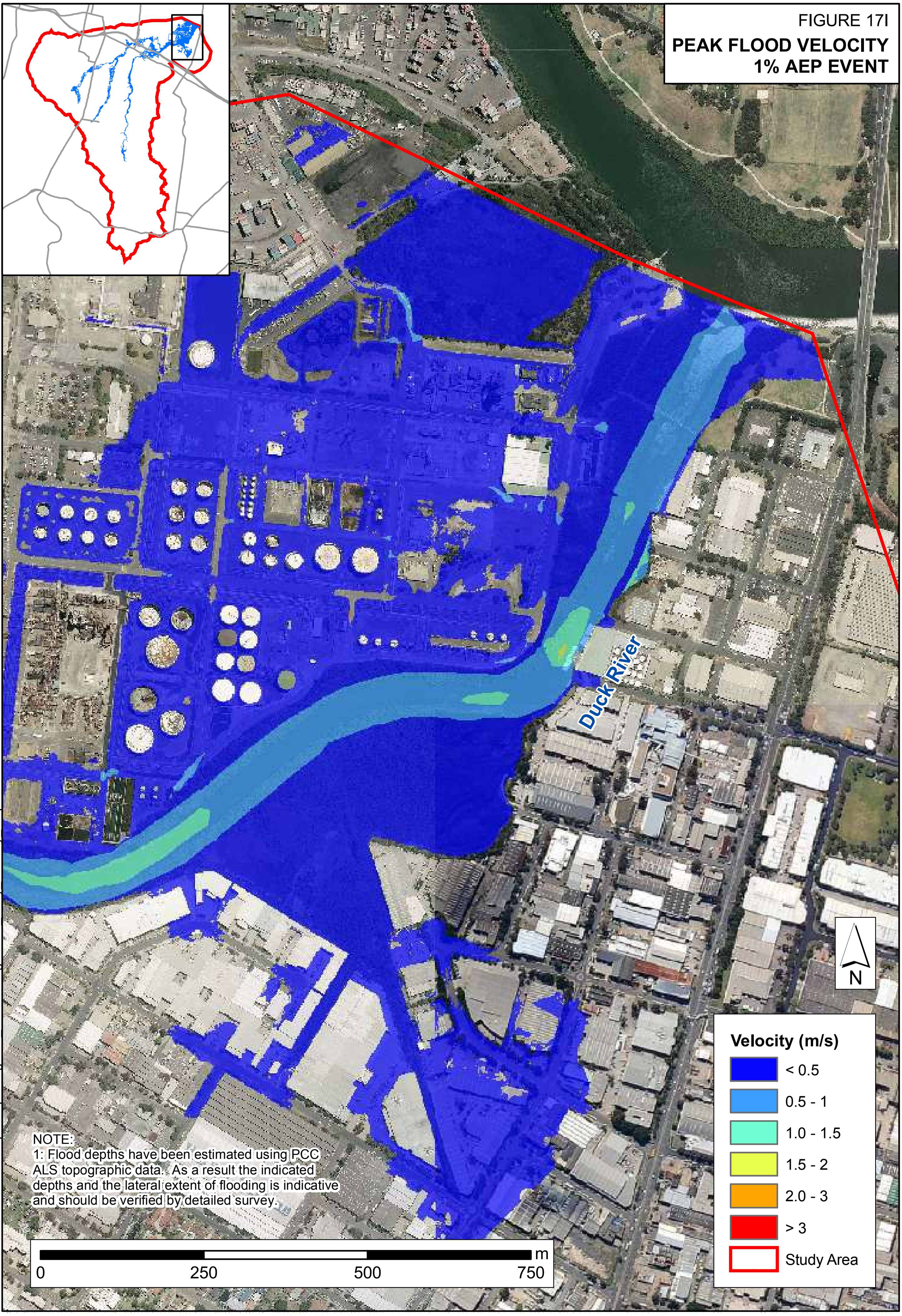
J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure17G_100y_velocity_Map6.mxd



J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure17H_100y_velocity_Map8.mxd

FIGURE 17I

PEAK FLOOD VELOCITY
1% AEP EVENT

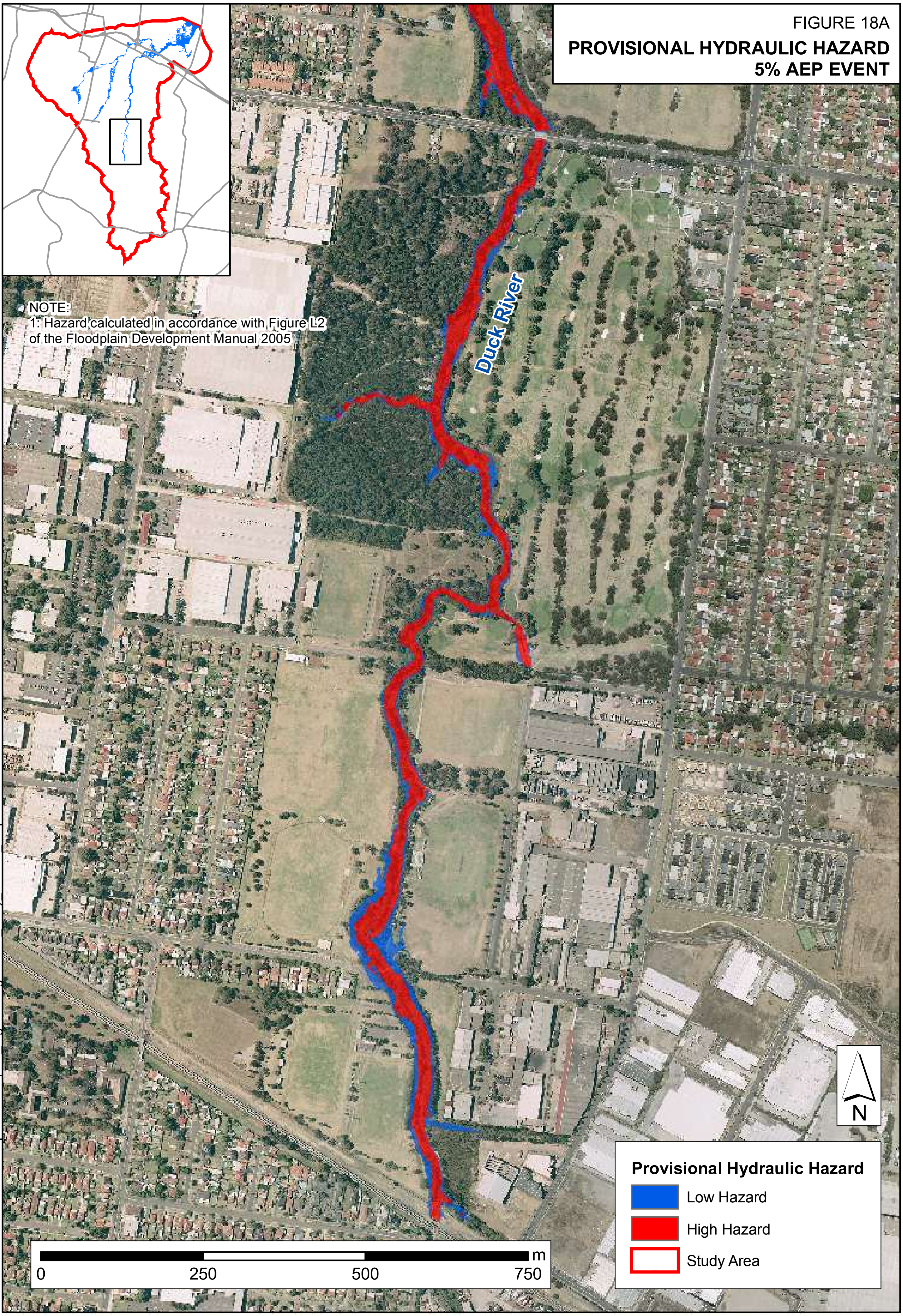


NOTE:
1: Flood depths have been estimated using PCC ALS topographic data. As a result the indicated depths and the lateral extent of flooding is indicative and should be verified by detailed survey.

J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure17I_100y_velocity_Map9.mxd

FIGURE 18A

PROVISIONAL HYDRAULIC HAZARD
5% AEP EVENT



J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure18A_020y_hazard_Map1.mxd

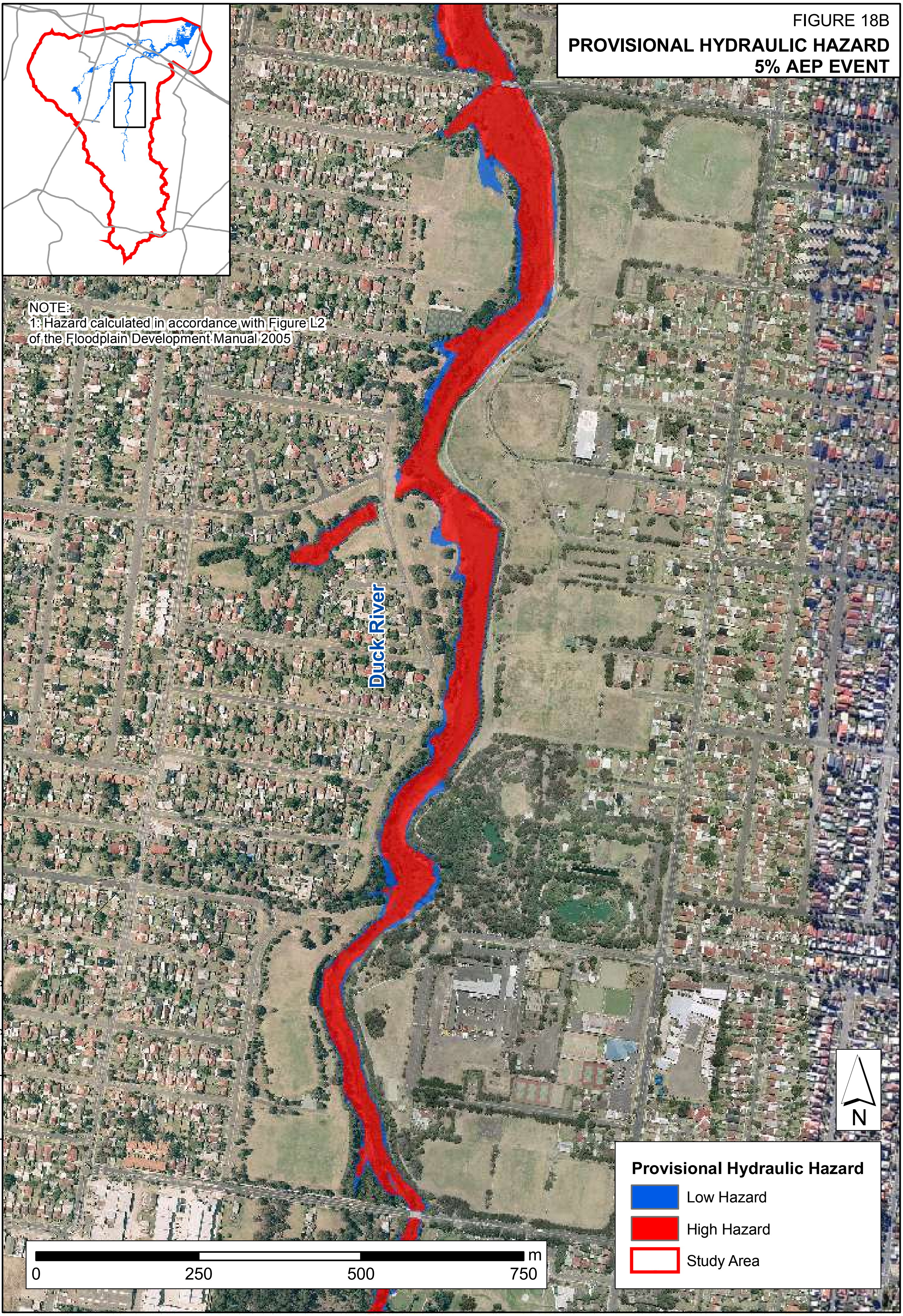
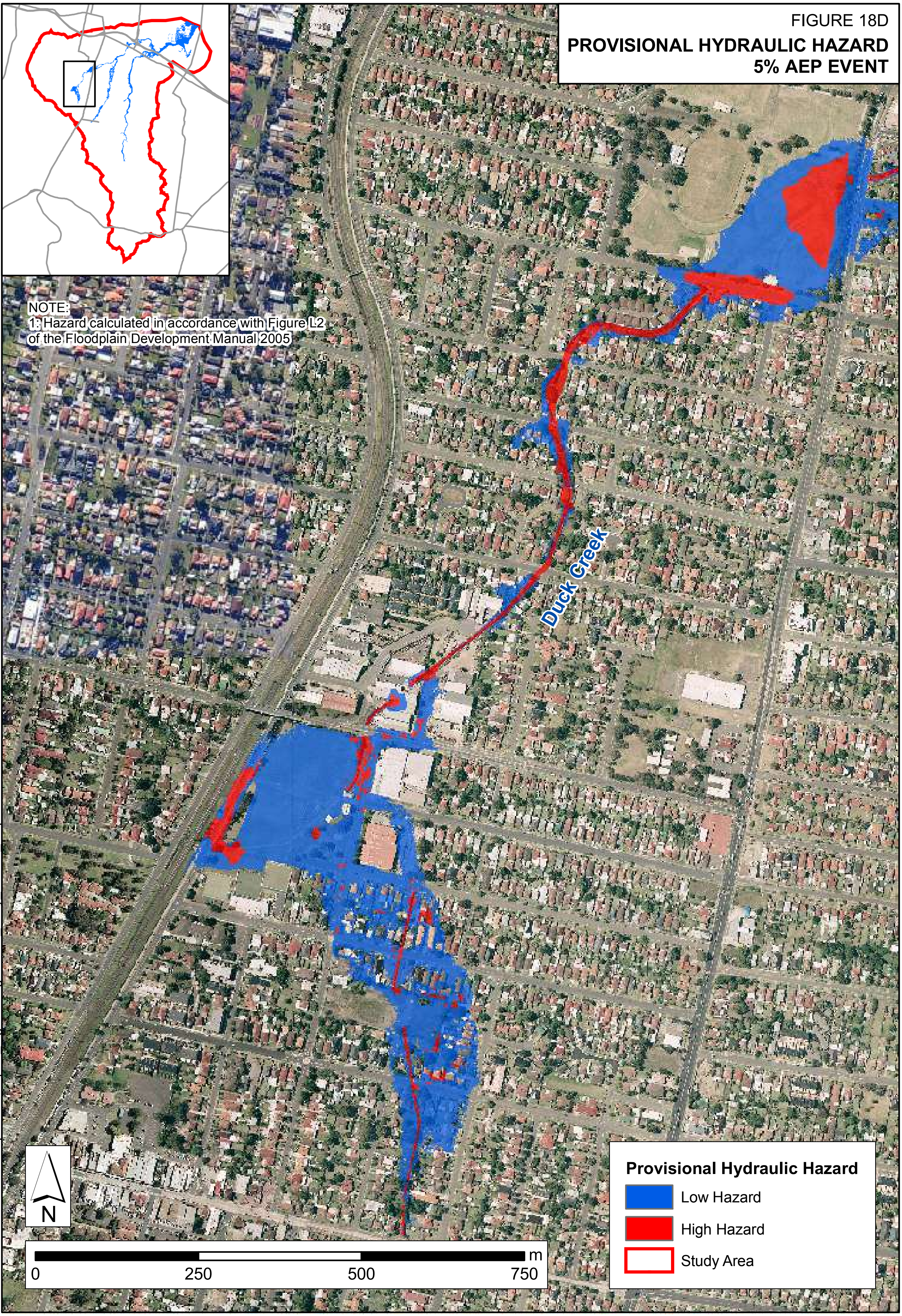


FIGURE 18B
PROVISIONAL HYDRAULIC HAZARD
5% AEP EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure18B_020y_hazard_Map2.mxd

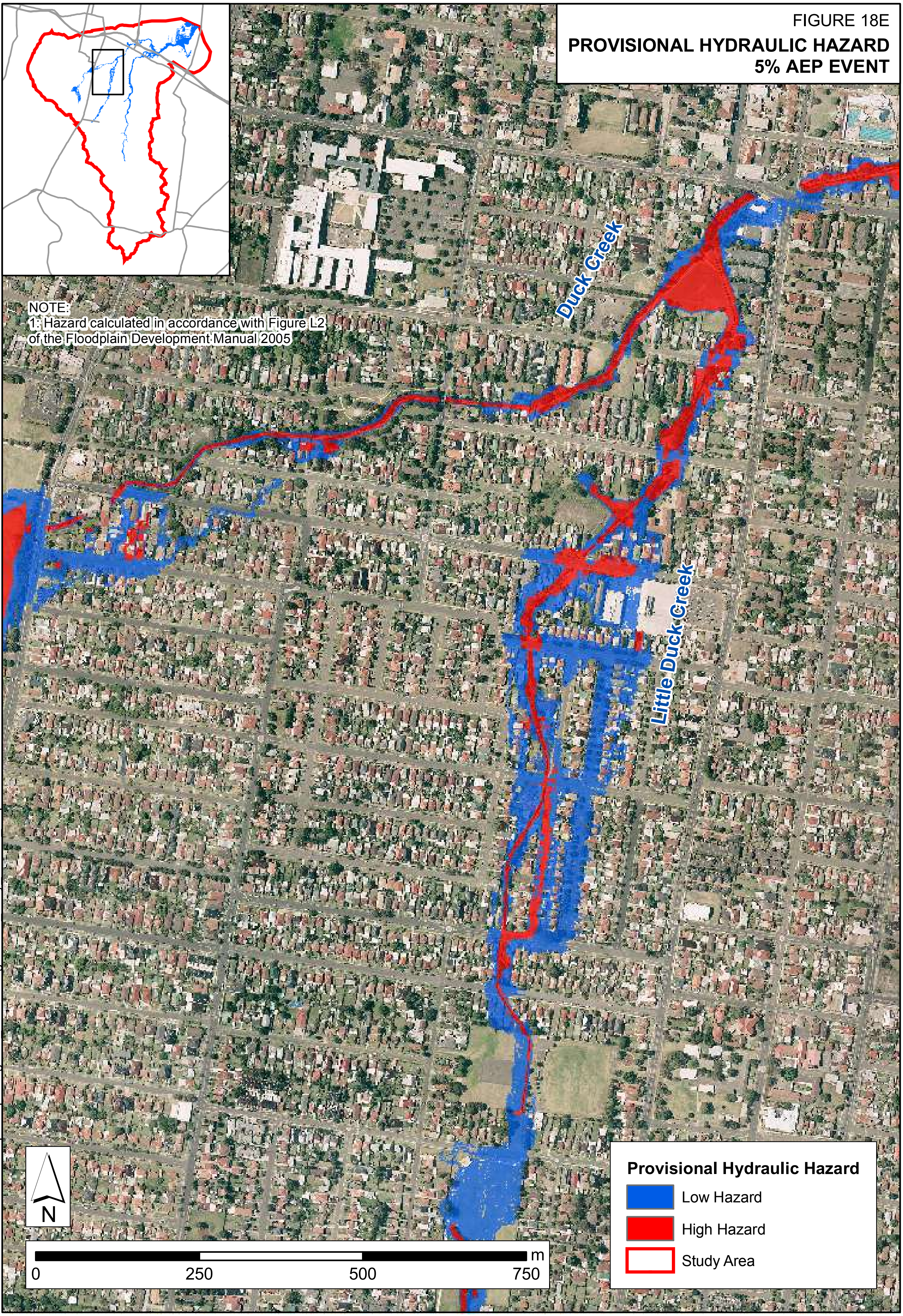
J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport Figures\Figure18C 020y hazard Map3.mxd



J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure18D_020y_hazard_Map4.mxd

FIGURE 18E

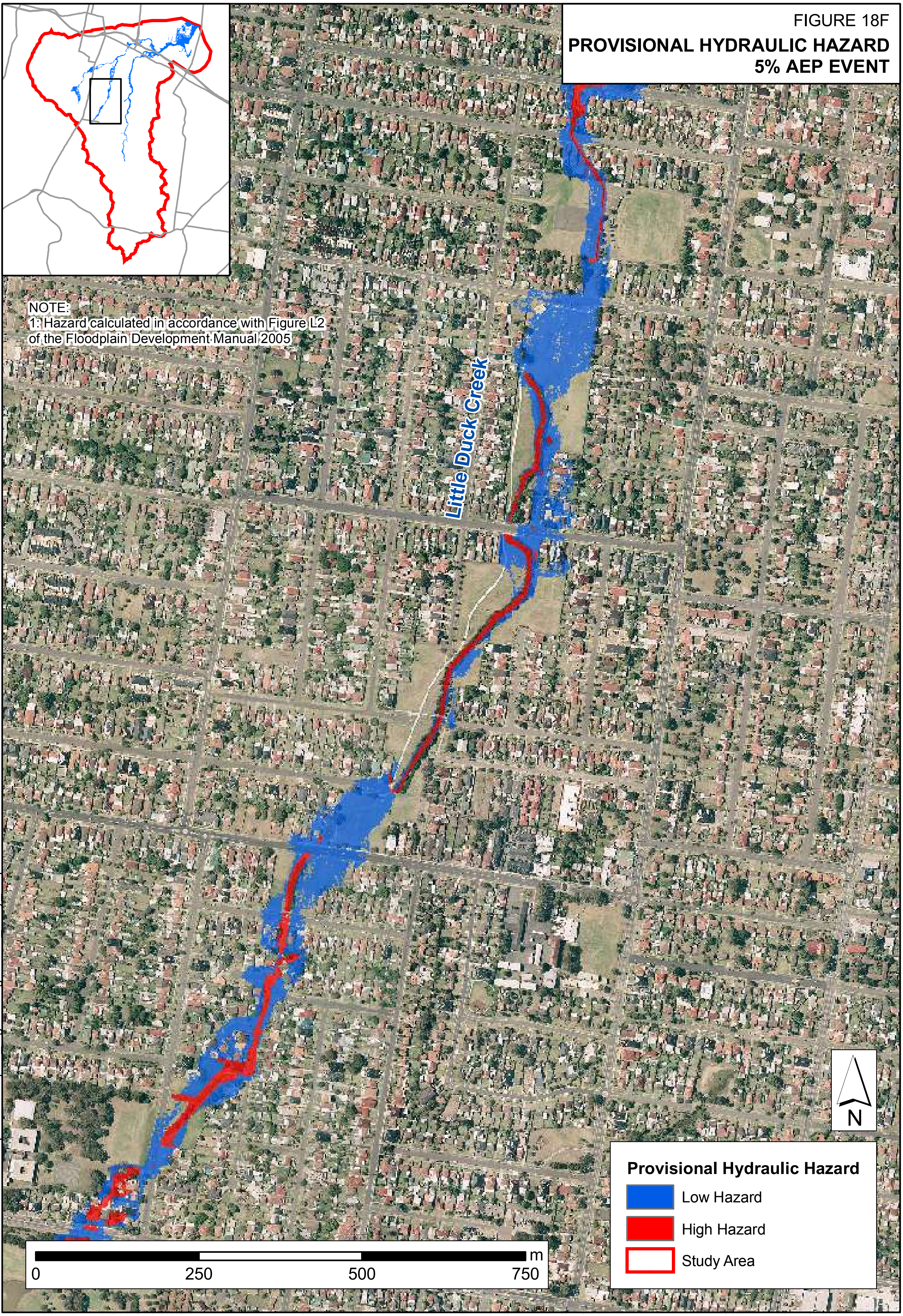
PROVISIONAL HYDRAULIC HAZARD
5% AEP EVENT



J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure18E_020y_hazard_Map5.mxd

FIGURE 18F

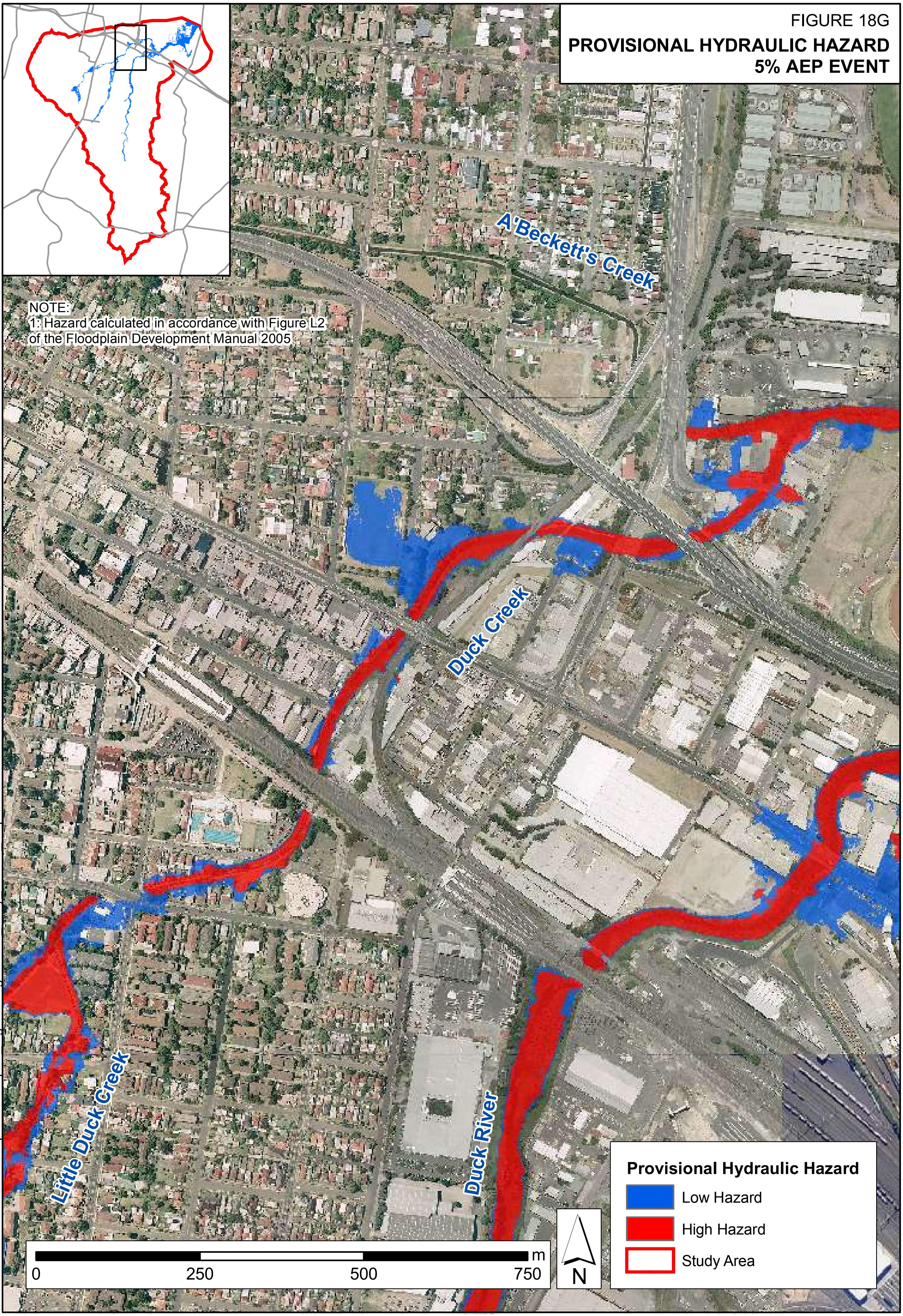
PROVISIONAL HYDRAULIC HAZARD 5% AEP EVENT



J:\Jobs\29035\ArcMaps\DraftReport Figures\Figure18F 020y Map6.mxd

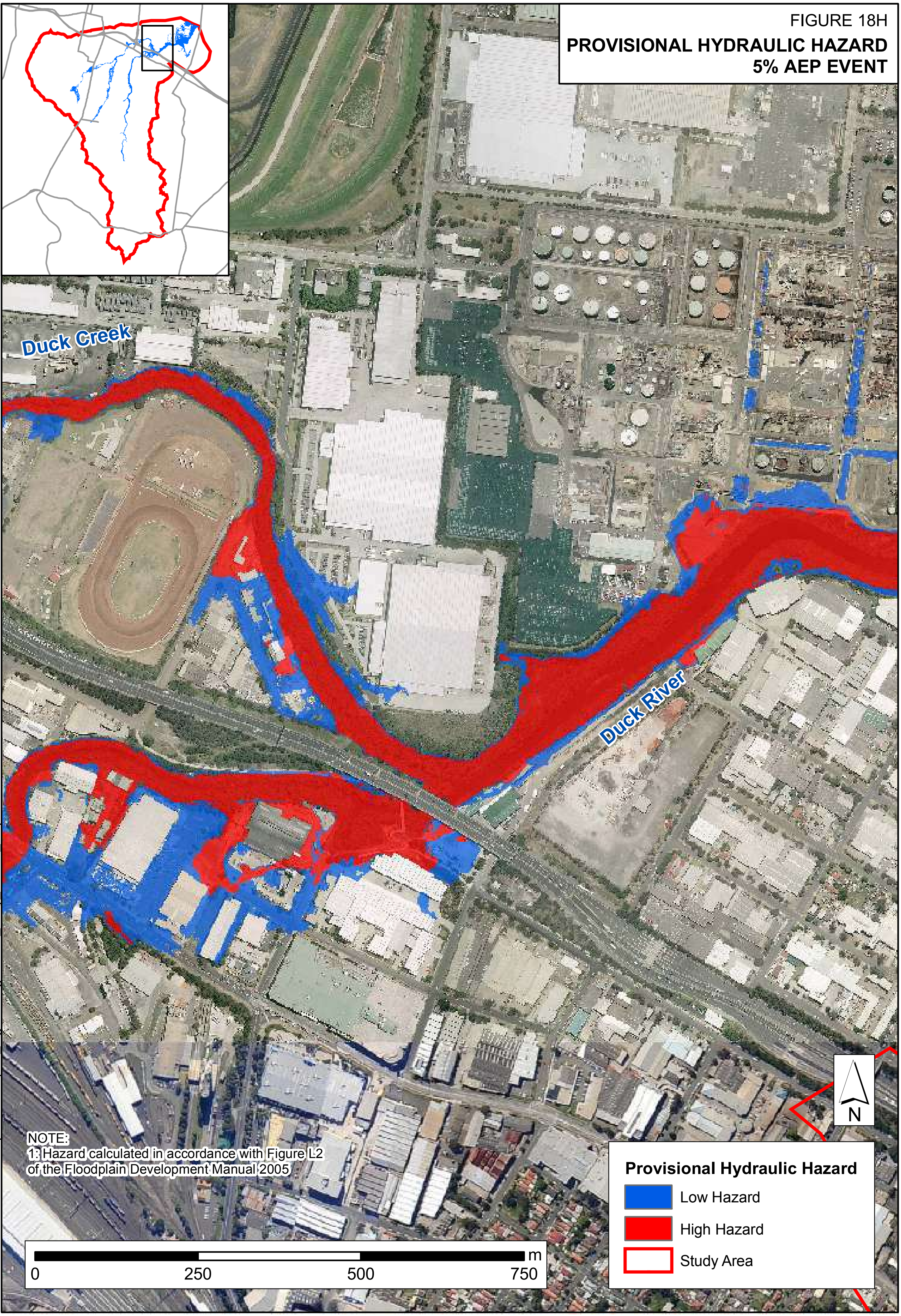
FIGURE 18G

PROVISIONAL HYDRAULIC HAZARD 5% AEP EVENT



J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure18G_020y_hazard_Map7.mxd

FIGURE 18H
PROVISIONAL HYDRAULIC HAZARD
5% AEP EVENT



J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport Figures\Figure18H 020y hazard Map8.mxd

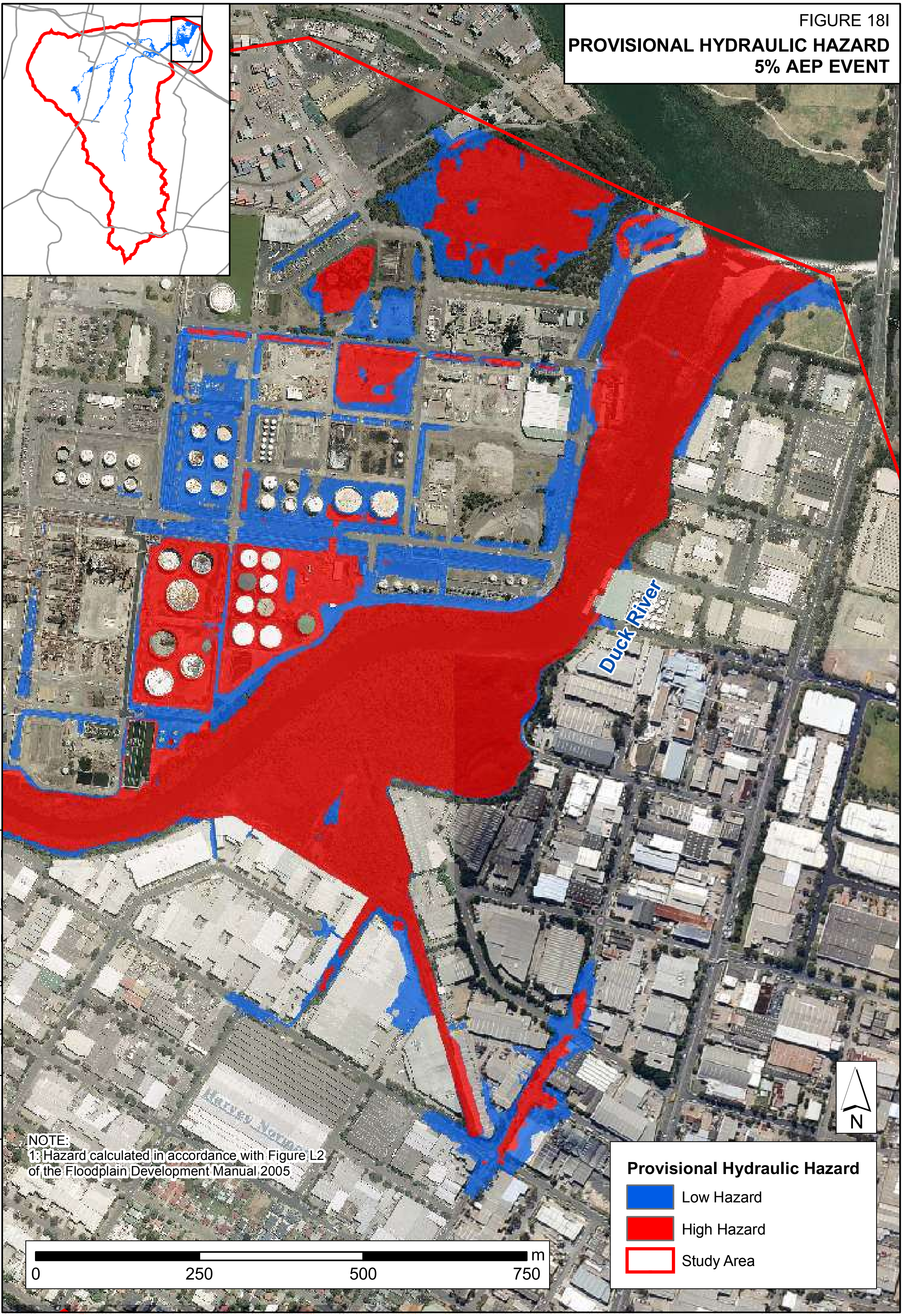


FIGURE 18I
PROVISIONAL HYDRAULIC HAZARD
5% AEP EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure18I_020y_hazard_Map9.mxd

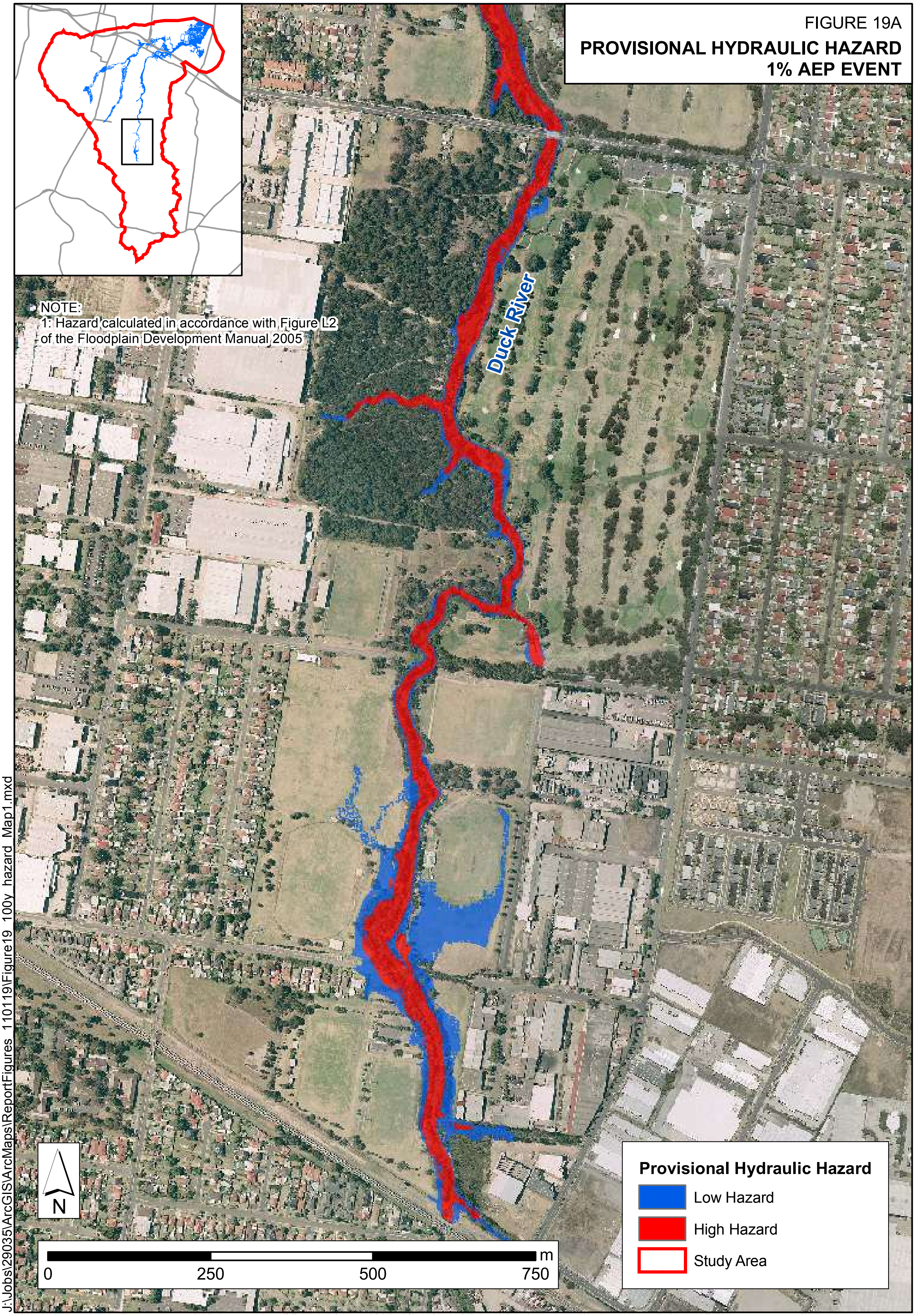


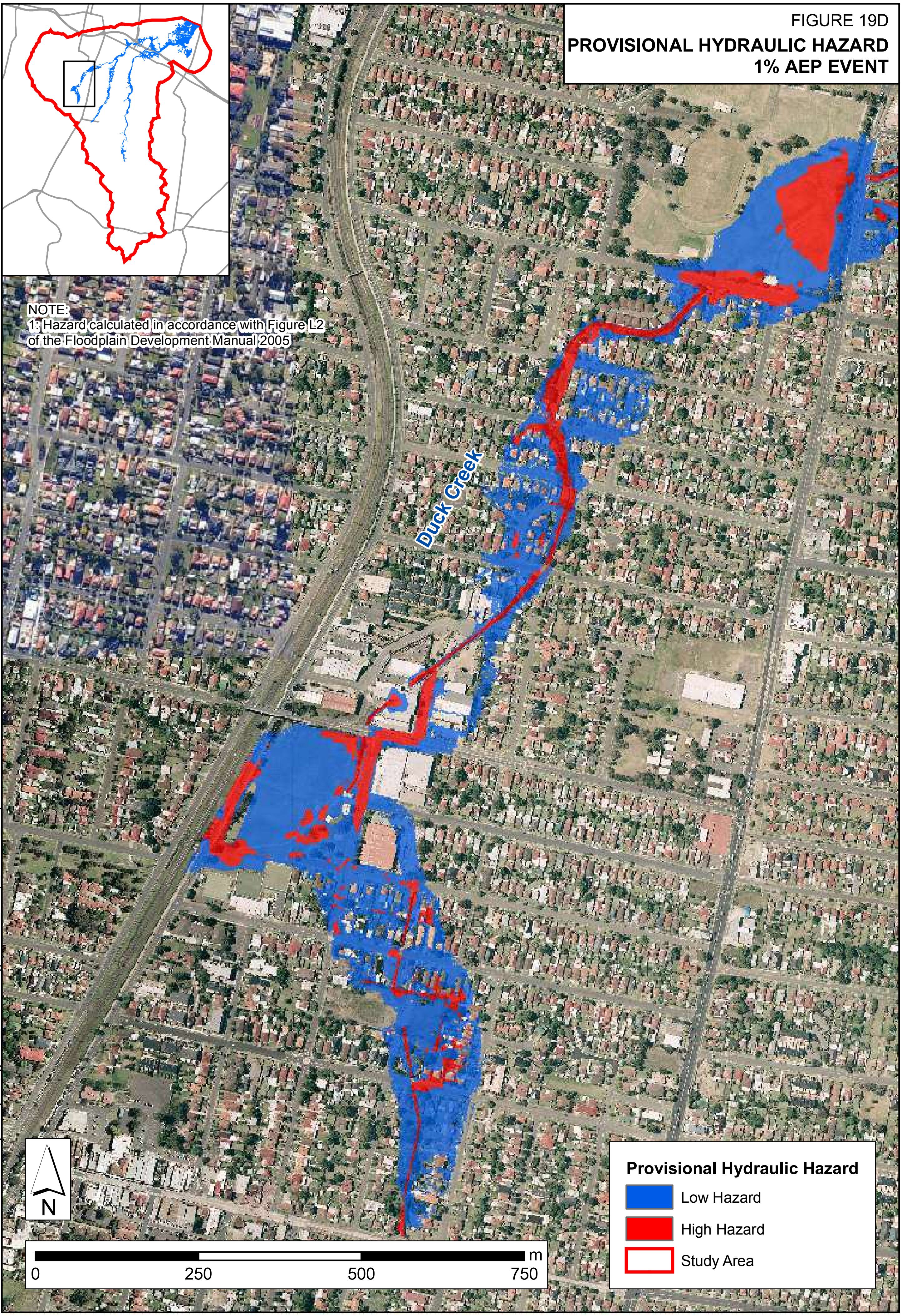
FIGURE 19A
PROVISIONAL HYDRAULIC HAZARD
1% AEP EVENT
NOTE:
1: Hazard calculated in accordance with Figure L2
of the Floodplain Development Manual 2005
Duck River
Provisional Hydraulic Hazard
Low Hazard
High Hazard
Study Area
N
0
250
500
750
m
J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure19_100y_hazard_Map1.mxd

FIGURE 19B
PROVISIONAL HYDRAULIC HAZARD
1% AEP EVENT
NOTE:
1: Hazard calculated in accordance with Figure L2
of the Floodplain Development Manual 2005
Duck River
N
0
250
500
750
m
Provisional Hydraulic Hazard
Low Hazard
High Hazard
Study Area
J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure19B_100y_hazard_Map2.mxd

FIGURE 19C
PROVISIONAL HYDRAULIC HAZARD
1% AEP EVENT
Duck River
NOTE:
1: Hazard calculated in accordance with Figure L2
of the Floodplain Development Manual 2005
Provisional Hydraulic Hazard
Low Hazard
High Hazard
Study Area
N
0
250
500
750
m
J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure19C_100y_hazard_Map3.mxd

FIGURE 19D

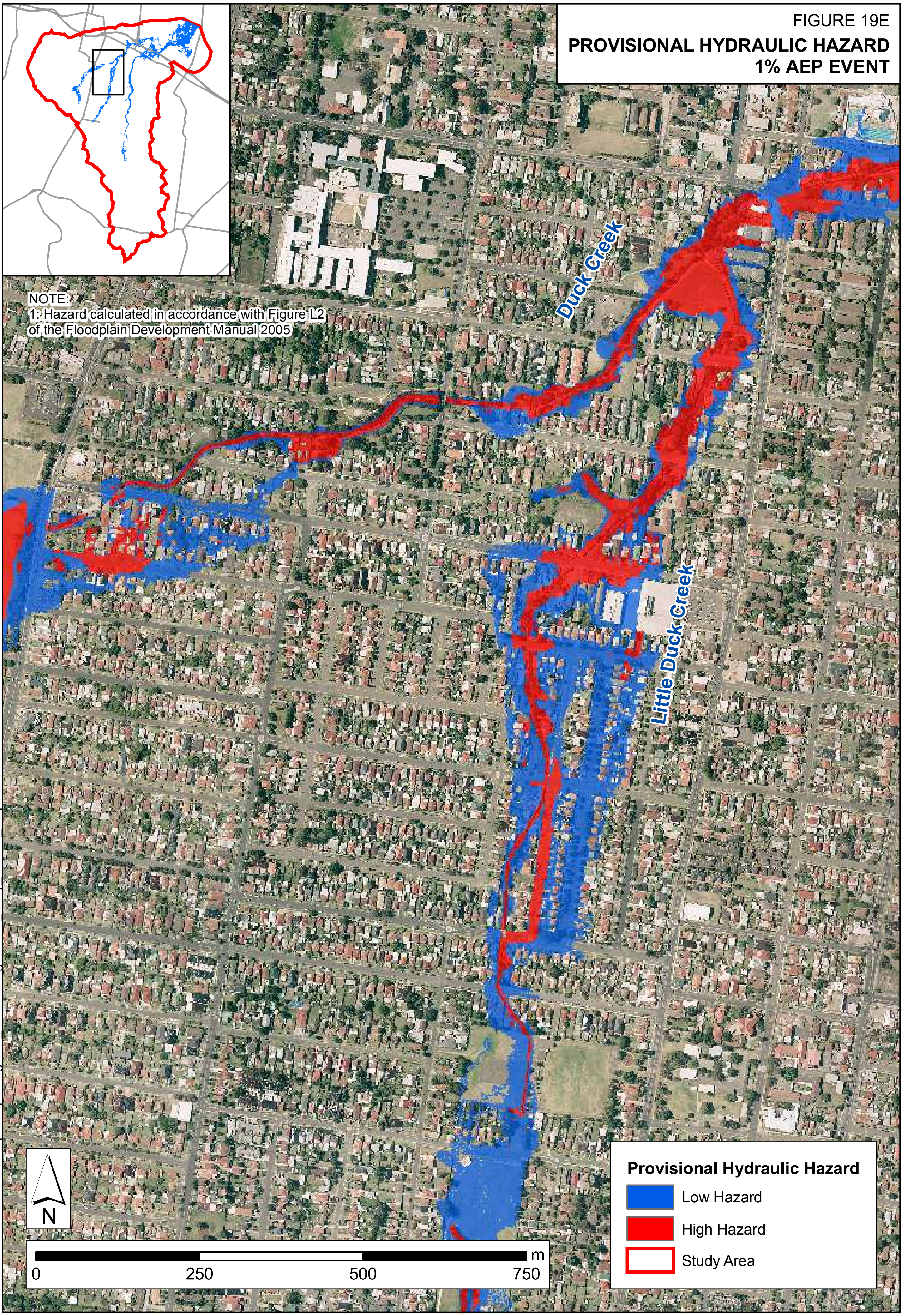
PROVISIONAL HYDRAULIC HAZARD
1% AEP EVENT



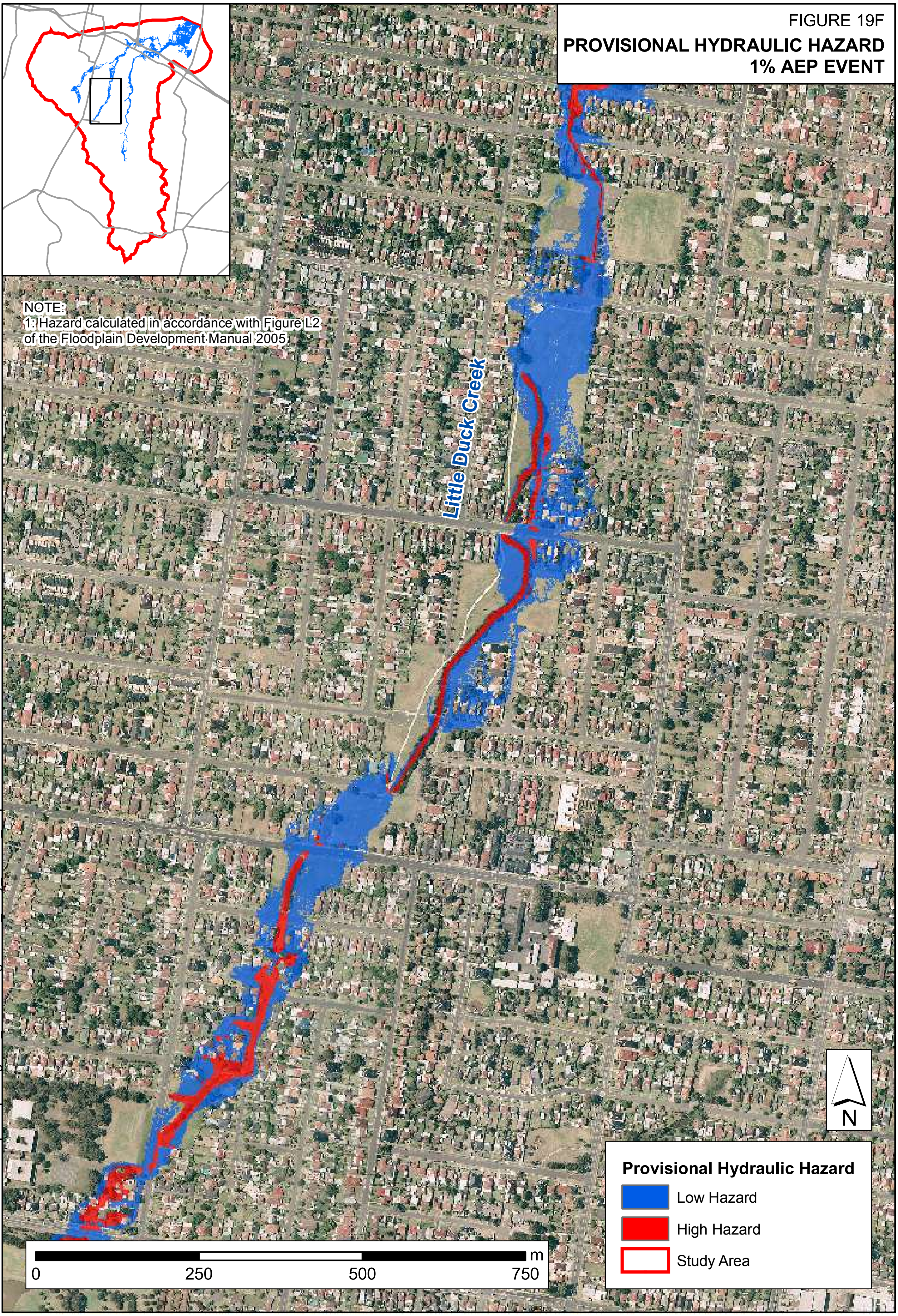
J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures 110119\Figure19D 100y hazard Map4.mxd

FIGURE 19E

PROVISIONAL HYDRAULIC HAZARD
1% AEP EVENT



J:\Jobs\29035\ArcMaps\ReportFigures_110119\Figure19E_100y_hazard_Map5.mxd

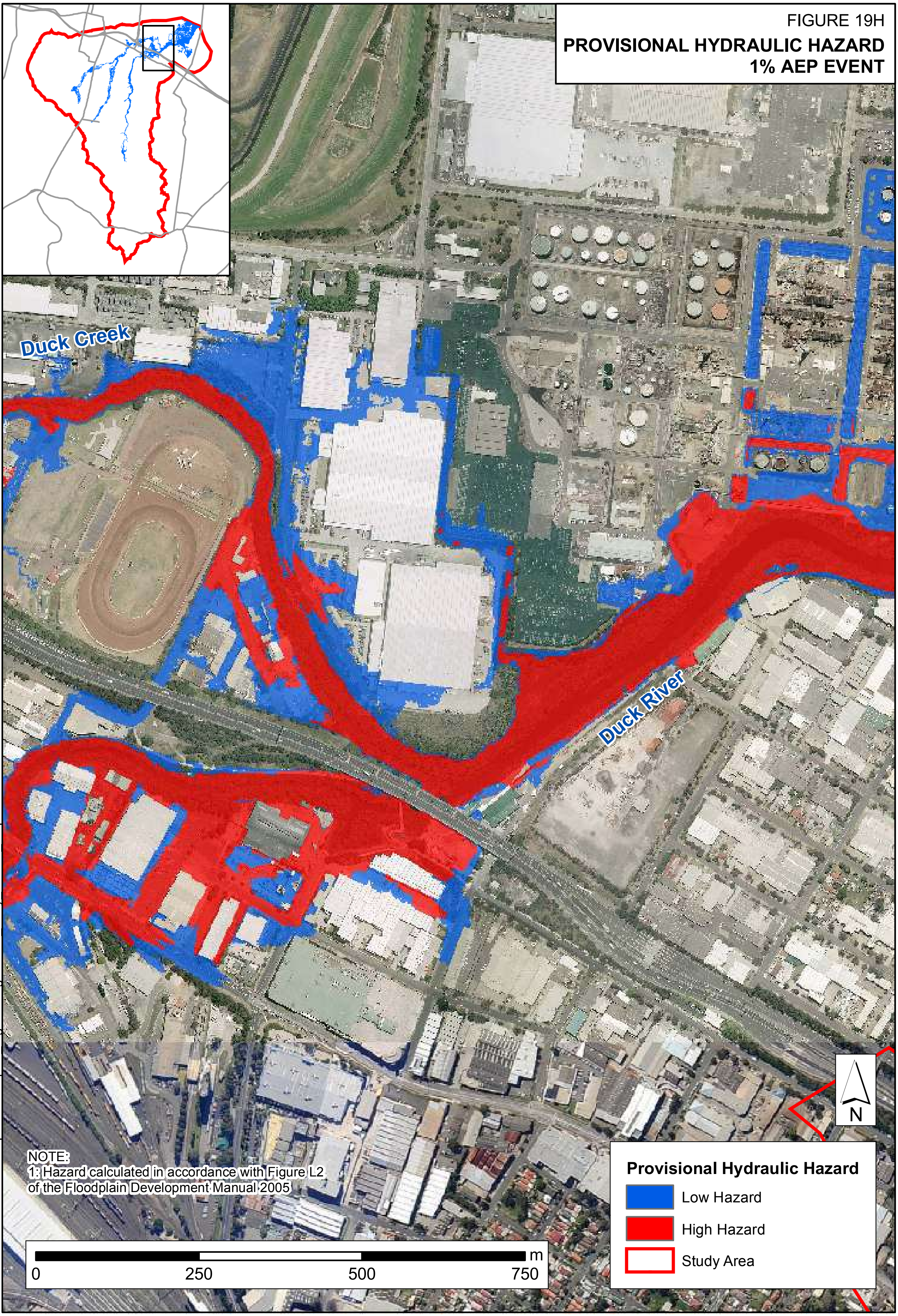


J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure19F_100y_hazard_Map6.mxd

FIGURE 19G
PROVISIONAL HYDRAULIC HAZARD
1% AEP EVENT

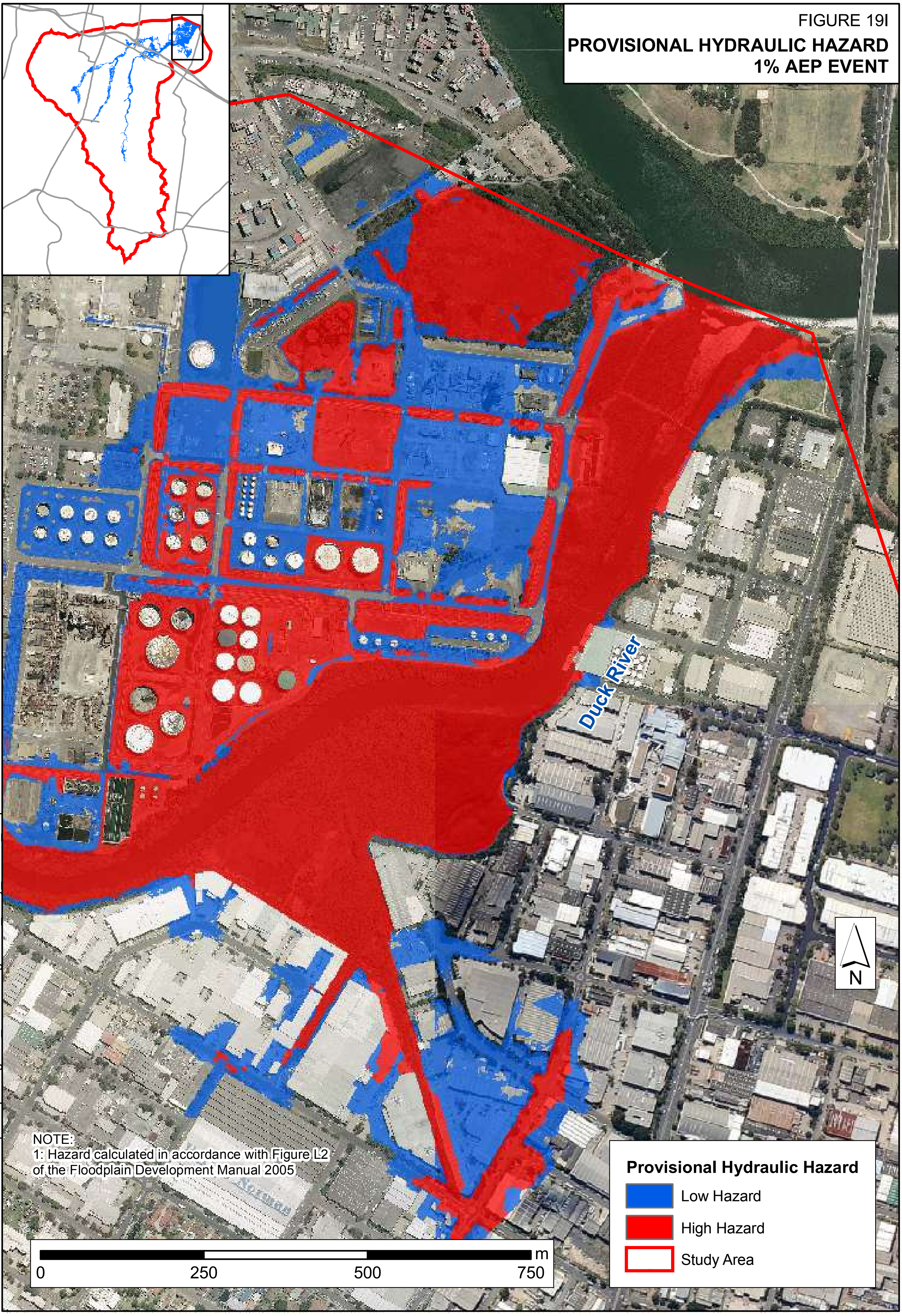
J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures_110119\Figure19G_100y_hazard_Map6.mxd

FIGURE 19H
PROVISIONAL HYDRAULIC HAZARD
1% AEP EVENT

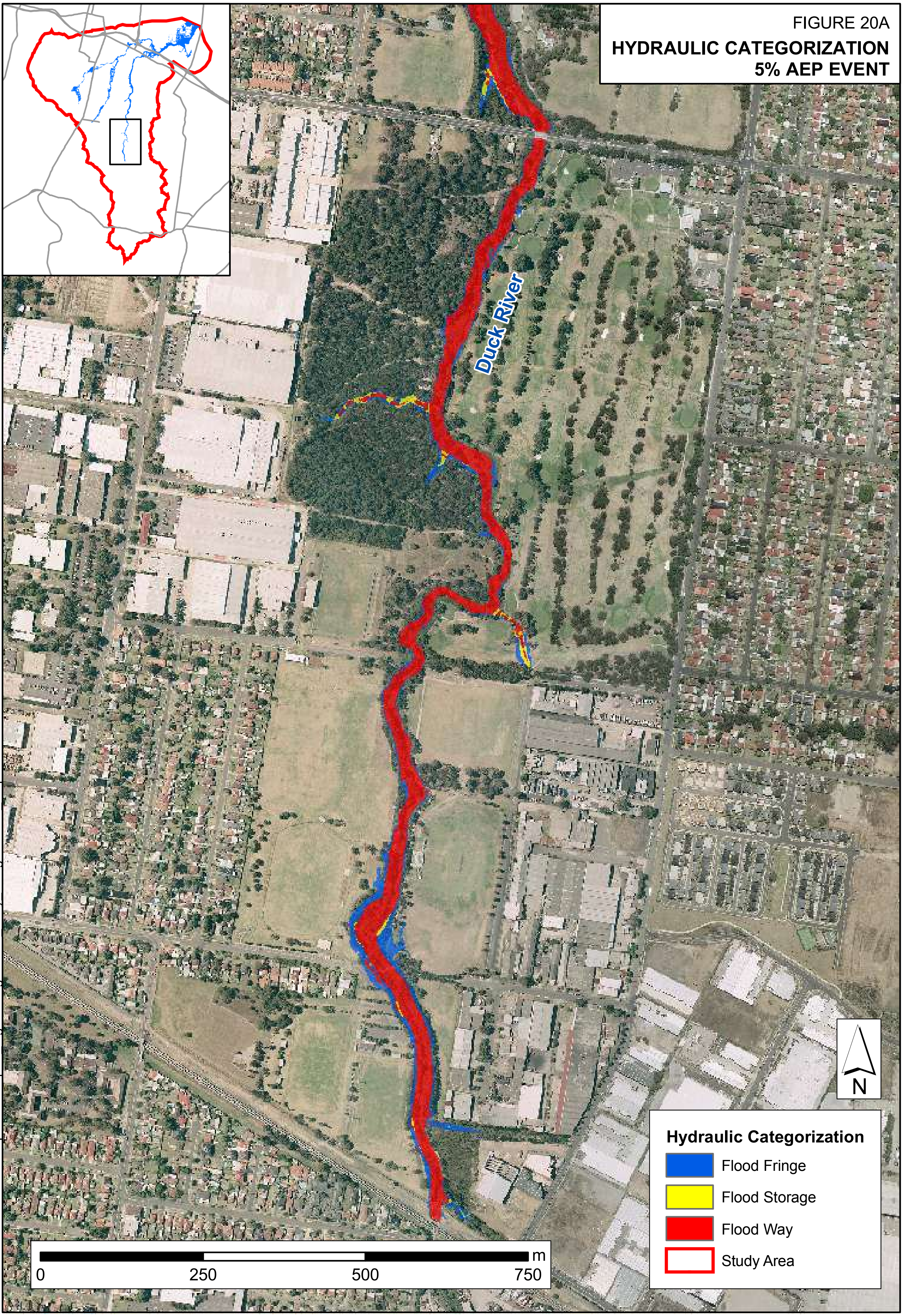


J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure19H_100y_hazard_Map8.mxd

FIGURE 19I
PROVISIONAL HYDRAULIC HAZARD
1% AEP EVENT



J:\Jobs\29035\ArcGIS\ArcMaps\ReportFigures 110119\Figure19I 100y hazard Map9.mxd



J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure20A_020y_categorization_Map1.mxd

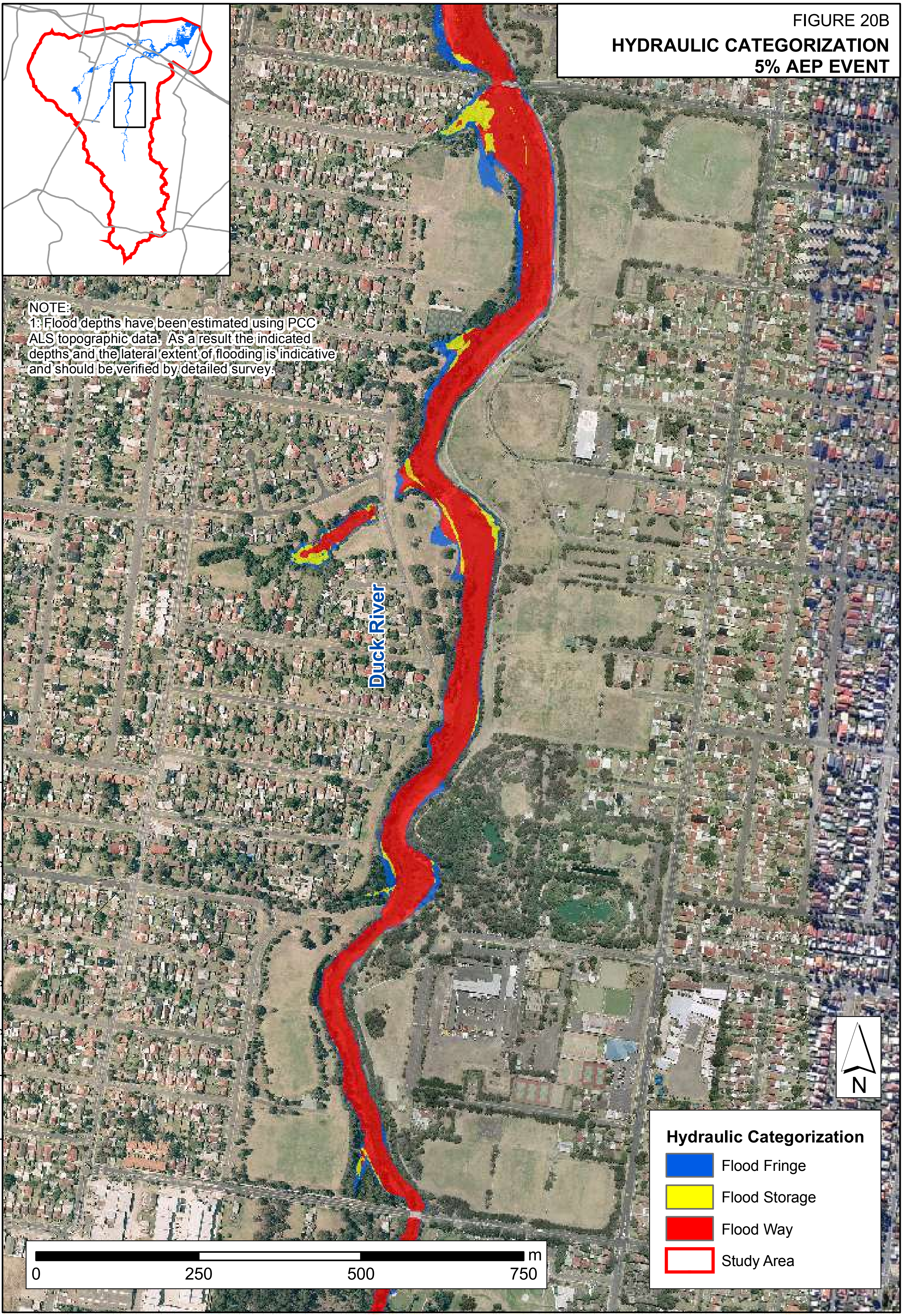


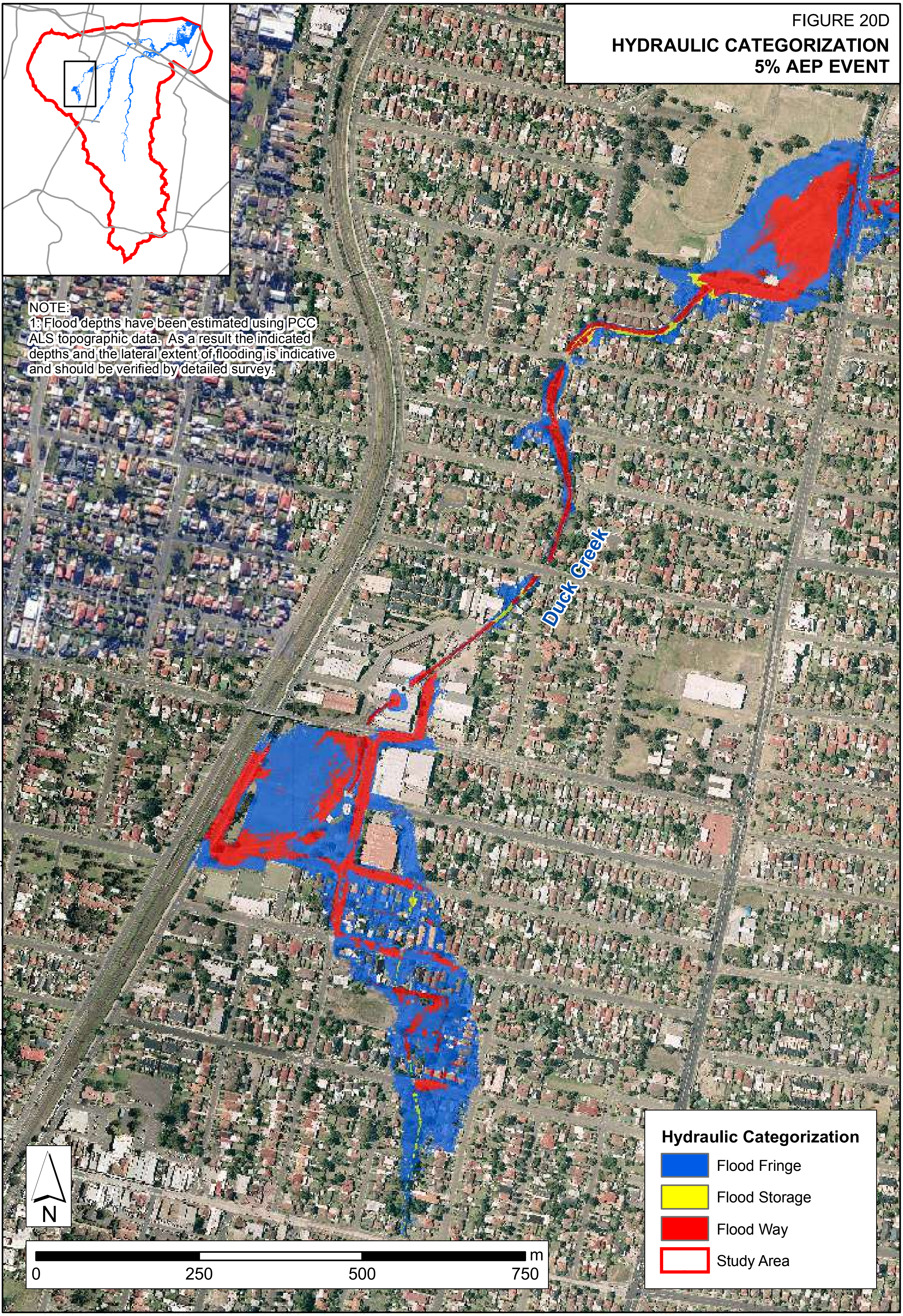
FIGURE 20B
HYDRAULIC CATEGORIZATION
5% AEP EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure20B_020y_categorization_Map2.mxd

FIGURE 20C

HYDRAULIC CATEGORIZATION
5% AEP EVENT

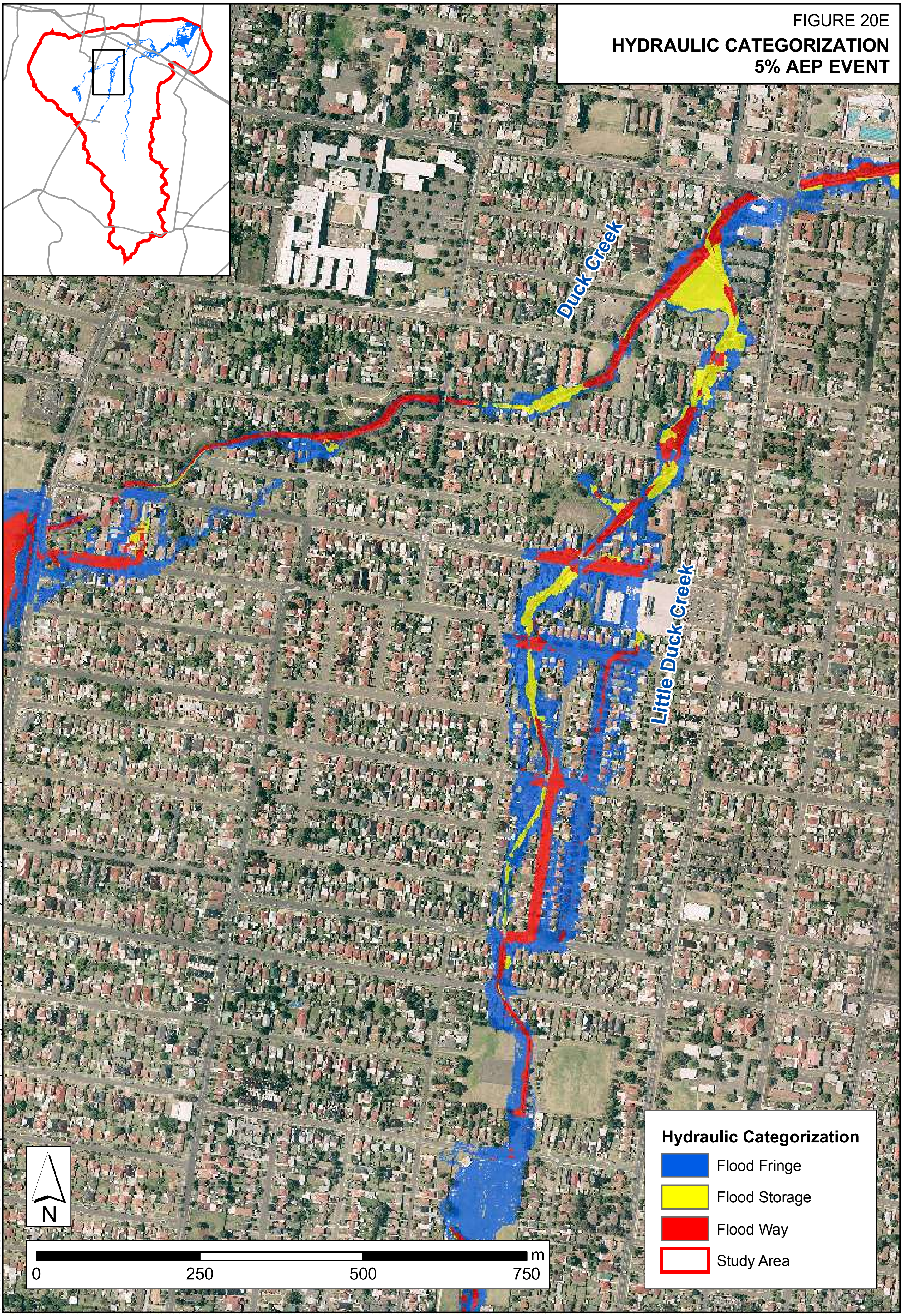
J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport Figures\Figure20C 020y categorization Map3.mxd



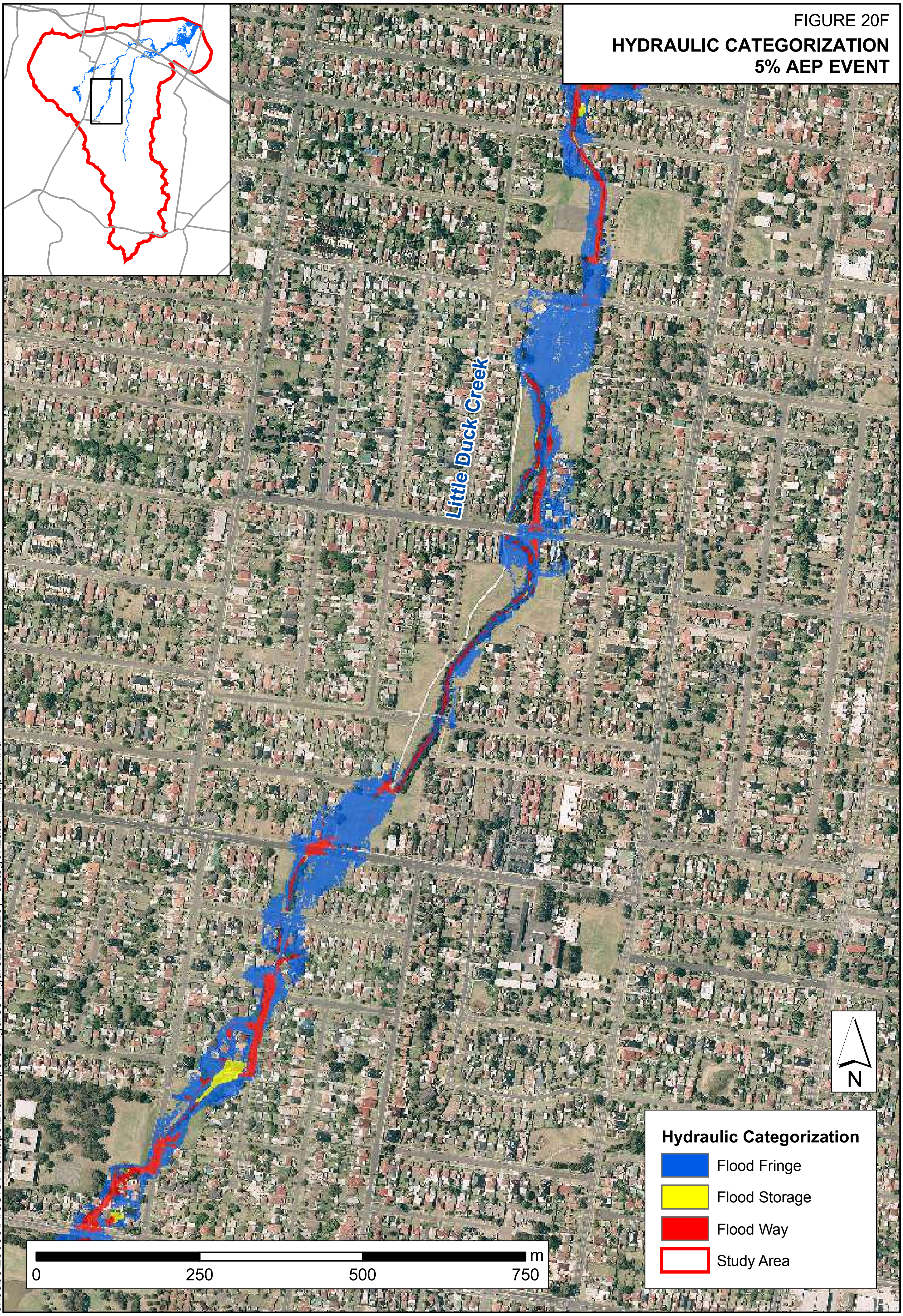
J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport Figures\Figure20D 020y categorization Map4.mxd

FIGURE 20E

HYDRAULIC CATEGORIZATION
5% AEP EVENT



J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure20E_020y_categorization_Map5.mxd



J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport Figures\Figure20F 020y categorization Map6.mxd

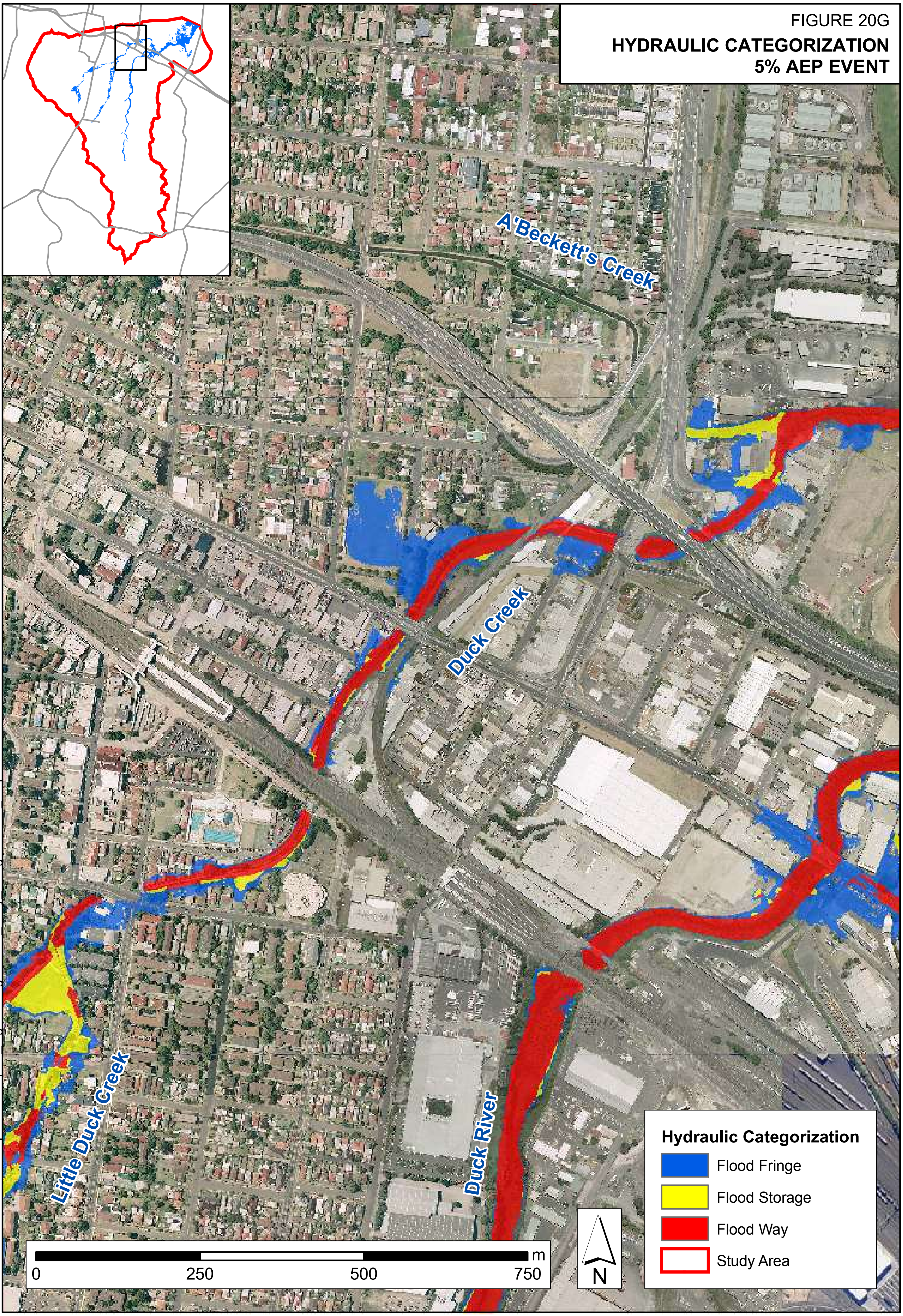
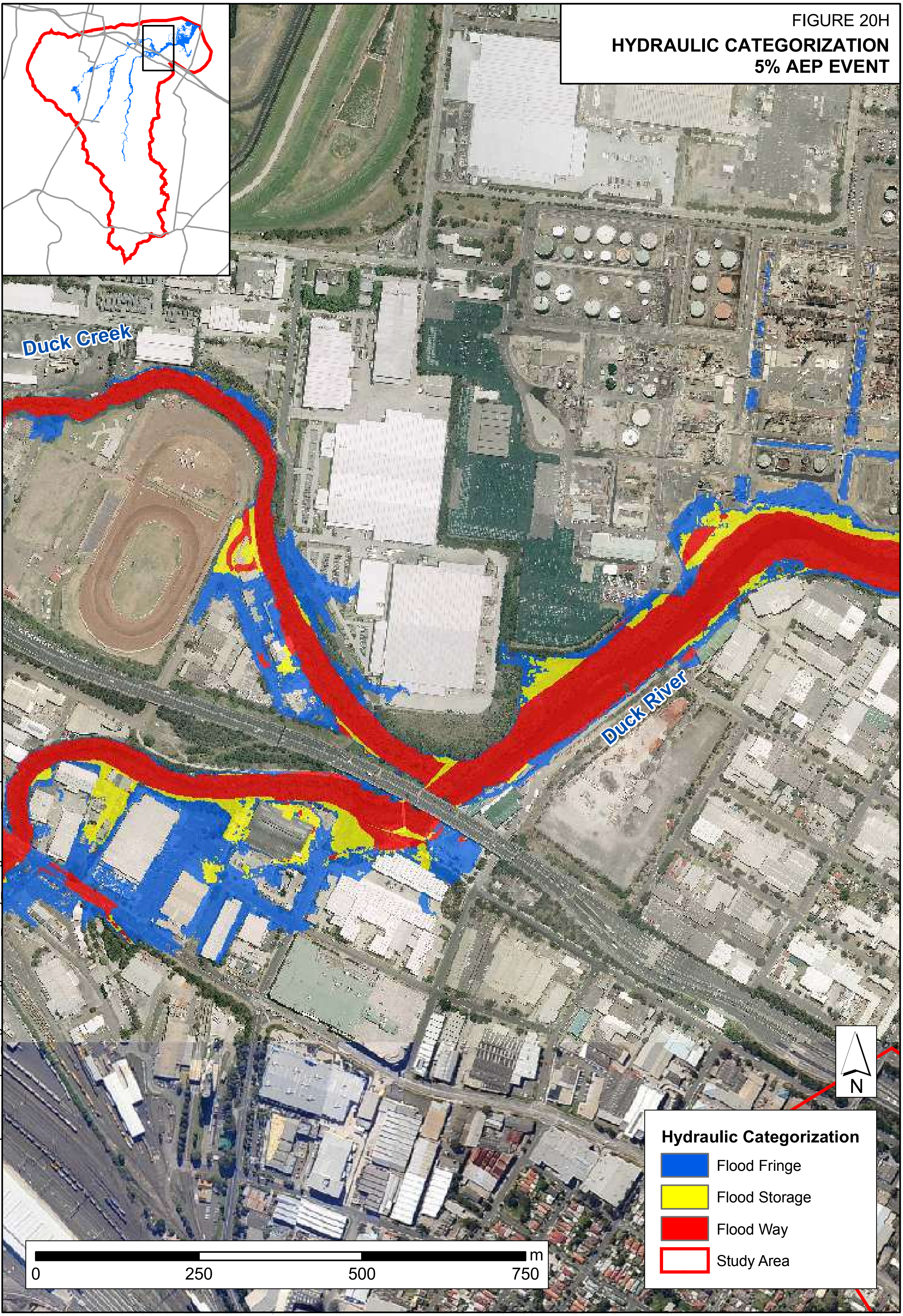


FIGURE 20G
HYDRAULIC CATEGORIZATION
5% AEP EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure20G_020y_categorization_Map7.mxd

FIGURE 20H

HYDRAULIC CATEGORIZATION
5% AEP EVENT



J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure20H_020y_categorization_Map8.mxd

FIGURE 20I

HYDRAULIC CATEGORIZATION
5% AEP EVENT

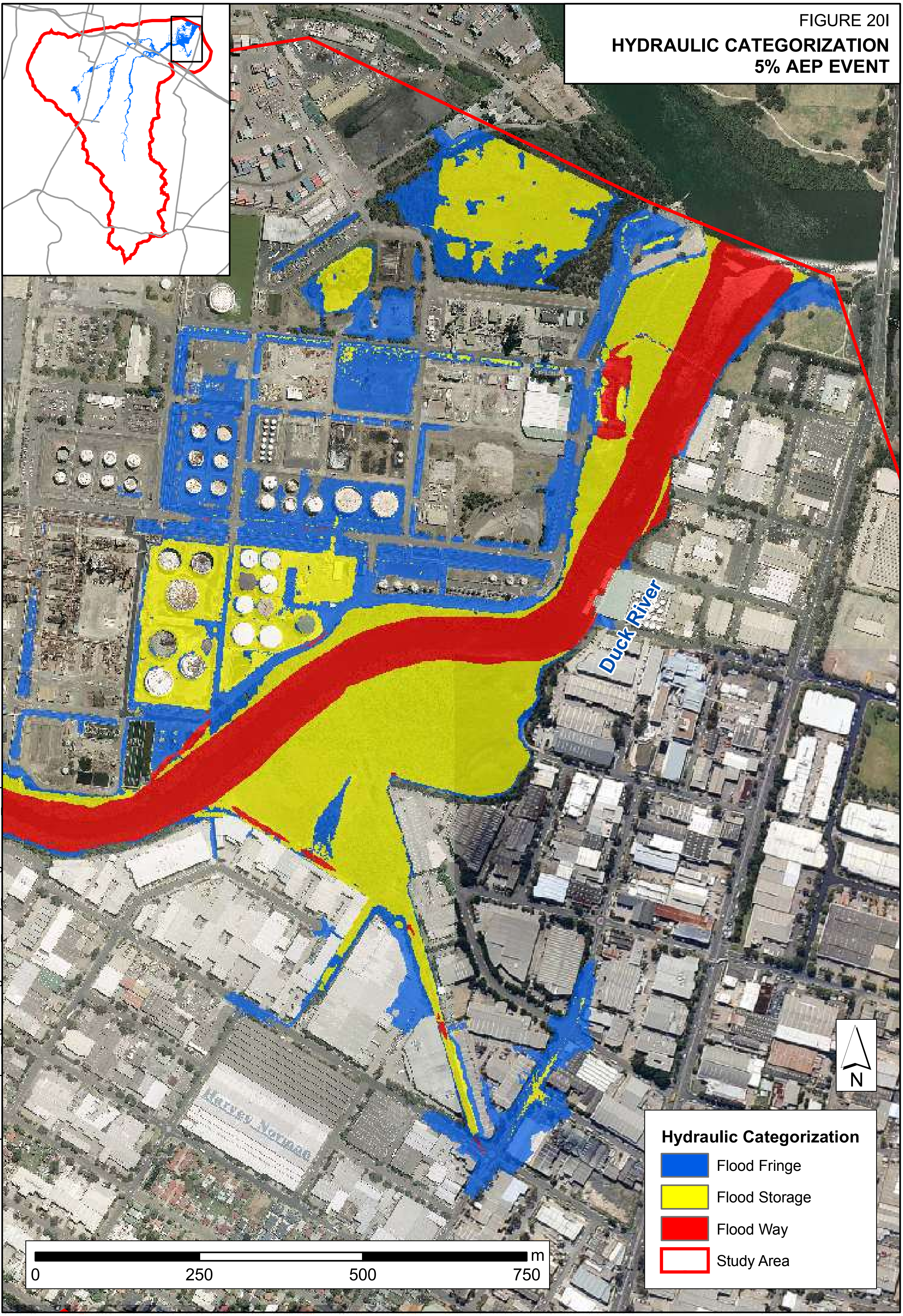


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FIGURE 21A

HYDRAULIC CATEGORIZATION 1% AEP EVENT

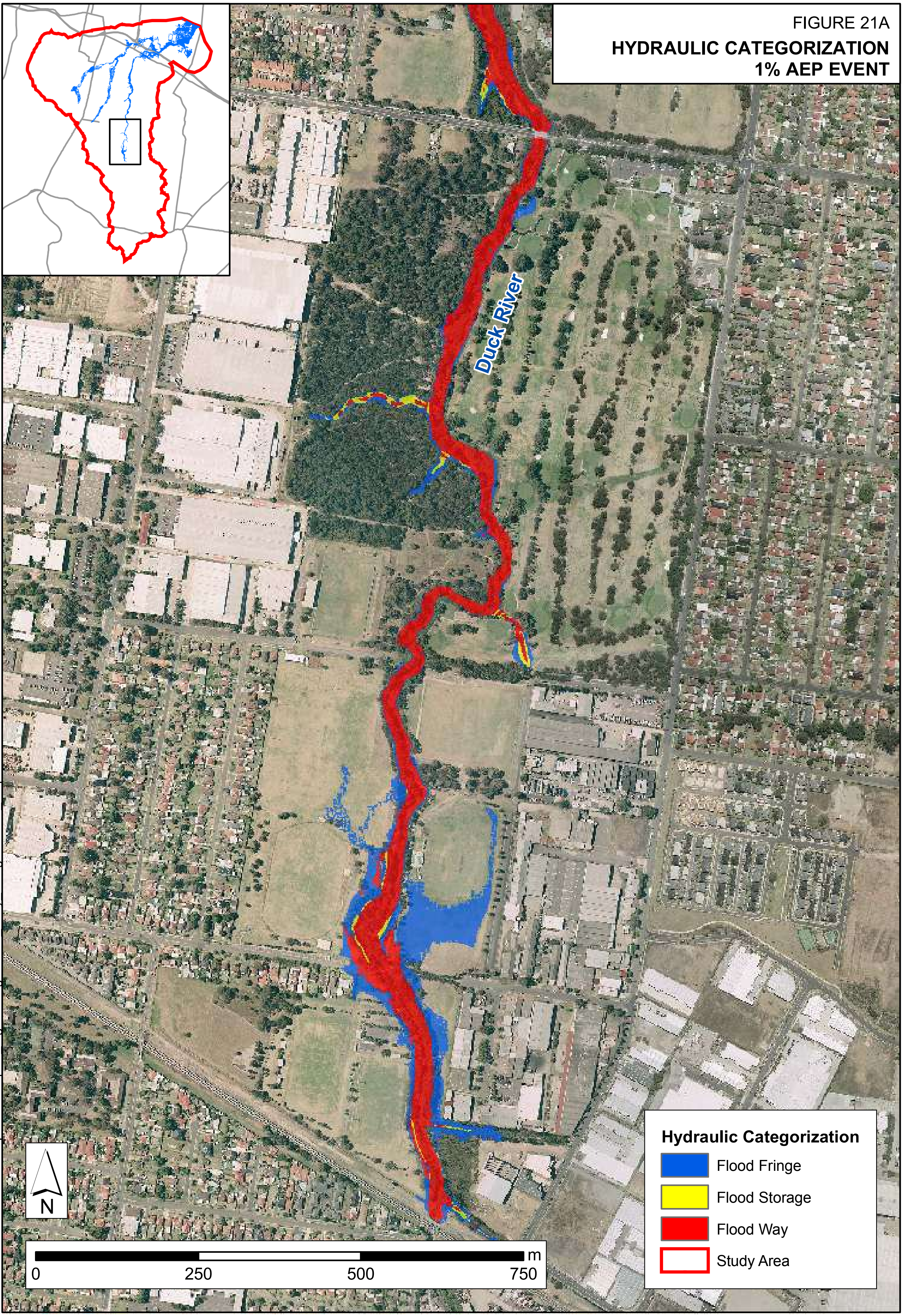

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FIGURE 21C

HYDRAULIC CATEGORIZATION 1% AEP EVENT

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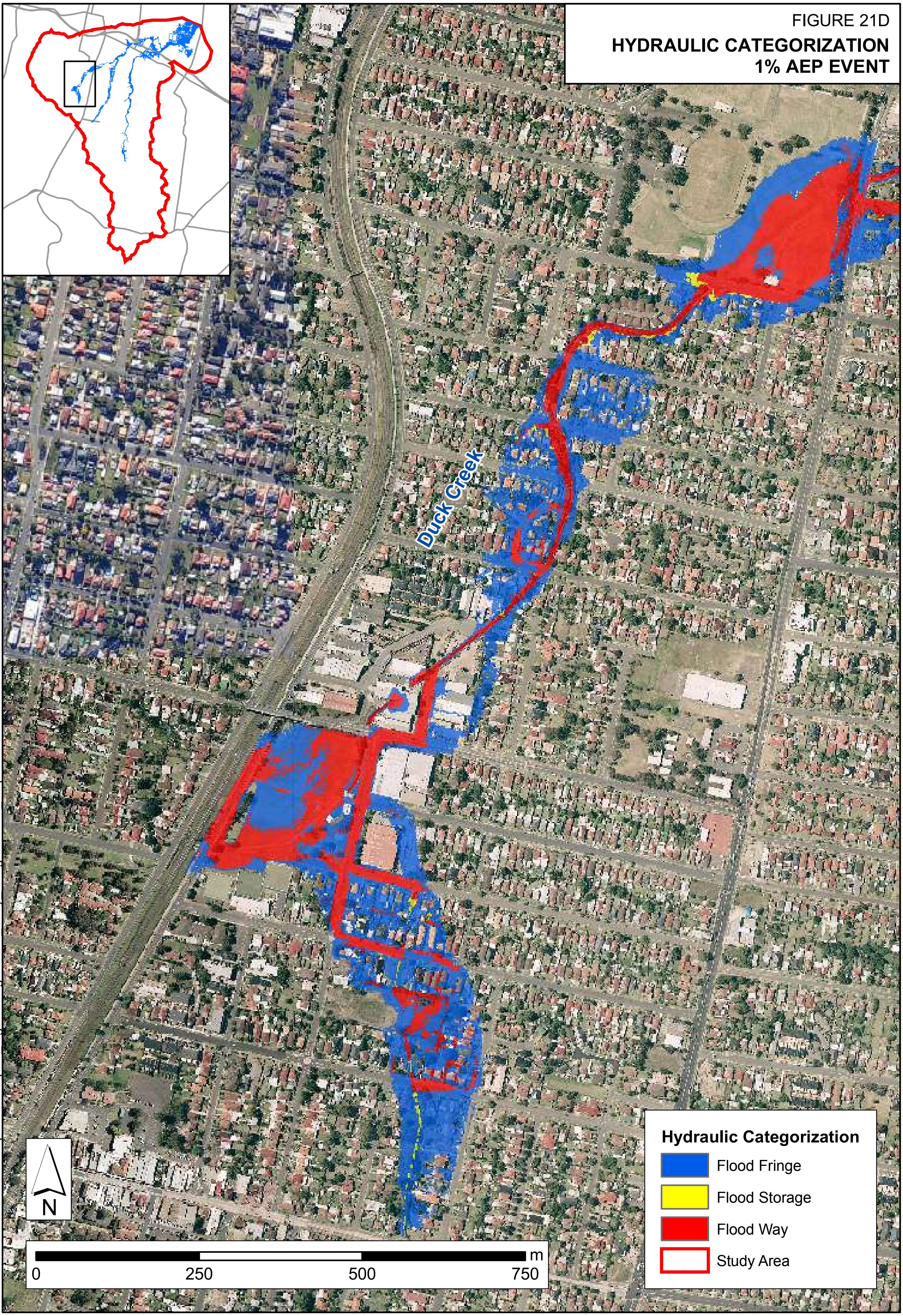

FIGURE 21D
HYDRAULIC CATEGORIZATION
1% AEP EVENT

J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure21D_100y_categorization_Map4.mxd

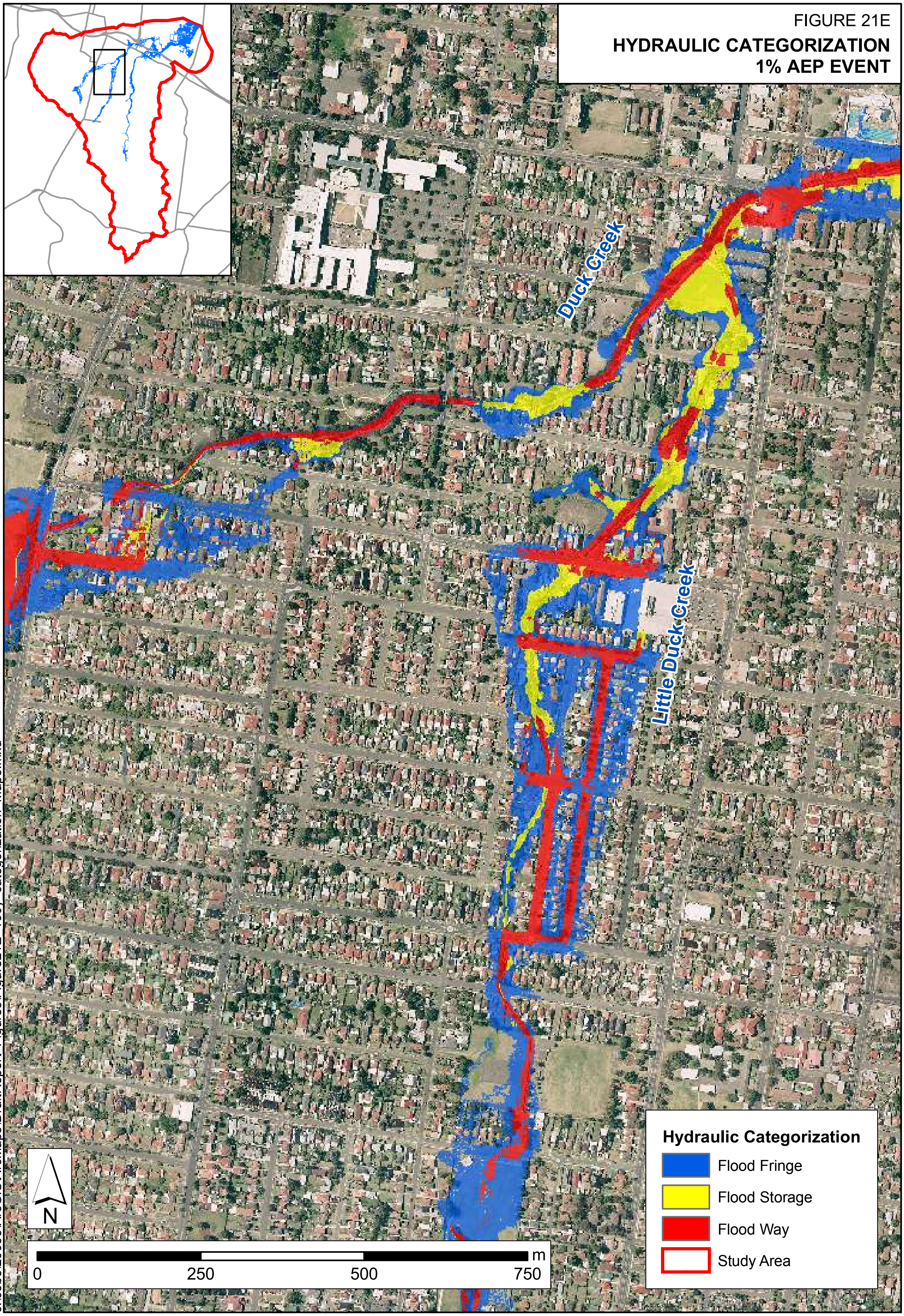

FIGURE 21E
HYDRAULIC CATEGORIZATION
1% AEP EVENT

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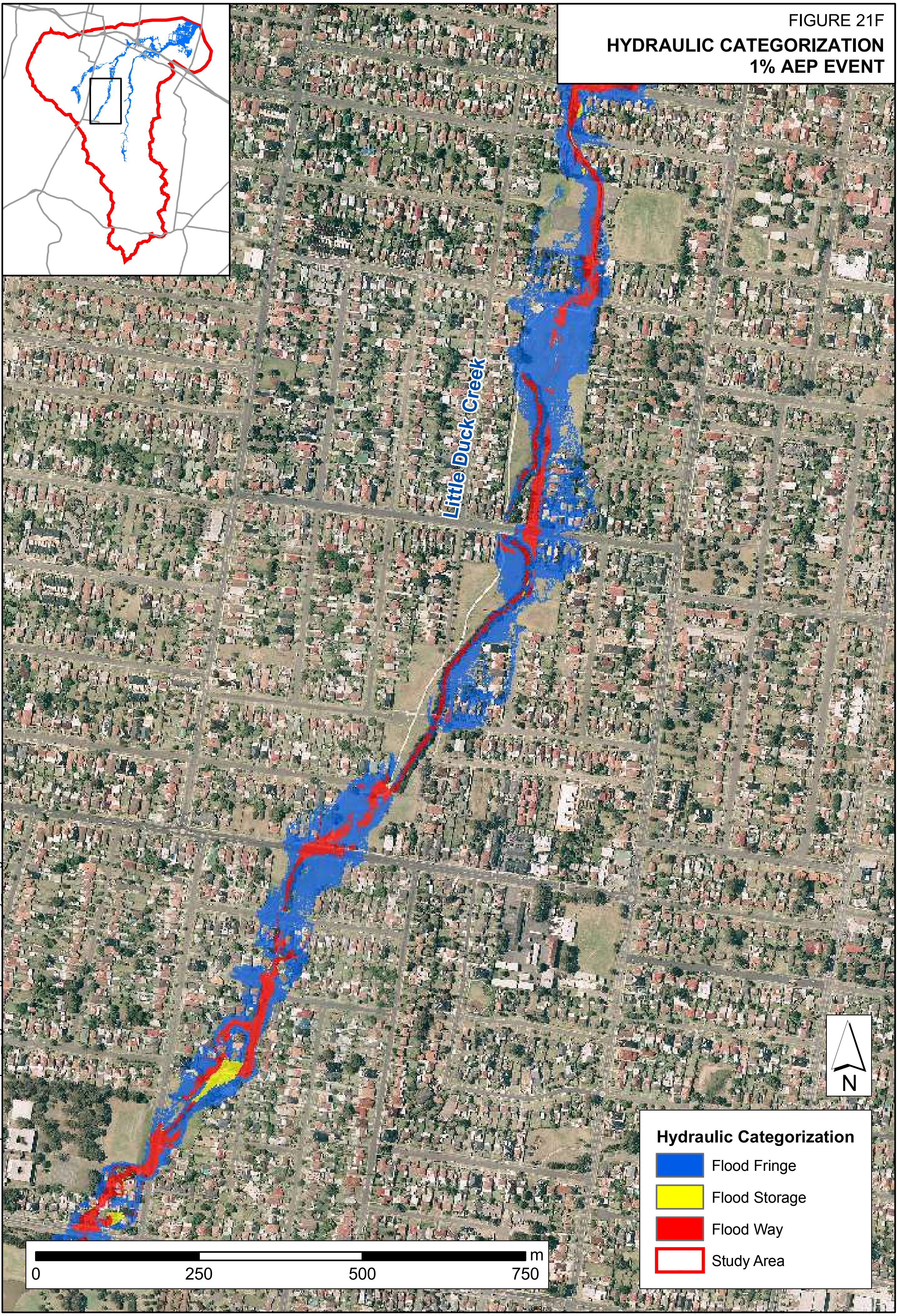
FIGURE 21F

HYDRAULIC CATEGORIZATION
1% AEP EVENT



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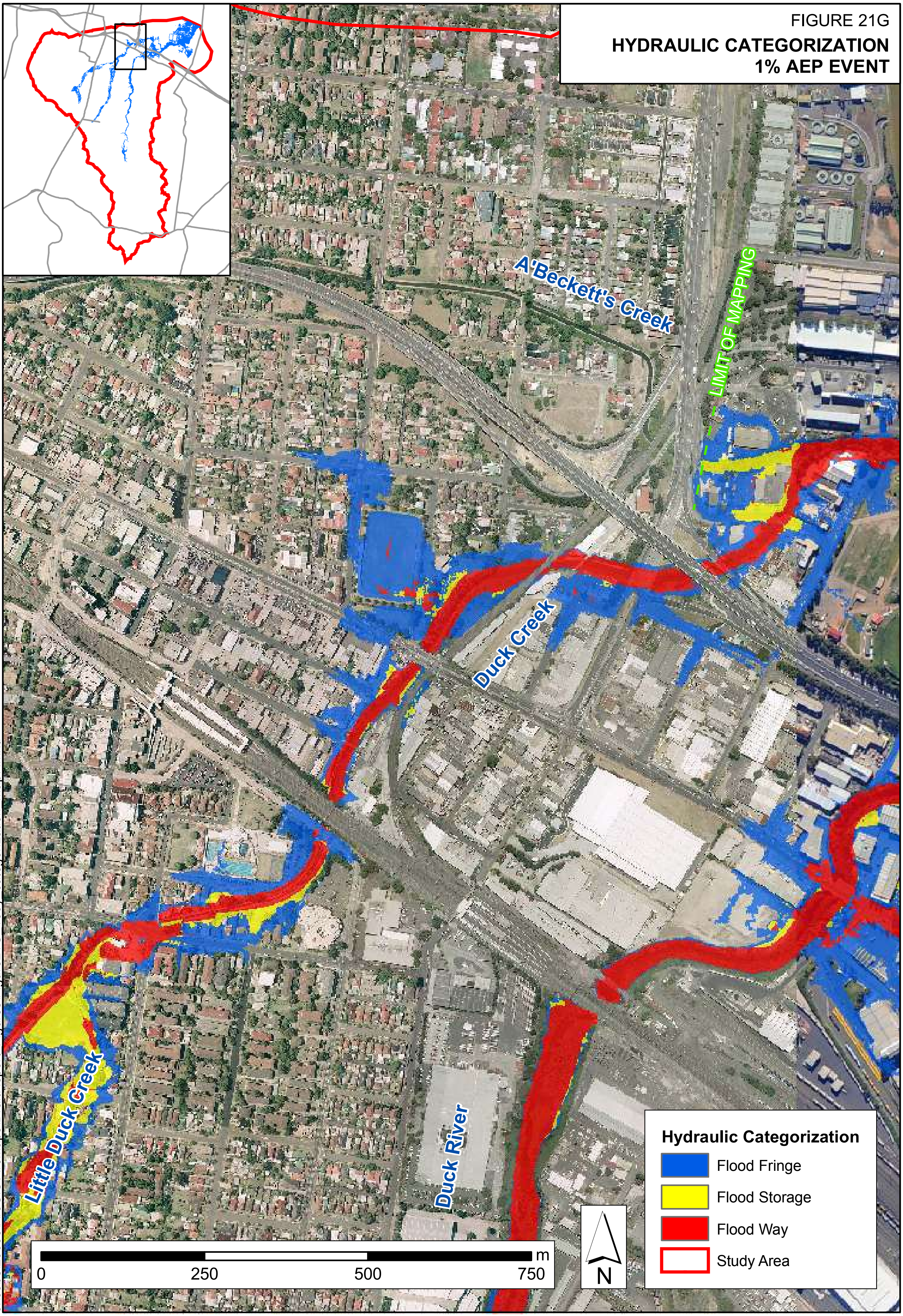

FIGURE 21G

HYDRAULIC CATEGORIZATION 1% AEP EVENT

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FIGURE 21H

HYDRAULIC CATEGORIZATION
1% AEP EVENT

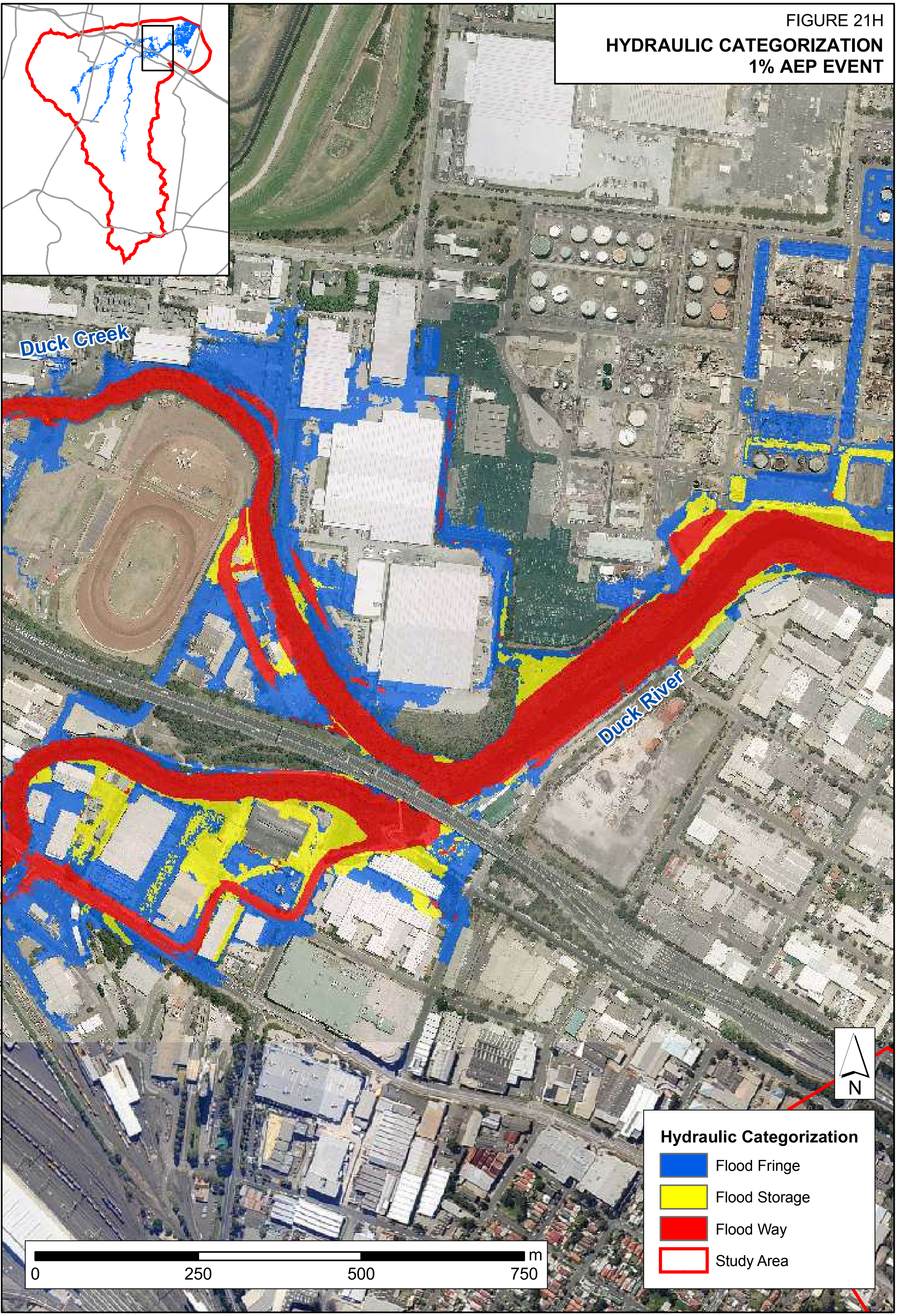

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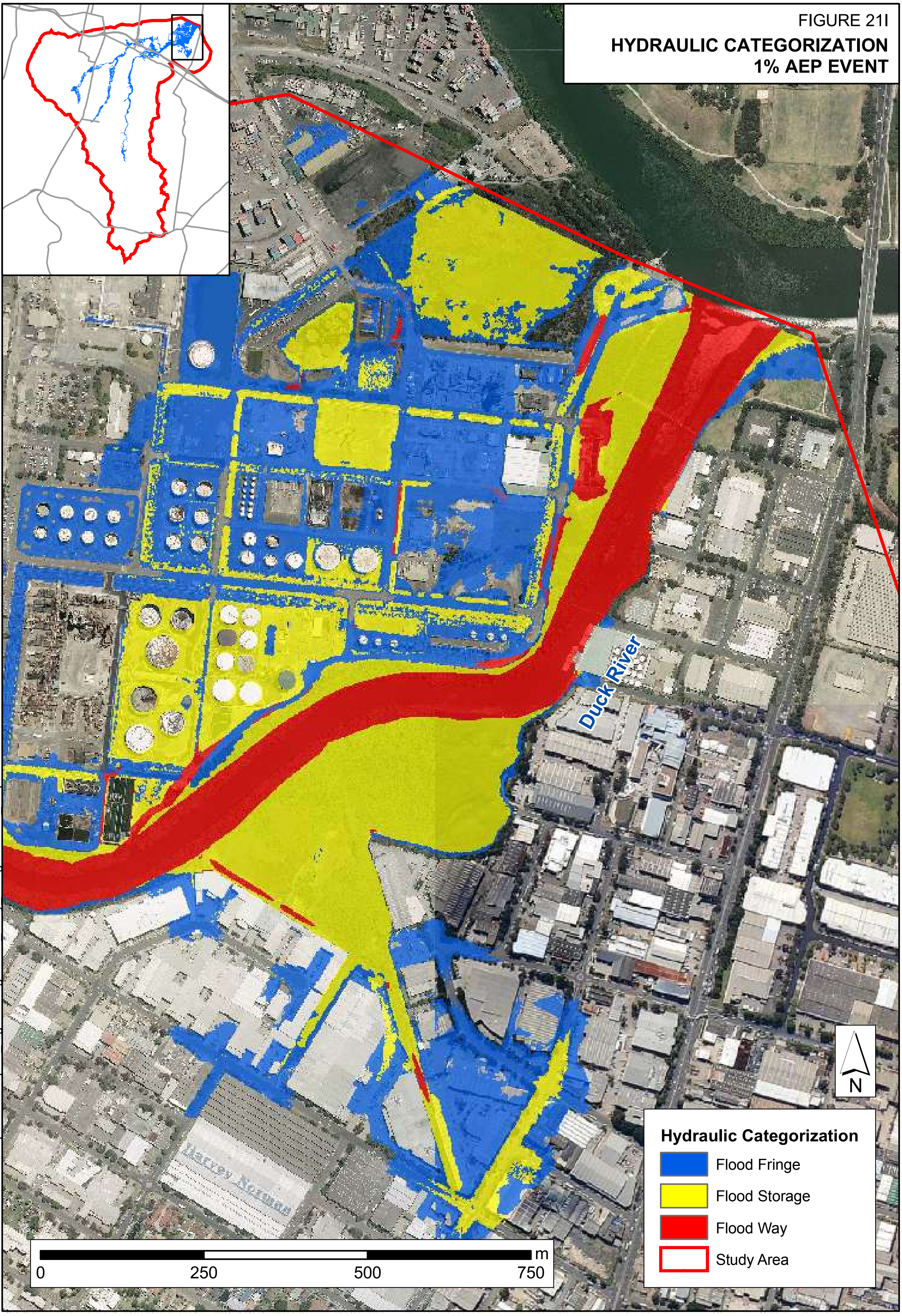
FIGURE 21I

HYDRAULIC CATEGORIZATION 1% AEP EVENT



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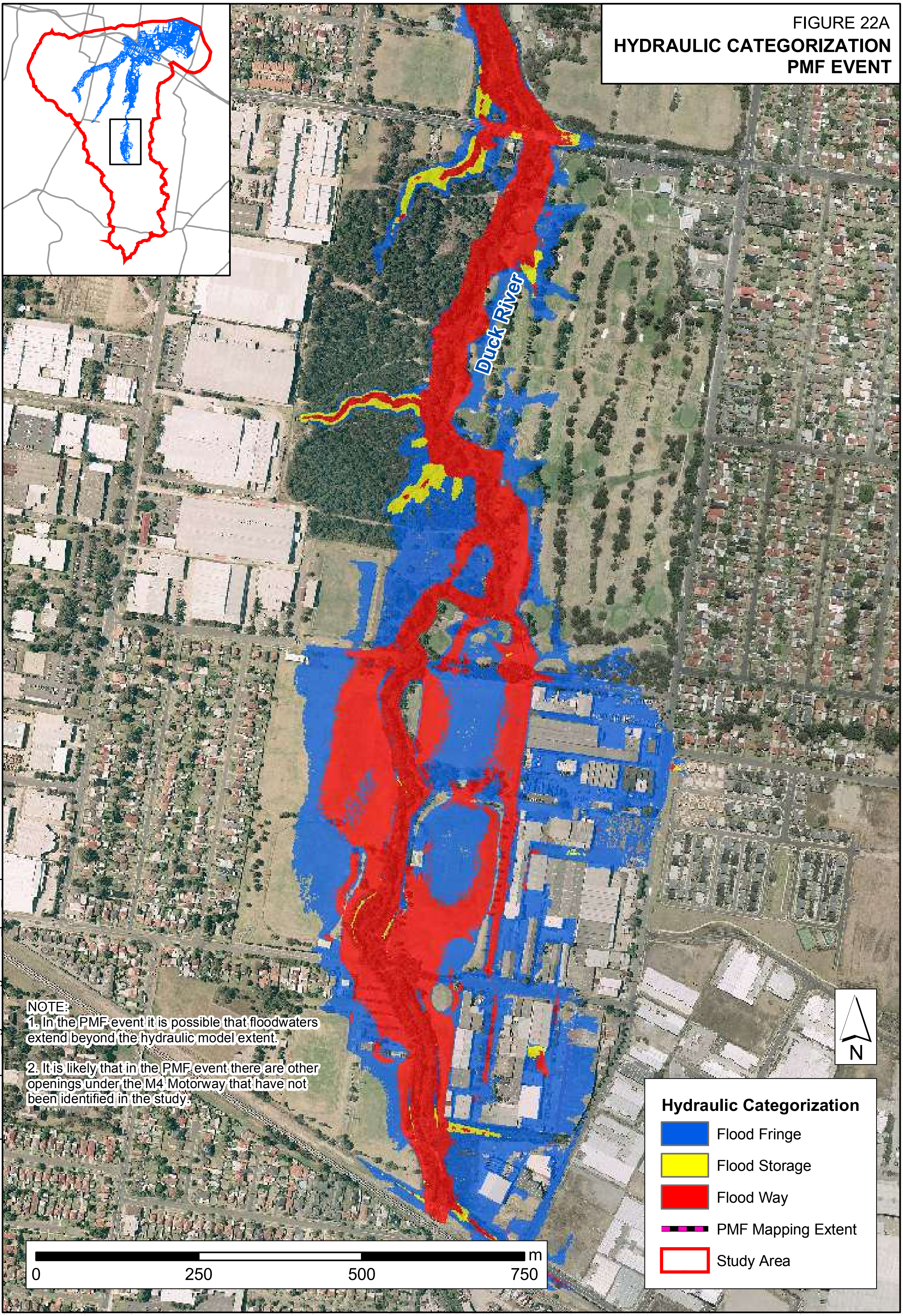

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FIGURE 22B
HYDRAULIC CATEGORIZATION
PMF EVENT

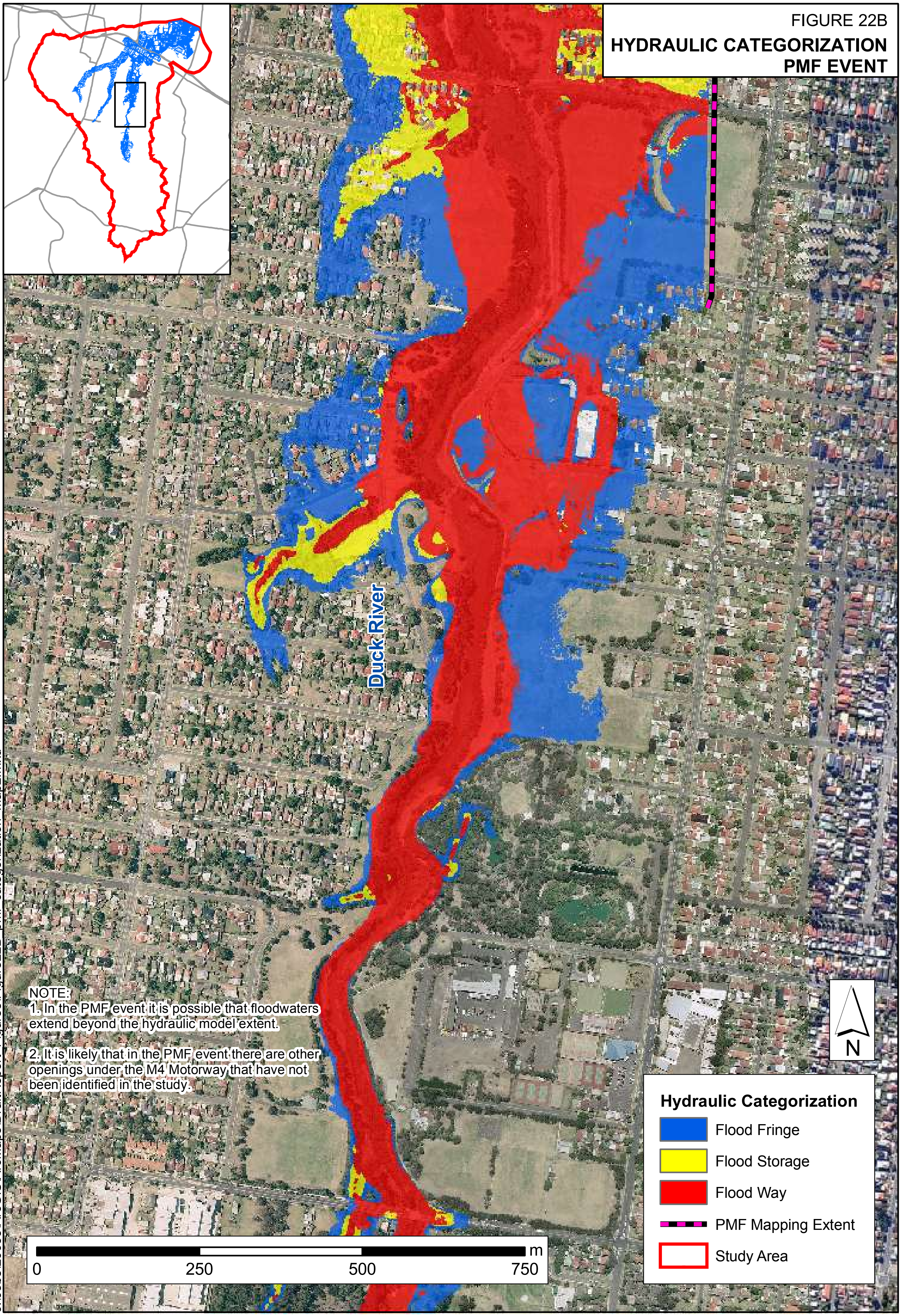

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FIGURE 22C

HYDRAULIC CATEGORIZATION PMF EVENT

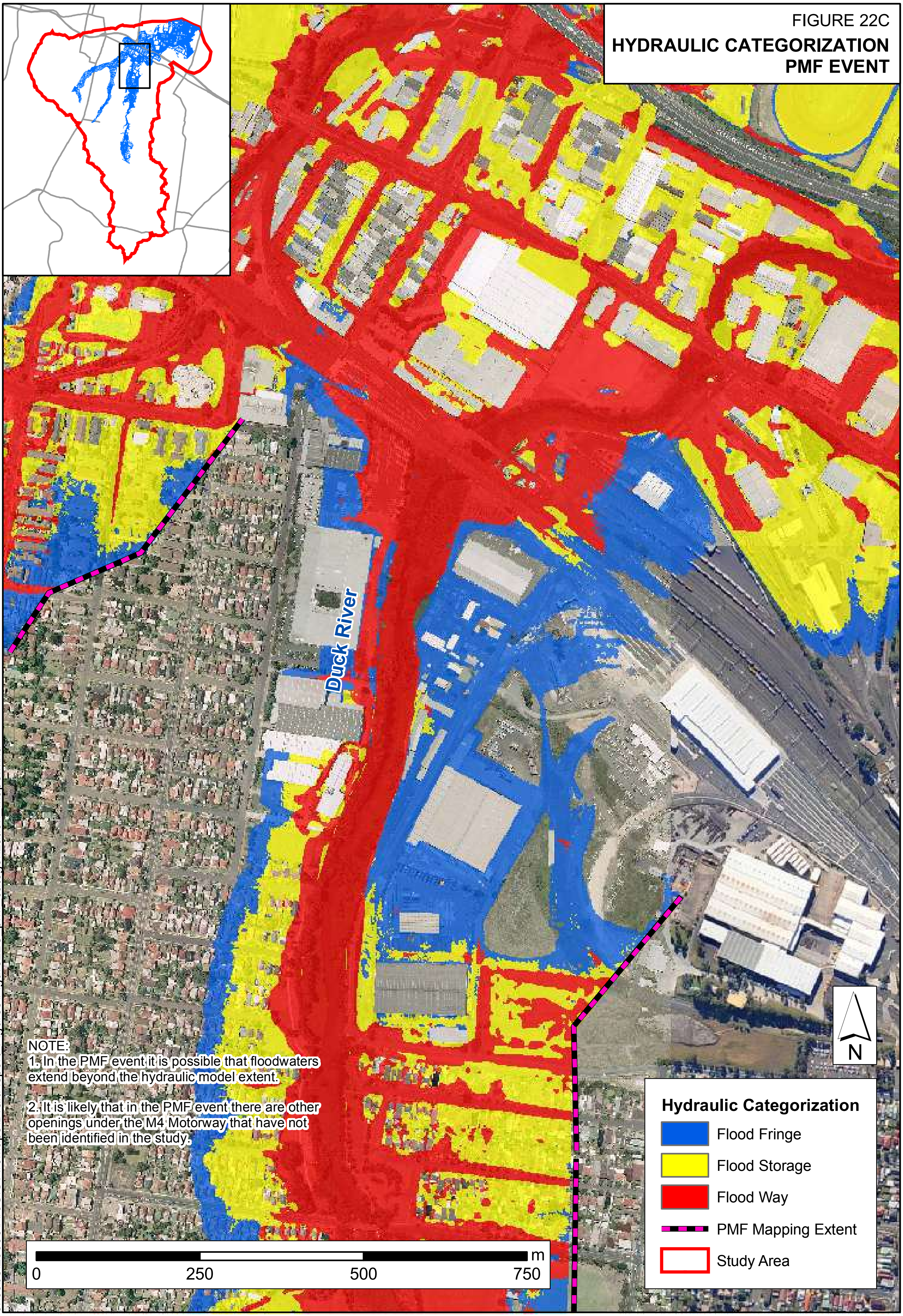
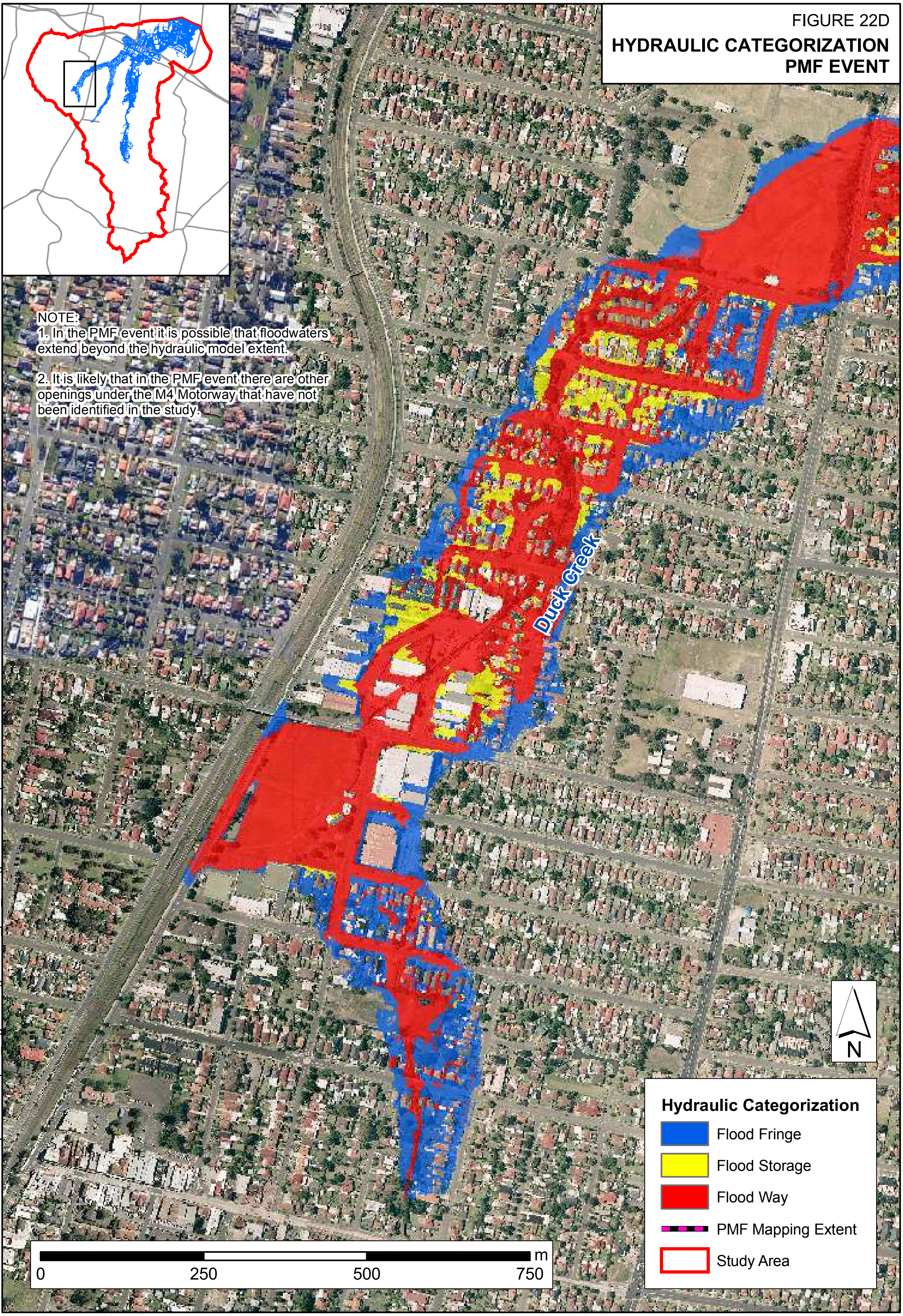


FIGURE 22D

HYDRAULIC CATEGORIZATION PMF EVENT



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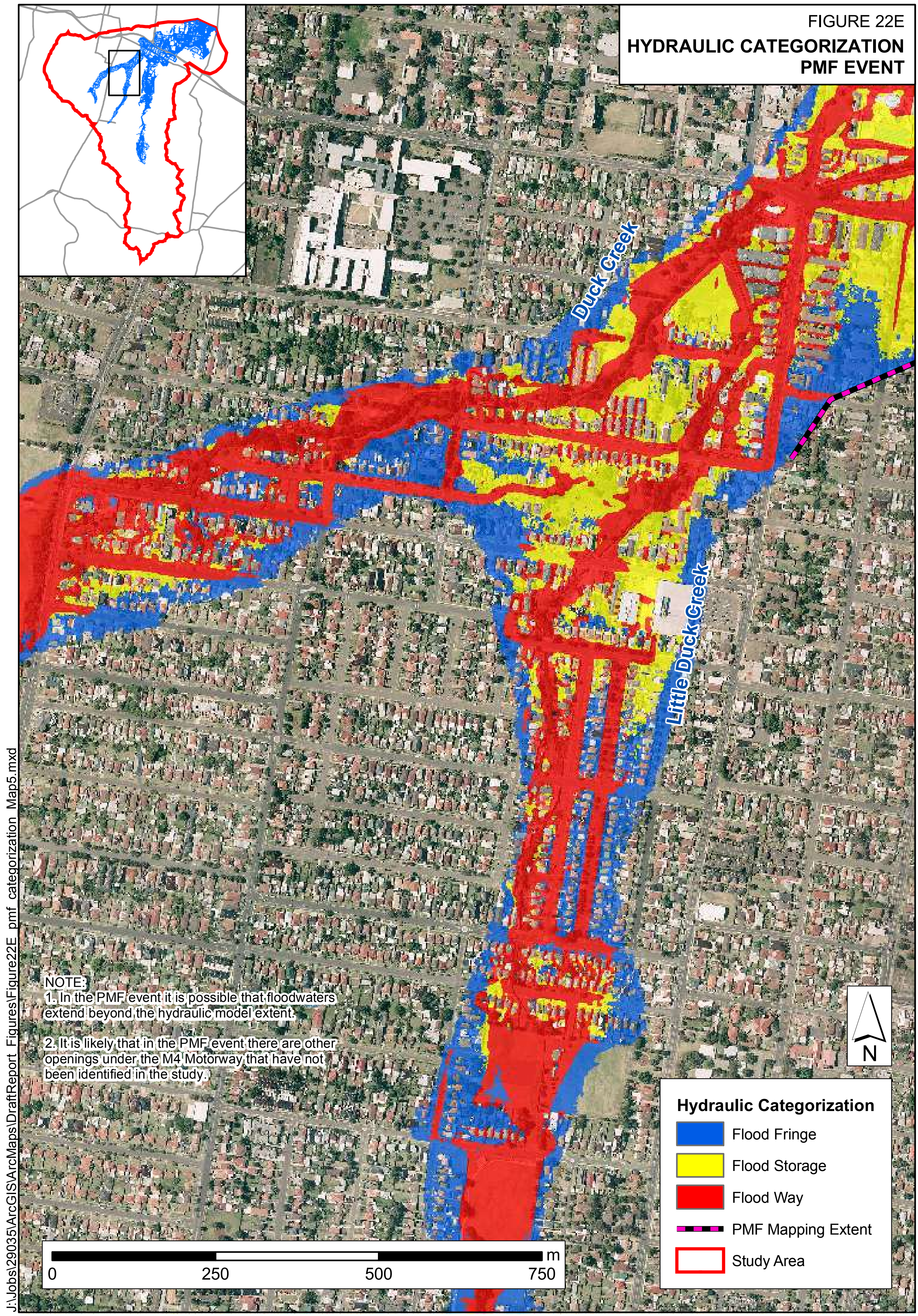

FIGURE 22E
HYDRAULIC CATEGORIZATION
PMF EVENT
Duck Creek
Little Duck Creek
NOTE:
1. In the PMF event it is possible that floodwaters extend beyond the hydraulic model extent.
2. It is likely that in the PMF event there are other openings under the M4 Motorway that have not been identified in the study.
N
Hydraulic Categorization
Flood Fringe
Flood Storage
Flood Way
PMF Mapping Extent
Study Area
0
250
500
750
m
J:\Jobs\29035\ArcGIS\ArcMaps\DraftReport_Figures\Figure22E_pmf_categorization_Map5.mxd

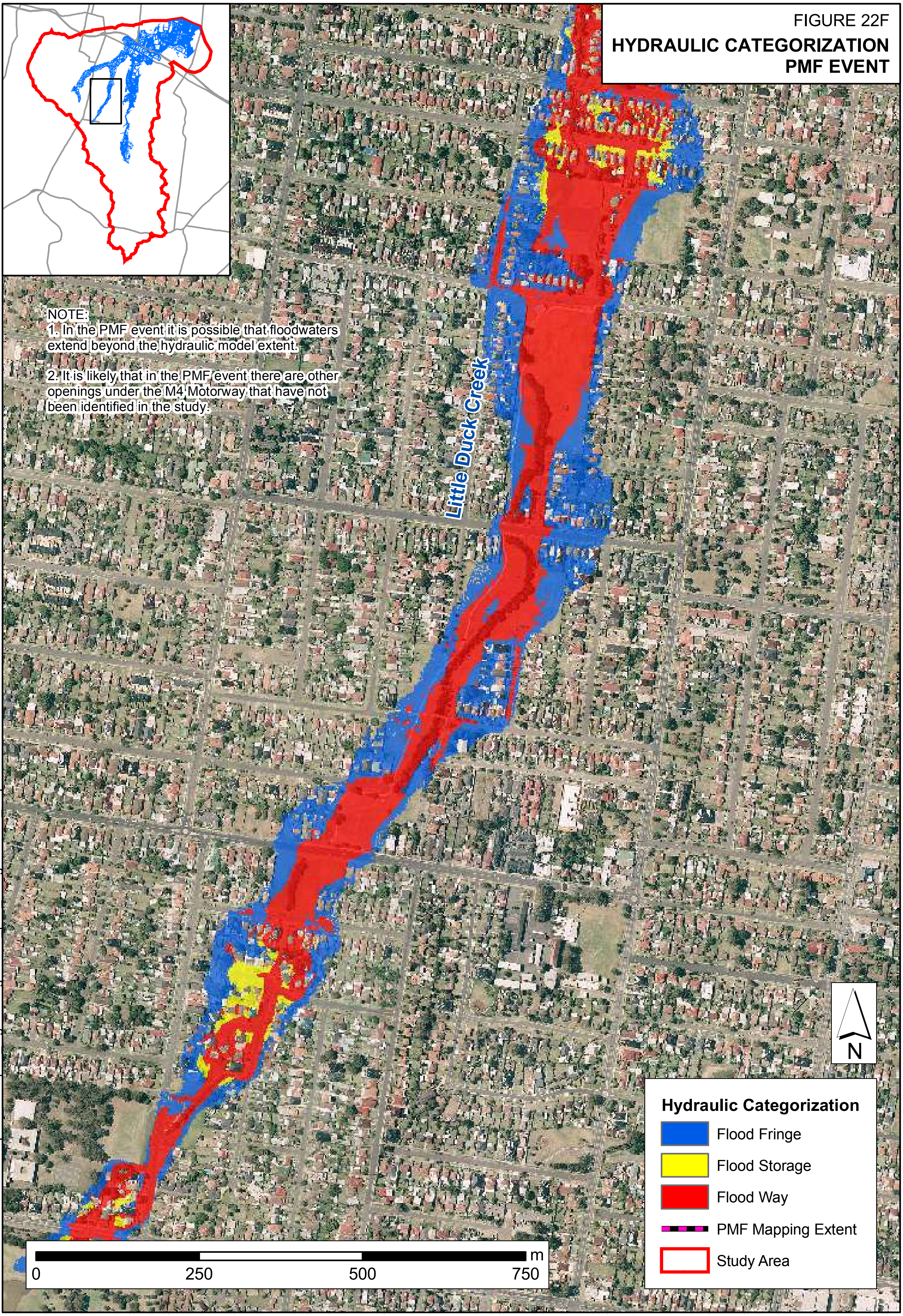

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FIGURE 22G

HYDRAULIC CATEGORIZATION PMF EVENT

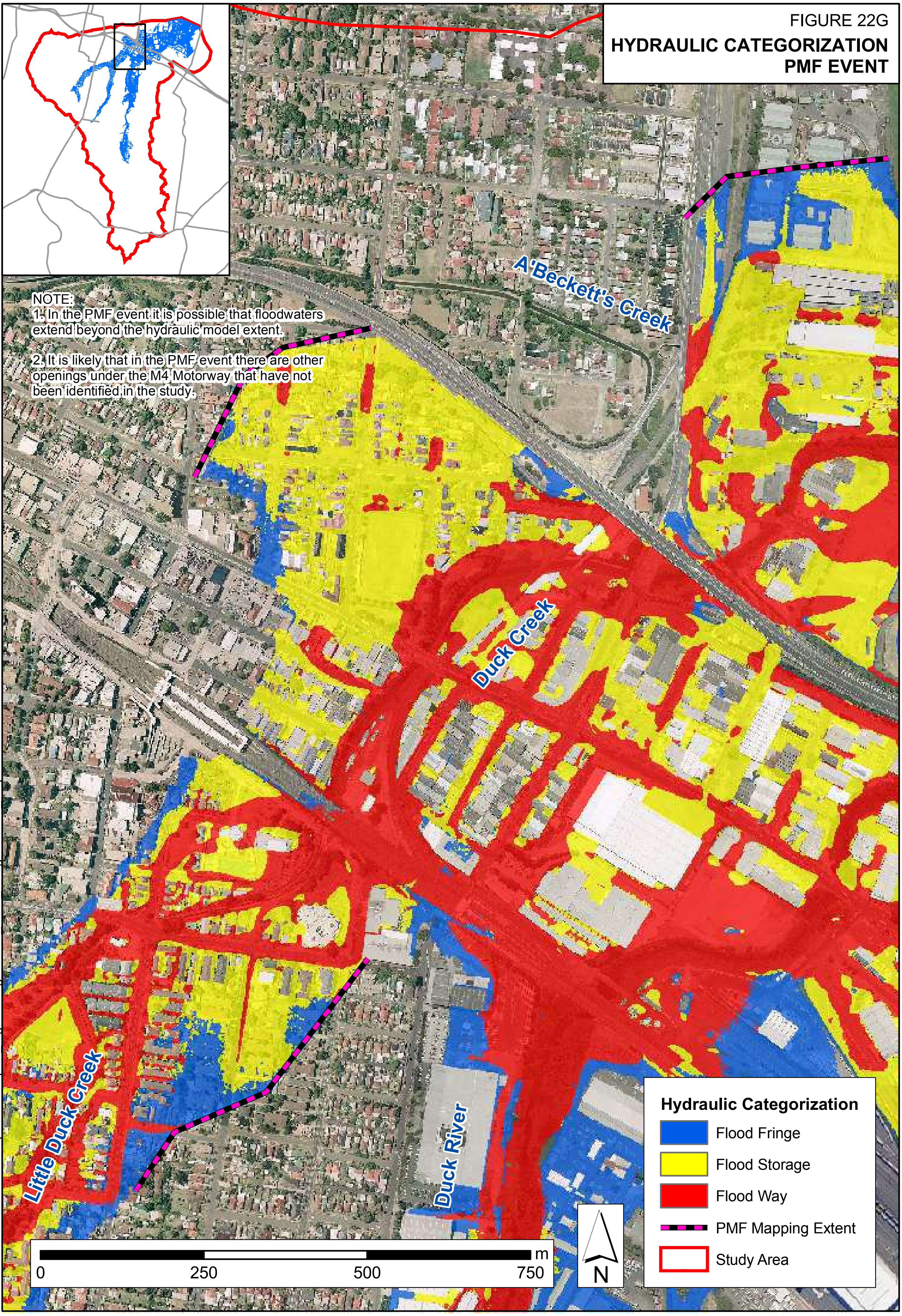

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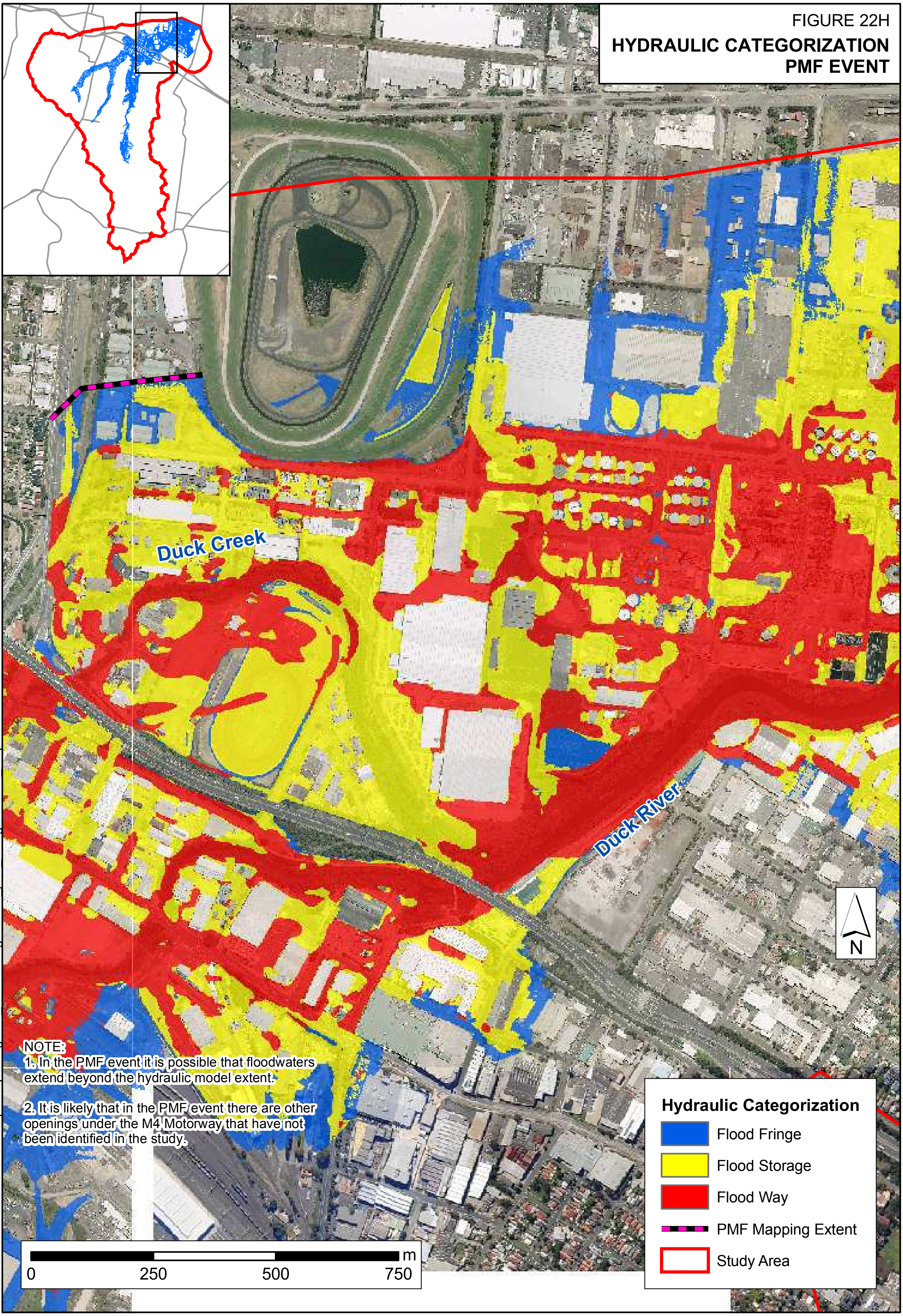
FIGURE 22H

HYDRAULIC CATEGORIZATION PMF EVENT



NOTE:
1. In the PMF event it is possible that floodwaters extend beyond the hydraulic model extent.

2. It is likely that in the PMF event there are other openings under the M4 Motorway that have not been identified in the study.

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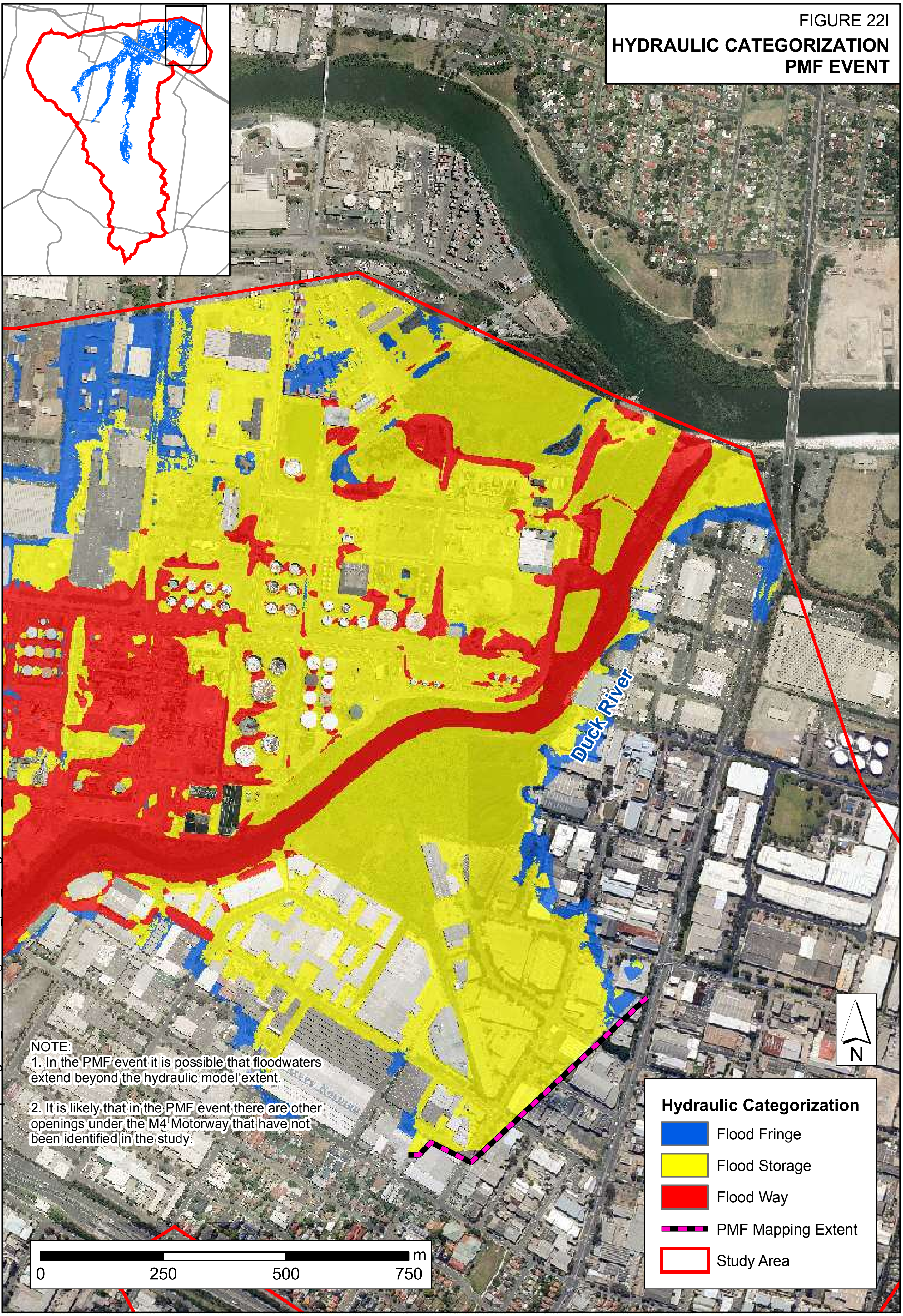

FIGURE 22I
HYDRAULIC CATEGORIZATION PMF EVENT

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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)	FPLs are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the standard flood event in the 1986 manual.
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	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.