DARLING HARBOUR CATCHMENT FLOODPLAIN RISK MANAGEMENT STUDY

FINAL REPORT

SEPTEMBER 2016

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FOREWORD

The NSW State Government's Flood Prone Land 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 Flood Prone Land Policy, the management of flood liable land remains the responsibility of local government. The NSW Government, administered through the Office of Environment and Heritage (OEH), provides financial assistance and specialist technical advice to assist councils in the discharge of their floodplain management responsibilities. The Australian Government may also provide financial assistance in some circumstances.

The Flood Prone Land Policy provides for specialist technical and financial support to Councils by the NSW Government through the stages set out in the "Floodplain Development Manual – the management of flood liable land, NSW Government, 2005". This Manual is provided to assist Councils to meet their obligations and responsibilities in managing flood liable land. These stages are:

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 Darling Harbour Catchment Floodplain Risk Management Study and Plan constitute the second and third stages of this management process. This study has been prepared by WMAwater for the City of Sydney (Council) under the guidance of Council's floodplain management committee (Committee). This study provides the basis for the future management of those parts of the catchments which are flood liable.

EXECUTIVE SUMMARY

This Floodplain Risk Management Study assesses floodplain management issues in the Darling Harbour catchment, and investigates potential management options for the area. The study, which follows on from the Darling Harbour Catchment Flood Study (Reference 2), has been undertaken in accordance with the NSW Government's Flood Policy. A full assessment of the existing flood risk in the catchment has been carried out, including flood hazard across the catchment, overfloor flooding of residential, commercial and industrial properties, road flooding and emergency response during a flood event. A range of measures aimed at managing this flood risk were also assessed for their efficacy across a range of criteria, which allowed certain measures to be recommended, forming the basis of the Floodplain Risk Management Plan for the area. Assessed measures included upgraded pit and pipe networks, detention basins, emergency management measures and various property modification measures.

Background

The Darling Harbour catchment is located in Sydney's inner city suburbs of Haymarket, Surry Hills and parts of Pyrmont, Ultimo and Sydney, and has an area of 307 hectares. The area has been extensively developed for urban usage. Land use is predominantly high-density commercial and residential developments. The catchment experiences overland flooding, with some tidal influence in the vicinity of Darling Harbour.

The Darling Harbour Catchment Flood Study (2014) was carried out to define existing flood behaviour for the Darling Harbour catchment in terms of flood levels, depth, velocities, flows, hydraulic categories and provisional hazard. A 1D/2D TUFLOW hydraulic model was established and verified by a calibration/verification process. Following this, the model was used to define flood liability for the range of design flood events. Several flooding hotspots were also identified in the study. In addition, a floor level survey and damages assessment were undertaken to identify properties that are liable to over floor inundation.

Existing Flood Environment

A number of locations within the catchment are flood liable. This flood liability mainly relates to the nature of the topography within the study area as well as the capacity of service provided by drainage assets. Urbanisation throughout the catchment occurred prior to the installation of road drainage systems in the 19th century and many buildings have been constructed on overland flow paths or in unrelieved sags. Due to these drainage restrictions, topographic depressions can cause localised flooding as excess flows have no opportunity to escape via overland flow paths. Sub-surface drainage is not able to route flow from these ground depressions unrelieved by overland flow paths, as the majority of the drainage network reaches capacity during small events (i.e. 0.5 EY).

193 properties within the catchment are liable to over floor inundation in the 1% AEP event, while 86 properties are liable in the 0.2 EY event. A flood damages assessment for existing development was undertaken, with the average annual damage estimated to be approximately $3.7 million for the catchment.

Flooding hotspots in the catchment were identified at the following locations: Commonwealth Street near Ann Street, Pyrmont Street near Jones Bay Road, Elizabeth Street near Belmore park, Hay Street from Elizabeth Street to Haymarket and Darling Harbour near Tumbalong Park, Chinese Gardens and King Street Wharf. The study identified that effective warning time is zero and that evacuation in place is therefore the default response to extreme floods.

Flood Risk Management Measures

A range of floodplain risk management measures were investigated as part of the study. Fourteen measures were considered in detail, as shown in the below table, which ranks them according to the results of the multi-criteria assessment. The assessment of management options involved gathering feedback from the community on the measures, who were informed about the study and the various measures via a brochure and questionnaire, as well as an information session. Measures were also considered in the context of relevant policies and planning controls, including City of Sydney's Interim Floodplain Management Policy.

Rank	Ref	Measure	Score
1	PM-DH02	Property Modification - Development Control Planning	10
2	PM-DH01	Property Modification - Flood Planning Levels	9
3=	PM-DH04	Property Modification - Feasibility Study for City of Sydney Flood Proofing	8
3=	RM-DH01	Response Modification - Flood Warning and Evacuation	8
3=	RM-DH03	Response Modification - Community Awareness Programme	8
6	RM-DH02	Response Modification - Flood Emergency Management	7
7	FM-DH01	Drainage Upgrade – Commonwealth Street	6
8	PM-DH03	Property Modification - Flood Proofing	5
9	FM-DH05	Drainage Upgrade – Elizabeth Street to Outlet	2
10	FM-DH07	Drainage Upgrade – Black Wattle Place	1
11	FM-DH02	Drainage Upgrade – Elizabeth Street	0
12=	FM-DH04	Park Adjustment – Belmore Park	-1
12=	FM-DH06	Drainage Upgrade – Pyrmont Street to Outlet	-1
14	FM-DH03	Road Adjustment – Elizabeth Street	-2

A summary of the measures, including their time-frame, priority and responsibility, is given in the Darling Harbour Floodplain Risk Management Plan. Three of the assessed measures were not recommended in the plan as they were assessed to be unviable.

Draft reports of the City Area Floodplain Risk Management Study and Plan were placed on Public Exhibition from the 8th of March till the 11th of April 2016 in order to present the findings of the study to the public. Several submissions were received in regard to the Study and Plan exhibited, responses to which have been summarised in Table 8.

Council adopted the Floodplain Risk Management Study and Plan on the 15th August 2016.

1. INTRODUCTION

1.1. Study Area

The Darling Harbour catchment is located in Sydney's inner city suburbs of Haymarket, Surry Hills and parts of Pyrmont, Ultimo and Sydney (refer Figure 1: Study Area – Darling Harbour Catchment). This region lies within the City of Sydney Local Government Area (LGA) and has been fully developed for urban and commercial usage which provides little opportunity for water to infiltrate due to the high degree of impervious surfaces. Land use is predominantly high-density housing and commercial development, with some areas of open space including parts of Hyde Park. The catchment also includes the large development sites of the Sydney Entertainment Centre, Sydney Exhibition Centre and University of Technology, Sydney.

The catchment covers an area of approximately 307 hectares which drains into Sydney Harbour at various locations, with the main drainage outlets at Darling Harbour. The drainage network includes covered channels, in-ground pipes, culverts and pits. The majority of the trunk drainage is owned by Sydney Water Corporation (SWC) and City of Sydney.

The topography within Darling Harbour catchment varies from steep surface slopes in excess of 10% in the upper catchment to the near flat lower catchment adjacent to the Sydney Harbour shoreline. Within the catchment there are various excavations and cuttings, resulting in some vertical drops of over 10 m. The catchment therefore has regions where surface water runoff within the road network has high velocity and shallow depths, whilst in the lower catchment surface water is more likely to pond in sag points with lower velocities. The lower reaches of the catchment fringing the Sydney Harbour are potentially affected by elevated water levels within the Harbour.

A number of locations within the catchment are flood liable, and flooding is known to occur in some areas for all rainfall events greater than the 0.5 EY. Urbanisation throughout the catchment occurred prior to the installation of road drainage systems in the 19th century and many buildings have been constructed on overland flow paths or in unrelieved sags. Due to these drainage restrictions, topographic depressions can cause localised flooding as excess flows have no opportunity to escape via overland flow paths where sub-surface systems are running at capacity. This creates a significant drainage/flooding problem in many areas throughout the catchment, with roads and pedestrian areas forming major flow paths, with associated high velocities and flood depths.

1.2. The Floodplain Risk Management Process

As described in the Floodplain Development Manual (Reference 1), the floodplain risk management process is formed of sequential stages:

- Data Collection;
- Flood Study;
- Floodplain Risk Management Study;
- Floodplain Risk Management Plan; and
- Plan Implementation.

The first key stage of the process has been undertaken with the completion of the Darling Harbour Catchment Flood Study (Reference 2). Following this, the Floodplain Risk Management Study and Plan (FRMS&P) are undertaken for the catchment in two phases:

Phase I – Floodplain Risk Management Study in which the floodplain management issues confronting the study areas are assessed, management measures investigated and recommendations made. The objectives for this phase include:

- Review the current Darling Harbour Catchment Flood Study (2014) and update hydraulic model were necessary to ensure it is fit for purpose;
- Engage community and key stakeholders throughout the project;
- Review Council's existing environmental planning policies and instruments, identify modifications required to current policies;
- Identify residential flood planning levels and flood planning area;
- Identify and assess works, measures and restrictions aimed at reducing the impacts and losses caused by flooding and consider their impacts if implemented, taking into account the potential impacts of climate change; and
- Review the local flood plan, examine the present flood warning system, community flood awareness and emergency response measures (involvement with the NSW State Emergency Service).

As well as considering measures appropriate to the catchment as a whole, specific measures were investigated for the hotspots' identified in the Flood Study. These 'hotspots' are:

- Commonwealth Street between Ann Street and Reservoir Street;
- Pyrmont Street between Jones Bay Road and Union Street;
- Elizabeth Street between Reservoir Street and Campbell Street;
- Hay Street between Elizabeth Street and Quay Street; and
- Darling Harbour near Tumbalong Park and Chinese Gardens.

Phase II – Floodplain Risk Management Plan which is developed from the floodplain risk management study and details how flood prone land within the study areas is to be managed moving forward. The primary aim of the Plan is to reduce the flood hazard and risk to people and property in the existing community and to ensure future development is controlled in a manner consistent with the flood hazard and risk at this time and ensuring that such plans are informed to a degree by climate change sensitivity. The Plan consists of prioritised and costed measures for implementation.

2. BACKGROUND

2.1. Darling Harbour Catchment

2.1.1. Land Use

The land use zones as identified in the Sydney LEP 2012 are shown as Figure 2. The majority of the catchment is classed as either *Metropolitan Centre, Mixed Use* or *DH Development Plan*. The remainder of the catchment is a mixture of *Public Recreation, General Residential* and *Infrastructure* as well as a small area classed *Neighbourhood Centre* in the western part of the catchment.

2.1.2. Social Characteristics

Information is available from the 2011 census (http://www.abs.gov.au/) to understand the social characteristics of this study area which includes the suburbs of Haymarket, Surry Hills and parts of Ultimo, Pyrmont and Sydney. Understanding the social characteristics of the area can help in ensuring that the right floodplain risk management practices are adopted. Table 1 below shows some selected characteristics for suburbs in the catchment area.

Table 1: 2011 Census data by location

	NSW	Haymarket	Surry Hills	Ultimo*	Pyrmont*	Sydney*
Population Age: **0 – 14 years** **15 - 64 years** **> 65 years**	 19.2% 66.1% 14.7%	 4.5% 92.3% 3.1%	 5.1% 86.6% 8.3%	 5.8% 89.9% 4.1%	 8.7% 85.1% 6.1%	 4.1% 91.1% 4.8%
Average people per dwelling	2.6	2.6	1.8	2.0	2.1	2.1
Own/mortgage property **Rent property**	66.6% 30.1%	31.5% 63.5%	34.9% 62.0%	29.7% 67.6%	37.3% 60.7%	33.7% 63.4%
Moved into are: **- within last year** **- within last five years**	 - -	 37% 73%	 28% 65%	 38% 73%	 28% 65%	 34% 74%
No cars at dwelling	10.9%	63.6%	47.0%	53.7%	28.0%	59.2%
Speak only English at home	72.5%	15.9%	61.2%	29.0%	53.3%	26.4%
Other languages spoken		Mandarin (17%), Thai (14.4%), Indonesian (9.6%), Cantonese (7.6%), Korean (6.4%)	Cantonese (2.9%), Mandarin (2.3%), Thai (2.2%), Greek (1.4%), French (1.3%)	Mandarin (15.5%), Cantonese (9.4%), Indonesian (2.5%), Thai (2.4%	Mandarin (6.7%), Cantonese (5.2%), Korean (2.8%), Thai (1.8%), Japanese (1.6%)	Mandarin (12.5%), Indonesian (7.9%), Thai (6.9%), Cantonese (6.3%), Korean (5.6%)

* only parts of these suburbs are located within the Darling Harbour catchment however statistics are provided for the entire suburb.

From this data it is apparent that the Darling Harbour comprises a much higher portion of 15 – 64 year olds than the state average. There is a marginally lower average number of people per dwelling compared to the state average. There is also a particularly high proportion of households without access to cars, which should be taken into account when considering evacuation and access routes and flood depths which remain safely traversable.

The high proportion of renters and the large number of languages spoken by residents will need to be considered in any flood awareness/education programmes. Renters are typically more transient than owner-occupiers, and therefore it is likely the turnover of residents within the catchment is high, meaning a more frequent program may be required in order to retain an acceptable level of flood awareness. Furthermore, it is likely that communication material will need to be provided in languages other than English, as a high proportion of residents speak languages other than English at home.

2.1.3. Local Environment

The Darling Harbour catchment is completely urbanised and has no remnant vegetation. Areas of parkland exist at Belmore Park, Darling Harbour and in various small pockets of land, and some streets are lined with mature trees. The limited natural environment means that flooding does not play any role environmentally, and that impact of possible mitigation works on the local environment is minimal.

City of Sydney aspires to protect and expand the LGA's urban forest. This includes a list of protected Significant Trees, of which a number of trees in the catchment are listed. Mitigation measures assessed by this study will consider the value that is placed upon trees in the catchment when there is a potential impact.

Other environmental features of interest in the catchment are;

- Parts of the catchment are classified as general conservation areas with a number of conservation buildings identified;
- There are no currently listed contaminated sites in the catchment; and
- The majority of the Darling Harbour catchment has an Acid Sulphate Soils classification of 5 (works within 500m adjacent of an area classified 1 -4 and likely to reduced groundwater levels by 1m or more are likely to present an environmental risk). Areas of Class 1 (any works undertaken in this area are likely to present an environmental risk) are located around Darling Harbour, and Class 2 in the Barangaroo development site (any works undertaken in this area below ground level or which lower the water table are likely to present an environmental risk).

2.1.4. Drainage System

The original natural drainage system comprised rock gullies draining to small pockets of mangroves along the shoreline. As development proceeded within the catchment, the land use changed to a higher proportion of impervious surfaces leading to increased runoff volumes and peak flows. It followed that the natural drainage lines were incorporated into the constructed drainage system of open channels. By the late 19th century much of the channel system was progressively covered over and piped, with much of the original system forming the backbone of the drainage system in place today. There are no open channels within the study area.

An extensive network of stormwater infrastructure exists in the study area to provide drainage to the Darling Harbour catchment. This infrastructure primarily comprises of a 'pit and pipe' stormwater network and does not include open channels as part of the trunk drainage system. City of Sydney own and manage the smaller upper catchment elements, and SWC the trunk drainage assets.

Pit types within the study area include circular, rectangular and oviform pipes. Circular and rectangular pipes are modern extruded concrete, whereas oviform and clay pipes are very old, built in the late 1800's, with irregular dimensions. Figure 3 shows the location and type of pipe across the study area.

The study area also contains the Hay Street Stormwater Channel which has been listed on the Heritage and Conservation Register as maintained by SWC. The channel is one of the first five original combined sewers constructed in Sydney around the 1860 period. This feature now only conveys stormwater, giving the pipe a relatively higher flow conveyance compared with newer drainage elements.

In rainfall events where flows exceed the minor system (i.e. pit/pipe system) capacity, surface water runoff is generally conveyed as uncontrolled flow via the major drainage system which consists of an unplanned network of roads, laneways and pedestrian areas. When this occurs, there is potential for high hazard flood conditions resulting from flow velocities and depths.

2.1.4.1. Darling Harbour Live Development

The catchment's drainage system is currently undergoing large-scale changes as part of the Darling Harbour Live development. The development is located between the west end of Hay Street and the catchment outlet, and consists of large-scale re-development of part of the Darling Harbour area for commercial and residential use. Recent plans of the ongoing development show significant changes to the sub-surface drainage, including additional feeder pipes on Darling Drive, between Pier Street and the Western Distributor, between Hay Street and Pier Street, and on Hay Street near Harbour Street. New or modified drainage elements have not been included in the current study's 'existing' catchment conditions, as they are still under construction. However, the impact of the proposed drainage has been tested and has been shown to increase drainage flow rates and benefit Darling Harbour's flood affectation. Mitigation options tested as part of the current study have also been assessed with consideration of the proposed changes.

2.1.5. Historical Floods

Major historical storm events are known to have occurred on June 1949, November 1961, March 1973, November 1984, January 1991 and February 2001, although Council indicates that flooding can occur at various locations across the catchment in events starting from the 0.5 EY. The 2014 Flood Study analysed rainfall records from the Observatory Hill gauge for these events and estimated the design frequency of these events, as shown in Table 2.

A more recent event occurred on 24 August 2015, with heavy rainfall over a short duration (approx. 10 min) resulting in flooding in the neighbouring catchment on Pitt Street Mall, King Street between Pitt and George Streets, and at Circular Quay. There is anecdotal evidence of flooding in parts of the Darling Harbour catchment. Rainfall data indicates that for a 10 minute duration, the intensity was between a 0.2 EY and 10% AEP event.

Table 2: Historical Flood Events

Event	Equivalent Design Frequency
15 June 1949	~ 0.2 EY
18 – 19 November 1961	~5% AEP
March 1973	Gauge failed
9 November 1984	> 0.2% AEP
27 January 1991	~2% AEP
February 2001	Gauge failed
24 August 2015	~10% AEP

2.2. Previous Studies

A limited number of previous studies have been undertaken for the Darling Harbour catchment as summarised below.

2.2.1. Darling Harbour Flood Study, BMT-WBM, October 2014 (Reference 2)

This flood study was carried out as part of the Floodplain Risk Management Programme to define existing flood behaviour in the Darling Harbour catchment through the establishment of appropriate numerical models. The study produced information on flood flows, velocities, levels and extents for a range of flood event magnitudes under existing catchment conditions.

Community consultation was undertaken as part of the study which aimed to inform the community about the study and its likely outcome as a precursor to floodplain management activities.

The hydrologic and hydraulic modelling was combined in a TUFLOW 1D/2D model, using the “direct rainfall” approach. The entire Darling Harbour catchment was modelled in the 2D domain, with approximately 26km of sub-surface pipe network modelled as 1D elements dynamically linked to the 2D domain.

Two historical flood events (8 November 1984 and 26 January 1991) were used for model calibration and verification, and the 8 March 2012 for a general verification of flood behaviour. The model was found to provide a good representation of the observed flood behaviour.

The study defined flood behaviour of the 0.5 EY, 0.2 EY, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.2% AEP and PMF design events, including peak flood levels, depths and velocities. The study also undertook sensitivity testing and considered the impact of future climate change on design events.

The study identified the following ‘hotspots’:

- Commonwealth Street between Ann Street and Reservoir Street;
- Pyrmont Street between Jones Bay Road and Union Street;
- Elizabeth Street between Reservoir Street and Campbell Street;
- Hay Street between Elizabeth Street and Quay Street; and
- Darling Harbour near Tumbalong Park and Chinese Gardens.

2.2.2. City Area SWC30 Capacity Assessment, Sydney Water, 1996 (Reference 3)

This report assessed the quantitative performance of stormwater drainage elements within SWC’s City Area SWC30 which covers a greater area than the current study. Details of pipe capacity as well as dimensions and hydraulic parameterisation are extensively detailed within this report.

The performance was assessed by firstly analysing the capacity of various elements of the drainage system. This was determined by defining the storm event which results in a peak flow equal to that of the hydraulic capacity of the drainage element. The catchment was then zoned into one of four categories based on land use – low density residential, business/commercial, highways/freeways and CBD. Each category corresponds with a design standard (in terms of pipe capacity) typically adopted in the past for that particular land use. For example, low density residential corresponds with a 0.2 EY event. The drainage system capacity was then compared to the design standard and results are provided in terms of percentage of the drainage length situated in each of the four categories that is able to satisfactorily handle the range of design events.

The results found that whilst business areas where generally better serviced than residential areas, the overall catchment had a relatively poor performance.

2.3. Flood Study Model Review

WMAwater have carried out a review of the Darling Harbour model established as part of the 2014 Flood Study (Reference 2). This was carried out with the aim of establishing that the model developed was suitable for carrying out FRMS&P work. The review consisted of checking the model system and approach, the schematisation of the catchment, including model parameters and the base data, as well as the model results.

The review found that the model was generally of a high standard and produced design flood results for the 1% AEP event in line with best practice. No issues relating to the model stability were identified and the peak flow rates were found to be reasonable based the catchment size and type. The representation of the roads' crown and kerb lines was assessed. Table 3 summarises the findings of the review.

Table 3: Model Review Summary

Model Component	Comment
Model System and Approach	A 2D hydraulic model (TUFLOW) was used with the Direct Rainfall Method in place of a traditional hydrologic model. The model approach is similar to that used in other City of Sydney catchments.
Base Data	The model topography is based on 2007 LiDAR data. Comparison to ground survey and another LiDAR dataset show the data used to be generally accurate.
Model Schematisation	Schematisation of the catchment is sound. It was noted that kerb and crown lines were not 'stamped' into the model grid, but this would only effect representation of minor floods.
Model Parameters	Mannings 'n' values in the model fall within standard ranges. It was noted that conservative pit blockage has been used (pits in sags are 100% blocked) and that a reduced blockage will be used in testing mitigation options.
Model Results	Model results showed no indication of numerical instability. Due to the lack of calibration data, unit flow rates were assessed as an indication of model accuracy. Unit flow rates were satisfactory based on the catchment location and its high imperviousness.

2.4. Flood Study Model Updates

Updates to the previously established model were made where new data was available and where the model review identified areas of improvement. Overall, the model updates that were made are considered to be small refinements, and there were no major revisions. The following updates were made:

1. The tunnel entrance on Harbour Street was updated to the schematisation of the other tunnels (i.e., runoff was allowed to enter it).
2. Revision to the pit/pipe data based on recent survey from SWC. Survey data was provided that had revised dimensions and alignments of some pits and pipes. Changes were minimal and there were no widespread effects on design flood behaviour.

3. EXISTING FLOOD ENVIRONMENT

3.1. Overview of Flood Behaviour

The topography within the Darling Harbour catchment varies from steep surface slopes in excess of 10% in the upper catchment to the near flat lower catchment adjacent to the Sydney Harbour shoreline. The catchment therefore has regions where surface water runoff within the road network has high velocity with shallow depths, whilst in the lower catchment surface water is more likely to pond in sag points with typically lower flow velocities. The lower reaches of the catchment fringing Sydney Harbour are potentially affected by elevated water levels within the Harbour.

The entire catchment is highly developed with little opportunity for water to infiltrate due to the high degree of impervious surfaces. Most residential properties are brick or sandstone construction with common walls to neighbours. There are very few opportunities to flow to pass through or between properties and as a result the roads form the primary overland flow paths (major drainage system) and the areas of highest risk in a flood. Ground floors of some buildings are flood affected; however, flow velocities will be much lower than on the roads and evacuation to a higher level is usually possible.

The catchment is serviced by entirely by a piped network system and there are no open channels within the area. In rainfall events where flow exceed the piped system capacity, surface water runoff is generally conveyed within the road system as uncontrolled flow. When this occurs, there is potential for high hazard flood conditions resulting from combined high flow velocities and depths.

The catchment is divided into two distinct areas by the Western Distributor. Flows underneath the Western Distributor arrive from the Surry Hills area to the south-east. North of the Western-Distributor, flood waters have very small catchment areas and flow quickly to Cockle Bay/Sydney Harbour by the shortest distance. High in the catchment, upstream of the Western Distributor (in south-east Surry Hills), steep streets quickly convey flows downstream to the Darling Harbour area. Downstream of Elizabeth Street and the railway line, the catchment slope starts to reduce. Sub-surface conduits become very important in relieving flood waters. North of the Western Distributor, flooding is from localised catchments with small upstream areas. These catchments may drain to trapped low points such as Pyrmont Road where piped infrastructure is critical in relieving flooding.

The catchment's small size results in a small degree of 'scaling' between small and large flood events. That is, the depth of inundation across the catchment is similar in flood events of different frequency, e.g., the 10% and 1% AEP event. For example, at Mary Street near Foveaux Street, there is around 0.2 m of depth in a 10% AEP and 0.3 m in the 1% AEP. There is slightly more scaling in the downstream areas of the catchment, for example the 1% AEP depth is 0.2 m higher than the 10% AEP on Hay Street. The small scaling results in affectation being quite similar across the range of design flood events (excluding very rare events).

The capacity of the existing stormwater network is exceeded in most flood events, with around half of the area's drainage full in a 0.5 EY event, and around 80% full in a 10% AEP event. It should be noted that the network's function is largely determined by the degree of blockage in a particular event, with regards to both the pits (particularly in topographic sags) and pipes. Table 4 lists the peak flow in various stormwater pipes for the 0.2 EY and 1% AEP design events, as well as an estimate of the pipe's approximate capacity. The locations are shown in Figure 3. As shown in the table, upper sections of the main trunk line have quite large capacity (approximately 1% AEP), despite most of the catchment's drainage being full in a frequent event.

Table 4: Pipe Peak Flow and Approximate Capacity

Stormwater Drain Location	Peak flows (m^3/s)- 0.2 EY	Peak flow (m^3/s) - 1%AEP	Approx. Capacity
1. Reservoir Street upstream of Elizabeth Street	2.8	5.3	1% AEP
2. Elizabeth Street near Belmore Park	3.5	6.0	10% AEP
3. Hay Street near Belmore Park	15.9	21.3	1% AEP
4. Hay Street at George Street	18.8	24.5	< 0.2 EY
5. Darling Harbour near Tumbalong Park (6 parallel pipes)	35.4	45.6	< 0.2 EY
6. Pyrmont Street near Jones Bay Road	1.6	2.7	< 0.2 EY

3.2. Hydraulic Categories

The 2005 NSW Government's Floodplain Development Manual (Reference 6) defines three hydraulic categories which can be applied to different areas of the floodplain; namely floodway, flood storage or flood fringe. Floodway describes areas of significant discharge during floods, which, if partially blocked, would cause a significant redistribution of flood flow. Flood storage areas are used for temporary storage of floodwaters during a flood, while flood fringe is all other flood prone land.

There is no single definition of these three categories or a prescribed method to allocate the flood prone land into them. Rather, their categorisation is based on knowledge of the study area, hydraulic modelling and previous experiences. Based on analysis of similar catchments, as well as literature review (Reference 6), the Flood Study (Reference 2) hydraulic categories have been defined as:

Floodway:		Velocity x Depth > 0.25 m^2/s AND Velocity >0.25 m/s
	OR	Velocity > 1 m/s
Flood Storage:		Land outside the floodway where Depth > 0.2m
Flood Fringe		Land outside the floodway where Depth < 0.2m

The hydraulic categories for the 5% AEP, 1% AEP and PMF events are shown on Figure 6 to Figure 8. In the 5% AEP event there is a well-defined floodway along the length of Hay Street, while flood storage areas exist around the downstream end of Hay Street and in various isolated areas in Pyrmont. In the 1% AEP event these features are more pronounced, with more prominent floodways in Ann Street and Reservoir Street in Surry Hills, and through parts of Darling Harbour.

In the PMF event, floodways exist in the same areas, as well as on George Street, Eddy Avenue and through most of Darling Harbour.

3.3. Flood Hazard Classification

Flood hazard is a measure of the overall adverse effects of flooding and the risks they pose. The 2005 NSW Government's Floodplain Development Manual (Reference 1) describes two *provisional flood hazard* categories; High and Low, based on the product of the depth and velocity of floodwaters. These hazard categories do not consider other factors which may influence the flood hazard (Figure L2 of the Floodplain Development Manual); hence they are provisional estimates only with "true" hazard to be defined through the process of the current study. The boundary of the provisional High and Low hazard classification will change according to the magnitude of the flood in question.

Provisional hazard was established as part of the Flood Study (Reference 2) based on the Floodplain Development Manual criteria (Appendix L of the Floodplain Development Manual). Due to the combination of high flood depths and velocities, many regions of the catchment are affected by high hazard flows. Figure 9 to Figure 16 show the flow hazard classification throughout the catchment for the 0.5 EY, 0.2 EY, 10%, 5%, 2%, 1%, 0.2% AEP and PMF events. As shown in the figures, high hazard inundation is concentrated on Hay Street, with small localised areas in trapped depressions and gutters. As with inundation in general, high hazard occurs almost exclusively on roadways, with no flowpaths passing through buildings. Vehicles and pedestrians are therefore most vulnerable to the hazardous flow, and not buildings and structures.

To assess the true flood hazard, all adverse effects of flooding have to be considered. This includes the provisional (hydraulic) hazard, threat to life, danger and difficulty in evacuating people and possessions and the potential for damage, social disruption and loss of production. These factors are considered under a qualitative assessment, as described in Table 5.

Table 5: Hazard Classification

Criteria	Weight [1]	Comment
Size of the Flood	Medium	Relatively low flood hazard is associated with more frequent minor floods while the less frequent major floods are more likely to present a high hazard situation.
Depth & Velocity of Floodwaters	High	The provisional hazard is the product of depths and velocity of flood waters. These can be influenced by the magnitude of the flood event.
Rate of Rise of Floodwaters	High	Rate of rise of floodwaters is relative to catchment size, soil type, slope and land use cover. It is also influenced by the spatial and temporal pattern of rainfall during events.
Duration of Flooding	Low	The greater the duration of flooding the more disruption to the community and potential flood damages. Permanent inundation due to sea level rise is of indefinite duration.
Flood Awareness and Readiness of the Community	High	General community awareness tends to reduce as the time between flood events lengthens and people become less prepared for the next flood event. Even a flood aware community is unlikely to be wise to the impacts of a larger, less frequent, event.
Effective Warning & Evacuation Time	Medium	This is dependent on rate at which waters rise, an effective flood warning system and the awareness and readiness of the community to act.
Effective Flood Access	Medium	Access is affected by the depths and velocities of flood waters, the distance to higher ground, the number of people using and the capacity of evacuation routes and good communication.
Evacuation Problems	Medium	The number of people to be evacuated and limited resources of the SES and other rescue services can make evacuation difficult. Mobility of people, such as the elderly, children or disabled, who are less likely to be able to move through floodwaters and ongoing bad weather conditions is a consideration.
Provision of Services	Low	In a large flood it is likely that services will be cut (sewer and possibly others). There is also the likelihood that the storm may affect power and telephones. Permanent inundation from sea level rise may lead to permanent loss of services.
Additional Concerns	Low	Floating debris, vehicles or other items can increase hazard. Sewerage overflows can occur when river levels are high preventing effective discharge of the sewerage system.

[1] Relative weighting in assessing the hazard for the Darling Harbour catchment

Larger flood events in the catchment are associated with increased depths and velocities; however, this is largely accounted for by the provisional hazard criteria being considered over a range of events. Furthermore, the nature of flooding in the catchment results in only small increases in flood levels between design events.

Floodwaters have hazardous depth and velocity in frequent flood events, with overland flow passing down several roads in the catchment. The main risk associated with the flowpaths is that pedestrians or vehicles will attempt to cross a flowpath (for example, when crossing Hay Street) and will be de-stabilised. Pedestrians can injure themselves when falling over, and cars can lose power and become stranded, or lose traction and be carried downstream. The areas of risk are well-described by the maps of hydraulic hazard, which show areas of high hazard in each event.

The concept of rate of rise of flood waters is more applicable to mainstream flooding scenarios, where a fast rate of rise can leave residents unaware of the flood event, and they can become stranded. However, the rate of rise in this catchment is very fast (up to 1-2 m/hour in the 5% AEP and 2-2.5 m/hour in the 1% AEP – both 90 minute storm duration) and flood prone areas will become inundated soon after the rainfall event begins.

Flood awareness in the community appears to be low, with 40% of questionnaire respondents aware of flooding in the catchment (Reference 2). As described in the flood study, the area's residential population is largely transient, with only 25% of residents living in the same address 5 years prior when surveyed for the 2011 census. Experience in similar urban catchments indicates residents, people who work in the area and in this case tourists are all generally sceptical of the possibility of large floods and therefore may not ascribe the appropriate level of risk to floodwaters when they are encountered. This is especially true in this area where there is no resemblance to a natural catchment, that is, it is completely urbanised.

Effective warning and evacuation time in the catchment is very low, as the flooding is likely to be sudden, with a fast rate of rise. For a person in the area without additional warning or forecast, flood events will initially resemble more benign (but still heavy) storms, with awareness of the flood coming from direct experience of it. However, effective access, which refers to an exit route that remains trafficable for sufficient time to evacuate people and possessions, is likely to be available to the majority of affected residents, as the flood extents are not wide. The areas where access is an issue are those areas identified as having high hydraulic hazard, shown on Figure 14 for the 1% AEP event. The vehicular and pedestrian access routes are all along sealed roads and present no unexpected hazards if the roads have been adequately maintained.

At depths of 0.3 m wading should be possible for most mobile adults, but could be problematic for children, elderly or disabled people. The majority of flood prone properties in the catchment do have access with flood depths of 0.3 m or less. Areas that do have depths of 0.3 m or more in the 1% AEP include:

- Commonwealth Street near Reservoir Street;
- Parts of Elizabeth Street near Hay Street;
- Hay Street between Belmore Park and Darling Drive;
- Large parts of Darling Harbour between Hay Street and the waterfront;
- Sections of Darling Drive;
- Pyrmont Street near Jones Bay Road; and
- Harris Street near Allen Street.

At depths of 0.3 m, larger vehicles can easily travel through water at this depth and aid evacuation. Nevertheless, for areas within the catchment without effective flood access, evacuation is generally not recommended considering the short duration of flooding experienced as residents are more likely to put themselves in harm's way by evacuating.

The impact of debris is unlikely to be a significant factor due to the low flood depths and/or velocities for large parts of the catchment. It would impact the time of inundation as waters would take longer to recede, however as the duration of the flooding is generally short across the catchment this is not considered significant. Figure 17 shows the length of inundation taken at each of the drainage pit inlets in the 1% AEP, 1.5 hour event. This shows that the duration of flooding is typically less than 1 hour except in the low points of Darling Harbour, on Commonwealth

Street and near the west end of Hay Street, where it may take up to four hours to drain, assuming the piped network is operating efficiently (i.e. without blockages).

3.4. Hotspots

The flood study identified a number of potential flooding problem areas, where flooding is likely to present a significant issue to businesses, residents, pedestrians and/or vehicles. These were reviewed as part of the current study, and used to form a set of flooding hotspots. These areas are shown in Figure 4 and discussed in Table 6. Further to the list of hotspots, flooding exists at various locations in the catchment, but is minor relative to the hotspot flooding. These locations are summarised in Table 7.

Table 6: Hotspots - Darling Harbour Catchment

Location	Description	Flood characteristics	Provisional Hazard (from Flood Study)
Commonwealth Street, near Ann and Reservoir Streets	Trapped low point which is sensitive to pit blockage. Capacity is first exceeded in the 10% AEP event. Mixture of commercial and residential properties. Terrace style.	Peak depths exceed 1.0m in the 1% AEP event and 1.6m in the PMF.	5% AEP: High in sag, other areas Low / Medium 1% AEP: High in sag, other areas Medium
Pyrmont Street, near Jones Bay Road and Union Street	Trapped low point which is sensitive to pit blockage. Capacity is first exceeded in the 10% AEP event	Peak depths exceed 1.1 m in the 1% AEP event, and more than 4.3 m in the PMF.	5% AEP: Medium in sag, other areas Low 1% AEP: High in sag, other areas Low / Medium
Elizabeth Street	The railway line along Elizabeth Street only allows flood water to pass through to the lower catchment at the under bridge crossings at Eddy Ave, Hay Street and to a lesser extent Campbell Street.	In the 1% AEP event a peak flood depth of 0.5m occurs on Elizabeth Street upstream of Hay St and Campbell St, and 0.2m upstream of Eddy Ave. Depths of exceed 1.3 m upstream of Hay St in the PMF event.	5% AEP: Low 1% AEP: Low
Hay Street, from Elizabeth Street to Haymarket	This reach has a provisional high hydraulic hazard for the 1% AEP event and presents a significant potential risk to pedestrians, motorists and property	Peak depths of more than 1.0 m and velocity of almost 3 m/s in the 1% AEP event. Depths reach 2.5 m in sag points in the PMF.	5% AEP: High in sag points, other areas predominantly Low 1% AEP: Predominantly High, some areas Low / Medium
Darling Harbour, near Tumbalong Park, Chinese Gardens and King Street Wharf.	This area is sensitive to sea level rise. It is a highly pedestrianised area with many restaurants and tourist attractions. At the Haymarket Tram Station, the concentrated flow path along Hay Street spreads out and reduces in velocity.	Near Tumbalong Park flooding first occurs in the 5% AEP event with depths greater than 0.3 m and velocities greater than 0.8 m/s. In the PMF depths can exceed 1.8 m. Around King Street Wharf, velocities are generally lower, between 0.1 – 0.3 m/s but depths exceed 1 m in the 1% AEP event. Ponding also occurs around a substation located at Black Wattle Place.	5% AEP: Low 1% AEP: Predominantly Low, some areas Medium

Table 7: Other Flooding Locations

Location	Description	Flood characteristics	Provisional Hazard (from Flood Study)
Chalmers Lane, near Rutland Street and Devonshire Street	Trapped low point which is sensitive to pit blockage. The area is a back lane and has some garage entries and back doors to property. Not a pedestrian or vehicle thoroughfare.	Over 0.5 m depth in the 1% AEP flood.	1% AEP: Low
Ultimo Road, between Harris Street and Darling Drive	Slight topographic sag beneath rail line has high depth of flow in large floods. No property affectation but moderate pedestrian and vehicle traffic.	Over 0.7 m depth at some points below rail line, remaining around 0.5 m or less.	1% AEP: Mix of high and low hazard
Mary Ann Street	Overland flow blocked by rail line, causes ponding at the east end of the street. Minimal use by cars or pedestrians, and minimal property affectation.	Around 0.4 m depth in the 1% AEP at the east end of the street.	1% AEP: Low
Harris Street, near Fig Street and Allen Street	Slight topographic sag in block of Harris Street, causes ponding. Moderate pedestrian and vehicle traffic through the area, minimal property affectation as floor levels raised.	Over 0.5 m depth in the 1% AEP flood.	1% AEP: Low
Sussex Street, north of Druitt Street	Slight topographic sag in block north of Druitt Street causes ponding. Moderate pedestrian and vehicle traffic through the area, minimal property affectation and one underground car park potentially flooded.	Over 0.7 m depth at some points, remaining around 0.5 m or less.	1% AEP: Mostly low, one high hazard section

4. STAKEHOLDER CONSULTATION

4.1. Community Consultation

One of the central objectives of the FRMS process is to actively liaise with the community throughout the process, keep them informed about the current study, identify community concerns and gather information from the community on potential management options for the floodplain. The consultation programme consisted of:

- Distribution of brochure and questionnaire survey;
- Information Sessions; and
- Public Exhibition.

4.1.1. Previous Consultation

As part of the Flood Study (Reference 2), an extensive community questionnaire survey was undertaken during May 2013 to gather historical data for model calibration. 21,250 surveys were distributed to residents and businesses across both the City Area and Darling Harbour catchments. 244 responses were received, which equates to a return rate of 1.1%, of which 186 were received from the Darling Harbour catchment. The most significant events reported through the consultation were 12 February 2010 (approximately 10% AEP event), 8 March 2012 (approximately 0.5 EY event) and 3 April 2013 (approximately 1 EY event).

4.1.2. Consultation as Part of This Study

Further community questionnaire survey was undertaken as part of this study to inform residents of the next stage of the floodplain management process as well as to gather flood information and community's preferred options of managing flood risks within the catchment. With assistance from Council, 2,487 copies of the newsletters and questionnaires were printed and delivered to the owners of properties located within the PMF extents as identified in the 2014 Flood Study (Reference 2). Results are shown in Figure 18, while Appendix B contains the newsletter and questionnaire mail-out.

The results show that respondents to date have little experience of flooding and the majority are in residential lots. Of the respondents, thirteen have experienced flooding, with seven of those having floodwaters inside their house/business, four observing road flooding and two observing it in the neighbourhood. There was not a clear trend in what respondents' least preferred management option is, but 'Education of the community' and 'Improved Flood Flow Paths' were the least preferred. Around a third of residents preferred pit and pipe upgrades (the most favoured type) and 'Flood forecasting, Warnings, Evacuation Planning' was also preferred.

4.1.3. Community Information Session

A community information session was held on Sunday the 13th of March 2016 at Fig Lane Reserve, Fig St, Pyrmont and a workshop held at Ward Park, Surry Hills on the 25th of October 2015. WMAwater and City of Sydney Staff manned a booth and discussed flooding issues with several interested community members.

4.2. Floodplain Committee Meetings

The Floodplain Management Committee (FMC) oversees and assists with the floodplain risk management process being carried out within the Council LGA. The committee is comprised of representatives from various stakeholders, including local Councillors, OEH, emergency services, SWC and community representatives.

4.3. Public Exhibition

Draft reports of the City Area Floodplain Risk Management Study and Plan were placed on Public Exhibition from the 8th of March till the 11th of April 2016 in order to present the findings of the study to the public. The exhibition period was advertised via a letter sent to property owners within the catchment, public notice in the local newspapers and online versions of the reports were made publicly available on the City of Sydney website.

Several submissions were received in regard to the Study and Plan exhibited, responses to which have been summarised in Table 8. Please note that the submissions for the Darling Harbour FRMS&P have also been addressed here as there was some overlap between respondents.

Table 8 Public Exhibition Submissions and Responses

ID	Query	Response	Report Reference
A01	Study and plan provides minimal consideration to the downstream effects of flooding	The Study and Plan have been completed in accordance with the NSW Floodplain Development Manual, 2005. The primary objective of the plan is to "Reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods, utilising ecologically positive methods wherever possible." The impact of proposed floodplain risk management options on the harbour water quality or bay morphology is considered as part of the multi-criteria assessment of options (which forms the ranking of preferred options). The FRMS&P is a high level assessment of flood risk, options to address existing water quality or bay morphology issues are outside the scope of this work. However the City has identified water as a key issue, and set targets in *Sustainable Sydney 2030* which are to deliver 10% of water supply by local water capture and reduce stormwater pollutants by 50%. Furthermore, the City has developed the Decentralised Water Masterplan which, amongst other goals, aims to *"Reduce sediments and suspended solids by 50% and nutrients by 15% discharged into the waterways from stormwater run-off generated across the City of Sydney LGA by 2030".* The City's work to improve water quality is on-going and concurrent to the Floodplain Risk Management Study and Plan process. Where opportunities arise the city is committed to incorporating water quality improvement measures into the implementation of Floodplain Risk Management works.	No amendments to the report.
A02	Encourage the city to examine the pollution of the harbour from drainage and identify all available measures that would assist in minimising the entry of debris into the drainage system and its discharge into the harbour	As above.	No amendments to the report.
B01	Draft FRMP not provided a complete and thorough economic evaluation of the costs of flooding therefore the scoring system used to rank options may not be robust.	The Damages Assessment has been carried out as per best practice under the NSW FRMP and current information available and is considered fit for purpose. Its purpose is to provide a basis for the comparison of various mitigation options to determine their ranking.	No amendments to the report.
B02	No clear plan on how the flood proofing option (PM-CA03) may be implemented and if Council has any intention in contributing to the funding.	Specific details pertaining to the implementation of ALL proposed options will require further investigation and assessment following adoption of the Floodplain Risk Management Plan by Council. Such a level of detail as would be required to implement any options is outside the scope of the FRMP.	No amendments to the report.
B03	Option FM-CA09 "Carry out a catchment specific flood damages assessment for the Sydney CBD" has been incorrectly labelled.	While not a flood modification measure itself, this option pertains directly to the proposed flood modification measures and has therefore been labelled as such.	No amendments to the report, defined in Section 9.3.9.
B04	More frequent design storms have not been adequately considered in terms of direct and secondary costs.	The focus of work carried out under the NSW FRMP is the 1% AEP event and larger, however more frequent events certainly have been modelled and included in assessment of Average Annual Damages numbers. Modelled events included the 1yr, 2yr, 5yr, 10yr, 20yr, 50yr, 100yr, 500yr ARI events and the PMF.	No amendments to the report.
B05	Physical flood protection measures should not be allocated low priority scored on the basis of insufficient economic data.	As noted above the damages assessment has been carried out as per best practice under the NSW FRMP. We believe this gives an adequate representation of flooding costs and hence the economic viability of works for the purpose of comparison with other proposed flood mitigation works, both within this catchment and others across New South Wales. Furthermore, as per option FM-CA09, the City is committed to investigating the economic damages further to verify the current assessment. This option also incorporates a reassessment of the reduction in damages and reconsideration of prioritisation of the mitigation options based on the new information.	No amendments to the report.
B06	Recommend the document is not finalised until an adequate (if not complete) understanding of all tangible and intangible costs and benefits are understood.	As noted above the Study and Plan have been completed in accordance with the NSW Floodplain Development Manual 2005 to meet the City's obligations under section 733 of the Local Government Act 1993. Also, as described above, the understanding of the costs is considered adequate as it has been based on the best available information and in line with best practice under the FRMP. As Floodplain Risk Management is an ongoing process there is no justification for delaying finalisation of the Plan, as it will be revised and updated as new information becomes available.	No amendments to the report.
B07	Recommend the gap analysis reviewed and draft policy is supplemented as needed for further comment	Confirm the gap analysis provided has been reviewed.	No amendments to the report.

ID	Query	Response	Report Reference
513261	Strong support for response measures, moderate support for capital works.	No response required	No amendments to the report.
518553	The Floodplain Risk Management Study and Plan are generally a misallocation of City funds. The result of the Rushcutters Bay FMRP has not resolved long term flooding on Craigend St near the corner of Neild Avenue, which I believe could be solved with drains from the bridge to allow drainage into the stormwater channel rather than a plan costing hundreds of thousands of dollars. In Nield Avenue, what was essentially a dam wall was built around the Weigall Sports Hall, causing issues that could be remedied with better drainage through the retaining wall and deeper Indonesian-style stormwater drains.	Study and Plan are required to be completed in accordance with the NSW Floodplain Development Manual 2005 to meet the City's obligations under section 733 of the Local Government Act 1993. The submission's comments refer to Rushcutters Bay, however this Study and Plan examines other catchments within the City of Sydney's LGA. Specific points raised in regard to Neild Avenue and Craigend St are not addressed here but the reader is referred to the work done in the Rushcutters Bay FRMS&P. The Floodplain Risk Management Process seeks to address such issues via practical, economic and effective solutions for implementation in the short or long term. As they are undertaken (and jointly funded) under the NSW Floodplain Risk Management Program, the City is not necessarily able to dictate the work flow of such projects.	No amendments to the report.

5. ECONOMIC IMPACT OF FLOODING

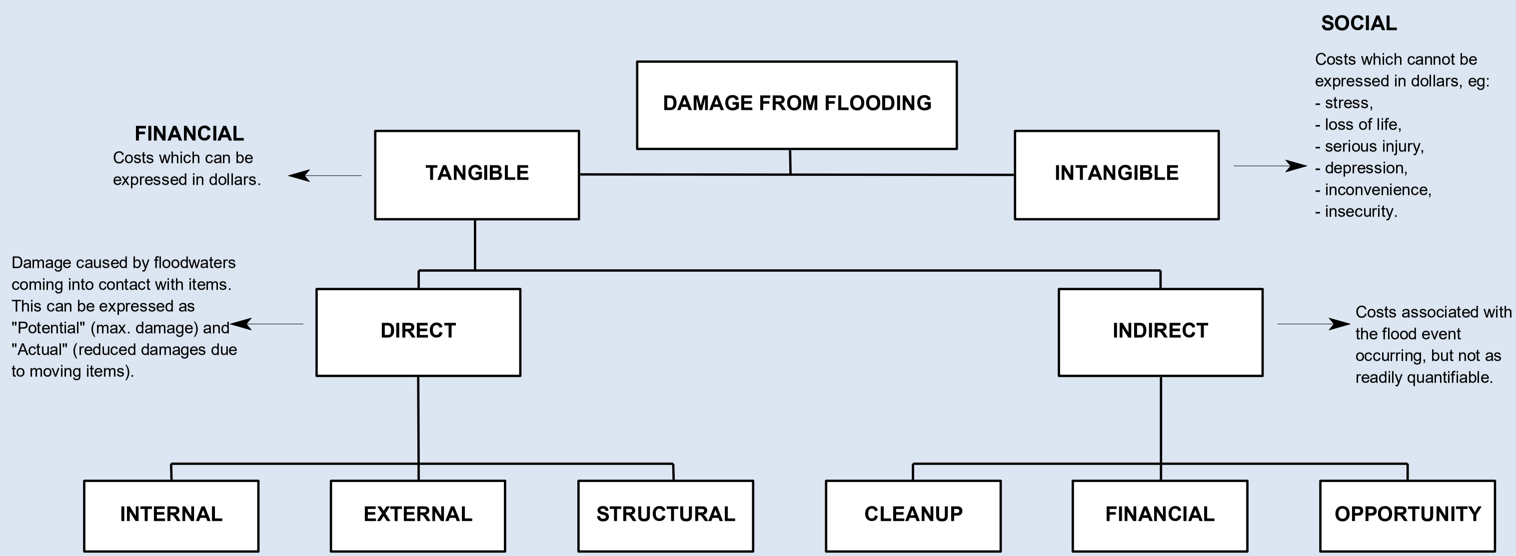
The impact of flooding can be quantified through the calculation of flood damages. Flood damage calculations do not include all impacts associated with flooding. They do, however, provide a basis for assessing the economic loss of flooding and also a non-subjective means of assessing the merit of flood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

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

The estimation of flood damages tends to focus on the physical impact of damages on the human environment but there is also a need to consider the ecological cost and benefits associated with flooding. Flood damages can be defined as being tangible or intangible. Tangible damages are those for which a monetary value can be easily assigned, while intangible damages are those to which a monetary value cannot easily be attributed. Types of flood damages are shown in Table 9.

The assessment of flood damages not only looks at potential costs due to flooding but also identifies when properties are likely to become flood affected by either flooding on the property or by over floor flooding as shown on Figure 20.

Table 9: Flood Damages Categories (including damage and losses from permanent inundation)



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

5.1. Tangible Flood Damages

Tangible flood damages are comprised of two basic categories; direct and indirect damages (refer Table 9). Direct damages are caused by floodwaters wetting goods and possessions thereby damaging them and resulting in either costs to replace or repair or in a reduction to their value. Direct damages are further classified as either internal (damage to the contents of a building including carpets, furniture), structural (referring to the structural fabric of a building such as foundations, walls, floors, windows) or external (damage to all items outside the building such as cars, garages). Indirect damages are the additional financial losses caused by the flood for example the cost of temporary accommodation, loss of wages by employees etc.

Given the variability of flooding and property and content values, the total likely damages figure in any given flood event is useful to get a feel for the magnitude of the flood problem, however it is of little value for absolute economic evaluation. Flood damages estimates are also useful when studying the economic effectiveness of proposed mitigation measures. Understanding the total damages prevented over the life of the measure in relation to current damages, or to an alternative option, can assist in the decision making process.

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

In order to quantify the damages caused by inundation for existing development a floor level survey was undertaken. As part of this floor level survey work an indicative ground level was recorded for use in the damages assessment. This was used in conjunction with modelled flood level information to calculate damages. Damage calculations were carried out for all properties within the 1% AEP flood extent, and floor level survey was undertaken for these properties. It should be noted that properties that are inundated in events above the 1% AEP have not been included in the assessment. Therefore damage calculations for the PMF event are likely to be underestimated.

A flood damages assessment was undertaken as part of the Flood Study (Reference 2) for existing development in accordance with current OEH guidelines (Reference 7) and the Floodplain Development Manual (Reference 1). As additional properties floor levels were surveyed as part of this study (and old flood models revised), the estimated flood damages were revised. The damages were calculated using a number of height-damage curves which relate the depth of water above the floor with tangible damages. Each component of tangible damages is allocated a maximum value and a maximum depth at which this value occurs. Any flood depths greater than this allocated value do not incur additional damages as it is assumed that, by this level, all potential damages have already occurred.

Damages were calculated for residential and commercial\industrial properties separately and the process and results are described in the following sections. The combined results are provided as Table 10. This flood damages estimate does not include the cost of restoring or maintaining public services and infrastructure. It should be noted that damages calculations do not take into account flood damages to any basements or cellars, hence where properties have basements damages may be under estimated.

Table 10: Estimated Combined Flood Damages for Darling Harbour Catchment

Event (ARI)	Number of Properties Flood Affected	No. of Properties Flooded Above Floor Level	Total Tangible Flood Damages	Average Tangible Damages Per Flood Affected Property
2	74	56	$ 3,739,000	$ 50,500
5	118	86	$ 5,211,800	$ 44,200
10	174	123	$ 11,732,400	$ 67,400
20	224	155	$ 15,014,800	$ 67,000
50	246	173	$ 17,893,900	$ 72,700
100	274	193	$ 21,443,100	$ 78,300
500	332	235	$ 29,940,600	$ 90,200
PMF	437	299	$ 73,470,600	$ 168,100
Average Annual Damages (AAD)			**$ 3,723,800**	**$ 8,500**

5.1.1. Residential Properties

The flood damages assessment for residential development was undertaken in accordance with OEH guidelines (Reference 7). For residential properties damages were calculated by the summation of direct (over-floor) flooding and basement flooding. For direct flooding, damages were calculated on the multiplication of:

- An input damages curve, with values dependent on the number of storeys, whether the property floor level was greater than 0.5 m above the ground and the height of the flood above the floor level; and
- A ground level multiplier dependent on the number of units on the ground floor.

For basement flooding damages were calculated from an input damages curve, with values dependent on the number of storeys, whether the property floor level was 0.5 m above the ground and the height of the flood above basement level.

A summary of the residential flood damages for the Darling Harbour catchment is provided in Table 11. Overall, for residential properties in the catchment there is little difference in the average tangible damages per property for all the design events analysis up to the 1% AEP event. This is reflective of the relatively small differences in flood levels between the design flood events. Average damage per property increases at events larger than the 1% AEP when more properties become flooded above floor level. Note that the terminology used refers to a property or lot being the land within the ownership boundary. Flooding of a property does not necessarily mean flooding above floor level of a building on that property/lot.

Table 11: Estimated Residential Flood Damages for Darling Harbour Catchment

Event (ARI)	Number of Properties Flood Affected	No. of Properties Flooded Above Floor Level	Total Tangible Flood Damages	Average Tangible Damages Per Flood Affected Property
2	35	23	$ 2,630,300	$ 75,200
5	52	31	$ 3,507,600	$ 67,500
10	84	55	$ 4,974,100	$ 59,200
20	111	66	$ 5,926,800	$ 53,400
50	121	74	$ 6,512,300	$ 53,800
100	133	83	$ 7,104,800	$ 53,400
500	155	99	$ 8,512,000	$ 54,900
PMF	200	124	$ 11,217,000	$ 56,100
Average Annual Damages (AAD)			**$ 1,912,200**	**$ 9,600**

5.1.2. Commercial and Industrial Properties

The tangible flood damage to commercial and industrial properties is more difficult to assess. Commercial and industrial damage estimates are more uncertain and larger than residential damages. Commercial and industrial damage estimates can vary significantly depending on:

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

Costs to business can occur for a range of reasons, some of which will affect some businesses more than others dependent on the magnitude of flooding and the type of business. Common flood costs to businesses are:

- Removal and storage of stock before a flood if warning is given (not applicable here);
- Loss of production – caused by damaged stock, assets and availability of staff;
- Loss of stock and/or assets;
- Reduced stock through reduced or no supplies;
- Trade loss – by customers not being able to access the business or through business closure;
- Cost of replacing damages or lost stock or assets; and
- Clean-up costs.

No specific guidance is available for assessing flood damages to non-residential properties. Therefore for this Study, commercial and industrial damages were calculated using the methodology for residential properties but with the costs/damages increased to a value which is consistent with commercial/industrial development. For commercial properties damages were calculated by the summation of direct (over-floor) flooding and basement flooding along with a commercial property loading of 55%. For direct flooding, damages were calculated on the multiplication of:

- An input damages curve, with values dependent on the size of the commercial property and the height of the flood above the floor level; and
- An area multiplier for commercial properties greater than 650 m^2.

For basement flooding damages were calculated from an input damages curve with values dependent on the size of the commercial property and the height of the flood above basement level.

Though the original OEH guidelines for flood damages calculations are not applicable to non-residential properties, they can still be used to create comparable damage figures. The damages value figure should not be taken as an actual likely cost rather it is useful when comparing potential management options and for benefit-cost analysis.

A summary of the commercial/industrial flood damages for the Darling Harbour catchment is provided in Table 12. AAD for the surveyed commercial/industrial properties is generally equal to residential properties, with commercial properties having higher damages per property for the larger events. This reflects the higher costs that businesses would incur compared to residential dwellings when flooded above floor level. On a per property basis the AAD is approximately the same between the two property types.

Table 12: Estimated Commercial and Industrial Flood Damages for Darling Harbour Catchment

Event (ARI)	Number of Properties Flood Affected	No. of Properties Flooded Above Floor Level	Total Tangible Flood Damages	Average Tangible Damages Per Flood Affected Property
2	39	33	$ 1,108,700	$ 28,400
5	66	55	$ 1,704,200	$ 25,800
10	90	68	$ 6,758,300	$ 75,100
20	113	89	$ 9,088,000	$ 80,400
50	125	99	$ 11,381,600	$ 91,100
100	141	110	$ 14,338,300	$ 101,700
500	177	136	$ 21,428,600	$ 121,100
PMF	237	175	$ 62,253,600	$ 262,700
Average Annual Damages (AAD)			**$ 1,811,600**	**$ 7,600**

5.2. Intangible Flood Damages

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

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

During any flood event there is the potential for injury as well as loss of life due to causes such as drowning, floating debris or illness from polluted water. Generally, the higher the flood velocities and depths the higher the risk. Within the Darling Harbour catchment area, the high hazard areas include Hay Street (high flow) and areas with a significant accumulation of depth, e.g. at Commonwealth Street, Pyrmont Street and in low-lying parts of Darling Harbour. However, there will always be local high risk (high hazard) areas where flows may be concentrated around buildings or other structures within low hazard areas.

6. FLOOD EMERGENCY RESPONSE ARRANGEMENTS

6.1. Flood Emergency Response

The majority of flooding within the Darling Harbour catchment is characterised by overland flow, with no mainstream flooding and only a small area of tidal influence near Darling Harbour. The critical duration is between 1 and 2 hours across most of the catchment, with the peak of the flood reached approximately 30 minutes to 1 hour after the start of the storm. This is considered short duration “flash” flooding.

Due to the short interval between the start of the storm and the peak of the flood, there is little in the way of warning that can be provided. Any warning provided would be for immediate safety precautions such as temporary refuge (if available nearby or onsite), raising of items off the ground and accounting for people on site.

The short duration until flooding occurs does not allow sufficient time to evacuate residents and workers from their properties. In these situations, evacuation is generally not recommended as the response during a flood event as it is likely to be hurried and uncoordinated, which can expose evacuees to a hazardous situation. As such, the preferred response to flooding in flash flooding catchments is for people to remain within the property, preferably above the ground floor level. The suitability of the shelter-in-place approach should be considered in consultation with the State Emergency Service (SES) for the preparation of a Local Flood Plan. Assessment of evacuation and emergency response arrangements is given in Sections 9.4.5 and 9.4.6.

It is important that residents and workers are aware of signs that will signal an approaching flood, and are aware of the correct response such that the small time period before the flood arrives may be used as effectively as possible to move people and belongings to a close, safe location.

The nature of the flood problem in the study area does not lend itself to a managed flood response. The issues undermining a planned response are as follows:

- Lack of effective warning time;
- Flood issue is distributed rather than aggregated;
- Difficulty with vehicle movement during an event; and
- The flash nature of the flooding. Note that where rainfall exceeds 0.2 EY intensity generally speaking vehicle movement will be limited by visibility.

As such, and given the lack of a specific response plan at this time, it is reasonable to suggest that SES response will be ad hoc and demand based. Arguably then the most critical element of SES response will be flexibility.

The largest impediment to operational flexibility is likely to be vehicle movement. As such in looking at improving flood risk via enhanced flood emergency response the study has focussed on the roads that may be cut in the event of flooding.

Given the relatively low risk nature of most property flooding it is reasonable to assume that flooded roads will be one of the highest risk areas during flooding. As such road locations subject to inundation must be a priority for management.

6.2. Flood Emergency Responses Documentation

Flood emergency measures are an effective means of reducing the costs of flooding and managing the continuing and residual risks to the area. Current flood emergency response arrangements for managing flooding in the Darling Harbour catchment are discussed as follows.

6.2.1. Regional Emergency Plan (REMPLAN)

The Darling Harbour catchment is located within the Sydney East Emergency Management District. Flood emergency management for the study area is organised under the NSW State Emergency Plan (2012) (EMPLAN). No Regional Emergency Plan (REMPLAN) has been prepared for this district.

The EMPLAN details emergency preparedness, response and recovery arrangement for NSW to ensure the coordinated response to emergencies by all agencies having responsibilities and functions in emergencies.

The EMPLAN has been prepared to coordinate the emergency management options necessary at State level when an emergency occurs, and to provide direction at Regional and Local level.

The plan is consistent with regional plans prepared for areas across NSW and covers the following aspects at a state level:

- Roles and strategies for prevention of disasters;
- Planning and preparation measures;
- Control, coordination and communication arrangements;
- Roles and responsibilities of agencies and officers;
- Conduct of response operations; and
- Co-ordination of immediate recovery measures.

The EMPLAN states that:

"*Each Regional and Local Emergency Management Committee is to develop and maintain its own Regional / Local Disaster Plan, with appropriate Supporting Plans and Sub Plans, as required by Functional Area Coordinators and Combat Agency Controllers at the appropriate level. Supporting plans are to be the exception at local level and their development must be approved by Regional Functional Area Coordinators*."

It is recommended that a REMPLAN be prepared for the Sydney East Emergency Management Region to outline an emergency response arrangement specific to the region. In particular the purpose of a REMPLAN is to:

- Identify responsibilities at a Region and Local level in regards to the prevention, preparation, response and recovery for each type of emergency situation likely to affect the region;
- Detail arrangements for coordinating resource support during emergency operations at both a Region and Local level;
- Outline the tasks to be performed in the event of an emergency at a Region and Local level;
- Specifies the responsibilities of the East Metropolitan Region Emergency Operations Controller and Local Emergency Operations Controllers within the East Metro EM Region;
- Detail the responsibilities for the identification, development and implementation of prevention and mitigation strategies;
- Detail the responsibilities of the Region and Local Emergency Management Committees within the Region;
- Detail agreed Agency and Functional Area roles and responsibilities in preparation for, response to and recovery from, emergencies;
- Outline the control, coordination and liaison arrangements at Region and Local levels;
- Detail arrangements for the acquisition and coordination of resources;
- Detail public warning systems and responsibility for implementation;
- Detail public information arrangements and public education responsibilities;
- Specifies arrangements for reporting before, during and after an operation; and
- Detail the arrangements for the review, testing, evaluation and maintenance of the Plan.

6.2.2. Local Emergency Management Plan (LEMPLAN)

A LEMPLAN has not been prepared for the local area containing the Darling Harbour catchment. As such, the New South Wales State Flood Sub-plan (2015) is used to set out the arrangements for the emergency management of flooding.

The State Flood Sub-plan is a sub-plan to the state EMPLAN. The Sub-plan sets out the emergency management aspects of prevention, preparation, response and initial recovery arrangements for flooding and the responsibilities of agencies and organisations with regards to these functions.

There is a requirement for the development and maintenance of a Flood Sub-plan for:

- The State of New South Wales;
- Each SES Region; and
- Each council area with a significant flood problem. In some cases the flood problems of more than one council area may be addressed in a single plan or the problems of a single council area may be addressed in more than one.

Annex B of the Sub-plan lists the Local Flood Sub Plans that exist or are to be prepared in New South Wales and indicates which river, creek and/or lake systems are to be covered in each plan.

The City of Sydney is not listed in Annex B. However, the Local Emergency Management Committee should prepare a Consequent Management Guide – Flood to outline the following details:

- Evacuation centres in close proximity to the floodplain which allow flood free access to the centres and are flood free sites;
- Inclusion of a description of local flooding conditions;
- Identification of potentially flood affected vulnerable facilities; and
- Identification of key access roads subject to flooding.

6.2.3. Emergency Service Operators

The emergency response to any flooding of the Darling Harbour catchment will be coordinated by the lead combat agency, the SES, from their Local Command Centre located at Erskineville. However, the City of Sydney Security and Emergency Unit located at Town Hall is on the notification list for SES flood warning alerts and direct liaison between the SES.

The Manager - Security and Emergency Management may then pass on the flood warnings to any affected Council or Community Buildings within the Darling Harbour catchment and provide additional resources to the SES where possible.

The Security and Emergency Management Unit will continue to receive regular updates from the SES throughout a flood event.

The relevant flood information from the Darling Harbour Flood Study (Reference 2) should be transferred to the Local Emergency Management Committee.

6.2.4. Flood Warning Systems

The critical duration and response times for the catchment limit the implementation of a flood warning system. The short duration flooding experienced in local systems is not well suited to flood warning systems. However, for areas prone to flash flood within the catchment, the BoM provides general warning services, including:

- Severe Thunderstorm Warnings
- Severe Weather Warnings
- Flood Watches

These services are typically issued for a much larger region, or catchment, that includes the local flash flood site. This information can sometime be used at a local level as discussed below.

6.2.4.1. Flood Warnings Issued by BOM

The Darling Harbour catchment is affected by flash flooding (i.e. floods where the warning time is less than 6 hours). As such it is difficult to provide any flood warning in advance of floods. Where possible, the Bureau of Meteorology (BoM) will issue a severe weather / flood warning to the Regional SES headquarters in Bankstown. Where that alert is relevant to the Darling Harbour catchment, the SES Regional Command will pass the BoM's warning on to the Local Command based in Erskineville. In some cases, 2-3 days advanced notice may be available (e.g. where an East Coast Low develops off Sydney). However, at other times it may only be possible to issue a flood warning a few hours in advance, if at all.

6.2.4.2. Activation of Local SES Command

SES staff are advised and placed on alert when the SES Local Command has been issued with a flood warning by the BoM. The BoM's flood warning is also forwarded by SMS to the relevant individuals and organisations, including the City of Sydney Security and Emergency Management Unit located at Town Hall.

It is noted that the SES is the designated lead combat agency in an emergency such as a flood event. However, local authorities may wish to act on the advice provided by the SES to minimize the level of risk in the lead up to the flood event. Depending on the amount of lead time provided, Council may undertake any relevant priority works, such as cleaning out storm water pits to reduce the risk of blockage. In addition, Council's Rangers are placed on standby and report any issue directly to the SES (e.g. cars parked in overland flow paths, etc.).

6.3. Access and Movement During Flood Events

Any flood response suggested for the study area must take into account the availability of flood free access, and the ease with which movement may be accomplished. Movement may be evacuation from flood affected areas, medical personnel attempting to provide aid, or SES personnel installing flood defences.

The catchment area has several arterial roads that are flood affected, and a number of other roads where traffic will be impeded in a flood event. The busiest roads affected by flooding are George Street, Elizabeth Street and Harris Street. A small section of Harbour Street near Black Wattle Place is also affected by ponding.

As shown in Table 13, the depth of inundation on the road varies from 0.0 - 0.7 m in a 0.5 EY event, to 0.5-1.5 m in a 1% AEP and up to 4.3 m in the PMF. This depth refers to the accumulation in the gutter on either side of the road, while the road centre will typically have 0.3 m less depth, for example, there is up to 0.6 m in the 1% AEP but only 0.3 m in the middle of the road. Figure 21 shows the locations of the reported points.

Table 14 lists the rate of rise in metres per hour for the same locations listed in Table 13, for the 1.5 hour duration storm. It should be noted that the rate of rise will vary with other event durations, and therefore the values presented are only to give a general approximation of rate of rise and how it varies in the catchment. Also, the five locations reach their peak depth within one hour of the event occurring, hence the rates of rise are greater than the peak flood depths. Rate of rise is similar across the locations, with Pyrmont Street having the fastest increase overall, while Elizabeth Street and Commonwealth Street are relatively slow. The rate of rise is generally around 1.0 m/hour for frequent events and between 1 and 3 m/hour for rarer events, for the 1.5 hour event.

Table 13: Major Road Peak Flood Depths (m) for Various Events

ID	Road Location	0.5 EY	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	0.2% AEP	PMF
1	Commonwealth St near Ann St	0.0	0.1	0.8	0.9	1.0	1.1	1.2	1.4
2	Elizabeth St between Campbell St and Foveaux St	0.3	0.4	0.4	0.4	0.5	0.5	0.6	1.0
3	Hay St between Elizabeth St and Harbour St	0.7	0.9	1.0	1.1	1.2	1.3	1.5	2.2
4	Darling Harbour between Hay St and Western Distributor Fwy	0.7	1.0	1.1	1.2	1.4	1.5	1.6	2.5
5	Pyrmont St between Jones Bay Rd and Union St	0.2	0.3	1.0	1.1	1.2	1.3	1.5	4.3

Table 14: Major Road Flooding Rate of Rise (m/hour) for Various Events (1.5 hour duration event)

ID	Road Location	0.5 EY	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP	0.2% AEP	PMF
1	Commonwealth St near Ann St	0.1	0.2	1.6	1.7	1.9	2.0	2.3	5.3
2	Elizabeth St between Campbell St and Foveaux St	0.6	0.7	0.7	0.8	0.9	1.0	1.2	3.2
3	Hay St between Elizabeth St and Harbour St	1.2	1.5	1.7	1.9	2.0	2.2	2.5	4.1
4	Darling Harbour between Hay St and Western Distributor Fwy	1.3	1.7	1.4	1.7	1.9	2.0	2.2	3.5
5	Pyrmont St between Jones Bay Rd and Union St	0.3	0.7	1.9	2.1	2.2	2.4	2.7	3.4

For the 1% AEP flood event, roads cut (as per Figure 21) are shown in Table 15.

Table 15: Major Roads Cut in the 1% AEP Event

Road Location	Description
Elizabeth Street near Hay Street	Flood depths are around 0.3 m and persist for a period of 15-30 minutes given the critical storm modelled (1.5 hour).
George Street at intersection with Hay Street	Flood depths are 0.3-0.5 m and persist for a period of 15-30 minutes given the critical storm modelled (1.5 hour)
Harris Street near Allen Street	Flood depths are 0.3-0.5 m and persist for a period of 15-30 minutes given the critical storm modelled (1.5 hour)

Following a review of this information revised SES plans might allot responsibility for management of these road closures (for example to Police). Note SES involvement is likely to be required given the presumable limited mobility of Council employees in the event of a severe flood event.

6.4. Flood Emergency Response Classifications

To assist in the planning and implementation of response strategies, the SES in conjunction with OEH has developed guidelines to classify communities according to the impact that flooding has upon them. These Emergency Response Planning (ERP) classifications (Reference 5) consider flood affected communities as those in which the normal functioning of services is altered, either directly or indirectly, because a flood results in the need for external assistance. This impact relates directly to the operational issues of evacuation, resupply and rescue. Based on the guidelines, communities are classified as either; Flood Islands; Road Access Areas; Overland Access Areas; Trapped Perimeter Areas or Indirectly Affected Areas and when used with the SES Requirements Guideline (Reference 5)). The ERP classification can identify the type and scale of information needed by the SES to assist in emergency response planning (refer to Table 16).

Table 16: Emergency Response Planning Classifications of Communities

	Response Required		
Classification	**Resupply**	**Rescue/Medivac**	**Evacuation**
High flood island	Yes	Possibly	Possibly
Low flood island	No	Yes	Yes
Area with rising road access	No	Possibly	Yes
Area with overland escape routes	No	Possibly	Yes
Low trapped perimeter	No	Yes	Yes
High trapped perimeter	Yes	Possibly	Possibly
Indirectly affected areas	Possibly	Possibly	Possibly

Key considerations for flood emergency response planning in these areas include:

- Cutting of external access isolating an area;
- Key internal roads being cut;
- Transport infrastructure being shut down or unable to operate at maximum efficiency;
- Flooding of any key response infrastructure such as hospitals, evacuation centres, emergency services sites;
- Risk of flooding to key public utilities such as gas, power, sewerage; and
- The extent of the area flooded.

Flood liable areas within the study area have been classified according to the ERP classification above, with the additional criteria of flood depths being greater than 0.1 m. If only the flood extent was used in the Darling Harbour catchment, areas surrounded by less than 0.1 m would be classified as flood islands, when in reality, people could move through this water without concern. Therefore, all flood depths of less than 0.1 m were removed from the PMF flood extents prior to classification. The ERP classifications for the study area are shown in Figure 5.

7. POLICIES AND PLANNING

7.1. Legislative and Planning Context

The Darling Harbour catchment is located within the City of Sydney LGA where development is controlled through the Sydney Local Environment Plan (LEP) 2012 and Sydney Development Control Plan (DCP) 2012. The LEP is a planning instrument which designates land uses and development in the LGA while the DCP regulates development with specific guidelines and parameters. Management policies and plans are often used to provide additional information regarding development guidelines and parameters. This section reviews flood controls covered by the LEP, DCP, and other relevant policies and plans.

7.1.1. NSW Flood Prone Land Policy

The NSW Floodplain Development Manual (Reference 1) guides local government in managing the floodplain and the development of flood liable land for the purposes of Section 733 of the Local Government Act 1993 and incorporates the NSW Flood Prone Land Policy.

The primary objective of the NSW Government's Flood Prone Land Policy is to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property and reduce public and private losses resulting from floods whilst utilising ecologically positive methods wherever possible.

The Manual outlines a merits based approach to floodplain management. At the strategic level this allows for the consideration of social, economic, cultural, ecological and flooding issues to determine strategies for the management of flood risk. The Manual recognises differences between urban and rural floodplain issues. Although it maintains that the same overall floodplain management approach should apply to both, it recognises that a different emphasis is required for each type of floodplain.

7.1.2. Existing Council Policy

Councils use Local Environment Plans (LEP) and Development Control Plans (DCP) to set a range of policies and development controls, including floodplain management. City of Sydney adopted the Sydney Local Environmental Plan 2012 and Sydney Development Control Plan 2012 and these are discussed in the following sections in relation to flood risk and management. Council has also prepared an Interim Floodplain Management Policy that will operate until Council completes floodplain risk management plans for its entire LGA and then integrates these outcomes into the LEP and DCP.

Sydney LEP 2012

This planning instrument provides overall objectives, zones and core development standards, including provisions related to "flood planning" applicable to land at or below the flood planning level. Clause 7.15 of the Plan states the following objectives in relation to flood planning:

- To minimise the flood risk to life and property associated with the use of land;
- To allow development on land that is compatible with the land's flood hazard, taking into consideration projected changes as a result of climate change; and
- To avoid significant adverse impacts on flood behaviour and the environment.

The Clause stipulates that consent will not be granted to development on land to which this Clause applies unless Council is satisfied that the development:

- Is compatible with the flood hazard of the land;
- Is not likely to significantly adversely affect flood behaviour resulting in detrimental increases in the potential flood affectation of other development or properties;
- Incorporates appropriate measures to manage risk to life from flood;
- Is not likely to significantly adversely affect the environment or cause avoidable erosion, siltation, destruction of riparian vegetation or a reduction in the stability of river banks or watercourses; and
- Is not likely to result in unsustainable social and economic costs to the community as a consequence of flooding.

Under this Clause, the flood planning level is defined as the level of a 1% AEP flood event plus 0.5 metres freeboard.

The LEP contains a number of land use zones as shown in Figure 2. For each zone, the LEP specifies development which may be carried out with or without consent, prohibited development and objectives for development.

Sydney DCP 2012

The purpose of this plan is to supplement the LEP and provide more detailed provisions to guide development. It came into effect on the same day as the LEP and must be read in conjunction with the provision of the LEP.

Prescriptive planning controls are provided in Section 3.7 of the document. The objectives of these planning controls are to:

- Ensure an integrated approach to water management across the City through the use of water sensitive urban design principles;
- Encourage sustainable water use practices;
- Assist in the management of stormwater to minimise flooding and reduce the effects of stormwater pollution on receiving waterways;
- Ensure that development manages and mitigates flood risk, and does not exacerbate the potential for flood damage or hazard to existing development and to the public domain; and
- Ensure that development above the flood planning level as defined in the Sydney LEP 2012 will minimise the impact of stormwater and flooding on other developments and the public domain both during and after the event.

Whilst these objectives are clearly defined in the Sydney DCP 2012, no specific development controls are provided to achieve these objectives (except for those relating to-site detention). Requirements for site specific flood studies are also outlined in the document but there seems to be some inconsistency between this document and the LEP, as the DCP states that site specific flood studies may be required by Clause 7.17 of the Sydney LEP 2012. There is no mention of flood management in Clause 7.17 and no reference as to when a site specific flood study may be required in the LEP. It is recommended that this be clarified at the next LEP/DCP amendment.

Interim Floodplain Management Policy (2014)

This interim Policy (Reference 4) provides direction with respect to how floodplains are managed within the LGA of the City of Sydney. This Policy has been prepared having regard to the provisions of the NSW Flood Prone Land Policy and NSW Floodplain Development Manual (Reference 1) and is to be read in conjunction with the provisions of the LEP and DCP. The draft Policy was on exhibition in September and October 2013 and adopted by Council in May 2014.

The Policy outlines Council responsibilities in managing the floodplain and it provides controls to facilitate a best practice approach for the management of flood risk within the LGA. This interim Policy will be withdrawn once Council complete Floodplain Risk Management Plans for the entire LGA and then integrate outcomes from these plans into the LEP and DCP.

The document provides general requirements for proposed development on flood prone land, Flood Planning Level requirements for different development types and guidelines on flood compatible materials. It makes the following requirements of new development on flood prone land:

- It stipulates the information that is to be provided with a development application relevant to the various controls, for example building layouts and floor plans;
- It gives a criterion that must be satisfied in the case of a development not meeting the relevant Prescriptive Provisions in Sydney DCP 2012. These criteria include the development being compatible with established flood hazard of the land, not impacting flood behaviour so that other properties' affectation is worsened and incorporating appropriate measures to manage risk to life from flood;
- Concession is made to minor additions being made to existing properties, as these additions are acknowledged to not present an unmanageable risk to life. The concession can be given to dwelling additions of up to 40 m^2 and commercial industrial/commercial additions of up to 100 m^2 or 20% of Gross Floor Area. The concession is granted no more than once per development;
- It gives general requirements for development on flood prone land, including design requirements for fencing, minimum floor level, car parking, filling of flood prone land and the impact of climate change;
- It sets flood planning levels to be adhered to by various types of development. For example habitable rooms affected by mainstream flooding are to be at or above the 1% AEP flood level + 0.5 m. Other levels are given for properties affected by local drainage flooding (as

per the Policy's definition), industrial/commercial development, car parks and critical facilities; and

- It specifies flood compatible materials for various components of a development, for example use of concrete slab-on-ground monolith construction or suspended reinforced concrete slab for flooring.

City of Sydney Technical Specification – Drainage Design

City of Sydney's technical specification includes prescribed design flood events for the design of the stormwater network. New sections of the network are required to be in accordance with the major/minor design concepts outlined in Australian Rainfall and Runoff, with the 1% AEP and 5% AEP used for the major/minor events, respectively. This is also in accordance with City of Sydney's vision to ultimately have 5% AEP capacity for the pit/pipe drainage system across the LGA.

Mitigation options investigated as part of the current study have used this vision when selecting design events for mitigation options (see Section 9.3). As most areas of the LGA are fully developed and therefore difficult to make major upgrades to stormwater infrastructure, the 10% AEP event has also been used for some mitigation options.

7.2. Planning Recommendations

Based on the review of the planning documents presented in the previous sections, the following recommendations have been made:

- There is a lack of consistency between the Sydney LEP 2012 and the Sydney DCP 2012. It is recommended that both the LEP and the DCP are updated to ensure accurate cross referencing between the two documents. Also the requirements for a site specific flood study are provided in the Sydney DCP 2012. Though the DCP notes that the Sydney LEP 2012 outlines when a site specific flood study is required, the LEP does not contain this information. The LEP or the DCP should be updated to ensure this information is provided;
- Flood related development controls and requirements are provided in the Interim Floodplain Management Policy (Reference 4). Reference to this policy should be included in the DCP or the key controls outlined in the Policy could also be included in the DCP. Council's current position on climate change requirements should also be informed in the DCP as outlined in the Policy;
- Consideration of emergency response provisions in new development with regards to short duration flooding in the catchment should also be included in the Interim Floodplain Management Policy (Reference 4); and
- There may be opportunities to incorporate flood management measures into new developments as a condition of consent, Section 94 contribution offsets or government related funding. The nature of the flood controls implemented will be dependent on the location of the development, the flooding behaviour and the type of development. However, allowance and / or requirements for these works could be identified through amendments to the Sydney DCP 2012 or the Interim Floodplain Management Policy (Reference 4).

8. FLOOD PLANNING

8.1. Flood Planning Level (FPL)

The FPL is the minimum height for floor levels of new development within the floodplain. The FPL is set to provide adequate protection for buildings against floods. Due to the mixture of residential and commercial development in the Darling Harbour catchment, a variety of FPLs may be applicable depending on where in the catchment development is being considered and also based on the type of development being proposed.

A variety of factors need to be considered when calculating the FPL for an area. A key consideration is the flood behaviour and resultant risk to life and property. The Floodplain Development Manual (Reference 1) identifies the following issues to be considered:

- Risk to life;
- Long term strategic plan for land use near and on the floodplain;
- Existing and potential land use;
- Current flood level used for planning purposes;
- Land availability and its needs;
- FPL for flood modification measures (e.g. height of levee banks);
- Changes in potential flood damages caused by selecting a particular flood planning level;
- Consequences of floods larger than that selected for the FPL;
- Environmental issues along the flood corridor;
- Flood warning, emergency response and evacuation issues;
- Flood readiness of the community (both present and future);
- Possibility of creating a false sense of security within the community;
- Land values and social equity;
- Potential impact of future development on flooding; and
- Duty of care.

8.1.1. Likelihood of Flooding

As a guide, Table 17 has been reproduced from the NSW Floodplain Development Manual 2005 to indicate the likelihood of the occurrence of an event in an average lifetime to indicate the potential risk to life.

Analysis of the data presented in Table 17 gives a perspective on the flood risk over an average lifetime. The data indicates that there is a 50% chance of a 100 Year ARI (1% AEP) event occurring at least once in a 70 year period. Given this potential, it is reasonable from a risk management perspective to give further consideration to the adoption of the 1% AEP flood event as the basis for the FPL. Given the social issues associated with a flood event, and the non-tangible effects such as stress and trauma, it is appropriate to limit the exposure of people to floods.

Note that there still remains a 30% chance of exposure to at least one flood of a 200 Year ARI (0.5% AEP) magnitude over a 70 year period. This gives rise to the consideration of the adoption of a rarer flood event (such as the PMF) as the flood planning level for some types of development.

Table 17: Likelihood of given design events occurring in a period of 70 years

Likelihood of Occurrence in Any Year (ARI)	Probability of Experiencing At Least One Event in 70 Years (%)	Probability of Experiencing At Least Two Events in 70 Years (%)
10	99.9	99.3
20	97	86
50	75	41
100	50	16
200	30	5

8.1.2. Land Use and Planning

The hydrological regime of the catchment can change as a result of changes to the land-use, particularly with an increase in the density of development. The removal of pervious areas in the catchment can increase the peak flow arriving at various locations, and hence the flood levels and flood hazards can be increased.

A potential impact on flooding can arise through the intensification of development on the floodplain, which may either remove flood storage or impact on the conveyance of flows. The Sydney DCP 2012 currently outlined controls relating to the installation of onsite detention to manage increased impervious area. No provisions exist within the current DCP 2012 or LEP 2012 to limit development within floodway or areas or limit filling in storage areas. Provisions to these issues, however, have been included in the Interim Floodplain Management Policy (Reference 4).

8.1.3. Freeboard Selection

A freeboard ranging from 0.3 – 0.5 metres is commonly adopted in determining the FPL. The freeboard accounts for uncertainties in deriving the design flood levels and as such should be used as a safety margin for the adopted FPL. The freeboard may account for factors such as:

- Changes in the catchment;
- Changes in flowpath vegetation;
- Accuracy of the model inputs (e.g. ground survey, design rainfall inputs for the area); and
- Model sensitivity:
  - Local flood behaviour (due to local obstructions);
  - Wave action (e.g. wind induced waves or waves from vehicles);
  - Blockage of drainage network; and
  - Climate change (affecting both rainfall and ocean levels).

The various elements factored into a freeboard can be summarised as follows:

- Afflux (local increase in flood levels due to small local obstructions not accounted for in the modelling) (+0.1 m);
- Local wave action (trucks and other vehicles) (allowance of +0.1 m is typical);
- Climate change impacts on rainfall (0.02 m to 0.32 m, mean 0.08 m, as per Darling Harbour Flood Study (2014));
- Climate change impacts on sea level rise (0.0 m to 0.11 m, mean 0.01 m, as per Darling Harbour Flood Study (2014)); and
- Sensitivity of the model +/-0.05 m.

Based on this analysis, the total sum of the likely variations is between 270 mm and 680 mm, depending on climate change, which has a varying effect across the catchment. Based on this range, the freeboard recommended in the Interim Floodplain Management Policy (Reference 4) is suitable for the catchment. The policy specifies a freeboard of 500 mm, except for in areas with local drainage flooding. In the policy, local drainage flooding refers to where there the 1% AEP depth is less than 0.25 m and the area is not in, or influenced by, a trapped low point. In these areas, the flood planning level is two times the depth of flow with a minimum of 0.3 m. Although the sum of the likely variations is above 500 mm, a 500 mm freeboard should be chosen so as to not choose a flood level (e.g. 1% AEP + 680 mm) that resembles a much larger flood, such as the PMF. Given the difference in flood depth between the 1% AEP and the PMF in the catchment, which is less than 0.3 m for the majority of the catchment, this freeboard is suitable for local drainage flooding.

When applied to design events less than the PMF, the freeboard may still result in the FPL being higher than the PMF in certain cases.

8.1.4. Current FPL as Adopted by Council

FPL requirements have been outlined by Council in their Interim Floodplain Management Policy (Reference 4). The policy provides further details regarding flood planning levels for various types of development within the floodplain and these are outlined in Reference 4.

Table 18: Adopted Flood Planning Levels in Interim Floodplain Management Policy (Reference 4)

Development		Type of flooding	Flood Planning Level
Residential	Habitable rooms	Mainstream flooding	1% AEP flood level + 0.5 m
		Local drainage flooding	1% AEP flood level + 0.5 m or Two times the depth of flow with a minimum of 0.3 m above the surrounding surface if the depth of flow in the 1% AEP flood is less than 0.25 m
		Outside floodplain	0.3 m above surrounding ground

Development		Type of flooding	Flood Planning Level
	Non-habitable rooms such as a laundry or garage (excluding below-ground car parks)	Mainstream or local drainage flooding	1% AEP flood level
Industrial or Commercial	Business	Mainstream or local drainage flooding	Merits approach presented by the applicant with a minimum of 1% AEP flood level
	Schools and child care facilities	Mainstream or local drainage flooding	Merits approach presented by the applicant with a minimum of 1% AEP flood level + 0.5m
	Residential floors within tourist establishments	Mainstream or local drainage flooding	1% AEP floor level + 0.5 m
	Housing for older people or people with disabilities	Mainstream or local drainage flooding	1% AEP flood level + 0.5 m or a the PMF, whichever is the higher
	On-site sewer management (sewer mining)	Mainstream or local drainage flooding	1% AEP floor level
	Retail Floor Levels	Mainstream or local drainage flooding	Merits approach presented by the applicant with a minimum of the 1% AEP flood. The proposal must demonstrate a reasonable balance between flood protection and urban design outcomes for street level activation.
Below-ground garage/ car park	Single property owner with not more than 2 car spaces.	Mainstream or local drainage flooding	1% AEP floor level + 0.5 m
	All other below-ground car parks	Mainstream or local drainage flooding	1% AEP flood level + 0.5 m or the PMF (whichever is the higher)
	Below-ground car park outside floodplain	Outside floodplain	0.3 m above the surrounding surface
Above ground car park	Car parks	Mainstream or local drainage flooding	1% AEP flood level
	Open car parks	Mainstream or local drainage	5% AEP flood level
Critical Facilities	Floor level	Mainstream or local drainage flooding	1% AEP flood level + 0.5m or the PMF (whichever is higher)
	Access to and from critical facility within development site	Mainstream or local drainage flooding	1% AEP flood level

In the policy, Council also provided clarity in the definition of local drainage flooding as opposed to mainstream flooding as follows:

1. Local drainage flooding occurs where:
    - The maximum cross sectional depth of flooding in the local overland flow path through and upstream of the site is less than 0.25 m for the 1% AEP flood; and
    - The development is at least 0.5 m above the 1% AEP flood level at the nearest downstream trapped low point; and
    - The development does not adjoin the nearest upstream trapped low point; and
    - Blockage of an upstream trapped low point is unlikely to increase the depth of flow past the property to greater than 0.25 m in the 1% AEP flood.
2. Mainstream flooding occurs where the local drainage flooding criteria cannot be satisfied.
3. A property is considered to be outside the floodplain where it is above the mainstream and local drainage flood planning levels including freeboard.

The establishment of the flood planning levels in conjunction with the publication of the Interim Floodplain Management Policy is a positive step forward for Council in setting development controls for new developments within the Darling Harbour catchment. Nevertheless, it could be helpful to provide several case studies to illustrate how these levels could be applied to individual developments to assist in development applications.

9. FLOODPLAIN RISK MANAGEMENT MEASURES

The FRMS aims to identify and assess risk management measures which could be put in place to mitigate flooding risk and reduce flood damages. The risk management measures should be assessed against the legal, structural, environmental, social and economic conditions or constraints of the local area. The NSW Government's Floodplain Development Manual (2005) separates floodplain management measures into three broad categories.

9.1. Floodplain Risk Management Measures

Flood modification measures modify the flood's physical behaviour (depth, velocity) and include flood mitigation dams, retarding basins and levees.

Property modification measures modify land use including development controls. This is generally accomplished through such means as flood proofing (house raising or sealing entrances), planning and building regulations (zoning) or voluntary purchase.

Response modification measures modify the community's response to flood hazard by educating flood affected property owners about the nature of flooding so that they can make informed decisions. Examples of such measures include provision of flood warning and emergency services, improved information, awareness and education of the community and provision of flood insurance.

A number of methods are available for judging the relative merits of competing measures. The benefit/cost (B/C) approach has long been used to quantify the economic worth of each option enabling the ranking against similar projects in other areas. The B/C is the ratio of the net present worth of the reduction in flood damages (benefit) compared to the cost of the works. Generally, the ratio only expresses the reduction in tangible damages as it is difficult to accurately include intangibles (such as anxiety, risk to life, ill health, etc.).

The potential environmental or social impacts of any proposed flood mitigation measure are of great concern to society and these cannot be evaluated using the classic B/C approach. For this reason, a matrix type assessment has been used which enables a value (including non-economic worth) to be assigned to each measure. The public consultation program has ensured that identifiable social and environmental factors were considered in the decision making process of the Darling Harbour catchment.

A summary of the measures considered for the catchment and at the specific hotspot locations is provided in and discussed in the following sections.

Table 19: Flood Affected Areas and Investigated Management Options

Hotspot	Flooding issues	Investigated Measures	Measures Reference
Commonwealth Street, near Ann and Reservoir Streets	Frequent inundation with moderate depth, several properties flooded above floor and roadway becomes impassable.	Pit and pipe upgrade for Commonwealth Street	FM-DH01
Pyrmont Street, near Jones Bay Road and Union Street	Inundation to moderate depth, minor property flooding and impact to road and footpath use.	Pit and pipe upgrade from low point to the outlet	FM-DH06
Elizabeth Street	Inundation to around 0.3 m across a wide section of the street, which has high traffic (three lanes each way).	Trunk upgrade on Elizabeth Street (DH02), diversion of overland flow (DH03), storage in Belmore Park (DH04) and large-scale pressurised drainage pipe to Darling Harbour outlet (DH05)	FM-DH02, FM-DH03, DH04, FM-DH05
Hay Street, from Elizabeth Street to Haymarket	Significant flow down Hay Street posing risk to pedestrians and cars. Overfloor inundation occurs towards downstream in Chinatown area.	Flood storage area in Belmore Park (DH04) and large-scale pressurised drainage pipe to Darling Harbour outlet (DH05)	FM-DH04, FM-DH05
Darling Harbour, near Tumbalong Park, Chinese Gardens and King Street Wharf	Widespread inundation in parts of Darling Harbour area, posing significant risk to pedestrians. Minor overfloor flooding with mostly open spaces.	Large-scale pressurised drainage pipe to Darling Harbour outlet (DH05), relief of flooding at Blackwater Place via a pit and pipe upgrade (DH07)	FM-DH05, FM-DH07
Various Hotspots	Various, as described	Data collection – specialised flood damages assessment	FM-DH08
Catchment-wide	**General flood risk, inundation of major roads**	Flood Warning and Evacuation	RM-DH01
		Flood Emergency Management	RM-DH02
		Community Awareness Programme	RM-DH03
		Flood Planning Levels	PM-DH01
		Development Control Planning	PM-DH02
		Flood Proofing	PM-DH03
		Feasibility Study for City of Sydney Flood Proofing	PM-DH04

9.2. Measures Not Considered Further

During the early phase of this study a review of all possible floodplain management measures and their application in the Darling Harbour catchment was undertaken. The measures not taken forward for further consideration, and the reasons for their exclusion, are summarised in the following sections.

9.2.1. Flood Modification - Dams and Retarding Basins

Flood mitigation dams and their smaller urban counterparts termed retarding basins have frequently been used in NSW to reduce peak flows downstream. As a flood passes through the dam or basin, it is progressively filled to the point of overflow, providing temporary storage for the floodwaters.

They are rarely used as a flood mitigation measure for existing development on account of the:

- high cost of construction;
- high cost of land purchase;
- risk of failure of the dam wall;
- likely low B/C ratio; and
- lack of suitable sites as a considerable volume of water needs to be impounded by the dam in order to provide a significant reduction in flood level downstream.

The last point is particular true in the Darling Harbour catchment which is already heavily developed. For the above reasons, this option was excluded from further consideration.

9.2.2. Flood Modification - Levees, and floodgates

Levees are built to exclude previously inundated areas of the floodplain from the river up to a certain design events, and are commonly used on large river systems (e.g. Hunter and Macleay Rivers), but can also be found on small creek systems in urban areas. Flood gates allow local waters to be drained from the leveed area when the external level is low, but when the river is elevated, the gates prevents floodwaters from entering. Pumps are also generally associated with levee designs. They are installed to remove local floodwaters from behind levees when flood gates are closed or there are no flood gates.

These measures were not considered further due to the absence of an open channel in the catchment.

9.2.3. Flood Modification - Floodways

Floodways or bypass channels redirect some of the floodwaters away from the main channel, reducing the flood levels between the bypass offtake and inflows. However, they may also exacerbate flood problems in the area of the bypass channel as well as downstream, once the channels have re-joined. The opportunities for their implementation are limited by topography, availability of land, and ecological considerations.

Floodways were excluded from further consideration due to the lack of open channel and issues surrounding land take, and topography.

9.2.4. Property Modification - Voluntary purchase

Voluntary purchase involves the acquisition of flood affected residential properties (particularly those frequently inundated in high hazard areas) and demolition of the residence to remove it from the floodplain. Generally the land is returned to open space, however there may be an opportunity for a new house to be built at a higher floor level, either on fill or on a higher part of the property.

Voluntary purchase is mainly implemented in high hazard areas over a long period as a means of removing isolated or remaining buildings and thus freeing both residents and potential rescuers from the danger and cost of future floods. It also helps to restore the hydraulic capacity of the floodplain (storage volume and waterway area).

Voluntary purchase has no environmental impacts although the economic cost and social impacts can be high. Many residents do not accept voluntary purchase because it would have significant impact on their community and way of life. Among these concerns are:

- It can be difficult to establish a market value that is acceptable to both the State Valuation Office and the resident;
- In many cases residents may not wish to move for a reasonable purchase price;
- Progressive removal of properties may impose stress on the social fabric of an area; and
- It may be difficult to find alternative equivalent priced housing in the nearby area with similar aesthetic values or features.

A voluntary purchase scheme is not considered appropriate in the Darling Harbour catchment due to the limited number of residential properties located in high hazard areas, and the high property costs. Also, voluntary purchase involves returning severely-affected land on a floodway to the floodplain. In the Darling Harbour catchment, affected properties are not necessarily on a floodway and restoring an area's natural flowpath (for example, in a trapped depression) would adversely impact downstream properties and may impact an area's streetscape and character. A modified scheme where buildings are upgraded to enforce flood resilience, raised as part of the Woolloomooloo FRMS&P, may be feasible for parts of Surry Hills, but overall is not suited given the very high cost of property and the nature of property ownership in the CBD.

9.2.5. Property Modification - Voluntary house raising

House raising has been widely used throughout NSW to eliminate or significantly reduce flooding of habitable floors particularly in lower hazard areas of the floodplain, albeit in limited overall numbers. However it has limited application as it is not suitable for all building types being more suitable for non-brick single storey buildings. This measure only becomes economically viable when above flood inundation occurs frequently (say in a 10% AEP flood event or less).

The benefit of house raising is that it eliminates above floor flooding and consequently reduces flood damages. House raising also provides a safe refuge during a flood, assuming that the building is suitably designed for the water and debris loading. However the potential risk to life is still present if residents choose to enter floodwaters or are unable to leave the house during a medical emergency, or larger floods than the design flood occurs particularly in high hazard areas.

Property raising is not an option for any commercial or industrial properties as most are brick on concrete structures. Most of the residential properties in the Darling Harbour catchment are brick, concrete or sandstone structures, with adjoining walls to neighbouring properties, and therefore cannot be raised.

House raising is not considered to be the most cost effective option for the type of flooding in the Darling Harbour catchment and not appropriate in the majority of cases as discussed above.

9.3. Site Specific Management Options

Site specific management options involve works aimed at managing the flood risk in a particular part of the catchment. Modifying the flood behaviour at a particular location involves either detaining runoff or improving the drainage capacity. The catchment has limited open space and therefore little opportunity for even a small retarding basin. Given this constraint, upgrading the drainage capacity has been focussed upon.

Measures to increase the capacity or efficiency of the existing piped drainage network include upgrading pipe capacity; re-profiling the pipe network; removing fixed blockages or impediments to flow and improved maintenance. This measure was assessed in detail for a number of flood affected areas within the catchment. An overview of the flood affected areas and proposed mitigation options are provided in Table 20 and shown in Figure 22. These options are discussed in detail in Sections 9.3.1 to 9.3.7.

Table 20: Flood Affected Areas and Proposed Mitigation Options

Flood Affected Streets/Areas	Proposed Mitigation Options	Reference
Commonwealth Street	Upgrade pit capacity of drainage on Commonwealth Street and the trunk capacity on Elizabeth Street.	FM - DH01
Elizabeth Street	Upgrade capacity of trunk drainage along Elizabeth Street and Darling Drive	FM - DH02
Elizabeth Street	Road levels changed to divert flow from Elizabeth Street	FM - DH03
Elizabeth Street, Hay Street	Belmore Park designed to provide flood storage	FM - DH04
Elizabeth Street, Hay Street, Darling Harbour area	New pressurised drainage pipe from Elizabeth Street to Darling Harbour outlet	FM - DH05
Pyrmont Street	Upgrade pit capacity of drainage on Pyrmont Street and the trunk capacity along Jones Bay Road.	FM - DH06
Utility building on Black Wattle Place	Upgrade pit and trunk capacity of drainage on Harbour Street and Black Wattle Place	FM - DH07

As described in the following sections, each mitigation option was based on a design event, depending on the nature of the flood risk. This was either the 10%, 5% or 1% AEP event. Where possible a larger event was chosen, however, nearly all options involved construction of large pipes that may not be feasible in heavily urbanised areas. Previous experience in similar urban catchments suggests that mitigating large floods (e.g. greater than 2% AEP) requires very large pipe sizes. For this reason, only a single design event has been presented for each option.

An additional option has been identified by City of Sydney for alleviating flooding on Crown Street in Surry Hills. The option involves a pipe upgrade for the slight topographic sag on Crown Street between Ann Street and Jesmond Street. The area is flood prone with multiple reports of flooding in 2015 alone. Council have found that pit blockage is not causing the inundation and that extra pits and slightly larger feeder pipes would alleviate the issue. The drainage currently consists of two 300 mm diameter pipes joining to a 750 mm diameter pipe.

9.3.1. Drainage Upgrade – Commonwealth Street (FM – DH01)

Option Description

Option FM – DH-01 describes a pit and pipe upgrade in Commonwealth Street and Elizabeth Street with the goal of reducing property affectation in the 5% AEP event. The 5% AEP event is used as it corresponds with Council's objective to upgrade the stormwater network to the 5% AEP event. The proposed upgrade includes the following elements:

- Upgrade of the pits and feeder pipes at the topographic sag in Commonwealth Street. The required additional drainage in the 5% AEP event is 0.4 m^3/s, which requires approximately four additional kerb inlets to what currently exists; and
- Additional drainage on Elizabeth Street (1 m x 1 m culvert near Hay Street) to accommodate the additional trunk drainage flow.

These drainage elements are in addition to what currently exists in the location, which would remain in place and is shown on Figure 23. Figure 24 shows the new drainage elements.

Modelled Impacts

The proposed works achieve a significant reduction in flood level for the topographic sag on Commonwealth Street. The impact of the proposed works on the 5% AEP flood level is shown on Figure 24. The reduction in flood level shown on the figure is 0.2 – 0.3 m, which reduces the flooding to below 0.1 m in that event. This reduction corresponds to removing the overfloor flooding on the street in the 5% AEP and below. The figure also shows the increase in peak flow out of the street down Reservoir Street is 0.4 m^3/s, which is accommodated by capacity in the existing system. The new drainage on Elizabeth Street is necessary to offset the impact caused by having increased pipe flow, which reduces drainage of overland flow on Elizabeth Street.

Evaluation

The proposed upgrade would provide benefit to the area's flood risk, largely through mitigating the area's property flooding. The topographic sag that exists on Commonwealth Street is flooded when the drainage capacity is exceeded, and the upgrade raises the drainage capacity to a 5% AEP level. Assessment of overfloor flooding has identified 13 properties on the street that are flooded above floor in the 5% AEP, which would be largely offset by the upgrade.

The works do not involve wide-scale pipe upgrades and are therefore considered generally feasible with respect to constructability. The upgrade shown consists of four new feeder pipes on Commonwealth, but this alignment is flexible and can be positioned around existing services, so long as the same drainage capacity is achieved. The additional drainage required for Elizabeth

Street is likely to be harder to achieve, as the required pipes are large and must be incorporated into the existing subsurface features. Economic assessment of the option is given in Section 9.3.9.

9.3.2. Drainage Upgrade – Elizabeth Street (FM – DH02)

Option Description

Option FM – DH-02 describes a trunk upgrade in Elizabeth Street and Quay Street with the goal of reducing road affectation in the 10% AEP event. The 10% AEP event is used as it corresponds with Council's objective to mitigate road flooding up to a 10% AEP event. The proposed upgrade includes the following elements:

- Additional trunk drainage on Elizabeth Street near Hay Street consisting of 4 new pipes (1.5 m x 1.5 m each);
- Upgrade of the pits and feeder pipes to ensure the upgraded trunk system drains the 10% AEP inundation; and
- Additional drainage on Quay Street (1.5 m x 1.5 m culvert near Hay Street) to accommodate the additional trunk drainage flow.

These drainage elements are in addition to what currently exists in the location, which would remain in place and is shown on Figure 23. Figure 25 shows the new drainage elements.

Modelled Impacts

The proposed works achieve a significant reduction in flood level for the topographic sag on Elizabeth Street. The impact of the proposed works on the 10% AEP flood level is shown on Figure 25. The reduction in flood level shown on the figure is 0.1 – 0.5 m on Elizabeth Street, which reduces the flooding to below 0.1 m in that event. There is also a minor decrease along Hay Street of up to 0.1 m. The new drainage on Quay Street is necessary to offset the impact caused by having increased pipe flow, which reduces drainage of overland flow on Quay Street.

Evaluation

The proposed upgrade would provide benefit to the area's flood risk, largely through mitigating the road flooding. The inundated section of Elizabeth Street experiences widespread flooding to a depth large enough to disable cars driving through it. The upgrade would mean the road is serviced by the drainage for up to a 10% AEP event. This would have significant benefit to the road users, given that Elizabeth Street is a heavily used route for cars and buses.

The works involve large-scale pipe upgrades and therefore may face constructability issues. The upgraded pipes are several metres in width and would take up a significant portion of the roadway, which likely already has many services beneath it. The upgrade may be unable to be incorporated into these existing services. The flat grade of the area and the flowpath down Hay Street results in larger pipes being required to drain the runoff (than if a steeper grade were present). Furthermore, the benefit of the option largely relates to improves road serviceability, which is not measured by the standard flood damages assessment, and the flooding poses relatively minimal risk to life. These factors make it less justifiable under a multi-criteria matrix assessment (see Section 9.5).

9.3.3. Road Adjustment – Elizabeth Street (FM – DH03)

Option Description

Option FM – DH-03 involves raising a section of Elizabeth Street with the goal of reducing road affectation downstream in the 10% AEP event. The 10% AEP event is used as it corresponds with Council's objective to mitigate road flooding up to a 10% AEP event. The section of road, which has been raised by 0.3 m, was tested as a means to divert runoff before it reached the low section of Elizabeth Street. The diverted flow would pass along Campbell Street before re-joining the main flowpath on Hay Street. The option does not involve changes to the sub-surface drainage. The Elizabeth Street hotspot's flood behaviour is shown on Figure 23 while Figure 26 shows the location of the raised section.

Modelled Impacts

The proposed works achieve minimal reduction in flood level for Elizabeth Street and adversely impact Campbell Street. The impact of the proposed works on the 10% AEP flood level is shown on Figure 26. The reduction in flood level shown on the figure is less than 0.1 m and does not impact the majority of the affected area of Elizabeth Street, which is south of Hay Street. This is likely due to the raised area only affecting one of several flowpaths onto the Elizabeth Street low point. Also, the diversion of some flow results in an increased peak flood level on Campbell Street, before it re-joins the flowpath on Hay Street.

Evaluation

The raised section would provide only minor benefit to the area's flood risk, and would adversely affect flooding on Campbell Street. The diverted flow does not have any benefit in the majority of the Elizabeth Street hotspot. The increase in peak flood level on Campbell is minor (less than 0.02) but is unacceptable as an adverse impact. It is likely that a higher raised section may be able to divert more flow and benefit Elizabeth Street; however, there would be a corresponding increase in adverse impact to Campbell Street. This is true of other overland flowpaths onto the hotspots: although they are shallow and could be diverted with minor features, this would invariably lead to an adverse impact in the diverted area.

9.3.4. Park Adjustment – Belmore Park (FM – DH04)

Option Description

Option FM – DH-04 involves lowering part of Belmore Park for floodplain storage with the goal of reducing road affection on Hay Street and Elizabeth Street in the 10% AEP event. The 10% AEP event is used as it corresponds with Council's objective to mitigate road flooding up to a 10% AEP event. Belmore Park lies adjacent to the catchment's main flowpath and is on the few areas of green space in the catchment. The ground surface in approximately the north third of the park was lowered by up to 0.8 m to a level of 6.5 mAHD. The area is approximately 6500 m^2, which creates a volume of approximately 5000 m^3. It should be noted that the depth and area of excavation is based on a 'first-pass' assessment where only the effect on flooding is determined. If there is shown to be a benefit, the environmental and social constraints would be carefully considered. The option does not involve changes to the sub-surface drainage (although more detailed design would likely involve drainage of the lowered area to the existing trunk system). The Elizabeth Street hotspot's flood behaviour is shown on Figure 27 while Figure 28 shows the location of the lowered area.

Modelled Impacts

The proposed works achieve significant reduction in flood level on Hay Street and no reduction on Elizabeth Street. The impact of the proposed works on the 10% AEP flood level is shown on Figure 28. The reduction shown on the figure is 0.1 – 0.2 m on Hay Street between Elizabeth Street and George Street, with less reduction downstream of George Street. The reduction results in the majority of Hay Street having 0.1 – 0.2 m of depth in the 10% AEP event. As shown on the figure, the peak overland flow on Hay Street is reduced from 4.9 m^3/s to 1.2 m^3/s. There is also a minor increase on Elizabeth Street which is a result of the changed flow behaviour on Hay Street slightly reducing the flow onto Hay Street from Elizabeth Street. The reduction in flow and level is due to the lowered park area acting as a retarding basin which captures a portion of the overland flow and attenuates the flow downstream. The reduction in level also corresponds to some reduction in property affectation; however, it is generally small as most affected properties on Hay Street are downstream of George Street.

Evaluation

The lowered park would provide only minor benefit to the area's flood risk and would have significant social and environmental costs. The volume of storage captures only a percentage of the 10% AEP runoff and so there is still significant road affectation on Hay Street, while Elizabeth Street has no benefit. The affected section of Hay Street (mostly upstream of George Street) has little traffic relative to the surrounding area with only light rail access between Pitt Street and George Street. The social and environmental costs of the option are as follows:

- Significant impact on the visual amenity and pedestrian function of the park, which rises as it moves towards Central Station and contains a busy pedestrian path. The lowered park would involve walking down into the park and then back out and would involve large-scale re-landscaping of the park;
- Impact on well-established trees that are part of City of Sydney's 'Significant Trees' register. The basin has been located in an area that is generally free of trees but there is not enough cleared space to place a basin that does not affect at least some trees. The 'Significant Trees' register lists 7 species of trees in the area and lists their age and location in a historically-significant park as being factors in the trees' value; and
- Possible contamination issues with excavating land. The extent of possible contamination issues is not known for Belmore Park but experience of other parks in inner Sydney suggest there may be contaminated fill.

Overall, the benefits resulting from the lowered park are not large enough to offset the significant social and environmental impacts resulting from the works. The benefit is a reduction in flood level on Hay Street that removes part of the road flood risk in a 10% AEP event. Given that the road inundation on Elizabeth Street is not addressed, which has a much higher volume of traffic than Hay Street, and the likely social and environmental impacts are significant, the option is not considered viable.

9.3.5. Drainage Upgrade – Elizabeth Street to Outlet (FM – DH05)

Option Description

Option FM – DH-05 describes a trunk upgrade between Elizabeth Street and the outlet with the goal of mitigating flooding in the 1% AEP event. The 1% AEP event is used as the existing flood behaviour inundates many commercial premises and mitigation works may be able to offset the requirements of an FPL in the catchment that is set at the 1% AEP level. The proposed upgrade consists of an approximately 1.3 km long 1.8 m diameter pipe between Elizabeth Street and the outlet at Darling Harbour, following the existing trunk drainage line. The pipe only drains runoff at Elizabeth Street so as to avoid drainage pits along its length that reduce its hydraulic pressure. Although it only drains runoff at Elizabeth Street, the pipe is designed to benefit Hay Street and Darling Harbour downstream, by reducing flow into these areas from Elizabeth Street. As the pipe is full from its drainage on Elizabeth Street, this is essentially the same as having a series of drainage points along Elizabeth Street and Hay Street. The additional hydraulic pressure is designed to offset the flat gradient of the catchment through Hay Street and Darling Harbour, which inhibits pipe peak flow rates. The Elizabeth Street and Hay Street hotspots' flood behaviour is shown on Figure 23 and Figure 27 while Figure 29 shows the location of the raised section.

Modelled Impacts

The proposed works achieve significant reduction in flood level on Hay Street and on Elizabeth Street. The impact of the proposed works on the 1% AEP flood level is shown on Figure 29. The reduction shown on the figure is around 0.2 m on Hay Street between Elizabeth Street and Harbour Street, while Elizabeth Street also has around 0.2 m reduction. The reduction results in a depth on Hay Street of around 0.1 m at Belmore Park, 0.3 m upstream of George Street and 0.4 – 0.8 m downstream of George Street, while Elizabeth Street has less 0.1 m depth. As shown on the figure, the overland flow reduces by 5.8 m^3/s near Belmore Park and by 1.5 m^3/s at the downstream end of Hay Street. The reduction in flow and level corresponds to increased road serviceability, particularly on Elizabeth Street, and reduced overfloor flooding, particularly downstream of George Street. However, the reduction in flood level and property affectation in 1% AEP event is limited downstream of George Street, as a significant depth of flow remains. In general, the pipe has more limited effect in the downstream areas where there is more contributing catchment from the CBD area, while the pipe takes flow from the Surry Hills part of the catchment.

Figure 30 shows the change in hydraulic hazard in the 1% AEP event due to the upgrade. The figure shows that the upgrade's reduction in overland flow significantly changes the area's hydraulic hazard. The main area of change is on Hay Street between Pitt Street and Elizabeth Street where the high hazard flowpath is reduced to low hazard. There are also areas of reduction in parts of Darling Harbour. The high hazard flowpath downstream George Street on Hay Street is largely unchanged.

Evaluation

The upgraded trunk drainage would provide significant benefit to the area's flood risk but would have significant constructability issues and would not completely relieve 1% AEP flooding on Hay Street. The new drainage pipe drains a significant portion of runoff on Elizabeth Street, which in turn reduces flow downstream on Hay Street and into Darling Harbour. This corresponds to increased serviceability for Elizabeth Street, which would be largely flood free up to a 1% AEP event, and Hay Street, while also improving property flooding along Hay Street. The large contributing catchment at the west end of Hay Street means that the inundation at this location is only partially mitigated by the option. The proposed works are extensive and would likely involve significant constructability issues in two main areas: incorporating the 1.8 m diameter pipe into the high density of existing services (including stormwater drainage) and design of the additional pit inlet capacity on Elizabeth Street and surrounds. Economic assessment of the option is given in Section 9.3.9.

9.3.6. Drainage Upgrade – Pyrmont Street to Outlet (FM – DH06)

Option Description

Option FM – DH-06 describes a trunk upgrade from Pyrmont Street to the outlet with the goal of reducing road affectation in the 10% AEP event. The 10% AEP event is used as it corresponds with Council's objective to mitigate road flooding up to a 10% AEP event. The proposed upgrade includes the following elements:

- Additional pit capacity at the topographic sag on Pyrmont Street to drain an additional 0.2 m^3/s into the existing drainage line towards Jones Bay Road;
- Additional drainage on Jones Bay Road to the outlet consisting of a 1.5 m x 1.5 m pipe on Jones Bay Road which becomes 2 x 1.5 m x 1.5 m where the drainage turns north, until the outlet into Jones Bay; and
- No additional drainage line on Pyrmont Street as the existing system has capacity to drain the 10% AEP runoff.

These drainage elements are in addition to what currently exists in the location, which would remain in place and is shown on Figure 23. Figure 32 shows the new drainage elements.

Modelled Impacts

The proposed works achieve a significant reduction in flood level for the topographic sag on Pyrmont Street. The impact of the proposed works on the 10% AEP flood level is shown on Figure 32. The reduction in flood level shown on the figure is 0.2 – 0.3 m on Pyrmont Street, which reduces the flooding to below 0.1 m in that event. The new drainage downstream on Jones Bay Road ensures that there is no adverse impact downstream due to the increased pipe flow from Pyrmont Street.

Evaluation

The proposed upgrade would provide minor benefit to the area's flood risk, largely through mitigating the road flooding. The inundated section of Pyrmont experiences localised flooding to a depth large enough to disable cars driving through it. The upgrade would mean the road is serviced by the drainage for up to a 10% AEP event. This would have significant benefit to the road users and pedestrians that use Pyrmont Street. Although there is benefit to the road serviceability, it is a relatively minor road and, compared to other flood-affected roads in the catchment, would not cause significant delays if blocked for 1-3 hours. There is also negligible benefit to property flooding in the hotspot, with only one property identified as benefitting from the reduced flood level.

The works involve large-scale pipe upgrades and therefore may face constructability issues. The upgraded pipes are over 3 m in width towards the outlet and would take up a significant portion of the roadway, which likely already has many services beneath it. The upgrade may be unable to be incorporated into these existing services. The hotspot itself could be serviced by relatively minor works involving additional drainage pits on Pyrmont Street; however, this would cause unacceptable adverse impacts downstream. Furthermore, the benefit of the option largely relates to improves road serviceability, which is not measured by the standard flood damages assessment, and the flooding poses relatively minimal risk to life. These factors make it less justifiable under a multi-criteria matrix assessment (see Section 9.5).

9.3.7. Drainage Upgrade – Black Wattle Place (FM – DH07)

Option Description

Option FM – DH-07 describes a drainage upgrade on Black Wattle Place and Harbour Street with the goal of reducing property affectation in the 5% AEP event. The 5% AEP event is used as it corresponds with Council's objective upgrade the stormwater network to the 5% AEP event. The proposed upgrade includes the following elements:

- Additional pit capacity at the topographic sag Harbour Street where it passes beneath the freeway south of Black Wattle Place, and at Black Wattle Place adjacent to the existing Ausgrid electricity substation; and
- Additional drainage from these two locations consisting of a 0.6 m diameter pipe connected to the existing system beneath Cockle Bay Wharf, which discharges into Darling Harbour.

These drainage elements are in addition to what currently exists in the location, which would remain in place and is shown on Figure 27. Figure 33 shows the new drainage elements.

Modelled Impacts

The proposed works achieve a significant reduction in flood level for the topographic sag on Black Water Place and Harbour Street. The impact of the proposed works on the 5% AEP flood level is shown on Figure 33. The reduction in flood level shown on the figure is 0.2 – 0.4 m on the two streets, which reduces the flooding to below 0.1 m in that event. The new drainage elements ensure the two topographic sags are drained and that affectation at the building and on the road is reduced.

Evaluation

The proposed upgrade would provide minor benefit to the area's flood risk, through both reducing affectation around the substation and improving road serviceability. The building is currently surrounded by around 0.5 m in the 5% AEP event. It is not known what property damage this corresponds to as the internal floor level of the building is not known, or whether there are internal features that can be damaged by inundation. The road flooding is relatively minor except for localised inundation on Harbour Street south-west of the substation.

The construction feasibility of the two 0.6 m pipes is high relative to other options, which require much larger works. The main issues would relate to managing any impact of the construction on the road, which is a major thoroughfare, and secondly to incorporating the drainage into existing services.

9.3.8. Data Collection – Catchment Specific Flood Damages Assessment (FM – DH08)

Description

Option FM-DH08 consists of a catchment specific flood damages assessment of properties in the Sydney CBD and review of cost/benefit analysis of recommended flood modification measures. The catchment specific flood damages assessment would investigate the various property types in the Darling Harbour catchment, describe how properties' different construction materials, entrance types and nature and location of stock relate to the cost of flooding on a property type basis and review both the estimation of flood damages across the catchment and cost/benefit analysis of recommended flood modification measures.

The measure has been included as a site-specific flood modification measure, as it would largely inform the construction of site-specific measures in the catchment. It has also not been scored in the multi-criteria assessment matrix in Section 9.5 as most of the criteria are not relevant to the measure (e.g. impact on flooding, social/environmental cost).

Discussion

Several floodplain risk management options involving large scale drainage upgrades have been evaluated for the Darling Harbour Catchment that have costs in the order of $10 million. The cost/benefit ratios of these options have been estimated at less than 0.6, i.e. reduction in flood damages due to the works is less than half the total cost of the works.

This cost benefit analysis is used to justify and prioritise works and is based on the estimation for flood damages described in Section 5 which relates a depth of flooding to an economic cost on a property basis. This method has several limitations when used for estimating flood damages for the Darling Harbour catchment including:

- Many of the properties are commercial (rather than residential) for which no standard damage curve exists;
- Construction material and building standards within the catchment are variable, with buildings ranging from the 1800s to the present day;
- Type of commercial premises are variable, with a wide range of retail, cafes, bars and restaurants, and specialty services; and
- Many properties within the area have multi floor basements.

These limitations provide some uncertainty as to the accuracy of the estimated flood damages and the cost benefit analysis of proposed flood mitigation works. A catchment specific flood damages assessment would provide an in-depth evaluation the vulnerability of various property types to flooding and provide standard damage curves for typical properties within the catchment. These damage curves will result in a higher degree of accuracy in the assessment of flood damages and provide more reliable estimates of the reduction in damages for various mitigation options.

Evaluation

The catchment specific flood damages assessment will provide more accurate information on flood damages within the Darling Harbour catchment and provide a more reliable assessment of the benefits of flood mitigation options, potentially providing a greater economic justification for the large-scale pit and pipe works in the catchment.

9.3.9. Economic Assessment of Site Specific Options

The cost effectiveness of the site specific management options in reducing flood liability within the catchment was determined using the benefit/cost (B/C) approach. A costing was estimated for each option and this was compared, where appropriate, to the option's reduction in AAD. Where no significant benefit to AAD was found, the option's cost effectiveness was assessed qualitatively.

Costing

Detailed cost estimates have been prepared for each option and these are summarised in Table 21, with detailed costing in Appendix C. It is important to note that these are estimates and should be revised prior to the detailed design phase of the options to obtain a more accurate costing. For the trunk drainage upgrade options, the large capacity of the upgrade's pipes meant that the width of the upgrade was comparable to the width of the available area (i.e. roadway and footpaths). Such a large upgrade would incur additional costs due to the re-location of existing services, and this has been accounted for by a higher contingency multiplier in the costing estimates.

Table 21: Costings of Management Options

Option	Capital	Maintenance per year
FM-DH01 Drainage Upgrade – Commonwealth Street	$ 1,200,000	$ 12,540
FM-DH02 Drainage Upgrade – Elizabeth Street	$ 8,096,900	$ 4,920
FM-DH03 Road Adjustment – Elizabeth Street	ND*	ND
FM-DH04 Park Adjustment – Belmore Park	ND	ND
FM-DH05 Drainage Upgrade – Elizabeth Street to Outlet	$ 10,454,900	$ 12,810
FM-DH06 Drainage Upgrade – Pyrmont Street to Outlet	$ 3,897,500	$ 4,860
FM-DH07 Drainage Upgrade – Black Wattle Place	$ 894,500	$ 1,730

*Not Determined. Option not costed as produced no significant benefit to flood behaviour (DH03) or has large social and environmental impacts (DH04)

Table 21 shows that the drainage capacity upgrade Option FM – DH05 is the most costly, as it involves the longest section of trunk drainage being upgraded, followed by the more localised upgrades, all of which require significantly large works. It should be noted that all cost estimates are largely approximate due to the uncertainty around possible additional costs arising from construction complications in a densely urbanised area. The costs should be used as an indication of order of magnitude and of the relative cost between the options.

Damage Assessment of Options

The total damage costs were evaluated for two of the options and compared against the existing base case, as shown in Table 22. The assessment for the two options was carried out in accordance with OEH guidelines utilising data obtained from the flood level survey and height-damage curves that relate the depth of water above the floor with tangible damages. The damages were evaluated for a range of design events from the 0.5 EY up to the PMF. The mitigation measures' AAD and the 'Existing' AAD that they were compared with each used a less conservative blockage scenario (kerb inlet pits 20% blocked, sag pits 50% blocked) than in the other design results (kerb inlet pits 50% blocked, sag pits 100% blocked), which corresponds to the City's design blockage for pits with lintels > 1.0 m.

The reason for the other five options not being assessed in this way are:

- FM-DH02, FM-DH03, FM-DH06 and FM-DH07 do not produce significant reduction in overfloor inundation; and
- FM-DH04 has some benefit to property flooding but has unacceptable social and environmental impacts.

Table 22: Average Annual Damage Reduction of Management Options

Option	AAD	Reduction in AAD due to Option
FM-DH01 Drainage Upgrade – Commonwealth Street	$ 2,749,241	$ 48,241
FM-DH05 Drainage Upgrade – Elizabeth Street to Outlet	$ 2,702,986	$ 94,496

The results show that the pressurised pipe from Elizabeth Street to the outlet has the greatest reduction in AAD, but that both options have little change to the catchment's economic damages. The Commonwealth Street upgrade reduces flooding for around 13 properties; however, they are still flood affected in events greater than the 5% AEP and the reduction is small relative to the catchment's overall property damage. The large pipe upgrade mostly benefits Elizabeth Street and Hay Street upstream of George Street, while property inundation is more concentrated downstream of George Street. It should be noted that all of the options may underestimate the reduction in flood damages, as the effects of flooding at each commercial property can only be roughly approximated, and that some premises cannot be accurately assessed using the standard damages assessment due to the complexity of flow through them.

Benefit Cost Ratio of Options

Following estimation of the option's cost and AAD, the benefit/cost ratio (B/C) of two of the options was calculated. The B/C is the ratio of the net present worth of the reduction in flood damages (benefit) compared to the cost of the works and is used to compare the economic worth of a set of works to others in the area. Table 23 lists the reduction in AAD due to the options, and compares this to the works' capital and maintenance costs to produce a B/C. The options' B/C was between

0.1 and 0.6, with values above 1 indicating that the economic benefit of the option is greater than its cost.

Table 23: Benefit/Cost Ratio for Management Options

Options	Benefit			Cost Estimate			
	AAD	Reduction in AAD	NPW of AAD Reduction*	Capital	Maintenance (Annual)	NPW of Costs*	B/C Ratio
FM-DH01	$2,749,241	$48,241	$ 712,368	$ 1,200,000	$ 12,540	$ 1,214,900	0.6
FM-DH05	$2,702,986	$94,496	$ 1,395,399	$ 10,454,900	$ 12,810	$ 10,644,100	0.1

* NPW: Net present worth calculated over 50 years at 7%,

The two options presented in Table 23 have a B/C of less than 1, indicating they are not economically feasible. However, as described in this section, the high-density urban area means that both the cost of works and the estimate of property damage have large uncertainties. As described, the cost has factored the space constraints into the estimate, but there may be further construction issues that increase the cost.

The analysis does not consider social factors, environmental factors and risk to life which cannot be quantified in monetary terms but would have been a net contributor to the benefits that could be gained from these management options.

9.4. Catchment Wide Management Options

9.4.1. Property Modification - Flood Planning Levels (PM – DH01)

The flood planning level (FPL) is used to define land subject to flood related development controls and is generally adopted as the minimum level to which floor levels in the flood affected areas must be built. The FPL includes a freeboard above the design flood level. It is common practice to set minimum floor levels for residential buildings, garages, driveways and even commercial floors as this reduces the frequency and extent of flood damages. Freeboards provide reasonable certainty that the reduced level of risk exposure selected (by deciding upon a particular event to provide flood protection for) is actually provided.

The main aim of the FPLs is to reduce the damages experienced by the property owner during a flood. Elevating a house floor level above the FPL will ensure that flood damages are significantly reduced. Council have specified FPL requirements in their *Interim Floodplain Management Policy* prior to the completion of the Floodplain Risk Management Plans for the entire LGA and we endorse this move. It is important that the same requirements are applied throughout the LGA to new development or redevelopments regardless of whether the Floodplain Risk Management Plan have been completed for the catchment or not. The only exception would be if the Floodplain Risk Management Plan proposes a change to these FPLs.

9.4.2. Property Modification - Development Control Planning (PM – DH02)

The Interim Floodplain Management Policy provides general requirements for new developments on flood liable land within the catchment, Flood Planning Level requirements for different development types and guidelines on flood compatible materials. This document serves as an interim policy for managing floodplain within the Council LGA which will be withdrawn once Council complete Floodplain Risk Management Plans for the entire LGA and then integrate outcomes from these plans into planning controls.

9.4.3. Property Modification - Flood Proofing (PM – DH03)

An alternative to house raising for buildings that are not compatible or not economically viable, is flood proofing or sealing off the entry points to the building. This measure has the advantage that it is generally less expensive than house raising and causes less social disruption. Flood proofing requires sealing of doors and possibly windows (new frame, seal and door); sealing and re-routing of ventilation gaps in brick work; sealing of all underfloor entrances and checking of brickwork to ensure there are no gaps or weaknesses in mortar. It is generally only suitable for brick buildings with concrete floors and it can prevent ingress from outside depths of up to one metre. Greater depths may cause structural problems (buoyancy) unless water is allowed to enter. Generally an existing house can be sealed for approximately $10,000. New development and extensions allow the inclusions of flood appropriate materials and designs meaning the actual cost of flood proofing can be significantly less when compared to buildings requiring retro-fitting of flood proofing measures.

Flood proofing should also consider suitable electrical installation to as to avoid the risk of electrocution. A minimum aim should be to have all properties in flood hazard areas to, at least, be fitted with a circuit breaker although ideally for all new development all unsealed electrical circuits should be at the Flood Planning Level (FPL).

Additionally, flood proofing can involve the raising of easily damaged/high cost items such as commercial stock, equipment and machinery. New buildings should have floor levels above the flood planning level.

Permanent flood proofing measures are more suitable for commercial and industrial buildings where there are only limited entry points and aesthetic considerations are less of an issue. Also there are issues of compliance with other regulations such as fire safety and maintenance issues as well as access issues. However flood compatible building or renovating techniques should be employed for extensions or renovations where appropriate.

Minimising the chance of electrocution by turning off the electricity supply during a flood should be standard practice for both residents and commercial owners during floods. The risk of electrocution can also be reduced by installing electrical circuits above, at least, the flood planning level.

With regards to commercial properties in the catchment, responsibility for flood-proofing should fall to property owners, and should be initiated by the City. The majority of buildings in these areas have a single owner that then leases different floors or suites to tenants. The majority of ground floor premises are commercial, with some properties having multiple ground floor tenants. Commercial premises are varied in nature, with the degree of flood risk often dependant on a store's contents and its location relative to the ground. This means that different flood-affected premises require different types of flood-proofing. The building owners can determine the most appropriate measures for their property, depending on the degree of flood affectation and the nature of the commercial premises, and carry out suitable flood proofing. It is recommended that City of Sydney carry out a consultation program with flood affected properties (i.e. those in flooding hotspots) in order to provide information to building owners about possible flood proofing options.

9.4.4. Property Modification – Feasibility Study for City of Sydney Flood Proofing (PM – DH04)

DESCRIPTION

As discussed in the previous option, flood proofing involves modifications to a building's exterior in order to prevent the ingress of floodwater. The option recommended that for most of the catchment, flood proofing should be the responsibility of property owners. For residential houses in the catchment (largely in Surry Hills and Pyrmont), where flood proofing is not undertaken by property owners, it may be possible for City of Sydney to undertake mitigation works if the property is put up for sale. That is, for a severely flood affected properties, City of Sydney may purchase the property so that works on it can be undertaken, and then the property is put up for sale soon after. Such a scheme would be most suited to areas with significant overfloor flood affectation where structural measures (for example, drainage upgrades) are not feasible.

DISCUSSION

A Council-led program that involves the purchase, renovation and selling of flood-affected land is a straightforward variation on other Council-led property modification measures, and will provide benefit to properties that do not have other available options. The nature of the flood issue in the catchment is that although there is significant overfloor flood affectation, it is concentrated in several localised areas. This makes structural options difficult to justify, and it is possible that a property's flood risk will remain indefinitely.

As the option can only be implemented when an affected property is put on sale, such a program's implementation would be very gradual and would be undertaken over a long period of time. In this sense, the option is an extension of Council's FPL policy, whereby minimum floor levels are required when a flood-affected property is re-developed. A Council-led flood proofing program would account for the flood affected properties that are not re-developed and therefore would not otherwise have their floor levels raised.

Although such a program has some similarity to a voluntary purchase scheme, it would be markedly less obtrusive and would not reduce the number of dwellings in the catchment. Voluntary purchase involves returning severely-affected land on a floodway to the floodplain, whereas in the Darling Harbour catchment, affected properties are not necessarily on a floodway and restoring an area's natural flowpath (for example, in a trapped depression) would adversely impact downstream properties and may impact an area's streetscape and character. Most significantly, a flood proofing program would only involve properties that are available for purchase, meaning there would be no disruption to the existing property market. This would be further ensured by having no publicly available information on which properties would be targeted by such a program.

EVALUATION

A flood proofing program undertaken by the City of Sydney could significantly alleviate property affectation and give Council an alternative to drainage upgrades in areas where they are prohibitively expensive and not cost-effective. It would also allow Council to extend their objective of raising flood affected properties (via an FPL) to affected properties by improving properties that may not otherwise have their floor level raised. Although such a program has several apparent benefits, its feasibility should be investigated further to determine whether it can be cost-effective (based on the cost of purchasing, flood-proofing and re-selling a property compared to the existing economic cost of flooding) and what social impacts may exist.

9.4.5. Response Modification - Flood Warning and Evacuation (RM – DH01)

Flood warning can significantly reduce damages and risk to life and studies have shown that flood warning systems generally have high benefit/cost ratio if sufficient warning time is provided.

Flood warning and the implementation of evacuation procedures by the SES are widely used throughout NSW to reduce flood damages and protect lives. The Bureau of Meteorology (BoM) is responsible for flood warnings on major river systems and the SES is disseminating these warning to the local community. Adequate warning gives residents time to move goods and cars above the reach of floodwaters and to evacuate from the immediate area to designated evacuation points or flood free ground. The effectiveness of a flood warning scheme, known as the effective flood warning time, depends on:

- The maximum potential warning time before the onset of flooding;
- The actual warning time provided before the onset of flooding. This depends on the adequacy of the information gathering network and the skill and knowledge of the operators; and
- The flood awareness of the community responding to a warning.

For overland flow flooding providing a flood warning is more difficult than for area impacted by mainstream floods. For river systems, predictions of potential peak flood height and timing are possible with a high degree of reliability afforded by upstream gauges. However, predicting urban overland flow peak flood levels is not necessarily practicable. Overland flooding usually occurs soon after, or at the same time, as intense rainfall. Spatial differences in the rainfall patterns may go undetected by the sparse rainfall gauge network. Furthermore the extent of flood levels can vary over the study area. Therefore, weather warnings are often more useful with regard to providing warning to residents and businesses. Weather warnings issued by BOM can advise if flooding is expected.

Given the speed with which floods can occur a more realistic system may be the additional service of communication of flood risk via SMS alerts or online social media, i.e. Twitter, Facebook etc. the responsibility for which would be SES with assistance from City of Sydney, RMS and other authorities. The measure may also involve establishing a system where existing electronic signage on major roads is used to warn of a flood event occurring, and not to drive into floodwaters. The SES would be responsible for this with assistance from City of Sydney, RMS and other authorities.

The changing use of the CBD over the course of a day means that the response will be largely dependent on the time of day the flooding occurs. For example, flooding during rush hour (approximately 7:30 am to 9:30 am and 4:30 pm to 6:30 pm on weekdays) will disrupt a large number of commuters and drivers, with most city streets having constant traffic between 7:00 am and 7:00 pm on weekdays. This means that people are likely to react to flooding as a crowd, whereby observed danger to a single person (e.g. crossing fast moving or deep water) will then influence the onlookers, and generally improve pedestrians' decision making. A flood event then will also mean emergency services will have very impaired road access. A flood event outside these hours will affect far fewer people, with most buildings empty at night, but there is higher risk of an individual taking a dangerous action (e.g. walking or driving into floodwaters).

9.4.6. Response Modification - Flood Emergency Management (RM – DH02)

It may be necessary for some occupants to evacuate buildings in a major flood. This would usually be undertaken under the direction of the lead agency under the EMPLAN, the SES. Some people may choose to leave on their own accord based on flood information from the radio or other warnings, and may be assisted by local residents. The main problems with all flood evacuations are;

- They must be carried out quickly and efficiently;
- There can be confusion about 'ordering' evacuations, with rumours and well-meaning advice taking precedence over official directions which can only come from the lead agency, the SES;
- They are hazardous for both rescuers and the evacuees;
- Residents are generally reluctant to leave their homes, causing delays and placing more stress on the rescuers;
- People (residents and visitors) do not appreciate the dangers of crossing floodwaters; and
- In dense urban areas (such as the Darling Harbour catchment), a designated evacuation area will become quickly congested, and it will generally be safer to stay indoors on an above-ground level.

For this reason, the preparation of a flood emergency response plan helps to minimise the risk associated with evacuations by providing information regarding evacuation routes, refuge areas and what to do/not to do during floods. It is the role of the Regional Emergency Management Committee and Local Emergency Management Committee to develop these plans for vulnerable communities.

A REMPLAN should be prepared for the Sydney West Emergency Management Region (of which Darling Harbour catchment is part) to outline emergency response arrangement specific to the district.

Further, it is recommended that a LEMPLAN with consequent management guide - flood by the Local Emergency Management Committee to outline the following details:

- Evacuation centres in close proximity to the floodplain which are flood free sites with flood free access;
- Recommend and organise responsibility for the use of Variable Message Signs for use during a flood event for flood affected roads;
- Inclusion of a description of local flooding conditions;
- Identification of potentially flood affected vulnerable facilities; and
- Identification of key access road subject to flooding.

Although flood warning is limited, a local disaster plan should be continually updated to include the latest information on design flood levels and details on roads, properties, and other facilities which would be flood affected. The plan should give particular focus to the severely affected areas and identify areas where people can simply move up within a building to escape flood risk. In this catchment, moving up to an above ground level of a building will greatly reduce the flood risk to an individual. Areas with some of the highest flood risk will be underground garages/car parks in areas with significant flood affectation, where runoff can potentially inundate and fill the below-ground space. Discussion of evacuation should also acknowledge the difficulty with moving out of the catchment during a flood event (due to the high density of people and the limited road/footpath capacity) and that people will often be safest remaining in above ground levels of buildings, for example, in shops, department stores, shopping malls, office buildings or hotels.

9.4.7. Response Modification - Community Awareness Programme (RM – DH03)

The success of any flood warning system and the evacuation process in reducing flood losses and damages depends on:

- *Flood Awareness*: How aware is the community of the flood threat? Has it been adequately informed and educated?
- *Flood Preparedness*: How prepared is the community to react to the threat of flooding? Do they (or the SES) have damage minimisation strategies (such as sand bags, raising possessions) which can be implemented?
- *Flood Evacuation*: How prepared are the authorities and the residents to evacuate households to minimise damages and the potential risk to life during a flood? How will the evacuation be done, where will the evacuees be moved to?

Public information and the level of public awareness are keys in reducing flood damages and losses. A more aware community will suffer less losses and damage than an unprepared community.

The importance of flood awareness was noted by City of Sydney after flooding on the 24th August 2015. The event, which caused flooding in most of the hotspots, confirmed expected flood behaviour in a number of areas, including Pitt Street Mall and King Street in the adjacent catchment. It was noted that data from this event, particularly photos and videos that showed the flood behaviour in well-known locations, clearly communicated the possible flooding behaviour in the area. It was also noted that such data was not necessarily shared with City of Sydney from people who took photos or videos, and that a coordinated campaign, such as a dedicated website or social media account methods for collecting people's experiences, is required to collect a more complete picture of the event. It is recommended that this be incorporated into any community awareness programme set up for the area.

9.5. Assessment Matrix

9.5.1. Background

Multi-variate decision matrices are recommended in the Floodplain Development Manual (Reference 1) and therefore it is also a recommendation of this report that multi-variate decision matrices be developed for specific management areas, allowing detailed benefit/cost estimates, community involvement in determining social and other intangible values, and local assessment of environmental impacts.

The criteria assigned a value in the management matrix are:

- Risk to life;
- Impact on flood behaviour (reduction in flood level, hazard or hydraulic categorisation) over the range of flood events;
- Number of properties benefited by measure;
- Technical feasibility (design considerations, construction constraints, long-term performance);
- Community acceptance and social impacts;
- Economic merits (capital and recurring costs versus reduction in flood damages);
- Financial feasibility to fund the measure;
- Long term performance;
- Environmental and ecological benefits;
- Impacts on the State Emergency Services;
- Political and/or administrative issues; and
- Long-term performance given the potential impacts of climate change.

The scoring system for the above criteria is provided in Table 24 and largely relates to the impacts in a 1% AEP event. The matrix below is designed to set out a general scheme to illustrate how a local matrix might be developed. These criteria and their relative weighting may be adjusted in the light of community consultations and local conditions. Tangible costs and damages are also used as the basis of B/C analysis for some measures.

Table 24: Matrix Scoring System

SCORE:	-3	-2	-1	0	1	2	3
Impact on Flood Behaviour	>100mm increase	50 to 100mm increase	<50mm increase	no change	<50mm decrease	50 to 100mm decrease	>100mm decrease
Number of Properties Benefited	>5 adversely affected	2-5 adversely affected	<2 adversely affected	none	<2	2 to 5	>5
Technical Feasibility	major issues	moderate issues	minor issues	neutral	moderately straight-forward	Straight-forward	no issues
Community Acceptance	majority against	most against	some against	neutral	minor	most	majority
Economic Merits	major disbenefit	moderate disbenefit	minor disbenefit	neutral	low	medium	high
Financial Feasibility	major disbenefit	moderate disbenefit	minor disbenefit	neutral	low	medium	high
Environmental & Ecological Benefits	major disbenefit	moderate disbenefit	minor disbenefit	neutral	low	medium	high
Impacts on SES	major disbenefit	moderate disbenefit	minor disbenefit	neutral	minor benefit	moderate benefit	major benefit
Political / administrative Issues	major negative	moderate negative	minor negative	neutral	few	very few	none
Long Term Performance	major disbenefit	moderate disbenefit	minor disbenefit	neutral	positive	good	excellent
Risk to Life	major increase	moderate increase	minor increase	neutral	minor benefit	moderate benefit	major benefit

9.5.2. Results

The assessment matrix is given in Table 25, with each of the assessed management options scored against the range of criteria. It is important to note that the approach undertaken does not provide an absolute “right” answer as to what should be included in the Management Plan but is rather for the purpose of providing an easy framework for comparing the various options on an issue by issue basis which stakeholders can then use to make a decision. For the same reason, the total score given to each measure, and the subsequent rank, is only an indicator to be used for general comparison.

Table 25: Multi-Criteria Assessment of Management Options

Ref	Option	Section in Report	Design Event (AEP)	Impact on Flood Behaviour	Number of Properties Benefited	Technical Feasibility	Community Acceptance[1]	Economic Merits	Financial Feasibility	Environmental/Ecological Benefits	Impact on SES	Political/Admin Issues	Long Term Performance	Risk to Life	Total Score	Rank (Total)
Flood Modification Measures																
FM-DH01	Pit and Pipe Upgrade – Commonwealth Street	9.4.1	5%	2	3	-2	-1	2	-2	0	2	-2	1	2	5	7
FM-DH02	Trunk Upgrade – Elizabeth Street	9.4.2	10%	2	2	-3	-1	1	-3	0	2	-3	1	1	-1	11
FM-DH03	Road Adjustment – Elizabeth Street	9.4.3	10%	0	0	-1	-1	0	-1	0	0	-2	2	0	-3	14
FM-DH04	Park Adjustment – Belmore Park	9.4.4	10%	2	1	0	-1	1	-1	-3	1	-3	1	0	-2	12
FM-DH05	Trunk Upgrade – Elizabeth Street to Outlet	9.4.5	1%	3	3	-3	-1	2	-3	-1	2	-3	1	1	1	9
FM-DH06	Trunk Upgrade – Pyrmont Street to Outlet	9.4.6	10%	1	1	-2	-1	1	-2	-1	1	-2	1	1	-2	12
FM-DH07	Drainage Upgrade – Black Wattle Place	9.4.7	5%	2	1	-1	-1	1	-2	0	1	-2	1	0	0	10
Property Modification Measures																
PM-DH01	Property Modification - Flood Planning Levels	9.5.1	N/A	0	0	0	0	2	2	0	1	0	3	1	9	2
PM-DH02	Property Modification - Development Control Planning	9.5.2	N/A	0	0	0	0	2	2	0	1	1	3	1	10	1
PM-DH03	Property Modification - Flood Proofing	9.5.3	N/A	0	0	-1	0	2	1	0	1	-1	2	1	5	7
PM-DH04	Property Modification - Feasibility Study for City of Sydney Flood Proofing	9.5.4	N/A	0	0	0	0	1	2	0	1	2	1	1	8	3
Response Modification Measures																
RM-DH01	Response Modification - Flood Warning and Evacuation	9.5.5	N/A	0	0	-1	0	1	2	0	2	2	0	2	8	3
RM-DH02	Response Modification - Flood Emergency Management	9.5.6	N/A	0	0	-1	0	2	2	0	2	1	0	1	7	6
RM-DH03	Response Modification - Community Awareness Programme	9.5.7	N/A	0	0	2	0	2	2	0	2	1	-2	1	8	3

[1] *Community Acceptance scores were based on a limited number of submissions received following the public exhibition period.*

As shown in the matrix, most the structural measures score lowly on economic merit, as they do not have favourable B/C ratios, and on financial feasibility, as all require a large capital outlay. In addition, they have technical feasibility issues, either relating to the potential issues in the design of the required drainage or ground lowering. Low scores in these three categories result in a much lower score than most of the response modification and property modification measures.

The five highest ranking measures scored between 8 and 10, which indicates that they are all generally equivalent under this assessment. They all require relatively little financial outlay, and will lower the economic cost of flooding in the catchment. Flood Proofing also scores well, but ranks lower due to its potential political/administrative issues and lower technical feasibility

Voluntary purchase is difficult to justify as it is has issues with its technical feasibility, in that it would be very different to a typical VP scheme, and the political/administrative issues associated with buying flood-affected houses.

Based on the matrix, the options for future implementation are ranked in the order as tabulated in Table 26.

Table 26: Ranking of Management Options

Rank	Ref	Options	Score
10	PM-DH02	Property Modification - Development Control Planning	0
10	PM-DH01	Property Modification - Flood Planning Levels	0
3=	PM-DH04	Property Modification - Feasibility Study for City of Sydney Flood Proofing	0
3=	RM-DH01	Response Modification - Flood Warning and Evacuation	8
3=	RM-DH03	Response Modification - Community Awareness Programme	8
6	RM-DH02	Response Modification - Flood Emergency Management	7
7=	FM-DH01	Pit and Pipe Upgrade – Commonwealth Street	5
7=	PM-DH03	Property Modification - Flood Proofing	0
9	FM-DH05	Trunk Upgrade – Elizabeth Street to Outlet	1
10	FM-DH07	Drainage Upgrade – Black Wattle Place	0
11	FM-DH02	Trunk Upgrade – Elizabeth Street	-1
12=	FM-DH04	Park Adjustment – Belmore Park	-2
12=	FM-DH06	Trunk Upgrade – Pyrmont Street to Outlet	-2
14	FM-DH03	Road Adjustment – Elizabeth Street	-3

Note: '=' denotes equal position. E.g. '3=' refers to equal third rank.

Of the 14 management options presented here, 11 have been recommended for implementation as part of the Darling Harbour Catchment Floodplain Risk Management Plan. The three discarded options are FM-DH04, DM-DH06 and FM-DH03. These options have very minor benefit (FM-DH06), have adverse impacts (FM-DH03) or have significant social and environmental impacts (FM-DH04).

10. ACKNOWLEDGEMENTS

WMAwater wish to acknowledge the assistance of the City of Sydney Council staff and the Floodplain Management Committee in carrying out this study as well as the NSW Government (Office of Environment and Heritage) and the residents and business operators of the Darling Harbour catchment. This study was jointly funded by the City of Sydney Council and the NSW Government. The cover page image is used courtesy of Wikimedia Commons user Adam.J.W.C.

11. REFERENCES

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   Floodplain Development Manual
   April 2005

2. BMT-WBM
   Darling Harbour Flood Study
   Final Report, 2014

3. Sydney Water
   City Area (SWC 29) Capacity Assessment
   December 1991

4. City of Sydney
   Interim Floodplain Management Policy
   May 2014

5. NSW Department of Environment and Climate Change
   Flood Emergency Response Classification of Communities
   October 2010

6. Howells *et. al.*
   Defining the Floodway – Can One Size Fit All?
   2004

7. NSW Department of Environment and Climate Change
   Floodplain Risk Management Guideline – Residential Flood Damages
   October 2007

Figures

FIGURE 1
STUDY AREA
DARLING HARBOUR CATCHMENT

J:\Jobs\114095\ArcGIS\Darling_Harbour\Maps\Stage_2\Figure01_StudyArea.mxd

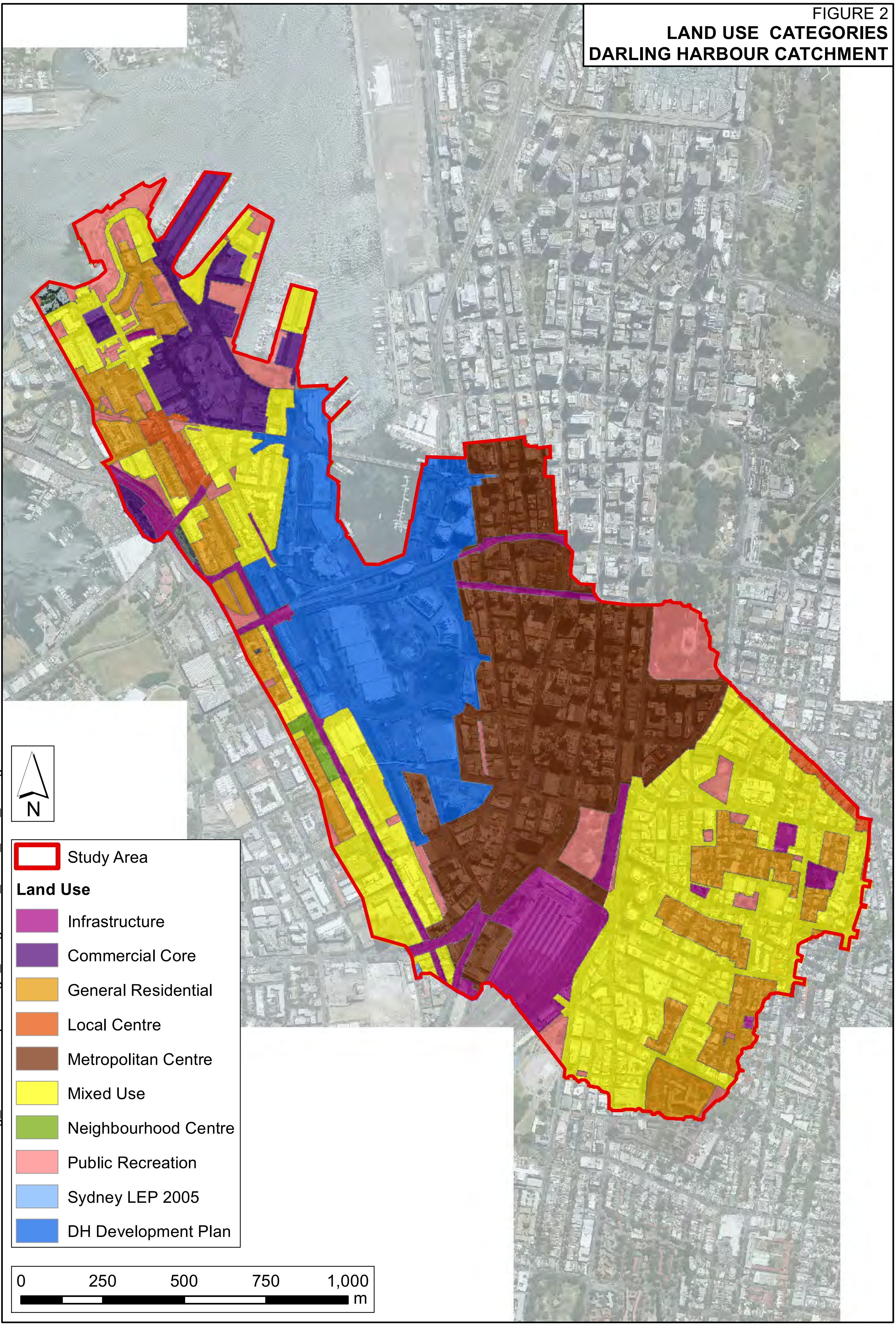
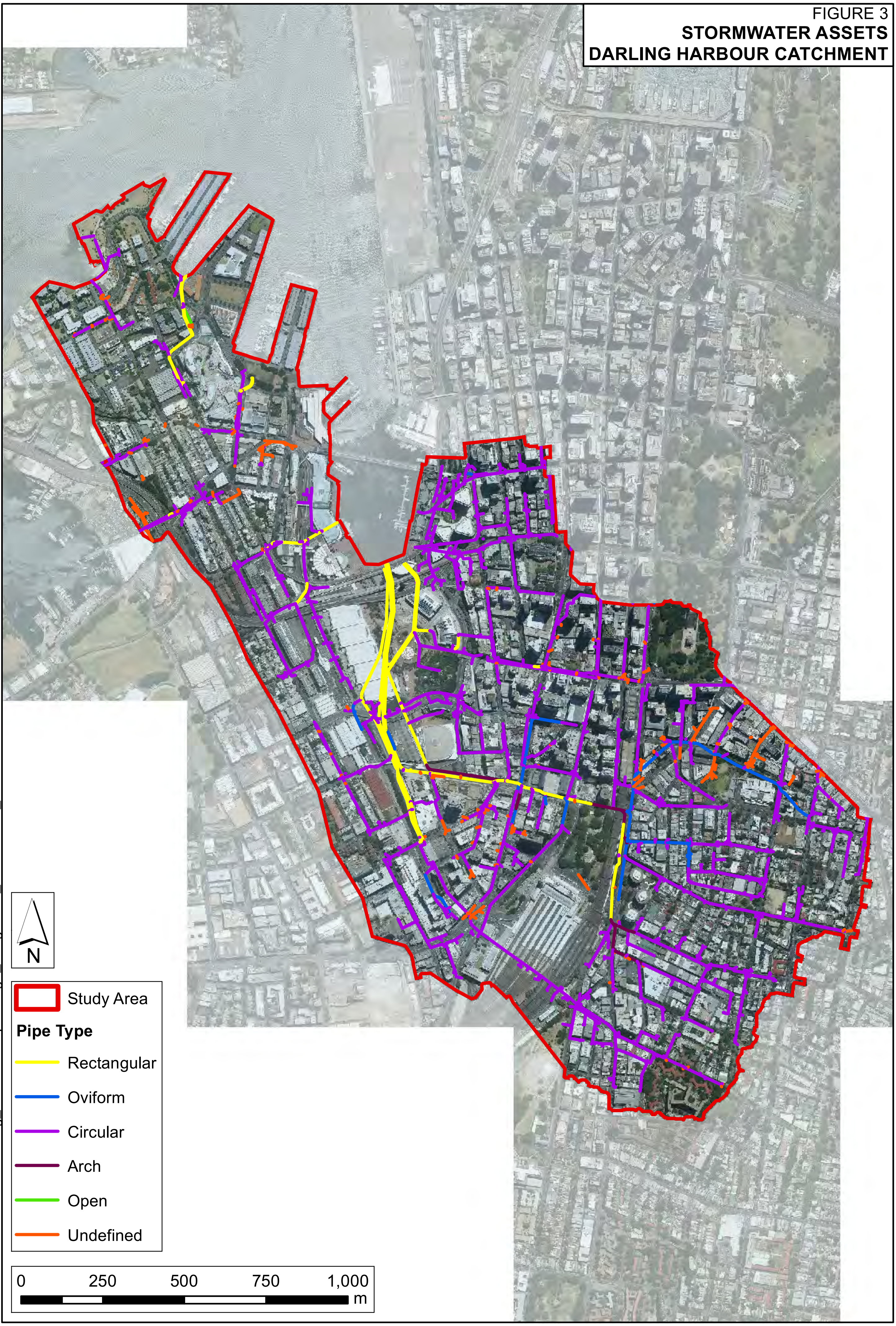


FIGURE 2
LAND USE CATEGORIES
DARLING HARBOUR CATCHMENT

J:\Jobs\114095\ArcGIS\Darling_Harbour\Maps\Stage_2\Figure02_Land_Use_Categories.mxd

FIGURE 3
STORMWATER ASSETS
DARLING HARBOUR CATCHMENT



J:\Jobs\114095\ArcGIS\Darling_Harbour\Maps\Stage_2\Figure03_Stormwater_Assets.mxd


FIGURE 4
HOTSPOT LOCATIONS
DARLING HARBOUR CATCHMENT
0.7 m
Near Tumbalong Park
1.1 m
Hay St near Thomas St
Union St
Western Distributor Freeway
George St
Hay St
Pitt St
Commonwealth St
0.5 m
Elizabeth St and Hay St
1.1 m
Commonwealth St near Reservoir St
N
Approx. 1% AEP Flood Level
Study Area
Hotspot Locations
0
250
500
750
1,000
m
J:\Jobs\114095\ArcGIS\Darling_Harbour\Maps\Stage_2\Figure04_Hotspots_Locations.mxd

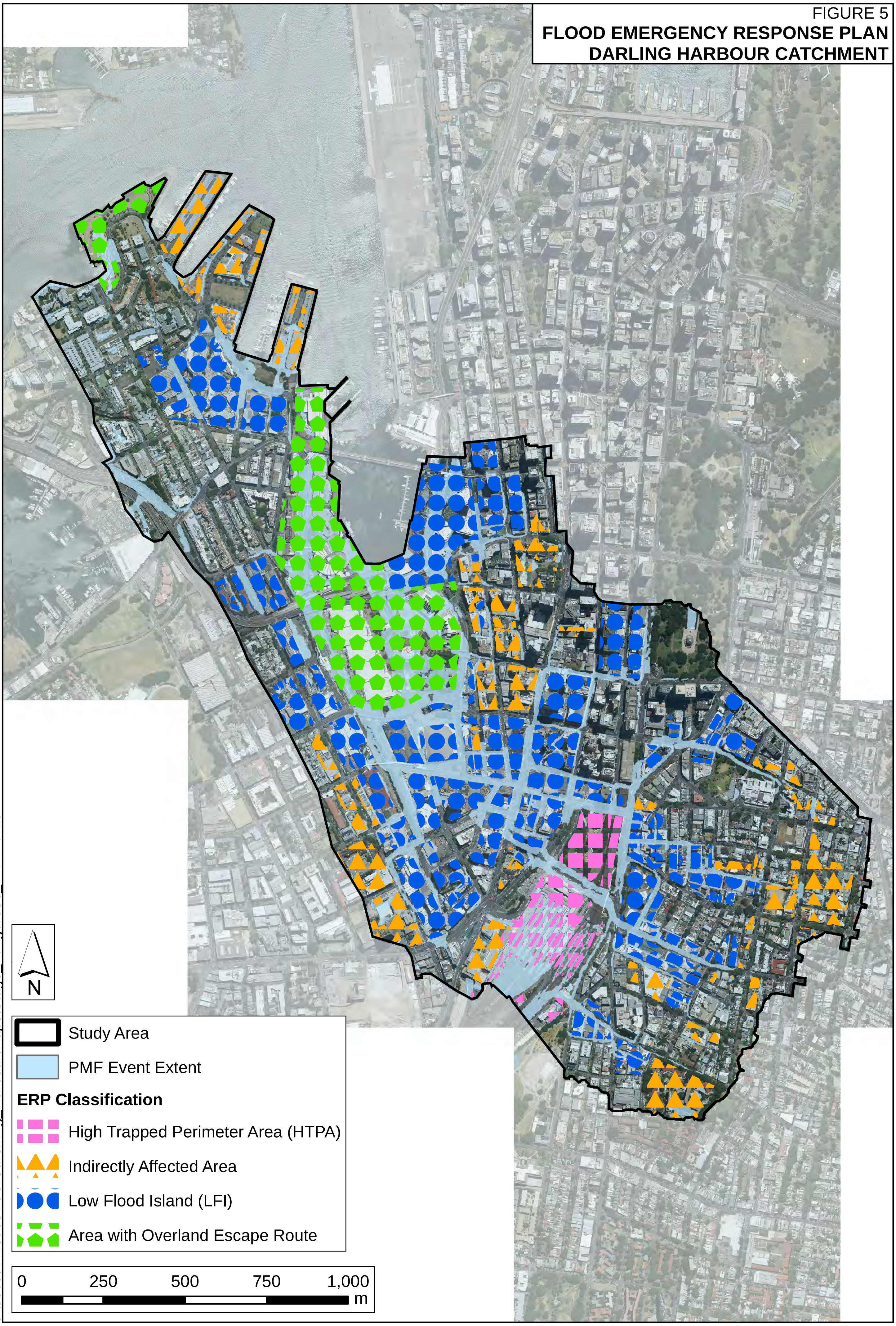
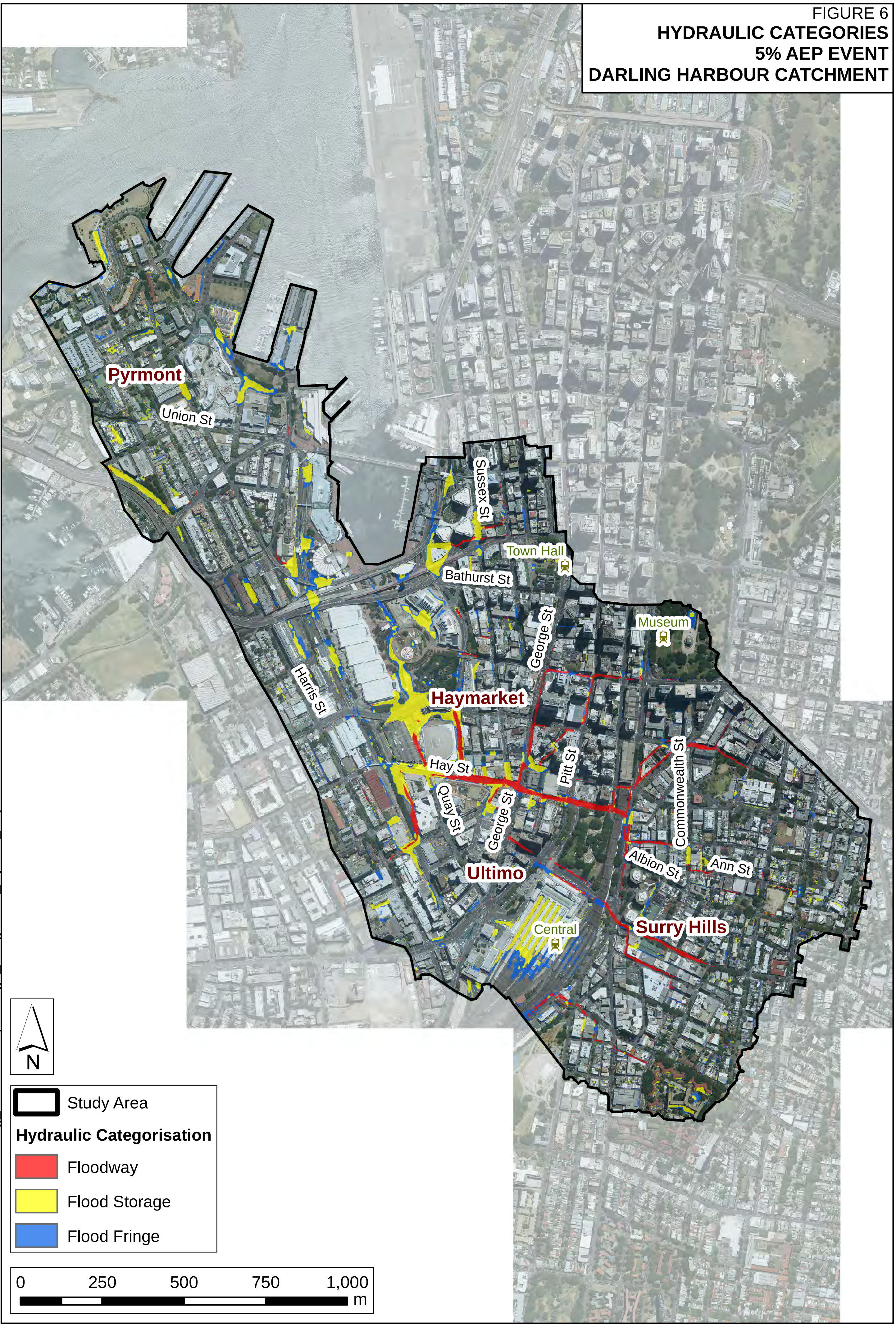


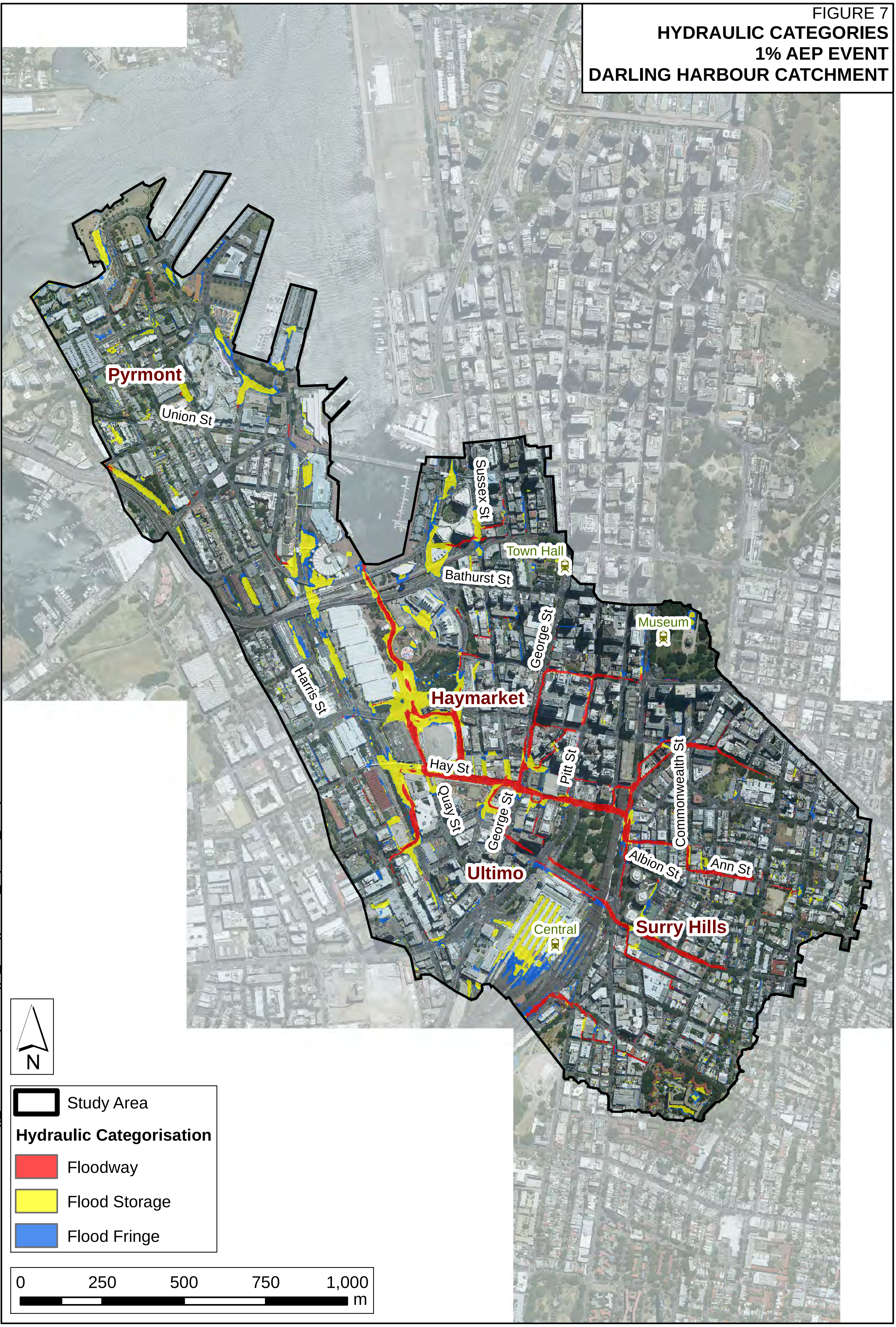
FIGURE 5
FLOOD EMERGENCY RESPONSE PLAN
DARLING HARBOUR CATCHMENT
N
Study Area
PMF Event Extent
ERP Classification
High Trapped Perimeter Area (HTPA)
Indirectly Affected Area
Low Flood Island (LFI)
Area with Overland Escape Route
0
250
500
750
1,000
m
J:\Jobs\114095\ArcGIS\Darling_Harbour\Maps\Stage_2\Figure05_FERP.mxd

FIGURE 6
HYDRAULIC CATEGORIES
5% AEP EVENT
DARLING HARBOUR CATCHMENT



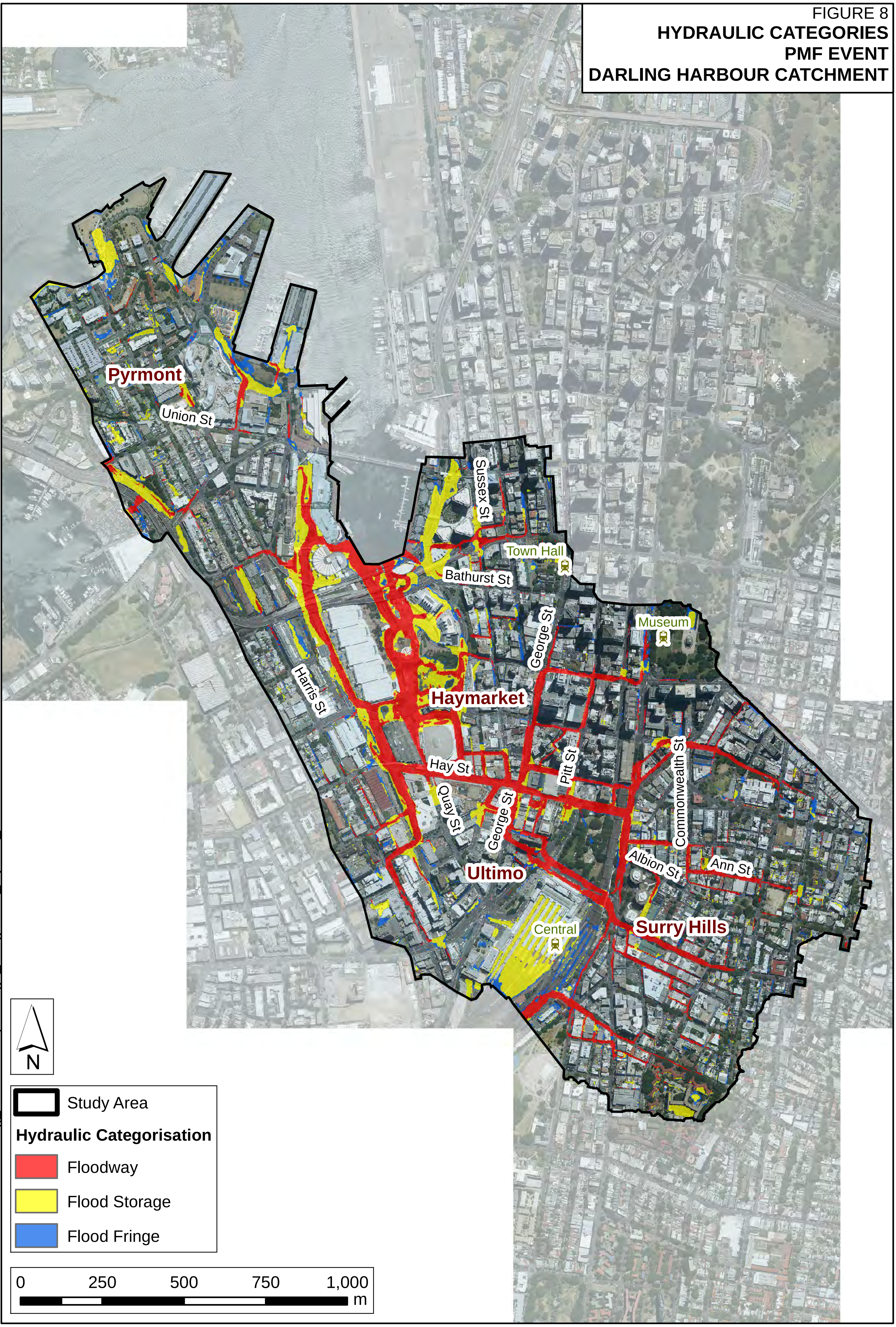
J:\Jobs\114095\ArcGIS\Darling_Harbour\Maps\Stage_2\Figure06_Hydcat_20y.mxd

FIGURE 7
HYDRAULIC CATEGORIES
1% AEP EVENT
DARLING HARBOUR CATCHMENT



J:\Jobs\114095\ArcGIS\Darling_Harbour\Maps\Stage_2\Figure07_Hydcat_100y.mxd

FIGURE 8
HYDRAULIC CATEGORIES
PMF EVENT
DARLING HARBOUR CATCHMENT



J:\Jobs\114095\ArcGIS\Darling_Harbour\Maps\Stage_2\Figure08_Hydcat_PMF.mxd

FIGURE 9
HAZARD CATEGORIES
0.5 EY EVENT
DARLING HARBOUR CATCHMENT
Pyrmont
Union St
Sussex St
Town Hall
Bathurst St
George St
Museum
Harris St
Haymarket
Hay St
Pitt St
Commonwealth St
Quay St
George St
Albion St
Ann St
Ultimo
Central
Surry Hills
N
Study Area
Hazard Categories
Low Hazard
High Hazard
0
250
500
750
1,000
m
J:\Jobs\114095\ArcGIS\Darling_Harbour\Maps\Stage_2\Figure09_Haz_2y.mxd

FIGURE 10

HAZARD CATEGORIES
0.2 EY EVENT
DARLING HARBOUR CATCHMENT

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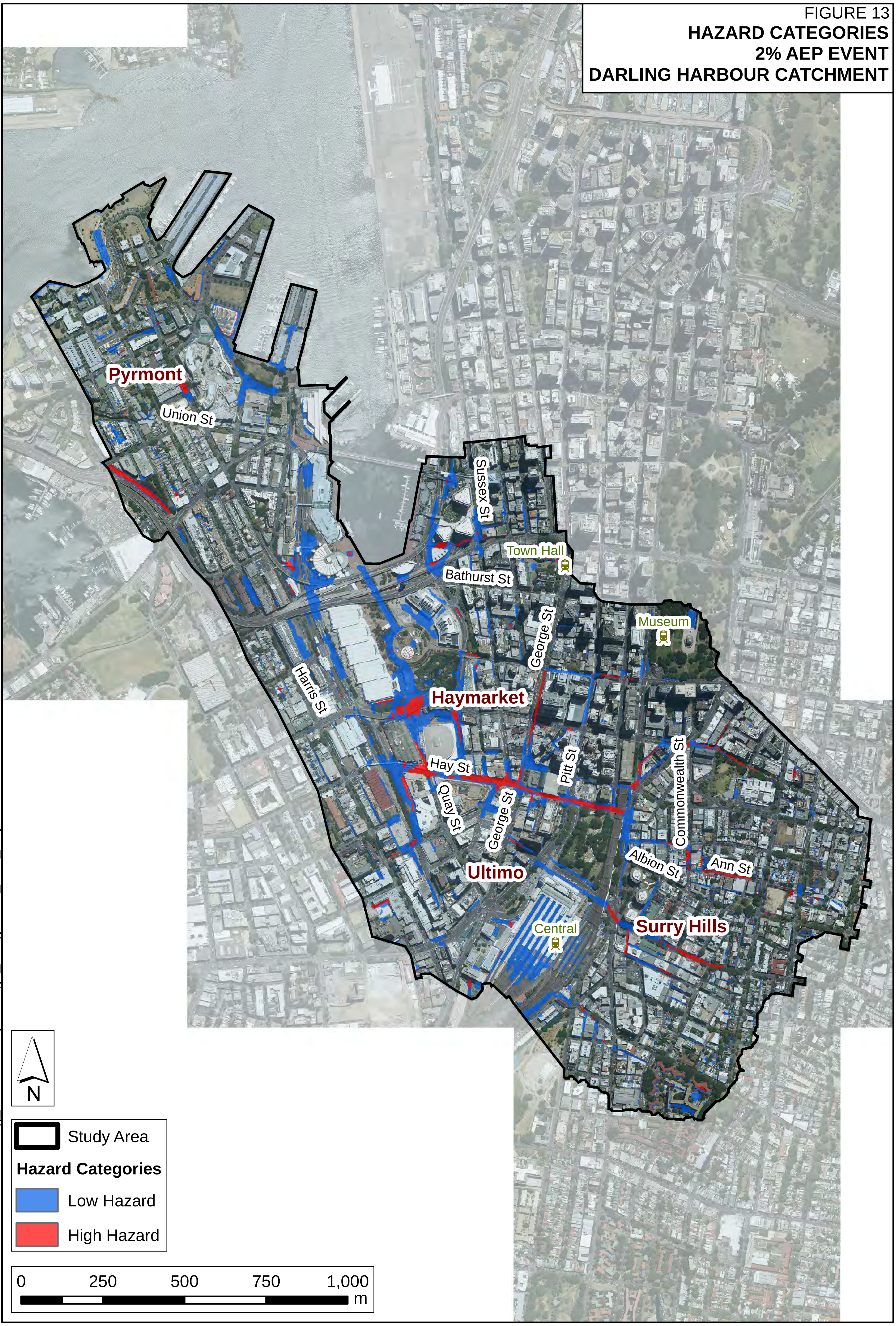
FIGURE 11
HAZARD CATEGORIES
10% AEP EVENT
DARLING HARBOUR CATCHMENT

J:\Jobs\114095\ArcGIS\Darling_Harbour\Maps\Stage_2\Figure11_Haz_10y.mxd

FIGURE 12
HAZARD CATEGORIES
5% AEP EVENT
DARLING HARBOUR CATCHMENT

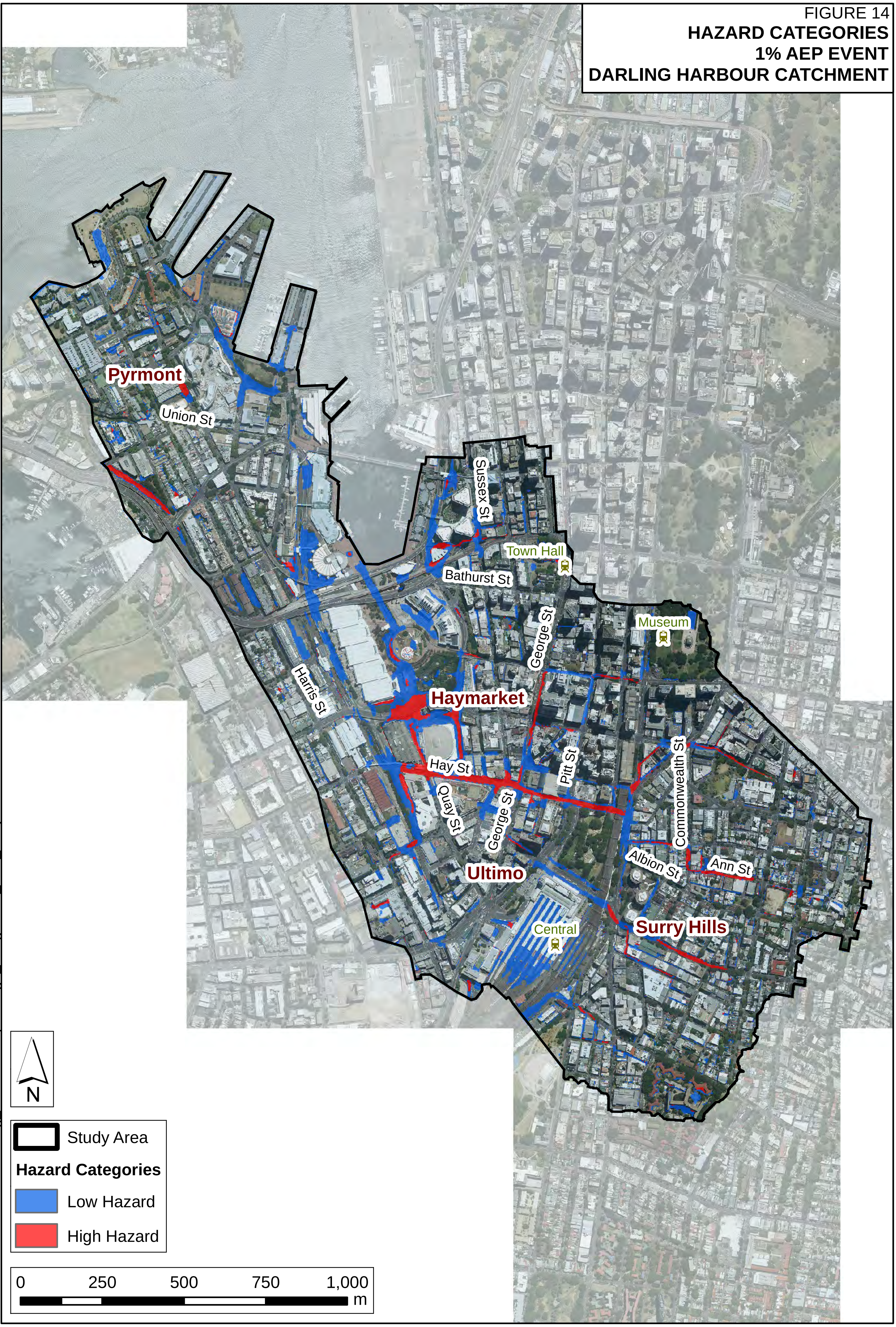
J:\Jobs\114095\ArcGIS\Darling_Harbour\Maps\Stage_2\Figure12_Haz_20y.mxd

FIGURE 13
HAZARD CATEGORIES
2% AEP EVENT
DARLING HARBOUR CATCHMENT



J:\Jobs\114095\ArcGIS\Darling_Harbour\Maps\Stage_2\Figure13_Haz_50y.mxd

FIGURE 14
HAZARD CATEGORIES
1% AEP EVENT
DARLING HARBOUR CATCHMENT



J:\Jobs\114095\ArcGIS\Darling_Harbour\Maps\Stage_2\Figure14_Haz_100y.mxd

FIGURE 15
HAZARD CATEGORIES
0.2% AEP EVENT
DARLING HARBOUR CATCHMENT

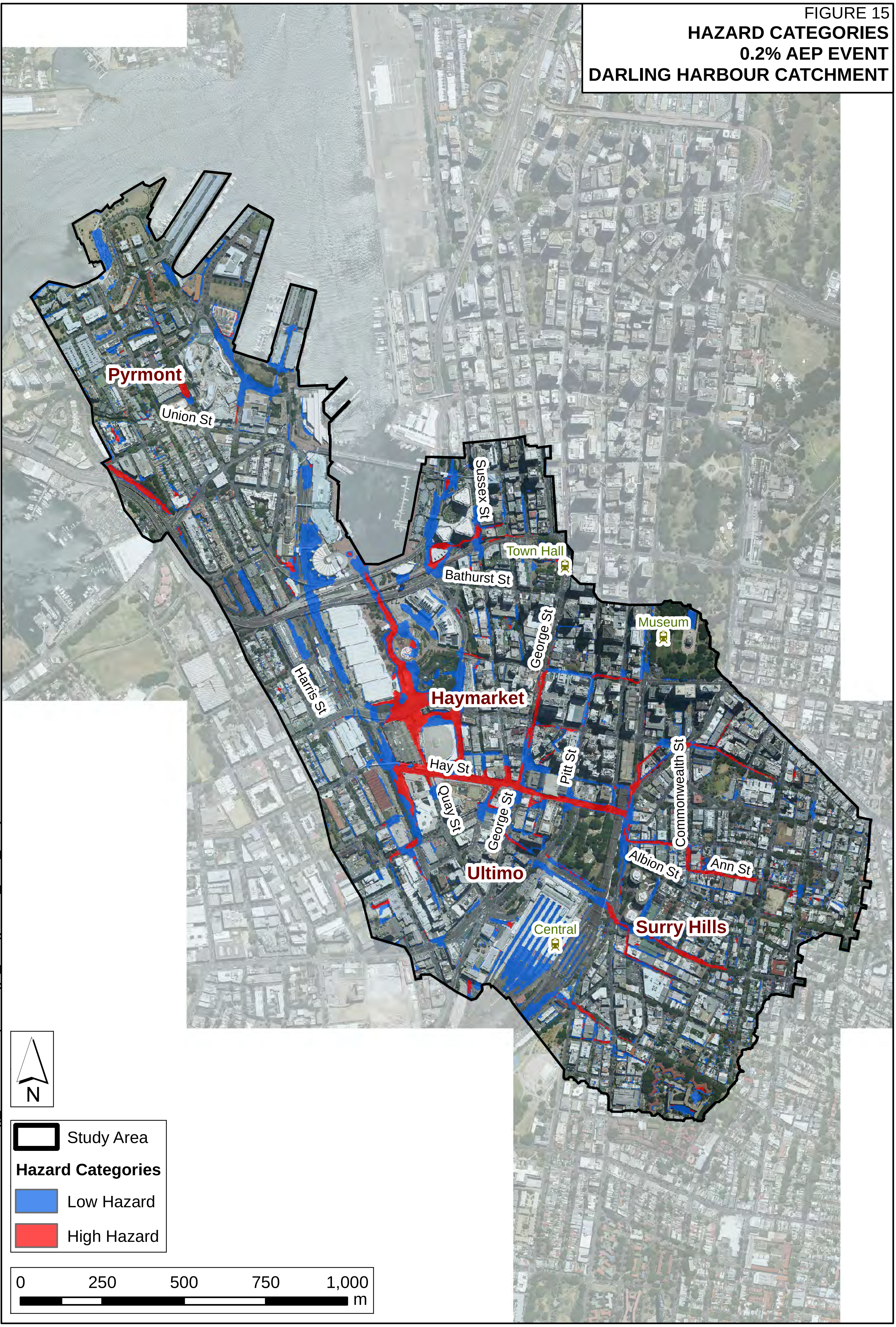


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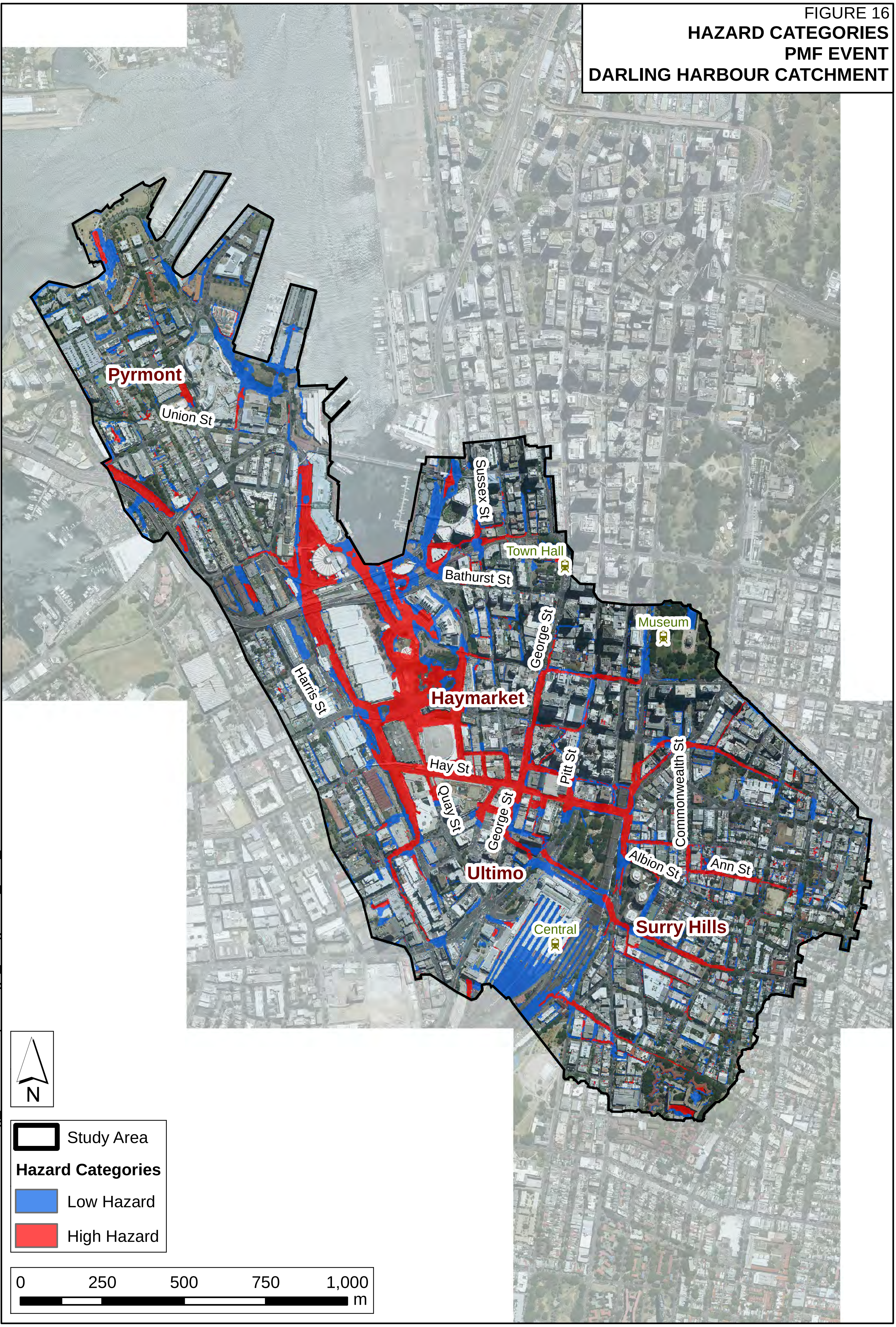
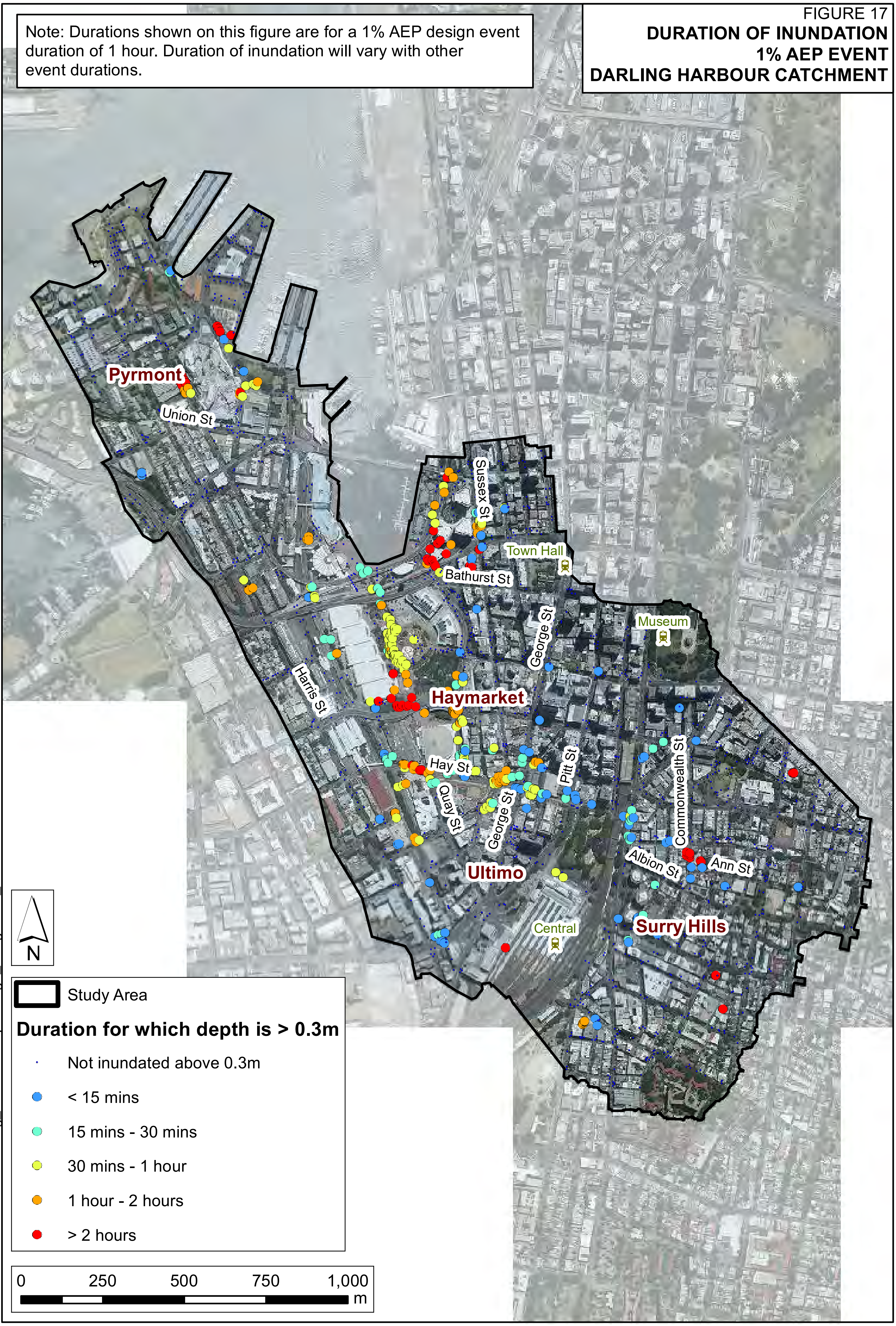
FIGURE 16
**HAZARD CATEGORIES
PMF EVENT
DARLING HARBOUR CATCHMENT**



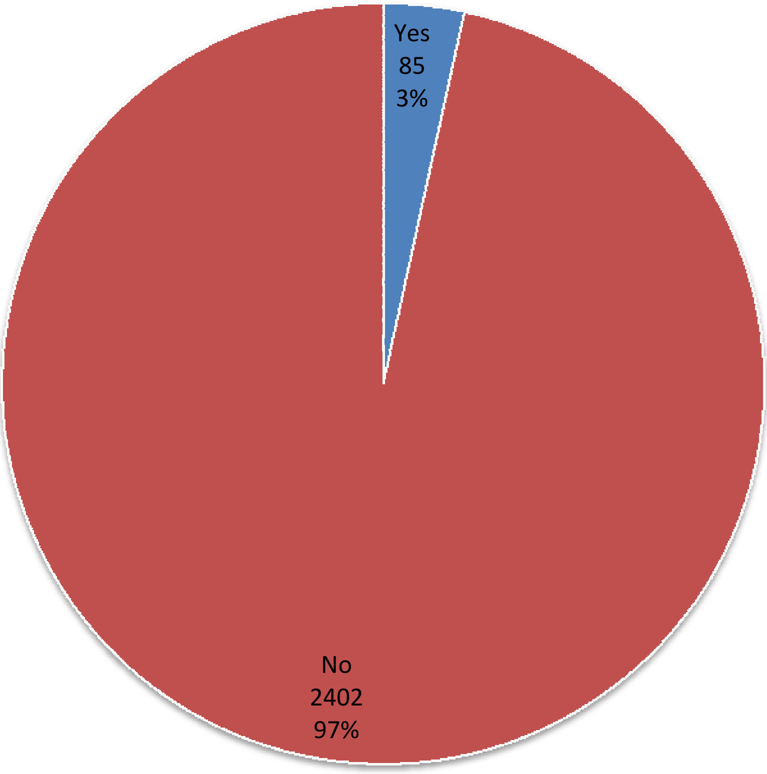
J:\Jobs\114095\ArcGIS\Darling_Harbour\Maps\Stage_2\Figure16_Haz_PMF.mxd

FIGURE 17
DURATION OF INUNDATION
1% AEP EVENT
DARLING HARBOUR CATCHMENT

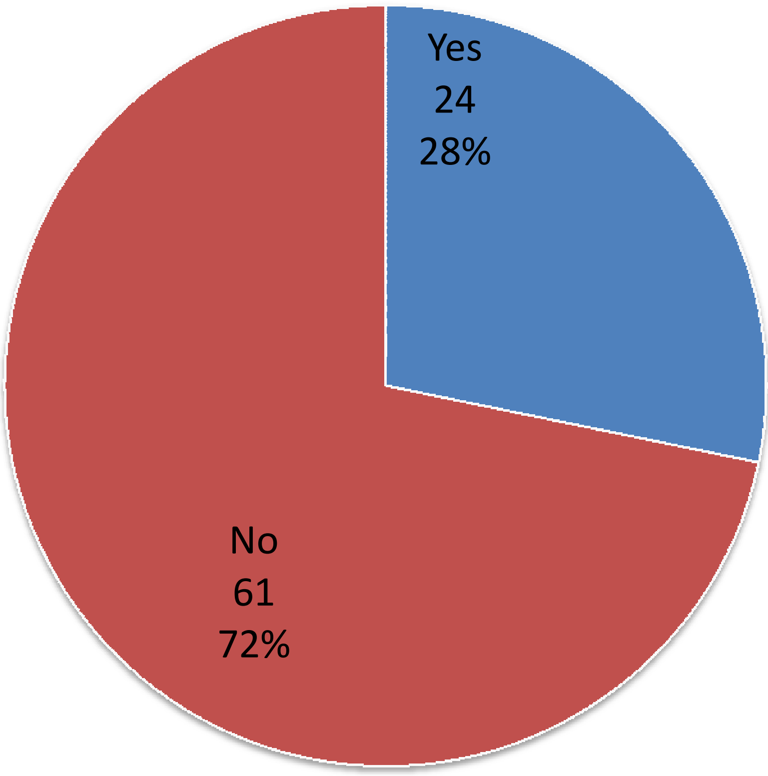
Note: Durations shown on this figure are for a 1% AEP design event duration of 1 hour. Duration of inundation will vary with other event durations.



A: Number of Respondents



B: Experienced Flooding



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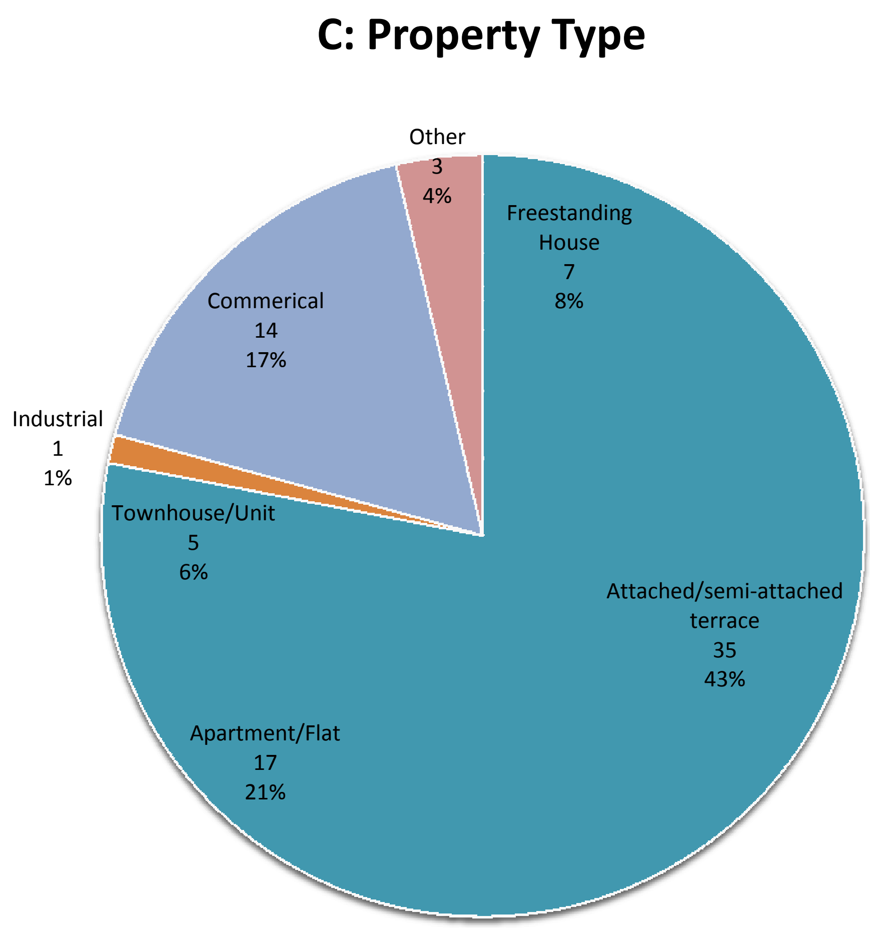

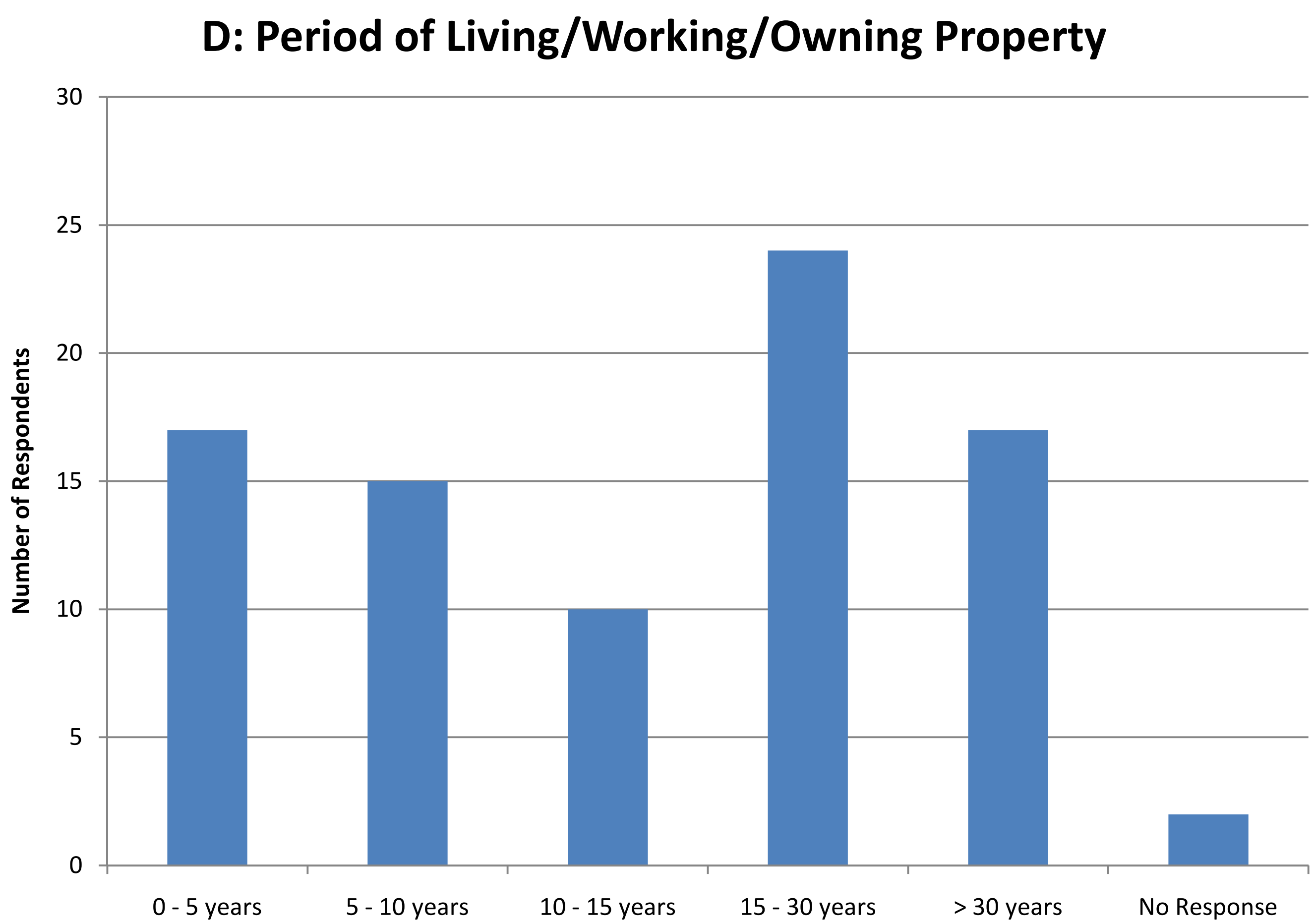

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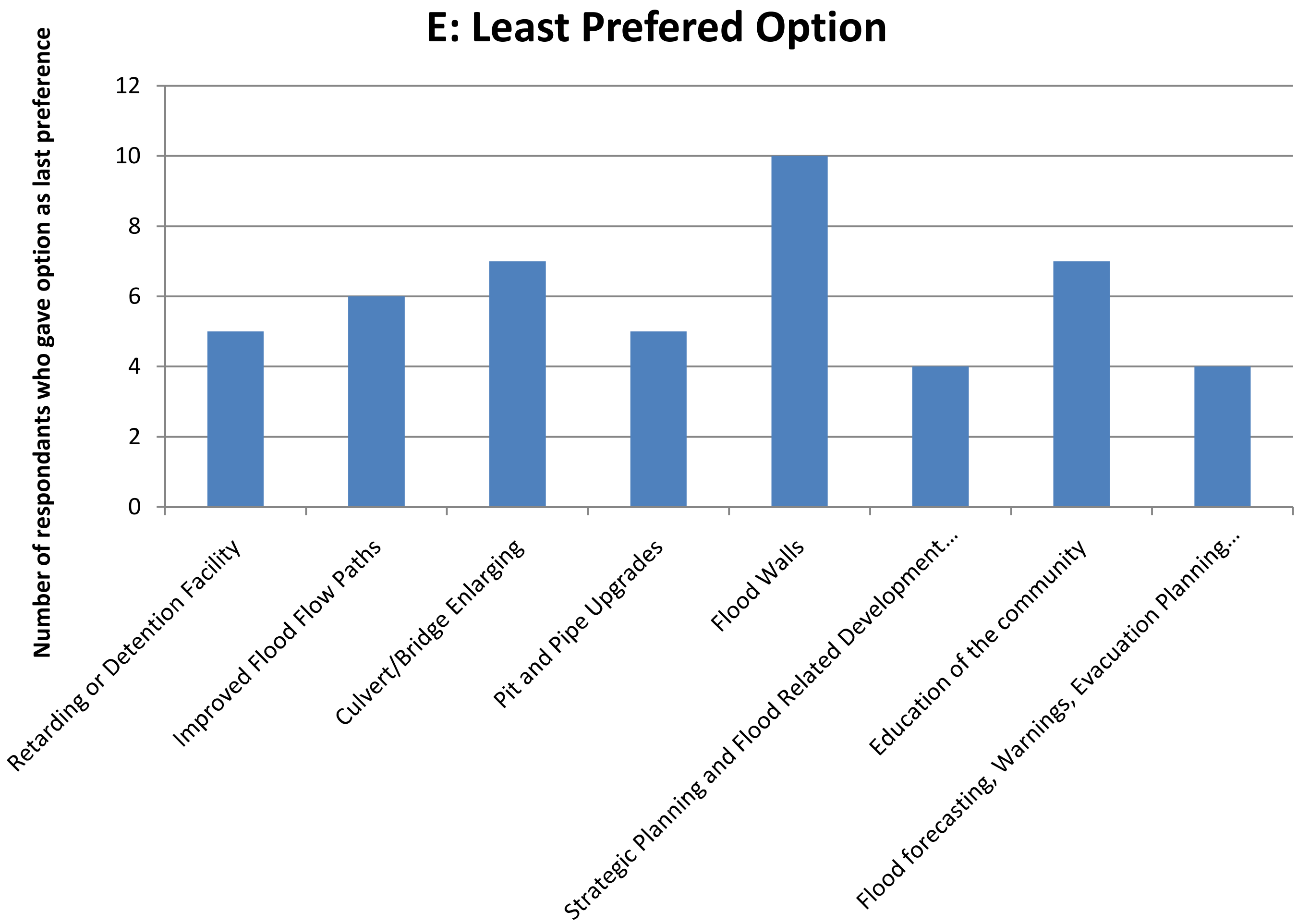

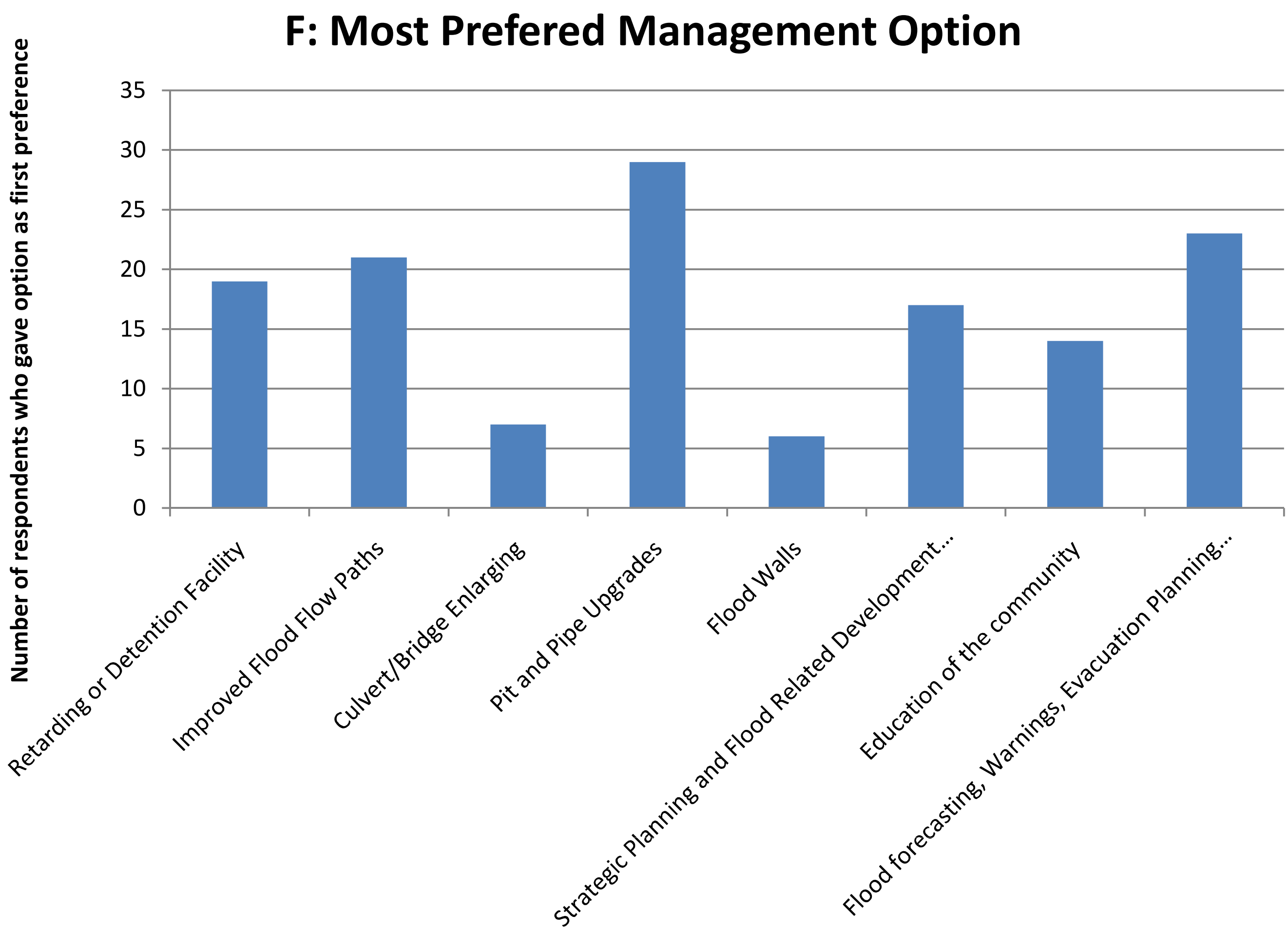

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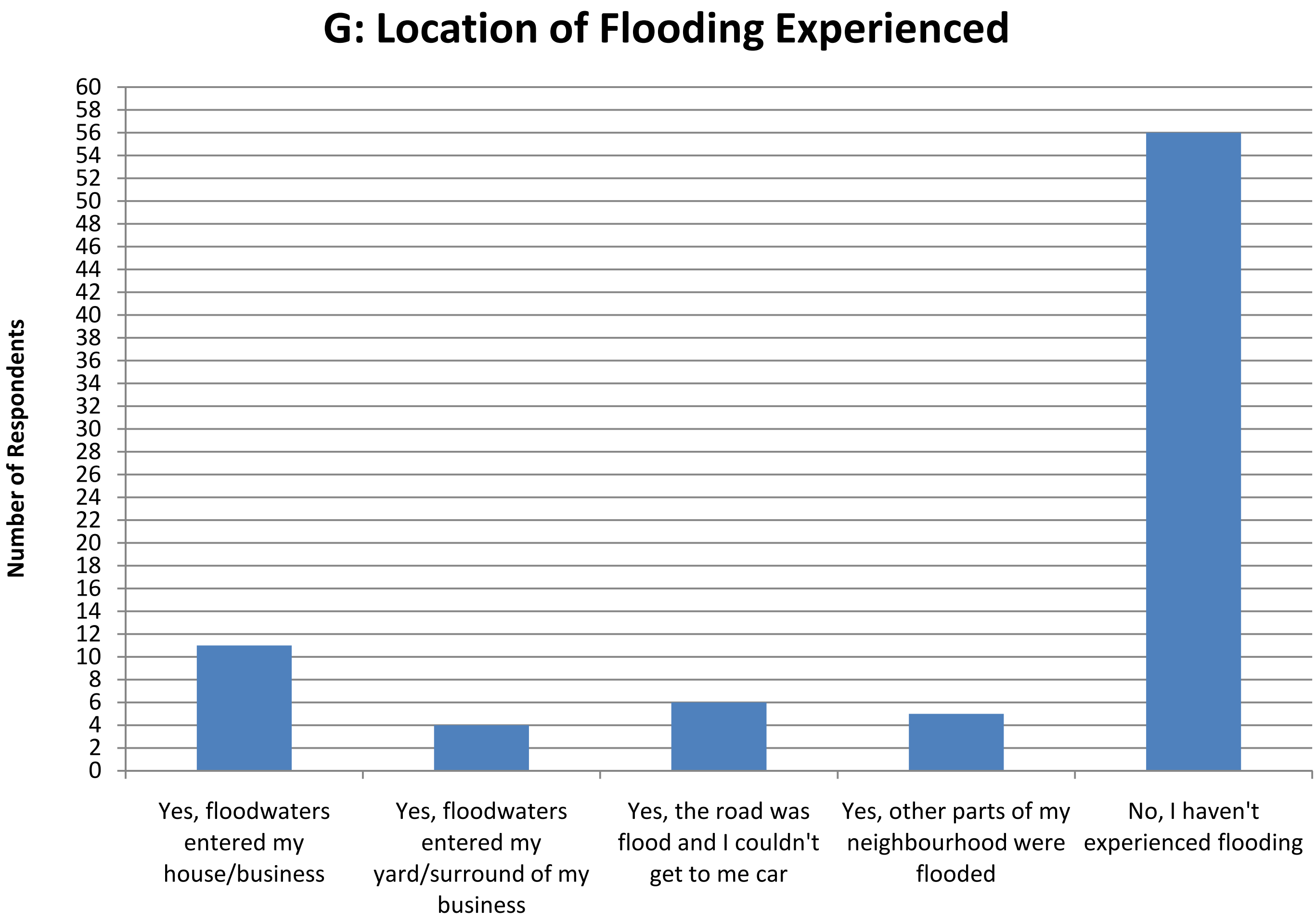

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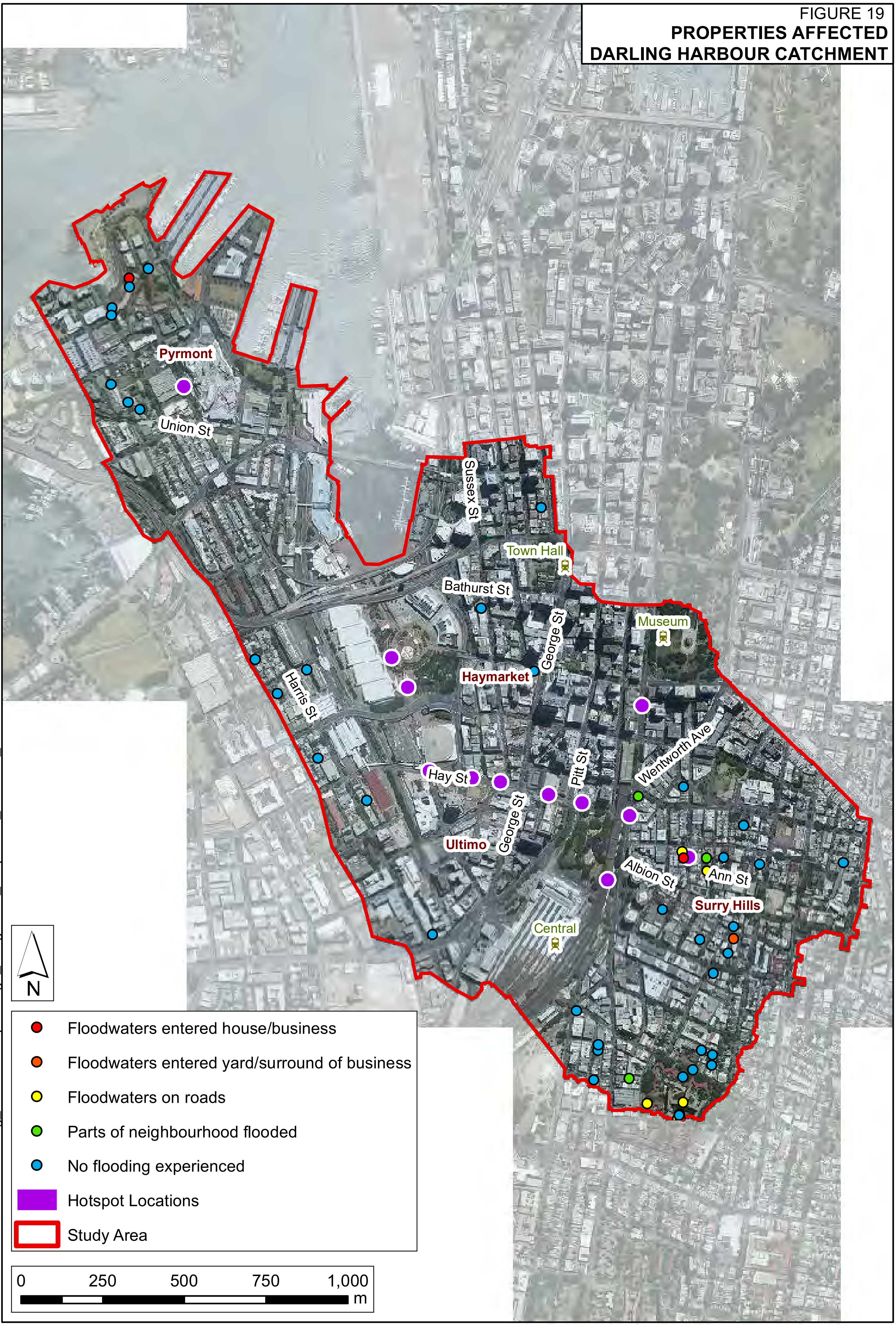


FIGURE 19
PROPERTIES AFFECTED
DARLING HARBOUR CATCHMENT
Pyrmont
Union St
Sussex St
Town Hall
Bathurst St
George St
Museum
Haymarket
Harris St
Wentworth Ave
Pitt St
Hay St
George St
Ultimo
Albion St
Ann St
Surry Hills
Central
N
Floodwaters entered house/business
Floodwaters entered yard/surround of business
Floodwaters on roads
Parts of neighbourhood flooded
No flooding experienced
Hotspot Locations
Study Area
0
250
500
750
1,000
m
J:\Jobs\114095\ArcGIS\Darling_Harbour\Maps\Stage_2\Figure19_Properties_Affected_DH.mxd

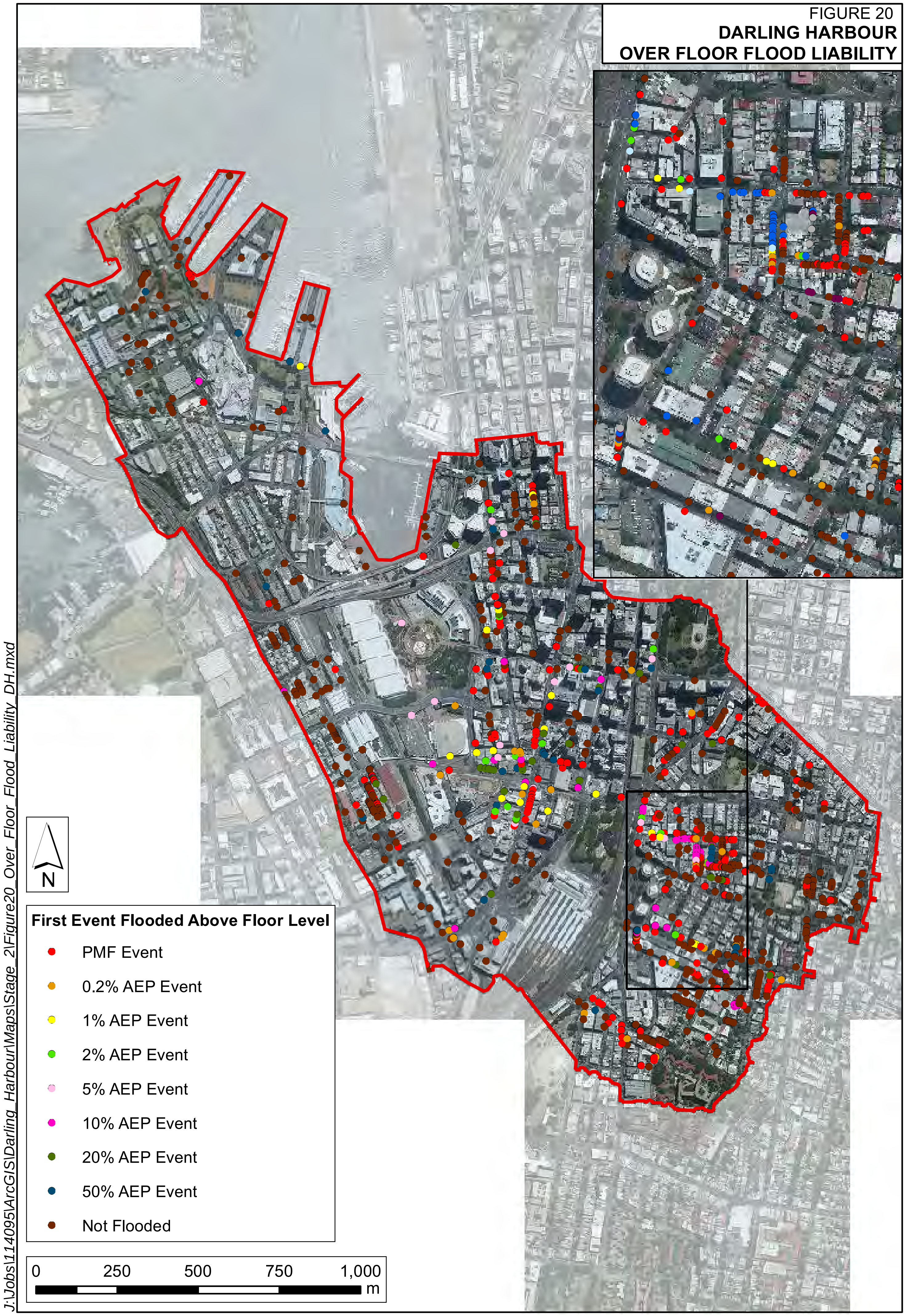
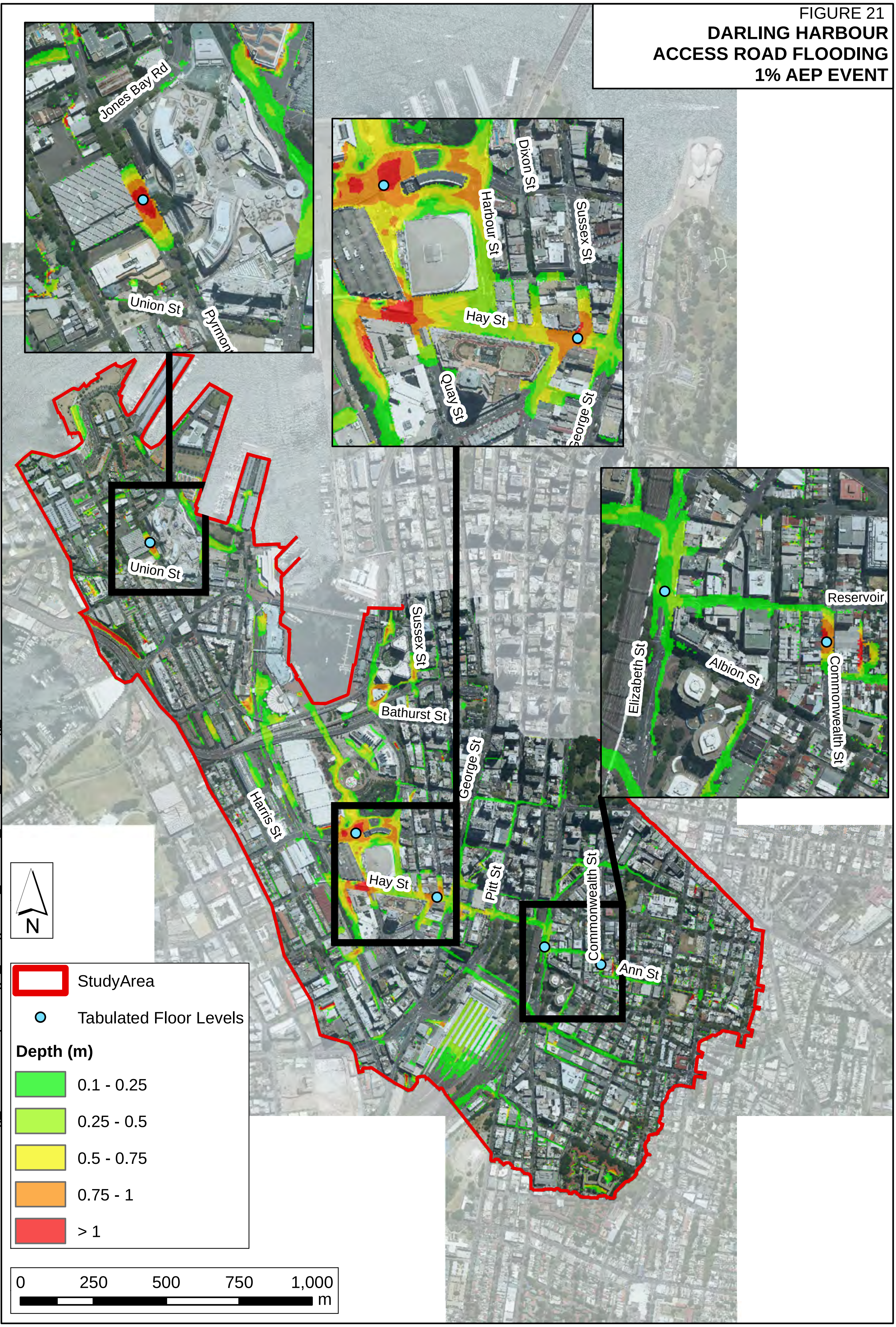


FIGURE 20
DARLING HARBOUR
OVER FLOOR FLOOD LIABILITY
First Event Flooded Above Floor Level
PMF Event
0.2% AEP Event
1% AEP Event
2% AEP Event
5% AEP Event
10% AEP Event
20% AEP Event
50% AEP Event
Not Flooded
N
0
250
500
750
1,000
m
J:\Jobs\114095\ArcGIS\Darling_Harbour\Maps\Stage_2\Figure20_Over_Floor_Flood_Liability_DH.mxd

FIGURE 21
DARLING HARBOUR ACCESS ROAD FLOODING 1% AEP EVENT



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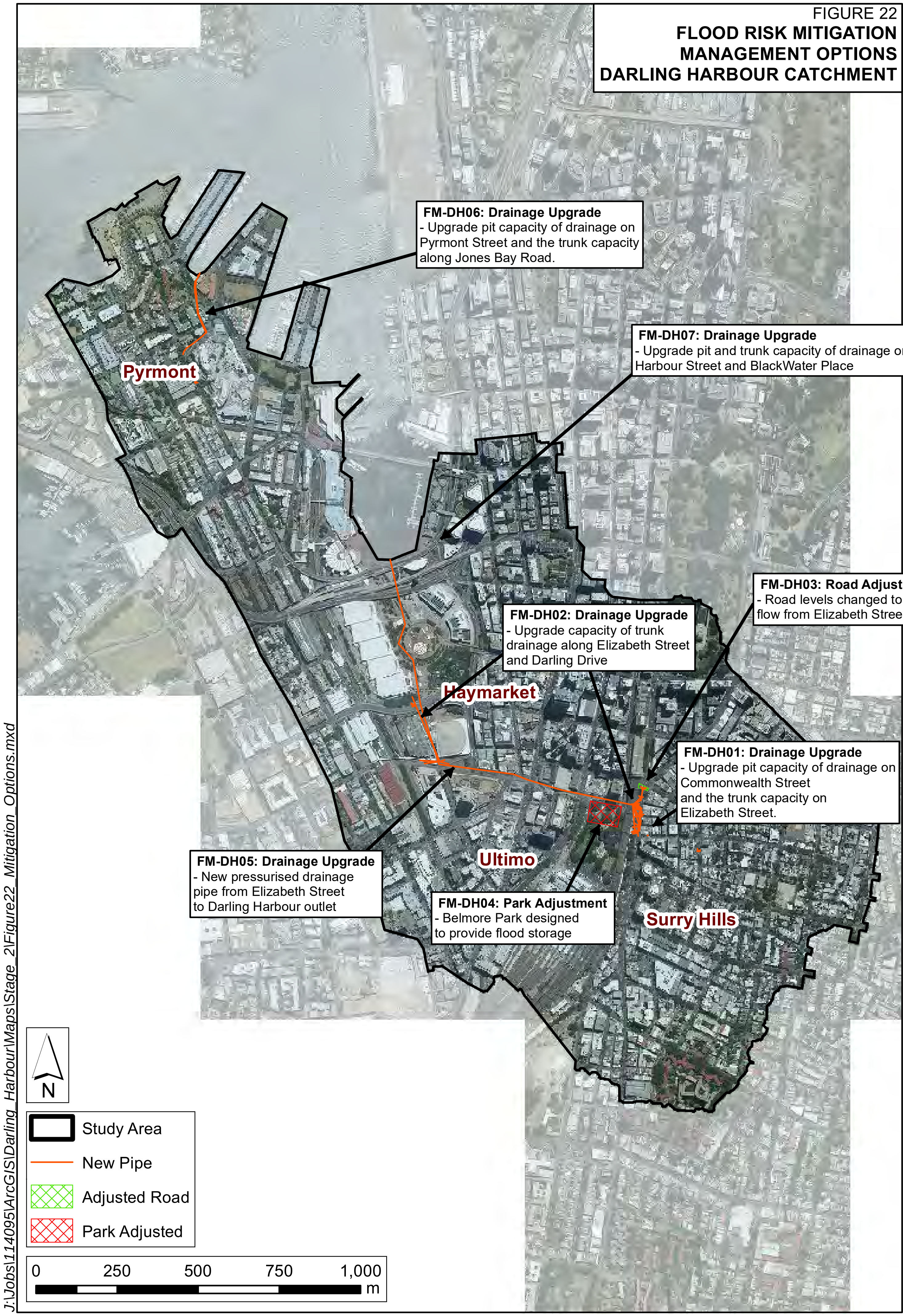

FIGURE 22
FLOOD RISK MITIGATION
MANAGEMENT OPTIONS
DARLING HARBOUR CATCHMENT
FM-DH06: Drainage Upgrade
- Upgrade pit capacity of drainage on Pyrmont Street and the trunk capacity along Jones Bay Road.
FM-DH07: Drainage Upgrade
- Upgrade pit and trunk capacity of drainage on Harbour Street and BlackWater Place
FM-DH03: Road Adjustment
- Road levels changed to divert flow from Elizabeth Street
FM-DH02: Drainage Upgrade
- Upgrade capacity of trunk drainage along Elizabeth Street and Darling Drive
FM-DH01: Drainage Upgrade
- Upgrade pit capacity of drainage on Commonwealth Street
and the trunk capacity on Elizabeth Street.
FM-DH05: Drainage Upgrade
- New pressurised drainage pipe from Elizabeth Street to Darling Harbour outlet
FM-DH04: Park Adjustment
- Belmore Park designed to provide flood storage
Pyrmont
Haymarket
Ultimo
Surry Hills
N
Study Area
New Pipe
Adjusted Road
Park Adjusted
0
250
500
750
1,000
m
J:\Jobs\114095\ArcGIS\Darling_Harbour\Maps\Stage_2\Figure22_Mitigation_Options.mxd

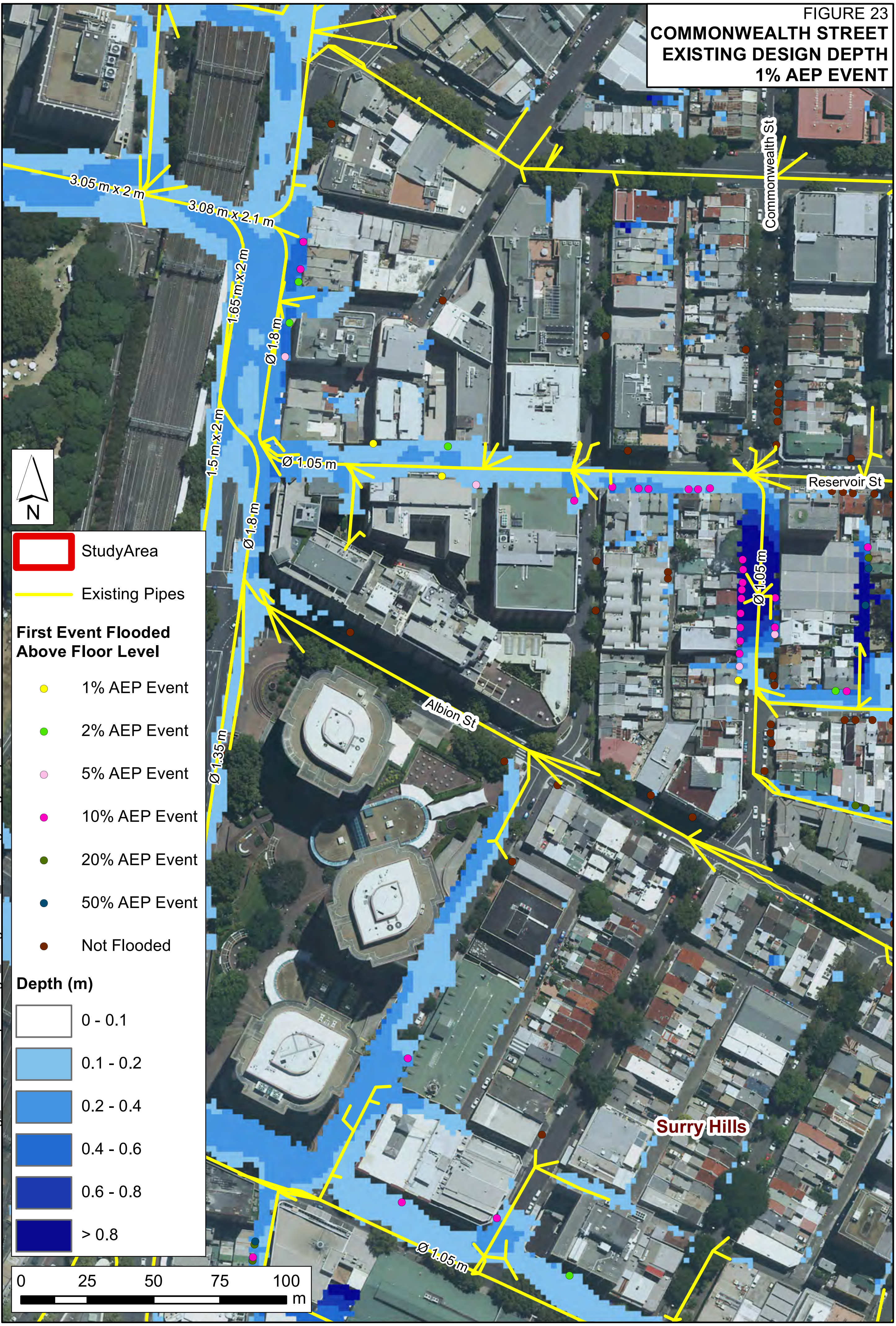

FIGURE 23
COMMONWEALTH STREET EXISTING DESIGN DEPTH 1% AEP EVENT

J:\Jobs\114095\ArcGIS\Darling_Harbour\Maps\Stage_2\Figure23_ExistingDesignDepth_CommonwealthSt.mxd

J:\Jobs\114095\ArcGIS\Darling_Harbour\Maps\Stage_2\Figure24_Impact_CS02.mxd

FIGURE 25
OPTION FM - DH02
10% AEP EVENT FLOOD IMPACT

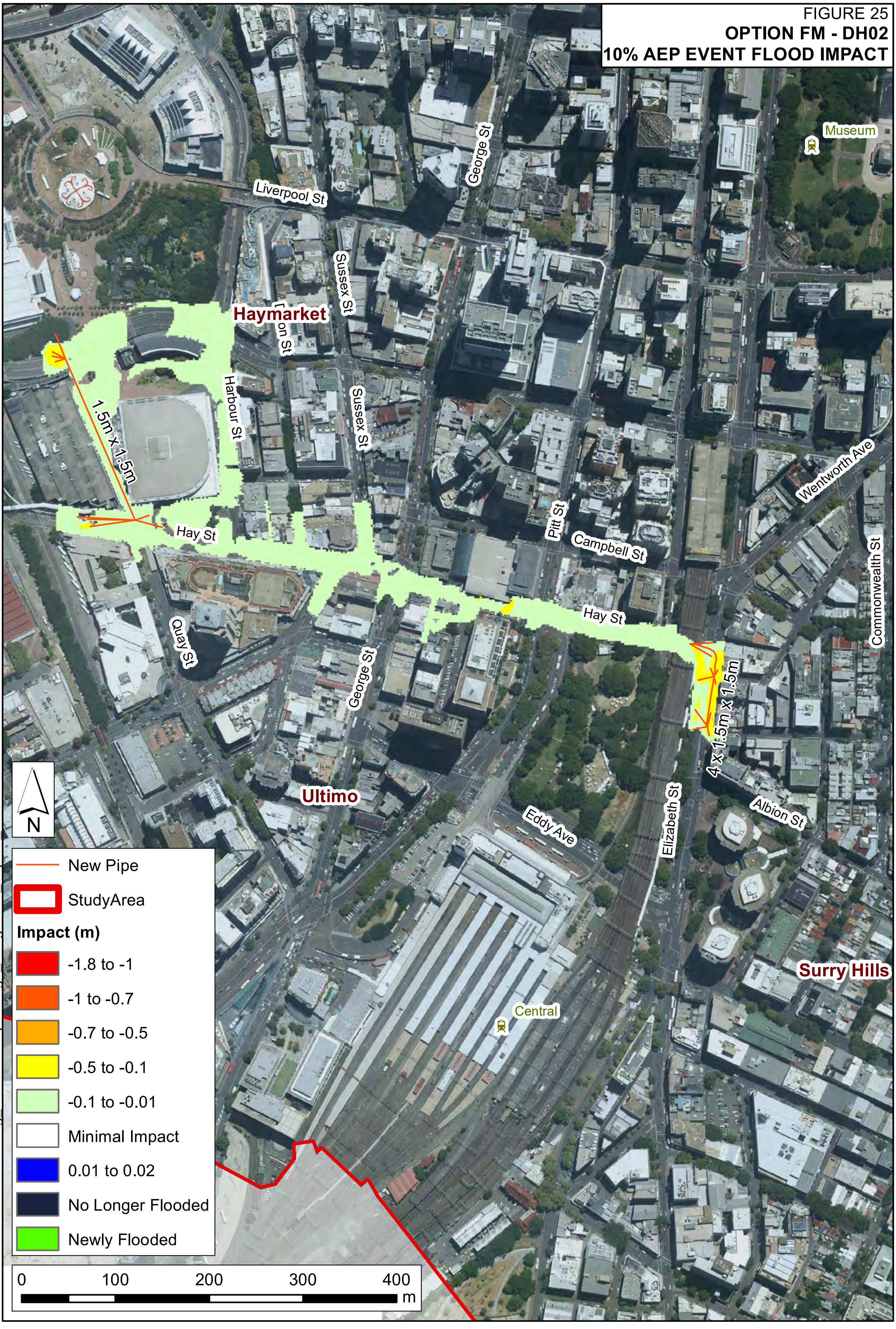

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FIGURE 26
OPTION FM - DH03
10% AEP EVENT FLOOD IMPACT

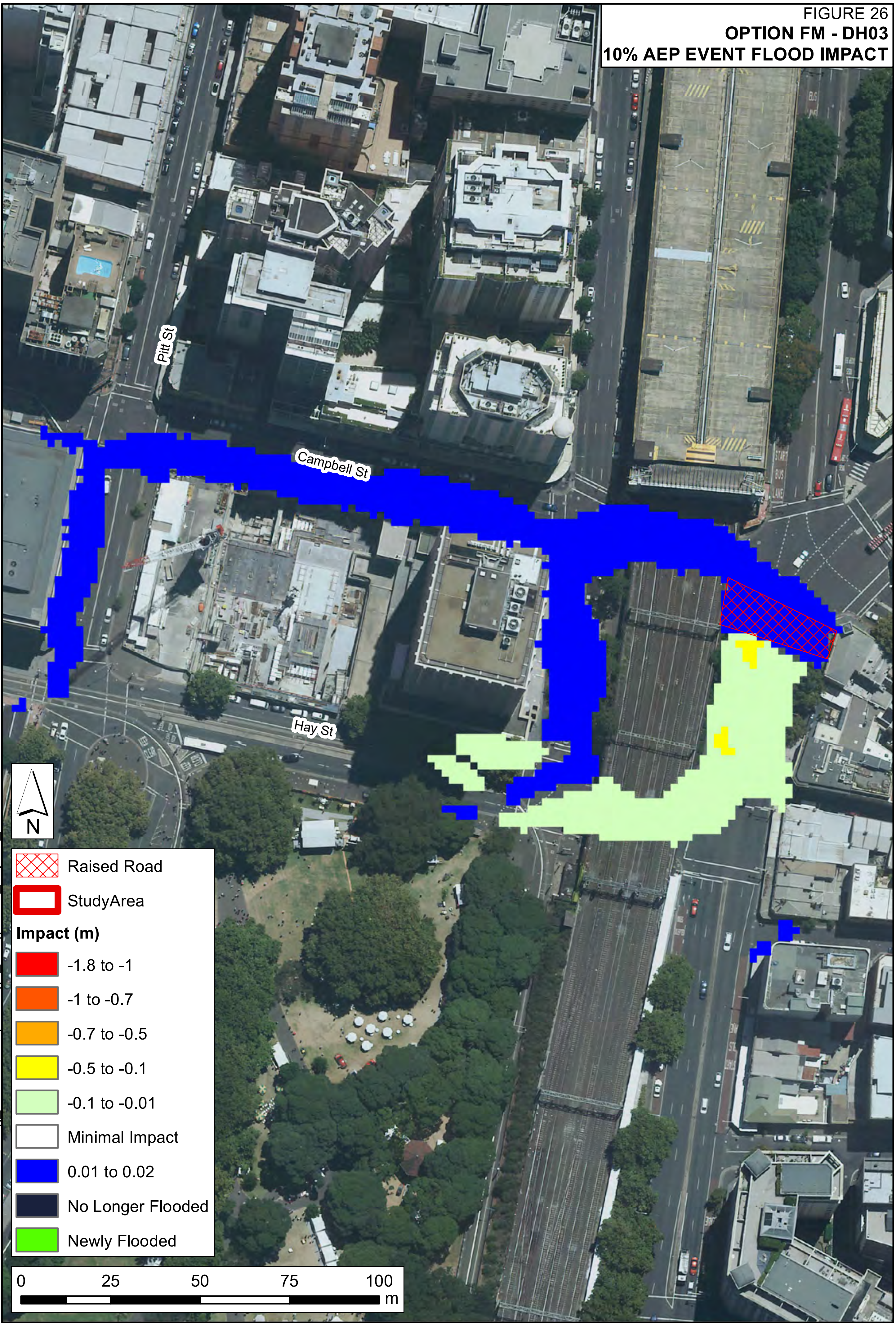

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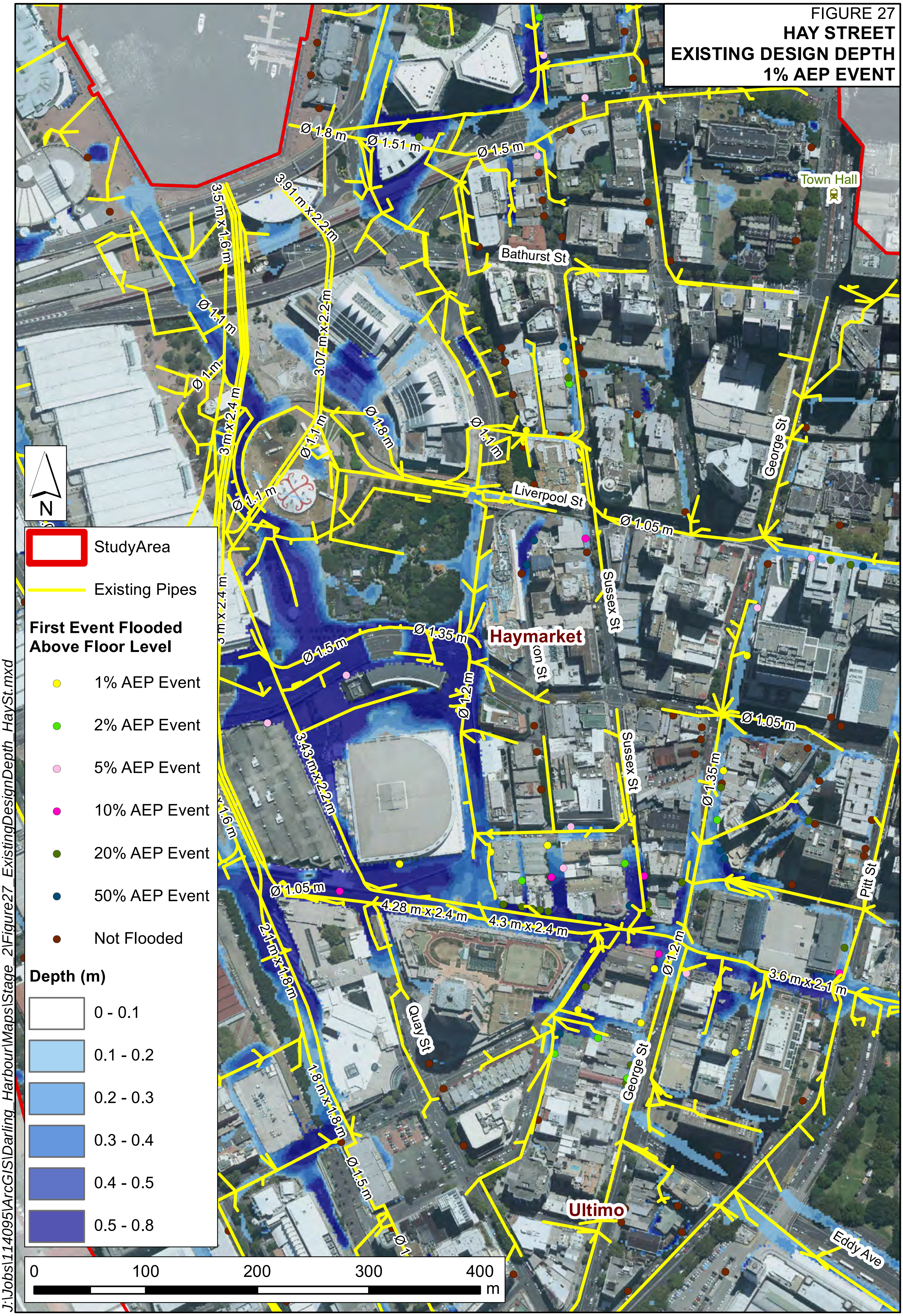
FIGURE 27
HAY STREET EXISTING DESIGN DEPTH 1% AEP EVENT



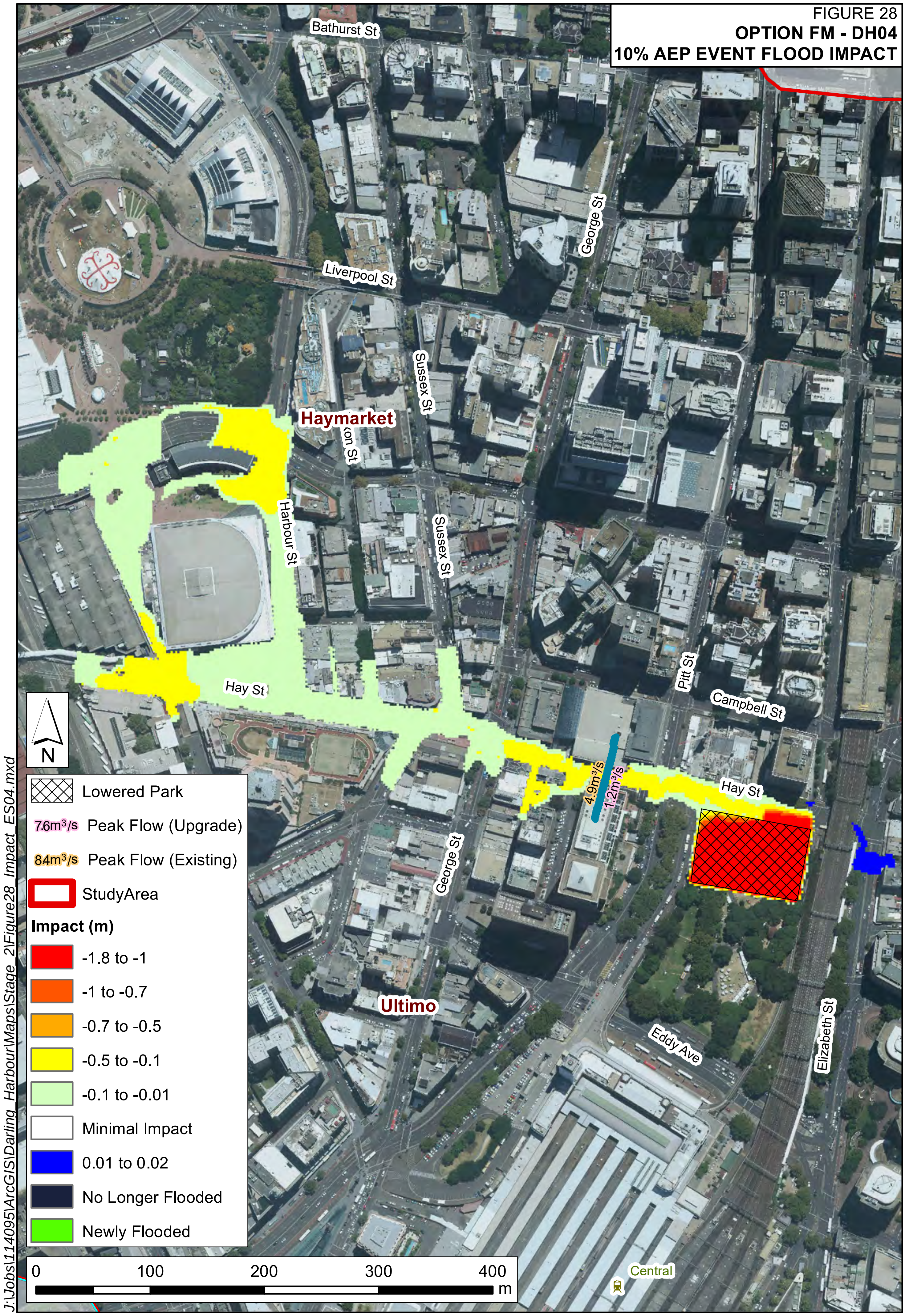


FIGURE 28
OPTION FM - DH04
10% AEP EVENT FLOOD IMPACT
Bathurst St
Liverpool St
George St
Sussex St
Haymarket
Harbour St
Hay St
Pitt St
Campbell St
Hay St
4.9m³/s
1.2m³/s
N
Lowered Park
7.6m³/s Peak Flow (Upgrade)
8.4m³/s Peak Flow (Existing)
StudyArea
Impact (m)
-1.8 to -1
-1 to -0.7
-0.7 to -0.5
-0.5 to -0.1
-0.1 to -0.01
Minimal Impact
0.01 to 0.02
No Longer Flooded
Newly Flooded
George St
Ultimo
Eddy Ave
Elizabeth St
Central
0
100
200
300
400
m
J:\Jobs\114095\ArcGIS\Darling_Harbour\Maps\Stage_2\Figure28_Impact_ES04.mxd

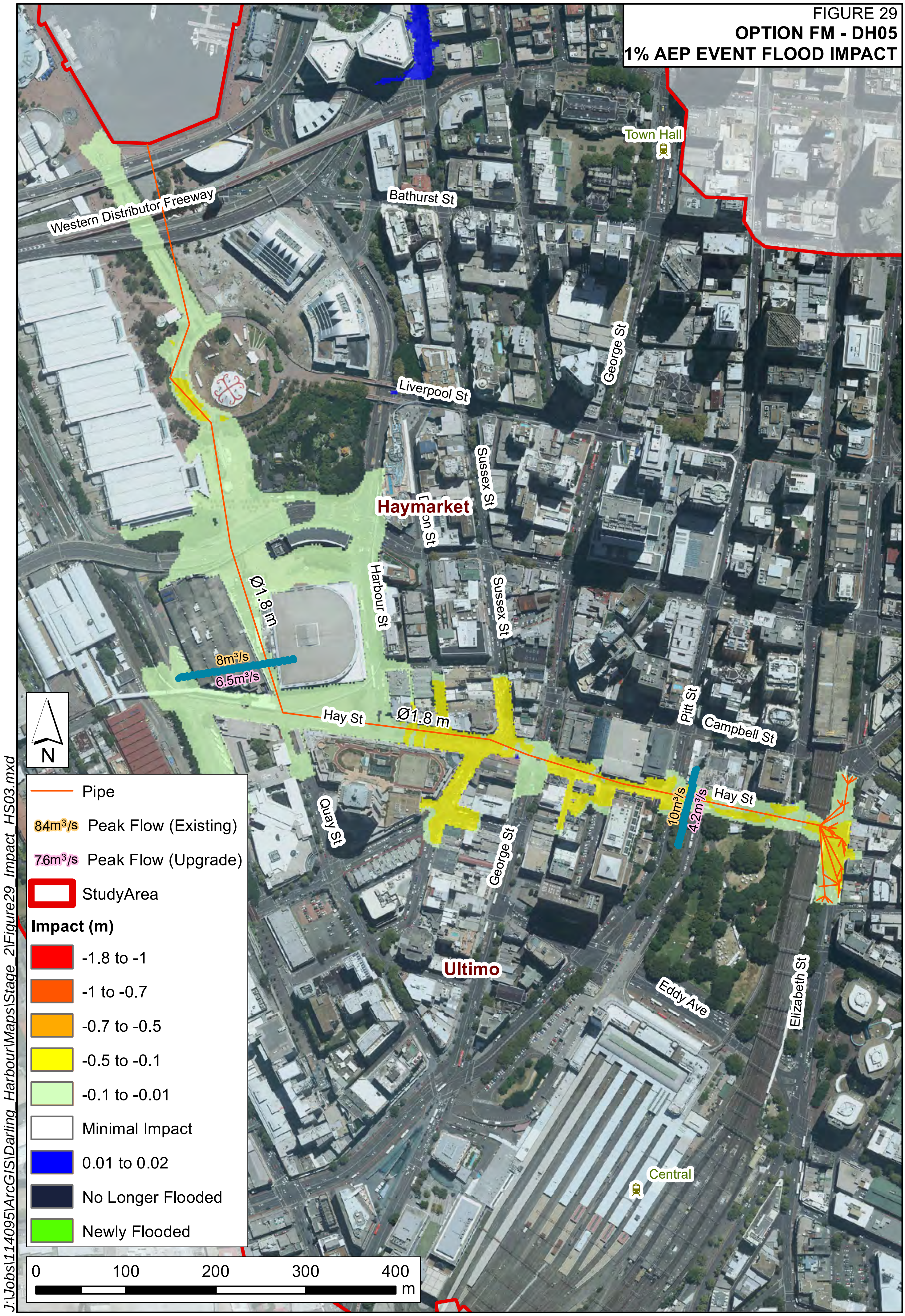


FIGURE 29
OPTION FM - DH05
1% AEP EVENT FLOOD IMPACT
Town Hall
Bathurst St
Western Distributor Freeway
George St
Liverpool St
Sussex St
Haymarket
Harbour St
Ø1.8 m
8m³/s
6.5m³/s
Hay St
Ø1.8 m
Pitt St
Campbell St
10m³/s
4.2m³/s
Hay St
Quay St
George St
Ultimo
Eddy Ave
Elizabeth St
Central
N
Pipe
84m³/s Peak Flow (Existing)
7.6m³/s Peak Flow (Upgrade)
StudyArea
Impact (m)
-1.8 to -1
-1 to -0.7
-0.7 to -0.5
-0.5 to -0.1
-0.1 to -0.01
Minimal Impact
0.01 to 0.02
No Longer Flooded
Newly Flooded
0
100
200
300
400
m
J:\Jobs\114095\ArcGIS\Darling_Harbour\Maps\Stage_2\Figure29_Impact_HS03.mxd

FIGURE 30
OPTION FM - DH05
1% AEP EVENT CHANGE IN HAZARD

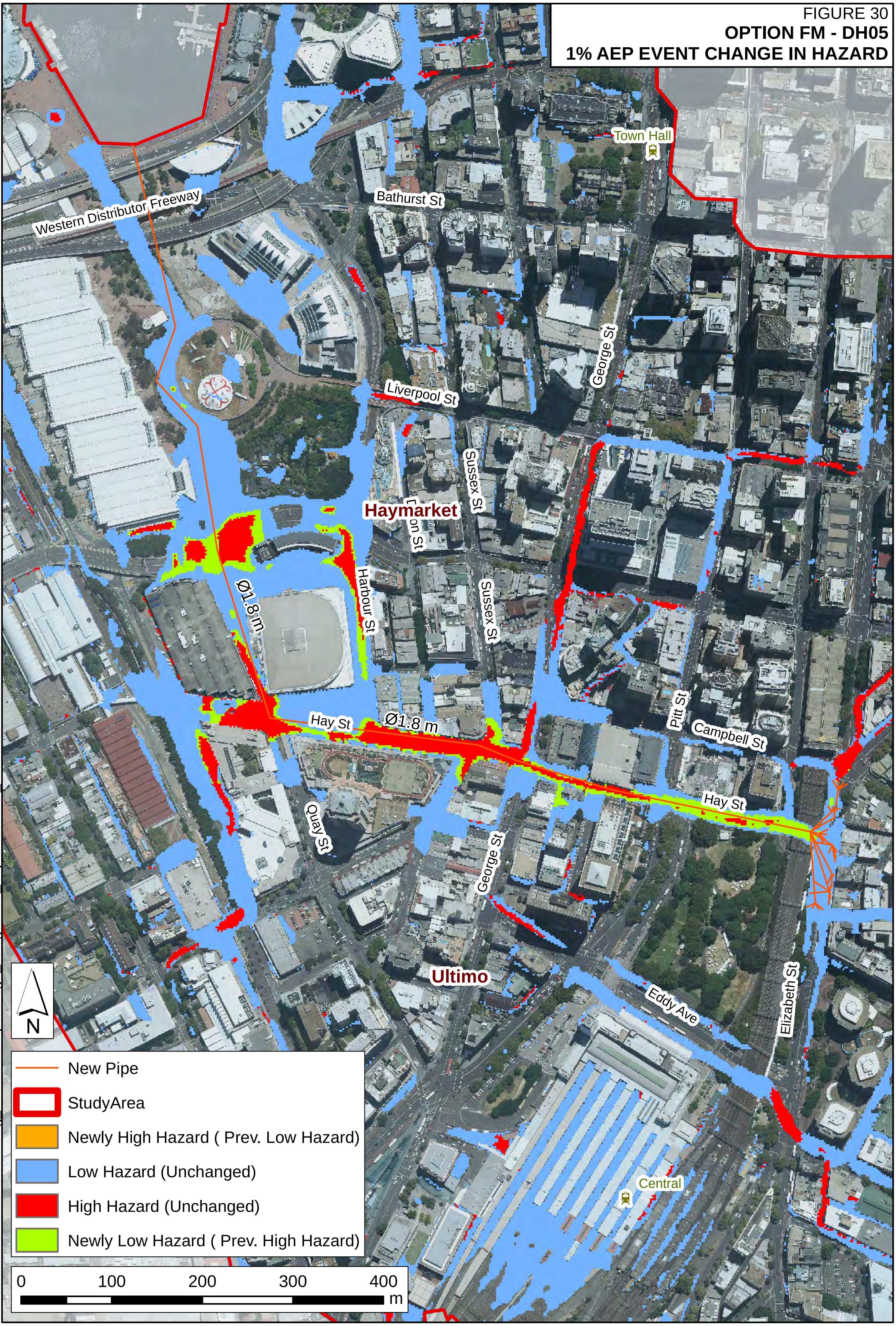


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FIGURE 31
PYRMONT STREET EXISTING DESIGN DEPTH 1% AEP EVENT

J:\Jobs\114095\ArcGIS\Darling_Harbour\Maps\Stage_2\Figure31_ExistingDesignDepth_PyrmontSt.mxd

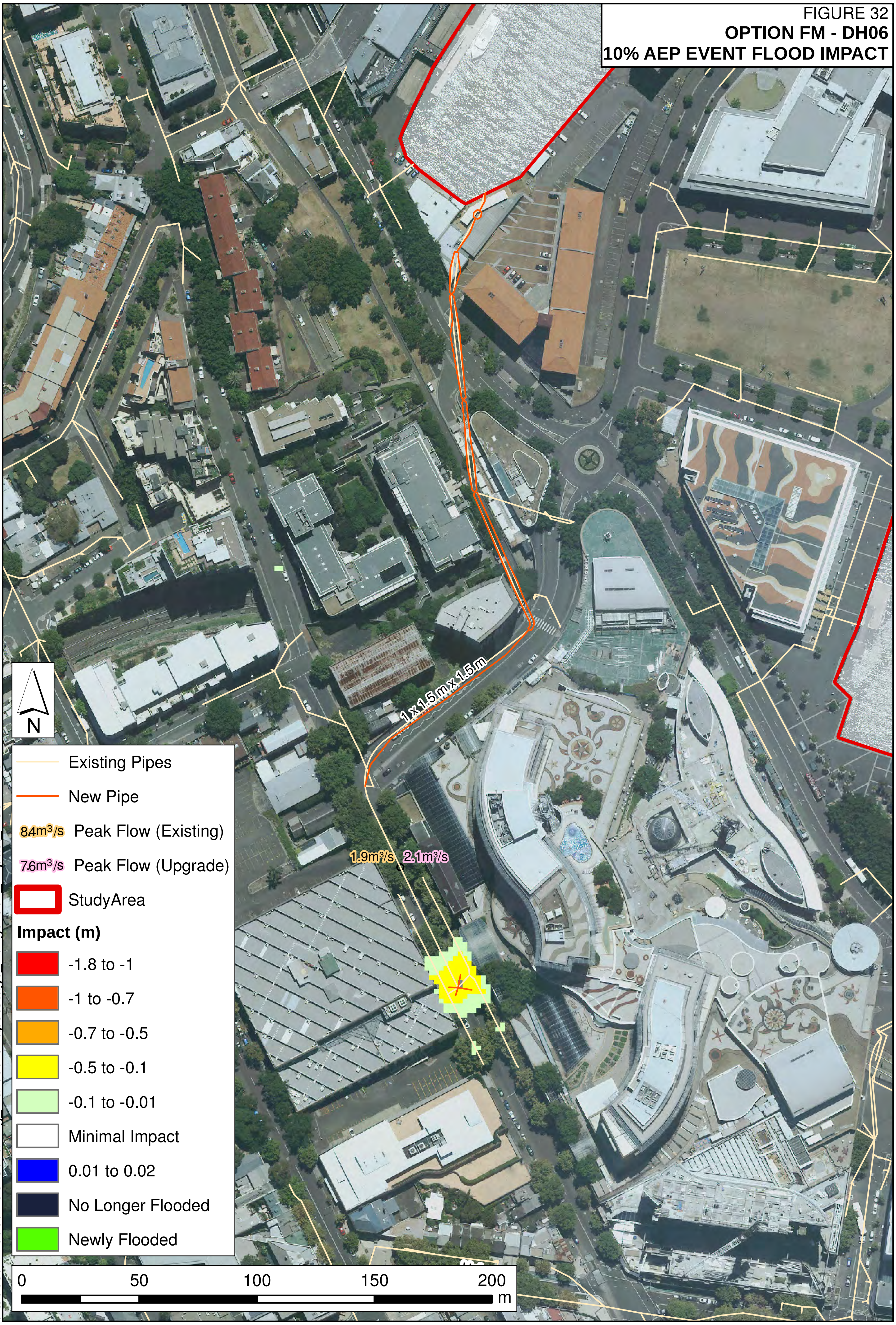
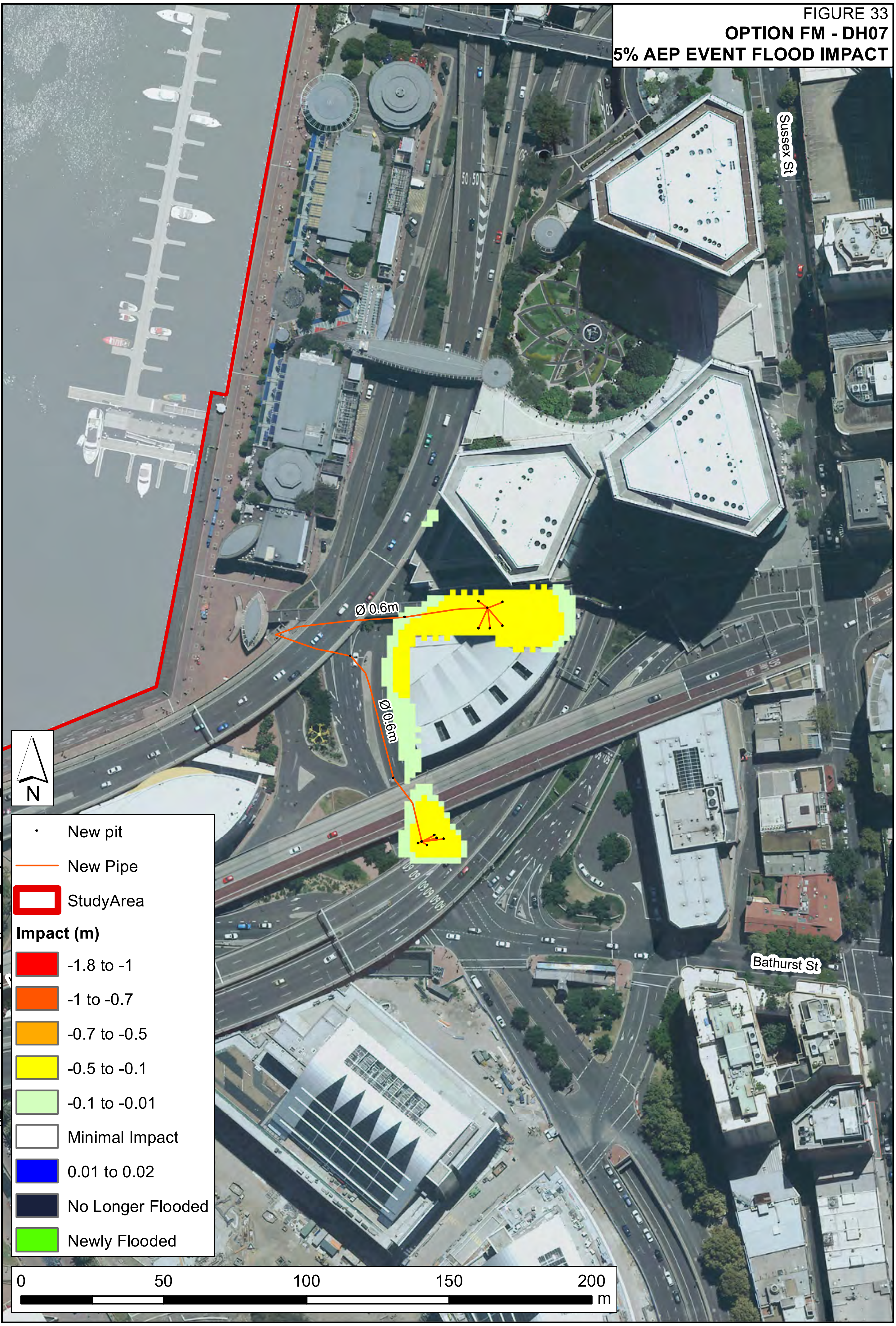


FIGURE 32
OPTION FM - DH06
10% AEP EVENT FLOOD IMPACT
1 x 1.5 m x 1.5 m
1.9m³/s
2.1m³/s
N
Existing Pipes
New Pipe
84m³/s Peak Flow (Existing)
7.6m³/s Peak Flow (Upgrade)
StudyArea
Impact (m)
-1.8 to -1
-1 to -0.7
-0.7 to -0.5
-0.5 to -0.1
-0.1 to -0.01
Minimal Impact
0.01 to 0.02
No Longer Flooded
Newly Flooded
0
50
100
150
200
m
J:\Jobs\114095\ArcGIS\Darling_Harbour\Maps\Stage_2\Figure32_Impact_PS01.mxd

FIGURE 33
OPTION FM - DH07
5% AEP EVENT FLOOD IMPACT



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Glossary of Terms

Appendix A

APPENDIX A: GLOSSARY

Taken from the Floodplain Development Manual (April 2005 edition)

acid sulfate soils	Are sediments which contain sulfidic mineral pyrite which may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual published by Acid Sulfate Soil Management Advisory Committee.
Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Annual Damage (AAD)	Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
Average Recurrence Interval (ARI)	The long term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
caravan and moveable home parks	Caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the LG Act.
catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
consent authority	The Council, government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the Council, however legislation or an EPI may specify a Minister or public authority (other than a Council), or the Director General of DIPNR, as having the function to determine an application.
design flood	A hypothetical flood representing a specific likelihood of occurrence (for example the 100 year ARI or 1% AEP flood). It is a probabilistic or statistical estimate, generally being based on some form of probability analysis of flood or rainfall data.
design rainfall	Used in the estimation of a flood or the design of a particular component or feature of a hydraulic structure. Design rainfall estimates are based on the intensity, frequency and duration of the storm bursts. The use of a design rainfall in the estimation of a flood does not imply that if such rainfall occurred at a given time, the estimated flood elevations would result.
development	Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act). **infill development:** refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current

	zoning of the land. Conditions such as minimum floor levels may be imposed on infill development. **new development:** refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power. **redevelopment:** refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services.
disaster plan (DISPLAN)	A step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.
discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
ecologically sustainable development (ESD)	Using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act 1993. The use of sustainability and sustainable in this manual relate to ESD.
effective warning time	The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.
emergency management	A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.
flash flooding	Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
flood awareness	Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.
flood education	Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves and their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.
flood fringe areas	The remaining area of flood prone land after floodway and flood storage areas have been defined.
flood liable land	

	Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).
flood mitigation standard	The average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.
floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
floodplain risk management options	The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
floodplain risk management plan	A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and 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.

Appendix B

Darling Harbour Catchment Floodplain Risk Management Study and Plan

April 2015

CITY OF SYDNEY

Sydney2030/Green/Global/Connected

The City of Sydney is preparing a Floodplain Risk Management Study and Plan for the Darling Harbour catchment area and we would like your help.

The study will tell us about the type of flood mitigation solutions feasible for the catchment and help us plan for and manage any flood risks.

Good management of flood risks can help reduce damage and improve social and economic opportunities.

city of villages

To access the questionnaire online visit

cityofsydney.nsw.gov.au/floodplain-management



The City of Sydney has engaged WMAwater to assist with the preparation of the Darling Harbour Floodplain Risk Management Study and Plan.

The Darling Harbour Flood Study was completed in October 2014, giving the City of Sydney a better understanding of the nature of flooding in your area. A copy of the draft Flood Study is available at **cityofsydney.nsw.gov.au**
The next step in the NSW Government Flood Management Process is the preparation of a Floodplain Risk Management Study and Plan. The purpose of this study and plan is to identify and recommend appropriate actions to manage flood risks in the Darling Harbour area.

This brochure is an introduction to the Floodplain Risk Management Study and Plan and its objectives.

Stages of the NSW Government Floodplain Management Process

1. Formation of a Committee – complete
2. Data Collection – complete
3. Flood Study – complete
4. **Floodplain Risk Management Study**
5. **Floodplain Risk Management Plan**
6. Implementation of Plan.

Study area and flooding issues

The Darling Harbour study area includes the inner city suburbs of Haymarket, Surry Hills, and parts of Ultimo, Pyrmont and Sydney. This includes land under the control of the Sydney Harbour Foreshore Authority.

Much of the flooding in this catchment occurs due to natural depressions and low points. In the past, flooding has caused property damage and posed a hazard to people and property located near drainage areas. The Floodplain Risk Management Study and Plan currently being undertaken is to manage these flood risks.

Have your say

We want your comments about previous flood experiences and potential mitigation options.

The local knowledge of residents and business operators, including your personal experiences of flooding, is a valuable source of information.

The information you provide in the accompanying questionnaire will help the City of Sydney determine how to manage the floods in your area.

For more information about this project, please contact the City of Sydney or WMAwater via the details provided.

Floodplain risk management options

The following list of floodplain risk management options are examples of the type of strategies that could be considered to minimise risk and reduce the impact of flooding in the catchment. These options will be investigated in more detail during the preparation of the Management Study and Plan. The general categories of these options are:

Flood modification options.
Examples include:

- Construction of detention/retarding facilities to reduce the peak flow downstream;
- Upgrading of drainage systems, upgrade of existing pipes or construction of new pipes; and
- Regrading of roads to provide better overland flowpaths.

Property modification options and planning control.
Examples include:

- Building and development controls; and
- Flood-proofing measures, such as flood barriers.

Response modification options.
Examples include:

- Revision of the Local Disaster Plan;
- Public awareness and education – locality-based flooding information for residents;
- Public awareness and education – flooding information for schools;
- Flood depth markers at major (flood-affected) road crossings;
- Continuation of existing public awareness and education campaigns; and
- Data collection strategies for future floods.

For more information please contact:

WMAwater
Steve Gray
Phone 02 9299 2855
Fax: 02 9262 6208
gray@wmawater.com.au

City of Sydney
Sean Howie
Phone: 02 9246 7349
showie@cityofsydney.nsw.gov.au

CITY OF SYDNEY 2030

Sydney2030/Green/Global/Connected

Local Resident/Land Owner Survey

The City of Sydney is carrying out a Floodplain Risk Management Study and Plan for the Darling Harbour catchment. Please return your completed questionnaire in the reply-paid envelope by 10 May 2015. Or complete the questionnaire online at www.cityofsydney.nsw.gov.au/floodplain-management.

1

Please provide the following details as we may contact you to discuss some of the information you have provided us. This is optional.

Name: ....

Address: ....

Contact phone number:..

Email: ....

2

What is the best way to contact you?

☐ Letter (post) ☐ Email ☐ Phone

3

How many people regularly live/work on this property?

....

....

....

4

How many of the permanent residents/workers are in age group below:

☐ 0–4 years ☐ 5–14 years ☐ 15–64 years ☐ 65+ years

5

What is the main language spoken at this address?

☐ English

☐ Other (please specify) ....

6

Is your property (please tick)

☐ Residential, owner-occupied
☐ Residential, occupied by a tenant
☐ Business, owner-occupied
☐ Business, occupied by a tenant
☐ Other (please specify)...

7

What type of structure is your property/business? (please tick)

☐ Freestanding house
☐ Dual occupancy
☐ Attached/semi-attached terrace
☐ Industrial
☐ Apartment/flat
☐ Commercial
☐ Townhouse/unit
☐ Other (please specify)...

8

How long have you lived, worked at, and/or owned this property?

Years ....

Months ....

9

Have you ever experienced flooding since living and/or working in the Darling Harbour catchment? (please tick relevant boxes)

☐ Yes, floodwaters entered my house/business
☐ Yes, floodwaters entered my yard/surrounds of my business
☐ Yes, the road was flooded and I couldn't get to my car
☐ Yes, other parts of my neighbourhood were flooded
☐ No, I haven't experienced flooding

10

Do you have any materials or photos you can provide to evidence the flooding you experienced? If yes, when did this flood occur?

☐ No
☐ Yes – the flooding occurred on: ....

....

11

Are you aware of the draft Darling Harbour Flood Study?

☐ Yes ☐ No

If yes, was your property identified as being at risk of flooding or near a flood area?

☐ Yes ☐ No ☐ Don't know

12

As a local resident, or business owner, who may have witnessed flooding/drainage problems, you may have your own ideas about how to reduce flood risks. Which of the following do you prefer (1=most preferred, 5=least preferred)?

Proposed option	Preference
Retarding or detention facility (these temporarily hold water and reduce peak flood flows) — Suggested location/other comments:	1 2 3 4 5
Improved flood flow paths — Suggested location/other comments:	1 2 3 4 5
Culvert/bridge enlarging — Suggested location/other comments:	1 2 3 4 5
Pit and pipe upgrades — Suggested location/other comments:	1 2 3 4 5
Flood walls — Suggested location/other comments:	1 2 3 4 5
Strategic planning and flood related development controls — Suggested location/other comments:	1 2 3 4 5
Education of the community, providing greater awareness of potential hazards — Suggested location/other comments:	1 2 3 4 5
Flood forecasting, flood warnings, evacuation planning and emergency response measures — Suggested location/other comments:	1 2 3 4 5

Other (please specify any options you think are suitable): ....

....

....

If you have any further comments that relate to the Darling Harbour Floodplain Management Study and Plan, please write them in the space below. Feel free to attach additional pages if necessary.

....

....

Glossary

Culvert – a piped drain or covered channel that passes under a road or railroad.

Flood wall – an embankment or wall, usually constructed from earth or concrete, to help prevent overflow of flood waters.

Retarding/detention facility – large storage that captures and holds stormwater runoff allowing it to slowly drain into the adjoining drainage line.

Barangaroo
The Rocks
Circular Quay
Western Distributor Freeway
Wynyard
Erskine St
Martin Place
Pyrmont
St James
Sussex St
Town Hall
Park St
Western Distributor Freeway
Museum
George St
Liverpool St
Harris St
Haymarket
Wattle St
Wentworth Ave
Darlinghurst
Pitt St
Oxford St
Ultimo
Central
Broadway
Surry Hills
N
Study Area

Appendix C

Table C1: Cost Estimate - Option FM-DH01					
Item No.	Description of work	Quantity	Unit	Rate	Cost
1	General Construction Costs				
1.1	Site establishment, security fencing, facilities and disestablishment	1	item	0	0
1.2	Provision of sediment and erosion control	1	item	0	0
1.3	Construction setout and survey	1	item	0	0
1.4	Work as executed survey and documentation	1	item	0	0
1.5	Geotechnical supervision, testing and certification	1	item	0	0
	SUBTOTAL (Assumed as 15% of works cost)				$ 94,858
2	Demolition and Clearing				
2.1	Clearing and grubbing	0	sq. m	11	0
2.2	Strip topsoil and stockpile for re-use (assuming 150mm depth)	0	cu. m	27	0
2.3	Dispose of excess topsoil (nominal 10% allowance)	0	cu. m	65	0
2.4	Pull up and dispose existing road surface	303	sq. m	38	11,453
	SUBTOTAL				$ 11,453
4	Installation of Drainage				
4.20	Supply, excavate, bed, lay, joint, backfill and provide connections 1.0m x 1.0m culvert	39	lin. m	2,268	88,452
4.50	Supply, excavate, bed, lay, joint, backfill and provide connections twin 0.3m dia. Pipe	36	lin. m	1,900	68,400
4.65	Supply, excavate, bed, lay, joint, backfill and provide connections quadruple 1.5m x 1.5m culvert	26	lin. m	12,096	314,496
4.78	Install new drainage/junction pit (assumed 1 pit per 5m of pipe)	20	each	4,320	86,400
4.87	Adjustment of existing services (nominal allowance) (assumed 10% of drainage installation cost)				55,775
	SUBTOTAL				$ 527,123
7	Footpath and Road Surfaces				
7.1	Reinstate disturbed road pavement, including demolition and disposal of additional material to provide good jointing	303	sq. m	130	39,269
	SUBTOTAL				$ 39,269
9	Traffic Management				
9.1	Control of traffic during works (nominal allowance) (assumed $500 per lin.m)	101	lin. m	540	54,540
	SUBTOTAL				$ 54,540
	CONSTRUCTION SUBTOTAL				$ 727,243
11	Contingencies				$ -
11.1	50% construction cost				$ 363,621
	CONSTRUCTION TOTAL, exc. GST				$ 1,090,864
	GST				$ 109,086
	CONSTRUCTION TOTAL, inc. GST				$ 1,199,951
	CONSTRUCTION TOTAL, rounded				$ 1,200,000
11	MAINTENANCE				
11.1	Maintenance of mitigation option				$ 1,010

Table C2: Cost Estimate - Option FM-DH02					
Item No.	Description of work	Quantity	Unit	Rate	Cost
1	**General Construction Costs**				
1.1	**Site establishment, security fencing, facilities and disestablishment**	1	item	0	0
1.2	**Provision of sediment and erosion control**	1	item	0	0
1.3	**Construction setout and survey**	1	item	0	0
1.4	**Work as executed survey and documentation**	1	item	0	0
1.5	**Geotechnical supervision, testing and certification**	1	item	0	0
	SUBTOTAL (Assumed as 15% of works cost)				**$ 650,625**
2	**Demolition and Clearing**				
2.1	**Clearing and grubbing**	0	sq. m	11	0
2.2	**Strip topsoil and stockpile for re-use (assuming 150mm depth)**	0	cu. m	27	0
2.3	**Dispose of excess topsoil (nominal 10% allowance)**	0	cu. m	65	0
2.4	**Pull up and dispose existing road surface**	2,181	sq. m	38	82,442
	SUBTOTAL				**$ 82,442**
4	**Installation of Drainage**				
4.23	**Supply, excavate, bed, lay, joint, backfill and provide connections 1.5m x 1.5m culvert**	217	lin. m	3,024	656,208
4.49	**Supply, excavate, bed, lay, joint, backfill and provide connections 0.3m dia. Pipe**	48	lin. m	950	45,600
4.53	**Supply, excavate, bed, lay, joint, backfill and provide connections 0.375m dia. Pipe**	41	lin. m	990	40,590
4.54	**Supply, excavate, bed, lay, joint, backfill and provide connections 1.05m dia. Pipe**	161	lin. m	1,430	230,230
4.55	**Supply, excavate, bed, lay, joint, backfill and provide connections twin 1.5m dia. Pipe**	155	lin. m	4,860	753,300
4.64	**Supply, excavate, bed, lay, joint, backfill and provide connections triple 1.5m x 1.5m culvert**	105	lin. m	9,072	952,560
4.78	**Install new drainage/junction pit (assumed 1 pit per 5m of pipe)**	145	each	4,320	626,400
4.87	**Adjustment of existing services (nominal allowance) (assumed 30% of drainage installation cost)**				901,333
	SUBTOTAL				**$ 3,579,821**
7	**Footpath and Road Surfaces**				
7.1	**Reinstate disturbed road pavement, including demolition and disposal of additional material to provide good jointing**	2,181	sq. m	130	282,658
	SUBTOTAL				**$ 282,658**
9	**Traffic Management**				
9.1	**Control of traffic during works (nominal allowance) (assumed $500 per lin.m)**	727	lin. m	540	392,580
	SUBTOTAL				**$ 392,580**
	CONSTRUCTION SUBTOTAL				**$ 4,988,126**
11	**Contingencies**				**$ -**

11.1	**50% construction cost**				**$ 2,494,063**
	CONSTRUCTION TOTAL, exc. GST				**$ 7,482,188**
	GST				**$ 748,219**
	CONSTRUCTION TOTAL, inc. GST				**$ 8,230,407**
	CONSTRUCTION TOTAL, rounded				**$ 8,230,400**
11	**MAINTENANCE**				
11.1	**Maintenance of mitigation option**		item		**$ 7,270**

Table C3: Cost Estimate - Option FM-DH06					
Item No.	**Description of work**	**Quantity**	**Unit**	**Rate**	**Cost**
1	**General Construction Costs**				
1.1	**Site establishment, security fencing, facilities and disestablishment**	1	item	0	0
1.2	**Provision of sediment and erosion control**	1	item	0	0
1.3	**Construction setout and survey**	1	item	0	0
1.4	**Work as executed survey and documentation**	1	item	0	0
1.5	**Geotechnical supervision, testing and certification**	1	item	0	0
	SUBTOTAL (Assumed as 15% of works cost)				**$ 310,284**
2	**Demolition and Clearing**				
2.1	**Clearing and grubbing**	0	sq. m	11	0
2.2	**Strip topsoil and stockpile for re-use (assuming 150mm depth)**	0	cu. m	27	0
2.3	**Dispose of excess topsoil (nominal 10% allowance)**	0	cu. m	65	0
2.4	**Pull up and dispose existing road surface**	1,458	sq. m	38	55,112
	SUBTOTAL				**$ 55,112**
4	**Installation of Drainage**				
4.23	**Supply, excavate, bed, lay, joint, backfill and provide connections 1.5m x 1.5m culvert**	467	lin. m	3,024	1,412,208
4.75	**Supply, excavate, bed, lay, joint, backfill and provide connections twin 1.5m x 1.2m culvert**	0	lin. m	5000	0
4.78	**Install new drainage/junction pit (assumed 1 pit per 50m of pipe)**	10	each	4,320	43,200
4.87	**Adjustment of existing services (nominal allowance) (assumed 10% of drainage installation cost)**				145,541
	SUBTOTAL				**$ 1,557,749**
7	**Footpath and Road Surfaces**				
7.1	**Reinstate disturbed road pavement, including demolition and disposal of additional material to provide good jointing**	1,458	sq. m	130	188,957
	SUBTOTAL				**$ 188,957**
9	**Traffic Management**				
9.1	**Control of traffic during works (nominal allowance) (assumed $500 per lin.m)**	467	lin. m	540	252,180
	SUBTOTAL				**$ 252,180**
	CONSTRUCTION SUBTOTAL				**$ 2,378,846**
11	**Contingencies**				**$ -**
11.1	**50% construction cost**				**$ 1,189,423**
	CONSTRUCTION TOTAL, exc. GST				**$ 3,568,269**
	GST				**$ 356,827**
	CONSTRUCTION TOTAL, inc. GST				**$ 3,925,096**
	CONSTRUCTION TOTAL, rounded				**$ 3,925,100**
11	**MAINTENANCE**				
11.1	**Maintenance of mitigation option**		item		**$ 4,860**

Table C4: Cost Estimate - Option DH05					
Item No.	**Description of work**	**Quantity**	**Unit**	**Rate**	**Cost**
1	**General Construction Costs**				
1.1	**Site establishment, security fencing, facilities and disestablishment**	1	item	0	0
1.2	**Provision of sediment and erosion control**	1	item	0	0
1.3	**Construction setout and survey**	1	item	0	0
1.4	**Work as executed survey and documentation**	1	item	0	0
1.5	**Geotechnical supervision, testing and certification**	1	item	0	0
	SUBTOTAL (Assumed as 15% of works cost)				**$ 972,237**
2	**Demolition and Clearing**				
2.1	**Clearing and grubbing**	0	sq. m	11	0
2.2	**Strip topsoil and stockpile for re-use (assuming 150mm depth)**	0	cu. m	27	0
2.3	**Dispose of excess topsoil (nominal 10% allowance)**	0	cu. m	65	0
2.4	**Pull up and dispose existing road surface**	1,458	sq. m	38	55,112
	SUBTOTAL				**$ 145,265**
4	**Installation of Drainage**				
4.23	**Supply, excavate, bed, lay, joint, backfill and provide connections 1.5m x 1.5m culvert**	467	lin. m	3,024	1,412,208
4.75	**Supply, excavate, bed, lay, joint, backfill and provide connections twin 1.5m x 1.2m culvert**	0	lin. m	5000	0
4.78	**Install new drainage/junction pit (assumed 1 pit per 50m of pipe)**	10	each	4,320	43,200
4.87	**Adjustment of existing services (nominal allowance) (assumed 10% of drainage installation cost)**				581,036
	SUBTOTAL				**$ 5,146,520**
7	**Footpath and Road Surfaces**				
7.1	**Reinstate disturbed road pavement, including demolition and disposal of additional material to provide good jointing**	1,458	sq. m	130	188,957
	SUBTOTAL				**$ 498,053**
9	**Traffic Management**				
9.1	**Control of traffic during works (nominal allowance) (assumed $500 per lin.m)**	467	lin. m	540	252,180
	SUBTOTAL				**$ 691,740**
	CONSTRUCTION SUBTOTAL				**$ 7,453,815**
11	**Contingencies**				**$ -**
11.1	**50% construction cost**				**$ 3,726,907**
	CONSTRUCTION TOTAL, exc. GST				**$ 11,180,722**
	GST				**$ 1,118,072**
	CONSTRUCTION TOTAL, inc. GST				**$ 12,298,794**
	CONSTRUCTION TOTAL, rounded				**$ 12,298,800**
11	**MAINTENANCE**				
11.1	**Maintenance of mitigation option**		item		**$ 12,810**

Table C5: Cost Estimate - Option DH07					
Item No.	**Description of work**	**Quantity**	**Unit**	**Rate**	**Cost**
1	**General Construction Costs**				
1.1	**Site establishment, security fencing, facilities and disestablishment**	1	item	0	0
1.2	**Provision of sediment and erosion control**	1	item	0	0
1.3	**Construction setout and survey**	1	item	0	0
1.4	**Work as executed survey and documentation**	1	item	0	0
1.5	**Geotechnical supervision, testing and certification**	1	item	0	0
	SUBTOTAL (Assumed as 15% of works cost)				**$ 70,712**
2	**Demolition and Clearing**				
2.1	**Clearing and grubbing**	0	sq. m	11	0
2.2	**Strip topsoil and stockpile for re-use (assuming 150mm depth)**	0	cu. m	27	0
2.3	**Dispose of excess topsoil (nominal 10% allowance)**	0	cu. m	65	0
2.4	**Pull up and dispose existing road surface**	519	sq. m	38	19,618
	SUBTOTAL				**$ 19,618**
4	**Installation of Drainage**				
4.23	**Supply, excavate, bed, lay, joint, backfill and provide connections 1.5m x 1.5m culvert**	0	lin. m	3,024	0
4.75	**Supply, excavate, bed, lay, joint, backfill and provide connections twin 1.5m x 1.2m culvert**	0	lin. m	5000	0
4.78	**Install new drainage/junction pit (assumed 1 pit per 50m of pipe)**	9	each	4,320	38,880
4.87	**Adjustment of existing services (nominal allowance) (assumed 10% of drainage installation cost)**				212,139
	SUBTOTAL				**$ 291,114**
7	**Footpath and Road Surfaces**				
7.1	**Reinstate disturbed road pavement, including demolition and disposal of additional material to provide good jointing**	519	sq. m	130	67,262
	SUBTOTAL				**$ 67,262**
9	**Traffic Management**				
9.1	**Control of traffic during works (nominal allowance) (assumed $500 per lin.m)**	173	lin. m	540	93,420
	SUBTOTAL				**$ 93,420**
	CONSTRUCTION SUBTOTAL				**$ 542,127**
11	**Contingencies**				**$ -**
11.1	**50% construction cost**				**$ 271,063**
	CONSTRUCTION TOTAL, exc. GST				**$ 813,190**
	GST				**$ 81,319**
	CONSTRUCTION TOTAL, inc. GST				**$ 894,509**
	CONSTRUCTION TOTAL, rounded				**$ 894,500**
11	**MAINTENANCE**				
11.1	**Maintenance of mitigation option**		item		**$ 1,730**