

CITY AREA CATCHMENT
FLOODPLAIN RISK
MANAGEMENT STUDY
FINAL REPORT





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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 City of Sydney Catchment Floodplain Risk Management Study and Final 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 City Area catchment, and investigates potential management options for the area. The study, which follows on from the City Area 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 options aimed at managing this flood risk were also assessed for their efficacy across a range of criteria, which allowed certain options to be recommended, forming the basis of the Floodplain Risk Management Plan for the area. Assessed options included upgraded pit and pipe networks, emergency management options and various property modification options.

Background

The City Area catchment is located in Sydney's inner city suburbs of Millers Point, Dawes Point, The Rocks, Barangaroo, and parts of Sydney, and has an area of 199 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 Circular Quay.

The City Area Catchment Flood Study (2014) was carried out to define existing flood behaviour for the 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 drainage assets. Urbanisation of 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. The main watercourse in the catchment, the Tank Stream, was covered over in the 1850s. Due to these drainage restrictions, topographic depressions often correspond with areas of localised flooding as excess flows have no opportunity to escape via overland flow paths and sub-surface drainage has insufficient capacity. The majority of the drainage network reaches capacity during small events (i.e. 0.5 EY).

There are 118 properties within the catchment identified as liable to over floor inundation in the 1% AEP event, while 60 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 \$1.9 million for the catchment.

Flooding hotspots in the catchment were identified at the following locations: Pitt Street, George Street between King Street and Hunter Street, King Street between Pitt and George Streets, Martin Place between Pitt and George Streets, Angel Place, Curtin Place, Bond Street, Hunter Street, Phillip Street and Alfred Street. 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 Options

A range of floodplain risk management options were investigated as part of the study.

Fourteen options 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 options, who were informed about the study via a brochure and questionnaire. Options were also considered in the context of relevant policies and planning controls, including City of Sydney's Interim Floodplain Management Policy.

Rank	Ref	Option	Score
1	PM-CA02	Property Modification - Development Control Planning	10
2	PM-CA01	Property Modification - Flood Planning Levels	9
3=	RM-CA01	Response Modification - Flood Warning and Evacuation	8
3=	RM-CA03	Response Modification - Community Awareness Programme	8
5	RM-CA02	Response Modification - Flood Emergency Management	7
6	FM-CA05	Overland Flowpath – Surface Adjustment to Pitt Street Mall	6
7=	PM-CA03	Property Modification - Flood Proofing	5
7=	FM-CA01	Trunk Drainage Upgrade – Alfred Street to Market Street	5
9=	FM-CA04	Trunk Drainage Upgrade – New Drainage to Darling Harbour	4
9=	FM-CA08	Drainage Upgrade – Phillip Street	4
11=	FM-CA06	Overland Flowpath – Surface Adjustment to Martin Place	2
11=	FM-CA02	Trunk Drainage Upgrade – Pitt Street and King Street	2
13	FM-CA03	Trunk Drainage Upgrade – Alfred Street to Bridge Street	1
14	FM-CA07	Trunk Drainage Upgrade – George Street near Wynyard	-3

A summary of the options, including their time-frame, priority and responsibility, is given in the City Area Floodplain Risk Management Plan. Three of the assessed options 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 7.

The Floodplain Risk Management Study and Plan was adopted by Council on the 15th of August 2016.

1. INTRODUCTION

1.1. Study Area

The City Area catchment is located in Sydney's inner city suburbs of Millers Point, Dawes Point, The Rocks, Barangaroo, and parts of Sydney (refer to Figure 1). 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 Observatory Park and parts of Hyde Park.

The catchment covers an area of approximately 199 hectares and drains into Sydney Harbour at various locations, with the majority of the catchment discharging to Sydney Cove via Sydney Water Corporation's (SWC) main trunk drainage system (refer Figure 3). An extensive sub-surface drainage system exists, with Council's minor stormwater system draining the upper areas and entering SWC trunk assets in the lower catchment.

The topography within the catchment varies from steep slopes in excess of 15% on the western sides, to the near-flat lower catchment near Circular Quay and the other Sydney Harbour shoreline locations. 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 and flow velocities will be lower. The lower reaches of the catchment fringing 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 City Area 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 options investigated and recommendations made. The objectives for this phase include:

- Review the current City Area Catchment Flood Study (2014) and update the 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 options (involvement with the NSW State Emergency Service).

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

- Pitt Street;
- George Street, between King Street and Hunter Street;
- King Street, between Pitt Street and George Street;
- Martin Place, between Pitt Street and George Street;
- Angel Place;
- Curtin Place;
- Bond Street;
- Phillip Street; and
- Hickson Road, Walsh Bay.

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 options for implementation.

2. BACKGROUND

2.1. City Area 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 *Metropolitan Centre* corresponding to Sydney's Central Business District. There are two major development/redevelopment areas – Barangaroo (classed *SEPP Major Development 2005*) and Sydney Cove (*Sydney Cove Redevelopment Authority Scheme*). The remainder of the catchment is a mixture of *Roads, Public Recreation, General Residential* and *Railways*.

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 Millers Point, Dawes Point, The Rocks, Barangaroo and parts of Sydney CBD. 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. Barangaroo was not examined due to the significant redevelopment which has occurred since 2011.

Table 1: 2011 Census data by location

	NSW	Millers Point	Dawes Point	The Rocks	Sydney*
Population Age:					
0 – 14 years	19.2%	5.9%	8.3%	5.6%	4.1%
15 - 64 years	66.1%	77.2%	78.0%	80%	91.1%
> 65 years	14.7%	16.9%	13.8%	14.6%	4.8%
Average people per dwelling	2.6	1.8	2.0	1.5	2.1
Own/mortgage property	66.6%	34%	44.0%	31.0%	33.7%
Rent property	30.1%	62.9%	53.4%	64.7%	63.4%
Moved into area:					
- within last year	-	23%	18%	23%	34%
- within last five years	-	57%	56%	54%	74%
No cars at dwelling	10.9%	26.4%	18.4%	39.7%	59.2%
Speak only English at home	72.5%	59.2%	69.4%	47.6%	26.4%
Other languages spoken		Cantonese (2%), Vietnamese (1.8%), Japanese (1.6%), Spanish (1.3%), Hindi (1.3%)	Cantonese (4.6%), Mandarin (3.0%), French (1.8%), Italian (1.3%), Spanish (0.9%)	Cantonese (3.1%), Spanish (2.8%), Mandarin (2.3%), Japanese (1.6%), French (1.2%)	Mandarin (12.5%), Indonesian (7.9%), Thai (6.9%), Cantonese (6.3%), Korean (5.6%)

* only parts of Sydney are located within the City Area catchment; however, statistics are provided for the entire suburb.

From this data it is apparent that the City Area comprises a higher portion of 15 – 64 year olds than the state average. There is a lower average number of people per dwelling compared to the state average which may need to be considered in evacuation and emergency planning (that is, more dwellings to account for than perhaps anticipated if population size alone was considered). There is also a 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 City Area catchment is completely urbanised and has no remnant vegetation. Areas of parkland exist at Hyde Park, Observatory Hill 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 options 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;
- Millers Point Gasworks is a known contaminated site which is currently undergoing remediation; and
- The majority of the City Area 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) besides a small area adjacent to Circular Quay which is classed as 2 (any works undertaken in this area below ground level or which lower the water table are likely to present an environmental risk), and a small section classed as 1 (any works undertaken in this area are likely to present an environmental risk) in the Barangaroo development site.

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 City Area. 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 Tank Stream, running parallel to George Street and Pitt Street, which has been listed on the State Heritage Register. The Tank Stream has cultural significance as the original water supply for Sydney, a role it served until 1826. It is said that discovery of the stream by Captain Arthur Phillip was a key factor in choosing the location for the first white settlement (Reference 3). At that time, the stream was a natural creek with a small riparian zone. Extensive urbanisation in the early settlement polluted the waterway, and it changed from a water supply source to an open sewer. It was covered with sandstone blocks in the 1850s to form the drain which still exists today. Its outlet is near the south-west corner of Circular Quay. It is currently managed by SWC.

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 and laneways. When this occurs, there is potential for high hazard flood conditions resulting from flow velocities and depths.

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 on Pitt Street Mall, King Street between Pitt and George Streets, and

at Circular Quay. 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 City Area catchment, as summarised below.

2.2.1. City Area 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 City Area 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 City Area catchment was modelled in the 2D domain, with approximately 27 km 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':

- Pitt Street between Park Street and Alfred Street
- George Street between King Street and Hunter Street
- King Street between Pitt Street and George Street
- Martin Place between Pitt Street and George Street
- Angel Place
- Curtin Place
- Bond Street
- Phillip Street
- Hickson Road, Walsh Bay

2.2.2. City Area SWC29 Capacity Assessment, Sydney Water, 1996 (Reference 4)

This report assessed the quantitative performance of stormwater drainage elements within SWC's City Area SWC29 which covers approximately the same extent as 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 were generally better serviced than residential areas, the overall catchment had a relatively poor performance.

2.3. Flood Study Modelling Review and Model Updates

WMAwater have carried out a review of the City Area 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, as was the inclusion of car parks which can store runoff. 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. Also, low-lying car parks were not included in the model, and so their effect was determined using a sensitivity analysis.
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. 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. Minor revision to the Mannings 'n' representation in Martin Place. The model review identified the area as requiring a slightly smoother hydraulic roughness than was previously used.
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 were mainly located in the northern half of the catchment. There were no widespread effects on design flood behaviour.
3. Minor changes to the buildings in the model where the previous model did not represent a building. These were located at Australia Square on Pitt Street, at the northern end of Macquarie Street and a small building in Walsh Bay.

2.4.1. Car Park Representation

Changes to the representation of car parks were not included in the model update but will be considered in assessing flood risk in the catchment. The model review identified several car parks in the area that are located adjacent to floodwaters and that will act as flood storage areas in a large event. The model review determined that the flood level at localised areas of the catchment was sensitive to the volume of runoff that enters the car park, with several locations having a reduction of 0.5 m or more in both frequent and rare events.

Although inclusion of car parks is considered to improve the model accuracy, the actual flood behaviour at each location is dependent on the assumptions about the entry of the car park, as well as the behaviour inside the car park. In addition, the car park entrance or interior will change in the future and will no longer act as a storage area. Given that there is no formal recognition of the car parks' functioning in a flood (i.e. that they may fill up with water), and that planning controls require new car parks to have flood-free entrances, their function as storages will be gradually be removed in the future. This will reduce the flood risk associated with becoming trapped in the car park, and will also give more certainty about the flood behaviour in the vicinity of the car park.

Given these uncertainties, the design flood behaviour for the catchment will be based on assuming car parks are fully blocked (as per the flood study model). However, the assessment of risk across the catchment will consider the model results that represent the car parks as receiving runoff. That is, the assessment of flood hazard and the description of flood behaviour at each of the hotspots will be based on the results which allow runoff into the car parks.

3. EXISTING FLOOD ENVIRONMENT

3.1. Overview of Flood Behaviour

The topography within the City Area catchment varies from steep surface slopes in excess of 15% on the western side to the near flat lower catchment near Circular Quay and the other Sydney Harbour shoreline locations. 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. In the CBD numerous high rise buildings are built above the surrounding ground levels and obstruct flow. There are very few opportunities for flow to pass through or between properties and as a result the roads form the primary overland flow paths (major drainage system) and are 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 a piped network system and there are no open channels within the area. In rainfall events where flow exceeds 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.

Pitt Street forms the primary overland flow path that drains the majority of the City Area catchment. The top of the Pitt Street catchment is bounded by Hyde Park to the east, Liverpool Street to the south and York Street to the west. Runoff from the catchment extremities drains quickly to the primary overland flow path along Pitt Street downstream to Circular Quay (i.e. in a northerly direction). Flooding occurs in the 0.5 EY event and larger. Flooding in the rest of the catchment is generally a result of concentration of overland flow from localised catchments in trapped low points where limited drainage capacity currently exists.

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, for example, the 10% and 1% AEP event. For example, at King Street near Pitt Street, there is around 1.0 m of depth in a 10% AEP and 1.1 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 Bond 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.

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. Pitt St from Market Street to Martin Place	0.8	2.7	0.5 EY
2. Pitt Street from Martin Place to Young Street	2.8	3	0.5 EY
3. Tank Stream from Young St to the Opera House	6	6.2	<0.5 EY
4. Tank Stream from King Street to Hunter Street	1.5	3	<0.5 EY
5. Tank Stream from Martin Place to Bridge Street	3	3	<0.5 EY
6. Tank Stream from Bridge Street to Circular Quay	2.5	5	<0.5 EY
7. Loftus Street near Macquarie Place	1.1	1.5	0.2 EY
8. Phillip Street near Bent Street	1.5	1.8	0.2 EY
9. King/Phillip St up to downstream Phillip Street	0.6	0.6	1% AEP

3.2. Hydraulic Categories

The 2005 NSW Government's Floodplain Development Manual (Reference 7) 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 7), the Flood Study (Reference 2) defined hydraulic categories as:

<i>Floodway:</i>	Velocity x Depth > 0.25 m ² /s AND Velocity >0.25 m/s OR Velocity > 1 m/s
<i>Flood Storage:</i>	Land outside the floodway where Depth > 0.2m
<i>Flood Fringe</i>	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 on Pitt Street between Market Street and Alfred Street, as well as on George Street near Wynyard, while flood storage areas exist on King Street, Angel Place and Alfred Street. In the 1% AEP event these features are more pronounced, including the floodway from Hyde Park down Market Street. The flood storage areas at Barangaroo are also more prominent. In the PMF event, floodways exist in the same areas, as well as on King Street, Martin Place, Hunter Street and various lanes adjoining Pitt Street.

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 and 0.2 EY, 10%, 5%, 2%, 1%, 0.2% AEP and PMF events. As shown in the figures, high hazard inundation is concentrated to Pitt Street and the small adjacent trapped depressions, including King Street, Angel Place and Bond Street. 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 City Area 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 Pitt 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 2-3 m/hour in the 5% AEP and 2-3.5 m/hour in the 1% AEP – both 90 minute storm duration) and flood prone areas will become inundated soon after the rainfall event begins. Underground car parks with entrances at sag points will have significant hazard arising from the rate of rise. As discussed in Section 2.4.1, there are several flood prone car parks, with flood behaviour that is difficult to predict due to uncertainties around the flow at the entrance driveway and then how the flow behaves inside.

Nevertheless, runoff that accumulates in a car park located along the main depression (i.e. on or near Pitt Street), can potentially rise quickly and trap people inside the car park.

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 23% 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 300 mm or more in the 1% AEP include:

- The majority of Pitt Street Mall;
- King Street between George and Pitt Street;
- Some parts of Pitt Street between King and Hunter Street;
- The majority of Pitt Street between Hunter and Alfred Street, and the adjoining laneways to the west;
- Part of Phillip Street near Martin Place;
- Circular Quay between the Overseas Passenger Terminal and the Museum of Contemporary Art; and
- Parts of Barangaroo (the area is currently under construction, results are based on pre-development conditions and are likely to change).

At depths of 300 mm, 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 hour event. This shows that the duration of flooding is typically less than 1 hour except in the known trapped depressions on King Street, Angel Place, Curtin Place, Phillip Street and Bond 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 amended to include Alfred Street and Hunter Street, and eliminate Hickson Road, to form a set of flooding hotspots. These changes were made when considering the overall risk presented by the hotspot in comparison to other areas in the catchment. Hickson Road was not considered any more significant than other flooded areas, whilst Alfred and Hunter Street were considered to have potentially higher impacts. Phillip Street was identified as a minor flooding hotspot due to the low degree of affectation compared to other hotspots. These areas are shown in Figure 12 and discussed in Table 6.

Table 6: Hotspots - City Area Catchment

Location	Description	Flood characteristics	Hydraulic Hazard
Pitt Street	Pitt Street acts as the primary overland flow path for the majority of the catchment. The flows and velocities present a significant risk to pedestrians, motorists and property along the majority of Pitt Street, from Park Street in the south to Alfred Street/Circular Quay in the north. This includes significant area of prime commercial / business activity.	Isolated areas of overland flooding first occur in the 0.5 EY event. In the 1% AEP event, approximately 20 m ³ /s is conveyed along Pitt Street at depths exceeding 0.5 m in some locations, and velocities up to 2.5 m/s. In the PMF event peak depths exceed 1.5m (to as much as 1.8m) in some locations.	5% AEP : High from just upstream Martin Place to Alfred Street, otherwise Low 1% AEP : High from King Street to Alfred Street, otherwise Low
George Street, between King Street and Hunter Street	For a limited stretch of George Street there is a concentration of overland flow which flows from King Street before collecting in Hunter Street.	Overland flooding occurs from the 0.2 EY event (although a very small section between Martin Place and Pitt Street is shown to be affected in the 0.5 EY event). Depths of up to 0.3 m and velocities of up to 2.0 m/s are experienced in the 1% AEP event. Peak depths of 0.5m occur in some locations in the PMF event	5% AEP: Low 1% AEP: Low
King Street, between Pitt Street and George Street	At this location King Street slopes down from both George and Pitt Street, resulting in significant ponding of floodwaters in events as small as the 0.5 EY. The street is bounded by commercial properties which trap the floodwaters at this location. Properties on the northern side of the road are generally raised more than 1m above King Street, whilst those on the southern side are at, or near, street level. Directly opposite the sag point is a basement car park entry, with the driveway sloping down away from King Street at a steep grade.	In the 0.5 EY event water ponds to depths of up to 0.75 m, rising to over a metre in the 1% AEP event (and exceeding 1.6m in the PMF event). Floodwaters moving into King Street from George Street reach velocities of more than 1 m/s in the 1% AEP event.	5% AEP: High around sag point, some Medium, otherwise Low 1% AEP: High around sag point, some Medium, otherwise Low
Martin Place, between Pitt Street and George Street	At this location George Street and Pitt Street act as overland flow paths. In events from the 10% AEP, water breaks out and flows through Martin Place to Pitt Street.	In the 10% AEP event, velocities are less than 0.5 m/s and shallow depths of approximately 0.1 m. This increases to approximately 0.3 m in the 1% AEP event, although velocities remain relatively low. In the PMF depths can exceed 0.8 m near the junction with Pitt Street.	5% AEP: Low 1% AEP: Low
Angel Place	Floodwaters flow into Angel Place, which grades down away from Pitt Street, and collects in the sag point outside the City Recital Hall. There are commercial properties surrounding this location.	Depths of up to 0.5 m occur in the 0.5 EY event, rising to over 1.0 m in the 1% AEP event, and exceeding 2.0 m in the PMF.	5% AEP: High 1% AEP: High
Curtin Place	A trapped low point in Curtin Place results in ponding water in all events from the 0.5 EY. Immediately adjacent to the	Depths of 0.5 m and velocities of 2 m/s occur in the 0.5 EY event, rising to over 1.0 m and 3 m/s in the	5% AEP: High

Location	Description	Flood characteristics	Hydraulic Hazard
	low point is the entry to a basement car park, with the driveway sloping down away from Curtin Place. The nearby commercial properties are raised above street level and unlikely to be inundated, though access to and from these properties may be impeded.	1% AEP event. In the PMF event peak depths exceed 2.0 m.	1% AEP: High
Bond Street	A low point on Bond Street traps floodwaters in all events from the 0.5 EY.	Depths of 0.1 m and velocities of 0.8 m/s occur in the 0.5 EY event, rising to over 1.0 m and more than 1 m/s in the 1% AEP event. In the PMF event peak depths exceed 2.0 m.	5% AEP: High 1% AEP: High
Hunter Street	Overland flow originating from both George Street and Pitt Street accumulates in Hunter Street, where it becomes trapped by the surrounding buildings	Velocities in excess of 2 m/s occur from the 10% AEP event. Flood depths range from less than 0.5 m in the 10% AEP event to more than 0.8 m in the 1% AEP event, and nearing 2.0 m in the PMF.	5% AEP: High 1% AEP: High
Alfred Street	Alfred Street, at the bottom of Pitt Street in Circular Quay, begins ponding in events from the 0.5 EY as the overland flows from Pitt Street accumulate in the lower catchment. This is a busy area, being adjacent to the ferry terminals at the Wharf, as well as near significant tourist attractions, and attracts a high number of pedestrians.	Depths exceed 0.25 m and velocities exceed 0.4 m/s in the 0.5 EY event, rising to more than 0.5 m and more than 1 m/s in the 1% AEP event. In the PMF peak depths exceed 1.2 m.	5% AEP: Mainly Low with some areas of Medium/High near intersection with Pitt Street 1% AEP: Mainly Low with some areas of Medium/High near intersection with Pitt Street
Phillip Street Between Martin Pl and Hunter St	Slight topographic depression on Phillip Street between Martin Place and Hunter Street that causes runoff to accumulate in the area.	Limited affectation – depths of 0.1 m occur in the 0.2 EY, rising to over 0.3 m in the 2% AEP event. Velocities do not exceed 0.09 m/s even in the PMF.	5% AEP: Low 1% AEP: Low

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 is to consist of:

- Distribution of brochure and questionnaire survey;
- Media release; and
- Public meetings.

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 58 were received from the City Area 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 survey was undertaken as part of this study to inform specific residents of the next stage of the floodplain management process as well as to gather flood information and community's preferred options for managing flood risks within the catchment. With assistance from City of Sydney, 951 newsletters and questionnaires were distributed 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 mailout.

The results show that respondents to date have little experience of flooding and the majority have commercial premises. Of the respondents, three have experienced flooding, with three of those having floodwaters inside their house/business, and one observing it in the neighbourhood. Respondents did not favour pit and pipe upgrades or structural options, and most identified 'Flood Walls' as their most preferred management option.

With regards to mitigation options, most respondents favoured unblocking drains, pit and pipe upgrades and flood walls. The majority of responses did not give a written response in regards to mitigation options, but those that did favoured nearly all favoured unblocking pits and pipes. The number ratings showed relatively high preference for flood walls and pit and pipe upgrades, while respondents rated improved flow paths, retarding basins and pit upgrades as the least preferred.

The low number of responses means that statistically, the responses are unlikely to be representative of the catchment's population.

4.1.3. Community Information Session

A community information session was held on Sunday the 25th of October 2015 at Ward Park, Surry Hills and Sunday 13th of March at Fig Street Reserve, Ultimo. 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 all properties within the catchment, public notice in the local newspapers and online version of the report 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 7. Please note that the submissions for the Darling Harbour FRMS&P have also been addressed here as there was some overlap between respondents.

Table 7 Public Exhibition Submissions and Responses

ID	Query	Response	Report Reference
A01	Study and plan provides minimal consideration to the downstream effects of flooding	<p>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."</p> <p>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 <i>Sustainable Sydney 2030</i> 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".</p> <p>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.</p>	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.	<p>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.</p> <p>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.</p>	No amendments to the report.

ID	Query	Response	Report Reference
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.
51326 1	Strong support for response measures, moderate support for capital works.	No response required	No amendments to the report.
51855 3	<p>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.</p> <p>In Neild 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.</p>	<p>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.</p>	No amendments to the report.

5. ECONOMIC IMPACT OF FLOODING

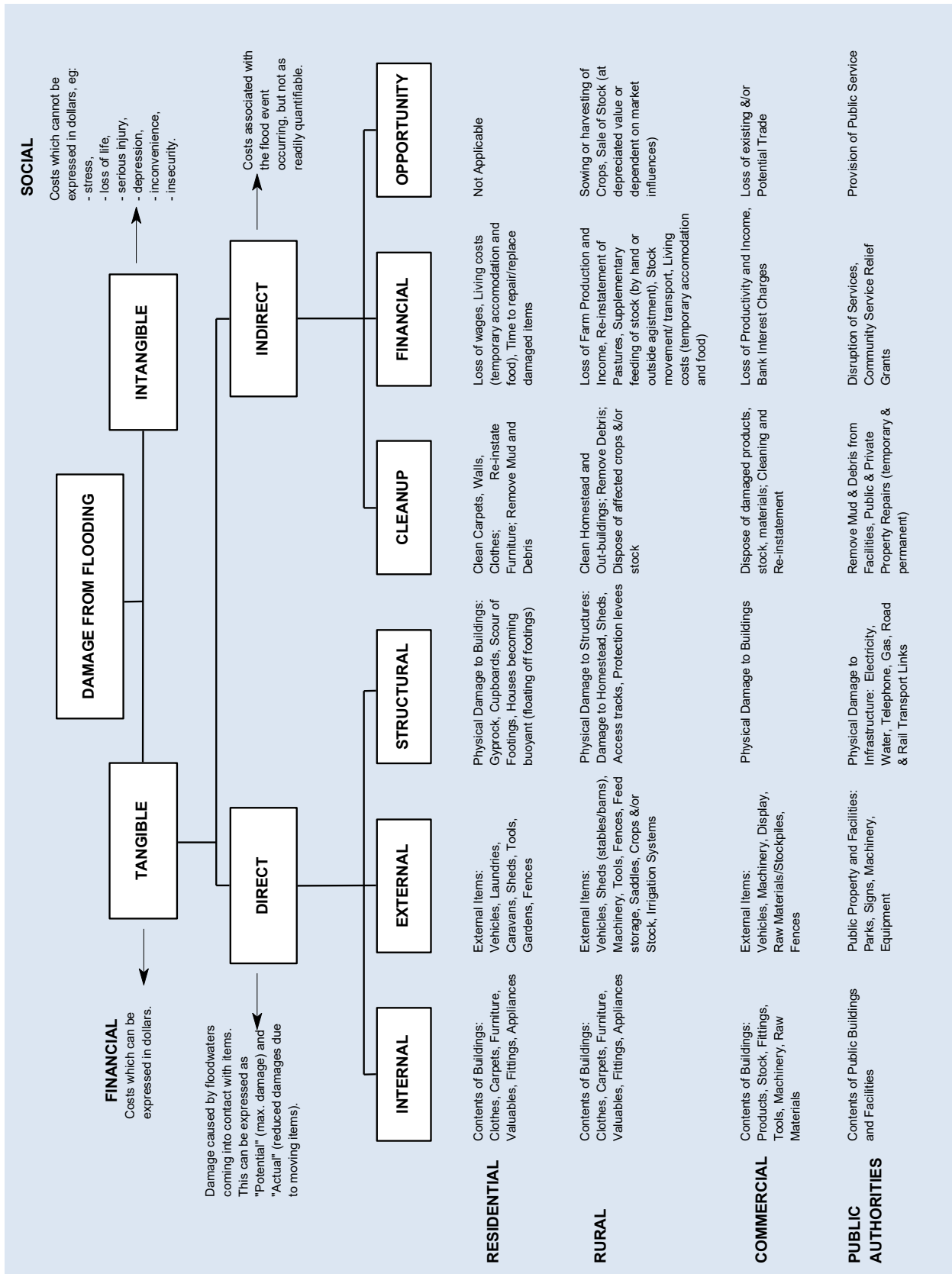
The impact of flooding can be quantified through the calculation of flood damages. Flood damage calculations do not include all impacts associated with flooding. They do, however, provide a basis for assessing the economic loss of flooding and also a non-subjective means of assessing the merit of flood 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 options 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 8.

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



5.1. Tangible Flood Damages

Tangible flood damages are comprised of two basic categories; direct and indirect damages (refer Table 8). 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 options. Understanding the total damages prevented over the life of the option in relation to current damages, or to an alternative option, can assist in the decision making process.

The standard way of expressing flood damages is in terms of average annual damages (AAD). AAD represents the equivalent average damages that would be experienced by the community on an annual basis, by 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 8) 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 9. This flood damages estimate does not include the cost of restoring or maintaining public services and infrastructure.

Table 9: Estimated Combined Flood Damages for City Area 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	47	40	\$ 2,584,000	\$ 55,000
5	75	60	\$ 3,512,000	\$ 46,800
10	95	74	\$ 4,496,300	\$ 47,300
20	123	95	\$ 5,968,800	\$ 48,500
50	136	105	\$ 6,734,700	\$ 49,500
100	154	118	\$ 7,702,600	\$ 50,000
500	171	131	\$ 9,973,100	\$ 58,300
PMF	245	170	\$ 18,452,800	\$ 75,300
Average Annual Damages (AAD)			\$ 1,896,400	\$ 7,700

5.1.1. Residential Properties

The flood damages assessment for residential development was undertaken in accordance with OEH guidelines (Reference 8). 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 City Area catchment is provided in Table 10. 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 10: Estimated Residential Flood Damages for City Area 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	13	10	\$ 769,800	\$ 59,200
5	19	15	\$ 984,500	\$ 51,800
10	23	16	\$ 1,239,800	\$ 53,900
20	27	18	\$ 1,592,800	\$ 59,000
50	30	19	\$ 1,726,000	\$ 57,500
100	39	24	\$ 1,927,300	\$ 49,400
500	44	28	\$ 2,639,800	\$ 60,000
PMF	82	38	\$ 4,486,300	\$ 54,700
Average Annual Damages (AAD)			\$ 530,800	\$ 6,500

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 is 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 be 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 m².

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 City Area catchment is provided in Table 11. AAD for the surveyed commercial/industrial properties is greater than that for residential properties and the number of flood affected properties for commercial/industrial is 2 to 3 times more than that of residential. 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 11: Estimated Commercial and Industrial Flood Damages for City Area 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	34	30	\$ 1,814,200	\$ 53,400
5	56	45	\$ 2,527,500	\$ 45,100
10	72	58	\$ 3,256,500	\$ 45,200
20	96	77	\$ 4,376,000	\$ 45,600
50	106	86	\$ 5,008,700	\$ 47,300
100	115	94	\$ 5,775,300	\$ 50,200
500	127	103	\$ 7,333,300	\$ 57,700
PMF	163	132	\$ 13,966,500	\$ 85,700
Average Annual Damages (AAD)			\$ 1,365,600	\$ 8,400

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 City Area catchment area, the high hazard areas include Pitt Street (high flow) and trapped low points with high flood depths, e.g. at King Street, Angel Place and Curtin Place. 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 City Area catchment is characterised by overland flow, with no mainstream flooding and only a small area of tidal influence near Circular Quay. 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 9.4.4 and 9.4.5.

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 City Area catchment are discussed as follows.

6.2.1. Regional Emergency Plan (REMPAN)

The City Area 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 (REMPAN) 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 (LEMPAN)

A LEMPLAN has not been prepared for the local area containing the City Area 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 City Area 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 City Area 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 City Area 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 City Area 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 City Area 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, Pitt Street and King Street, with Pitt Street containing the area's main overland flowpath, lesser flow in parallel on George Street, and King Street having significant ponding between Pitt Street and George Street.

As shown in Table 12, the depth of inundation on the road varies from 0.0 - 0.8 m in a 0.5 EY event, to 0.3-1.8 m in a 1% AEP and up to 2.1 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. Table 12 also lists the depths for other roads in the catchment, the worst-affected of which is Angel Place, while Figure 21 shows their locations.

Table 13 lists the rate of rise in metres per hour for the same locations listed in Table 12, for the 1 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 eight 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 Curtin Place having the fastest increase overall, while George Street, Hickson Road and Martin Place are relatively slow. The rate of rise is generally around 0.8 m/hour for frequent events and between 1 and 3 m/hour for rarer events, for the 1 hour event.

Table 12: 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	Phillip Street near Martin Place	0.3	0.4	0.6	0.6	0.6	0.6	0.6	0.7
2	Angel Place near George Street	1.2	1.5	1.7	1.7	1.7	1.8	1.8	2.1
3	Martin Place near George Street	0.0	0.0	0.2	0.3	0.3	0.3	0.4	0.6
4	King Street near George Street	0.8	1.0	1.1	1.2	1.2	1.2	1.3	1.5
5	Pitt Street between Alfred St and Park St	0.5	0.6	0.7	0.8	0.8	0.9	1.0	1.3
6	George Street between Hunter St and King St	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.5
7	Hickson Road near Walsh Bay	0.2	0.3	0.3	0.3	0.3	0.3	0.4	0.5
8	Curtin Place near Pitt Street	1.1	1.2	1.5	1.6	1.7	1.7	1.8	2.1

Table 13: Major Road Flooding Rate of Rise (m/hour) for Various Events (1 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	Phillip Street near Martin Place	0.7	0.7	1.1	1.2	1.2	1.2	1.3	2.4
2	Angel Place near George Street	1.4	2.3	2.8	3.0	3.1	3.2	3.4	5.6
3	Martin Place near George Street	0.0	0.0	0.4	0.5	0.5	0.6	0.7	1.8
4	King Street near George Street	1.1	1.7	2.1	2.2	2.3	2.4	2.5	4.9
5	Pitt Street between Alfred St and Park St	0.8	1.0	1.1	1.3	1.5	1.6	1.8	3.0
6	George Street between Hunter St and King St	0.3	0.3	0.5	0.5	0.6	0.7	0.8	1.7
7	Hickson Road near Walsh Bay	0.5	0.5	0.6	0.6	0.6	0.7	0.7	1.0
8	Curtin Place near Pitt Street	2.1	2.3	2.6	3.0	3.2	3.4	3.5	6.1

For the 1% AEP flood event, roads cut (as per Figure 21) are shown in Table 14.

Table 14: Major Roads Cut in the 1% AEP Event

Road Location	Description
Pitt Street between Market and Alfred Street	Flood depths are around 0.3 m (but as high as 0.6 m at downstream end) and persist for a period of 30 minutes to one hour given the critical storm modelled (1 hour).
King Street between George and Pitt Street	Flood depths are up to 1.2 m and persist for a period of over 2 hours given the critical storm modelled (1 hour)
George Street near Wynyard	Flood depths are up to 0.3 m and persist for a period of less than 15 minutes given the critical storm modelled (1 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 6) 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 6). The ERP classification can identify the type and scale of information needed by the SES to assist in emergency response planning (refer to Table 15).

Table 15: Emergency Response Planning Classifications of Communities

Classification	Response Required		
	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 City Area 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 City Area 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 9.4 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 m² and commercial industrial/commercial additions of up to 100 m² 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 5). 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 5); 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 5).

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 City Area 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 options (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 16 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 16 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 16: 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 5).

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 0.15 m, mean 0.05 m, as per City Area Flood Study (2014))
- Climate change impacts on sea level rise (0.0 m to 0.04 m, mean 0.01 m, as per City Area 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 440 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 5) 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. Given the difference in flood depth between the 1% AEP and the PMF in 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 5). The policy provides further details regarding flood planning levels for various types of development within the floodplain and these are outlined in Reference 5.

Table 17: Adopted Flood Planning Levels in Interim Floodplain Management Policy (Reference 5)

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
	Non-habitable rooms such as a laundry or garage (excluding below-ground car parks)	Mainstream or local drainage flooding	1% AEP flood level

	Development	Type of flooding	Flood Planning 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 City Area 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 2005 NSW Government's Floodplain Development Manual separates risk management measures into three broad categories.

9.1. Risk Management Measures Categories

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 City Area catchment.

A summary of the options considered for the catchment and at the specific hotspot locations is provided in Table 18 and discussed in the following sections.

Table 18: Flood Affected Areas and Investigated Management Options

Hotspot	Flooding issues	Investigated Options	Options Reference
Pitt Street and adjacent low points	Frequent inundation with moderate depth and velocity, flooding of major roads, many properties flooded above floor	Trunk drainage upgrade along Pitt Street and into adjacent depressions (CA01), upgrade at and near King Street (CA02), upgrade downstream of Bridge Street (CA03) and new drainage from King Street to Darling Harbour (CA04)	FM-CA01, FM-CA02, FM-CA03, FM-CA04
Pitt Street Mall	Frequent inundation with moderate depth and velocity, several properties flooded above floor. High-traffic pedestrian area.	In addition to drainage upgrades on Pitt Street, also assessed surface adjustment to Pitt Street Mall.	FM-CA05
Martin Place	Low hazard inundation in section between George and Pitt Streets. High-traffic pedestrian area.	Surface adjustment to Martin Place.	FM-CA06
George Street	Low hazard inundation near Wynyard with several properties flooded above floor. High-traffic pedestrian area.	Drainage upgrade along George Street between Margaret Street and Wynyard Street	FM-CA07
Phillip Street	Low hazard inundation near Martin Place – some property affectation.	Drainage upgrade of feeder pipe system and drainage pits at trapped low point.	FM-CA08
Various Hotspots	Various, as described	Data collection – specialised flood damages assessment	FM-CA09
Catchment-wide General flood risk, inundation of major roads		Flood Warning and Evacuation	RM-CA01
		Flood Emergency Management	RM-CA02
		Community Awareness Programme	RM-CA03
		Flood Planning Levels	PM-CA01
		Development Control Planning	PM-CA02
		Flood Proofing	PM-CA03

9.2. Options Not Considered Further

During the early phase of this study a review of all possible floodplain management measures and their application in the City Area 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 City Area catchment which is already heavily developed. For the above reasons, this measure 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 City Area.

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 City Area 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 City Area 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 FRMSP, is also not feasible given the very high cost of property and the nature of property ownership throughout the catchment.

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 City Area 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 City Area catchment and not appropriate in the majority of cases as discussed above.

9.3. Site Specific Management Measures

Site specific management measures 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 measures are provided in Table 19 and shown in Figure 22. These measures are discussed in detail in Sections 9.3.1 to 9.3.8.

Table 19: Flood Affected Areas and Proposed Mitigation Measures

Flood Affected Streets/Areas	Proposed Mitigation Measures	Reference
Pitt Street and adjacent low points (King Street, Angel Place, Curtain Place, Bond Street)	Upgrade capacity of trunk drainage along Pitt Street between Alfred Street and Market Street	FM - CA01
Pitt Street and adjacent low points (King Street, Angel Place, Curtain Place, Bond Street)	Upgrade capacity of trunk drainage along Pitt Street and King Street	FM - CA02
Pitt Street near Circular Quay	Upgrade capacity of trunk drainage along Pitt Street between Alfred Street and Bridge Street	FM - CA03
Pitt Street and adjacent low points (King Street, Angel Place, Curtain Place, Bond Street)	New trunk drainage from King Street to Darling Harbour	FM - CA04
Pitt Street Mall	Surface adjustment to Pitt Street Mall to convey flow, with grated cover	FM - CA05
Martin Place near George Street	Surface adjustment to a section of Martin Place to convey flow, with grated cover	FM - CA06
George Street near Wynyard	Upgrade capacity of trunk drainage along George Street between Margaret Street and Wynyard Street	FM - CA07
Phillip Street near Martin Place (identified as a minor flooding hotspot)	Upgrade capacity of drainage along Macquarie Street between Phillip Street and Martin Place	FM - CA08

As described in the following sections, each mitigation measure 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 measures 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 measure.

9.3.1. Trunk Drainage Upgrade – Alfred Street to Market Street (FM – CA01)

Option Description

Option FM – CA-01 describes a trunk drainage upgrade along Pitt Street between Market Street and Alfred Street with the goal of reducing property and road affectation in the 1% AEP. 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 includes the following elements:

- Upgrade of the pit and feeder pipe capacity to ensure that the upgraded trunk elements are full in the 1% AEP event, including upgrades on King Street, Angel Place, Hunter Street, Curtin Place, Bond Street, Bridge Street, Dalley Street and Underwood Street.
- A new trunk drainage line connected to this feeder system from Market Street to Alfred Street, with pipes of the following approximate dimensions:
 - 2 x 1.5 m x 1.5 m upstream of Martin Place
 - 2 x 2.4 m x 1.5 m downstream of Hunter Street
 - 2 x 3 m x 2.7 m upstream of Alfred Street

These drainage elements are in addition to what currently exists in the location, which would remain in place and is shown on Figure 23 and Figure 24. Figure 25 shows the new drainage elements.

Modelled Impacts

The proposed works achieve a significant reduction in flood level for the majority of the hotspots in the catchment. The impact of the proposed works on the 1% AEP flood level is shown on Figure 25, while Figure 26 shows the change in hazard in the same event. The reduction in flood level is as follows:

- 0.2 – 0.4 m lower on Pitt Street
- 0.5 – 1.0 m lower on King Street
- Over 1 m lower on Bond Street, Hunter Street, Angel Place, Curtin Place, Dalley Street and Underwood Street.

The reduction is such that the majority of Pitt Street has less than 100 mm depth in the 1% AEP event. There are small sections on the west side of the street (which is lower than the east side) that have up to 200 mm depth, but this could likely be contained in the kerb-gutter system. Between Bond Street and Alfred Street, there is a prominent area of high hazard flow which is reduced to low hazard under the upgrade, as is a large part of George Street near Wynyard. The remainder of Pitt Street up to Market Street (and the adjacent low points) is also newly low hazard. The option does not result in adverse impacts on peak flood levels.

Evaluation

The proposed upgrade would provide immense benefit to the area's flood risk, including benefit for property flooding, minimum floor level requirements and reducing hazard to vehicles and pedestrians. At present, Pitt Street forms a major overland flowpath in large floods, with over 20

m³/s of overland flow at its northern end in a 1% AEP event, and significant ponding in the adjacent low points to the west. The new drainage line would all but remove this overland flow and avoid ponding in the series of low points. The benefits of this change are numerous and include:

- Reducing overland flow that has hazardous depth and velocity which poses risk to vehicles and pedestrians and restrict access during a flood. The high density of the area means there is a large population that would be benefitted;
- Preventing hazardous inundation of underground car parks located at the low points. Although the flood behaviour at each car park in a 1% AEP flood is not well understood, there is significant risk of some or many of the car parks filling with runoff, possibly without sufficient warning time to evacuate them;
- Significantly reducing the over-floor property flooding that occurs in the hotspot. Due to properties in the CBD containing multiple commercial premises, the exact number of affected properties is not known, but it is likely over 100; and
- Facilitating future development in the area by lowering the area's FPL. There is a large number of high value commercial premises along Pitt Street and the affected areas, development of which would be significantly impeded under the existing flood behaviour, which would see a minimum floor level set at 0.3 m – 0.5 m above the ground (and higher in the trapped low points).

Despite the drainage upgrade producing a range of benefits, the upgrade is both technically and financially difficult, and may not be justified under a conservative benefit-cost ratio analysis (see Section 9.3.10). The difficulty of implementing the upgrade is related to the required pipe sizes, the alignment of the trunk system down Pitt Street, and the highly urbanised nature of the area. As shown on Figure 25, the upgrade has pipes that are generally larger than 5 m² in cross-sectional area, with the section near Circular Quay being larger than 16 m². Coupled with the very large pipe sizes being proposed, the alignment of the trunk is along densely populated streets which have a number of sub-surface services and passes Martin Place train line, as well as being beneath buildings. These factors combine to make the drainage upgrade both technically difficult and prohibitively expensive.

9.3.2. Trunk Drainage Upgrade – Pitt Street and King Street (FM – CA02)

Option Description

Option FM – CA02 describes a trunk drainage upgrade on the low section of King Street and along Pitt Street Mall, with the goal of reducing property and road affectation in the 1% AEP. The upgrade was tested as an alternative to FM – CA01 to determine the relative effectiveness of upgrading a smaller section than that measure. The proposed upgrade includes two new large pipes under Pitt Street Mall (2 x 1.5 m x 1.5 m) and a new pipe in the adjacent block of King Street (also 2 x 1.5 m x 1.5 m). The upgrade is in addition to what currently exists, and is shown on Figure 27.

Modelled Impacts

The proposed works result in some improvement along the Pitt Street hotspot but is not sufficient to alleviate the 1% AEP flood affectation. The impact of the proposed works on the 1% AEP flood

level is shown on Figure 27. The reduction in peak flood level is between 0.1 and 0.5 m for most of Pitt Street, with the results showing there is still around 0.5 m at the north end of the street, and over 0.5 m in the trapped low points. As shown on the figure, the drain peak flow downstream of the upgrade is not increased, but it is full for more of the flood event. This indicates that the trunk downstream of the upgrade is at capacity and is not able to take a higher flow.

Evaluation

The measure does not meet its objectives and is not considered feasible for this reason. The objectives for the upgrade are to alleviate flooding in the 1% AEP event such that the area's FPL is not as onerous as what currently exists, and properties (particularly commercial premises) can be built without a step at the entrance. As described, the measure's reduction in flood level does not remove flooding to the extent that the much larger upgrade did (CA01). While this objective is not met, the measure does lower peak flood levels in many of the hotspots and may be considered as part of works to generally lower the areas flood risk (with regards to property and road affectation).

9.3.3. Trunk Drainage Upgrade – Alfred Street to Bridge Street (FM – CA03)

Option Description

Option FM – CA03 describes a trunk drainage upgrade on the northern end of Pitt Street, with the goal of reducing property and road affectation in the 1% AEP. As with FM- CA02, the upgrade was tested as an alternative to FM – CA01 to determine the relative effectiveness of upgrading a smaller section than that measure. The proposed upgrade includes new large pipes on Pitt Street between Bridge Street, where the pipes are 1.5 m x 2 m, and Alfred Street, where they increase to 2 x 3 m x 2 m. Besides the large pipe sizes involved, the measure requires a large network of pits and feeder pipes at Bridge Street, in order to capture all of the overland flow at this point (approx. 22 m³/s) and contain it in the stormwater network. Given that pits typically take in the order of 0.1 m³/s, it is possible that the overland flow cannot be captured unless the entire Bridge/Pitt Street intersection is re-built as a grated mesh.

Modelled Impacts

The proposed works result in significant improvement for the northern end of Pitt Street and Alfred Street on Circular Quay. The impact of the proposed works on the 1% AEP flood level is shown on Figure 28. The reduction in peak flood level is around 0.2 m, with over 0.5 m at the intersection with Alfred Street. Depths are reduced to less than 0.1 m on the south side of Alfred Street, while there is still significant inundation (0.4 m) on the street's northern kerb. As shown on the figure, the overland flow is all but captured by the upgraded drainage, with the 22 m³/s at Bridge Street reducing to 3.3 m³/s peak overland flow and 0 m³/s closer to Alfred Street.

Evaluation

The option achieves significant reduction in peak flood level for the area upgrade but may not be technically feasible. The objectives for the upgrade to alleviate flooding in the 1% AEP event (as per FM - CA01 and FM - CA02) are met for the section of upgrade (Pitt Street between Alfred and Bridge Streets) as well as for Alfred Street near Pitt Street. However, as previously stated, the measure involves capturing a very large overland flow (> 20 m³/s) in a small area. While this is

technically possible via large-scale drainage works, it may not be possible to incorporate such surface drainage into what is currently a high-density urban area with high volumes of pedestrian and vehicle traffic. The measure highlights the need to collect runoff further upstream in the catchment if the 1% AEP event is to be mitigated by drainage works.

9.3.4. Trunk Drainage Upgrade – New Drainage to Darling Harbour (FM – CA04)

Option Description

Option FM – CA04 describes a new trunk drainage line from King Street to Darling Harbour, with the goal of reducing property and road affectation in the 1% AEP. As with the previous two options, the new pipe was tested as an alternative to FM – CA01 to determine the relative effectiveness of alternatives to that option. The proposed upgrade consists of three 1.5 m x 1.5 m pipes from King Street to a new outlet into Darling Harbour near the west end of King Street, as well as two new 1.5 m x 1.5 m pipes under Pitt Street Mall. The length of the new pipes to Darling Harbour is approximately 630 m and there is a fall of around 15 m, which gives a grade of approximately 2.3%. In comparison, the trunk upgrade along Pitt Street is around 1.6%.

Modelled Impacts

The proposed new drainage line results in significant improvement for King Street and the downstream area. The impact of the proposed works on the 1% AEP flood level is shown on Figure 29, while Figure 30 shows the change in hazard in the same event. The reduction in flood level is as follows:

- 0.3 – 0.4 m lower on Pitt Street Mall
- 0.6 – 1.1 m lower on King Street
- 0.1 – 0.2 m lower on Pitt Street north of King Street
- 0.1 – 0.2 m lower on George Street from King Street to Hunter Street

The reduction in flood level is widespread and is comparable to that achieved by FM - CA01, with around the same benefit from Pitt Street Mall up to Martin Place, and less benefit (from FM - CA04) for the hotspots north of Martin Place. The reduction in hazard is also widespread, with all high hazard removed from Pitt Street up to Circular Quay, as well as on the low points adjacent to Pitt Street. There is no adverse impact at Darling Harbour or on King Street.

Evaluation

New drainage from King Street to Darling Harbour would provide significant reduction in flood risk while also being feasible as part of a larger program of works. The drainage would remove a significant portion of runoff from the southern hotspots (Pitt Street Mall and King Street) which then benefits the remaining hotspots along Pitt Street. The benefit relates to property flooding (significantly reduced around King Street), hazardous road and pedestrian area flooding, and improving the FPL requirements for the area. As an alternative to the three previously described measures, it has the advantage of benefitting one area without causing downstream adverse impacts. For this reason, the option could be carried out prior to (or instead of) a larger upgrade such as FM - CA01, which may not be feasible for cost and practicality issues.

9.3.5. Overland Flowpath – Surface Adjustment to Pitt Street Mall (FM – CA05)

Option Description

Option FM - CA01 describes modification to Pitt Street Mall with the goal of mitigating inundation of property and the pedestrian area in the 1% AEP event. Pitt Street Mall has many commercial properties that are flooded overfloor in a 1% AEP event. Reduction of the peak flood level in this area is a desired alternative to property modification options such as flood proofing or raised floor levels. The option involves lowering all of Pitt Street Mall by 0.3 m in order to increase the conveyance of the overland flowpath which flows north through the mall. The lowered section has an area of approximately 4000 m². The option also includes a new stormwater pit near the north of the mall to drain the lowered area into the existing stormwater network. In order to maintain the existing floor levels and entrances in the mall, the lowered area would have a permeable covering (e.g. a grate) to the height of the current ground surface. The lowered area may also be concentrated to the sides or the middle of the mall, in which case the depth may need to be greater (e.g. 0.5 m).

Modelled Impacts

Lowering Pitt Street Mall is able to achieve a significant reduction in the peak flood level and benefit the affected properties. The impact of the proposed works on the 1% AEP flood level is shown on Figure 31. The reduction in flood level is around 0.3 m for most of the lowered section, with 0.1-0.2 m reduction at the King Street end. There is no adverse impact downstream, while the upstream area near the intersection with Market Street has minimal reduction (<0.01 m). In the existing conditions, flood depths along the mall are 0.2-0.3 m on the east side and 0.3-0.4 m on the west side. Therefore, the reduction achieved by the works accounts for the majority of the overfloor flood depth at the location. However, while the depth above floor will be reduced for the properties, the depth on Pitt Street Mall is largely unchanged, as the ground has been lowered.

Evaluation

The measure achieves a significantly reduced flood level for the properties along Pitt Street Mall, however, it may be difficult to implement. The lowered flood level corresponds to significant reduction in the property affectation in the area, with the 0.3-0.4 m depth of flow along most of Pitt Street Mall in the existing case reduced to less than 0.1 m. There is also a large reduction in the area's flood risk, given the high pedestrian usage in the area and the change in hazard to

pedestrians when the majority of the flow is moved below a grated surface. The main constraints with regards to the measure are incorporating the works into the existing streetscape, given that there is likely a high density of services under Pitt Street Mall.

9.3.6. Overland Flowpath – Surface Adjustment to Martin Place (FM – CA06)

Option Description

Option FM – CA06 describes modifications to Martin Place aimed at improving overland flow behaviour. The modifications consist of lowering the existing ground surface by 0.3 m on the north and south side of the section of Martin Place between Pitt Street and George Street. The lowered areas would act as swales to divert runoff to the trunk drain on Pitt Street. Currently, the area's grading means that sheet flow across the area flows towards Pitt Street. The lowered area also includes small pipes (0.1 m diameter) to discharge runoff in a regular rainfall event. The works were assessed for their impact on the 5% AEP event, when hazardous flow occurs in the area.

Modelled Impacts

The measure redistributes overland flow and does not result in adverse impacts downstream. The impact of the two lowered areas on the 5% AEP flood level is shown on Figure 31, which also shows the location of the works. The reduction in peak flood level is around 0.05 m in the area, with the existing depth of 0.1 m on the northern side of Martin Place reduced to less than 0.05 m. The two swales have around 0.3 m of depth.

Evaluation

The measure improves overland flow behaviour in Martin Place, however, the benefit is limited to the reduced hazard for pedestrians. The redistributed flow means the overland flowpath, which in the 5% AEP event is around 0.1 m deep with velocities of 0.5 m/s (on the north side), is almost wholly contained in a swale, which would be covered with a grate or similar cover. The existing flood behaviour is categorised as low hydraulic hazard and would not pose a threat to most pedestrians. However, Martin Place's function as a pedestrian thoroughfare in the CBD means that improving the area's flood risk is warranted. The proposed works are straightforward to construct (relative to the other structural measures) and could be incorporated into other surface works occurring in the area.

9.3.7. Trunk Drainage Upgrade – George Street near Wynyard (FM – CA07)

Option Description

Option FM – CA07 describes a drainage upgrade on George Street with the goal of reducing property and road affectation in the 1% AEP on George Street. George Street has an overland flowpath running parallel to the flowpath on Pitt Street, but with less flow as it is higher and less catchment area. The majority of the overland flow turns right at Hunter Street and connects to the Pitt Street flow. The proposed upgrade consists of a new pipe (0.9 m diameter) on George Street from Wynyard Street to Hunter Street, where it connects to the existing trunk drainage. The new drainage will include additional pits along the section of George Street.

Modelled Impacts

The proposed works result in minor improvement for the upgraded section and the downstream area on Hunter Street and Pitt Street. The impact of the proposed works on the 1% AEP flood level is shown on Figure 33, which also shows the location of the upgrade. The reduction in peak flood level is around 0.01 m on George Street, 0.09 m on Hunter Street and 0.03 to 0.06 m on Pitt Street. The minor reductions mean that significant depth and flow remains in each of the areas. The new pipe conveys up to 0.8 m³/s; however, its flow is reduced at the downstream end where it connects to the trunk drainage, which is already full from the upstream area.

Evaluation

The measure does not provide significant improvement for the George Street hotspot and highlights the difficulty of upgrading sections of the stormwater network. The reduction in the 1% AEP peak flood level is minor and would not justify large-scale drainage works as has been assessed. The performance of the new drainage is limited by the downstream drainage, which does not have any capacity to take additional flow from George Street. This also indicates that larger upgrades to that assessed will also be limited by the downstream capacity.

9.3.8. Drainage Upgrade – Phillip Street (FM – CA08)

Option Description

Option FM – CA08 describes a drainage upgrade on Phillip Street with the goal of reducing property and road affectation in the 10% AEP event. The section of Phillip Street between Martin Place and Hunter Street has a slight topographic depression that causes runoff to accumulate in the area. The ponding is minor relative to other flood affected areas in the catchment, and it has been included as a minor hotspot for this reason. The design event has been chosen based on the City's goal for the stormwater network to mitigate road flooding up to the 10% AEP event (there is limited property affectation at the hotspot). The upgrade consists of additional pit and pipe capacity to increase flow to the existing stormwater pipe, which does not require upgrade.

Modelled Impacts

The proposed works result in significant improvement for the affected section of Phillip Street and are relatively feasible. The impact of the proposed works on the 10% AEP flood level is shown on Figure 35, which also shows the location of the new drainage, while Figure 34 shows the existing flood behaviour in the 10% AEP event. The reduction in flood level is up to 0.5 m and the 10% AEP depth is all but removed under the measure. The figure also shows that pipe flow out of the area increases from 0.4 to 0.6 m³/s. This indicates that the existing drainage has capacity to take additional flow, but that this requires the additional pit/pipe drainage. The measure of only increasing the pit sizes was also tested and was found to not produce the same benefit, demonstrating the feeder pipe capacity requires upgrade.

Evaluation

The measure results in significant improvement for the Phillip Street area (minor hotspot) and is straightforward to implement, relative to other investigated works. The pit and pipe upgrade increases flow in the street's drainage and drains the above-ground ponding in a 10% AEP event. In the existing case, the ponding of just over 0.5 m depth is associated with risk of submerged vehicles and blocked building entrances. As with other areas in the catchment, there is a high

density of people in the area, especially on weekdays during business hours. The required works are small-scale and could be incorporated into other drainage or sub-surface works in the area.

9.3.9. Data Collection – Catchment Specific Flood Damages Assessment (FM – CA09)

Description

Option FM-CA09 consists of a catchment specific flood damages assessment of properties in the Sydney CBD and review of cost benefit analysis of recommended flood modifications measures. The catchment specific flood damages assessment would investigate the various property types in the City Area 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 the both estimation of flood damages across the catchment and cost benefit analysis of flood modification measures.

The option has been included as a site-specific flood modification measure as it would largely inform the construction of site-specific measure 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 measures involving large scale drainage upgrades have been evaluated for the City Area Catchment that have costs in the order of \$10-30 million. The cost/benefit ratios of these options have been estimated at less than 0.5 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 City Area 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 City Area. 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 City Area catchment and provide a more reliable assessment of the benefits of flood mitigation measures, potentially providing a greater economic justification for the large-scale pit and pipe works in the catchment.

9.3.10. Economic Assessment of Site Specific Measures

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

Costing

Detailed cost estimates have been prepared for each measure and these are summarised in Table 20, 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 measures to obtain a more accurate costing. For the trunk drainage upgrade measures, 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. For surface adjustment measures, previous works in the area have indicated that construction of this nature is far more expensive in the CBD than in other areas, largely due to the very high density of development and the resulting complications. This means that costing estimation does not yield realistic estimates. Estimates have therefore been based on the most recent refurbishment of Pitt Street Mall, which cost approximately \$11 million.

Table 20: Costings of Management Measures

Option	Capital	Maintenance per year
FM-CA01 Trunk Drainage Upgrade – Alfred Street to Market Street	\$ 30,080,100	\$ 12,540
FM-CA02 Trunk Drainage Upgrade – Pitt Street and King Street	\$ 8,096,900	\$ 4,920
FM-CA03 Trunk Drainage Upgrade – Alfred Street to Bridge Street	\$ 18,650,600	\$ 7,200
FM-CA04 Trunk drainage Upgrade – New Drainage to Darling Harbour	\$ 21,704,800	\$ 8,200
FM-CA05 Overland Flowpath – Surface Adjustment to Pitt Street Mall	\$ 13,000,000	\$ 10,000
FM-CA06 Overland Flowpath – Surface Adjustment to Martin Place	\$ 5,000,000	\$ 10,000
FM-CA07 Trunk Drainage Upgrade – George Street near Wynyard*	ND*	ND
FM-CA08 Drainage Upgrade – Phillip Street	\$ 575,800	\$ 540

*Not Determined. Option not costed as produced no significant benefit to flood behaviour

Table 20 shows that the drainage capacity upgrade Measure FM – CA01 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 measures.

Damage Assessment of Measures

The total damage costs were evaluated for three of the measures and compared against the existing base case, as shown in Table 21. The assessment for the three measures 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-CA02 does not produce significant reduction in overfloor inundation;
- FM-CA03 has significant constructability issues as it involves diverting around 20 m³/s of overland flow into the subsurface drainage, within very limited space;
- FM-CA06 is aimed at mitigating flow hazardous to pedestrians and so has minimal effect on overfloor inundation;
- FM-CA07 produces negligible benefit to flood behaviour; and
- FM-CA08 significantly improves road affectation on Phillip Street but does not affect property inundation, except for one property.

Table 21: Average Annual Damage Reduction of Management Measures

Measure	AAD	Reduction in AAD due to Measure
FM-CA01 Trunk Drainage Upgrade – Alfred Street to Market Street	\$ 815,822	\$ 862,377
FM-CA04 Trunk drainage Upgrade – New Drainage to Darling Harbour	\$ 1,269,976	\$ 408,223
FM-CA05 Overland Flowpath – Surface Adjustment to Pitt Street Mall	\$ 1,563,524	\$ 114,675

The results show that the large scale Pitt Street drainage upgrade has the greatest reduction in AAD, with a reduction of \$862,377 that approximately halves the catchment’s AAD. The other two measures also have significant benefit and are proportional to their scope of works. It should be noted that all of the measures 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, for example a below ground area below a building which is connected to other buildings.

Benefit Cost Ratio of Measures

Following estimation of the measure’s cost and AAD, the benefit/cost ratio (B/C) of three of the measures 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 22 lists the reduction in AAD due to the measures, and compares this to the works’ capital and maintenance costs to produce a B/C. The measures’ B/C was between 0.3 and 4.7, with values above 1 indicating that the economic benefit of the measure is greater than its cost.

Table 22: Benefit/Cost Ratio for Management Measures

Measures	Benefit			Cost Estimate			
	AAD	Reduction in AAD	NPW of AAD Reduction*	Capital	Maintenance (Annual)	NPW of Costs*	B/C Ratio
FM- CA01	\$815,822	\$862,377	\$ 12,734,500	\$ 30,080,100	\$ 12,540	\$ 30,265,300	0.4
FM- CA04	\$1,269,976	\$408,223	\$ 6,028,100	\$ 21,704,800	\$ 8,200	\$ 21,826,000	0.3
FM- CA05	\$1,563,524	\$114,675	\$ 1,693,400	\$ 13,000,00	\$ 10,000	\$ 13,147,670	0.1

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

The three measures presented in Table 22 have a B/C of less than 1, indicating they are not justifiable on economic grounds alone. 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. With regards to damages, they may be much higher than has been estimated (and therefore the reduction in damages also larger), but are difficult to estimate in further detail without damage curves specific to the various types of commercial development.

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 measures.

9.4. Catchment Wide Management Measures

9.4.1. Property Modification - Flood Planning Levels (PM – CA01)

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 – CA02)

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 – CA03)

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 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 options 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.

Responsibility for flood-proofing in the City Area catchment should fall to property owners, and should be initiated by the City. The majority of buildings in the catchment 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 options 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. Response Modification - Flood Warning and Evacuation (RM – CA01)

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 which the SES disseminates 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).

9.4.5. Response Modification - Flood Emergency Management (RM – CA02)

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 City Area 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 City Area 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 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.

9.4.6. Response Modification - Community Awareness Programme (RM – CA03)

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. 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 even social media 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 for the catchment.

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 23 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 23: 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 24, with each of the assessed management measures 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 24: 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-CA01	Trunk Drainage Upgrade – Alfred Street to Market Street	9.4.1	1%	3	3	-3	-1	2	-3	-1	3	-3	1	3	4	8
FM-CA02	Trunk Drainage Upgrade – Pitt Street and King Street	9.4.2	1%	1	2	-2	-1	1	-2	0	2	-2	1	1	1	11
FM-CA03	Trunk Drainage Upgrade – Alfred Street to Bridge Street	9.4.3	1%	2	2	-3	-1	1	-2	0	1	-2	1	1	0	13
FM-CA04	Trunk Drainage Upgrade – New Drainage to Darling Harbour	9.4.4	1%	2	2	-2	-1	1	-2	0	2	-2	1	2	3	9
FM-CA05	Overland Flowpath – Lower Pitt Street Mall	9.4.5	1%	2	2	-1	-1	1	-1	-1	2	-2	2	2	5	7
FM-CA06	Overland Flowpath – Lower Martin Place	9.4.6	10%	1	1	-1	-1	0	0	0	1	-2	2	0	1	11
FM-CA07	Trunk Drainage Upgrade – George Street near Wynyard	9.4.7	1%	1	1	-2	-1	1	-2	0	0	-3	1	0	-4	14
FM-CA08	Drainage Upgrade – Phillip Street	9.4.8	10%	2	1	-1	-1	1	-1	0	1	-1	1	1	3	9
Property Modification Measures																
PM-CA01	Property Modification - Flood Planning Levels	9.5.1	N/A	0	0	0	1	2	2	0	1	0	3	1	10	2
PM-CA02	Property Modification - Development Control Planning	9.5.2	N/A	0	0	0	1	2	2	0	1	1	3	1	11	1
PM-CA03	Property Modification - Flood Proofing	9.5.3	N/A	0	0	-1	1	2	1	0	1	-1	2	1	6	6
Response Modification Measures																
RM-CA01	Response Modification - Flood Warning and Evacuation	9.5.4	N/A	0	0	-1	1	1	2	0	2	2	0	2	9	3
RM-CA02	Response Modification - Flood Emergency Management	9.5.5	N/A	0	0	-1	1	2	2	0	2	1	0	1	8	5
RM-CA03	Response Modification - Community Awareness Programme	9.5.6	N/A	0	0	2	1	2	2	0	2	1	-2	1	9	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

Based on the matrix, the measures for future implementation are ranked in the order as tabulated in Table 25.

Table 25: Ranking of Management Measures

Rank	Ref	Options	Score
1	PM-CA02	Property Modification - Development Control Planning	11
2	PM-CA01	Property Modification - Flood Planning Levels	10
3=	RM-CA01	Response Modification - Flood Warning and Evacuation	9
3=	RM-CA03	Response Modification - Community Awareness Programme	9
5	RM-CA02	Response Modification - Flood Emergency Management	8
6	PM-CA03	Property Modification - Flood Proofing	6
7	FM-CA05	Overland Flowpath – Lower Pitt Street Mall	5
8	FM-CA01	Trunk Drainage Upgrade – Alfred Street to Market Street	4
9=	FM-CA04	Trunk Drainage Upgrade – New Drainage to Darling Harbour	3
9=	FM-CA08	Drainage Upgrade – Phillip Street	3
11=	FM-CA06	Overland Flowpath – Lower Martin Place	1
11=	FM-CA02	Trunk Drainage Upgrade – Pitt Street and King Street	1
13	FM-CA03	Trunk Drainage Upgrade – Alfred Street to Bridge Street	0
14	FM-CA07	Trunk Drainage Upgrade – George Street near Wynyard	-4

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 City Area Catchment Floodplain Risk Management Plan. The three discarded options are FM-CA02, FM-CA03 and FM-CA07. These measures either have very minor benefit (FM-CA07), are less effective than alternatives (FM-CA02) or are not considered technically feasible (FM-CA03).

10. ACKNOWLEDGEMENTS

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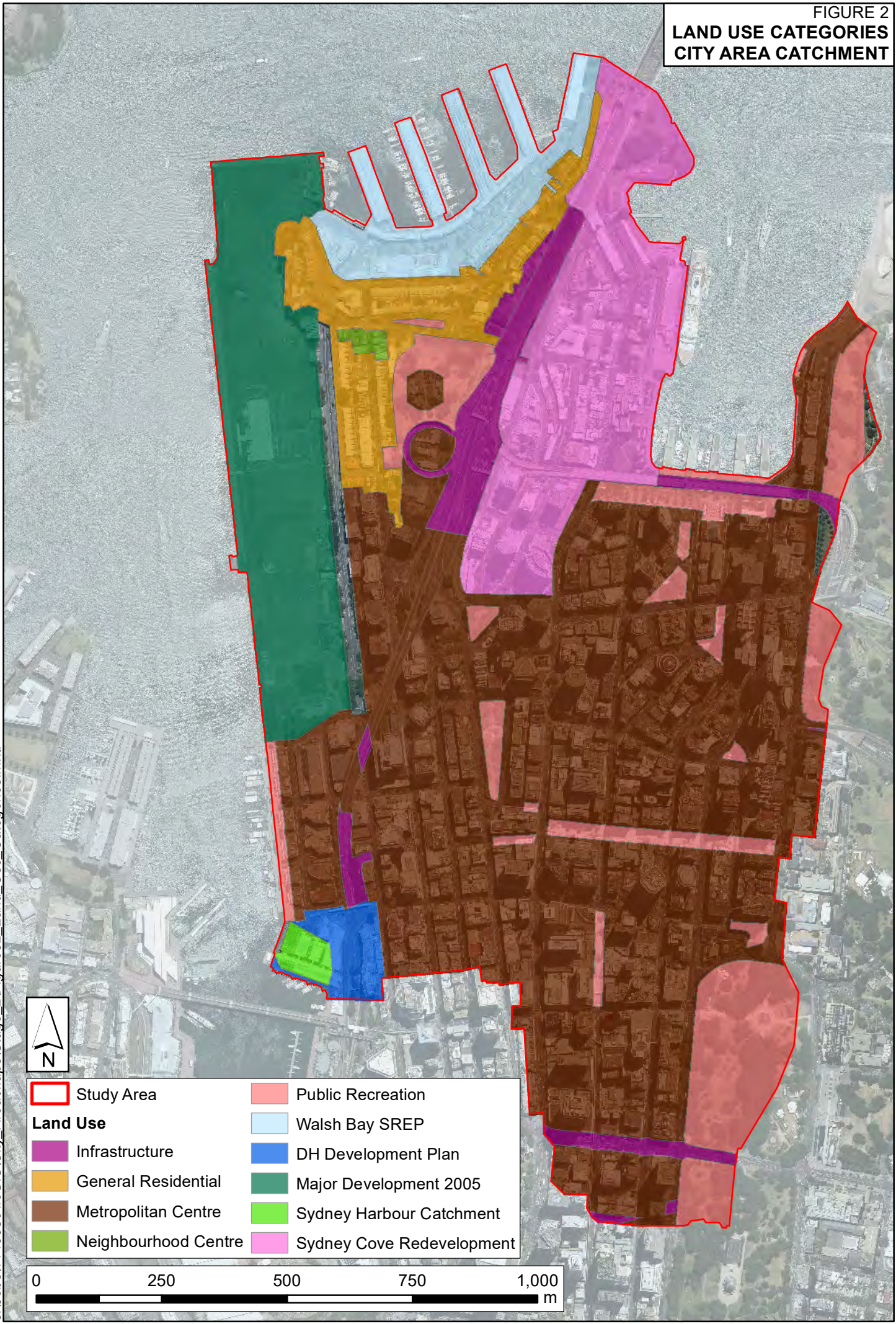
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









FIGURE 1
STUDY AREA
CITY AREA CATCHMENT



FIGURE 2
LAND USE CATEGORIES
CITY AREA CATCHMENT



	Study Area		Public Recreation
Land Use			
	Infrastructure		Walsh Bay SREP
	General Residential		DH Development Plan
	Metropolitan Centre		Major Development 2005
	Neighbourhood Centre		Sydney Harbour Catchment
	Sydney Cove Redevelopment		

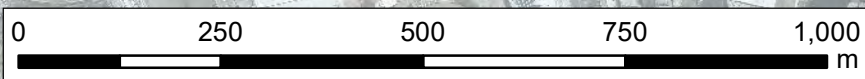
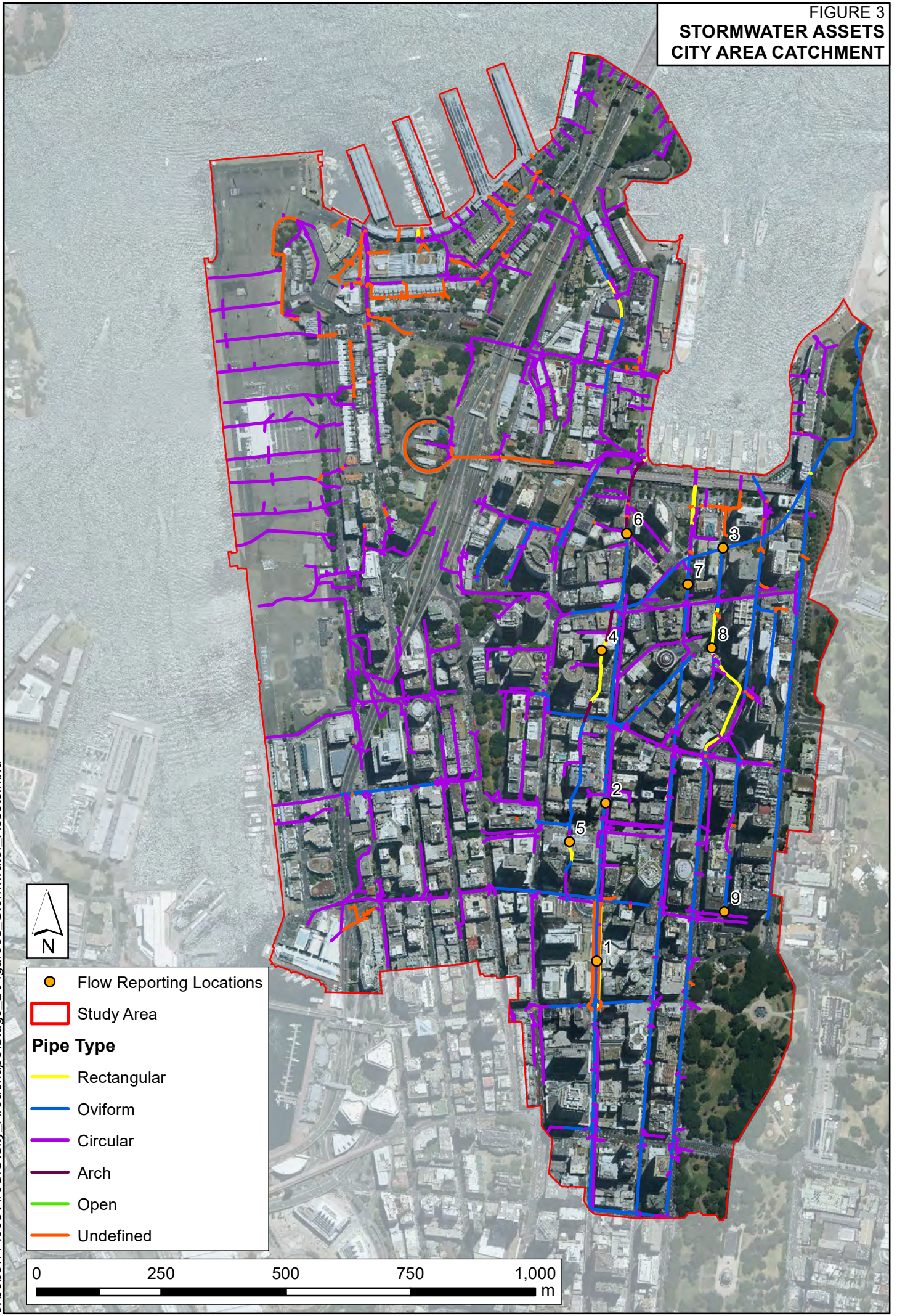
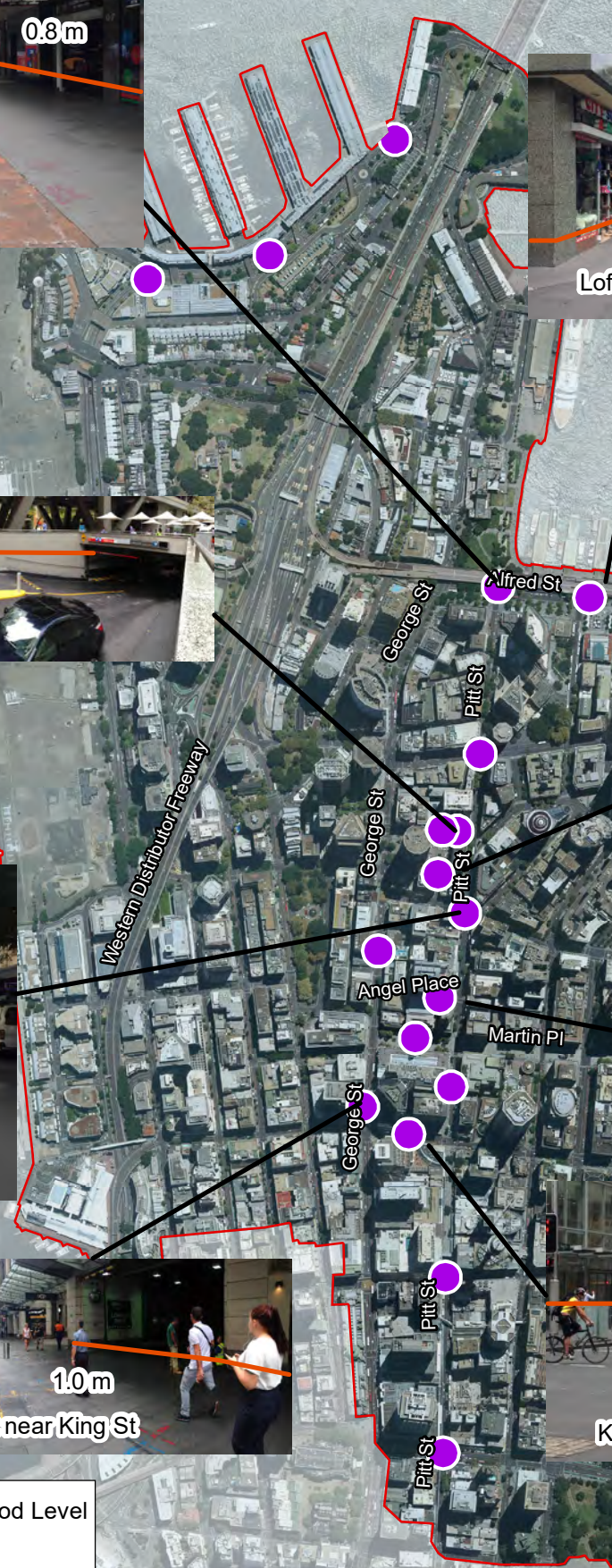
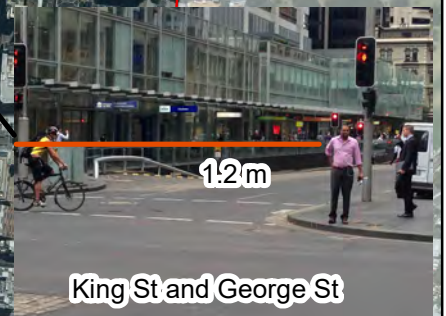
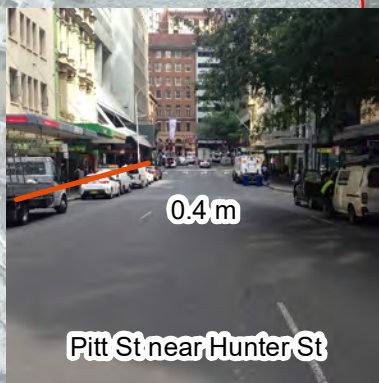


FIGURE 3
STORMWATER ASSETS
CITY AREA CATCHMENT



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FIGURE 4
HOTSPOT LOCATIONS
CITY AREA CATCHMENT



- Approx. 1% AEP Flood Level
- Study Area
- Hotspot Locations



FIGURE 5
FLOOD EMERGENCY RESPONSE PLAN
CITY AREA CATCHMENT

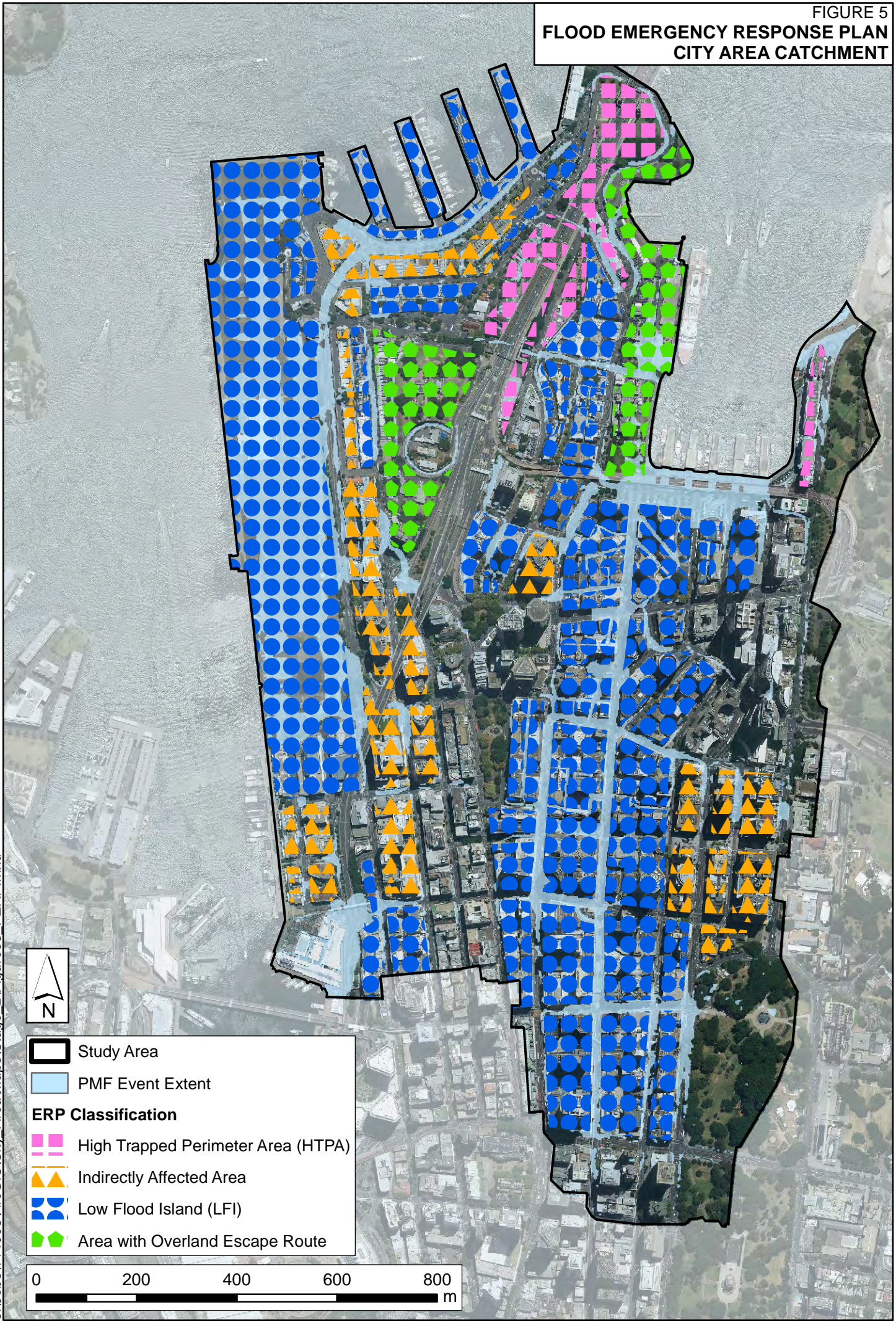
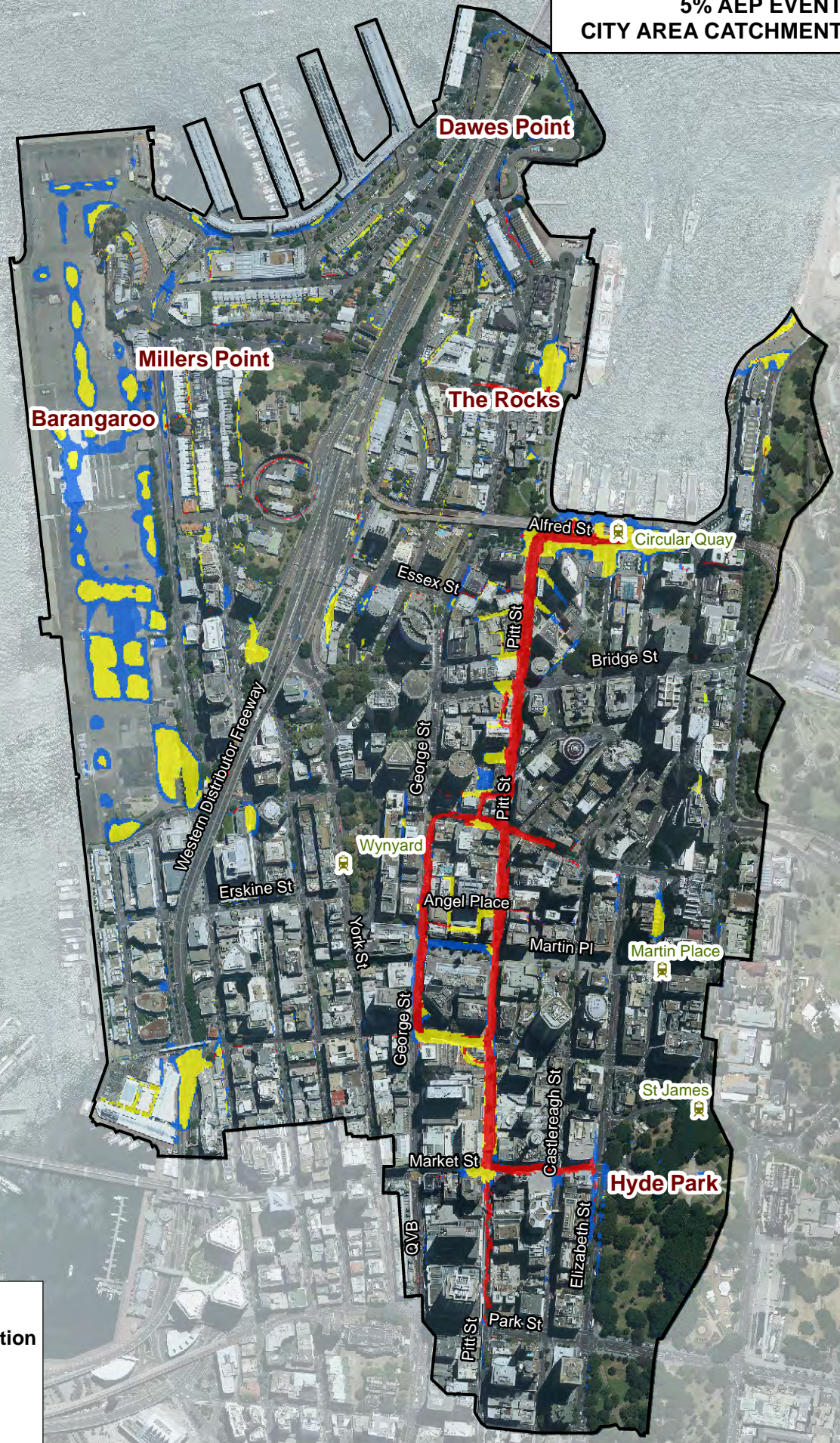


FIGURE 6
HYDRAULIC CATEGORIES
5% AEP EVENT
CITY AREA CATCHMENT



Study Area

Hydraulic Categorisation

- Floodway
- Flood Storage
- Flood Fringe

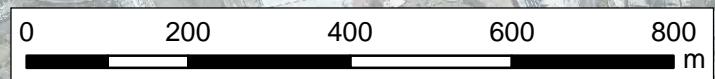


FIGURE 7
HYDRAULIC CATEGORIES
1% AEP EVENT
CITY AREA CATCHMENT



- Study Area
- Hydraulic Categorisation**
- Floodway
- Flood Storage
- Flood Fringe

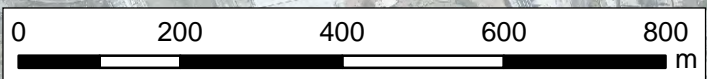


FIGURE 8
HYDRAULIC CATEGORIES
PMF EVENT
CITY AREA CATCHMENT



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Study Area

Hydraulic Categorisation

- Floodway
- Flood Storage
- Flood Fringe

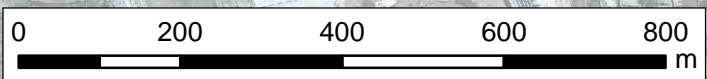


FIGURE 9
HAZARD CATEGORIES
0.5 EY EVENT
CITY AREA CATCHMENT

