ATTACHMENT C

CITY AREA CATCHMENT FLOODPLAIN RISK MANAGEMENT STUDY (DRAFT REPORT)

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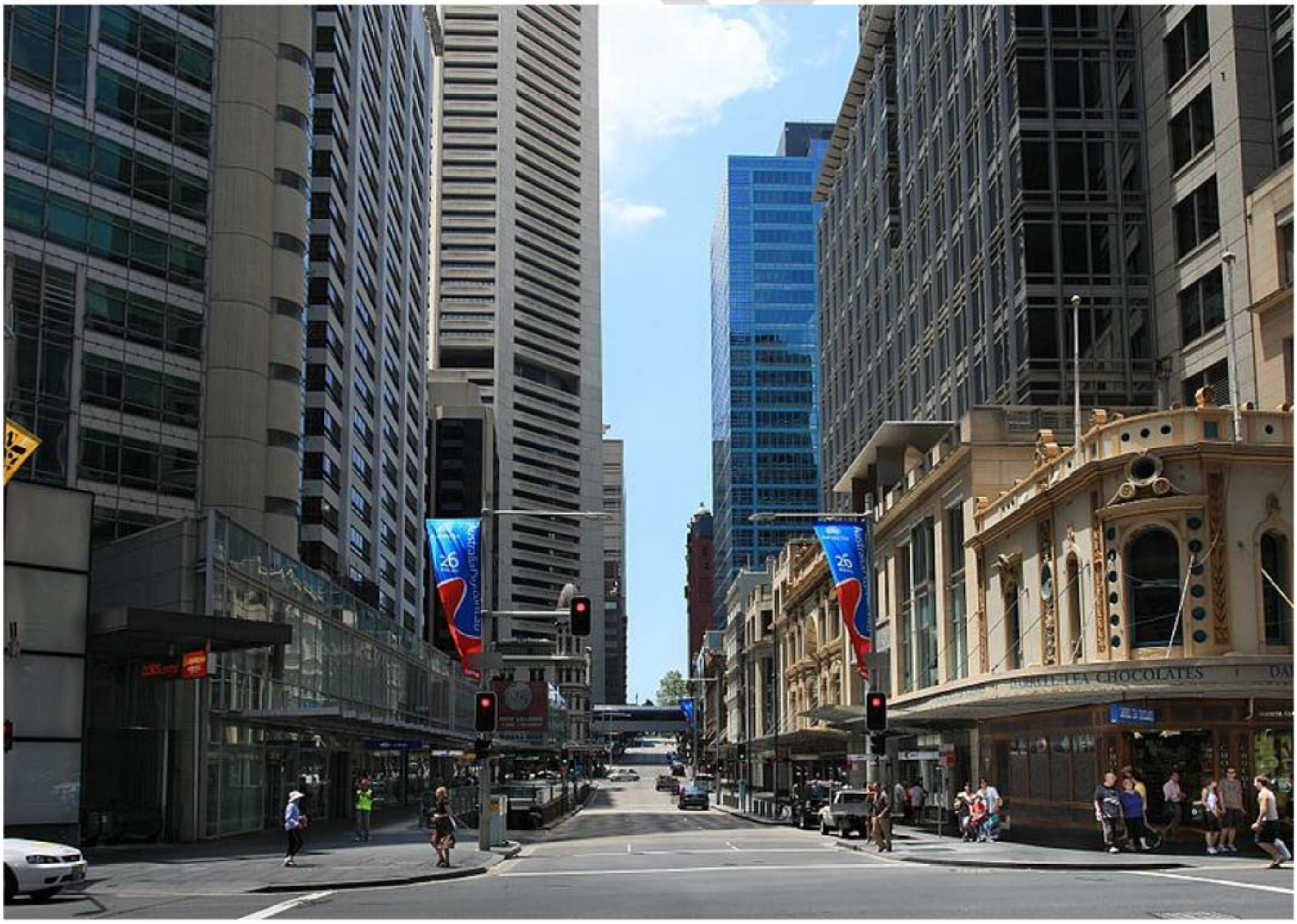
DRAFT



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CITY AREA CATCHMENT FLOODPLAIN RISK MANAGEMENT STUDY

DRAFT REPORT

JANUARY 2016

Project City Area Catchment Floodplain Risk Management Study	**Project Number** 114095
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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 Draft 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 and within the City of Sydney local government area.

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 draft 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 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 draft City Area Floodplain Risk Management Plan. Three of the assessed options were not recommended in the plan as they were assessed to be unviable.

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 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;
- Draft 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,
- Hickson Road, Walsh Bay.

Phase II – Draft 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** **15 - 64 years** **> 65 years**	 19.2% 66.1% 14.7%	 5.9% 77.2% 16.9%	 8.3% 78.0% 13.8%	 5.6% 80% 14.6%	 4.1% 91.1% 4.8%
Average people per dwelling	2.6	1.8	2.0	1.5	2.1
Own/mortgage property **Rent property**	66.6% 30.1%	34% 62.9%	44.0% 53.4%	31.0% 64.7%	33.7% 63.4%
Moved into area: **- within last year** **- within last five years**	 - -	 23% 57%	 18% 56%	 23% 54%	 34% 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	Cantonese (4.6%), Mandarin (3.0%), French (1.8%), Italian (1.3%),	Cantonese (3.1%), Spanish (2.8%), Mandarin (2.3%), Japanese	Mandarin (12.5%), Indonesian (7.9%), Thai (6.9%), Cantonese (6.3%),

		(1.3%), Hindi (1.3%)	Spanish (0.9%)	(1.6%), French (1.2%)	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,
- 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 pedestrian (etc.). When this occurs, there is potential for high hazard flood conditions resulting from flow velocities and depths. Further, under Council policy resultant 1% AEP levels inform required commercial flood levels.

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 20% 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 where 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 obstructing 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 20% AEP 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)- 20%AEP	Peak flow (m^3/s) - 1%AEP	Approx. Capacity
1. Pitt St from Market Street to Martin Place	0.8	2.7	50% AEP
2. Pitt Street from Martin Place to Young Street	2.8	3	50% AEP
3. Tank Stream from Young St to the Opera House	6	6.2	<50% AEP
4. Tank Stream from King Street to Hunter Street	1.5	3	<50% AEP
5. Tank Stream from Martin Place to Bridge Street	3	3	<50% AEP
6. Tank Stream from Bridge Street to Circular Quay	2.5	5	<50% AEP
7. Loftus Street near Macquarie Place	1.1	1.5	20% AEP
8. Phillip Street near Bent Street	1.5	1.8	20% AEP
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:

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

The hydraulic categories for the 5% AEP, 1% AEP and PMF events are shown on Figure 6 to Figure 8. In the 5% AEP event there is a well-defined floodway 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 50%, 20% 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
- 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 and Phillip Street, 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. That is, Philip Street and Hickson Road were not considered any more significant than other flooded areas, whilst Alfred and Hunter Street were considered to have potentially higher impacts. 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

	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

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.

4.2. 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, emergency services, OEH, SWC and community representatives.

5. ECONOMIC IMPACT OF FLOODING

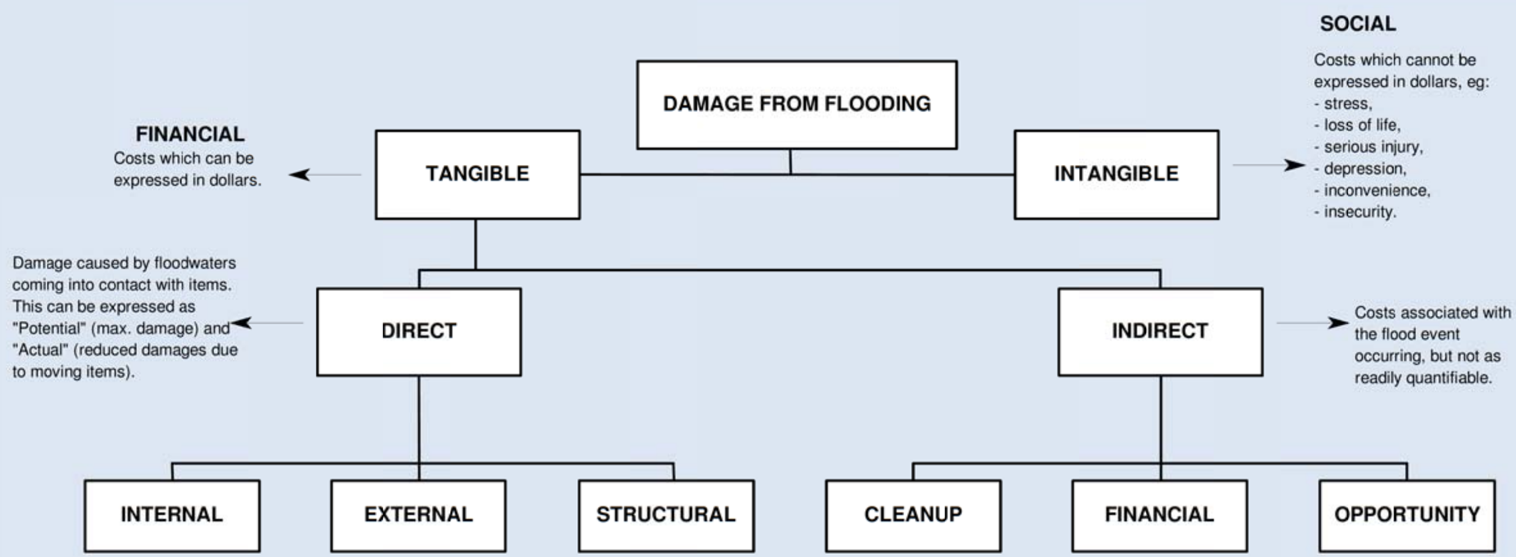
The impact of flooding can be quantified through the calculation of flood damages. Flood damage calculations do not include all impacts associated with flooding. They do, however, provide a basis for assessing the economic loss of flooding and also a non-subjective means of assessing the merit of flood 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 7.

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



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

5.1. Tangible Flood Damages

Tangible flood damages are comprised of two basic categories; direct and indirect damages (refer Table 7). 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 8. This flood damages estimate does not include the cost of restoring or maintaining public services and infrastructure.

Table 8: 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
- 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 9. 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.