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 if closed but when access to it becomes available;
- Ability to move stock or assets before onset of flooding - some large machinery will not be able to moved and in other instances there may not be sufficient warning time to move stock to dry locations; and
- Ability to transfer business to a temporary location.

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

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

No specific guidance is available for assessing flood damages to non-residential properties. Therefore for this Study, commercial and industrial damages were calculated using the methodology for residential properties but with the costs/damages increased to a value which is consistent with commercial/industrial development. For commercial properties damages were

calculated by the summation of direct (over-floor) flooding and basement flooding along with a commercial property loading of 55%. For direct flooding, damages were calculated on the multiplication of:

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

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

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

A summary of the commercial/industrial flood damages for the 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. Emergency Management Plan

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 Management Plan (2012) (EMPLAN). No Regional Emergency Management Plan (REMPLAN) has been prepared for this district.

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

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

The plan is consistent with district 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 District / 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 District Functional Area Coordinators.*"

It is recommended that a REMPLAN be prepared for the Sydney East Emergency Management District to outline an emergency response arrangement specific to the district. 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 Flood Plan

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 Building 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 City of Sydney Security and Emergency Management Unit.

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

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

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

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

Flood liable areas within the study area have been classified according to the ERP classification above, with the additional criteria of flood depths being greater than 0.1 m. If only the flood extent was used in the 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 m^2 and commercial industrial/commercial additions of up to 100 m^2 or 20% of Gross Floor Area. The concession is granted no more than once per development;
- It gives general requirements for development on flood prone land, including design requirements for fencing, minimum floor level, car parking, filling of flood prone land and the impact of climate change;
- It sets flood planning levels to be adhered to by various types of development. For example habitable rooms affected by mainstream flooding are to be at or above the 1% AEP flood level + 0.5 m. Other levels are given for properties affected by local drainage flooding (as per the Policy's definition), industrial/commercial development, car parks and critical

facilities; and

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

City of Sydney Technical Specification – Drainage Design

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

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

7.2. Planning Recommendations

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

- There is a lack of consistency between the Sydney LEP 2012 and the Sydney DCP 2012. It is recommended that both the LEP and the DCP are updated to ensure accurate cross referencing between the two documents. Also the requirements for a site specific flood study are provided in the Sydney DCP 2012. Though the DCP notes that the Sydney LEP 2012 outlines when a site specific flood study is required, the LEP does not contain this information. The LEP or the DCP should be updated to ensure this information is provided;
- Flood related development controls and requirements are provided in the Interim Floodplain Management Policy (Reference 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
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
Pit 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 m^3/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 m^2 in cross-sectional area, with the section near Circular Quay being larger than 16 m^2. Coupled with the very large pipe sizes being proposed, the alignment of the trunk is along either densely populated streets which have a number of sub-surface services pass through 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 m^3/s) and contain it in the stormwater network. Given that pits typically take in the order of 0.1 m^3/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 m^3/s at Bridge Street reducing to 3.3 m^3/s peak overland flow and 0 m^3/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 m^3/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