5.1. Tangible Flood Damages

Tangible flood damages are comprised of two basic categories; direct and indirect damages (refer Table 4). 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 potential 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 the flood level information for design events as established in the Flood Study (Reference 2) and amended as part of this Study, to take into account the recent changes in the floodplain. Damages 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 by including only those properties in the 1% AEP extent, properties that are inundated in rarer events have not been accounted for. Therefore damage calculations for the PMF event are likely to be underestimated.

The floor level survey used as part of this study is given in Appendix E.

It was not considered viable to survey all properties within the PMF extent for the purpose of damage calculations. The selection of all properties in the 1% AEP extent would be expected to include all properties that have overfloor flooding in the PMF, given the relatively small difference in the 1% AEP and PMF flood level across the catchment.

A flood damages assessment was undertaken as part of the Flood Study (Reference 2) for existing development in accordance with current OEH guidelines (Reference 9) and the Floodplain Development Manual (Reference 1). As additional properties floor levels were surveyed as part of this study, 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.

Woolloomooloo has a small catchment size (160 hectares) that limits the volume of runoff that occurs in a rainfall event. This limited volume, combined with the relatively short duration of the flood event (typically a few hours), means there is limited opportunity for floodwaters to enter premises. This is especially true of basement flats - flats where the entry is below the level of the footpath. For example, a basement flat may have a floor level two metres below the design flood level, but will not experience two metres of depth throughout the dwelling, due to the limited runoff volume. To account for this, the maximum depth of inundation in the damages calculation for each property is 0.5 m.

Similarly, the damages calculation was augmented so as to avoid designating these basement flats as being flooded over floor in frequent flood events. This change was made after detailed assessment of the properties in question, as well residents' experiences via the questionnaire, suggested that these basement flats were typically not flooded in frequent flood events (e.g. a 1 in 2 year ARI event). The damages calculation was augmented by not designating properties as flooded overfloor when the depth on the footpath is less than 0.15 m. This is not to say that a depth of 0.15 m cannot inundate a low-lying property. Rather, that without this threshold, the flood affectation is overestimated, and so the threshold improves the estimate of the affectation.

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 5. This flood damages estimate does not include the cost of restoring or maintaining public services and infrastructure. It should be noted that damages calculations do not take into account flood damages to any basements or cellars, hence where properties have basements damages can be under estimated.

Table 5: Estimated Combined Flood Damages for Woolloomooloo Catchment

Event	Number of Properties Flood Affected	No. of Properties Flooded Above Floor Level	Total Tangible Flood Damages	Average Tangible Damages Per Flood Affected Property
PMF	314	249	$ 23,734,400	$ 75,600
0.2%	294	179	$ 17,339,900	$ 59,000
1%	287	148	$ 14,700,400	$ 51,200
2%	277	128	$ 13,022,700	$ 47,000
5%	241	100	$ 10,465,900	$ 43,400
10%	206	65	$ 7,190,000	$ 34,900
20%	191	34	$ 4,193,000	$ 22,000
50%	160	12	$ 1,894,800	$ 11,800
Average Annual Damages (AAD)			**$ 3,055,500**	**$ 10,400**

Section 9.3.7 presents results of the damages assessment undertaken for the potential mitigation options which were compared against the existing scenario so that the feasibility of the options can be determined.

5.1.1. Residential Properties

Flood damages assessment for residential development was undertaken in accordance with OEH guidelines (Reference 9). For residential properties, external damages (damages caused by flooding below the floor level) were set at $6,700 and additional costs for clean-up as $4,000. For additional accommodation costs or loss of rent a value of $220 per week was allowed assuming that the property would have to be unoccupied for up to three weeks. Internal (contents) damages were allocated a maximum value of $33,750 occurring at a depth of 0.5 m above the building floor level (and linearly proportioned between the depths of 0 to 0.5 m). Structural damages vary on whether the property is slab/low set or high set. For the purpose of this study, any property with a floor level of 0.5 m or more above ground level was assumed to be high set. For two storey properties, damages (apart from external damages) are reduced by a factor of 70% where only the ground floor is flooded as it is assumed some contents will be on the upper floor and unaffected and that structural damage costs will be less. In some instances external damage may occur even where the property is not inundated above floor level and therefore tangible damages include external damages which may occur with or without house floor inundation.

A summary of the residential flood damages for the Woolloomooloo catchment is provided in Table 6. 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 6: Estimated Residential Flood Damages for Woolloomooloo Catchment

Event	Number of Properties Flood Affected	No. of Properties Flooded Above Floor Level	Total Tangible Flood Damages	Average Tangible Damages Per Flood Affected Property
PMF	202	158	$ 8,702,200	$ 43,100
0.2%	193	109	$ 6,225,200	$ 32,300
1%	187	85	$ 4,994,400	$ 26,700
2%	179	71	$ 4,299,000	$ 24,000
5%	147	53	$ 3,328,400	$ 22,600
10%	116	34	$ 2,264,000	$ 19,500
20%	109	18	$ 1,364,200	$ 12,500
50%	94	5	$ 558,500	$ 5,900
Average Annual Damages (AAD)			**$ 969,200**	**$ 5,000**

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 be no 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 businesses. Common flood costs to businesses are:

- Removal and storage of stock before a flood if warning is given;
- 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 example, the maximum value of internal (contents) damages was increased to $95,625 since the building contents are of higher value whilst loss of rent was set at $1,000 per week to account for the loss of business through having to close for a period. Flooding below floor level uses the same damages curve as the residential properties.

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 Woolloomooloo catchment is provided in Table 7. AAD for the surveyed commercial/industrial properties is less than that for residential properties but there are no flood affected properties above floor level for the commercial/industrial properties.

Table 7: Estimated Commercial and Industrial Flood Damages for Woolloomooloo Catchment

Event	Number of Properties Flood Affected	No. of Properties Flooded Above Floor Level	Total Tangible Flood Damages	Average Tangible Damages Per Flood Affected Property
PMF	112	91	$ 15,032,200	$ 134,200
0.2%	101	70	$ 11,114,700	$ 110,000
1%	100	63	$ 9,706,000	$ 97,000
2%	98	57	$ 8,723,800	$ 89,000
5%	94	47	$ 7,137,500	$ 75,900
10%	90	31	$ 4,926,000	$ 54,700
20%	82	16	$ 2,828,700	$ 34,500
50%	66	7	$ 1,336,300	$ 20,200
Average Annual Damages (AAD)			**$ 2,086,400**	**$ 20,700**

5.1.3. Climate Change

A damages assessment was carried out for a climate change scenario to estimate the potential increase in flood damages. This scenario entailed combining one of the rainfall increase scenarios (10% increase) with the 2050 sea level rise scenario (+0.4 m) and producing the range of design flood results under these conditions. It should be noted that large uncertainty exists in the estimation of climate change effects on extreme rainfall, and so the scenario is only an example of one possible climate change scenario. For this reason, it should be used as an indication of general sensitivity of the economic damages to changes in rainfall, and not an accurate estimate of what damages will be in the future. Table 8 lists the damages estimate.

Table 8: Estimated Combined Flood Damages Under Climate Change Scenario

Event	Number of Properties Flood Affected	No. of Properties Flooded Above Floor Level	Total Tangible Flood Damages	Average Tangible Damages Per Flood Affected Property
PMF	314	253	$ 24,218,500	$ 77,100
0.2%	298	196	$ 18,610,700	$ 62,500
1%	293	174	$ 16,637,800	$ 56,800
2%	286	155	$ 15,344,100	$ 53,700
5%	277	134	$ 13,374,400	$ 48,300
10%	241	98	$ 10,344,000	$ 42,900
20%	223	53	$ 6,210,900	$ 27,900
50%	175	16	$ 2,586,700	$ 14,800
Average Annual Damages (AAD)			**$ 4,159,400**	**$ 14,000**

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 Woolloomooloo catchment area, the high hazard areas include Stream Street and Busby Lane and parts of Crown Street, Riley Street, William Street, Palmer Street, Bourke Street and Victoria Street. 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 Woolloomooloo catchment is characterised by overland flow, with no mainstream flooding and only a small area of tidal influence near Cowper Wharf Road. The critical duration is between 1 and 2 hours across 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 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 within the upper levels if available. 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 9.4.2 and 9.4.4.

It is important that residents 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 finally
- The flash nature of the flooding. Note that where rainfall exceeds 5 year ARI 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 Woolloomooloo catchment are discussed as follows.

6.2.1. DISPLAN

The Woolloomooloo catchment is located within the Sydney East Emergency Management District. Flood emergency management for the study area is organised under the NSW Disaster Plan (2010) (DISPLAN). No district DISPLAN has been prepared for this district.

The DISPLAN 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 DISPLAN has been prepared to coordinate the emergency management measures 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 DISPLAN states that:

"*Each District 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 DISPLAN be prepared for the Sydney East Emergency Management District to outline emergency response arrangement specific to the district. In particular the purpose of a District DISPLAN is to:

- Identify responsibilities at a District and Local level in regards to the prevention, preparation, response and recovery for each type of emergency situation likely to affect the district;
- Detail arrangements for coordinating resource support during emergency operations at both a District and Local level;
- Outline the tasks to be performed in the event of an emergency at a District and Local level;
- Specifies the responsibilities of the East Metropolitan District Emergency Operations Controller and Local Emergency Operations Controllers within the East Metro EM District;
- Detail the responsibilities for the identification, development and implementation of prevention and mitigation strategies;
- Detail the responsibilities of the District and Local Emergency Management Committees within the District;
- 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 District 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 local flood plan has not been prepared for the local area containing the Woolloomooloo catchment. As such, the New South Wales State Flood Sub-plan (2008) 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 DISPLAN. 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, it may be useful for the City of Sydney to prepare a Local Flood Plan in conjunction with the SES 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 Woolloomooloo 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 Management Centre located at Town Hall is on the notification list for SES flood warning alerts and direct liaison between the SES and the Security and Emergency Management Centre may be conducted via a dedicated radio frequency.

The Manager - Security and Emergency Management may then pass on the flood warnings to any affected Council or Community Building within the Woolloomooloo catchment.

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

The relevant flood information from the draft Woolloomooloo Flood Study (Reference 2) should be transferred to the Security and Emergency Management Centre.

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 Woolloomooloo 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 Woolloomooloo 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 Centre 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.

6.3.1. Access Road Flooding

The catchment area has one arterial road (William Street) that is flood affected, and a number of other roads where traffic will be impeded in a flood event. William Street is the main arterial road leading east from the CBD, and has a topographic sag that is flood affected (also described in Section 3.3.1). As shown in Table 9, the depth of inundation on the road varies from 0.1 m in a 2 year ARI event, to 0.6 m in a 1% AEP and 1.4 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 9 also lists the depths for other roads in the catchment, the worst-affected of which is Palmer Street, while Figure 21 shows their locations.

Table 10 lists the rate of rise in metres per hour for the same locations listed in Table 9, 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 four 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 Crown Street experiencing a faster increase in frequent events. The rate of rise is generally around 0.5 m/hour for frequent events and between 1 and 2 m/hour for rarer events, for the 1 hour event.

Table 9: Major Road Peak Flood Depths (m) for Various Events

ID	Road Location	2 year ARI	5 year ARI	10% AEP	5% AEP	2% AEP	1% AEP	0.2% AEP	PMF
1	William Street near Riley Street	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.4
2	Crown Street near Cathedral Street	0.5	0.6	0.7	1.0	1.1	1.2	1.2	1.9
3	Palmer Street near Cahill Expressway	0.3	0.6	0.7	0.9	1.4	1.4	1.5	1.8
4	Bourke Street near Cowper Wharf Road	0.0	0.1	0.2	0.5	0.7	0.7	0.7	1.2

Table 10: Major Road Flooding Rate of Rise (m/hour) for Various Events (1 hour duration event)

ID	Road Location	2 year ARI	5 year ARI	10% AEP	5% AEP	2% AEP	1% AEP	0.2% AEP	PMF
1	William Street near Riley Street	0.3	0.4	0.7	1.0	1.4	1.6	2.3	7.0
2	Crown Street near Cathedral Street	0.8	1.1	0.9	1.2	1.6	1.8	2.2	7.4
3	Palmer Street near Cahill Expressway	0.4	1.0	1.2	1.1	1.7	2.1	2.6	7.0
4	Bourke Street near Cowper Wharf Road	0.1	0.1	0.2	0.7	1.0	1.0	1.3	4.3

For the 1% AEP flood event, roads cut (as per Figure 21) are shown in Table 11.

Table 11: Major Roads Cut in the 1% AEP Event

Road Location	Description
William Street near Riley Street	Flood depths are up to 0.6 m and persist for a period of 30 minutes to one hour given the critical storm modelled (2 hour)
Crown Street near Cathedral Street	Flood depths are up to 1.2 m and persist for a period of over 1.5 hours given the critical storm modelled (2 hour)
Palmer Street near Cahill Expressway	Flood depths are up to 1.4 m and persist for a period of up to 1.5 hours given the critical storm modelled (2 hour)
Bourke Street near Cowper Wharf Road	Flood depths are up to 0.7 m and persist for a period of 30 minutes to one hours given the critical storm modelled (2 hour)

Following a review of this information revised SES plans might allot responsibility for management of these road closures. 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 7) 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 7). The ERP classification can identify the type and scale of information needed by the SES to assist in emergency response planning (refer to Table 12).

Table 12: 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 Woolloomooloo 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 6.

This figure shows that only one area, at Stream Street near William Street, has been classified as low flood island. This is due to the high depths that accumulate at the north end of the street in frequent flood events. Other areas have been classified as high flood island as they are only isolated in PMF flooding.

7. POLICIES AND PLANNING

7.1. Legislative and Planning Context

The NSW State Government's Flood Policy provides a framework to ensure the sustainable use of floodplain environments. The Policy is specifically structured to provide solutions to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any new development is compatible with the flood hazard and does not create additional flooding problems in other areas. Under the Policy, the management of flood liable land remains the responsibility of local government. Furthermore, Section 117(2) of the 1979 Environmental Planning and Assessment Act Direction 15 states that Council must ensure development is appropriate in regard to flood risk and that furthermore it does not cause impacts on adjoining property.

Councils have a number of planning tools available to them in order to fulfil this role, including the Local Environment Plan (LEP) and Development Control Plans (DCPs). Detail of the specific planning documents relevant to Woolloomooloo is provided below.

7.1.1. 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 NSW Floodplain Development Manual (Reference 1) relates to 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 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

With regards to flood risk management, Councils use Local Environment Plans (LEP) and Development Control Plans (DCP) to set policies and development controls. City of Sydney recently 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 planning controls.

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.

Sydney DCP 2012

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

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

- Ensure an integrated approach to water management across the City through the use of water sensitive urban design principles;
- Encourage sustainable water use practices;
- Assist in the management of stormwater to minimise flooding and reduce the effects of stormwater pollution on receiving waterways;
- Ensure that development manages and mitigates flood risk, and does not exacerbate the potential for flood damage or hazard to existing development and to the public domain; and

- Ensure that development above the flood planning level as defined in the Sydney LEP 2012 will minimise the impact of stormwater and flooding on other developments and the public domain both during and after the event.

Interim Floodplain Management Policy

This interim Policy (Reference 6) was adopted in May 2014 and 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 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.

The Policy outlines Council responsibilities in managing floodplains and it provides controls to facilitate a consistent, technically sound and 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 planning controls.

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 in the area:

- 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.

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 either the LEP or the DCP or both 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. Either the LEP or the DCP or both should be updated to ensure this information is provided;
- Flood related development controls and requirements are provided in the Interim Floodplain Management Policy (Reference 6). 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 6); 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 6).

8. FLOOD PLANNING

8.1. Flood Planning Level (FPL)

The FPL is the height at which new building floor levels should be built. Due to the mixture of residential and commercial development in the Woolloomooloo catchment, a variety of FPLs may be applicable depending on where in the catchment development is being considered and also based on the type of development being proposed.

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

- Risk to life;
- Long term strategic plan for land use near and on the floodplain;
- Existing and potential land use;
- Current flood level used for planning purposes;
- Land availability and its needs;
- FPL for flood modification measures (levee banks etc);
- 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;
- Duty of care.

8.1.1. Likelihood of Flooding

As a guide, Table 13 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 13 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 13: 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 6).

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);
- 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 0.19 m, mean 0.08 m, as per Woolloomooloo Flood Study (2013))
- Climate change impacts on sea level rise (0.0 m to 0.13 m, mean 0.05m, as per Woolloomooloo Flood Study (2013)); and
- Sensitivity of the model +/-0.05 m.

Based on this analysis, the total sum of the likely variations is between 250 mm and 500 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 6) 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 6). This policy was tested each time a development application was received. The policy provides further details regarding flood planning levels for various types of development within the floodplain and these are outlined in Table 14.

Table 14: Adopted Flood Planning Levels in CoS Interim Floodplain Management Policy (Reference 6)

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 Woolloomooloo 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

9.1. General

The NSW Government's Floodplain Development Manual (2005) separates floodplain management measures into three broad 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 Woolloomooloo catchment.

A summary of the measures considered for the catchment and at the specific hotspot locations is provided in Table 15 and discussed in the following sections.

Table 15: Flood Affected Areas and Investigated Management Options

Hotspot	Flooding issues	Investigated Measures	Measure Reference
Stream Street, Busby Lane, Crown Street,	Inundation with high depth or velocity, flooding of major roads, many properties	Trunk Drainage Upgrade from Stream Street to Outlet	FM-WLM01

Palmer Street, Bourke Street	flooded above floor		
Earl Street	Localised inundation with moderate depth, few properties flooded above floor.	Drainage Upgrade from Earl Street to Victoria Street	FM-WLM02
Victoria Street	Frequent inundation with moderate depth and velocity, several properties flooded above floor.	Drainage Upgrade - 1m x 1m pipe	FM-WLM03
		Drainage Upgrade – Lowered Footpath	FM-WLM04
		Drainage Upgrade – 900 mm pipe	FM-WLM05
Catchment-wide	General flood risk, inundation of major roads	Variable Message Display on Major Roads	RM-WLM01
		Evacuation Planning	RM-WLM02
		Public Information and Raising Flood Awareness	RM-WLM03
		Local Flood Plan and DISPLAN	RM-WLM04
		Flood Planning Levels	PM-WLM01
		Flood Proofing of Affected Properties	PM-WLM02
		Voluntary Purchase	PM-WLM03
		Development Control Planning	PM-WLM04

9.2. Measures Not Considered Further

During the early phase of this study a review of all possible floodplain management measures and their application in the Woolloomooloo 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. However, dams 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,
- 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.

This measure was not considered further for the above reasons.

9.2.2. Flood Modification - Levees, Flood Gates and Pumps

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 a defined channel or river in the catchment area.

9.2.3. Response Modification – Catchment-Wide Flood Warning

During a major flood it may be necessary for some residents to evacuate their homes. Whilst not all will have their house floors inundated, it is possible that their power, water and sewerage systems could be affected. The amount of evacuation time depends on the available warning time. Providing sufficient warning time has the potential to reduce the social impacts of the flood as well as reducing the strain on emergency services.

The effectiveness of a flood warning systems depends on:

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

At present there is no flood warning system in place for the Woolloomooloo catchment area. This is a result of the short time from the start of the rainfall to the flood peak (around 1 hour for the critical storm duration), which would not allow sufficient time for evacuation to occur prior to the flood event. Furthermore, flood risk in the catchment is concentrated at several separate locations, meaning a warning system would not benefit the majority of the area. This option was not considered further for these reasons.

9.2.4. Property modification - House raising

House raising has been widely used throughout NSW to eliminate inundation from habitable floors. However, it has limited application as it is not suitable for all building types. It is also more common in areas where there is a greater depth of inundation that in the Woolloomooloo catchment.

House raising is suitable for most non-brick, single storey buildings on piers and is particularly relevant to those houses situated in low hazard areas of the floodplain. The benefit of house raising is that it eliminates inundation to the height of the floor, and consequently reduces the flood damages.

Due to the nature of development and the heavily urbanised city catchment, it is considered highly unlikely that any of the flood affected buildings would be suitable for house raising. As such, this measure has not been considered further.

9.3. Site Specific Management Options

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

Measures to increase the capacity or efficiency of the existing piped drainage network include upgrading pipe capacity; re-profiling the pipe network; removing fixed blockages or impediments to flow and improved maintenance. This type of measure was assessed in detail for a number of flood affected areas within the catchment. An overview of the flood affected areas and assessed mitigation options are provided in
Table 16 and shown in Figure 22. These options are discussed in detail in Sections 9.3.1 to 9.3.6.

Through the flood mitigation option development process, at some locations more than one option has been tested for the mitigation of flood risk. So for example at Victoria Street various options are put forward. Given the scale of these works and the fact that their feasibility and eventual cost will be significantly impacted by existing services, further analysis is required prior to a decisive selection being made. This analysis should focus specifically on feasibility of construction and if feasible, cost estimates should then be estimated by a quantity surveyor. It is recommended that the further feasibility analysis is carried out when funding is available for the works.

Note that based on the public exhibition feedback some options for Victoria Street developed as part of the study will require revision. Priority number one for Victoria St becomes a revised investigation utilizing observations in response to the August 24th event.

9.3.1. Trunk Drainage Upgrade – Stream Street to Outlet (FM - WLM01)

Option Description

Option FM – WLM01 describes a trunk drainage upgrade between Stream Street in East Sydney and the outlet, which is adjacent to the Woolloomooloo Finger Wharf. The upgrade has been designed with the goal of mitigating property and road inundation in the 10% AEP event. The 10% AEP event is used as this ties in with City of Sydney's goal to reduce flood hazard on major roads for the 10% AEP event.

Table 16: Drainage Network Modifications

Suburb	Flood Affected Streets/Areas	Potential Management Options	Ref
Darlinghurst and Woolloomooloo	Stream Street, William Street, Busby Lane, Riley Street, Crown Street, Palmer Street and Bourke Street	Trunk drainage upgrade from Stream Street to outlet	FM - WLM01
Potts Point	Earl Street	Drainage upgrade for Earl Street pipe connecting to Victoria Street	FM - WLM02
Potts Point	Victoria Street near Orwell Street	Drainage upgrade for 500 m section of Victoria Street	FM - WLM03
		Footpath on Victoria Street lowered	FM - WLM04
		Drainage upgrade for 190 m section of Victoria Street	FM – WLM05

Although more localised upgrades are possible (i.e. only upgrading a section of the trunk drain), a large-scale upgrade has been assessed for several reasons. Firstly, the majority of the hotspots in Woolloomooloo lie along the trunk drainage line, and so there is an opportunity to produce wide-scale benefits that alleviate flooding in several areas. Secondly, any upgrade in pipe capacity will increase discharge in the trunk system, which tends to increase the peak flood level downstream of the upgrade. This can be acceptable if there is a park or similar land in the downstream area, but there are very few such areas in the catchment. Also, Sydney Water Corporation have expressed interest in a pre-feasibility assessment of upgrades to the stormwater network, as there are plans to decouple the stormwater and sewerage in the area, which could be combined with pit and pipe upgrades.

The drainage works are extensive and are at the upper limit of what may be considered financially and technically feasible. The upgrade is to demonstrate the maximum benefit that may be achieved with pit/pipe upgrades. The works include the following elements:

- Upgrade of the pit and feeder pipe capacity to ensure that the upgraded trunk elements are full in the 10% AEP event;
- Upgrade of the trunk drains between Stream Street and the outlet to box culverts of various sizes, ranging from 1.8 m x 1.2 m (2.16 m^2) to 3 m x 2.1 m twin culverts (12.6 m^2).

The largest upgrades are along Bourke Street, as this area is both at the downstream end of the system, and so receives the greatest flow, and also has a very flat grade and therefore has lower velocity flow and less efficient drainage. Without this very large pipe capacity at Bourke Street, the increased flow from the remainder of the upgrade causes an increase in the peak flood level in Bourke Street.

Modelled Impacts

The upgraded drainage achieve a significant reduction in flood level and hazard in several hotspots; however, there are small areas of adverse impact in some events. The impact of the upgraded drainage on the 10% AEP flood level and over floor flood liability in that event are shown in Figure 24, while Figure 25 shows the change in hydraulic hazard in the same event.

In Stream Street, there is a reduction of up to 3 m in the 10% AEP, which corresponds to the hydraulic hazard in the area changing to low hazard (previously high). The reduction in peak flood level is substantial and all but removes what was previously an area of significant flood risk in the catchment. The change is achieved by the upgraded trunk drainage, which now discharges up to 7.5 m^3/s in the 10% AEP event. The benefit also extends to Riley Street, which has a decrease of up to 1 m in the peak flood level and is now low hazard. Riley Street has three low-lying properties that are flooded overfloor in a 50% AEP event under existing conditions, which are first flooded in a PMF event given the works.

The trunk upgrade also achieves significant benefit for William Street, with a decrease of up to 0.4 m in the 10% AEP event and a large area no longer flooded on the road. William Street is a major thoroughfare leading into the Sydney CBD and therefore significant disruption occurs when it is flooded.

Busby Lane does not benefit from the trunk upgrade and experiences a minor increase in peak flood level (0.05 m in the 10% AEP and 0.23 m in the 1% AEP). This results from constraints on the grading of the trunk, which causes the hydraulic head in the trunk to be above the pit surface inverts in Busby Lane. The inlet pits have therefore been sealed to prevent surcharge of the trunk flow; however, this prevents drainage from the area and causes the impact.

The Crown Street hotspot has a reduction of up to 0.6 m in the 10% AEP event, with Bossley Terrace no longer flooded in that event. This is a substantial improvement for the area, which is known to flood in relatively frequent rainfall events. The upgrade lessens the hazard to pedestrian and vehicular traffic along the street, with the depth in the 10% AEP event less than 0.15 m under the upgraded works. It also benefits the overfloor inundation for dwellings on Crown Street; under existing conditions, houses on the east side of the street are first flooded overfloor in either a 10% or 5% AEP event, while under the upgrade, no house is flooded overfloor for events smaller than the 1% AEP event.

The Palmer Street hotspot has a reduction of up to 0.7 m in the 10% AEP event, reducing the flood depth in the area to around 0.1 m. At the north end of Palmer Street, its drainage runs parallel to the trunk pipe from Crown Street, at which point they have a combined flow of up to 12.4 m^3/s in the 10% AEP event under the upgrade.

Downstream of the Eastern Distributor, the trunk drainage follows Bourke Street until the outlet, and in this area the upgrade has limited benefit. The inverts of the trunk system are below sea level in this section, ranging from -0.3 mAHD near Wilson Street to -0.9 mAHD at Cowper Wharf Roadway. These inverts are constrained by the area's topography, which ranges from 2 mAHD to 1.6 mAHD in the same section. Both the flat grade of the trunk (approximately 0.4%) and the higher tailwater at the outlet (0 mAHD) significantly restrict discharge through the trunk system. As the remainder of the trunk upgrade conveys runoff away from areas that were previously significant flood storages (for example, Stream Street), the increase in discharge is greatest at

Bourke Street.

Without sufficient drainage to convey the additional discharge, there is an increase in the peak flood level upstream of the upgrade in Bourke Street, as well as at the rear of the properties at the north end of Bourke Street, in an area currently used as a car park. The adverse impacts are in the order of 0.03 to 0.05 m in the two areas in the 10% AEP event. Both areas may benefit from further iterations to the upgrade, for example by upgrading drainage further south on Bourke Street or that which drains the car park area.

The drainage upgrade produces minor benefit to the area in the Bourke Street hotspot. There is a decrease of around 0.05 m around the intersection of Bourke Street and Bland Street in the 10% AEP event. Properties in the area are generally raised above ground level and so overfloor inundation is not widespread until the 1% AEP event.

Evaluation

The drainage upgrade entails more than one kilometre of large-scale trunk upgrade, and, despite not producing uniform benefit across the area, significantly reduces the flood risk in the Woolloomooloo catchment. Several types of existing flood risk are addressed by the works, including:

- Hazardous depths of inundation, for example in Stream Street, Palmer Street, Riley Street and Crown Street, which pose risk to vehicles and pedestrians and restrict access during a flood.
- Fast-moving overland flowpaths, for example on Riley Street, which pose risk to vehicles and pedestrians and restrict access during a flood.
- Inundation of William Street, which is a major arterial road between the CBD and the eastern suburbs.
- Overfloor inundation of properties, for example in Crown Street and Riley Street, which has both large financial costs and more intangible effects.

Despite the drainage upgrade producing benefits across a range of areas, the upgrade is both technically and financially difficult, and is not justified under a benefit-cost ratio analysis (see Section 9.3.7). The difficulty of implementing the upgrade is related to the required pipe sizes, the alignment of the trunk system, and the highly urbanised nature of the area. As shown on Figure 24, upgrade has pipes that are generally larger than 2 m^2 in cross-sectional area, for example a 2.7 m x 2.4 m culvert is used on Sir John Young Crescent, a 3 m x 1.5 m culvert is used on part of Crown Street and Bourke Street has over 20 m^2 of pipe capacity in one section. Coupled with very large pipe sizes being proposed, the alignment of the trunk is along either densely populated streets which likely have a number of sub-surface services, as well as being beneath buildings (such as upstream and downstream of William Street) or beneath major infrastructure (the Eastern Distributor). These factors combine to make the drainage upgrade both technically difficult and prohibitively expensive.

9.3.2. Drainage Upgrade – Upgraded Pipe on Earl Street (FM - WLM02)

Option Description