ATTACHMENT I

CENTENNIAL PARK CATCHMENT
FLOODPLAIN RISK MANAGEMENT STUDY
(DRAFT REPORT)

CENTENNIAL PARK FLOODPLAIN RISK MANAGEMENT STUDY

DRAFT REPORT

DECEMBER 2015

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Project Centennial Park Catchment Floodplain Risk Management Study	**Project Number** 114014
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CENTENNIAL PARK CATCHMENT FLOODPLAIN RISK MANAGEMENT STUDY

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FOREWORD

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. The State Government subsidises flood mitigation works to alleviate existing problems and provides specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities.

The Policy provides for technical and financial support by the Government through four sequential stages:

1. ***Flood Study***
   - Determine the nature and extent of the flood problem.
2. ***Floodplain Risk Management***
   - Evaluates management options for the floodplain in respect of both existing and proposed development.
3. ***Floodplain Risk Management Plan***
   - Involves formal adoption by Council of a plan of management for the floodplain.
4. ***Implementation of the Plan***
   - Construction of flood mitigation works to protect existing development, use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

The Draft Centennial Park Catchment Floodplain Risk Management Study and Draft Plan constitute the second and third stages of this management process. This study has been prepared by WMAwater for City of Sydney (Council) under the guidance of Council's floodplain management committee (Committee). This study provides the basis for the future management of those parts of the Centennial Park catchment which are flood liable and within the City of Sydney Local Government Area.

1. INTRODUCTION

1.1. Study Area

The Centennial Park catchment is located in Sydney's inner city suburbs of Paddington, Moore Park and Centennial Park and is shown on Figure 1. The catchment lies within the City of Sydney Local Government Area (LGA) and has been extensively developed for urban usage. It covers an area of approximately 150 hectares and drains to Sydney Water Corporation's (SWC) major trunk drainage systems. When the pipe drainage is at capacity, water flows overland along streets and other open space. A number of locations in the area are flood liable, mainly as a result of the area's topography, which includes several unrelieved depressions, both in residential areas and around Moore Park. This creates a significant drainage/flooding problem in many areas in the catchment. Detailed description of the study area is given in Section 2.1.

1.2. The Floodplain Risk Management Process

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

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

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

Phase I – Draft Floodplain Risk Management Study in which the floodplain management issues confronting the study area are assessed, management options investigated and recommendations made. The objectives of this phase for the Centennial Park catchment include:

- Review the current Draft Centennial Park Catchment Flood Study (2013) and update the hydraulic model to accommodate recent changes in the catchment;
- Acquire any additional floor level survey required;
- Review Council's existing environmental planning policies and instruments, identify modifications required to current policies;
- Identify residential flood planning levels;
- Identify and assess works, measures and controls aimed at reducing the impacts and losses caused by flooding and consider their impacts if implemented, taking into account the potential impacts of climate change; and

- Review the local flood plan, examine the present flood warning system, community flood awareness and emergency response measures (involvement with the NSW State Emergency Service).
- Investigate flood mitigation options for flood affected streets and areas as identified in the revised Flood Study.

Phase II – Draft Floodplain Risk Management Plan which is developed from the Floodplain Risk Management Study and details how flood prone land within the study areas is to be managed moving forward. The primary aim of the Plan is to reduce the flood hazard and risk to people and property in the existing community and to ensure future development is controlled in a manner consistent with flood hazard now and in the future. The Plan consists of prioritised and costed measures for implementation.

1.3. Relevant Studies

Limited studies have been undertaken regarding flooding and stormwater in the Centennial Park catchment. Two flood studies have been undertaken for the catchment, the first covering the part of the catchment in the Randwick LGA and a second study covering the part in the City of Sydney LGA. Both are summarised in the following section.

1.3.1. Kensington – Centennial Park Flood Study, WMAwater, April 2013

The study (Reference 3) defined existing flood behaviour for design flood events up to the Probably Maximum (PMF) for the Centennial Park catchment within Randwick City Council's LGA. The study modelled the catchment hydrology using two models, MIKE-STORM and DRAINS and assessed hydraulic behaviour using a 1D/2D TUFLOW model. Two flood events in November 1984 were used as calibration and validation events for the models.

The study characterised the catchment as having a number of trapped low points, where the existing drainage was not sufficient to convey flows away from the depression. These include sections of Aboud Avenue, Cottenham Avenue, Barker Street, Market Street, Clovelly Road and Wentworth Street.

1.3.2. Centennial Park Catchment Draft Flood Study

The draft Flood Study report (Reference 2) which preceded the current study in the floodplain risk management process being undertaken for the area, defined existing flood behaviour for the Centennial Park catchment within City of Sydney's LGA. Flood behaviour was described as flood levels, depths, velocities, flows and extents for a range of design events up to the PMF. A 1D/2D TUFLOW hydraulic model was used in conjunction with a DRAINS hydrologic model. Insufficient data was available for a full model calibration and so only verification was carried out, which entailed comparing model results to anecdotal reports of flooding to several historical events and to various descriptions of flooding behaviour in the catchment. The study defined flood behaviour for the 2, 5, 10, 20, 50 and 100 year ARI as well as the PMF. Preliminary hydraulic hazard was determined for the 10, 20 and 100 year ARI flood events and the PMF, while hydraulic categories were determined for the 100 year ARI event. Hotspots were not identified by the study, but some description is given to trapped low points in the area. A floor level survey and damages assessment were carried out, of which the latter identified 29 properties that would be flooded above floor level in a 100 year ARI event.

The study found that the urbanisation of the catchment, particularly in the past 100 years, significantly altered the drainage characteristics of the catchment. For example, development on Leinster Street, Stewart Street, at Fox Studios and on Lang Road all block or impede natural flow paths, causing ponding that cannot be effectively drained by the subsurface drainage network. Similarly, low points on Driver Avenue and Lang Road are not efficiently drained by overland flowpaths and tend to store water in flood events.

The study identified a number of trapped low points in the catchment. This was taken into consideration along with properties' inundation and five hotspots were examined. The hotspots are shown on Figure 2 and were as follows:

1. Poate Road
2. Stewart Street and Leinster Street
3. Driver Avenue
4. Lang Road near Driver Avenue
5. Lang Road near Darvall Street

The study also considered the potential effects of climate change by modelling rainfall increases of 10, 20 and 30% on the 1% AEP flood event. Generally speaking, each incremental 10% increase in flow results in a 0.02 m to 0.05 m increase in peak flood levels at most of the locations analysed. A 30% increase in rainfalls would therefore not exceed the typical freeboard for most residential properties. Sea level rise was not relevant as none of the study area is tidal.

The key outcomes of the Flood Study which are to be discussed, considered or managed in this Study and Plan are:

- The areas identified as being flooding hot spots;
- Establish the "true" hydraulic category and hazard definitions;
- Identify mitigation measures to address the adverse impacts of new developments; and
- Identify risk management measures to reduce flood costs to properties within the catchment by either structural or non-structural measures.

1.3.3. Centennial Park Flood Study Review and Update

The draft Centennial Park Flood Study (Reference 2) was reviewed as part of this Management Study, to incorporate any recent changes to the catchment which had occurred. Three minor updates were made. Firstly, at the hotspot along Lang Road near Darvall Street pits were upgraded and a pipe was added, in line with a recent drainage upgrade in the area. This resulted in a reduction of 0.05 m in the 1% AEP event in the immediate vicinity of the upgrade.

Secondly, the inverts of several nodes along the trunk drainage line were re-estimated using updated interpolation techniques (no invert data was available). The amendment caused a reduction of 0.1 m in the 1% AEP event flood depth at Driver Avenue and some small increases and decreases within Moore Park.

Finally, two small changes to building outlines were made. These were updated when the flow paths between buildings were examined in more detail. The impacts of flood levels around the change were minimal.

2. CATCHMENT CHARACTERISTICS

2.1. Study Area

The Centennial Park catchment is located in Sydney's inner city suburbs of Paddington, Moore Park and Centennial Park. The catchment lies within the City of Sydney Local Government Area (LGA) and has been extensively developed for urban usage. Land use is predominantly medium to high-density housing as well as commercial and industrial developments, with some large open recreational spaces and facilities that include Moore Park, Sydney Cricket Ground, Sydney Football Stadium, Fox Studios and Heritage Park.

The catchment covers an area of approximately 150 hectares draining to Sydney Water Corporation's (SWC) major trunk drainage systems (known as SWC 58, 59 and 89) to route flows from the upper regions of the catchment. The trunk drainage system is linked to Council's local drainage system consisting of covered channels, in-ground pipes, culverts and kerb inlet pits. When these systems reach capacity, flow cannot enter the subsurface network and passes overland along streets and other open space. The drainage system is shown on Figure 3.

The topography of the catchment is steep with the greatest relief occurring at the top of the catchment along Oxford Street at elevations of 60 to 70 mAHD which slopes south to the Fox Studios site with grades of approximately 4%. Anzac Parade, extending along the western side of the study area, has a grade of approximately 1% from north to south. The downstream end of the study area is also the flattest part of the catchment; within the Parklands Tennis club, which has a relatively gentle ground gradient of 1% draining south towards Anzac Parade.

A number of locations within the catchment are flood liable. This flood liability mainly relates to the nature of the topography within the study area as well as the capacity of service provided by drainage assets. Urbanisation throughout the catchment occurred prior to the installation of road drainage systems in the 1900s and some buildings have been constructed on overland flow paths or in unrelieved sags. Due to these drainage restrictions, topographic depressions can cause localised flooding as excess flows have no opportunity to escape via overland flow paths. This is exacerbated by the relatively flat terrain in the lower section of the catchment (broadly, the area south of Moore Park Road and west of Cook Road), which results in a lack of flood gradient in this area. This lack of gradient, as well as insufficient pipe drainage causes localised flooding in several areas in the catchment.

Future development in this area is likely to be in the form of landuse changes in the SCG/SFS/Fox Studios/Moore Park area, as well as urban consolidation in the area's limited residential land. Around half of the land in the catchment is part of the Centennial Parklands and is managed by the Centennial Park and Moore Park Trust, a NSW Government agency. The Trust released a 'strategic land use vision' (Reference 4) in mid-2013 that includes increased commercialisation of parts of its park, including an underground car park under Moore Park and redevelopment of ES Marks Fields, at the southern tip of the catchment. Construction recently began on Tibby Cotter Bridge, a pedestrian bridge over Anzac Parade linking Moore Park West to Driver Avenue. Further mention must be made of the Sydney CBD and South East Light Rail Project (CSELR). Whilst at the time of writing works are yet to commence within the catchment, this significant infrastructure project will no doubt be of consequence in the future.

2.1.1. Land Use

The land use zones as identified in the Sydney LEP 2012 are shown in Figure 4. The land usage within the study area is a mix of urban residential development, parkland, commercial area and sporting grounds. Urban residential development is located on the northern and eastern sides of the catchment, with Paddington in the north having mostly two-storey terrace houses and Centennial Park to the east having a mix of apartment buildings and large, heritage-listed houses. Fox Studios, the Entertainment Quarter and two sports stadiums occupy the centre of the area, which have a mix of commercial and industrial use. The remainder of the land, in the south and west of the study area, is used for public recreation, and includes sports fields, tennis courts, and parklands.

2.1.2. Social Characteristics

Understanding the social characteristics of the area can help in ensuring that the floodplain risk management practices adopted are aligned with the communities at risk. For example, 'stable' communities (characterised by a high proportion of homeownership and low frequency of residents moving into or out-of the area) are more like to have a better understanding of the flood risks within the area.

Social characteristic data were obtained from the 2011 census (http://www.abs.gov.au/) for the study area. The census data shows that a significant number of households speak a language other than English at home (12%), for example Spanish (1.9%) and French (1.5%), which should be considered when organising flood awareness education or when issuing evacuation orders. The data also shows that a large number of people moved to the area within the 5-year period prior to the census at around 35% of the residents, and around 50% of residents are staying in a rented property. This suggests a high frequency of change of residents in the area, which may indicate a need for more frequently occurring flood awareness/community education programmes.

The catchment has a small dwelling size of only 1.8 people, and a high portion of single person dwellings (47.3% compared to the NSW average of 24.2%). This may need to be considered in any evacuation planning as it may indicate a higher than usual number of properties relative to population. There is also a small average number of motor vehicles per dwelling, with 23.3% of households having no motor vehicles (compared to a NSW average of 10.4%), which might need to be considered in any assumptions regarding evacuation routes (i.e. that they should be traversable by foot rather than vehicle as due to the small proportion of vehicle owners in the catchment).

Demographically, the catchment has a lower than average portion of greater than 65 year olds (9.9% compared to 14.7% for NSW), and a lower than average portion of under 14 year olds

(9.3% compared to 19.2% for the state), which suggests demographics shouldn't have a significant influence on the consideration of mitigation measures.

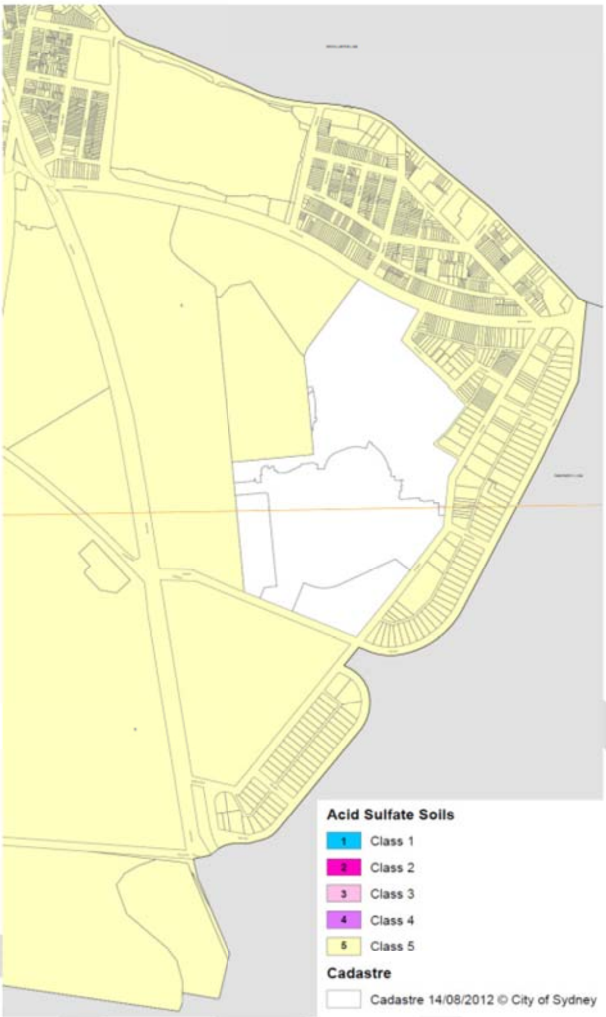
2.1.3. Environmental Features

Centennial Park catchment is developed and urbanised and therefore has limited areas of natural environment, other than some parkland and urban forests. Furthermore, the drainage system has been highly modified and is now completely man-made.

City of Sydney aspires to protect and expand the LGA's urban forest. This includes a list of protected Significant Trees, of which there are a significant number in the area, including the well-known Port Jackson and Moreton Bay Fig trees on Anzac Parade, Driver Avenue, Lang Road and Moore Park Road. These trees are well established and are unlikely to be affected by flood behaviour in the catchment. Mitigation measures assessed by this study will consider the value that is placed upon trees in the catchment when there is a potential impact.

Other environmental features of interest in the catchment are:

- The catchment is classified as a general conservation area with a number of conservation buildings identified. No aboriginal heritage sites have been identified in the catchment
- there are no Record of Notices of contaminated land in the catchment area.
- A large portion of the Centennial Park catchment has an Acid Sulphate Soils classification of 5 (works within 500m adjacent of an area classified 1 -4 and likely to reduced groundwater levels by 1m or more are likely to present an environmental risk). Maps of the Acid Sulphate Soils classification have been taken from the Sydney LEP (Reference 6) and are presented here.



Sheets ASS_024 and ASS_023 from Sydney LEP 2012

2.1.4. Historical Flood Events

The drainage characteristics of the catchment have been significantly altered as a result of urbanisation, particularly in the past 100 years.

Frequent flooding occurs in areas of the catchment including along Lang Road at localised depression storages which collect excess overland flow which is unable to be transported by the underground drainage network.

Historical records indicate flooding within the catchment at many locations for events in excess of the 1 in 20 year ARI. June 1949, November 1961, March 1975, November 1984, January 1991 and February 2001 were some of the major storm events in which the catchment experienced extensive flooding. Community consultation and City of Sydney's database provide information on events as early as November 1984. Multiple occurrences of flooding at Moore Park Road properties are reported for this period, while Driver Avenue, Stewart Street, Lang Road and Robertson Road experienced a combination of property and road inundation.

3. EXISTING FLOOD ENVIRONMENT

The existing flood risk for the Centennial Park catchment is defined by the design flood affection in the Flood Study (Reference 2). The design flood information is then used to determine the Hydraulic categories, Hazard classification and the Flood Emergency Response categories (the latter is detailed in Section 6.4). It also enables the identification of any key flood risk areas or 'hotspots' in the catchment. An overview of the previously undertaken climate change analysis is also given.

3.1. Hydraulic Categories

The 2005 NSW Government's Floodplain Development Manual (Reference 1) defines three hydraulic categories which can be applied to different areas of the floodplain; namely floodway, flood storage or flood fringe. Floodway describes areas of significant discharge during floods, which, if partially blocked, would cause a significant redistribution of flood flow. Flood storage areas are used for temporary storage of floodwaters during a flood, while flood fringe is all other flood prone land.

There is no single definition of these three categories or a prescribed method to allocate the flood prone land into them. Rather, their categorisation is based on knowledge of the study area, hydraulic modelling and previous experiences. Based on analysis of similar catchments, as well as literature review (Reference 9), the Flood Study (Reference 2) defined hydraulic categories as:

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

The hydraulic categories for the 5% AEP, 1% AEP and PMF events, are shown on Figure 6 to Figure 8. In the 5% AEP event there are significant flood storage areas on Driver Avenue, Poate Road and Lang Road and smaller storages on Leinster Street, as well as floodways on Errol Flynn Boulevard (the entrance to Fox Studios off Lang Road) and the southern section of Anzac Parade. In the 1% AEP event flood storage locations are generally similar, while the floodway is more pronounced, starting at Fox Studios, crossing Lang Road and Parklands tennis courts, continuing down Anzac Parade.

3.2. Flood Hazard Classification

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

Provisional hazard was established as part of the Flood Study (Reference 2) based on the Floodplain Development Manual criteria (Appendix L of the Floodplain Development Manual). Due to the combination of high flood depths and velocities, many regions of the catchment are affected by high hazard flows. Figure 9 to Figure 16 show the flow hazard classification throughout the catchment for the 50%, 20% 10%, 5%, 2%, 1% and 0.2% AEP and PMF events. As shown in the figures, hazard is quite consistent between the events, with the largest areas of high hazard at Driver Avenue, Poate Road and Lang Road. Of these, Lang Road and Driver Avenue are not adjacent to residential areas, but are transport thoroughfares (Lang Road more so) and present a flood risk to vehicles. Smaller sections of high hazard are on Stewart Street and Leinster Street, which will present a flood issue to residents in the area. There is some high hazard flow on Anzac Parade but it is generally not across the road, and would not affect more than one lane of traffic in either direction.

To assess the true flood hazard, all adverse effects of flooding have to be considered. This includes the provisional (hydraulic) hazard, threat to life, danger and difficulty in evacuating people and possessions and the potential for damage, social disruption and loss of production including those detailed in

The classification is a qualitative assessment, which results in two categorisations:

High Hazard - *an area or situation where there is possible danger to personal safety, evacuation by trucks is difficult and able-bodied adults would have difficulty in wading to safety. There could also be potential for significant structural damage to buildings.*

Low Hazard - *people and possessions can still be evacuated by trucks if necessary and able-bodied adults would have little difficulty wading to safety.*

Table 1: Hazard Classification

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

[1] Relative weighting in assessing the hazard for the Centennial Park catchment

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

Floodwaters have hazardous depth and velocity in frequent flood events, with overland flow passing down several roads in the catchment. There are associated risks of persons being swept into floodwaters, as well as cars being destabilised in areas with greater depth, such as Lang Road and Leinster Street. However, this component does not warrant more attention than others, as the risk posed by high hazard depths and velocities is already well-described by the provisional hydraulic hazard.

The concept of rate of rise of flood waters is more applicable to mainstream flooding scenarios, where a fast rate of rise can leave residents unaware of the flood event, and they can become stranded. However, the rate of rise in this catchment is very fast (up to 1.5-2 m/hour in the 5% AEP and 2-2.5 m/hour in the 1% AEP) and flood prone areas will become inundated soon after the rainfall event begins. If evacuation is required in the catchment, the fast rate of rise will likely mean it is undertaken after the peak flood level.

Flood awareness in the community appears to be moderate, with 63% of questionnaire respondents aware of flooding in the catchment (Reference 2) (this is likely to exaggerate the awareness, as aware residents are presumably more likely to respond). Given that only 10% of those surveyed responded, the confidence interval on the estimate is around 15% (i.e. the number of aware respondents is likely between 45 and 75%). The estimate is also complicated by the bias in the respondents, with those residents who are aware of flooding more likely to respond. Although it may be assumed that frequently flood-affected properties are aware of flooding, the high number of renters in the area means this awareness could too be exaggerated. Experience in similar urban catchments indicates residents are generally sceptical of the possibility of large floods and therefore may not ascribe the appropriate level of risk to floodwaters when they are encountered.

Effective warning and evacuation time in the catchment is relatively low, as the flooding is likely to be sudden, with a fast rate of rise. For a resident without additional warning or forecast, flood events will initially resemble more benign (but still heavy) storms, with awareness of the flood coming from direct experience of it. However, effective access, which refers to an exit route that remains trafficable for sufficient time to evacuate people and possessions, is likely to be available to the majority of affected residents, as the flood extents are not wide. The areas where access is an issue are those areas identified as having high hydraulic hazard, shown on Figure 14 for the 1% AEP event. The vehicular and pedestrian access routes are all along sealed roads and present to unexpected hazards if the roads have been adequately maintained.

At depths of 0.3 m wading should be possible for most mobile adults, but could be problematic for children, elderly or disabled people. The majority of flood prone properties in the catchment do have access with flood depths of 0.3 m or less. Areas that do have depths of 300 mm or more in the 1% AEP include:

- Stewart Street south of Alexander Street
- Leinster Street east of Oatley Road
- Leinster Road west of Furber Road
- Poate Road west of Furber Road
- Cook Road north of Darvall Street
- Lang Road north of Darvall Street

At depths of 300mm, larger vehicles can easily travel through water at this depth and aid evacuation. Nevertheless, for areas within the catchment without effective flood access, evacuation is generally not recommended considering the short duration of flooding experienced as residents are more likely to put themselves in harm's way by evacuating.

The impact of debris is unlikely to be a significant factor due to the low flood depths and/or velocities for large parts of the catchment. It would impact the time of inundation as waters would take longer to recede, however as the duration of the flooding is generally short across the catchment this is not considered significant. Figure 17 shows the length of inundation taken at each of the drainage pit inlets in the 1% AEP, 1 hour event. This shows that the duration of flooding is typically less than 1 hour except in the known trapped depressions on Grand Drive and Driver Avenue, where it may take up to four hours to drain, assuming the piped network is operating efficiently (i.e. without blockages).

3.3. Hotspots

Hotspots in the area are defined as those locations where there is a known flood issue. They are identified by considering accounts of previous floods, and by examining the flood behaviour as defined by the Flood Study (Reference 2). The latter involves identifying areas of high hazard flow where flooding of property occurs, and through consideration of subsurface drainage capacity.

The Flood Study (Reference 2) informally identified several such hotspots, which the current study then re-examined. Floor level survey undertaken as part of the current study gave further information on flood affectation of property in the catchment. Similarly, a community questionnaire and newsletter gave new information on residents' experience of flooding (see Section 4.1.2). Description of each hotspot in the following sections refers to depths of hydraulic hazard, which is shown on Figure 9 to Figure 16, duration of flooding (Figure 17) and overfloor inundation (Figure 19).

3.3.1. Poate Road

The section of Poate Road parallel to Poate Lane has a topographic depression that acts as a storage in a flood event. The depression is caused by the street sloping towards the south-west, and the masonry wall that blocks the natural gradient of the area. The pit and pipe network in the area drains the depression but its capacity is exceeded in frequent flood events. The road has a depth of 2.08 m in a 10% AEP event, while in the 1% AEP event has depths of up to 2.38 m. Figure 22 shows the hotspot in detail, including the areas where runoff accumulates and the area's drainage.

The large depths of inundation that occur in the hotspot result in significant areas of high hydraulic hazard across the range of design events. In a 50% AEP event, the eastern end at the elbow of the road has high hazard ponding, while in the 1% AEP event the high hazard area extends up to 120 m west along Poate Road. The area has a long duration of flooding relative to the rest of the catchment (though a shorter duration than other hotspots), but can still be expected to drain within 2 hours in a 1% AEP, 1 hour duration event, given the trunk drainage is functioning.

The hotspot has moderate property inundation and is not a pedestrian or vehicle thoroughfare. Three properties are flooded above floor in the 10% AEP event, and an additional property is first inundated in a 1% AEP event. Other properties on the street are relatively high above street level and flooding is limited to front yards. There is a risk of damage to cars parked on the street as depths are significant.

3.3.2. Stewart Street and Leinster Street

The topographic depressions on Stewart Street and Leinster Street detain a significant volume of runoff in a flood event and act as flood storages. As with Poate Road, the pit and pipe network drain the depressions, however, it has limited capacity and is exceeded in events larger than a 50% AEP event. At their lowest points, Stewart Street and Leinster Street have a depth of 0.84 m and 1.28m respectively in a 10% AEP event, while in the 1% AEP event they have depths of up to 1.18 m and 1.54 m respectively. Figure 25 shows the hotspot in detail, including the areas where runoff accumulates and the area's drainage.

The large depths of inundation that occur in the hotspot result in significant areas of high hydraulic hazard across the range of design events. In a 50% AEP event, Leinster Street has high hazard ponding, while in the 1% AEP event the high hazard area covers an 80 m section of Leinster Street and 40 m of Stewart Street. As with Poate Road, the area has a long duration of flooding relative to the rest of the catchment and storm duration. Stewart Street can still be expected to drain within an hour with Leinster Street taking more than 2 hours in a 1% AEP, 1 hour duration event, given the trunk drainage is functioning.

The hotspot has major property inundation but does not contain any pedestrian or vehicle thoroughfares. Stewart Street has 7 properties inundated in the 50% AEP event increasing to 17 properties in the 1% AEP event. As properties only back onto Leinster Street significant inundation of property is limited to flooded garages and yards. There is a risk of damage to cars within these garages.

3.3.3. Driver Avenue

The grading of Driver Avenue creates an unrelieved depression that acts as a flood storage area in flood events. The conveyance downstream is entirely through the pipe network system as the road slopes upwards from the depression. This drainage network is at capacity upstream of the hotspot, even in more frequent events such as the 50% AEP. The road has a depth of around 1.04 m in the 10% AEP event; while the 1% AEP event has depths of up to 1.4 m. Figure 30 shows the hotspot in detail, including the areas where runoff accumulates and the area's drainage.

The large depths of inundation that occur in the hotspot result in significant areas of high hydraulic hazard across the range of design events. In a 50% AEP event, the gutters in the area have high hazard ponding, while in the 1% AEP event the high hazard area covers a 180 m section of Driver Avenue and the park to the west. The area has a long duration of flooding relative to the rest of the catchment and hotspots, but can still be expected to drain within 3 hours in a 1% AEP, 1 hour duration event, given the trunk drainage is functioning.

The hotspot has no property inundation but does cut off a vehicle or pedestrian thoroughfare (Driver Avenue). Traffic in the area is highly variable, with high volumes during an event at Hordern Pavilion, the Entertainment Quarter, the cricket ground or the football stadium. There is a risk of damage to cars parked along the street, though there is limited parking.

3.3.4. Lang Road near Driver Avenue

There is a topographic depression at the intersection of Lang Road and Driver Avenue which detains runoff in frequent flood events. Runoff into the depression is from Lang Road itself, and from Driver Avenue and the parkland to the north. Piped drainage is relied on to transmit flow from the area, as the topography slopes up from the area (up Driver Avenue and along Lang Road), creating an unrelieved depression. The road has a depth of 0.84 m in the 10% AEP event in the centre; while the 1% AEP event has depths of up to 0.93 m. Figure 33 shows the hotspot in detail, including the areas where runoff accumulates and the area's drainage.

The large depths of inundation that occur in the hotspot result in significant areas of high hydraulic hazard across the range of design events. In a 50% AEP event, the gutters in the area and the parkland to the south have high hazard ponding, while in the 1% AEP event the high hazard area covers a 75 m section of Lang Road and the parkland to the south. The area has a long duration of flooding relative to the rest of the catchment and hotspots, but can still be expected to drain within 3 hours in a 1% AEP, 1 hour duration event, given the trunk drainage is functioning.

The hotspot has no property inundation but does inundate a vehicle and pedestrian thoroughfare, posing a significant risk in most flood events. The frequency of inundation of the area (there is typically ponding multiple times in a year) means that larger events may resemble the less hazardous frequent events, and people will attempt to cross the inundated section.

3.3.5. Lang Road near Darvall Street

A minor depression exists on Lang Road near Darvall Street where water ponds before discharging into Centennial Park. The local pit and pipe network drains the depression to the east into Centennial Park. The road has a depth of around 0.46 m in the 10% AEP event at the centre of the road; while the 1% AEP event has depths of up to 0.57 m. Figure 28 shows the hotspot in detail, including the areas where runoff accumulates and the area's drainage.

The depth of inundation that occur in the hotspot does not result in areas of high hydraulic hazard across the range of design events except in the PMF event. The area has a short duration of flooding relative to the rest of the catchment and hotspots, and can still be expected to drain in less than an hour in a 1% AEP, 1 hour duration event, given the local drainage is functioning.

The hotspot has no overfloor property inundation but does affect a vehicle and pedestrian thoroughfare. The area poses risk to both vehicles and pedestrians in frequent events such as the 50% AEP event and a significant risk in larger events.

Mitigation measures for the hotspots are discussed in Section 9.3.

3.4. Impact of Climate Change

The impact of climate change on flood behaviour has been assessed as part of the Flood Study (Reference 2) through a sensitivity analysis of rainfall increase due to climate change. The assessment followed NSW State Government guidelines, which require testing of rainfall increases of 10, 20 and 30%. Table 2 gives the results of the analysis.

Table 2: Results of Climate Change Analysis - 1% AEP Event Depths (m)

ID	Location	100 Year ARI Peak Flood Depth (m)	Rainfall Increase 10%	Rainfall Increase 20%	Rainfall Increase 30%
			Difference with 100 Year ARI Base Case (m)		
1	Stewart Street	0.9	0.05	0.09	0.12
2	Leinster Street	1.4	0.04	0.08	0.12
3	Poate Road	1.7	0.06	0.11	0.16
4	Driver Avenue	1.5	0.07	0.14	0.20
5	John Hargraves Ave	0.6	0.10	0.17	0.24
6	Erol Flynn Boulevard	0.4	0.03	0.05	0.06
7	Lang Road / Driver Ave	0.9	0.03	0.06	0.09
8	Parklands adjacent Lang Road / Driver Ave	0.9	0.03	0.06	0.09
9	Lang Road adjacent 62	0.6	0.02	0.03	0.05
10	Anzac Parade	0.5	0.02	0.05	0.07

The table shows that 1% AEP peak flood depths across the catchment will increase by around 0.05 m in a 10% rainfall increase, while a 30% rainfall increase will correspond to depth increases of around 0.1 m. The most sensitive areas are on John Hargraves Avenue, Driver Avenue and Poate Road.

4. STAKEHOLDER CONSULTATION

4.1. Community Consultation

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

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

4.1.1. Previous Consultation

As part of the Flood Studies (Reference 2), community questionnaire surveys were undertaken during October-November 2012 to gather historical data for model calibration. 560 surveys were distributed to residents within the Centennial Park catchment. 47 responses were received, which equates to a return rate of 8%. The most frequently recalled flood was the June 2007 storm, although other events were also mentioned by a significant number of respondents. Approximately 75% of respondents are aware of flooding or have some knowledge of flooding in the study area. Of the property areas flooded, one respondents reported flooding above floor, while others reported flooding of yard or garage.

4.1.2. Consultation as Part of This Study

Further community questionnaire survey work was undertaken during June-July 2014 to inform residents of the next stage of the floodplain management process as well as to gather flood information and community's preferred options of managing flood risks within the catchment. 557 copies of the newsletters and questionnaires were printed and delivered to the owners of properties likely to be aware of flooding issues. In total 57 responses were received constituting a 10% return rate and the results are as shown in Figure 18. The newsletter and questionnaire is shown in Appendix B.

37% of the respondents experienced some form of flooding within the catchment and three respondents reported floodwaters entering their houses or businesses. Of the three respondents, two reported flooding in the Stewart/Leinster Street hotspot, while the third was an SCG building on Driver Avenue. The responses confirmed the existence of hotspots at Stewart/Leinster Street, Driver Avenue, Poate Road and Lang Road, all of which contain topographic depressions that trap runoff.

Several residents identified blocked pits and pipes as a flooding-related issue in the catchment, with various respondents commenting that litter and leaves were frequently blocking the drainage. One respondent recommended trees be removed that are blocking drainage.

Among the preferred management options for managing flood risks within the catchment: pit and pipe upgrades, improved flow paths and retarding basins were the most popular, while levee banks, community education and flood forecasting were the least preferred.

The Sydney Cricket Ground and Sports Ground Trust were also contacted as part of the study. As operators of the SCG and SFS, experience of prior floods was provided, as well as information of their emergency response arrangement (described in Section 6.2.3.1)

4.1.3. Community Information Session

Two community information sessions were held. These were:

- July 25th at the Paddington Markets – WMAwater and City of Sydney staff manned a booth and discussed flooding issues in the catchment with interested members of the public. Several community members engaged with the material and made flooding specific observations; and
- August 1st at Kings Cross Organic Flood Markets – WMAwater and City of Sydney staff manned a booth and again discussed flooding issues with interested members of the public.

4.2. Floodplain Committee Meetings

The Floodplain Management Committee (FMC) oversees and assists with the floodplain risk management process being carried out within the Council LGA. The committee is comprised of representatives from various stakeholders, including local Councillors, emergency services, Sydney Water Corporation and community representatives. Progress on the current study has been regularly presented to the committee at FMC meetings (every 3 months), at which point questions or feedback from the various representatives was taken.

4.3. Internal Stakeholders Workshop

Workshops with internal stakeholders were held to gather feedback on the management measures being assessed for the study. The workshops, which were held in December 2014, consisted of presentation of the various measures, including their cost and impact on flooding and property affectation. Attendees included representatives from City of Sydney, OEH, SES and Sydney Water, and each provided input on the feasibility and suitability of the measures, as well as possible variations to the measures presented.

4.4. Public Exhibition

4.4.1. Summary of Submissions

The draft report has been exhibited. Two submissions have been received. The issues raised are as follows:

- No mention is made of the Sydney CBD and South East Light Rail (CSELR) Project and this needs to be rectified;

- A figure requires amendment;
- Request to note environmental constraints associated with mitigation work FM-CP05; and
- Inadequate drainage noted at a private property.

4.4.2. Discussion

The exhibition of the draft document occurred at the same time as the exhibition of draft documents for the Rushcutters Bay and Woolloomooloo Catchments. Of these only the latter received a significant number of detailed submissions from those impacted by flooding. This likely relates to the fact that at least two significant events have occurred in the Woolloomooloo Catchment during 2015 alone. Nevertheless the submissions in regard to the Centennial Park study herein have been noted and appropriate amendments to the report made.

5. ECONOMIC IMPACT OF FLOODING

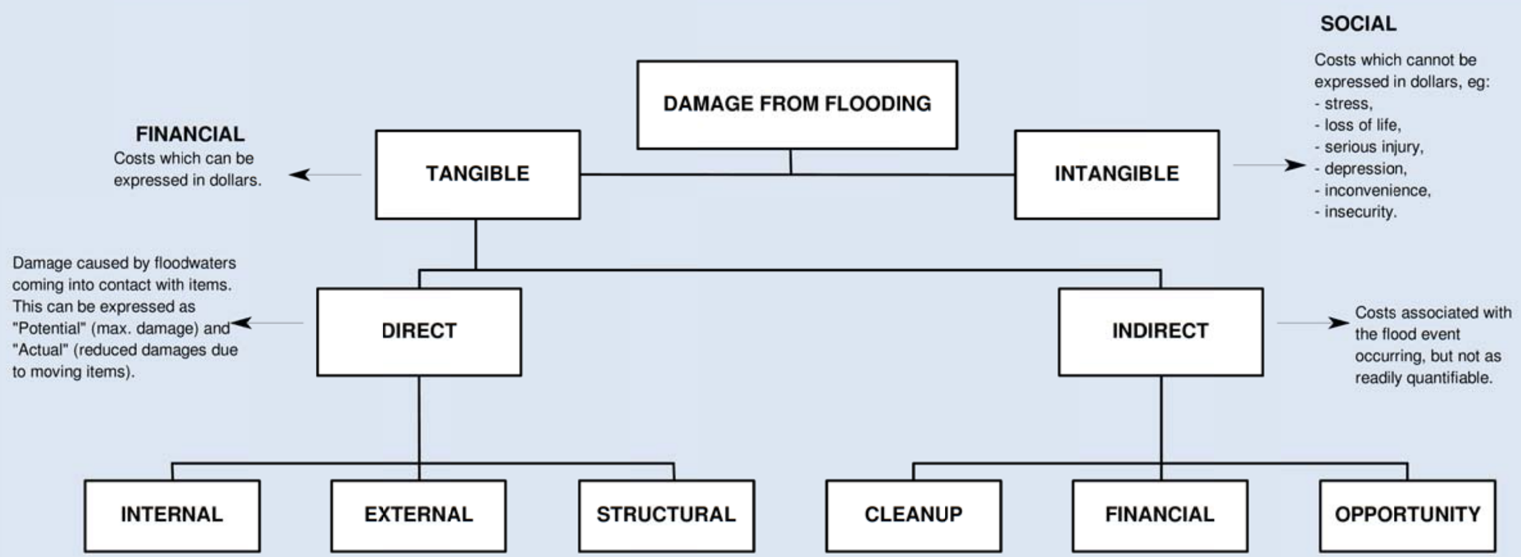
The impact of flooding can be quantified through the calculation of flood damages. Flood damage calculations do not include all impacts associated with flooding. They do, however, provide a basis for assessing the economic loss of flooding and also a non-subjective means of assessing the merit of flood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

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

The estimation of flood damages tends to focus on the physical impact of damages on the human environment but there is also a need to consider the ecological cost and benefits associated with flooding. Flood damages can be defined as being tangible or intangible. Tangible damages are those for which a monetary value can be easily assigned, while intangible damages are those to which a monetary value cannot easily be attributed. Types of flood damages are shown in Table 3.

The assessment of flood damages not only looks at potential costs due to flooding but also identifies when properties are likely to become flood affected by either flooding on the property or by over floor flooding as shown on Figure 19.

Table 3: Flood Damages Categories (including damage and losses from permanent inundation)



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

5.1. Tangible Flood Damages

Tangible flood damages are comprised of two basic categories; direct and indirect damages (refer Table 3). 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 slightly 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 10) 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.

Centennial Park has a small catchment size (150 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 4. 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 4: Estimated Combined Flood Damages for Centennial Park 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	90	57	$ 3,540,500	$ 39,300
0.2%	86	37	$ 2,427,900	$ 28,200
1%	84	28	$ 1,850,100	$ 22,000
2%	80	25	$ 1,668,600	$ 20,900
5%	77	23	$ 1,511,100	$ 19,600
10%	71	19	$ 1,287,300	$ 18,100
20%	64	13	$ 914,700	$ 14,300
50%	55	9	$ 612,900	$ 11,100
Average Annual Damages (AAD)			**$ 650,800**	**$ 7,800**