ATTACHMENT C

WOOLLOOMOOLOO CATCHMENT
FLOODPLAIN RISK MANAGEMENT STUDY
(DRAFT REPORT)

WOOLLOOMOOLOO CATCHMENT FLOODPLAIN RISK MANAGEMENT STUDY

DRAFT REPORT

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DRAFT REPORT

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Project Woolloomooloo Catchment Floodplain Risk Management Study	**Project Number** 114014
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WOOLLOOMOOLOO 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 Woolloomooloo 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 Woolloomooloo catchment which are flood liable and within the City of Sydney Local Government Area.

1. INTRODUCTION

1.1. Study Area

The Woolloomooloo catchment is located in Sydney's inner city suburbs of Potts Point, Darlinghurst, Sydney, Surry Hills and Woolloomooloo, 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 160 hectares and drains to several points in Woolloomooloo Bay, with a pit and pipe network draining the area, complemented by overland flowpaths, mostly along roads, when the pipe drainage is at capacity. A number of locations in the area are flood liable, mainly as a result of the area's topography which includes several unrelieved depressions and buildings located on overland flowpaths. 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 two key stages of the process have been undertaken with the completion of the Draft Woolloomooloo Flood Study (Reference 2). Following this, the Floodplain Risk Management Study and Plan (FRMS&P) are undertaken for the catchment in two phases:

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

- Review the Woolloomooloo Flood Study (2013) and update hydraulic model;
- Identify additional floor level survey requirements;
- 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).

Council has provided specific objectives for the investigation of flood mitigation options for flood affected streets and areas as identified in the current 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 the flood hazard and risk at this time and as a result of climate change. 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 Woolloomooloo catchment. An assessment of the stormwater capacity was carried out in 1996 and is summarised here, as well as the recent flood study.

1.3.1. City Area SWC 30 Capacity Assessment July 1996

This report (Reference 3) was prepared by SWC and investigated the performance of City Area SWC 30, which includes the Woolloomooloo Bay Subgroup, and gives an estimate of the impact of potential urban consolidation on that performance.

The study included detailed land investigations of both the hydraulic capacity of SWC's trunk drainage system as well as future land use potential.

The drainage data used for the study included the SWC trunk drainage system only and the analysis was undertaken using a spreadsheet based on:

- Urban rational method for inflows (ARR, 1987);
- Approximate capacities of pipes based on grade and area;
- Approximation of channel capacities using Manning's "n" formula and methods for composite roughness and compound sections; and the
- Hydraulic Grade Line Method

The hydraulic capacity of the Woolloomooloo Bay catchment is summarised in Table 1. Little hydraulic and hydrologic detail was available for the Domain as relevant analysis was not included in the report. The study is useful for determination of system capacity and locations for trunk drainage upgrades; however, as it does not define the overland flood hazard in the catchment, the impact of any trunk drainage improvement is unable to be assessed.

Table 1: Drainage Capacity, SWC Capacity Assessment

Sub system	System (km)	Percent Rated	Percent Satisfying, ARI of				
			2 yr	5 yr	10 yr	20 yr	100 yr
Domain	0.03	0%					
Sir John Young Crescent	0.94	60%	100%	18%	0%	0%	0%
Hospital Road	0.84	100%	100%	100%	100%	100%	36%
Woolloomooloo East	3.99	63%	73%	66%	51%	50%	14%
Woolloomooloo West	8.22	49%	57%	43%	39%	31%	15%
McElhone Street	0.26	69%	46%	62%	62%	62%	9%
Victoria Street	1.95	55%	40%	40%	40%	21%	1%
WOOLLOOMOOLOO BAY	16.23	57%	66%	53%	46%	40%	14%

Catchment performance results indicate that Sir John Young Crescent and Victoria Street catchments were the most under serviced (re: drainage capacity) and potentially the most at risk of flooding with 0% and 21% of the piped system with a 20 year ARI capacity respectively.

1.3.2. Draft Woolloomooloo Flood Study, WMAwater, July 2013

This flood study was carried out as part of the Floodplain Risk Management Programme to define existing flood behaviour for the Woolloomooloo catchment in terms of flood levels, depths, velocities, flows and extents. The mechanisms of flooding examined in this study include local overland flow as well as backwater flooding from receiving waters. A 1D/2D TUFLOW hydraulic model was used in conjunction with a DRAINS hydrologic model. The model was calibrated to one event (February 2010) and verified against historical flooding at eight locations across the catchment. The study defined flood behaviour for the 2, 5, 10, 20, 50 and 100 year ARI flood events as well as the PMF. Preliminary hazard and hydraulic categories were determined for the 10, 20 and 100 year ARI flood events and the PMF. Several flooding hotspots were also identified in the study. A floor level survey and damages assessment were carried out, of which the latter identified 160 properties (106 residential, 54 commercial) that would be flooded above floor level in a 100 year ARI event.

The study found that the widespread flood liability in the study area is a result of extensive development (filling of the floodplain and blocking of flow paths) in conjunction with pervious surfaces converted to impervious surfaces. Localised depressions in roads were found to collect excess overland flow and to not be able to effectively be drained by either subsurface drainage or above ground flow paths.

The study identified a number of hotspots and made a preliminary assessment of their flood affectation, including a breakdown of overland and pipe flow in each hotspot across a range of events. The hotspots are shown on Figure 2 and were as follows:

1. Stream Street in Darlinghurst
2. Busby Lane in Woolloomooloo
3. Crown Street near Bossley Terrace in Woolloomooloo
4. Palmer Street at its north end in Woolloomooloo
5. Bourke Street at its south end in Woolloomooloo
6. Victoria Street near Orwell Street in Potts Point

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.

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. Woolloomooloo Flood Study Review and Update

The draft Woolloomooloo 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, the recently developed apartment complex at 62 Sir John Young Crescent was added to the model. This development replaces a previously vacant lot, and has a minor effect on design flood levels on Sir John Young Crescent in the vicinity of the building.

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 minor localised impacts of between ±0.05 m in the 1% AEP event at various locations in the catchments.

Thirdly, the topographical representation of Victoria Street in the hydraulic model was updated based on recently acquired survey data. This survey data included cross-sections of the street, including the footpaths, the kerb/gutter height and the road elevation. The survey points were tinned and replaced the ALS data previously used in the area, which had been flagged in the flood study as having quality issues, due to the trees and buildings distorting the ground representation. It was found that previously undertaken quality control measures on the ALS data had produced a generally accurate representation and that the survey data only made minor refinements to this.

Finally, a small change to building outlines was made. This was on Earl Street where community questionnaire responses indicated flow passed through properties, where previously the houses were schematised as completely obstructing the flow. The impacts of flood levels around the change were minimal.

2. CATCHMENT CHARACTERISTICS

2.1. Study Area

The Woolloomooloo catchment is located in the City of Sydney LGA and includes the suburbs of Potts Point, Darlinghurst, Sydney, Surry Hills and Woolloomooloo. The catchment is fully developed and consists of medium to high-density housing and commercial development with some large open spaces that include Hyde Park, Sandringham Gardens, Fragrance Garden, The Domain Park, the Royal Botanic Gardens, Daffodil Park and a number of other smaller parks.

The catchment covers an area of approximately 160 hectares, all of it draining to SWC's major trunk drainage systems (known as SWC 30) taking flows from the upper regions of the catchment to Sydney Harbour at Woolloomooloo Bay. Drainage of the catchment occurs via pits, pipes and overland flowpaths (predominantly roads). Ownership of the pipe system is mixed with larger pipes in the catchment (also known as the trunk drainage system) owned by SWC. 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 any 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 which begins at Oxford Street at elevations of around 55 mAHD. At several locations in the catchment there are sharp drops including adjacent to Victoria Street where the elevation can drop by up to 20 metres towards Brougham Street. Generally the upper catchment areas have grades of approximately 2% to 4%. Grades reduce to approximately 1% north of William Street and closer to Woolloomooloo Bay, north of Harmer and Best Streets, the ground surface slope is closer to 0.5%.

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 many buildings have been constructed on overland flow paths or in unrelieved sags. Due to these drainage restrictions, topographic depressions can cause localised flooding as excess flows have no opportunity to escape via overland flow paths. This creates a significant drainage/flooding problem in many areas throughout the catchment.

Any future development in the area is likely to be in the form of urban consolidation, with aggregation of individual lots creating high density residential developments. An example of this is the recently completed apartment complex at 68 Sir John Young Crescent.

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 predominately urban residential and mixed residential/commercial, with some parkland on the western boundary of the catchment. Residential land in the area is predominately two-storey terrace houses, interspersed with apartment buildings. A number of parks used as recreational space are scattered throughout the area, with many less than 1 hectare in size. Commercial land use in concentrated along William Street, which has a number of high rise buildings, and Victoria Street and Darlinghurst Road in Kings Cross. Cook and Phillip Park, The Domain and the Botanic Gardens lie on the western boundary of the catchment, which are predominantly open, grassed area, as well as some sporting fields and other facilities.

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 (17-19%), for example French (1.9%) and Vietnamese (1.8%), 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 37-38% of the residents, and around 70% 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 1.7 people, and a high portion of single person dwellings (49.3% compared to the NSW average of 24.2%). This may need to be considered in any evacuation planning as it could indicate a higher than usual number of properties relative to population. There is also a small average number of motor vehicles per dwelling, with 46% of households having no motor vehicles (compared to a NSW average of 10.4%), which might also 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 (10.2% compared to 14.7% for NSW), and a lower than average portion of under 14 year olds (6.4% compared to 19.2% for the state), which suggests demographics shouldn't have a significant influence on the consideration of mitigation measures.

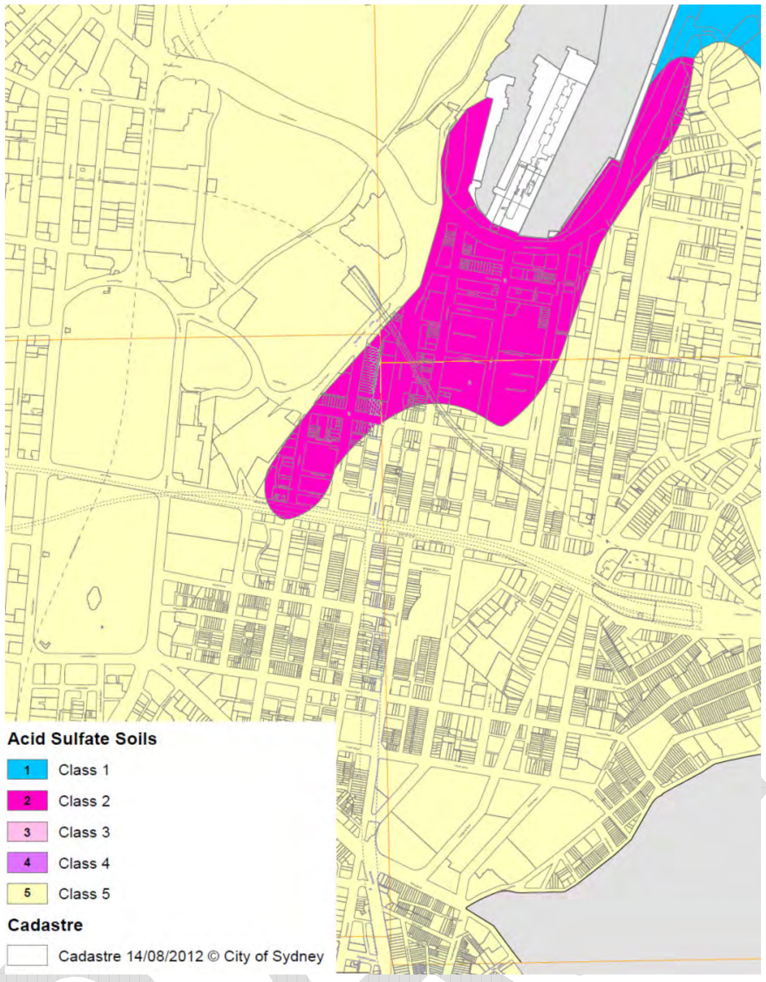
The suburb of Woolloomooloo has one of NSW's highest concentrations of homeless people, some of whom use public space that can be flood affected. Although homelessness is hard to quantify and measure, and can therefore not be afforded the same form of analysis that is given to other residents, any mitigation measures assessed by this study shall include consideration the use of public space as temporary or semi-permanent accommodation for homeless people.

2.1.3. Environmental Features

The natural environment in the Woolloomooloo catchment is limited to the trees in the area, as well as the limited park land. When considering environmental issues associated with flooding, focus is typically given to ecosystems located around a catchment's watercourses. In this catchment, there is no such watercourse, or associated ecosystems, as the drainage system is completely man-made. With respect to trees in the catchment, City of Sydney aspires to protect and expand the LGA's urban forest. This includes a list of protected Significant Trees, of which the London Plane trees on Victoria Street are listed. 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
- The majority of the Woolloomooloo 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), while there is also a significant area adjacent to the bay which is classed as 2 (any works undertaken in this area below the natural ground surface are likely to present an environmental risk). Maps of the Acid Sulphate Soils classification have been taken from the Sydney LEP (Reference 5) and are presented here.



Sheets ASS_015 and ASS_015 from Sydney LEP 2012

2.1.4. Historical Flood Events

In examining the flooding history it must be noted that the drainage characteristics of the catchment have been significantly altered as a result of urbanisation over the past 100 years. This includes construction of rail, road and drainage infrastructure that are likely to have had significant impacts on drainage behaviour. In recent times, construction of the Eastern Suburbs railway line to Bondi Junction and the Eastern Distributor road network have been major factors.

Frequent flooding including over floor inundation of some businesses and residences occurs in areas of the catchment including along Victoria Street, Stream Street, Crown Street and Dowling Street to the south of the railway viaduct. Flooding in many cases appears to be due to sags (localised depressions in roads) which trap overland flow and are unable to be effectively drained by overland flow paths. In other locations development has impeded natural overland flow paths and this has caused issues. One such example is Victoria Street. Flow, particularly from Orwell Street, used to fall off the cliff (due west) towards Brougham Street but is now diverted down Victoria Street, causing inundation of private properties and representing a significant hazard to pedestrians.

There have been many instances of flooding in the past with 8-9 November 1984, 5 August

1986, 10 April 1998 and 12 February 2010 being some of the most significant storm events recorded as causing extensive flooding throughout the catchment. During the 1980s it was reported that floodwaters were deep enough that cars were floating down Crown Street. However, at some locations, in Victoria Street for example, overfloor flooding of private property seems to occur on an annual to bi-annual basis.

2.1.5. Early Catchment Conditions

The drainage features of the catchment reflect the location of the natural watercourse and shoreline that existed prior to urbanisation of the area. That is, the catchment's main trunk drainage line is located along a natural topographic depression, which contained a creek in the 19th century. In the 19th and 20th centuries, the area was developed with increasing density, and this creek was filled in and replaced with subsurface drainage. Similarly, the flat topography of the area south of Cowper Wharf Road is a result of reclamation works that enlarged Woolloomooloo.

Figure 5 shows the area's creeks as they were recorded on the 'Riley Estate' map (dated 1844), overlaid on the current 5% AEP peak flood depth. The figure shows that the main concentrations of flow are where creeks used to exist in the catchment, and where land has been reclaimed.

3. EXISTING FLOOD ENVIRONMENT

The existing flood risk for the Woolloomooloo 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 delineate 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 8), 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 7 to Figure 9. In the 5% AEP event there is a significant flood storage area on Stream Street and Riley Street, Crown Street, Busby Lane and Palmer Street.

Areas of floodway in the catchment are not well delineated in frequent events, as the urbanised nature of the catchment means flow does not naturally accumulate into well-defined flowpaths. In the 5% AEP event, there is a floodway down Riley Street, which turns at Cathedral Street and then onto Palmer Street via Crown Street and Bossley Terrace. In the 1% AEP event, there are prominent floodways along many streets in the catchment, as nearly all runoff is flowing overland and not in the stormwater network.

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 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 10 to Figure 17 show the flow hazard classification throughout the catchment for the 50%, 20% 10%, 5%, 2%, 1% AEP and PMF events. As shown in the figures, in frequent events high hazard is limited to those areas identified as hotspots, for example Stream Street and Crown Street. These areas have hazardous depths of inundation, with more than a metre in Stream Street, which is relatively unused as a thoroughfare and has minimal residential frontage, whereas Crown Street has vehicle and pedestrian traffic and a number of residential properties.

Areas of high hazard are most prominent along the western trunk drainage line, approximately between Stream Street and the north end of Palmer Street. This section of high hazard, which is well defined in the 1% AEP event, is comprised of both hazardous depths (greater than 1 m) in unrelieved depressions and steeper roads with hazardous velocities (greater than 2 m/s), or a combination in large floods. In relatively frequent flood events, the areas of high hazard depth are Stream Street, which has close to 3 m of depth in a 50% AEP event, Busby Lane (1 m in the 50% AEP).

In a 1% AEP event, areas of high hazard are still quite limited, with the aforementioned Busby Lane and Stream Street areas, as well as:

1. Riley Street, which has over 1 m depth upstream of William Street, and shallower depths (less than 0.3 m) but high velocities (around 2 to 3 m/s) downstream of William Street, where there is a steep gradient.
2. Crown Street, which has around 1 m of depth.
3. Cathedral Street, which has around 0.5 m of depth and velocities of up to 2.5 m/s.
4. Palmer Street, which has depths of 0.5 to 1.5 m and velocities of up to 2 m/s.

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 Table 2. 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 2: 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 Woolloomooloo catchment

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 fast (up to 1-1.5 m/hour in the 5% AEP and 2 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 60% 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 5% 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 15 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. This obviously could be more of an issue for children, elderly or disabled people. The majority of flood prone properties in the catchment do have access with flood depths of 300mm or less. Areas that do have depths of 300 mm or more in the 1% AEP include:

- Stream Street, Yurong Street and Riley Street just south of William Street
- Crown Street and Bossley Terrace between Cathedral Street and Sir John Young Crescent
- Cathedral Street west of Crown Street
- Palmer Street north of Cathedral Street
- Harmer Street off Bourke Street
- Bourke Street north of Harmer Street
- Parts of Wilson Street, Dowling Street and Bland Street near Cowper Wharf Road
- Parts of Victoria Street, near Orwell Street

At a depth of 300 mm, larger vehicles can easily travel through water 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 18 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 (such as on Stream Street, Busby Lane, Crown Street, Bourke Street etc.) where it may take a few 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. The latter involves identifying areas that exhibit high hazard flows, areas where flooding of properties occurs, and consideration of subsurface drainage capacity.

The flood study (Reference 2) 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 10 to Figure 17, duration of flooding (Figure 18) and overfloor inundation (Figure 20).

3.3.1. Stream Street

The street, which follows the s-shaped alignment of a stream previously at the location, has a flood storage area at its north end, immediately upstream of William Street. Water pools when the pipe drainage to William Street is exceeded, which occurs in the 1 in 2 year ARI event. Floodwaters then accumulate in the area, which is around 2 m lower than William Street, to a depth of 3 m in the 10% AEP event. Overland flow is trapped by both the low ground elevation and the buildings at the north end of the street. Figure 23 shows the hotspot in detail, including the areas where runoff accumulates and the area's drainage.

Riley Street and Yurong Street, to the east and west of Stream Street respectively, are also part of the depression and are inundated in relatively frequent events. In a 10 year ARI, the affected section of Riley Street has over 1 m of inundation, while Yurong Street has up to 0.6 m. While the height of William Street prevents runoff from leaving the area, William Street itself has a dip in the east-west direction where runoff accumulates. There is between 0.2 m and 0.5 m of depth in the 10% AEP event and up to 0.8 m in the 1% AEP event.

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 northern half of Stream Street and parts of Riley Street have high hazard ponding, while in the 1% AEP event the high hazard area extends to Yurong Street, more of Riley Street and parts of William Street. For a 1-hour duration storm event (the critical duration for the catchment), the duration of flooding in the depression is around 2-3 hours (depending on the drain performance), which means the ponding is brief overall, but lengthy relative to the rest of the catchment.

Flood affectation of properties in the hotspot is significant, with several properties on Riley Street inundated in relatively frequent flood events. There are around ten properties in the hotspot that have overfloor inundation in a 2% AEP event, including three on Riley Street that are inundated in a 50% AEP event. With regard to vehicular and pedestrian traffic, Stream Street is not used as a thoroughfare, and Riley Street has a cul-de-sac before William Street, however, it is used by pedestrians. In contrast, William Street is a major arterial road to the CBD and its inundation is hazardous to traffic, which will likely try to cross the floodwaters.

3.3.2. Busby Lane

Similar to Stream Street, Busby Lane is a flood storage area, with flow off Riley Street accumulating in the area. Piped drainage is relied on to transmit flow from the lane, as the topography slopes up from the area (towards both Riley Street and William Street), creating an unrelieved depression. The lane has a depth of around 1.1 m in the 10% AEP event at its northern end; while the 1% AEP event has depths of up to 1.5 m. Figure 23 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 northern end of the lane has high hazard ponding, while in the 1% AEP event the high hazard area covers the northern half of the lane. As with Stream Street, the area has a long duration of flooding relative to the rest of the catchment, but can still be expected to drain within a few hours in a 1% AEP, 1 hour duration event, given the trunk drainage is functioning.

The hotspot has only minor property inundation and does not cut off any vehicle or pedestrian thoroughfares. As properties only back onto Busby Lane, significant inundation of property is limited to flooded parking garages, of which there are two at the northern end of the street. There is a risk of damage to cars within these garages, as they may be lower than the street level and so detain a significant volume of water.

3.3.3. Crown Street

The section of Crown Street between Cathedral Street and Sir John Young Crescent is inundated in frequent flood events. Similar to other hotspots nearby, there is a small depression along the section of the street, where the street slopes down and then up, with a maximum dip of around 0.75 m. Water pools in the depression, as well as at the west end of Bossley Terrace, when subsurface drainage is exceeded. There is up to 0.7 m depth in the 10% AEP event and up to 1.1 m in the 1% AEP event. Figure 23 shows the hotspot in detail, including the areas where runoff accumulates and the area's drainage.

Although there is widespread inundation of Crown Street and Bossley Terrace in relatively frequent events, high hydraulic hazard is not present for floods below the 5% AEP event. This is a result of the topographic depression causing water to accumulate rather than flow down the street, and so the high hazard is caused by the flow's depth (and not velocity). In the 1% AEP event, the majority of Crown Street between Cathedral Street and Sir John Young Crescent has high hazard inundation, as well as the part of Bossley Terrace perpendicular to Crown Street. As with Stream Street and Busby Lane, Crown Street acts as a flood storage in large events and so has a duration of flooding that is lengthy relative to the rest of the catchment, but is still quite brief, with a 1-hour design storm leading to inundation lasting several hours at most (depending on the performance of the drainage system).

The hotspot has significant property inundation, with many properties in area flooded above floor in a 5% AEP event. The affectation is concentrated on the east side of Crown Street, where fifteen properties are flooded overfloor in a 1% AEP event. The new residential development on the west side of the street is more elevated, and is not flooded in a 1% AEP event. There is also significant inundation of property on Cathedral Street adjacent to Crown Street, with around ten properties flooded over floor in a 5% AEP event. Crown Street has moderate vehicle and pedestrian traffic and there is a risk of people entering the floodwaters and becoming stranded or otherwise harming themselves.

3.3.4. Palmer Street

Water pools at the north end of Palmer Street where it passes under the elevated train line. There is a small depression in the road at this location, and water is also trapped by the Jersey Barriers dividing the street from the Eastern Distributor. Pit upgrades have recently been undertaken in the area. Flows can also spill onto the Eastern Distributor immediately to the east. The depth of inundation is 0.6 m in the 10% AEP event, and 1.3 m in the 1% AEP event. Figure 23 shows the hotspot in detail, including the areas where runoff accumulates and the area's drainage.

Similarly to Crown Street, there is not high hazard depth or velocity in frequent events, with only floods larger than the 10% AEP event showing significant amounts of high hazard flow. In a 1% AEP event the section of Palmer Street between its northern end and Bossley Terrace has high hydraulic hazard, which is a combination of high velocity closer to Bossley Terrace and hazardous depths towards the northern end. In a 1% AEP 1 hour storm event, Palmer Street near Bossley Terrace is drained within 1 hour, while the northern end of the street takes closer to 2 hours to drain.

The hotspot has several properties that are affected by overfloor inundation, and has significant vehicle traffic along it. Properties are located on the west side of the street (the Eastern Distributor is on the east side), with a single apartment building and a storage warehouse south of the rail overpass, and several houses at the northern end. Overfloor inundation is limited to the apartment buildings entrance (first inundated in a 1% AEP event), the warehouse (first inundated in a 20% AEP event) and some of the houses. As with Crown Street, there is vehicle traffic through the hotspot, and there is a risk that cars will enter floodwaters and become stranded.

3.3.5. Bourke Street

The north end of Bourke Street between Cowper Wharf Road and Wilson Street is inundated as Cowper Wharf Road has been raised above the natural elevation of the ground, creating an unrelieved area close to the catchment outlet at the bay. Bourke Street slopes down to 1.6 mAHD south of Cowper Wharf Road, which is around 2.2 mAHD. Despite its proximity to the bay, the level of Cowper Wharf Road has much greater influence on the flood level in the area than the ocean tailwater. The area has up to 0.2 m depth in the 20% AEP event and up to 0.8 m in the 1% AEP event. Figure 23 shows the hotspot in detail, including the areas where runoff accumulates and the area's drainage.

The tidal level also influences peak flood levels in the area, as it is adjacent to the trunk drainage outlet just north of Cowper Wharf Road. However, the influence is not widespread, with it generally limited to north of Plunkett Street. For example, in a 1% AEP event, a 1.4 mAHD tide produces peak flood levels around 0.2 m higher than a 0 mAHD tide, but the difference is limited to the area between Wilson Street and the outlet.

The topographic depression created by Cowper Wharf Road causes runoff to pond in the hotspot, creating low hydraulic hazard in most floods. In the 1% AEP event, the area has less than 1 m depth, resulting in virtually no areas of high hydraulic hazard. There is high hazard in the PMF event, as the water ponds to a depth of up to 1.3 m. Duration of flooding in the area is relatively short; for example, in a 1% AEP 1 hour event, there is a depth of 0.3 m for less than 1 hour.

The hotspot has several properties that are affected by overfloor inundation. Seven properties are flooded overfloor in a 1% AEP event, while several more are inundated in a PMF event. Flood levels along Bourke Street are generally elevated in the area and this benefits the degree of affectation. Floodwaters in the Bourke Street pose a risk to a vehicular and pedestrian traffic in the area, however, the depth and velocity of flow is not great enough to be considered to pose a risk to life to most people. The efficient discharge of runoff through the hotspot means the duration of flooding will be relatively short, for example, less than 15 minutes in a 1 hour storm.

3.3.6. Victoria Street

The section of Victoria Street near Orwell Street conveys overland flow in the gutter on the western side of the road, also inundating the footpath and houses on that side of the road. Several features contribute to the flood behaviour: the road cross-sectional shape is heavily sloped towards the western side of the street, the houses on that western side then block the flow (compared to the catchment's pre-developed state), and the limited pipe capacity in a flood event. The depth of flow is around 0.2 m in the 50% AEP event and 0.4 m in a 1% AEP event. Figure 28 shows the hotspot in detail, including the areas where runoff accumulates and the area's drainage.

Overland flow down Victoria Street is shallow and fast moving, and is generally not classified as having high hydraulic hazard in events up to and including the 1% AEP. Localised flow behaviour (which is not captured in the hydraulic model), such as the water cascading down the stairs to the basement levels of the houses, may be considered more hazardous than the footpath runoff, as a resident may be forced to use the stairs to enter or exit the basement level.

There is severe overfloor flood affectation in the hotspot, with a number of properties on the west side of Victoria Street experiencing inundation in relatively frequent flood events. There are nine properties downstream of Butler Stairs that are first inundated in between a 10% and 20% AEP flood event, mostly on their basement level. Several other properties are inundated in a 1% AEP or PMF event. The street has a significant volume of pedestrian and vehicle traffic, however, the concentration of the flow on the western footpath and gutter means cars may still use the road, and pedestrians can use the eastern footpath.

3.3.7. Earl Street

The section of Earl Street around 70 m from the street's southern end, where there is a bend in the road, has minor topographic features which concentrate flow towards the houses on Victoria Street which back onto Earl Street. The street is sloped towards its western side and there is a small topographic depression. A resident on Victoria Street has reported multiple occurrences of flow passing through their house towards Victoria Street. There is a depth of 0.3 m in the 20% AEP event and 0.4 m in the 1% AEP event. Two properties experience overfloor inundation in a 5% AEP event. The flow is not high hazard and no pedestrian or vehicle traffic is likely to be affected. Figure 26 shows the hotspot in detail, including the areas where runoff accumulates and the area's drainage.

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 and sea level rise due to climate change. The assessment followed the NSW State Government guidelines, which require testing of rainfall increases of 10, 20 and 30%, and sea level rise of 0.4 and 0.9 m by the years 2050 and 2100 respectively. Table 3 gives the results of the analysis.

Table 3: Results of Climate Change Analysis - 1% AEP Event Depths (m)

ID	Location	100 Year ARI Peak Flood Depth (m^3/s)	Rainfall Increase 10%	Rainfall Increase 20%	Rainfall Increase 30%	2050 Sea Level +0.4 m	2100 Sea Level +0.9 m
			Difference with 100 Year ARI Base Case (m^3/s)				
1	Francis Street	0.6	0.02	0.03	0.04	-	-
2	Francis Lane	1.9	0.03	0.06	0.08	-	-
3	Yurong Lane	3.4	0.06	0.12	0.17	-	-
4	Busby Lane	1.3	0.07	0.12	0.19	-	-
5	Sir John Young Crescent	1.2	0.07	0.12	0.17	-	-
6	Palmer Street	1.3	0.04	0.07	0.11	-	0.02
7	Cowper Wharf Road underpass	0.7	0.03	0.07	0.10	-	-
8	Bourke Street	0.9	0.03	0.06	0.09	0.05	0.13
9	The Domain	0.4	0.03	0.06	0.09	-	-
10	Victoria Street	0.4	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 Busby Lane, Yurong Lane and Sir John Young Crescent. The analysis also found that a rise in sea level has no impact in the majority of the catchment, with the only significant impact occurring at the downstream end of

Bourke Street near Cowper Wharf Road. This is due to the catchment's steep topography which means a higher sea level only impacts the very downstream end of the catchment, where the ground elevation is comparable to the sea level.

4. STAKEHOLDER CONSULTATION

4.1. Community Consultation

One of the key components 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;
- Public information sessions;
- Other stakeholder consultation; and
- Public exhibition

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. 537 surveys were distributed to residents within the Woolloomooloo catchment. 38 responses were received, which equates to a return rate of 7%. Unfortunately few flood levels or depths were provided although the reported flood observations were able to be used as a means of model verification. Eight historical events from April 1998 onwards were identified as having caused over-floor flooding, and a total of ten flood events were identified in this period. Approximately 75% of respondents are aware of flooding or have some knowledge of flooding in the study area. The most frequent overfloor inundation was reported in Victoria Street, with floodwaters regularly inundating properties near Orwell Street.

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 for managing flood risks within the catchment. 571 copies of the newsletters and questionnaires were printed and delivered to the owners of properties likely to be aware of flooding issues. In total 54 responses were received constituting a 9% return rate and the results are as shown in Figure 19. The newsletter and questionnaire is shown in Appendix B.

34% of the respondents experienced some form of flooding within the catchment and seven respondents reported floodwaters entering their houses or businesses. Of the seven, three were in Victoria Street (in areas identified as hotspots), while the remainder were in Cathedral Street, Bourke Street and Brougham Street. The responses confirmed the general observation that overfloor flooding occurs at low-lying properties that have a significant overland flow path.

Several residents expressed concern in regards to the alignment and maintenance of localised drainage features. For example, tree roots were identified as diverting flow, and blockage of stormwater pits due to leaves was observed by several respondents. There was also comment on the success of recently implemented measures, for example, the upgraded pits in Victoria Street.

Among the preferred management options for managing flood risks within the catchment: defined flow paths, pit/pipe upgrades, retarding basins, strategic planning and flood related development controls were the most popular. The least desired options were levees and retarding basins.

4.1.3. Community Information Session

Yet to be hosted.

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

Following approval by the Committee, this Floodplain Risk Management Study and draft Plan draft report will be put on public exhibition. This will be the opportunity for the community to examine the report and the study outcomes and make any comments or suggestions. Formal submissions from the community will be considered by Council and the Committee before finalisation of the report.

5. ECONOMIC IMPACT OF FLOODING

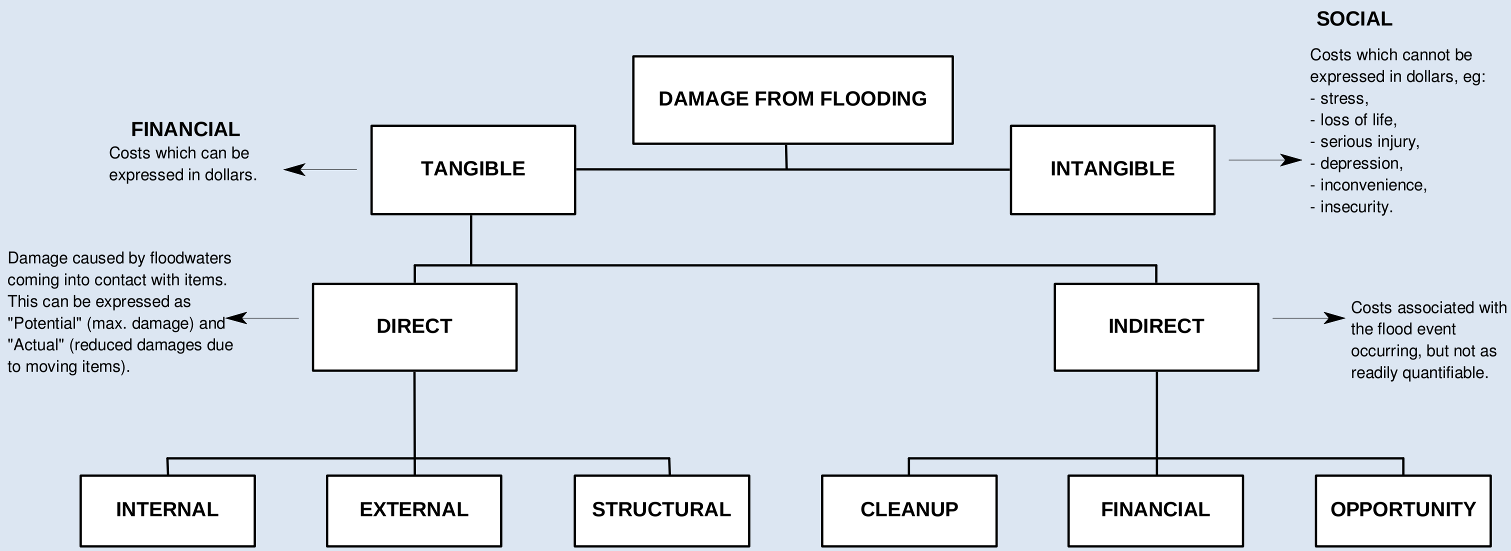
The impact of flooding can be quantified through the calculation of flood damages. Flood damage calculations do not include all impacts associated with flooding. They do, however, provide a basis for assessing the economic loss of flooding and also a non-subjective means of assessing the merit of flood mitigation works such as retarding basins, levees, drainage enhancement etc. The quantification of flood damages is an important part of the floodplain risk management process. By quantifying flood damage for a range of design events, appropriate cost effective management 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 4.

The assessment of flood damages not only looks at potential costs due to flooding but also identifies when properties are likely to become flood affected by either flooding on the property or by over floor flooding as shown on Figure 20.

Table 4: 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 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 9.3.6 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**

5.2. 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 8, 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 8 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 9 lists the rate of rise in metres per hour for the same locations listed in Table 8, 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 8: 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 9: 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 10.

Table 10: 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 11).

Table 11: 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 12 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 12 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 12: 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 13.

Table 13: 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 14 and discussed in the following sections.

Table 14: 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 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 15 and shown in Figure 22. These options are discussed in detail in Sections 9.3.1 to 9.3.5.

Table 15: 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

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.

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 9.3.6). 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

Option FM – WLM02 describes a pipe upgrade between the bend on Earl Street and its connection to the Victoria Street pipe system. The upgrade has been designed with the goal of preventing ingress of floodwaters into properties at the hotspot in the 5% AEP event. The pipe would also provide benefit in larger flood events. The upgrade consists of a 750 mm diameter pipe (currently 300 mm) combined with upgrades to the area's pits to ensure they convey adequate runoff into the pipe.

Modelled Impacts

The drainage upgrade achieves a significant reduction in the peak flood level in the hotspot; however, it also increases the peak flood level in Victoria Street. Figure 27 shows the location of the upgrade and its impact on the 5% AEP peak flood level. The impact includes a decrease of up to 0.3 m and an increase of up to 0.2 m on Victoria Street. It also removes the overland flowpath through the properties. The flow in the upgraded pipe has a peak of 0.15 m^3/s in the 5% AEP event, up from 0.07 m^3/s in the existing case.

Evaluation

The option is unlikely to be feasible, based on its downstream impact, but it does demonstrate that a small increase in flow away from the hotspot will significantly alleviate the existing flood issue. The downstream impact, which is approximately 0.1 m in the 5% AEP event, is widespread and affects an area that has its own flooding issue (Victoria Street). The upgraded pipe, which is not significantly larger than what already exists, achieves an improvement in the area by slightly increasing the low point's drainage. However, whether this improved drainage is via a pipe (as was assessed) or via improved overland conveyance, it will result in additional runoff to Victoria Street, which has been shown to have an adverse impact. The high cost of upgrading the pipe (see Section 9.3.6), relative to its limited benefit, also reduces the option's feasibility.

Given the localised nature of the hotspot, personal property measures on the flood-affected properties may be more feasible than modification of the flood behaviour. Flood-proofing on the rear of the properties could protect against overfloor inundation, while also allowing the area to continue to act as a storage. Furthermore, there is a manageable depth of water that requires protection against (0.3 m in the 10% AEP event, 0.5 m in the 1% AEP event), and the rear of the properties is already mostly walled off, with gates and doors as the current point of ingress. Section 9.4.6 has further description of flood proofing as a management option.

9.3.3. Trunk Drainage Upgrade – New Drainage on Victoria Street (FM - WLM03)

Option Description

Option FM – WLM03 describes a new pipe along Victoria Street from Earl Street to Challis Avenue. The pipe is approximately 540 m long and has dimensions of 1 m x 1 m. The upgrade has been assessed for a 50% AEP flood event.

Modelled Impacts

The upgrade achieves a significant reduction in the 50% AEP peak flood level, but does not provide uniform benefit across the area. The location of the upgrade and the flood level impact are shown in Figure 29. The figure shows that the first three properties downstream of Butlers Stairs have negligible change in flood level, while those further downstream have a reduction of between 0.1 and 0.2 m.

Evaluation

The drainage upgrade provides limited benefit in relation to the scale of works. That is, the benefit is either negligible or of small magnitude while the required pipe is over half a kilometre long and therefore of considerable cost. Furthermore, there is an abundance of services within the road reserve (Reference 4) and the street is littered with protected London Plane trees, both of which affect the cost and feasibility of any pipe upgrade.

As with FM - WLM02, the localised nature of the issue and the depths involved mean that personal property measures are more cost-effective and technically feasible than flood modification options.

Augmentations to the existing fence/gate line along the properties' frontage are likely to be capable of preventing ingress of floodwaters into the properties, preventing the overfloor inundation which currently occurs. Protection along the fence/gate to a height of 0.4 m above the footpath would be above design flood events up to and including the 1% AEP. Section 9.4.6 has further description of flood proofing as a management option.

9.3.4. Overland Flowpath – Lowered Footpath on Victoria Street (FM – WLM04)

Option Description

Option FM – WLM04 describes works on a section of the Victoria Street footpath in the Victoria Street hotspot. Specifically, 90 m of footpath starting from south of Butlers Stairs is lowered by 150 mm, in order to increase the conveyance in the overland flowpath. The upgrade has been assessed for a 50% AEP flood event.

Modelled Impacts

The upgrade achieves a significant reduction in the 50% AEP peak flood level, with the section of lowered footpath having a 50-70 mm decrease in peak flood level. The location of the upgrade and the flood level impact are shown in Figure 30. The figure shows that the impact is limited to the area of lowered footpath, with no adverse impacts downstream. The option increases the conveyance of the footpath which decreases the peak flood level.

Evaluation

The drainage upgrade provides some benefit to the flood-affected properties on Victoria Street; however, the works have a number of constraints, as identified by City of Sydney. The reduction in peak flood level (50-70 mm) is comparable to the existing depth in frequent events (e.g. 100-200 mm in the 50% AEP event) and will reduce the frequency of overfloor flooding for properties along the section of lowered footpath. However, there are numerous constraints in the design of the upgrade, including:

1. The works must be fit within the existing driveways, which limit the length of the upgrade and the grading at either end.
2. All trees within the extent of works will need to be removed. These trees are listed as Significant Trees (see Section 2.1.3).
3. There are a number of services in the footpath that will be required to be moved.
4. Other constraints relating to the re-design of the kerb-gutter system along the section.

As with FM - WLM03, the localised nature of the issue and the depths involved mean that personal property measures should be investigated as a potentially more cost-effective and technically feasible option. Section 9.4.6 has further description of flood proofing as a management option.

9.3.5. Trunk Drainage Upgrade – Upgraded Pipe on Victoria Street (FM – WLM05)

Option Description

Option FM – WLM03 describes a pipe upgrade along Victoria Street from upstream of Butlers Stairs to downstream of Hughes Street, as well as a smaller upgrade on Orwell Street. The Victoria Street upgrade is 190 m of the existing 450 mm diameter pipe increased to 900 mm, while the Orwell Street upgrade consists of 35 m of the existing 375 mm diameter pipe increased to 600 mm. The upgrade has been assessed for a 50% AEP flood event.

Modelled Impacts

The upgrade achieves limited reduction in the 50% AEP peak flood level, and does not result in adverse impacts downstream of the upgrade. The location of the upgrade and the flood level impact are shown in Figure 31. The figure shows that the upgrade benefits an area around Butlers Stairs (20 mm reduction), a larger area around and downstream of Orwell Street (20-30 mm reduction), and does not improve flooding for three affected properties at the Orwell Street – Victoria Street intersection.

Evaluation

The drainage upgrade provides limited benefit to the flood-affected properties in the area, and as with FM – WLM03, there are significant constraints in implementing the upgrade. The benefit to the frequently affected properties is between 20 and 30 mm reduction in the 50% AEP peak flood level, except for three of the properties which have no benefit. Constraints on the design of the upgrade include the multiple protected trees along the street, and the number of sub-surface services. Section 9.4.6 has further description of flood proofing as a management option.

As with previous measures, the localised nature of the issue and the depths involved mean that personal property measures should be investigated as a potentially more cost-effective and technically feasible option.

9.3.6. Economic Assessment of Site Specific Options

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

Costing

Detailed cost estimates have been prepared for each option and these are summarised in Table 16, with detailed costing in Appendix C. It is important to note that these are estimates and should be revised prior to the detailed design phase of the options to obtain a more accurate costing. For FM-WLM01, the very large capacity of the upgrade's pipes meant that the width of the upgrade was comparable to the width of the available area (i.e. roadway and footpaths). Such a large upgrade would incur additional costs due to the re-location of existing services, and this has been accounted for by a higher contingency multiplier in the costing estimates.

Table 16: Costings of Management Options

SUMMARY	Capital	Maintenance per year
FM - WLM01 - Trunk drainage upgrade from Stream Street to outlet	$32,324,300	$18,800
FM - WLM02 - Drainage upgrade for Earl Street pipe connecting to Victoria Street	$585,200	$1,300
FM - WLM03 - Drainage upgrade for 500 m section of Victoria Street	$3,495,600	$5,300
FM - WLM04 – Lowering 90 m of footpath on Victoria Street	$1,150,000*	n/a
FM - WLM05 - Drainage upgrade for 190 m section of Victoria Street and 35 m on Orwell Street	$1,009,500	$2,250

*Cost estimated by City of Sydney

Table 16 shows that the drainage capacity upgrade Option FM – WLM01 is the most costly followed by Option FM – WLM02, both of which involve significant drainage upgrades. Although FM-WLM01 is a far more expensive option, it addresses a number of hotspots in the catchment and as such the works have a far wider scope than other options. Drainage upgrades on Victoria Street cost between $1 million and $3.5 million, however, the number of services that require moving as part of these options means their cost could be much higher.

Damage Assessment

The total damage costs were also evaluated for FM – WLM01 (Trunk drainage upgrade from Stream Street to outlet). The assessment was carried out in accordance with OEH guidelines utilising data obtained from the flood level survey and height-damage curves that relate the depth of water above the floor with tangible damages, and was then compared to the same assessment under existing conditions. FM – WLM01 was found to have an annual average damages cost of $2,099,700, which is a reduction of $733,000 from the existing AAD. The damages estimation under the option is given in detail in Appendix D.

Damages calculations for other management options were not assessed, as they either produced negligible benefit in large events, or produced downstream impacts that meant the options were generally unfeasible.

Benefit Cost Ratio

Following estimation of the option's cost and AAD, the benefit/cost ratio (B/C) of FM – WLM01 was calculated. The B/C is the ratio of the net present worth of the reduction in flood damages (benefit) compared to the cost of the works and is used to compare the economic worth of a set of works to others in the area. The net present worth (NPW) of the AAD reduction was calculated to be $10,827,010, based on a lifespan of 50 years and a 7% discount rate, while the NPW of the cost of the option (capital + maintenance costs) was calculated to be $32,601,342. This gives the option a B/C of 0.3, which indicates the economic benefit of the option is less than half of its economic cost.

The analysis does not consider social factors, environmental factors and risk to life which cannot be quantified in monetary terms but would have been a net contributor to the benefits that could be gained from these management options.

9.3.7. Other Site Specific Management Options Considered

Each hotspot had a range of management options that were assessed to manage the flood risk in the area. Of these options, those that were determined to have the greatest benefit, or were the most technically or economically feasible, were assessed in detail. For the Woolloomooloo catchment, these are the previously described options, FM – WLM01 to FM - WLM05. Other options were assessed in the hotspots that were discarded, and these are presented in Table 17. The table also lists why the option was not considered further. For example, a number of options that addressed sections of the western trunk upgrade were found to cause downstream impacts and so the western trunk upgrade was presented as a single option.

Table 17: Other Site Specific Management Options Considered

Hotspot	Option	Reason Discarded
Stream Street	Upgrade pipes draining Stream Street and pits on William Street	Significant downstream impacts
Crown Street	Upgrading drainage from intersection of Crown and Cathedral Streets to the outlet	Achieves reduction on Crown Street, only addresses Crown Street in isolation
Palmer Street	Lower park beneath rail overpass and upgrade drainage until the outlet	Lowered park has limited storage capacity, drainage achieves benefit, only addresses in Palmer Street in isolation
Bourke Street	Lower Cowper Wharf Road at end of Bourke Street to relieve topographic depression on Bourke Street	Significant benefit, but very localised – does not extend south of Bland Street.
Victoria Street	Several options assessed by memorandum (Reference 4)	Options achieve minimal benefit, further discussion given in memorandum.
Victoria Street	Constructing a raised median strip in the middle of Victoria Street in the hotspot, so as to capture and re-direct runoff prior to it accumulating on the western kerb/footpath.	The median strip has negligible benefit to flooding in the hotspot, as there is little to no flow across the street (i.e. east-west direction).
Dowling Street (not identified as hotspot)	On the section of Dowling Street immediately north of William Street, the drainage line has a 400 mm diameter pipe, with a 750 mm diameter pipe up and downstream of it. Option modelled upgrading 400 mm diameter section to 750 mm diameter.	The upgraded pipe has negligible benefit on Dowling Street (and no impact elsewhere).

9.4. Catchment Wide Management Options

9.4.1. Response Modification – Variable Message Display (RM-WLM01)

DESCRIPTION

Although a catchment wide flood warning system has been excluded as described in Section 9.2.3, there may be an opportunity to develop localised warning and notifications to alert the community during a flood to areas that are flooded or will be in the near future. Variable message displays on main roads in the area would be able to warn drivers not to enter floodwaters. William Street, which is inundated in frequent flood events near Riley Street, is the main arterial road in the area. The displays would likely be operated by Roads and Maritime

Services (RMS).

DISCUSSION

Variable Message Displays on major roads, such as William Street, would reduce the flood risk associated with vehicles entering floodwaters and becoming stranded. The William Street low point has 0.2 – 0.5 m in the 10% AEP event and is therefore capable of disabling a vehicle that drives through the ponding. The nature of urban areas means vehicles or pedestrians may underestimate flood hazard, and unknowingly try to cross the floodwaters. For example, in October 2014, a small flood inundated part of Parramatta Road in Summer Hill, and people became stranded in their cars and required SES assistance. The written warnings would aim to avoid this scenario by communicating the risk to people in the area and suggesting an alternative route.

EVALUATION

The measure is inexpensive relative to other options and it has the ability to manage the risk associated with people and vehicles entering floodwaters. However, people do not always heed flood warnings. Consideration should also be given to possible diversion routes and how traffic in a flood can be managed.

9.4.2. Response Modification - Evacuation Planning (RM – WLM02)

DESCRIPTION

Significant property inundation in a rare flood may force residents to evacuate their homes. Residents will either leave of their own accord, as they feel their property is uninhabitable, or they will be issued an evacuation order. The SES has responsibility for evacuating people due to flooding. The sudden nature of flooding in the catchment means little to no warning is available for a flood event, and so the evacuation would almost certainly take place during or after the storm event.

DISCUSSION

The main issues with all flood evacuations are:

- they must be carried out quickly and efficiently,
- they are hazardous for both rescuers and evacuees,
- residents are generally reluctant to leave their homes, causing delays and placing more stress on the rescuers,
- people do not appreciate the dangers of crossing floodwaters.

The nature of flooding in Woolloomooloo creates additional issues for evacuation. These include:

- The short duration of flooding in the catchment means that the evacuation itself will be of comparable time to remaining indoors and waiting for the flood to recede.
- The limited warning time means that many residents may evacuate at the same time, creating gridlock and placing them in a more dangerous situation than not evacuating. Furthermore, areas that require evacuation the most (i.e. where significant depths occur) will likely not be accessible in a standard vehicle, forcing residents to leave on foot.

EVALUATION

Evacuation of residents in the catchment has significant associated risks and may increase the flood risk in the brief time (typically, hours) that residents are flood affected. Furthermore, the more widespread the evacuation is, the greater the risk of gridlock and people becoming stranded. In general, evacuation should not be undertaken, unless there is exceptionally hazardous flooding at a property.

9.4.3. Response Modification - Public Information and Raising Flood Awareness (RM – WLM03)

DESCRIPTION

A community with high flood awareness will suffer less damage and disruption during and after a flood because people are knowledgeable about the flood and what is required of them. The success of any flood warning system and the evacuation process depends on:

Flood Awareness: How aware is the community to the threat of flooding? Has it been adequately informed or educated?

Flood Preparedness: How prepared is the community to react to the threat? Do they (or the SES) have damage minimisation strategies (such as sand bags, raising possessions) which can be implemented?

Flood Evacuation: How prepared are the authorities and the residents to evacuate households to minimise damages and the potential risk to life? How will the evacuation be done, where will the evacuees be moved to?

DISCUSSION

In catchments which regularly flood, there is often a large, local, unofficial warning network which has developed over the years and residents know how to effectively respond to warnings by raising goods, moving cars, lifting carpets, etc. The level of trauma or anxiety may be reduced as people have "survived" previous floods and know how to handle both the immediate emergency and the post rehabilitation phase in a calm and efficient manner.

The level of flood awareness within a community is difficult to evaluate. It will vary over time and depends on a number of factors including:

- *Frequency and impact of previous floods*. A major flood causing a high degree of flood damage in relatively recent times will increase flood awareness. If no floods have occurred, or there have been a number of small floods which cause little damage or inconvenience, then the level of flood awareness may be low. In Woolloomooloo, there is little experience of flooding that has caused major disruption to residents (e.g. overfloor flooding). There are, however, localised hotspots that have a high awareness of flooding, for example in Victoria Street.

- *History of residence.* Families who have owned properties for a long time will have established a considerable depth of knowledge regarding flooding and a high level of flood awareness. A community which consists predominantly of short lease rental homes will have a low level of flood awareness. As discussed in Section 2.1.2, a high portion of residents have only recently moved into the catchment and the most residents live in rented accommodation.

- *Whether an effective public awareness has been implemented.* It is understood that no large scale awareness program has been implemented in the catchment. However, flooding information is available via the publicly available Flood Study (Reference 2) completed for the catchment, and residents are well informed of the floodplain risk management process through newsletters sent out as part of each study.

For flood risk management to be effective it must become the responsibility of the whole community. It is difficult to accurately assess the benefits of an awareness program but it is generally considered that the benefits far outweigh the costs. The perceived value of information and levels of awareness diminishes as the time since the last flood increases. Often a major hurdle is convincing residents that major floods, larger than those previously experienced, will occur in the future. Table 18 lists tools that can be used to promote public awareness of flooding in an area.

Table 18: Public Information Tools

Method	Comment
Letter/Pamphlet from Council	These may be sent annually or biannually with the rate notice or separately. The pamphlet can inform residents of subsidies, changes to flood levels or any other relevant information.
School Project or Local Historical Society	This provides an excellent means of informing the younger generation about flooding. It may involve talks from various authorities and can be combined with topics relating to the natural environment, etc.
Displays at Libraries / community centres	This is an inexpensive, passive, way of informing the community and may be combined with related information.
Historical Flood Markers	Signs or marks can be prominently displayed on telegraph poles or such like to indicate the level reached in previous floods. Depth indicators advice of potential hazards.
Articles in Local Newspapers	Ongoing articles in newspapers will ensure that the problem is not forgotten. Historical features and remembrance of the anniversary of past events make good copy.
Collection of Data from Future Floods	Collection of data assists in reinforcing to the residents that Council is aware of the problem and ensures that the design flood levels are as accurate as possible.
Types of Information Available	Council may wish to advice interested parties on the flood information currently available and how it can be obtained at cost when they inquire during the property purchase process.
Establishment of Flood Affectation Database	A database would provide information on (say) which houses require evacuation, which public structures will be affected (e.g. telephone or power cuts). This database should be reviewed after each flood event.
Flood Preparedness Program	Providing information to the community regarding flooding helps to inform it of the problem and associated implications. However, it does not

	necessarily adequately prepare people to react effectively to the problem. A Flood Preparedness Program, led by the SES would ensure that the community is adequately prepared.
Foster Community Ownership of the Problem	Flood damages in future events can be minimised if the community is aware of the problem and takes steps to find solutions. Residents have a responsibility to advice Council if they see a problem such as potential debris blockage.

EVALUATION

A program aimed at raising flood awareness in the catchment is a cost-effective measure that will reduce the flood risk in the area. There is generally little perception of the risk of high hazard flooding in the area. In similar studies in urban areas that are not perceived as having a flood issue, photos of historical floods communicate well the possible floods that can occur.

9.4.4. Response Modification – Local Flood Plan and DISPLAN (RM – WLM04)

DESCRIPTION

As described previously, it may be necessary for a small number of residents to evacuate their homes in a major flood. This would usually be undertaken under the authority of the lead agency under the DISPLAN, the SES. Based on the duration of flooding in the catchment (typically, hours) and the risks associated with evacuation, it may be that evacuation is undertaken on a case by case basis. Some residents may choose to leave on their own accord based on flood information from the radio or other warnings, and may be assisted by local residents.

The preparation of a flood emergency response plan aims to minimise the risk associated with evacuations (described in Section 9.4.2) by providing information regarding evacuation routes, refuge areas, and generally what processes should be followed in a flood. It is the role of the SES to develop this plan for flood-affected communities.

DISCUSSION

As recommended in Section 6.2, a DISPLAN should be prepared for the Sydney East Emergency Management District (of which the Woolloomooloo catchment is part of) 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 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.

Further, it is recommended that the SES prepare a Local Flood Plan in conjunction with the City of Sydney (who shall supply the necessary data) to outline the following details:

- Evacuation centres in close proximity to the floodplain which are flood free sites with flood free access;
- Organise use of Variable Message Signs for use during a flood event for flood affected roads (specifically recommended in Section 9.4.1).
- Inclusion of a description of local flooding conditions;
- Identification of potentially flood affected vulnerable facilities; and
- Identification of key access road subject to flooding.

Details of access road flooding and recommended inclusions for the flood plan are provided in Section 6.

Although flood warning is limited, a local disaster plan should be continually updated to include the latest information on design flood levels and details on roads, properties, and other facilities which would be flood affected.

OUTCOME

The SES should ensure that a DISPLAN be prepared for the Sydney East Emergency Management District, and Council, with the help of the SES should prepare a Local Flood Plan for the study catchment. This should also take into account those properties not directly flood affected but which may have had access cut and become flood islands. These plans should be regularly kept up to date and should include feedback from recent major flood events and the recommendations of this Study once finalised.

9.4.5. Property Modification - Flood Planning Levels (PM – WLM01)

DESCRIPTION

The flood planning level (FPL) is used to define land subject to flood related development controls and is generally adopted as the minimum level to which floor levels in the flood affected areas must be built. The FPL includes a freeboard above the design flood level. It is common practice to set minimum floor levels for residential buildings, garages, driveways and even commercial floors as this reduces the frequency and extent of flood damages. Freeboards provide reasonable certainty that the reduced level of risk exposure selected (by deciding upon a particular event to provide flood protection for) is actually provided.

DISCUSSION

The main aim of the FPLs is to reduce the damages experienced by the property owner during a flood. Elevating a house floor level above the FPL will ensure that flood damages are significantly reduced. Council have specified FPL requirements in their *Interim Floodplain Management Policy* (Reference 6) prior to the completion of the Floodplain Risk Management Plans for the entire LGA and this study supports that measure. It is important that the same requirements are applied throughout the LGA to new development or redevelopments regardless of whether the Floodplain Risk Management Plan have been completed for the catchment or not.

EVALUATION

A review of the FPLs put forward by Council in their *Interim Floodplain Management Policy* (Reference 6) was carried out as part of this study. In order to ensure consistency throughout the LGA, the same principle for FPLs should be applied regardless of whether a Floodplain Risk Management Plan have been completed for the catchment or not. The only exception would be if the Floodplain Risk Management Plan proposes a change to these FPLs.

9.4.6. Property Modification - Flood Proofing (PM – WLM02)

DESCRIPTION

Flood Proofing involves the sealing of entrances, windows, vents, etc., to prevent or limit the ingress of floodwaters. It is only suitable for brick buildings with concrete floors and can prevent ingress for outside depths of approximately one metre. Greater depths may cause collapse of the structure unless water is allowed to enter.

DISCUSSION

In general, flood proofing requires sealing of doors (new frame, seal and door); sealing and re-routing of ventilation gaps in brickwork; sealing of all underfloor entrances and checking of brickwork to ensure that there are no gaps or weaknesses in the mortar. It will not reduce the flood hazard, and in fact may increase the true hazard if residents stay in their houses and a large flood eventually inundates the building. A typical benefit/cost ratio is high and there are no significant environmental and social problems.

An assessment of the variation in types of flood proofing, the flood depths to which can be protected, and the costs involved, is required before the option can be fully recommended. Past experience indicates that some types of flood proofing are affordable relative to the cost of flooding, for example, in some cases, an existing house could be sealed for approximately \$20,000. In the case of a new house of extension, the cost of flood proofing would be less if included as part of the construction. There is also variation in the types of property that can be proofed, for example, it is easier to apply to commercial premises where there are only one or two entrances, and maintenance and operation procedures can be better enforced.

As an example, such works have already been implemented at 123 Victoria Street, which uses a temporary flood barrier across the doorway that is installed each night (and presumably during the day if there is heavy rain). These barriers require daily use; however, the flood-affected properties immediately upstream on Victoria Street (see Section 3.3.6) already have a gate/fence barrier that, if made impermeable, would provide a permanent barrier. In the case of Victoria Street, it would only need to be to a height of 0.4 m to protect against all events below the PMF.

EVALUATION

Preliminary assessment has indicated that flood proofing is a good solution to reducing flood risk to commercial and industrial properties. Based on previous experience, the option can be cost-effective relative to drainage upgrades or other structural works, and easier to implement. Further assessment should be undertaken to ascertain the depth of ponding that flood proofing can protect against, what types of properties can be flood-proofed, the variation in cost for different cases, where responsibility lies for carrying out and funding the works, and any associated risks with the approach.

9.4.7. Property Modification – Feasibility Study for City of Sydney Flood Proofing (PM – WLM03)

DESCRIPTION

As discussed in the previous option, flood proofing involves modifications to a building's exterior in order to prevent the ingress of floodwater. Where flood proofing is not undertaken by property owners, it may be possible for City of Sydney to undertake mitigation works if the property is put up for sale. That is, for a severely flood affected properties, City of Sydney may purchase the property so that works on it can be undertaken, and then the property is put up for sale soon after. Such a scheme would be most suited to areas with significant overfloor flood affectation where structural measures (for example, drainage upgrades) are not feasible.

DISCUSSION

A Council-led program that involves the purchase, renovation and selling of flood-affected land is a straightforward variation on other Council-led property modification measures, and will provide benefit to properties that do not have other available options. The nature of the flood issue in Woolloomooloo is that although there is significant overfloor flood affectation, it is concentrated in several localised areas. This makes structural options difficult to justify, and it is possible that a property's flood risk will remain indefinitely.

As the option can only be implemented when an affected property is put on sale, such a program's implementation would be very gradual and would be undertaken over a long period of time. In this sense, the option is an extension of Council's FPL policy, whereby minimum floor levels are required when a flood-affected property is re-developed. A Council-led flood proofing program would account for the flood affected properties that are not re-developed and therefore would not otherwise have their floor levels raised.

Although such a program has some similarity to a voluntary purchase scheme, it would be markedly less obtrusive and would not reduce the number of dwellings in the catchment. Voluntary purchase involves returning severely-affected land on a floodway to the floodplain, whereas in Woolloomooloo, affected properties are not necessarily on a floodway and restoring an area's natural flowpath (for example, in a trapped depression) would adversely impact downstream properties and may impact an area's streetscape and character. Most significantly, a flood proofing program would only involve properties that are available for purchase, meaning there would be no disruption to the existing property market. This would be further ensured by having no publicly available information on which properties would be targeted by such a program.

EVALUATION

A flood proofing program undertaken by the City of Sydney could significantly alleviate property affectation and give Council an alternative to drainage upgrades in areas where they are prohibitively expensive and not cost-effective. It would also allow Council to extend their objective of raising flood affected properties (via an FPL) to affected properties by improving properties that may not otherwise have their floor level raised. Although such a program has several apparent benefits, its feasibility should be investigated further to determine whether it can be cost-effective (based on the cost of purchasing, flood-proofing and re-selling a property compared to the existing economic cost of flooding) and what social impacts may exist.

9.4.8. Property Modification - Development Control Planning (PM – WLM04)

DESCRIPTION

The catchment's location in inner Sydney means there is continuing pressures for both redevelopments of existing buildings as well as for new developments. The strategic assessment of flood risk can prevent development occurring in areas with a high hazard and/or with the potential to have significant impacts upon flood behaviour in other areas. It can also reduce the potential damage to new or redeveloped properties likely to be affected by flooding to acceptable levels.

DISCUSSION

The Interim Floodplain Management Policy (Reference 6) provides general requirements for new developments on flood liable land within the catchment, Flood Planning Level requirements for different development types and guidelines on flood compatible materials. This document serves as an interim policy for managing floodplain within the Council LGA which will be withdrawn once Council complete Floodplain Risk Management Plans for the entire LGA and then integrate outcomes from these plans into planning controls. A review of this document as well as the Sydney LEP 2012 and Sydney DCP 2012 has been undertaken and discussed in Section 7.1.2. Nevertheless the success of these policies can only be determined once implemented and specific problems/issues addressed as they arise.

OUTCOME

Recommendation for an update of the planning documents (i.e. Sydney DCP 2012 and Sydney LEP 2012) has been discussed in Section 7.2 in order to inform of the development controls as published in the Interim Floodplain Management Policy (Reference 6). Inclusion of these provisions would ensure that the controls can be enforced which also take into consideration the potential impact of climate change.

9.5. Assessment Matrix

9.5.1. Background

Multi-variate decision matrices are recommended in the Floodplain Development Manual (Reference 1) and therefore it is also a recommendation of this report that multi-variate decision matrices be developed for specific management areas, allowing detailed benefit/cost estimates, community involvement in determining social and other intangible values, and local assessment of environmental impacts.

The criteria assigned a value in the management matrix are:

- Risk to life;
- Impact on flood behaviour (reduction in flood level, hazard or hydraulic categorisation) over the range of flood events;
- Number of properties benefited by measure;
- Technical feasibility (design considerations, construction constraints, long-term performance);
- Community acceptance and social impacts;
- Economic merits (capital and recurring costs versus reduction in flood damages);
- Financial feasibility to fund the measure;
- Long term performance;
- Environmental and ecological benefits;
- Impacts on the State Emergency Services;
- Political and/or administrative issues; and
- Long-term performance given the potential impacts of climate change.

The scoring system for the above criteria is provided in Table 19 and largely relates to the impacts in a 1% AEP event. The matrix below is designed to set out a general scheme to illustrate how a local matrix might be developed. These criteria and their relative weighting may be adjusted in the light of community consultations and local conditions.

Tangible costs and damages are also used as the basis of B/C analysis for some measures.

Table 19: Matrix Scoring System

SCORE:	-3	-2	-1	0	1	2	3
Impact on Flood Behaviour	>100mm increase	50 to 100mm increase	<50mm increase	no change	<50mm decrease	50 to 100mm decrease	>100mm decrease
Number of Properties Benefited	>5 adversely affected	2-5 adversely affected	<2 adversely affected	none	<2	2 to 5	>5
Technical Feasibility	major issues	moderate issues	minor issues	neutral	moderately straight-forward	Straight-forward	no issues
Community Acceptance	majority against	most against	some against	neutral	minor	most	majority
Economic Merits	major disbenefit	moderate disbenefit	minor disbenefit	neutral	low	medium	high
Financial Feasibility	major disbenefit	moderate disbenefit	minor disbenefit	neutral	low	medium	high
Environmental & Ecological Benefits	major disbenefit	moderate disbenefit	minor disbenefit	neutral	low	medium	high
Impacts on SES	major disbenefit	moderate disbenefit	minor disbenefit	neutral	minor benefit	moderate benefit	major benefit
Political / administrative Issues	major negative	moderate negative	minor negative	neutral	few	very few	none
Long Term Performance	major disbenefit	moderate disbenefit	minor disbenefit	neutral	positive	good	excellent
Risk to Life	major increase	moderate increase	minor increase	neutral	minor benefit	moderate benefit	major benefit

A draft assessment matrix has been included in the following section. It will be updated for the final report with the results of the community consultation.

9.5.2. Results

The assessment matrix is given in Table 20, with each of the assessed management options scored against the range of criteria. 'Community Acceptance' has not been scored at this time, as the community information session is yet to be held (the matrix will be updated when the information is available). Also, it is important to note that the approach undertaken does not provide an absolute "right" answer as to what should be included in the Management Plan but is rather for the purpose of providing an easy framework for comparing the various options on an issue by issue basis which stakeholders can then use to make a decision. For the same reason, the total score given to each option, and the subsequent rank, is only an indicator to be used for general comparison.

Table 20: Multi-Criteria Assessment of Management Options

Ref	Options	Section in Report	Design Event (AEP)	Impact on Flood Behaviour	Number of Properties Benefited	Technical Feasibility	Community Acceptance	Economic Merits	Financial Feasibility	Environmental/Ecological Benefits	Impact on SES	Political/Admin Issues	Long Term Performance	Risk to Life	Total Score	Rank (Total)
	Flood Modification Measures															
FM-WLM01	Trunk Drainage Upgrade - Stream Street to Outlet	9.3.1	10%	3	3	-3	N/A	-2	-3	-1	2	-3	1	3	0	8=
FM-WLM02	Drainage Upgrade - Upgraded Pipe on Earl Street	9.3.2	5%	1	2	-1	N/A	-2	-2	0	0	-2	1	0	-3	11
FM-WLM03	Trunk Drainage Upgrade - New Drainage on Victoria Street	9.3.3	50%	2	2	-2	N/A	-2	-3	-1	1	0	1	2	0	8=
FM-WLM04	Overland Flowpath - Lowered Footpath on Victoria Street	9.3.4	50%	1	1	-1	N/A	-3	-2	-1	0	0	1	0	-4	12
FM-WLM05	Trunk Drainage Upgrade - Upgraded Pipe on Victoria Street	9.3.5	50%	1	1	-2	N/A	-3	-2	-1	0	0	1	0	-5	13
	Response Modification Measures															
RM-WLM01	Variable Message Display	9.4.1	N/A	0	0	2	N/A	2	2	0	2	1	0	1	10	2=
RM- WLM02	Evacuation Planning	9.4.2	N/A	0	0	-1	N/A	0	2	0	1	2	0	1	5	7
RM-WLM03	Public Information and Raising Flood Awareness	9.4.3	N/A	0	0	1	N/A	1	2	0	2	1	-2	1	6	6
RM-WLM04	Local Flood Plan and DISPLAN	9.4.4	N/A	0	0	0	N/A	2	2	0	2	2	1	2	11	1
	Property Modification Measures															
PM-WLM01	Flood Planning Levels	9.4.5	N/A	0	0	0	N/A	2	2	0	1	0	3	1	9	5
PM-WLM02	Investigate Flood Proofing	9.4.6	N/A	0	0	0	N/A	1	3	0	1	2	2	1	10	2=
PM-WLM03	Voluntary Purchase	9.4.7	N/A	0	0	-2	N/A	1	-1	0	1	-2	2	1	0	8=
PM-WLM04	Development Control Planning	9.4.8	N/A	0	0	0	N/A	2	2	0	1	1	3	1	10	2=

*'Community Acceptance' will be completed following a community information session as part of the Public Exhibition

As shown in the matrix, the structural measures score lowly on economic merit, as they do not have favourable B/C ratios, and on financial feasibility, as all require a large capital outlay. In addition, they have technical feasibility issues, either relating to the potential issues in the design of the required drainage, or due to their adverse downstream impacts. Low scores in these three categories result in a much lower score than most of the response modification and property modification measures.

The five highest ranking measures scored between 9 and 11, which indicates that they are all generally equivalent under this assessment. They all require relatively little financial outlay, and will lower the economic cost of flooding in the catchment. Public information and flood awareness also scores well, but ranks lower due to its limited long term performance, an issue also associated with evacuation planning. Voluntary purchase is difficult to justify as it is has issues with its technical feasibility, in that it would be very different to a typical VP scheme, and the political/administrative issues associated with buying flood-affected houses.

Based on the matrix, the options for future implementation are ranked in the order as tabulated in Table 21.

Table 21: Ranking of Management Options

Rank	Ref	Options	Score
1	RM-WLM04	Local Flood Plan and DISPLAN	11
2=	PM-WLM02	Investigate Flood Proofing	10
2=	RM-WLM01	Variable Message Display	10
2=	PM-WLM04	Development Control Planning	10
5	PM-WLM01	Flood Planning Levels	9
6	RM-WLM03	Public Information and Raising Flood Awareness	6
7	RM-WLM02	Evacuation Planning	5
8=	FM-WLM01	Trunk Drainage Upgrade - Stream Street to Outlet	0
8=	FM-WLM03	Trunk Drainage Upgrade - New Drainage on Victoria Street	0
8=	PM-WLM03	Voluntary Purchase	0
11	FM-WLM02	Drainage Upgrade - Upgraded Pipe on Earl Street	-3
12	FM-WLM04	Overland Flowpath - Lowered Footpath on Victoria Street	-4
13	FM-WLM05	Trunk Drainage Upgrade - Upgraded Pipe on Victoria Street	-5

Note: '=' denotes equal position. E.g. '3=' refers to equal third rank.

Of the 13 management options presented here, 11 have been recommended for implementation as part of the Woolloomooloo Catchment Floodplain Risk Management Plan. The two discarded options are FM-WLM02 and FM-WLM05. The former has an adverse impact downstream of the upgrade that increases downstream flood risk by an unacceptable amount. The latter produces minimal benefit to the Victoria Street hotspot and will have little to no effect on the property inundation in the area.

10. REFERENCES

1. NSW Government
   Floodplain Development Manual
   April 2005

2. WMAwater
   Woolloomooloo Flood Study
   Draft Report, July 2013

3. Sydney Water Corporation
   City Area SWC 30 Capacity Assessment
   Sydney Water Corporation, July 1996

4. WMAwater
   137 Victoria Street, Woolloomooloo Flood Mitigation
   November 2013

5. City of Sydney
   Sydney Local Environmental Plan 2012
   2012

6. City of Sydney
   Interim Floodplain Management Policy
   July 2013

7. NSW Department of Environment and Climate Change
   Flood Emergency Response Classification of Communities
   October 2010

8. Howells *et. al.*
   Defining the Floodway – Can One Size Fit All?
   2004

9. NSW Department of Environment and Climate Change
   Floodplain Risk Management Guideline – Residential Flood Damages
   October 2007

Figures

FIGURE 1
STUDY AREA
RUSHCUTTERS BAY

J:\Jobs\114014\GIS\ArcMap\FRMS_figures\RB\Figure01_Study_Area_Map_RB.mxd

FIGURE 2
RUSHCUTTERS BAY HOTSPOT LOCATIONS

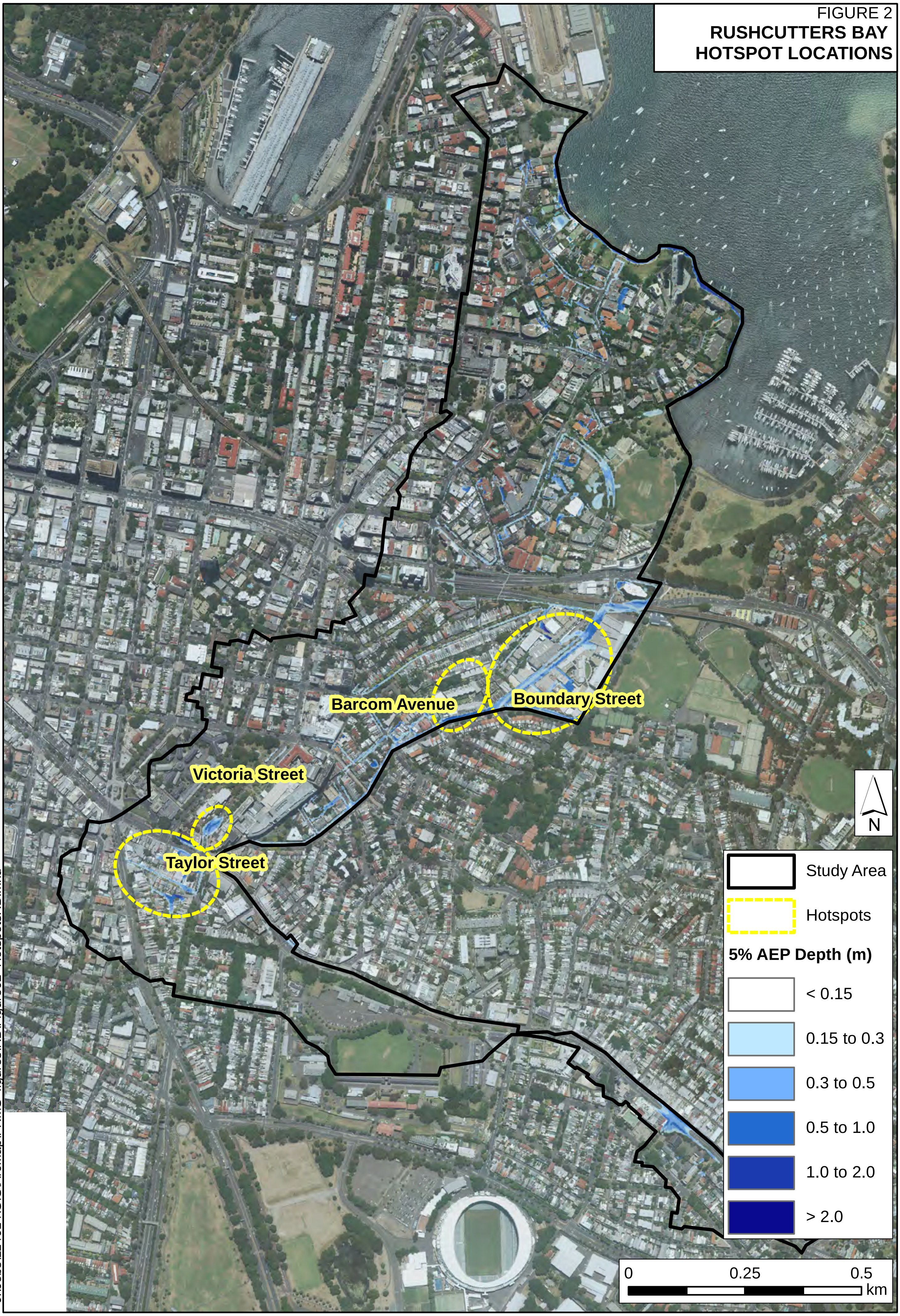


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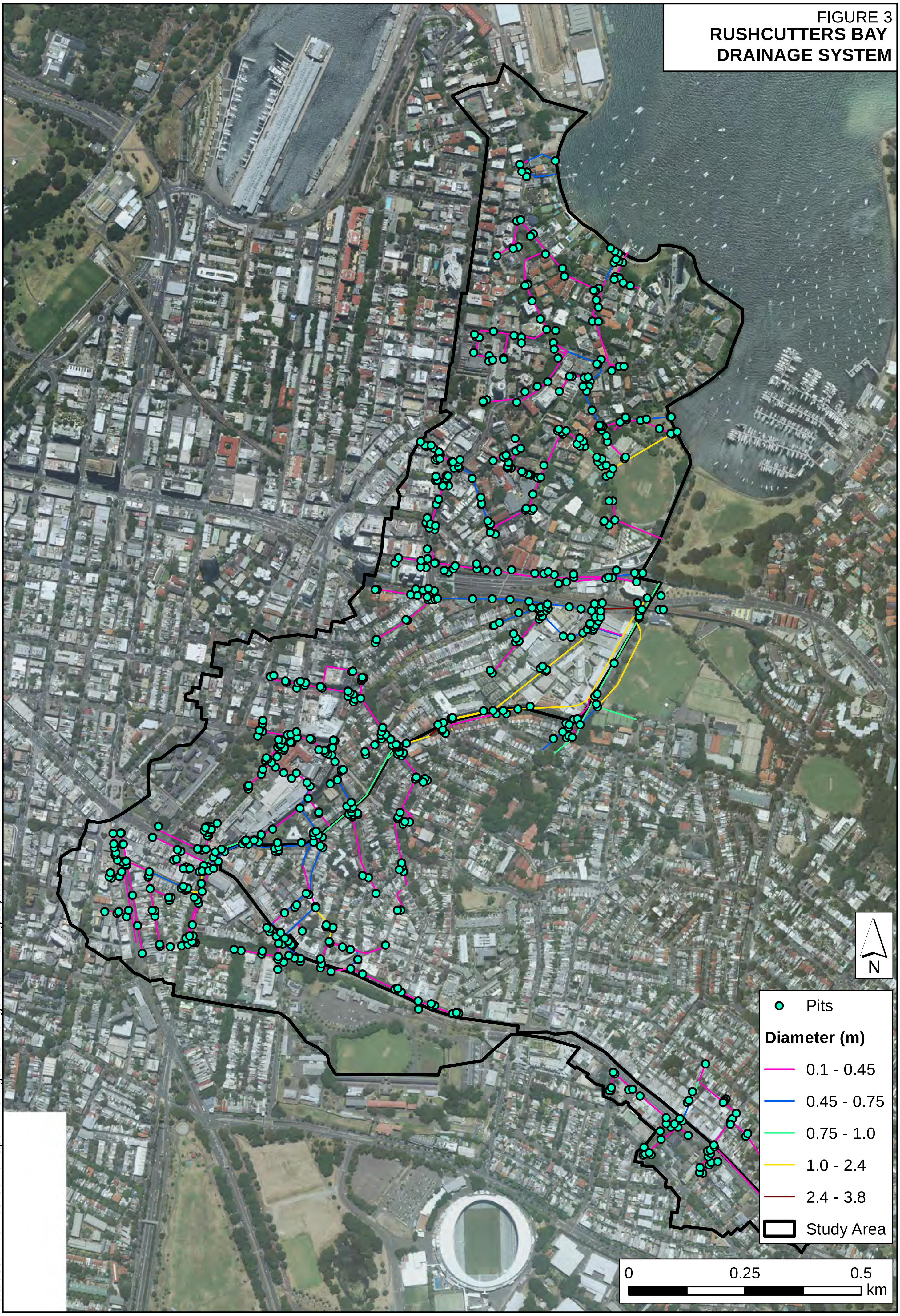
FIGURE 3
RUSHCUTTERS BAY DRAINAGE SYSTEM



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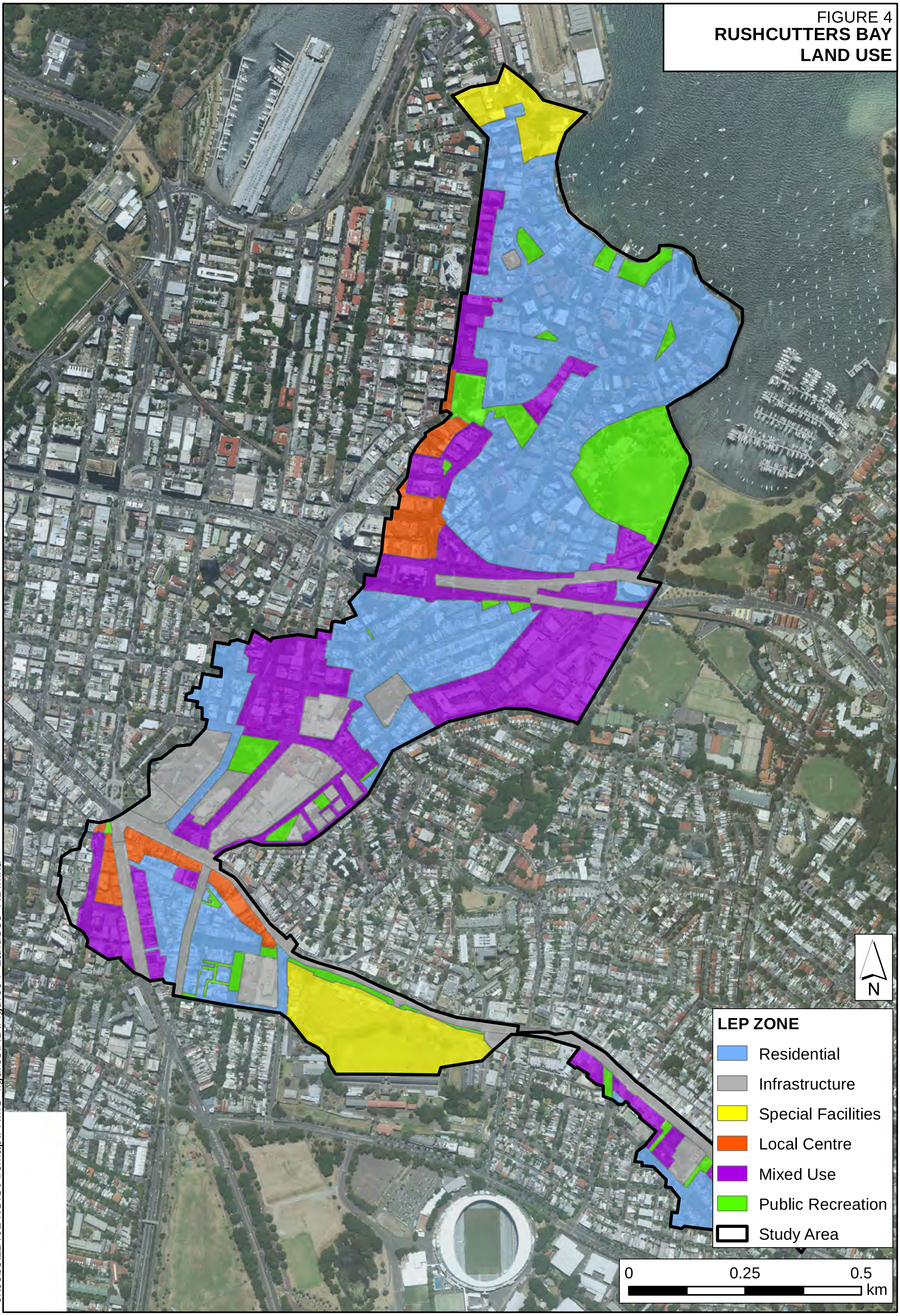

FIGURE 4
RUSHCUTTERS BAY
LAND USE
LEP ZONE
Residential
Infrastructure
Special Facilities
Local Centre
Mixed Use
Public Recreation
Study Area
N
0
0.25
0.5
km
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FIGURE 5

EARLY CATCHMENT FEATURES
HISTORIC CREEKS AND SHORELINE - 1854

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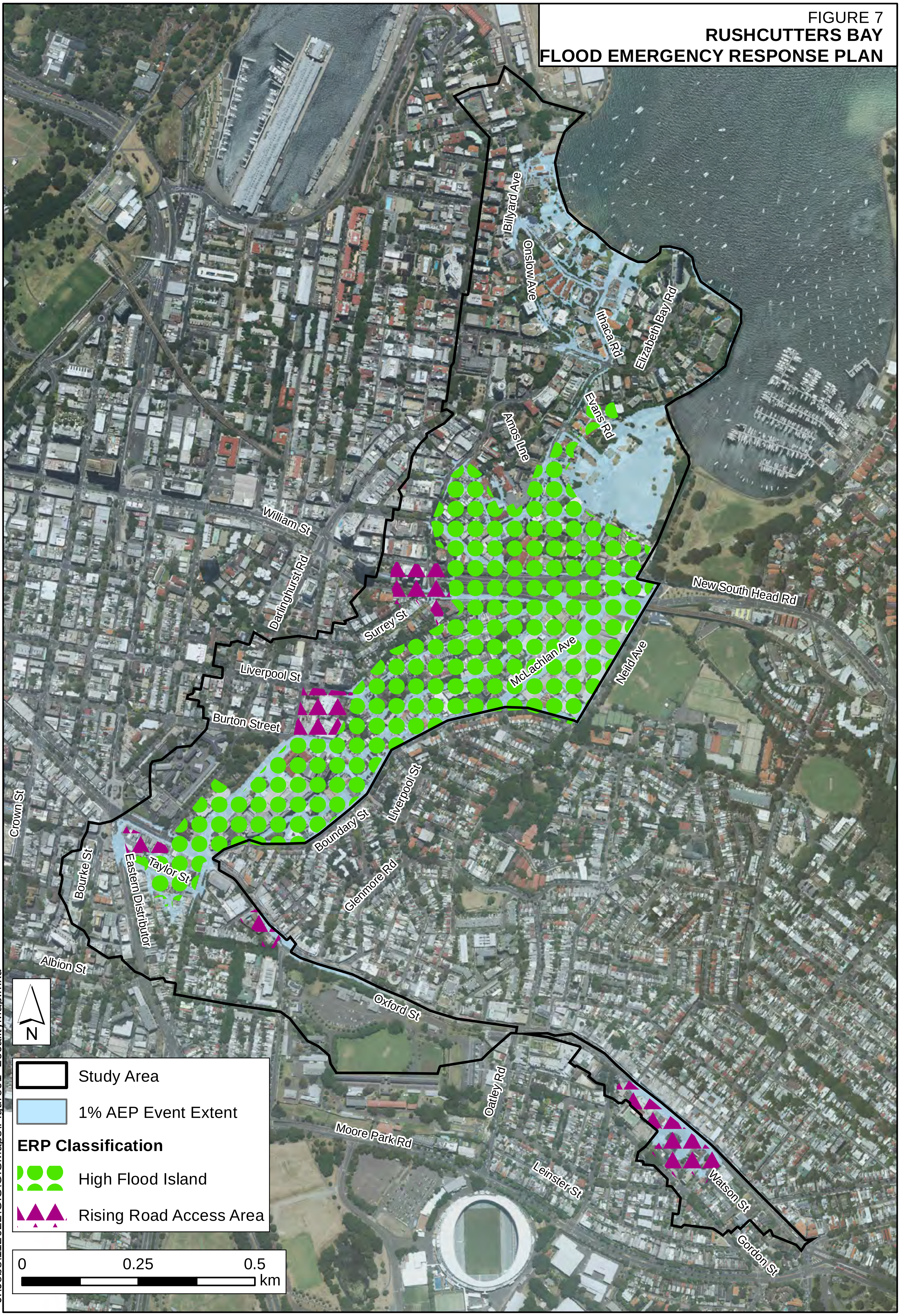
FIGURE 6
ELIZABETH BAY
PEAK FLOOD DEPTH
1% AEP EVENT
Billyard Ave
Ithaca Road
Greenknowe Ave
N
Study Area
Depth (m)
< 0.15
0.15 to 0.3
0.3 to 0.5
0.5 to 1.0
1.0 to 2.0
> 2.0
0
50
100
200
300
m
J:\Jobs\114014\GIS\ArcMap\FRMS_figures\RB\Figure06_EB_Peak_Flood_Depth.mxd

FIGURE 7
RUSHCUTTERS BAY
FLOOD EMERGENCY RESPONSE PLAN



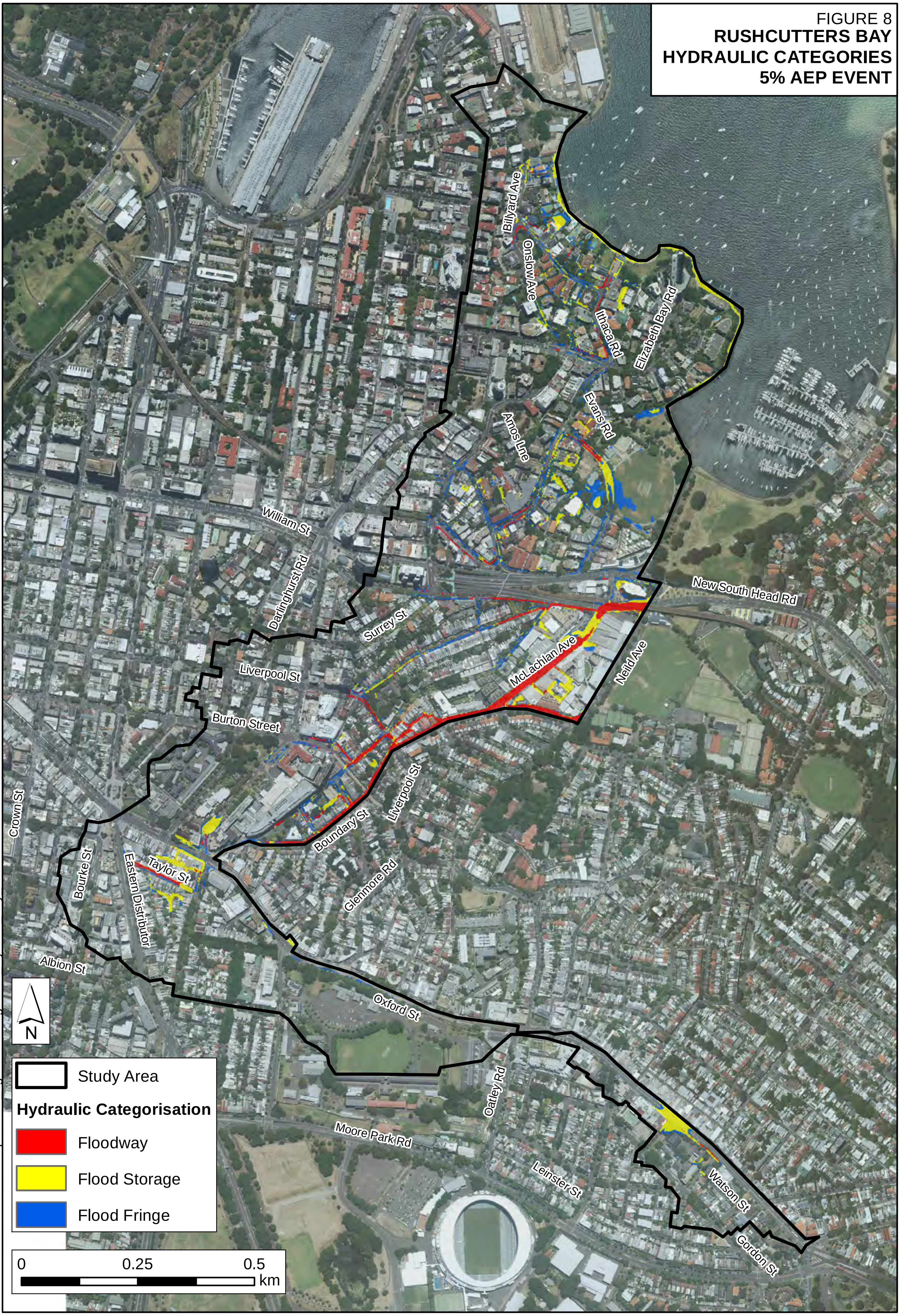


FIGURE 8
RUSHCUTTERS BAY
HYDRAULIC CATEGORIES
5% AEP EVENT
Billyard Ave
Onslow Ave
Ithaca Rd
Elizabeth Bay Rd
Evans Rd
Amos Lne
William St
Darlinghurst Rd
New South Head Rd
Surrey St
McLachlan Ave
Neild Ave
Liverpool St
Burton Street
Boundary St
Liverpool St
Crown St
Bourke St
Eastern Distributor
Taylor St
Glenmore Rd
Albion St
Oxford St
Oatley Rd
Moore Park Rd
Leinster St
Watson St
Gordon St
N
Study Area
Hydraulic Categorisation
Floodway
Flood Storage
Flood Fringe
0
0.25
0.5
km
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FIGURE 9
RUSHCUTTERS BAY
HYDRAULIC CATEGORIES
1% AEP EVENT

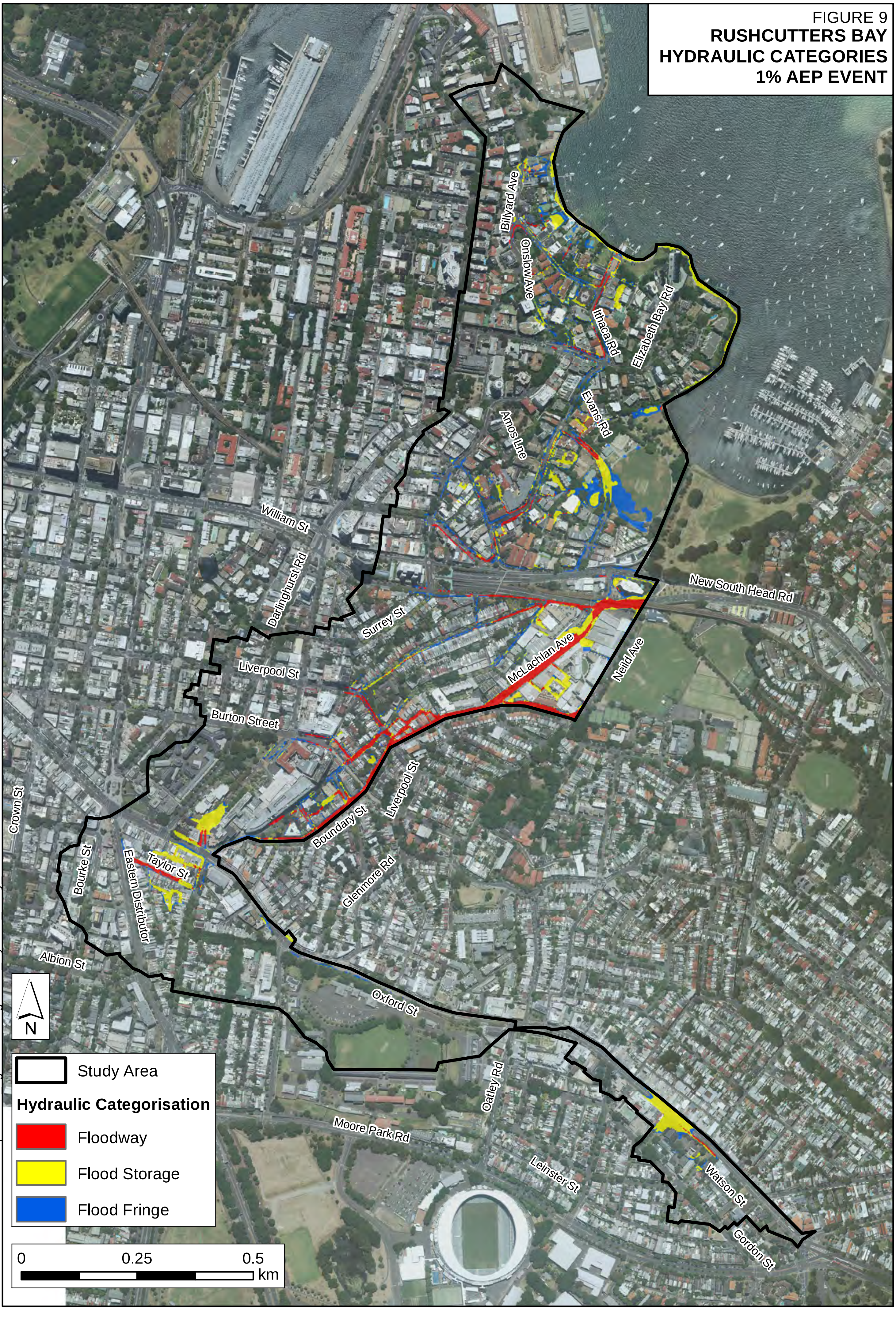


FIGURE 10
RUSHCUTTERS BAY HYDRAULIC CATEGORIES PMF EVENT

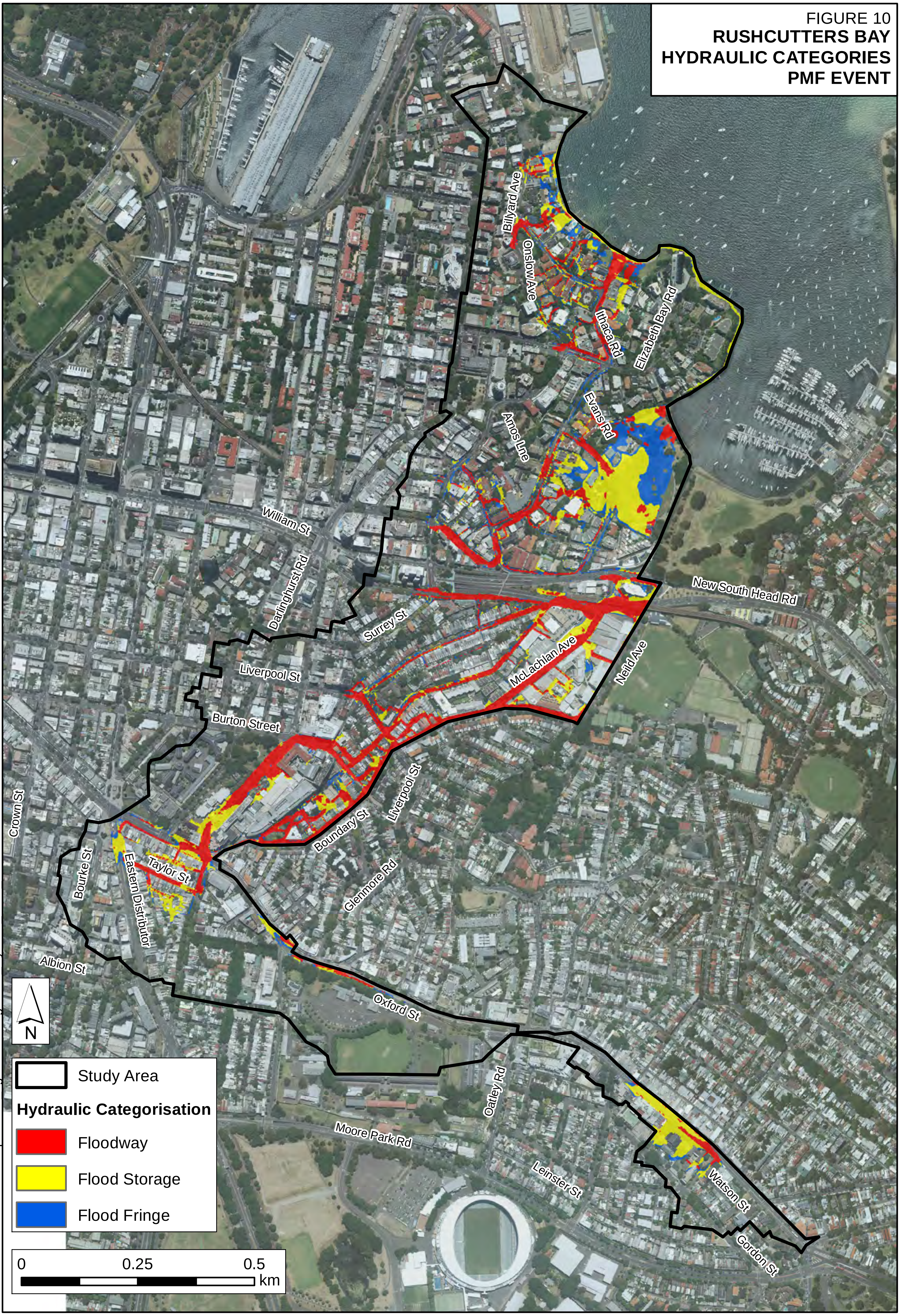


FIGURE 11
RUSHCUTTERS BAY HAZARD CATEGORIES 0.5 EY EVENT

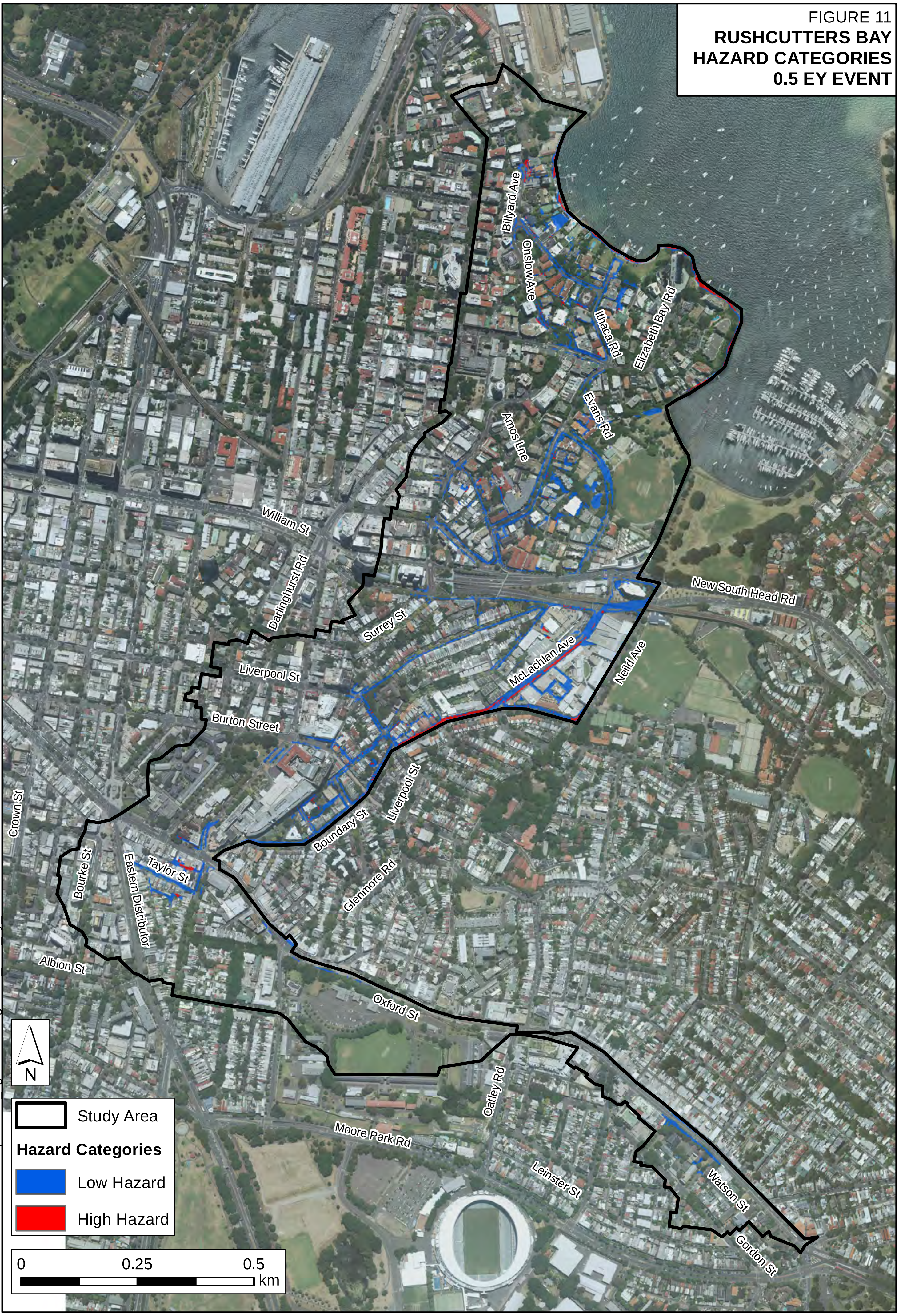


FIGURE 12
RUSHCUTTERS BAY HAZARD CATEGORIES 0.2 EY EVENT

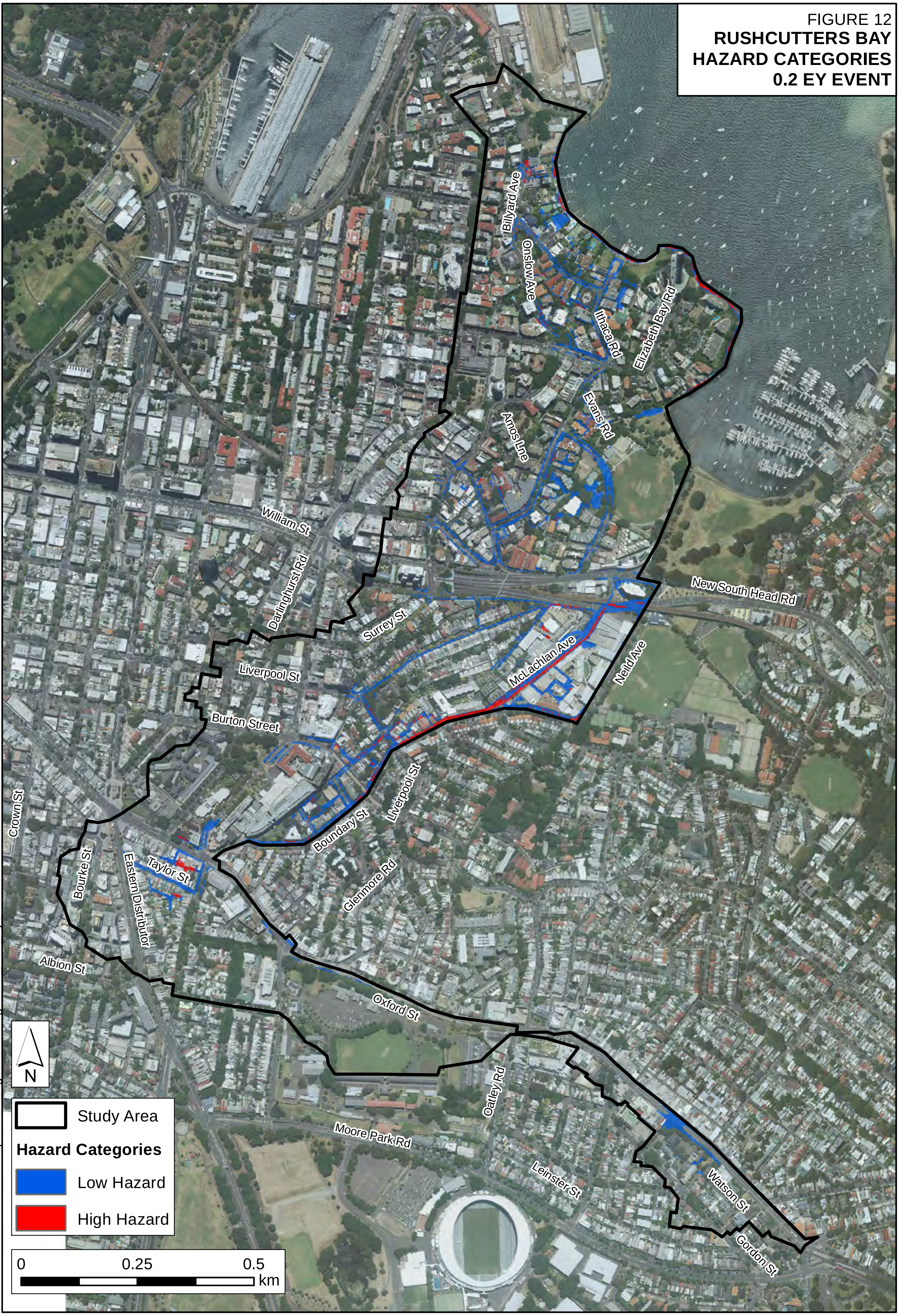
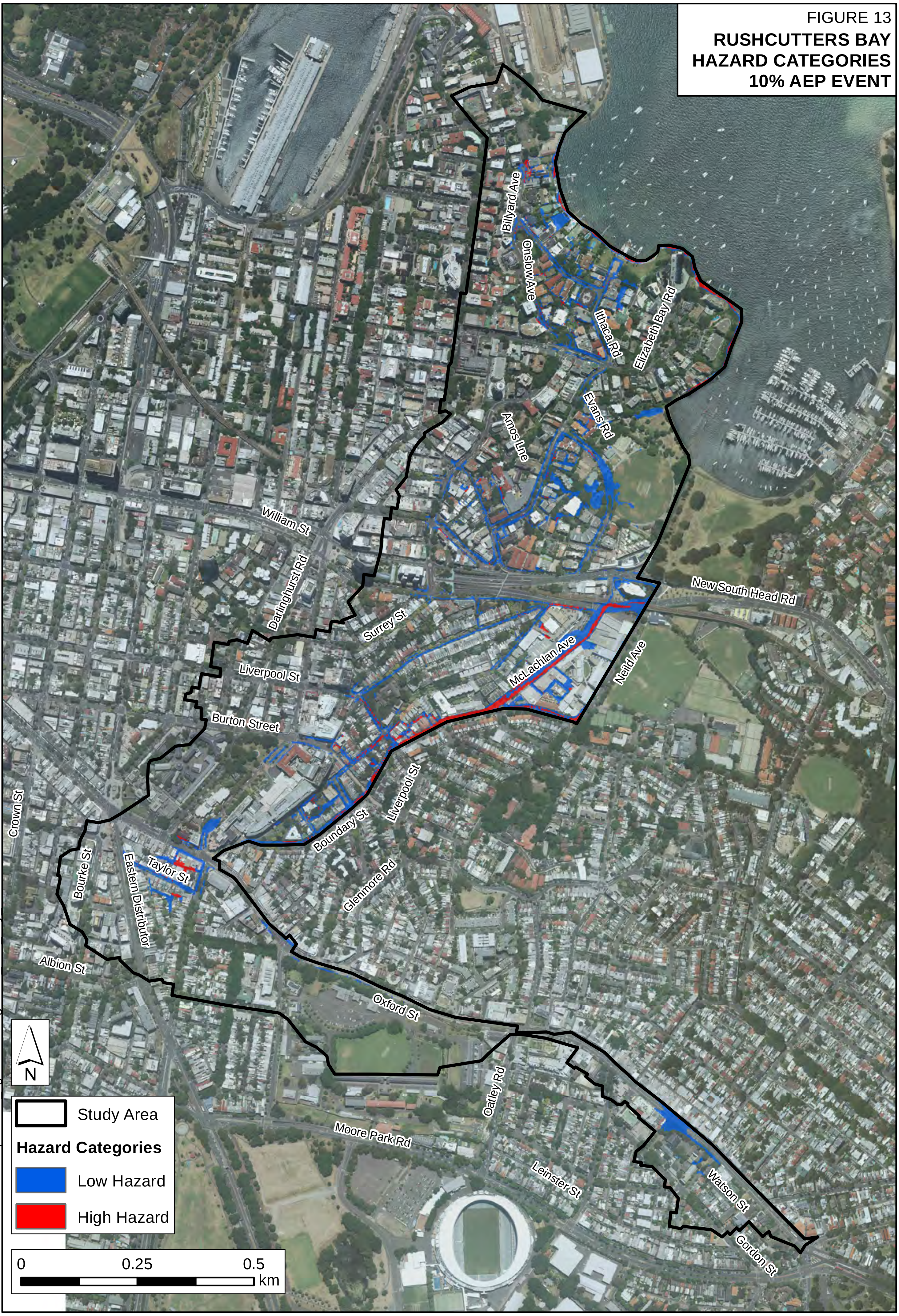


FIGURE 13
RUSHCUTTERS BAY HAZARD CATEGORIES 10% AEP EVENT



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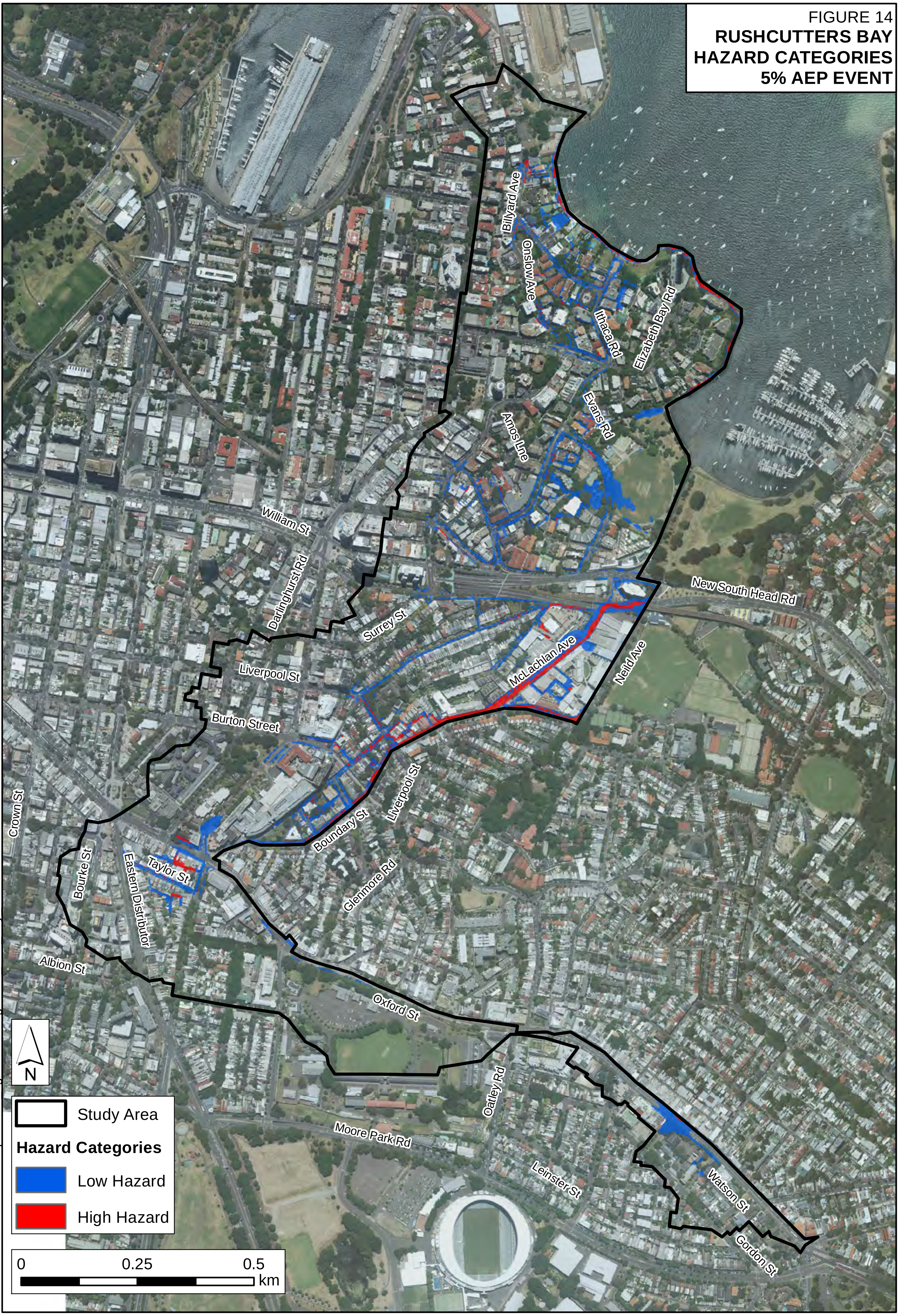
FIGURE 14
RUSHCUTTERS BAY
HAZARD CATEGORIES
5% AEP EVENT
Billyard Ave
Onslow Ave
Ithaca Rd
Elizabeth Bay Rd
Evans Rd
Amos Lne
William St
Darlinghurst Rd
New South Head Rd
Surrey St
McLachlan Ave
Neild Ave
Liverpool St
Burton Street
Liverpool St
Boundary St
Crown St
Bourke St
Eastern Distributor
Taylor St
Glenmore Rd
Albion St
Oxford St
Oatley Rd
Moore Park Rd
Leinster St
Watson St
Gordon St
N
Study Area
Hazard Categories
Low Hazard
High Hazard
0
0.25
0.5
km
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