RUSHCUTTERS BAY CATCHMENT FLOODPLAIN RISK MANAGEMENT STUDY

FINAL REPORT

APRIL 2016

Level 2, 160 Clarence Street
Sydney, NSW, 2000

Tel: 9299 2855
Fax: 9262 6208
Email: wma@wmawater.com.au
Web: www.wmawater.com.au

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Client City of Sydney	**Client's Representative** Shah Alam
Authors Isabelle Testoni Felix Taaffe Steve Gray	**Prepared by**
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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 Rushcutters Bay 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 Rushcutters Bay catchment which are flood liable and within the City of Sydney Local Government Area.

EXECUTIVE SUMMARY

This Floodplain Risk Management Study assesses floodplain management issues in the Rushcutters Bay catchment, and investigates potential management options for the area. The study, which follows on from the draft Rushcutters Bay Flood Study (Reference 2), has been undertaken in accordance with the NSW Government's Flood Prone Land Policy. A full assessment of the existing flood risk in the catchment has been carried out, including flood hazard across the catchment, over floor flooding of residential, commercial and industrial properties, road flooding and emergency response during a flood event. A range of measures aimed at managing this flood risk were also assessed for their efficacy across a range of criteria, which allowed certain options to be recommended, forming the basis of the Floodplain Risk Management Plan for the area. Measures included upgraded trunk drainage networks, emergency management measures, and various property modification measures including Development Control Planning.

Background

The Rushcutters Bay catchment is located 2 km east of the Sydney Central Business District (CBD), in the City of Sydney Local Government Area (LGA). The 90 hectare catchment is fully urbanised, with runoff in the catchment draining to Rushcutters Bay via the area's pit and pipe stormwater system. There are significant overland flowpaths in the catchment, which are active when the capacity of the pit and pipe network is exceeded. Flood liability exists across the area, including locations where overland flow is trapped by unrelieved depressions in the catchment topography, and where overland flow has hazardous depth and velocity.

The Rushcutters Bay Flood Study (2013) was carried out to define existing flood behaviour for the Rushcutters Bay catchment in terms of flood levels, depth, velocities, flows, hydraulic categories and provisional hazard. A 1D/2D TUFLOW hydraulic model was established and verified by a robust calibration/verification process. Following this, the model was used to define flood liability for the 2 year ARI, 5 year ARI, 10%, 5%, 2%, 1%, 0.2% AEP design flood and PMF events. Several flooding hot spots were also identified in the study. In addition, a floor level survey and damages assessment were undertaken to identify properties that are liable to over floor inundation.

Existing Flood Environment

A number of locations within the catchment are flood liable. This flood liability mainly relates to the nature of the topography within the study area as well as the capacity of 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. Sub-surface drainage is not able to route flow from these ground depressions unrelieved by overland flow paths, as the majority of the drainage network reaches capacity during small events (i.e. 2 year ARI).

100 residential properties within the catchment are liable to inundation on the property in the 1% AEP event, while 69 properties are liable in the 2 year ARI event. Of these 20 properties are liable

to over floor inundation in the 1% AEP event, and 3 in the 2 year ARI event. A flood damages assessment for existing development was undertaken, with the average annual damages estimated to be approximately $439,200 for the catchment.

Flooding hotspots in the catchment were identified at the following locations: Boundary Street, Taylor Street, Victoria Street South and the intersection of Barcom Avenue and Liverpool Street. The study identified that effective warning time is zero and that evacuation in place is therefore the default response to extreme floods.

Flood Risk Management Options

The floodplain risk management study also included an investigation of possible options for the management of flood risk in the area. These included structural works such as drainage upgrades, as well as planning measures and SES-related actions. The measures were assessed for their ability to reduce flood risk while also considering their economic, social and environmental impact. A multi-criteria matrix assessment was used to directly compare the options. Of the options investigated, 12 were recommended for implementation, with a priority and time frame assigned to each.

Ref	Options	Priority
RM-RB04	Local Flood Plan and DISPLAN for the Sydney East Emergency Management District	High Priority
PM-RB02	Investigate flood proofing for its feasibility across varied buildings types and flooding behaviour.	High Priority
RM-RB01	Use of Variable Message Displays on affected roads as part of emergency response arrangements	High Priority
PM-RB04	Update Sydney DCP 2012 and LEP 2012 based on FRMS&P outcomes and to inform of Council's Interim Floodplain Management Policy	High Priority
PM-RB01	Review FPLs following completion of FRMS&P for Rushcutters Bay catchment.	High Priority
RM-RB03	Develop ongoing flood awareness and public information programmes for the area	Medium Priority
RM-RB02	Evacuation planning (may be included in the area's DISPLAN and Local Flood Plan.)	Medium Priority
PM-RB03	Investigate the feasibility of a voluntary purchase scheme that includes flood proofing affected properties	Medium Priority
FM-RB02	Boundary Street trunk drainage upgrade from before the intersection of McLachlan Avenue, down Neild Avenue	Medium Priority
FM-RB01	Boundary Street trunk drainage upgrade from before the intersection of McLachlan Avenue, down part of Neild Avenue, outlet into Weigall Sportsground	Medium Priority
FM-RB04	Trunk drainage upgrade on Sims, Taylor, Sturt Streets, down Boundary Street up to Weigall Sportsground	Low Priority
FM-RB05	Pipe and drainage upgrades along Victoria Street	Low Priority

The options that are highly recommended, as per the table, are as follows:

Prepare DISPLAN for the Sydney West Emergency Management District (SES) – The plan would identify responsibilities at a District and Local level with regards to emergency management in preparation for, response to and recovery from flood events. The nature of flooding in the catchment means the focus is likely to be on management of flooded roads in the area. The measure has been given a high priority in the Floodplain Risk Management Plan, based on its positive effect on SES operation in the catchment and the resultant reduction in flood risk.

Investigate Flood Proofing – 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. The measure has been given high priority in the Floodplain Risk Management Plan, based on the number of properties it can benefit and its economic merits.

Use of variable message displays – Variable message displays can be used on main roads to warn motorists and pedestrians of a flood that is occurring. The hazardous nature of flooding on a main road can be underestimated in an urban area, where ponding of floodwaters may appear innocuous. The variable message displays are aimed at reducing the number of people who enter floodwaters by warning of the conditions and recommending an alternative route. The measure has been given a high priority in the Floodplain Risk Management Plan, based on its benefit to the SES and its relative ease of application.

Update Sydney DCP 2012 and LEP 2012 based on FRMS&P outcomes – 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. The measure has been given a high priority in the Floodplain Risk Management Plan, based on its positive effect on long term floodplain risk management in the catchment, and its financial feasibility. The update is recommended to be implemented within City of Sydney in the next 12 months.

Review FPLs following completion of FRMS&P – 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 measure has been given a high priority in the Floodplain Risk Management Plan, based on its positive effect on long term floodplain risk management in the catchment, and its economic merits.

1. INTRODUCTION

1.1. Study Area

The Rushcutters Bay catchment is located in the suburbs of Potts Point, Elizabeth Bay, Kings Cross, Darlinghurst, Paddington and Rushcutters Bay and is shown in 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 90 hectares and drains to Sydney Water Corporation's (SWC) trunk drainage line, which becomes an open channel near the outlet. Once the pipe drainage capacity has been exceeded, water flows overland along streets and other open space. A number of locations in the area are flood liable, mainly as a result of the area's topography, which includes several unrelieved depressions, as well as a major flow path down the LGA's western boundary. This creates a significant drainage/flooding problem in many areas in the catchment, a detailed description of the study area is provided in Section 2.1.

1.2. The Floodplain Risk Management Process

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

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

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

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

- Review the current Draft Rushcutters Bay Catchment Flood Study (2013) and update the hydraulic model to accommodate recent changes in the catchment;
- Extend the hydraulic model to provide design flood information for the adjoining Elizabeth Bay catchment;
- Acquire any additional floor level survey required;
- Review Council's existing environmental planning policies and instruments, identify modifications required to current policies;
- Identify residential flood planning levels;
- Identify and assess works, measures and controls aimed at reducing the impacts and

losses caused by flooding and consider their impacts if implemented, taking into account the potential impacts of climate change; and

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

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

1.3. Relevant Studies

A number of previous studies have been undertaken for the Rushcutters Bay catchment. Most of these are summarised in the Flood Study (Reference 2), however, the following sections provide a review of those which are key to this management study.

1.3.1. Rushcutters Bay SWC No. 84 Catchment Management Study

The Rushcutters Bay SWC No. 84 Catchment Management Study, 1991 (Reference 3) was undertaken as an overall investigation of stormwater drainage and water pollution issues in the catchment. The full length of the open channel and piped system controlled by Sydney Water, Woollahra and the City of Sydney Councils was examined.

A large part of the report covered water quality issues not relevant to this Floodplain Risk Management Study. However, the study also included a comprehensive questionnaire survey sent to 8,900 residents, the results of which have been reproduced in the Flood Study (Reference 2) as they are still relevant.

An ILSAX hydrological model and HEC-2 hydraulic model were developed, and based on the results a cost-benefit analysis was undertaken to assess measures to reduce flooding. The main recommendations from the report (relating to stormwater drainage) were to provide new pipe systems. The study found that many of the pipes in the catchment had a 1 in 1 year ARI capacity.

1.3.2. Rushcutters Bay Catchment Draft Flood Study

The draft Flood Study report (Reference 2) was prepared for City of Sydney by WMAwater in 2013, and examined flooding issues for the portion of the Rushcutters Bay catchment within the City of Sydney LGA.

The study identified a number of trapped low points in the catchment. From this, four hotspots were identified where significant property inundation was likely to occur. The hotspots, all of which are in Darlinghurst, are shown on Figure 2 and are as follows:

1. Taylor Street
2. Boundary Street
3. Barcom Avenue
4. Victoria Street South

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, as well as two sea level rise scenarios, of 0.4 m and 0.9 m. It was found that each incremental 10% increase in flow generally resulted in 0.03 to 0.05 m increase in peak flood levels at most of the locations analysed. The sea level rise scenarios resulted in negligible impact on flood levels within the catchment, the largest impact being 0.05m at Waratah Street assuming a 0.9 m level increase by 2100.

The key outcomes of the Flood Study which are to be discussed, considered or managed in this Management 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. Rushcutters Bay Flood Study Review and Update

The draft Rushcutters Bay 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 complex at 20 Neild Avenue was added to the model. This development regraded footpaths and a garden area within the area. The development has resulted in a reduction in a 1% AEP flood levels of up to 0.72 m on the path between Neild Avenue and McLachlan Avenue and an increase of up to 0.08 m on Neild Avenue. Outside the immediate vicinity of the development site there is minimal impact on the Neild Avenue and Weigall Sportsground.

Secondly, the inverts of several nodes along the trunk drainage line were re-estimated using updated interpolation techniques (no invert data was available). The amendment caused a localised reduction of 0.32 m in the 1% AEP event flood depth at Victoria Street outside St Vincent's Hospital.

Finally, two small changes to building outlines were made to ensure overland flow paths between buildings were more accurately modelled. The impacts of flood levels around the change were minimal.

1.3.4. Elizabeth Bay Flood Study Extension

A Flood Study has not previously been developed for the Elizabeth Bay catchment, and was included as part of the Flood Study review. The Rushcutters Bay model was extended to include the Elizabeth Bay area. Section 3.1 details the model build and results for Elizabeth Bay.

2. CATCHMENT CHARACTERISTICS

2.1. Study Area

The Rushcutters Bay catchment within the City of Sydney local government area (LGA) includes the suburbs of Potts Point, Elizabeth Bay, Kings Cross, Darlinghurst, Paddington and Rushcutters Bay. Land use is predominantly medium to high-density housing as well as commercial developments. The area includes a number of small parks, the largest of which is Rushcutters Bay Park at the catchment outlet.

The catchment encompasses an area of approximately 92 hectares. The catchment area drains into Sydney Harbour at Rushcutters Bay via the Sydney Water Corporation (SWC) open channel, which generally runs in a north-westerly direction between the Weigall and White City sports complexes. The channel floodplain is largely contained within a series of parks and open spaces. The SWC trunk drainage system is linked to Council's local drainage system consisting of covered channels, in-ground pipes, culverts and kerb inlet pits. The drainage system is shown on Figure 3.

The topography of the catchment is steep. The greatest relief occurs at the top of the catchment along Oxford Street (at elevations of 65 mAHD) which slopes north-east at grades of approximately 5% to 10%. The downstream end of the study area is also the flattest part of the catchment, comprising reclaimed lands within Rushcutters Bay Park, which has a relatively gentle ground gradient of 1%. The Elizabeth Bay catchment is reasonably steep with an overall gradient of approximately 10% with some cliff gradients as well.

A number of locations within the catchment are flood liable, driven by the topography and the drainage capacity. Urbanisation throughout the catchment occurred prior to the installation of road drainage systems in the 1900s and some buildings have been constructed on overland flow paths or in unrelieved sags. Due to these drainage restrictions, topographic depressions can cause localised flooding as excess flows have no opportunity to escape via overland flow paths. Aside from the unrelieved depressions, flow in the catchment accumulates along the western boundary of the LGA, which includes Boundary Street, McLachlan Avenue and Neild Avenue, causing a major high hazard overland flowpath in the roadway and flood liability for some of the lower-lying properties.

Any future development in the area is most likely to be in the form of urban consolidation, with aggregation of individual lots to create high density residential developments. An example of this is the recently completed apartment complexes at 20 Neild Avenue.

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 predominantly urban residential development, comprising a mixture of pre-1900 terrace buildings (mostly south of William Street) and new high-rise apartment buildings, including several medium- and high-density developments (mostly north of William Street). The non-residential development in the catchment includes several schools, parks (including the

Rushcutters Bay Park and Weigall Sportsgrounds), churches and community buildings including St Vincent's Hospital. There are no major industrial developments, and commercial developments are primarily concentrated in the upper catchment areas around Oxford Street and Kings Cross. There are some larger commercial sites such as car dealerships/workshops in the lower part of the catchment near Weigall Sportsgrounds.

The effect of urbanisation on the quantity (and quality) of runoff from the catchment was not previously assessed but has been deemed to have been significant as discussed in the Flood Study (Reference 2). As the catchment is already heavily urbanised any new developments are unlikely to produce further significant increases in peak flows.

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 (18-19%), for example French (2%) and Spanish (1.6%), 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 31% of the residents, and around 46 to 60% 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 1.59 people, and a high portion of single person dwellings (58.2% compared to the NSW average of 24.2%). This may need to be considered in any evacuation planning as it may indicate a higher than usual number of properties relative to population. There is also a small average number of motor vehicles per dwelling, with 46.7% of households having no motor vehicles (compared to a NSW average of 10.4%), which might need to be considered in any assumptions regarding evacuation routes (i.e. that they should be traversable by foot rather than vehicle as due to the small proportion of vehicle owners in the catchment).

Demographically, the catchment has approximately average portion of greater than 65 year olds (13.6% compared to 14.7% for NSW), but a lower than average portion of under 14 year olds (4.9% compared to 19.2% for the state), which suggests demographics shouldn't have a significant influence on the consideration of mitigation measures.

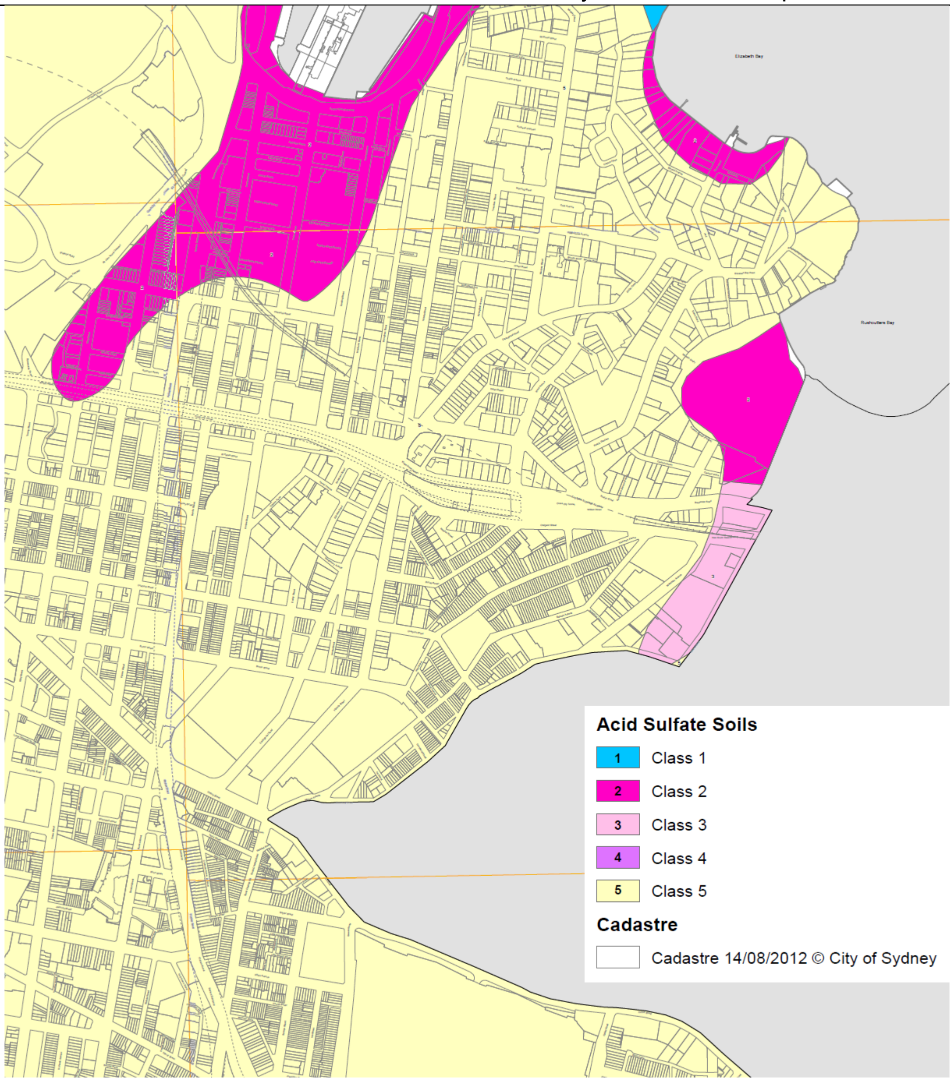
2.1.3. Environmental Features

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

City of Sydney aspires to protect and expand the LGA's urban forest. This includes a list of protected Significant Trees, of which a number of trees in Elizabeth Bay are listed, as well as some sporadically throughout the rest of the catchment. Mitigation measures assessed by this study will consider the value that is placed upon trees in the catchment when there is a potential impact.

Other environmental features of interest in the catchment are;

- The catchment is classified as a general conservation area with a number of conservation buildings identified. No aboriginal heritage sites have been identified in the catchment
- there are no Record of Notices of contaminated land in the catchment area
- The majority of the Rushcutters Bay catchment has an Acid Sulphate Soils classification of 5 (works within 500m adjacent of an area classified 1 -4 and likely to reduced groundwater levels by 1m or more are likely to present an environmental risk) besides a small area adjacent to the bay which is classed as 2 (any works undertaken in this area is likely to present an environmental risk). Maps of the Acid Sulphate Soils classification have been taken from the Sydney LEP (Reference 4) and are presented here.



Sheets ASS_021 and ASS_022 from Sydney LEP 2012

2.1.4. Historical Flood Events

Significant catchment development occurred in the latter part of the 19th century, alongside a major increase in the broader Sydney population between 1860 and 1890. The current catchment population is of the order of 15,000 (Reference 3). Early references clearly identify parts of the lower catchment as low lying and swampy. There was also mention of surface and stormwater problems (flooding and water quality).

The effect of urbanisation on the quantity (and quality) of runoff from the catchment has not been assessed but would have been significant. As the catchment is already heavily urbanised any new developments are unlikely to produce further significant increases in peak flows.

There have been many instances of flooding in the past with 8-9 November 1984, 6 January 1989 and 26 January 1991 being some of the more significant storm events causing extensive flooding throughout the catchment. Over a 20 minute duration, the 1989 event had an approximate ARI of 50 years, while the 1991 event was closer to a 40 year ARI.

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 (except for the open channel near the outlet).

Figure 5 shows the area's creeks as they were recorded on 'Woolcott & Clarke's Map of the City of Sydney' (dated 1854), 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, including at Taylor Street, Boundary Street and Neild Avenue. It should be noted that the misalignment of the creek with the current overland flowpath at the north end of Boundary Street has likely been caused by small inaccuracies in the original map.

3. EXISTING FLOOD ENVIRONMENT

The existing flood risk for the Rushcutters Bay catchment is defined by the design flood affection in the Flood Study (Reference 2). No similar study had already been undertaken for the Elizabeth Bay catchment, and so was assessed as part of the current study, the details of which are provided in Section 3.1 below.

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 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. Elizabeth Bay Flood Study Extension

Figure 6 the flood affection for the Elizabeth Bay area as determined by the flood study extension. This shows that the area does not have any significant locations of major hazard or flood affectation. The one area of significant depth in the area is a carpark just off the Esplanade at the bottom on the catchment. All floor levels in the catchment are at the second storey and so overfloor inundation is expected to be minimal.

The following sections detail the modelling process used to define the existing flood environment.

3.1.1. Hydrologic Modelling

Sub-Catchments

A hydrological model of the study catchment was established using the DRAINS software package (Reference 7).

Sub-catchment areas were delineated based on LiDAR survey and making the assumptions that:

- properties generally drain to streets or inlet pits; and
- flow in streets is along gutters and uni-directional.

The DRAINS hydrologic runoff-routing model was used to determine hydraulic model inflows for the local sub-catchments within the study area.

Key Model Parameters

Model parameters used in the Elizabeth Bay model were directly taken from either;

- Terrain information (imperviousness percentage etc.) or,
- The Rushcutters Bay DRAINS model.

To provide consistency between the extension and the existing model the same parameters were used. This is a valid assumption as the catchment is immediately adjacent to the existing modelled area.

3.1.2. Hydraulic Modelling

A TUFLOW model (Reference 6) of Elizabeth Bay was developed as part of this study. It was added onto the existing Rushcutters Bay model and the model area was extended.

Terrain Model
A digital terrain model was established using the existing LiDAR dataset. A computational grid cell size of 2 m by 2 m was adopted, as it provided an appropriate balance between providing sufficient detail for roads and overland flow paths, while still resulting in practicable computational run-times. It was also consistent with the grid size used in the Rushcutters Bay model.

Buildings and other structures likely to act as significant flow obstructions were incorporated into the terrain model. These features were identified from the available aerial photography and modelled as impermeable obstructions to the flood flow (i.e. they were removed from the model grid).

The footpath representation in Elizabeth Bay was given in-depth attention particularly on Ithaca Road. The schematisation of the footpath on Ithaca Road is crucial as the street is a flow path and properties on the street may be inundated. Flow paths between buildings on Ithaca Road were also investigated through aerial photos and a site visit.

Boundary Conditions
The tailwater conditions used the in Rushcutters Bay model were adopted for Elizabeth Bay. The details of these can be found in the Rushcutters Bay Flood Study (Reference 2).

Hydraulic Roughness
The adopted roughness values are consistent with the Rushcutters Model and previous experience with modelling similar catchment conditions.

Table 1 - Mannings ‘n’ values

Surface Type	Manning’s “n” value
Very short grass or sparse vegetation	0.035
General overland areas, gardens, roadside verges, low density residential lots etc. (default)	0.045
Medium density vegetation	0.060
Heavy vegetation	0.100
Roads, paved surfaces	0.025
Concrete pipes	0.013

Culvert Type	Manning’s “n” value
Concrete pipes	0.013
Clay Pipes	0.025
Brick	0.014
PVC	0.011

Critical Duration

To determine the critical storm duration for various parts of the catchment, modelling of the 1% AEP event was undertaken for a range of design storm durations from 15 minutes to 12 hours. An envelope of the model results was created, and the storm duration producing the maximum flood depth was determined for each grid point within the study area.

The critical duration within the catchment varies. A significant portion of the catchment has a critical duration of 90 minutes, though for a number of locations this increased to 120 minutes. The resulting difference in peak levels however, was less than ±0.01 m. As the critical duration for Rushcutters Bay was 120 minutes and given the trivial difference in levels, it was considered appropriate to adopt the longer duration for Elizabeth Bay also.

Calibration and Validation

It is preferable to test the performance of the hydrological and hydraulic models against observed flood behaviour from past events within the catchment. The assumed model parameters can then be adjusted so that the modelled behaviour best represents the historical patterns of flooding. The process of adjusting model parameters to best reproduce observed flood behaviour is known as model *calibration*. Usually, the models are calibrated to a single flood event for which there is sufficient flood data available (e.g. peak-flood levels, observations regarding flow paths or flood extents etc.). The performance of the calibrated model can then be tested by simulating other historical floods and comparing the ability of the calibrated models to reproduce the observed behaviour. This process is known as model *validation*.

Model calibration and verification is reliant on sufficient amounts of historic flood data being available. The largest flood events known to have occurred within the catchment occurred on 8-9 November 1984, 6 January 1989 and 26 January 1991. For these major events, there is limited flood height data, and only anecdotal or approximate depths were available. However, the data available does not fall within the extension of the Rushcutters Bay model of Elizabeth Bay. Furthermore, there is no stream gauge within the Elizabeth Bay catchment. This meant it was not possible to conduct a thorough calibration of modelled flows to observed data. However, since the Rushcutters Bay model was able to be calibrated for a number of events and locations, the same parameters were used.

3.2. 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 9), the Flood Study (Reference 2) defined hydraulic categories as:

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

The hydraulic categories for the 5% AEP, 1% AEP and PMF events, are shown on Figure 8 to Figure 10. The main overland flow path is along Boundary Street, with the entire street classed as floodway. Other less significant floodways are present on Taylor Street and Barcom Avenue. Taylor Street is also in the area of flood storage on Sturt Street and Sims Street. Victoria Street has a significant area of flood storage just outside of St Vincent's hospital at the intersection of Oxford Street.

3.3. Flood Hazard Classification

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

Provisional hazard was established as part of the Flood Study (Reference 2) based on the Floodplain Development Manual criteria (Appendix L of the Floodplain Development Manual). Due to the combination of high flood depths and velocities, many regions of the catchment are affected by high hazard flows. Figure 11 to Figure 18 show the flow hazard classification throughout the catchment for the 50%, 20% 10%, 5%, 2%, 1% and 0.2% AEP and PMF events. It can be seen that during the 50% AEP flood event the Boundary Street-McLachlan Avenue flowpath has high hazard flows, as well as some south of Oxford Street in Sturt Street. These areas have slightly increased high hazard in the 1% AEP, as well as an area in front of St Vincent's Hospital.

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 Rushcutters Bay catchment

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

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

The concept of rate of rise of flood waters is more applicable to mainstream flooding scenarios, where a fast rate of rise can leave residents unaware of the flood event, and they can become stranded. However, the rate of rise in this catchment is fast (up to 1-1.5 m/hour in both the 5% and 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 16 for the 1% AEP event. The vehicular and pedestrian access routes are all along sealed roads and present to unexpected hazards if the roads have been adequately maintained.

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

- Oxford Street west of South Dowling Street,
- Taylor Street and Sims Street,
- Victoria Street north of Oxford Street,
- Hopewell Street north of Hopewell Lane,
- Comber Street south of Boundary Street,
- Boundary Street,
- McLachlan Avenue,
- Neild Avenue.

At a depth of 0.3 m, 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. This is further discussed in Section 9.4.2.

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 19 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 McLachlan Avenue, Nelid Street, Boundary Road, Oxford Street etc) where it may take a few hours to drain, assuming the piped network is operating efficiently (i.e. without blockages).

3.4. Hotspots

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

The Flood Study (Reference 2) informally identified several such hotspots. Additional flood level survey undertaken as part of the current study expanded the assessment of property flooding, but did not result in the identification of any additional hotspots. The current study also undertook some further assessment of the hotspots through more detailed analysis of the model in conjunction with the flood damages assessment. The refined hotspots are as follows:

3.4.1. Boundary Street

Boundary Street constitutes the main overland flowpath in the middle section of the Rushcutters Bay catchment, and as such, it conveys a significant overland flow in all flood events. The existing feeder pipes reach capacity in the 50% AEP event and as such excess discharge flows overland for events larger than this. Trunk drainage exists along Boundary Street and extends to the outlet at Rushcutters Bay. Along Boundary Street, there is between 0.2 m and 0.7 m of depth in the 10% AEP event and up to 0.9 m in the 1% AEP event.
Figure 24 shows the hotspot in detail, including the areas where runoff accumulates and the area's drainage.

The high velocities that occur in the hotspot result in significant areas of high hydraulic hazard across the range of design events. In a 50% AEP event, Boundary Street and McLachlan Avenue have high hazard in the gutters, while in the 1% AEP event the high hazard area covers the majority of Boundary Street, McLachlan Avenue and parts of Neild Avenue. The area has a long duration of flooding relative to the rest of the catchment, but can still be expected to drain within 2 hours in a 1% AEP, 1 hour duration event, given the trunk drainage is functioning.

The hotspot has significant property inundation and cuts off vehicle and pedestrian thoroughfares. 13 properties are inundated above floor level in the 50% AEP event, while there are 22 properties inundated in the 1% AEP event. There is significant risk of damage of property in the area with many properties directly at or below street level. There is also 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.

3.4.2. Taylor Street

The area consists of three trapped low points on Taylor, Sims and Sturt Street. Piped drainage is relied on to transmit flow from the area, as the topography slopes up from the area (towards both Oxford Street, South Dowling Street and Flinders Street), creating an unrelieved depression. Sturt Street has a depth of up to 1.65 m in the 10% AEP event; while the 1% AEP event has depths of up to 1.69 m. Figure 29 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, Sturt Street and the elbow of Sims Street has high hazard ponding, while in the 1% AEP event the high hazard area covers the east part of the Sturt Street, some spots on Taylor Street and the elbow and yards in Sims Street. Sims Street and Sturt Street have 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. In the same event, Taylor Street has a shorter duration of flooding of less than 30 minutes.

The hotspot has significant property inundation but does affect any vehicle or pedestrian thoroughfares. Two properties are inundated above floor level in the 50% AEP event, while there are 22 properties inundated in the 1% AEP event. There is significant risk of damage of property in the area with many houses directly on street level. Vehicles are also at risk of damage by street parking in the area and high flood depths.

3.4.3. Victoria Street South

Similar to Taylor Street, the area is a flood storage area. Piped drainage is relied on to transmit flow from the area, as the topography slopes up from the area (towards both Oxford Street and along Victoria Street to the north), creating an unrelieved depression. Victoria Street has a depth of 0.44 m in the 10% AEP event, while in the 1% AEP depths reach up the 1.1 m directly outside St Vincent's Hospital Clinic. Figure 34 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 areas of high hydraulic hazard from the 2% AEP event to rarer events. In a 50% AEP event, Victoria Street only has low hazard ponding, while in the 1% AEP event the high hazard area extends across the road in the lowest part of Victoria Street. Victoria Street has a long duration of flooding relative to the rest of the catchment, but can still be expected to drain within 2 hours in a 1% AEP, 1 hour duration event, given the trunk drainage is functioning.

The hotspot has no property inundation but does cut off a vehicle and pedestrian thoroughfare. The area poses risk to both vehicles and pedestrians in frequent events such at the 50% AEP event and a significant risk in larger events. It is also a potential risk to the Hospital's function, as there is a main entrance in the area. Although the hotspot does not occur at the emergency response entrance, it is still considered a significant issue as it impedes access to the hospital facilities.

3.4.4. Barcom Avenue

The area of interest is at the intersection of Barcom Avenue and Liverpool Street. The flood study (Reference 2) indicated that a number of houses would be inundated in the 50% AEP flood event even though depths on the road are not significant (less than 0.3 m). Through the community consultation it was made apparent that the assessment of over floor inundation in the 50% AEP event was overstated. The method for tagging properties as inundated was updated (Section 5.1) and the properties are no longer classified as flooded (in any event, up to and including the PMF). No further assessment of the area as a hotspot was made.

Mitigation measures for the hotspots are discussed in Section 9.3.

3.5. 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)	Rainfall Increase 10%	Rainfall Increase 20%	Rainfall Increase 30%	Sea Level Rise 2050	Sea Level Rise 2100
			Difference with 1% AEP Base Case (m)				
1	Sims Street	1.1	0.01	0.03	0.06	-	-
2	Oxford Street (West)	1.0	0.10	0.16	0.21	-	-
3	Victoria Street	1.8	-	-	0.03	-	-
4	Taylor Street	0.9	0.02	0.04	0.05	-	-
5	Sturt Street	0.5	0.03	0.08	0.11	-	-
6	Victoria St adjacent St Vincents Hospital	1.7	0.02	0.05	0.07	-	-
7	Boundary Street	1.3	0.06	0.11	0.15	-	-
8	McLachlan Ave	0.6	0.03	0.06	0.09	-	-
9	Neild Ave and New South Head Rd	0.8	0.03	0.05	0.08	-	-
10	Kellett Place	0.3	0.02	0.04	0.05	-	-
11	Waratah Street	0.8	0.03	0.05	0.07	-	-
12	Sims Street	0.5	0.02	0.04	0.06	-	-

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 Oxford Street, Sturt Street and Boundary Street. The analysis also found that a rise in sea level has no impact in the majority of the catchment. 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 open channel passes into the bay.

4. STAKEHOLDER CONSULTATION

4.1. Community Consultation

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

- Distribution of brochure and questionnaire survey;
- Media release;
- The Floodplain Risk Management Committee;
- City of Sydney's website; and
- Public meetings.

4.1.1. Previous Consultation

As part of the Flood Studies (Reference 2), community questionnaire surveys were undertaken during October-November 2012 to gather historical data for model calibration. 792 surveys were distributed to residents within the Rushcutters catchment. 36 responses were received, which equates to a return rate of 5%. Unfortunately few flood levels or depths were provided although the reported flood observations were able to be used as a means of model verification. It was found that there was not one historic event in particular that the residents within the study area identified as being significant, although June 2007 was identified as an event of notoriety. Approximately 75% of respondents are aware of flooding or have some knowledge of flooding in the study area. Further, almost half of the respondents reported flooding on roads, which serve as formalised overland flow paths in this catchment as the sub-surface drainage system is overwhelmed by the runoff volume associated with more extreme events.

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. 826 copies of the newsletters and questionnaires were printed and delivered to the owners of properties likely to be aware of flooding issues. In total 45 responses were received constituting a 5% return rate and the results are as shown in Figure 20. The newsletter and questionnaire is shown in Appendix B.

36% of the respondents experienced some form of flooding within the catchment and 4 respondents reported floodwaters entering their houses or businesses. Many residents expressed concern in regards to the maintenance of the drainage assets within the study area whereby leaves and debris have not been sufficiently cleared from the entry points resulting in local nuisance flooding and exacerbation of existing flood problems.

Among the preferred management options for managing flood risks within the catchment: defined flow paths, pit/pipe upgrades, education of the community and retarding basins were the most popular. The least desired options were levees and improved culverts.

4.1.3. Community Information Session

Two community information sessions were held. These were:

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

4.2. Floodplain Committee Meetings

The Floodplain Management Committee (FMC) oversees and assists with the floodplain risk management process being carried out within the Council LGA. The committee is comprised of representatives from various stakeholder groups and includes local Councillors, emergency services (SES), Sydney Water Corporation and community representatives. Progress on the current study has been presented to the committee at 3 month intervals, at which point questions or feedback from the various representatives were taken.

4.3. Internal Stakeholders Workshop

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

4.4. Public Exhibition

4.4.1. Summary of Submissions

Draft reports of the Rushcutters Bay Floodplain Risk Management Study and Plan were placed on Public Exhibition in August 2015 in order to present the findings of the study to the public. The exhibition period was advertised via a letter sent to property owners within the PMF flood extent, and online versions of the reports were made publicly available on the City of Sydney website. Further to this, stalls were setup at Paddington Markets (25th July) and Kings Cross Organic Food Market (1st August) to present the findings of the Rushcutters Bay FRMS&P alongside corresponding reports and plans for Woolloomooloo and Centennial Park.

No responses were received in regard to the report exhibited.

4.4.2. Discussion

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

5. ECONOMIC IMPACT OF FLOODING

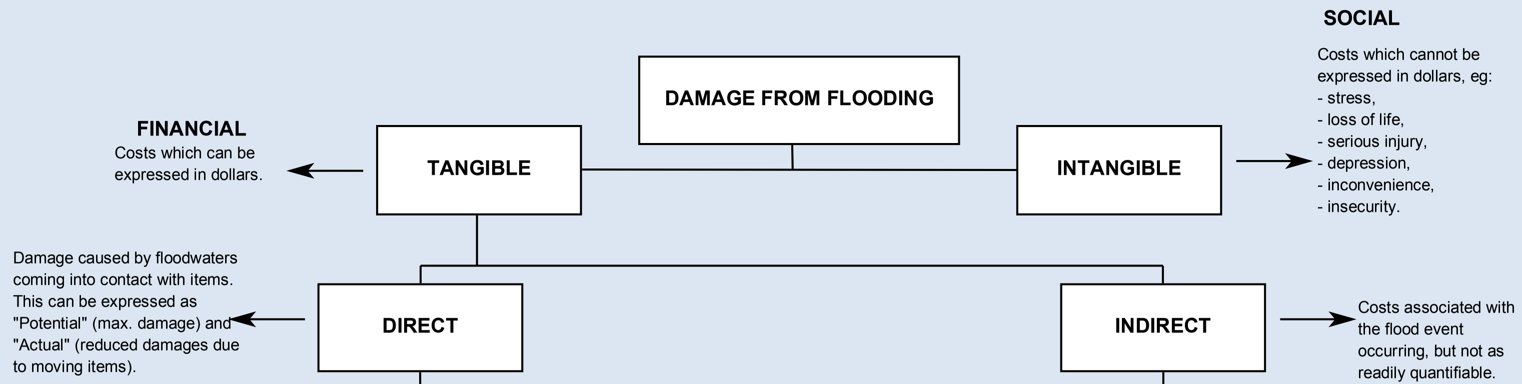
The impact of flooding can be quantified through the calculation of flood damages. Flood damage calculations do not include all impacts associated with flooding. They do, however, provide a basis for assessing the economic loss of flooding and also a non-subjective means of assessing the merit of flood 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 21.

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 proposed mitigation options. Understanding the total damages prevented over the life of the option in relation to current damages, or to an alternative option, can assist in the decision making process.

The standard way of expressing flood damages is in terms of average annual damages (AAD). AAD represents the equivalent average damages that would be experienced by the community on an annual basis, by taking into account the probability of a flood occurrence. This means the smaller floods, which occur more frequently, are given a greater weighting than the rare catastrophic floods.

In order to quantify the damages caused by inundation for existing development a floor level survey was undertaken. As part of this floor level survey work an indicative ground level was recorded for use in the damages assessment. This was used in conjunction with modelled flood level information to calculate damages. Damage calculations were carried out for all properties within the 1% AEP flood extent, and floor level survey was undertaken for these properties. It should be noted that 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.

A flood damages assessment was undertaken as part of the Flood Study (Reference 2) for existing development in accordance with current OEH guidelines (Reference 10) and the Floodplain Development Manual (Reference 1). As additional properties floor levels were surveyed as part of this study (and old flood models revised), the estimated flood damages were revised. The damages were calculated using a number of height-damage curves which relate the depth of water above the floor with tangible damages. Each component of tangible damages is allocated a maximum value and a maximum depth at which this value occurs. Any flood depths greater than this allocated value do not incur additional damages as it is assumed that, by this level, all potential damages have already occurred.

Rushcutters Bay has a small catchment size (92 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.

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 Rushcutters Bay 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	200	119	$ 11,558,600	$ 57,800
0.2%	156	55	$ 6,640,100	$ 42,600
1%	145	45	$ 5,434,200	$ 37,500
2%	137	41	$ 4,861,800	$ 35,500
5%	131	35	$ 4,248,900	$ 32,400
10%	117	23	$ 3,155,500	$ 27,000
20%	110	17	$ 2,570,300	$ 23,400
50%	92	14	$ 2,141,100	$ 23,300
Average Annual Damages (AAD)			**$ 1,967,900**	**$ 9,800**

Section 9.3.6 presents results of the damages assessment undertaken for the proposed mitigation options which were compared against the existing scenario so that the feasibility of the proposed mitigation options can be determined.

5.1.1. Residential Properties

The flood damages assessment for residential development was undertaken in accordance with OEH guidelines (Reference 10). 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 Rushcutters Bay 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 Rushcutters Bay 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	138	76	$ 4,438,100	$ 32,200
0.2%	106	24	$ 1,662,700	$ 15,700
1.0%	100	20	$ 1,395,200	$ 14,000
2.0%	94	19	$ 1,313,300	$ 14,000
5.0%	90	16	$ 1,140,400	$ 12,700
10.0%	84	9	$ 821,900	$ 9,800
20.0%	82	5	$ 610,300	$ 7,400
50.0%	69	3	$ 395,700	$ 5,700
Average Annual Damages (AAD)			**$ 439,200**	**$ 3,200**

5.1.2. Commercial and Industrial Properties

The tangible flood damage to commercial and industrial properties is more difficult to assess. Commercial and industrial damage estimates are more uncertain and larger than residential damages. Commercial and industrial damage estimates can vary significantly depending on:

- Type of business – stock based or not;
- Duration of flooding – affects how long a business may be closed for not just whether the business itself if closed but when access to it becomes available;

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

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

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

No specific guidance is available for assessing flood damages to non-residential properties. Therefore for this Study, commercial and industrial damages were calculated using the methodology for residential properties but with the costs/damages increased to a value which is consistent with commercial/industrial development. For 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 Rushcutters Bay catchment is provided in Table 7. AAD for the surveyed commercial/industrial properties is less than that for residential properties but the number of flood affected properties for the latter is 2 to 3 times more than that of the former. This reflects the higher costs that businesses would incur compared to residential dwellings when flooded above floor level. On a per property basis the AAD is approximately 5.8 times higher when comparing the commercial/industrial properties against the residential properties.

Table 7: Estimated Commercial and Industrial Flood Damages for Rushcutters Bay 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	62	43	$ 7,120,500	$ 114,800

0.2%	50	31	$ 4,977,400	$ 99,500
1.0%	45	25	$ 4,039,000	$ 89,800
2.0%	43	22	$ 3,548,400	$ 82,500
5.0%	41	19	$ 3,108,500	$ 75,800
10.0%	33	14	$ 2,333,600	$ 70,700
20.0%	28	12	$ 1,960,000	$ 70,000
50.0%	23	11	$ 1,745,300	$ 75,900
Average Annual Damages (AAD)			**$ 1,528,800**	**$ 24,700**

5.1.3. Climate Change

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

Table 8: Estimated Combined Flood Damages Under Climate Change Scenario

Event	Number of Properties Flood Affected	No. of Properties Flooded Above Floor Level	Total Tangible Flood Damages	Average Tangible Damages Per Flood Affected Property
PMF	201	131	$ 12,744,500	$ 63,400
0.2%	158	57	$ 6,828,200	$ 43,200
1.0%	149	52	$ 6,194,100	$ 41,600
2.0%	143	43	$ 5,238,400	$ 36,600
5.0%	137	41	$ 4,848,300	$ 35,400
10.0%	129	31	$ 3,862,300	$ 29,900
20.0%	126	27	$ 4,012,600	$ 31,800
50.0%	92	14	$ 2,141,100	$ 23,300
Average Annual Damages (AAD)			**$ 2,349,800**	**$ 11,700**

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 Rushcutters catchment area, the high hazard areas include Boundary Street and trapped low points with high flood depths, i.e. at Sturt and Taylor 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 Rushcutters Bay catchment is characterised by overland flow, with no mainstream flooding and only a small area of minor tidal influence near the downstream end of the catchment. The critical duration is between 30 minutes 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 Rushcutters Bay catchment are discussed as follows.

6.2.1. DISPLAN

The Rushcutters Bay 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 Rushcutters Bay 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 Rushcutters Bay 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 Rushcutters Bay 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 Rushcutters Bay 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 Rushcutters Bay 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 Rushcutters Bay 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 (New South Head Road) and one main road (Oxford Street) that are flood affected, and a number of other roads where traffic will be impeded in a flood event. Both arterial roads connect the CBD to the eastern suburbs and convey a significant volume of vehicle traffic. As shown in Table 9, the depth of inundation on Oxford Street varies from 0.1 m in frequent events to 0.3 m in a 1% AEP event and 0.7 m in the PMF, while New South Head Road has around 0.6 m in frequent events, 0.9 m in a 1% AEP event and 1.5 m in the PMF. Table 9 also lists the depths for other roads in the catchment, while Figure 22 shows their locations.

Table 10 lists the rate of rise in metres per hour for the same locations listed in Table 9, for the 2 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 higher for locations in the downstream half of the catchment, with Boundary Street and New South Head Road generally rising around 1 m/hour, for the 2 hour event.

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

ID	Road Location	2 year ARI	5 year ARI	10% AEP	5% AEP	2% AEP	1% AEP	0.2% AEP	PMF
1	Oxford Street near Victoria Street	0.1	0.1	0.1	0.2	0.2	0.3	0.4	0.7

2	Victoria Street near Oxford Street	0.2	0.3	0.4	0.6	0.8	1.0	1.4	1.8
3	Boundary Street near Neild Avenue	0.5	0.6	0.6	0.7	0.7	0.7	0.8	1.2
4	Craigend Street/New South Head Road near McLachlan Avenue	0.6	0.7	0.7	0.8	0.8	0.9	1.1	1.5

Table 10: Major Road Flooding Rate of Rise (m/hour) for Various Events (2 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	Oxford Street near Victoria Street	0.2	0.2	0.2	0.2	0.2	0.4	0.6	4.4
2	Victoria Street near Oxford Street	0.4	0.5	0.6	0.8	1.0	1.3	1.9	9.5
3	Boundary Street near Neild Avenue	1.0	1.1	1.2	1.2	1.3	1.3	1.4	9.0
4	Craigend Street/New South Head Road near McLachlan Avenue	0.8	1.0	1.0	1.1	1.2	1.3	1.4	7.4

For the 1% AEP flood event, roads cut (as per Figure 22) are shown in Table 11.

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

Road Location	Description
Oxford Street near Victoria Street	Flood depths are up to 0.3 m and persist for a period of 30 minutes to one hour given the critical storm modelled (2 hour)
Victoria Street near Oxford Street	Flood depths are up to 1.3 m and persist for a period of up to 2 hours given the critical storm modelled (2 hour)
Boundary Street near Neild Avenue	Flood depths are up to 0.7 m and persist for between 15 minutes and 2 hours, depending on the location along the street, for the 2 hour storm.
Craigend Street/New South Head Road near McLachlan Avenue	Flood depths are up to 0.9 m and persist for between 1 and 2 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 8) 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 8). The ERP classification can identify the type and scale of information needed by the SES to assist in emergency response planning (refer to Table 12).

Table 12: Emergency Response Planning Classifications of Communities

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

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

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

Flood liable areas within the study area have been classified according to the ERP classification above, with the additional criteria of flood depths being greater than 0.1 m. If only the flood extent was used in the Rushcutters 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 7.

This figure shows that a large proportion of the study area has been classified as high flood island due to the reasonably high depths that would occur in road reserves surrounding properties, prior to inundation of the properties themselves. Adjacent to this are several rising road access areas which allow access out of the flood affected area.

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 Rushcutters Bay and Elizabeth Bay are 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 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 5) 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 Policy outlines Council's responsibilities for 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 5). Reference to this policy should be included in the DCP or the key controls outlined in the Policy could also be included in the DCP. Council's current position on climate change requirements should also be informed in the DCP as outlined in the Policy;
- Consideration of emergency response provisions in new development with regards to short duration flooding in the catchment should also be included in the Interim Floodplain Management Policy (Reference 5); and
- There may be opportunities to incorporate flood management measures into new developments as a condition of consent, Section 94 contribution offsets or government related funding. The nature of the flood controls implemented will be dependent on the location of the development, the flooding behaviour and the type of development. However, allowance and / or requirements for these works could be identified through amendments to the Sydney DCP 2012 or the Interim Floodplain Management Policy (Reference 5).

8. FLOOD PLANNING

8.1. Flood Planning Level (FPL)

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

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

- Risk to life;
- Long term strategic plan for land use near and on the floodplain;
- Existing and potential land use;
- Current flood level used for planning purposes;
- Land availability and its needs;
- FPL for flood modification measures (levee banks etc);
- Changes in potential flood damages caused by selecting a particular flood planning level;
- Consequences of floods larger than that selected for the FPL;
- Environmental issues along the flood corridor;
- Flood warning, emergency response and evacuation issues;
- Flood readiness of the community (both present and future);
- Possibility of creating a false sense of security within the community;
- Land values and social equity;
- Potential impact of future development on flooding;
- Duty of care.

8.1.1. Likelihood of Flooding

As a guide, Table 13 has been reproduced from the NSW Floodplain Development Manual 2005 to indicate the likelihood of the occurrence of an event in an average lifetime to indicate the potential risk to life.

Analysis of the data presented in Table 13 gives a perspective on the flood risk over an average lifetime. The data indicates that there is a 50% chance of a 100 Year ARI (1% AEP) event occurring at least once in a 70 year period. Given this potential, it is reasonable from a risk management perspective to give further consideration to the adoption of the 1% AEP flood event as the basis for the FPL. Given the social issues associated with a flood event, and the non-tangible effects such as stress and trauma, it is appropriate to limit the exposure of people to floods.

Note that there still remains a 30% chance of exposure to at least one flood of a 200 Year ARI (0.5% AEP) magnitude over a 70 year period. This gives rise to the consideration of the adoption of a rarer flood event (such as the PMF) as the flood planning level for some types of development.

Table 13: Likelihood of given design events occurring in a period of 70 years

Likelihood of Occurrence in Any Year (ARI)	Probability of Experiencing At Least One Event in 70 Years (%)	Probability of Experiencing At Least Two Events in 70 Years (%)
10	99.9	99.3
20	97	86
50	75	41
100	50	16
200	30	5

8.1.2. Land Use and Planning

The hydrological regime of the catchment can change as a result of changes to the land-use, particularly with an increase in the density of development. The removal of pervious areas in the catchment can increase the peak flow arriving at various locations, and hence the flood levels and flood hazards can be increased.

A potential impact on flooding can arise through the intensification of development on the floodplain, which may either remove flood storage or impact on the conveyance of flows. The Sydney DCP 2012 currently outlined controls relating to the installation of onsite detention to manage increased impervious area. No provisions exist within the current DCP 2012 or LEP 2012 to limit development within floodway or areas or limit filling in storage areas. Provisions to these issues, however, have been included in the Interim Floodplain Management Policy (Reference 5).

8.1.3. Freeboard Selection

A freeboard ranging from 0.3 – 0.5 metres is commonly adopted in determining the FPL. The freeboard accounts for uncertainties in deriving the design flood levels and as such should be used as a safety margin for the adopted FPL. The freeboard may account for factors such as:

- Changes in the catchment;
- Changes in flowpath vegetation;
- Accuracy of the model inputs (e.g. ground survey, design rainfall inputs for the area);
- 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 (0.01 m to 0.21 m, mean 0.06 m, as per Rushcutters Bay Flood Study (2013))

- Climate change impacts on sea level rise (negligible impact, as per Rushcutters Bay 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 5) is suitable for the catchment. The policy specifies a freeboard of 500 mm, except for in areas with local drainage flooding. In the policy, local drainage flooding refers to where there the 1% AEP depth is less than 0.25 m and the area is not in, or influenced by, a trapped low point. In these areas, the flood planning level is two times the depth of flow with a minimum of 0.3 m. Given the difference in flood depth between the 1% AEP and the PMF in the catchment, this freeboard is suitable for local drainage flooding.

When applied to design events less than the PMF, the freeboard may still result in the FPL being higher than the PMF in certain cases.

8.1.4. Current FPL as Adopted by Council

FPL requirements have been outlined by Council in their Interim Floodplain Management Policy (Reference 5). This policy was tested each time a development application was received. The policy provides further details regarding flood planning levels for various types of development within the floodplain and these are outlined in Table 14.

Table 14: Adopted Flood Planning Levels in CoS Interim Floodplain Management Policy (Reference 5)

<table>
<tr><th colspan="2">Development</th><th>Type of flooding</th><th>Flood Planning Level</th></tr>
<tr><td rowspan="4">Residential</td><td rowspan="3">Habitable rooms</td><td>Mainstream flooding</td><td>1% AEP flood level + 0.5 m</td></tr>
<tr><td>Local drainage flooding</td><td>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</td></tr>
<tr><td>Outside floodplain</td><td>0.3 m above surrounding ground</td></tr>
<tr><td>Non-habitable rooms such as a laundry or garage (excluding below-ground car parks)</td><td>Mainstream or local drainage flooding</td><td>1% AEP flood level</td></tr>
<tr><td rowspan="2">Industrial or Commercial</td><td>Business</td><td>Mainstream or local drainage flooding</td><td>Merits approach presented by the applicant with a minimum of 1% AEP flood level</td></tr>
<tr><td>Schools and child care facilities</td><td>Mainstream or local drainage flooding</td><td>Merits approach presented by the applicant with a minimum of 1% AEP flood level + 0.5m</td></tr>
</table>

	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 Rushcutters Bay 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 Rushcutters Bay catchment.

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

Table 15: Flood Affected Areas and Investigated Management Options

Hotspot	Flooding issues	Investigated Measures	Measures Reference
Boundary Street	Frequent inundation with moderate depth and velocity, flooding of major roads, many properties flooded above floor	Trunk Drainage Upgrade from Boundary Street to either New South Head Road or to Weigall Sportsground	FM-RB01, FM-RB02
Taylor Street	Frequent inundation with moderate depth and velocity,	Drainage Upgrade from Sims Street, Taylor Street, Sturt	FM-RB03, FM-RB04

	several properties flooded above floor.	Street, South Dowling Street to either Oxford Street or to Weigall Sportsground	
Victoria Street South	Localised inundation with moderate depth, flooding of major roads.	Drainage Upgrade – 170 m of 1.5 m diameter pipe	FM-RB05
Catchment-wide General flood risk, inundation of major roads		Variable Message Display on Major Roads	RM-RB01
		Evacuation Planning	RM-RB02
		Public Information and Raising Flood Awareness	RM-RB03
		Local Flood Plan and DISPLAN	RM-RB04
		Flood Planning Levels	PM-RB01
		Flood Proofing of Affected Properties	PM-RB02
		Voluntary Purchase	PM-RB03
		Development Control Planning	PM-RB04

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 Rushcutters Bay 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 / riverway in the catchment area (except for the open channel at the outlet, which does not have associated flooding issues).

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 a present there is no flood warning system in place for the Rushcutters Bay catchment area. This is a result of the heavily modified drainage network as well as 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. This option was not considered further for these reasons, although site specific warnings are discussed further in Section 9.4.1.

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 is not suitable for all building types. It is also more common in areas where there is a greater depth of inundation then that in the Rushcutters Bay 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 measure was assessed in detail for a number of flood affected areas within the catchment. An overview of the flood affected areas and proposed mitigation options are provided in Table 16 and shown in Figure 23. These options are discussed in detail in Sections 9.3.1 to 9.3.5.

Table 16: Flood Affected Areas and Proposed Mitigation Options

Suburb	Flood Affected Streets/Areas	Proposed Mitigation Options	Ref
Darlinghurst	Boundary Street and McLachlan Avenue property inundation	Boundary Street trunk drainage upgrade from before the intersection of McLachlan Avenue, down Neild Avenue	FM - RB01
Darlinghurst	Boundary Street and McLachlan Avenue property inundation	Boundary Street trunk drainage upgrade from before the intersection of McLachlan Avenue, down part of Neild Avenue, outlet into Weigall Sportsground	FM - RB02
Darlinghurst	Taylor, Sturt and Sims Street trapped low points	Trunk drainage upgrade on Sims, Taylor, Sturt Streets, up to Oxford Street	FM - RB03
Darlinghurst	Taylor, Sturt and Sims Street trapped low points	Trunk drainage upgrade on Sims, Taylor, Sturt Streets, down Boundary Street up to Weigall Sportsground	FM - RB04
Darlinghurst	Victoria Street near Oxford Street trapped low point outside St Vincent's Hospital	Pipe and drainage upgrades along Victoria Street	FM - RB05

9.3.1. Trunk Drainage Upgrade – Boundary Street (FM - RB01)

Option Description

Option FM – RB01 describes a trunk drainage upgrade along Boundary Street and Neild Avenue 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.

The proposed works are extensive and 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;
- A new, additional trunk drainage pipe on Boundary Street ranging from 1.2 m diameter to a 1.5 m x 0.6 m box culvert
- Upgrade of the Neild Avenue pipe with one 1.5 m x 0.6 m box culvert until Craigend Street,

and then a 1.8 m x 1.2 m box culvert up to the open channel.

- Higher capacity feeder pipes on McLachlan Avenue in order to increase conveyance to the trunk drainage on that road.

These drainage elements are in addition to what currently exists in the location, which would remain in place and is shown on Figure 24. Figure 25 shows the new drainage elements.

Modelled Impacts

The proposed works achieve a significant reduction in flood level and hazard along the area of upgrade. The impact of the proposed works on the 10% AEP flood level and over floor flood liability is shown on Figure 25, while Figure 26 shows the change in hazard in the same event. The reduction in flood level is around 0.3 m on Boundary Street and McLachlan Avenue, and 0.02 m on Neild Avenue. The band of high hazard along the flowpath has been reduced to low hazard in a 10% AEP event, except for parts of the kerb/gutter on McLachlan Avenue which would remain high hazard. The upgrade produces significant relief of overfloor flooding, with eleven properties no longer flooded in the 50% AEP event, and eight properties in the 10% AEP, as shown on Figure 25. The option does not produce any adverse impacts downstream of the upgrade.

Evaluation

The proposed upgrade produces significant benefit for the affected streets, relieving the area of high hazard flooding; however, it requires large-scale pit and pipe upgrades. At present, there is significant relief on either side of the flowpath, with grades of up to 10%, that concentrates runoff onto Boundary Street and McLachlan Avenue, causing high hazard flow on the road and footpaths. The upgraded trunk system would convey this flow and mitigate the existing overland flowpath. The upgrade is in the downstream half of the catchment and does not increase flood levels downstream. The new drainage has a cross-sectional area of up to 2.2 m^2, which would require significant capital outlay and may be technically difficult to design. The option has both large-scale benefits and costs, which are further evaluated in Section 9.3.6.

9.3.2. Trunk Drainage Upgrade – Boundary Street to Weigall Sportsground (FM - RB02)

Option Description

Option FM – RB02 describes a trunk drainage upgrade along Boundary Street with the goal of mitigating property and road inundation in the 10% AEP event. It is largely similar to FM – RB01, with an outlet of the new trunk system into Weigall Sportsground, instead of along Neild Avenue. Having an outlet onto the sportsground removes the need to upgrade the trunk drainage along Neild Avenue, which is a large portion of the previous option's cost. As with FM – RB01, 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.

The proposed works are extensive and 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;
- A new, additional trunk drainage pipe on Boundary Street ranging from 1.2 m diameter to a 1.8 m x 1.5 m box culvert, which has an outlet in Weigall Sportsground.

- Higher capacity feeder pipes on McLachlan Avenue in order to increase conveyance to the trunk drainage on that road.

These drainage elements are in addition to what currently exists in the location, which would remain in place and is shown on Figure 24. Figure 27 shows the new drainage elements.

Modelled Impacts

The proposed works achieve a significant reduction in flood level and hazard along the area of upgrade, having largely the same effect as FM-RB01. The impact of the proposed works on the 10% AEP flood level and over floor flood liability is shown on Figure 27, while Figure 28 shows the change in hazard in the same event. As with FM-RB01, the reduction in flood level is around 0.3 m on Boundary Street and McLachlan Avenue, and 0.02 m on Neild Avenue. The band of high hazard along the flowpath has been reduced to low hazard in a 10% AEP event, except for parts of the kerb/gutter on McLachlan Avenue which would remain high hazard. The upgrade produces significant relief of overfloor flooding, with eleven properties no longer flooded in the 50% AEP event, and nine properties in the 10% AEP, as shown on Figure 27. Downstream impacts occur in Weigall Sportsground, with an area of approximately 1 hectare having an increase of around 0.01 m in the 10% AEP event. This is considered manageable, given that the area already has around 0.1 m depth, but will require further consultation with Sydney Grammar School.

Evaluation

The proposed upgrade produces significant benefit for the affected streets, relieving the area of high hazard flooding; however, it requires large-scale pit and pipe upgrades. As described for FM-RB01, the area becomes a hazardous flowpath in a flood event, and this can be mitigated by upgraded drainage. In relation to FM-RB01, it achieves a slightly better reduction in flood level, and requires fewer new drains to be constructed. These advantages are slightly offset by the adverse impact it causes in Weigall Sportsground. The upgraded drainage has a cross-sectional area of up to 2.7 m^2, which would require significant capital outlay and may be technically difficult to design. The option has both large-scale benefits and costs, which are further evaluated in Section 9.3.6.

9.3.3. Trunk Drainage Upgrade – Taylor, Sims and Sturt Street (FM – RB03)

Option Description

Option FM – RB03 describes a trunk drainage upgrade of the system in Taylor Street, Sims Street and Sturt Street, aimed at relieving the trapped depressions in the area. The option consists of upgraded pipes on each of the streets, which combine to drain towards Barcom Avenue and Boundary Street. The proposed works are extensive and include the following elements:

- Upgrade of pit and feeder pipe capacity to ensure that the upgraded trunk elements are at capacity in the 5% AEP event;
- New, additional drainage pipes of 0.9 m diameter along Sims Street and Taylor Street;
- A new, additional drainage pipe of 1.2 m diameter on part of Sturt Street;
- A new, additional drainage pipe of 0.6 m diameter on South Dowling Street; and
- New, additional drainage elements crossing Oxford Street, consisting of one 1.2 m diameter pipe and one 1.8 m x 1.2 m box culvert.

These drainage elements are in addition to what currently exists in the location, which would remain in place and is shown on Figure 29. Figure 30 shows the new drainage elements.

Modelled Impacts

The upgrade achieves a significant reduction in the peak flood level at each of the depressions in the hotspot; however, it also has a wide-scale adverse impact downstream of Oxford Street. Figure 30 shows the location of the upgrade and its impact on the 5% AEP peak flood level, while Figure 31 shows the change in hazard in the same event. The reduction in peak flood level is up to 1.5 m on Sturt Street, 0.4 m on Taylor Street and 0.7 m on Sims Street. The area of shallow inundation on Oxford Street is no longer flooded. The low section of Sturt Street is no longer high hazard in a 5% AEP event, and the small areas of high hazard on Taylor Street and Sims Street have been removed. The upgrade also alleviates the property flooding issue, with 15 properties no longer flooded overfloor in a 5% AEP event. The adverse downstream impact consists of a 0.04 m increase in peak flood level for most of the length of Boundary Street.

Evaluation

The upgrade greatly assists the existing flood issue in the area; however, it also produces adverse downstream impact and would require large-scale pipe upgrades. The benefit to the area is comprised of the reduction in high hazard ponding on the three low points on Sturt Street, Taylor Street and Sims Street respectively, and the benefit to the property flooding issue in the area – both via the reduced peak flood level. However, relieving the current flood storage in the area directs flow downstream, resulting in a wide-scale downstream impact. Under the floodplain management program, mitigation works must not adversely impact flooding in a developed area, and any upgrade will therefore require additional mitigation works to manage the downstream impact. Furthermore, the upgrade requires drainage of up to 2.4 m^2, which would require significant capital outlay and may be technically difficult to design.

9.3.4. Trunk Drainage Upgrade – Taylor Street to Boundary Street (FM - RB04)

Option Description

Option FM-RB04 describes a trunk drainage upgrade from the Taylor Street hotspot, along Boundary Street, up to a new outlet at Weigall Sportsground. It combines the upgraded sections from FM-RB02 and FM-RB03 as well as slightly upgrading the section in between those two options on Boundary Street. Both the 5% AEP and 10% AEP design events were used for the option as follows:

- For the Taylor Street area (i.e. drainage upgraded in FM-RB03), the drainage was sized to convey a 5% AEP event,
- For the lower Boundary Street area (i.e. drainage upgraded in FM-RB02), the drainage was sized to convey a 10% AEP event,
- For the section on Boundary Street in between the two areas, the drainage was sized so that the additional discharge from the Taylor Street area had no adverse impact in the 5% AEP event.

The option was assessed as it was found that more localised stormwater upgrades for the Taylor Street area produced an adverse impact downstream (see Section 9.3.3), and so were not viable without increased drainage capacity along Boundary Street.

The proposed works are extensive and include the following elements:

- Upgrade of pit and feeder pipe capacity to ensure that the upgraded trunk elements are at capacity in the 5% AEP event at the Taylor Street hotspot and 10% AEP at the Boundary Street hotspot;
- New, additional drainage pipes of 0.9 m diameter along Sims Street and Taylor Street;
- A new, additional drainage pipe of 1.2 m diameter on part of Sturt Street;
- A new, additional drainage pipe of 0.6 m diameter on South Dowling Street; and
- New, additional drainage elements crossing Oxford Street, consisting of one 1.2 m diameter pipe and one 1.8 m x 1.2 m box culvert.
- A new, additional drainage pipe of 1.5 m diameter along Boundary Street up until the intersection of Liverpool Road
- New, additional drainage elements along the lower section of Boundary Street, ranging from 1.2 m diameter to 1.8 m x 1.5 m area, and having an outlet into Weigall Sportsground.

These drainage elements are in addition to what currently exists in the location, which would remain in place and is shown on Figure 24 and Figure 29. Figure 32 shows the new drainage elements.

Modelled Impacts

The upgrade achieves a significant reduction in the peak flood level in both the Taylor Street and Boundary Street hotspots, while having minimal effect on the upper section of Boundary Street. Figure 32 shows the location of the upgrade and its impact on the 10% AEP peak flood level, while Figure 33 shows the change in hazard in the same event. Table 17 lists the impact at several locations in the two design events used. As can be seen, the impacts in the two design events are largely similar, with the largest reduction in the Taylor Street area where several depressions are relieved.

Table 17: Reduction in Peak Flood Level under FM-RB04

Location	10% AEP reduction	5% AEP reduction
Taylor Street	0.3 m	0.4 m
Sims Street	0.6 m	0.7 m
Sturt Street	1.5 m	1.6 m
Boundary Street near Liverpool Street	0 m	0 m
Boundary Street near McLachlan Avenue	0.2 m	0.2 m
McLachlan Avenue	0.2 m	0.2 m
Neild Avenue	0.02 m	0.02 m

The reduction in peak flood level also corresponds to reduced areas of high hazard. The Boundary Street hotspot has the majority of its high hazard removed in the 10% AEP event, while the small areas of existing high hazard on Taylor Street and Sims Street have been removed. The upgrade also alleviates the property flooding issue, with 21 properties no longer flooded overfloor in a 5% AEP event.

Evaluation

The upgrade alleviates the majority of the area's flood risk; however, it requires large-scale pipe upgrades in several areas. The benefit to the area is virtually a combination of the benefit provided by FM-RB02 and FM-RB03; there is reduced flooding in the Taylor Street area which reduces overfloor inundation and high hazard ponding, and the overland flow on Boundary Street becomes largely contained by the trunk system, which reduces property inundation and high hazard flows in that area. These benefits are the most widespread of the structural options assessed; however, this option also requires the largest stormwater drainage upgrades. The new drainage elements have a combined length of 1700 m, compared to between 500 and 750 m for the previous three options. As with the other options, the new drainage elements are generally large, with a cross-sectional area of up to 2.7 m^2. This would require significant capital outlay and may be technically difficult to design. The option has both large-scale benefits and costs, which are further evaluated in Section 9.3.6.

9.3.5. Trunk Drainage Upgrade – Victoria Street South (FM - RB05)

Option Description

Option FM – RB05 describes a trunk drainage upgrade connecting the trunk drainage at the southern end of Victoria Street to the branch further north on Victoria Street (see Figure 35). The proposed pipe upgrade includes approximately 120 m of new pipe and 30 m of upgraded existing pipe. The proposed works include the following elements:

- Upgrade of the pit and feeder pipe capacity to ensure that the upgraded trunk elements are at capacity in the 5% AEP event;
- Upgrade of 30 m of pipe on Victoria Street to one 1.5 m diameter pipe; and
- Addition of 120 m of one 1.5 m diameter pipe on Victoria Street.

Modelled Impacts

The upgrade resolves the flooding issue on Victoria Street for events up to the 5% AEP event, while also producing a localised downstream impact on the same street. Figure 35 shows the location of the upgrade and its impact on the 5% AEP peak flood level, while Figure 36 shows the change in hazard in the same event. The impact is up to 0.5 m at the hotspot, which reduces the flooding to either shallow ponding or no longer flooded. The depth of ponding that is currently high hazard in a 1% AEP event is reduced to low hazard. The impacts downstream, which are caused by conveying the runoff downstream, are up to a 100 mm in a localised area. The downstream impact does not extend as far as the entrance to the hospital's underground carpark.

Evaluation

The option largely resolves the flooding issue that currently exists in front of the hospital and the size of the upgrade is modest, relative to other measures assessed. At present, the ponding does not inundate the hospital in the 1% AEP event, and so the issue is largely with the ponding hindering access to the hospital. It should be noted that the ponding does not prevent access to the emergency section of the hospital, but rather is an entrance to the private hospital. When flooding does occur, the private hospital can still be accessed from other points on Victoria Street. If temporarily closing the affected entrance does not have a large impact on the hospital, it may be that a response measure, such as warning signage at the hotspot, is more feasible.

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 18, 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 the first four options, the 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 18: Costings of Management Options

Option	Capital	Maintenance per year
FM-RB01 Boundary Street trunk drainage upgrade from before the intersection of McLachlan Avenue, down Neild Avenue	$ 7,515,000	$ 7,500
FM-RB02 Boundary Street trunk drainage upgrade from before the intersection of McLachlan Avenue, down part of Neild Avenue, outlet into Weigall Sportsground	$ 5,578,100	$ 5,300
FM-RB03 Trunk drainage upgrade on Sims, Taylor, Sturt Streets, up to Oxford Street	$ 5,711,800	$ 7,200
FM-RB04 Trunk drainage upgrade on Sims, Taylor, Sturt Streets, down Boundary Street up to Weigall Sportsground	$ 15,987,900	$ 17,100
FM-RB05 Pipe and drainage upgrades along Victoria Street	$ 1,178,200	$ 11,700

Table 18 shows that the drainage capacity upgrade Option FM – RB04 is the most costly, as it involves the longest section of trunk drainage being upgraded, followed by the more localised upgrades, all of which require significantly large works. It should be noted that although FM-RB01 and FM-RB02 both entail upgrades on Boundary Street, FM-RB02 is around 25% cheaper due to the shorter section being upgraded (RB02 does not continue along Neild Avenue).

Damage Assessment of Options

The total damage costs were evaluated for four of the options and compared against the existing base case, as shown in Table 19. FM – RB05 has minimal effect on overfloor flooding and so has not been assessed. The assessment for the remaining four options 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. The damages were evaluated for a range of design events from the 2 year ARI up to the PMF.

Table 19: Average Annual Damage Reduction of Management Options

Option	AAD	Reduction in AAD due to Option
FM-RB01 Boundary Street trunk drainage upgrade from before the intersection of McLachlan Avenue, down Neild Avenue	$1,155,800	$867,500
FM-RB02 Boundary Street trunk drainage upgrade from before the intersection of McLachlan Avenue, down part of Neild Avenue, outlet into Weigall Sportsground	$1,165,200	$858,100
FM-RB03 Trunk drainage upgrade on Sims, Taylor, Sturt Streets, up to Oxford Street	$1,799,100	$224,200
FM-RB04 Trunk drainage upgrade on Sims, Taylor, Sturt Streets, down Boundary Street up to Weigall Sportsground	$1,009,500	$1,013,800
FM-RB05 Pipe and drainage upgrades along Victoria Street	ND	ND

* ND – Not determined

The results show that the Boundary Street drainage upgrades have the greatest reduction in AAD, with the first two options achieving around $900,000 reduction in AAD, and the combined option (FM-RB04) giving just over $1 million reduction. The Taylor Street upgrade also produces a large reduction ($224,200), while FM-RB05 was not assessed as it has minimal effect on property inundation. Given that the AAD in the catchment under existing conditions is $2,123,800, the four options assessed all achieve a significant reduction in the cost of flooding.

Benefit Cost Ratio of Options

Following estimation of the option's cost and AAD, the benefit/cost ratio (B/C) of four of the options 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. Table 20 lists the reduction in AAD due to the options, and compares this to the works' capital and maintenance costs to produce a B/C. The B/C of both options was between 0.7 and 2.2, with values above 1 indicating that the economic benefit of the option is greater than its cost. The damages estimation under the options is given in detail in Appendix D.

Table 20: Benefit/Cost Ratio for Management Options

Options	Benefit			Cost Estimate			
	AAD	Reduction in AAD	NPW of AAD Reduction*	Capital	Maintenance (Annual)	NPW of Costs*	B/C Ratio
FM- RB01	$1,155,800	$867,500	$ 12,809,390	$ 7,515,000	$ 7,500	$ 7,626,100	1.7
FM- RB02	$1,165,200	$858,100	$ 12,671,228	$ 5,578,100	$ 5,300	$ 5,656,900	2.2
FM- RB03	$1,799,100	$224,200	$ 3,310,779	$ 5,711,800	$ 7,200	$ 5,817,800	0.6
FM- RB04	$1,009,500	$1,013,800	$ 14,970,817	$ 15,987,900	$ 17,100	$ 16,239,900	0.9
FM- RB05	ND	ND	ND	$ 1,178,200	$ 11,700	1,351,100	ND

* NPW: Net present worth calculated over 50 years at 7%, ND – Not determined

The first two options presented in Table 20 have a B/C of greater than 1, indicating they are economically feasible. FM-RB01 has a B/C of 1.7, which reflects the large economic benefit the option has ($867,500 per year in today's dollars) relative to its total cost ($7.6 million). FM-RB02 has a similar benefit to the area but a cheaper construction cost, which gives it a higher B/C of 2.2. Such B/C values are not common in urban areas, where the flood risk is typically difficult to mitigate with structural works and the cost of such works is high. The B/C values demonstrate that the existing flood issue on Boundary Street has a large associated cost, and that the cost of works is comparable to the benefit they will achieve.

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 Rushcutters Bay catchment, these are the previously described options, FM – RB01 to FM – RB05. Other options were assessed in the hotspots that were discarded, and these are presented in Table 21. The table also lists why the option was not considered further. For example, re-instating a flowpath from Sims Street to Taylor Street relieved the issue on Sims Street but adversely impacted the peak depth at Taylor Street.

Table 21: Other Site Specific Management Options Considered

Hotspot	Option	Reason Discarded
Boundary Street	Establish a retarding basin at Weigall Sport ground (adjacent to Neild Avenue).	Basin would be downstream of flooding hotspots and therefore have limited benefit.
Boundary Street	Re-grade parts of trunk drain on Boundary Street.	Found to have negligible effect
Taylor Street	Remove house on Sims Street to relieve trapped depression via a new overland flowpath.	New flowpath has some benefit on Sims Street; however, has significant adverse impact on Taylor Street where flow is directed.
Victoria Street	Regrading Victoria Street near St Vincents Hospital.	Large-scale regrading would be required, not feasible given hospital location.
Victoria Street	Upgrade pipe system on Oxford Street to reduce inflow into Victoria Street.	Oxford Street drainage is already full in frequent events, would require very wide-scale upgrade, Victoria Street pipe more feasible.

9.4. Catchment Wide Management Options

9.4.1. Response Modification – Variable Message Display (RM-RB01)

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 and Craigend Street, which are at the downstream end of McLachlan Avenue, are the main affected roads in the area, as well as Oxford Street and Victoria Street outside St Vincent's Hospital. 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. Oxford Street near Taylor Street has up to 0.4 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 – RB02)

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 Rushcutters Bay 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 – RB03)

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 Rushcutters Bay, 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 4.1.2, 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 22 lists tools that can be used to promote public awareness of flooding in an area.

Table 22: 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 – RB04)

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 Rushcutters Bay 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 – RB01)

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 5) prior to the completion of the Floodplain Risk Management Plans for the entire LGA and we endorse this move. 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 5) 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 – RB02)

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.

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 – RB03)

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 Rushcutters Bay 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 Rushcutters Bay, 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 – RB04)

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 5) 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 5). 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

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 23 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 23: 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.

9.5.1. Results

The assessment matrix is given in Table 24, with each of the assessed management options scored against the range of criteria. 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 24: Multi-Criteria Assessment of Management Options

Ref	Options	Section in Report	Design Event (AEP)	Impact on Flood Behaviour	No. 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-RB01	Trunk Drainage Upgrade - Boundary Street	9.3.1	10%	3	2	-3	3	2	-3	-1	2	-2	1	1	5	9
FM-RB02	Trunk Drainage Upgrade - Boundary Street to Weigall Sportsground	9.3.2	10%	3	2	-3	3	3	-3	-1	2	-2	1	1	6	8
FM-RB03	Trunk Drainage Upgrade - Taylor, Sims and Sturt Street	9.3.3	10%	2	2	-3	3	-2	-2	-1	1	-2	1	1	0	12=
FM-RB04	Trunk Drainage Upgrade - Taylor Street to Boundary Street	9.3.4	5%, 10%	3	3	-3	3	0	-3	-1	2	-3	1	1	3	10
FM-RB05	Trunk Drainage Upgrade - Victoria Street South	9.3.5	5%	1	1	-1	3	-3	-2	0	1	-1	1	1	1	11
Response Modification Measures																
RM-RB01	Variable Message Display	9.4.1	N/A	0	0	2	1	2	2	0	2	1	0	1	11	2=
RM- RB02	Evacuation Planning	9.4.2	N/A	0	0	-1	2	0	2	0	1	2	0	1	7	7
RM-RB03	Public Information and Raising Flood Awareness	9.4.3	N/A	0	0	1	2	1	2	0	2	1	-2	1	8	6
RM-RB04	Local Flood Plan and DISPLAN	9.4.4	N/A	0	0	0	2	2	2	0	2	2	1	2	13	1
Property Modification Measures																
PM-RB01	Flood Planning Levels	9.4.5	N/A	0	0	0	2	2	2	0	1	0	3	1	11	2=
PM-RB02	Investigate Flood Proofing	9.4.6	N/A	0	0	0	1	1	3	0	1	2	2	1	11	2=
PM-RB03	Voluntary Purchase	9.4.7	N/A	0	0	-2	N/A	1	-1	0	1	-2	2	1	0	12=
PM-RB04	Development Control Planning	9.4.8	N/A	0	0	0	1	2	2	0	1	1	3	1	11	2=

As shown in the matrix, the structural measures have both higher and lower scores (i.e. more '3' and '-3' scores) than the response and property modification measures – due to their larger costs and larger benefits. For example, the first four options rate highly regarding impact on flood behaviour and the number of properties benefitted; however, the same four have low technical and financial feasibility (as they require large scale upgrades and significant capital outlays) and have potential political or administrative issues (as they affect a number of internal and external stakeholders). Overall, these structural options score lower than the other measures; however, they rank only just below some of the non-structural measures and should be considered as generally equivalent under this assessment (specifically FM-RB01 and FM-RB02).

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 25.

Table 25: Ranking of Management Options

Rank	Ref	Options	Score
1	RM-RB04	Local Flood Plan and DISPLAN	13
=2	RM-RB01	Variable Message Display	11
=2	PM-RB01	Flood Planning Levels	11
=2	PM-RB02	Investigate Flood Proofing	11
=2	PM-RB04	Development Control Planning	11
6	RM-RB03	Public Information and Raising Flood Awareness	8
7	RM- RB02	Evacuation Planning	7
8	FM-RB02	Trunk Drainage Upgrade - Boundary Street to Weigall Sportsground	6
9	FM-RB01	Trunk Drainage Upgrade - Boundary Street	5
10	FM-RB04	Trunk Drainage Upgrade - Taylor Street to Boundary Street	3
11	FM-RB05	Trunk Drainage Upgrade - Victoria Street South	1
=12	FM-RB03	Trunk Drainage Upgrade - Taylor, Sims and Sturt Street	0
=12	PM-RB03	Voluntary Purchase	0

Note: '=' denotes equal position. E.g. '=2' refers to equal second rank.

Of the 13 management options presented here, 12 have been recommended for implementation as part of the Rushcutters Bay Catchment Floodplain Risk Management Plan. The discarded option is FM-RB03, which has an adverse impact downstream of the upgrade that increases downstream flood risk by an unacceptable amount.

10. REFERENCES

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   Defining the Floodway – Can One Size Fit All?
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    Floodplain Risk Management Guideline – Residential Flood Damages
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Figures

FIGURE 1
STUDY AREA
RUSHCUTTERS BAY

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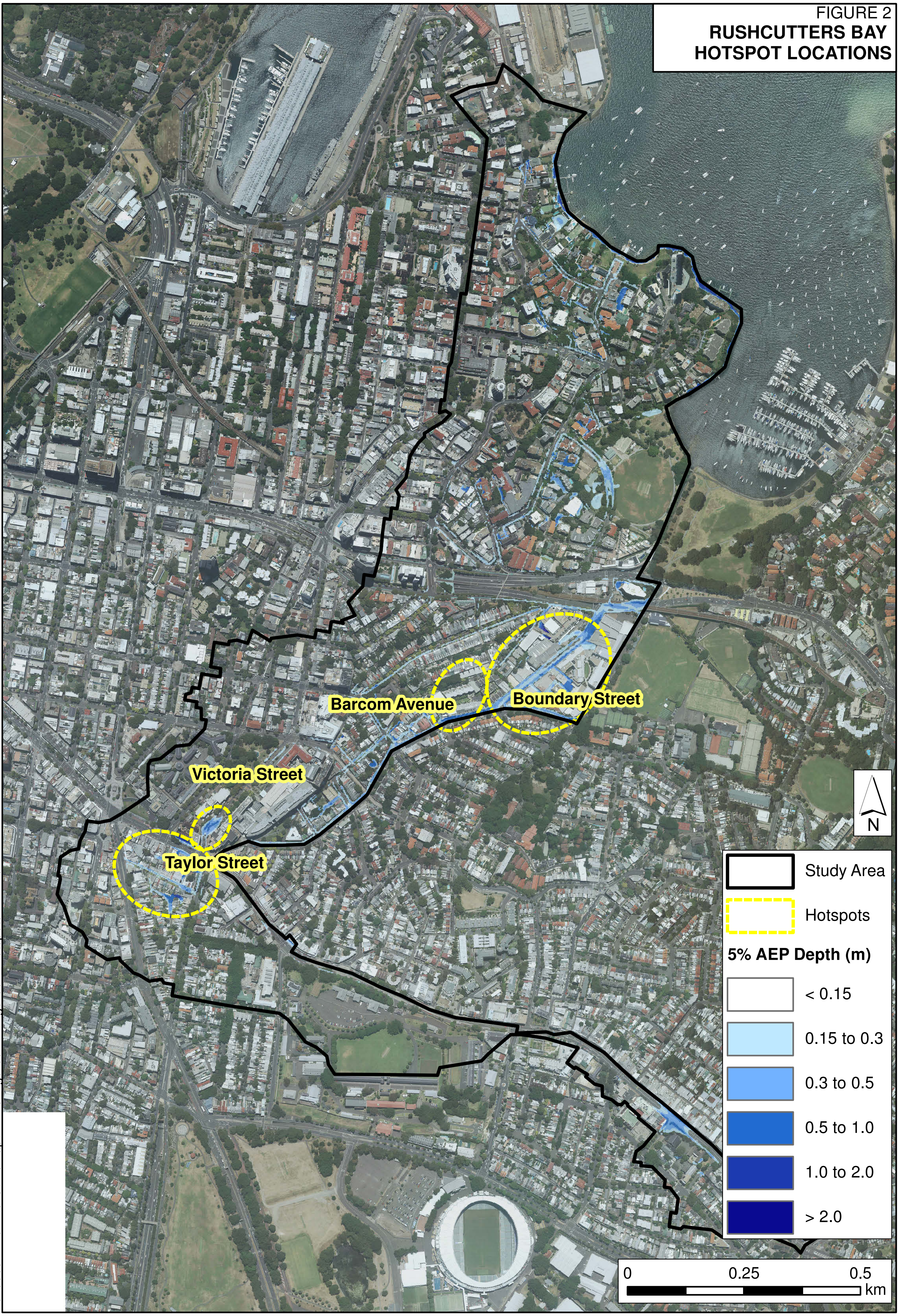
FIGURE 2
RUSHCUTTERS BAY HOTSPOT LOCATIONS



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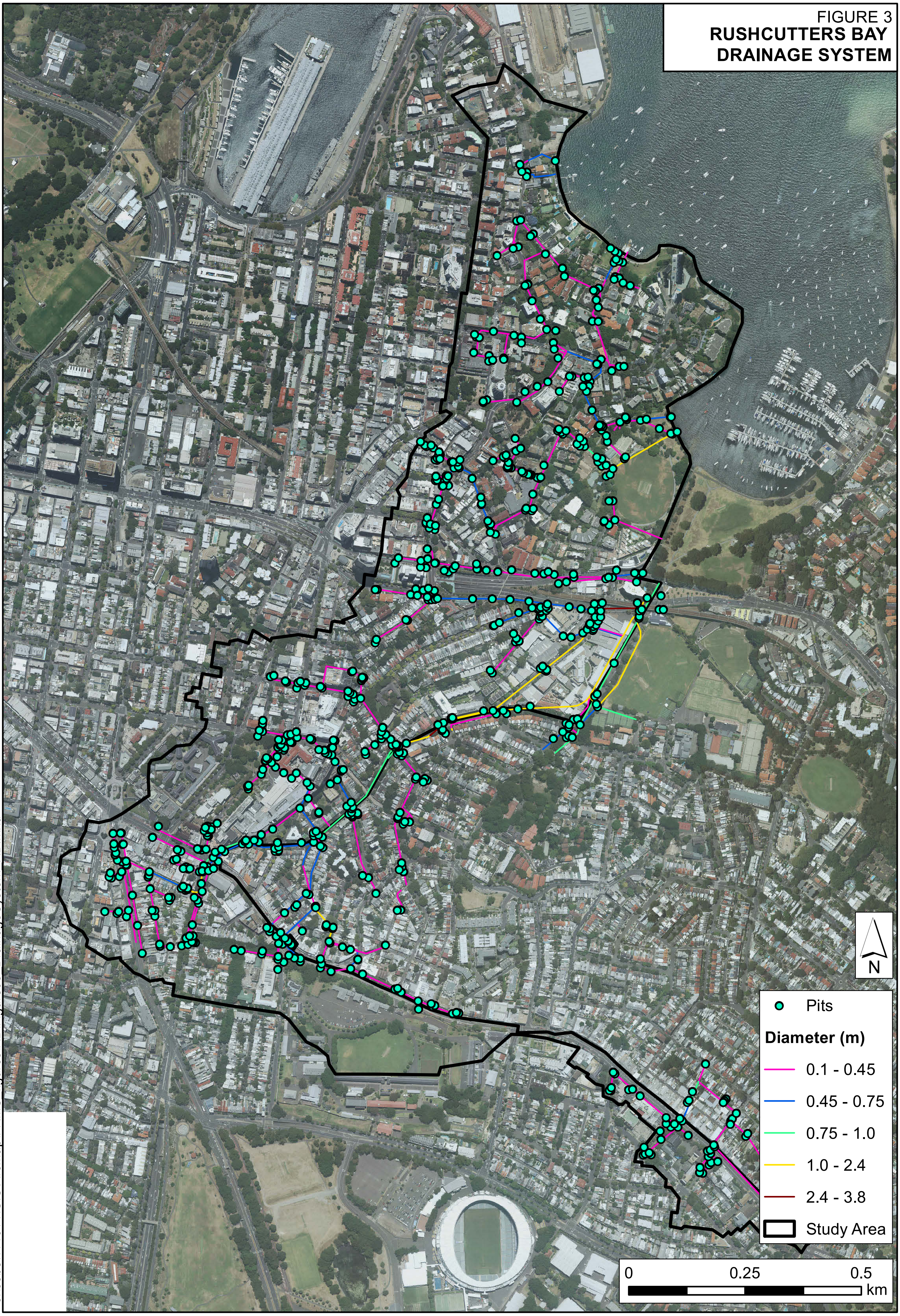

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FIGURE 4
RUSHCUTTERS BAY
LAND USE

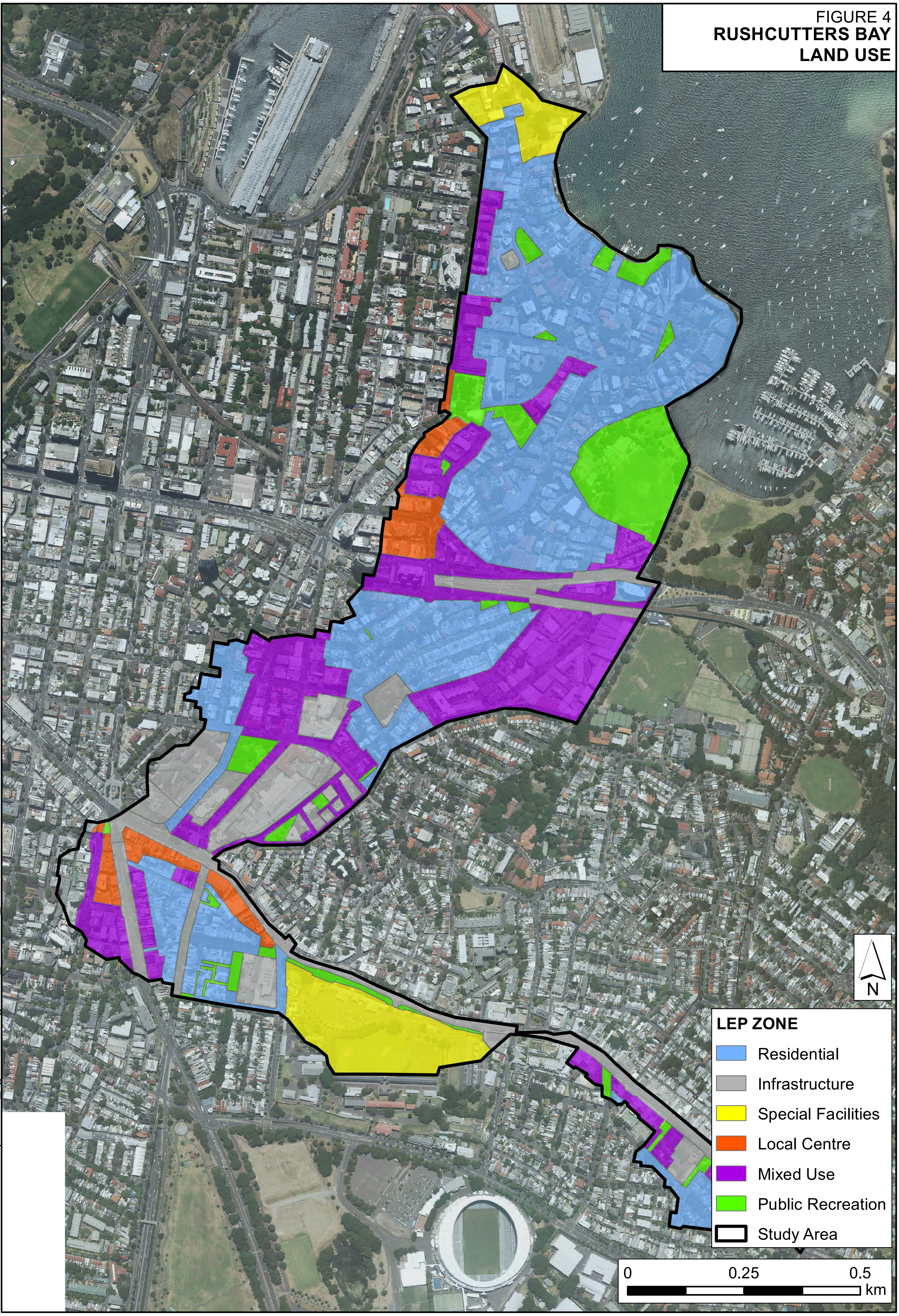

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FIGURE 5
EARLY CATCHMENT FEATURES
HISTORIC CREEKS AND SHORELINE - 1854
N
Creek
Shoreline
Study Area
5% AEP Depth (m)
< 0.15
0.15 to 0.3
0.3 to 0.5
0.5 to 1.0
1.0 to 2.0
> 2.0
0
0.25
0.5
km
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FIGURE 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
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FIGURE 7
RUSHCUTTERS BAY
FLOOD EMERGENCY RESPONSE PLAN