WOOLLAHRA MUNICIPAL COUNCIL

RUSHCUTTERS BAY FLOODPLAIN RISK MANAGEMENT STUDY and PLAN

MAY 2012

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RUSHCUTTERS BAY FLOODPLAIN RISK MANAGEMENT STUDY AND PLAN

MAY, 2012

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AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ALS	Airborne Laser Scanning
ARI	Average Recurrence Interval
BASIX	Building Sustainability Index
BOM	Bureau of Meteorology
CCTV	Closed Circuit Television
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCP	Development Control Plan
DECCW	Department of Environment, Climate Change and Water (now OEH)
DRAINS	Hydrologic (conversion of rainfall to runoff) computer model for analysing a stormwater pit and pipe network
FPL	Flood Planning Level
GPT	Gross Pollutant Trap
CSIRO	Commonwealth Scientific and Industrial Research Organisation
IPCC	Intergovernmental Panel on Climate Change
LEP	Local Environmental Plan
LGA	Local Government Area
m	metre
m^3/s	cubic metres per second
OEH	Office of Environment and Heritage
OSD	On-site Stormwater Detention
PMF	Probable Maximum Flood
SES	State Emergency Service
SOBEK	one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software program (hydraulic computer model)
SWW	Severe Weather Warning
WSUD	Water Sensitive Urban Design
1D	One dimensional hydraulic computer model
2D	Two dimensional hydraulic computer model

1. FOREWORD

The State Government's Flood Prone Land Policy is directed at providing solutions to existing flooding problems in developed areas and to ensuring that 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 flood management process in NSW has recently been up-dated to incorporate consideration of the effects of climate change, and particularly the effects of sea level rise, on mean water levels and on flood levels.

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

1. *Flood Study*
   - determine the nature and extent of the flood problem.

2. *Floodplain Risk Management Study*
   - 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/foreshore.

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 Rushcutters Bay Floodplain Risk Management Study and Plan constitutes the second and third stages of the management process for the Rushcutters Bay catchment. Funding for this study was provided from the State Government's Floodplain Risk Management Program and Woollahra Municipal Council on a 2:1 basis. It has been developed for the Woollahra Municipal Council's Floodplain Risk Management Committee by WMAwater (formerly Webb, McKeown & Associates) for the future management of flood liable lands in the Rushcutters Bay catchment.

A glossary of flood related terms is provided in Appendix A.

2. RUSHCUTTERS BAY FLOODPLAIN RISK MANAGEMENT PLAN

2.1. Introduction

The Rushcutters Bay Floodplain Risk Management Plan has been prepared in accordance with the NSW Floodplain Development Manual (April 2005 – Reference 1) and the August 2010 Flood Risk Management Guide – Incorporating sea level rise benchmarks in flood risk assessment (Reference 5) and:

- *Is based on a comprehensive and detailed evaluation of factors that affect and are affected by the use of flood prone land;*
- *Represents the considered opinion of the local community on how to best manage its flood risk and its flood prone land; and*
- *Provides a long-term path for the future development of the community.*

Rushcutters Bay has a catchment area of approximately 2.4 km^2. The area drains to Sydney Harbour and includes the suburbs of Paddington, Rushcutters Bay and parts of Edgecliff, Woollahra and Darlinghurst. The catchment is characterised by an upper and a lower section.

The upper section of the catchment comprises medium density urban developments, including terrace and free standing residences, commercial developments and limited areas of open space. Stormwater is carried within an underground piped network, or when this is exceeded, along roads or into private property. There have been several instances of flooding of roads and property in the past 20 years. It should be noted that most of the drainage infrastructure was built in the 1930's.

The lower section comprises the lower slopes where stormwater travels across Trumper Park and into the open channel through the White City tennis complex. Craigend Street and New South Head Road form significant barriers to flow as all stormwater is channelled into twin culverts under the roads. One culvert connects to a sandstone lined channel which enters Rushcutters Bay, the other exits directly into Rushcutters Bay. The channel is tidal to upstream of Craigend Street.

The NSW Government's Flood Policy provides for:

- a framework to ensure the sustainable use of floodplain environments,
- solutions to flooding problems,
- a means of ensuring new development is compatible with the flood hazard.

Implementation of the Policy requires a four stage approach, the first of which is preparation of a Flood Study to determine the nature and extent of the flood problem. This is followed by a Floodplain Risk Management Study which examines management measures. The subsequent Floodplain Risk Management Plan details the adopted measures and ultimately the works are undertaken in the final stage.

2.2. Rushcutters Bay Catchment Flood Study

The Rushcutters Bay Catchment Flood Study (Reference 2) was initiated as a result of flooding on roads and in residential areas, most recently in March 2003, February 2001, August 1998 and April 1998, as well as major catchment wide flooding in January 1991, January, March and April 1989, November 1984 and August 1983.

The specific aims of the Rushcutters Bay Flood Study were to:

- define flood behaviour in the Rushcutters Bay catchment,
- prepare flood hazard and flood extent mapping,
- prepare suitable models of the catchment and floodplain for use in a subsequent Floodplain Risk Management Study and Plan.

Hydrologic and hydraulic investigations were undertaken to determine the response of the drainage system to 5 year, 10 year, 20 year, 50 year, 100 year ARI events, and the Probable Maximum Flood (PMF). The results of these investigations were quantified as peak pipe capacities and peak overland flows in the upper reaches and peak flood levels, flows and velocities in the lower catchment. The key Flood Study phases undertaken were:

Review all available data: namely,

- reports, photographs, Council records,
- newsletter and questionnaire responses,
- review of Council's database of resident reports,
- review of rainfall data,
- a comprehensive Airborne Laser Scanning (ALS) survey,
- review and updating of Council's pit and pipe database,
- field survey of the open channel sections and the culverts under Craigend Street and New South Head Road.

Determine Approach: A rainfall_runoff approach was adopted due to the absence of long term historical flood data. This approach involved setting up a DRAINS hydrologic and hydraulic computer model that simulated flow both in the pipe system and as overland through private property and along roads. The DRAINS model covered the entire catchment. A two-dimensional (2D) SOBEK computer model was established in the lower reaches (open channel section from Hampden Street to Sydney Harbour at Rushcutters Bay) to convert the upstream flows obtained from DRAINS into flood levels and velocities.

Calibration to Historical Flood Levels: Due to the lack of data a rigorous calibration of the two computer models could not be undertaken. However, a limited calibration of the SOBEK model to historical flood height data was undertaken. This generally indicated that the SOBEK results were higher than the historical data. Reasons were provided for this difference.

Determination of Design Flood Flows and Levels: Design rainfall data from Council and design temporal patterns from Australian Rainfall and Runoff (1987) were obtained and input to the DRAINS model to determine design flood flows. The SOBEK model was then used to determine design flood levels in the lower catchment. The creek downstream of New South Head Road is influenced by catchment flows and elevated water levels in Rushcutters Bay.

Sensitivity analyses were undertaken on the DRAINS and SOBEK model results.

Existing Flood Problem: A flood damages assessment for existing development was undertaken for a range of design events. This assessment was based on a detailed survey of building floor levels but was only undertaken in the lower part of the catchment downstream of Hampden Street. The estimated number of building floors which are likely to be inundated in the 5 year ARI is 47 (41 residential and 6 non residential) and 54 in the 100 year ARI. In the PMF up to 91 building floors would be inundated. The annual average damages were estimated to be $1.3 million.

It should be noted that in the upper catchment additional floors would be inundated but no floor level survey has been undertaken in this area. No consideration has been given for damages to public structures or utilities (bridges, roads, pumping stations) or for the complete collapse of structures due to flooding.

Future Development: The majority of the catchment has been developed for residential usage but there is continuing pressure to increase the density of development and build on the remaining undeveloped parts and/or re develop existing properties on the floodplain.

2.3. Floodplain Risk Management Study

The specific aims of this study were to:

- review the results from the Flood Study,
- identify development and planning controls to regulate redevelopment in the flood affected properties and to ensure that future redevelopment does not significantly add to the overall potential damage,
- make recommendations to adopt Flood Planning Levels (FPL) appropriate for the catchment,
- investigate available floodplain risk management measures along with prioritisation, staging of works and preliminary costings.

2.3.1. Possible Floodplain Risk Management Measures

A list of all possible floodplain risk management measures which could be applied in the study area were initially developed for consideration. The assessment extended to examination of potential future development and its possible adverse impacts on flows and water quality. The measures were then assessed in terms of their suitability and effectiveness for reducing social, ecological, environmental, cultural and economic impacts. As part of this process a number of measures were identified as not being worthy of further consideration including:

- Flood mitigation dams (no available space in catchment),
- Channel modification works (dredging, straightening, concrete lining, removal of vegetation etc are not possible),
- Levees, flood gates and pumps,

- Flood warning (available warning time too short),
- House raising (no suitable buildings),
- Flood proofing of buildings (not suitable for residential buildings),
- Voluntary purchase except in isolated areas in the upper catchment.

A summary of the various floodplain management measures considered during the course of the study is presented in Table 1 together with a brief assessment of their viability for implementation as part of the Floodplain Risk Management Plan for the Rushcutters Bay catchment.

The evaluation process for assessing each measure involved interaction with the Floodplain Management Committee technical committee, the Floodplain Management Committee itself and meetings with local residents. Thus the proposed measures represent the considered opinion of both technical experts and local residents

2.3.2. Development Measures

Development measures relate to the management of future development from a flooding and water quality perspective. A summary of these measures is provided in Table 2.

Table 1: Review of Floodplain Management Measures

MEASURE	REFER SECTION in FRMS	PURPOSE	COMMENT	ECONOMIC ASSESSMENT	IMPLEMENTATION VIABILITY
			FLOOD MODIFICATION:		
DAMS AND RETARDING BASINS	Section 6.2.1 and 6.2.2	Reduce flows from upper catchment areas.	Major dams are not practical. Many issues (cost, social) would need to be resolved in order to justify construction of retarding basins and it is unlikely that the benefit would be significant beyond the immediate downstream area.	Generally not viable from a purely flooding perspective but more attractive if has water quality benefits.	To be considered as a means of mitigating the effects of urban development.
CHANNEL MODIFICATIONS	Section 6.2.3	Increase waterway conveyance to reduce flood levels.	Many issues (cost, environmental, social) and limited effectiveness on a lined channel system. The removal of major hydraulic restrictions (bridges) will provide a hydraulic benefit but are cost prohibitive. A maintenance scheme to reduce the likelihood of blockage and removal of small bridges will be beneficial.	Preventative maintenance is cost effective.	Most measures not viable except for removal of small bridges and preventative maintenance.
LEVEES, FLOOD GATES AND PUMPS	Section 6.2.4	Prevents or reduces the frequency of inundation of protected areas, assists in reducing problems with local runoff issues.	No appropriate sites.	Not undertaken.	Not applicable.
LOCAL DRAINAGE	Section 6.2.5	To identify and reduce local drainage problems.	The undulating roads result in ponding and/or diversion of runoff into footpaths and across private properties. Significant damage to yards and possibly buildings may occur as well as inconvenience to residents. Maintenance of a database would enable Council to identify issues and to determine an approach to resolve them.	Low cost.	Recommended that the database of flooding/ drainage issues be maintained.
STORM SURGE, WAVE RUNUP	Section 6.2.6	To identify the effects of wave runup at the mouth of the catchment	The magnitude and likely impact has been addressed in the flood study and will not impact on properties upstream of New South Head Road.	Not undertaken.	Not applicable.
			RESPONSE MODIFICATION:		
FLOOD WARNING	Section 6.3.1	Enables people to evacuate and take measures to reduce flood damages.	A specific flood warning system for the catchment is not possible	Not applicable.	Not viable.

MEASURE	REFER SECTION in FRMS	PURPOSE	COMMENT	ECONOMIC ASSESSMENT	IMPLEMENTATION VIABILITY
EVACUATION PLANNING	Section 6.3.2	To ensure that evacuation can be undertaken in a safe and efficient manner.	The SES should prepare a Local Flood Plan.	Relatively low cost.	Recommended.
PUBLIC INFORMATION AND RAISING FLOOD AWARENESS	Section 6.3.3	Educate people to minimise flood damages and reduce the flood risk.	A cheap and effective method but requires continued effort. Examples of methods are provided.	Benefits likely to be significant for relatively low cost. Effectiveness reduces with time since last flooding event.	Recommended.
			PROPERTY MODIFICATION MEASURES:		
HOUSE RAISING	Section 6.4.1 and Section 6.5.7	Prevent flooding of existing buildings by raising habitable floor levels.	No suitable houses.	Not applicable.	Not viable.
VOLUNTARY HOUSE PURCHASE	Section 6.4.2 and Section 6.5.8	To remove flood liable houses from the floodplain.	No applicable houses in the lower catchment possibly can be considered for the upper catchment.	Not undertaken but unlikely to be cost effective.	To be considered for the upper catchment
FLOOD PROOFING	Section 6.4.3 and Section 6.5.9	Prevents inundation of floodwaters.	Generally only suitable for non-residential buildings but may be the only option for some residential buildings.	Depends upon building. Not funded by the State Government.	To be promoted where applicable.
FLOOD PLANNING LEVELS	Section 6.4.4	To minimise flood damages to new developments.	Council has established appropriate controls that are currently being reviewed.	Negligible cost.	Recommended.
DEVELOPMENT CONTROL PLANNING	Section 6.4.5 and Section 6.5.11	To ensure new development reduces the flooding and drainage impacts on downstream properties, the pollutant loads and conserves potable water supplies.	Council has established appropriate guidelines that are currently being reviewed.	Negligible cost.	Recommended.
			MANAGEMENT MEASURES WITHIN UPPER CATCHMENT:		
VISUAL INSPECTION OF CATCHMENT	Section 6.5.2	To determine the magnitude of the flood problem.	This inspection provided an indication of the extent of the flood problem.	Nil	No action necessary
IDENTIFICATION OF HOUSES INUNDATED	Section 6.5.3	To determine the magnitude of the flood problem.	Requires a Flood Study of overland flooding initially.	Not applicable.	Should be considered.
PIT AND PIPE UPGRADE	Section 6.5.4	Increase capacity of sub-surface drainage network.	Many construction difficulties.	High cost and likely low benefit but should be undertaken at time of redevelopment.	To be considered.
REDIRECTION OF OVERLAND FLOW	Section 6.5.5	To redirect floodwaters away from affected properties.	Difficult to implement without adversely affecting others consequently may increase flood levels elsewhere.	Not undertaken as depends on nature of works	To be considered.
MANAGEMENT OF	Section 6.5.6	To ensure the efficient use of	A variety of means are available but it is	Not costed	Recommended.

MEASURE	REFER SECTION in FRMS	PURPOSE	COMMENT	ECONOMIC ASSESSMENT	IMPLEMENTATION VIABILITY
BLOCKAGE		the available infrastructure.	difficult to achieve 100% success.		
ON-SITE DETENTION	Section 6.5.10	Expand the policy to mitigate existing flood flows.	No other Council has undertaken this expanded policy.	Probably not viable.	Not recommended.

Table 2: Review of Development Measures

MEASURE	REFER SECTION in FRMS	PURPOSE	COMMENT	ECONOMIC ASSESSMENT	IMPLEMENTATION VIABILITY
CLIMATE CHANGE	Section 7.1	Assess possible impacts of climate change and include in Flood Planning Level.	The effect of sea level rise will only affect design flood levels downstream of New South Head Road. An increase in rainfall intensity will affect the entire catchment.	Unknown.	Council should consider introducing a climate change flood policy.
DEVELOPMENT INTENSIFICATION	Section 7.2	Ensure no adverse impacts on flooding or water quality.	Council has an existing policy which is under review.	Negligible.	Policy is recommended.
			WATER SENSITIVE URBAN DESIGN:		
REDUCE THE POTABLE WATER DEMAND	Section 7.3.2	To minimise runoff volume and rate of runoff.	Should be employed where opportunities arise.	Variable.	To be promoted.
TREAT URBAN STORMWATER	Section 7.3.4	To improve runoff quality.	Should be employed where opportunities arise.	Variable.	To be promoted.

2.4. Proposed Floodplain Management Measures

The proposed measures are described below (in no particular order within each priority group).

2.4.1. HIGH Priority

1. Local Drainage Issues – Maintain Drainage Database

- **Cost:** minimal,
- **Responsibility:** Council,
- **Timeframe:** ongoing.

OUTCOMES

Local drainage issues will arise from time to time and it is important that Council record all such instances. In order to assess their importance and determine whether a permanent solution is available the local drainage database which Council has used in the past must be maintained and where possible enhanced (include photographs). Woollahra Council has undertaken research on improving the kerb inlet pits to minimise blockage as well as to introduce some WSUD concepts.

ACTIONS

Council should maintain and where possible improve the existing database of reported local drainage issues and review the required actions following each major rainfall event (say an event of magnitude occurring once or twice a year). It is also important to obtain rainfall records to estimate the magnitude of the rainfall event. This can generally only be done using the pluviometer records as daily records do not identify a peak rainfall burst within a period of say 24 hours of rain.

2. Public Information and Raising Flood Awareness

- **Cost:** depends on extent of program,
- **Responsibility:** Council, SES,
- **Timeframe:** ongoing.

OUTCOMES

Based on feedback and general discussions, the residents within the lower catchment have a medium to high flood awareness due to frequency of flooding. However in the upper catchment it is expected there is a low level of flood awareness and preparedness. This is probably due to the quick onset of flooding and that it could occur at night plus a relatively high turnover of population.

A suitable Council wide flood awareness program should be implemented by Council using appropriate elements. The details of the program and necessary follow up should be properly documented to ensure that they do not lapse with time and to ensure the most cost effective means of communication.

ACTIONS

The SES in conjunction with Council should implement a public information program to raise the level of flood awareness within the community.

3. **Flood Planning Levels**
   - **Cost:** negligible,
   - **Responsibility:** Council,
   - **Timeframe:** ongoing.

OUTCOMES

Council is currently undertaking a formal review of the Draft Flood Risk Management DCP which would include review of flood planning levels, therefore no further action is required in this study.

ACTIONS

This Plan supports implementation of Council's Draft Flood Risk Management DCP.

4. **Development Control Planning**
   - **Cost:** negligible,
   - **Responsibility:** Council,
   - **Timeframe:** ongoing.

OUTCOMES

It is recommended that the Draft Flood Risk Management DCP and Draft Stormwater Drainage Management DCP be reviewed and accepted by Council. This would enable Council to implement sound floodplain management and drainage strategies across the catchment. It is also appropriate to ensure that works by Council (median strips, "speed humps", pavement re-design) do not exacerbate flooding.

ACTIONS

Council should include development on flood liable land in its LEP and in time formally adopt the Draft Flood Risk Management DCP and Draft Stormwater Drainage Management DCP.

5. **Upper Catchment – Overland Flow**
   - **Cost:** depends upon works,
   - **Responsibility:** Council, OEH, property owners,
   - **Timeframe:** ongoing.

BACKGROUND

In the upper catchment the "flood problem" is a mixture of significant overland flow (which would generally be described as a "flood") and "local drainage" (blockage of kerb pit, ponding in low spots, tree roots blocking kerb flow, minor flow diversion etc.) that causes inconvenience to local residents but no significant tangible damage. Local drainage is not considered within the framework of this study but should be reported to Council and will be addressed as appropriate.

Overland flow (caused by significant rainfall that causes runoff that exceeds the capacity of the pipe drainage system) has in the past resulted in excessive ponding that has entered properties and resulted in over floor inundation and redirection of flow into low lying properties (habitable premises and garages). The accumulation of overland flow at low points can result in inundation of property and can heighten any local drainage issues at these locations and at areas downstream.

Ponding at trapped low points is due to a significant amount of overland flow directed to a low point where there is no flowpath or the flowpath is higher than the low point. As the flows are large, provision of additional drainage (pits and pipes) is often not sufficient to alleviate flooding. To mitigate the flooding a suite of measures may be required, such as redirection of flow away from the low point within the upper catchment, augmentation of upstream drainage lines, construction of overland flow paths or individual property protection measures.

Large overland flows conveyed along roads potentially inundate basements, driveways or floor levels that are at road level or lower. Parked cars, debris in gutters, tree roots or similar may exacerbate the problem. These problems are generally associated with relatively small catchment areas and may occur during most heavy rainfall events (say every year).

Prior to investigating mitigation measures the existing flood behaviour need to be defined using ground survey and site specific hydraulic assessment. It is important that Council continues to monitor issues (refer maintenance of drainage database measure) to determine whether it is a permanent problem that requires a solution or whether it is a temporary problem (e.g. blocked pit or as a result of roadworks) that can be resolved. A range of management measures for the upper catchment are discussed below.

VISUAL INSPECTION: A detailed visual inspection of each street was undertaken and reported on in the Floodplain Risk Management Study, the results do not resolve the problem but can be used by Council to:

- Define the scale of the problem and therefore an overall management strategy and prioritisation of works. This needs to be undertaken before specific management strategies can be implemented in the upper catchment.
- Compare the results with "complaints" by residents following heavy rain. In this way the nature of the problem will be more closely identified and thus management measures more appropriately targeted.
- Ensure that future development in the local area does not exacerbate the problem and hopefully can be designed to reduce the extent of the problem.

Potential localised management measures include:

- pit and pipe upgrade,
- redistribution of overland flow away from inundated sites,
- management of blockage,
- voluntary house purchase,
- flood proofing properties,
- on-site stormwater detention,
- planning controls.

The application of management measures at individual locations should consider both the positive impacts at each site and the likely impacts to property and infrastructure downstream. To remove the flood risk for events up to a 100 year ARI would generally require either upgrading of the pit and pipe networks or house purchase where private properties are located at low points along flow paths.

IDENTIFICATION OF HOUSES INUNDATED: The number of houses inundated above floor level, over the range of flood events, has not been identified in the upper catchment, nor has the floor levels of the buildings. This information is required in order to accurately identify the problem and would require a detailed overland flow hydraulic model study for the upper catchment as well as collection of surveyed floor levels in the key areas. It is recommended that an overland flow hydraulic model study (using the existing DRAINS model flows) be undertaken for the upper catchment as well as collection of surveyed floor levels in the key areas.

PIT AND PIPE UPGRADE: Upgrading pit and pipe networks within the upper catchment will generally assist in reducing the amount of overland flow and consequently alleviate flood issues. The main drawback of this measure is the high construction costs (largely due to the additional cost to relocate services, obtain easements through private property, construct pipes under or around buildings etc.). For this measure to be successful often the pipe network needs to be augmented to the downstream outlet so that flooding in the downstream areas does not increase as a result of the pipe upgrades upstream. If there is a section of pipe which cannot be upgraded for some reason (narrow easement through private property) then the benefit can be severely limited. It is recommended that the major/minor design approach be adopted. The minor system is for pits and pipes that cater for events up to Council's design standard across the LGA (say 10 year ARI), with provision for major events (up to the 100 year ARI event) along roads or open space areas. Subject to the findings of the proposed overland flow hydraulic model study (see above) it is expected that the upgrade of pits and pipes in many areas would be an effective management measure.

REDIRECTION OF OVERLAND FLOW: This measure may involve raising kerbs or regrading roads to direct water away from a known flood affected location but without adversely affecting downstream properties. The redirection of overland flows, where applicable, will provide an effective management measure in the upper catchment and should be pursued.

MANAGEMENT OF BLOCKAGE: Blockage of inlet pits and pipes is unfortunately relatively common in urban areas and particularly in tree lined streets and where street parking is common. The three main issues are: sedimentation in pipes, blockage at pit inlets and the presence of parked cars or debris in gutters. Council are pro-active in keeping pipes clean as part of a maintenance program and have undertaken CCTV in many parts. Council's maintenance program includes regular street sweeping and encouraging the community to keep gutters clean through education programs. The street sweeping program and other water quality measures were reviewed in 2004. Council has also introduced parking restrictions to prevent vehicle parking on inlet pits. Unfortunately despite continued efforts by Council it is unlikely that 100% success can be achieved with this measure.

It is recommended that Council:

- maintain the current street sweeping program, regularly assess its effectiveness and in light of the outcomes review the adopted approach,
- consider adopting parking controls at locations where the flow is large and regularly inundates adjacent properties,
- adopt a maintenance program to inspect and rectify sedimentation in pipes, this may

mean the CCTV of all pipes.

VOLUNTARY PURCHASE: Voluntary purchase should be considered at locations where private property is sited at a low point, flood depths are greater than 1m or properties are subject to high velocities and no alternative strategy is available. This measure may be the most cost effective management measure where the upgrade of pit and pipe systems requires extensive inlet pits, long lengths of pipe upgrades or extensive services relocation. It is acknowledged that voluntary purchase may not support the heritage and community objectives of the LEP and may not be supported by the relevant property owners. This measure was considered in the past studies and found not to be economically feasible.

FLOOD PROOFING: Flood proofing of residential properties could be pursued by individual property owners in low hazard areas to prevent above floor inundation, however consideration would have to be given to the redistribution of flows to downstream properties and maintaining safety if the measure failed. This option would generally not be considered for State Government funding from the floodplain management program.

ON- SITE- DETENTION: All Councils in Sydney (including Woollahra) have an on-site stormwater detention (OSD) policy which ensures that there will be no increase in peak flows due to an increase in density of development. Woollahra Council's policy is in the draft Stormwater DCP which is currently under review. This measure is appropriate for ensuring that future development does not increase peak catchment flows but cannot be used as a mitigation measure to reduce existing peak flows on equity grounds (a new development should only be required to not worsen the existing flood situation and not provide some form of mitigation that would help others). OSD is not favoured by many developers as it provides "no benefit" to the property. In recent times Council has offset the need for OSD if the developer constructs a large water reuse tank. This approach is attractive to developers as it provides a tangible benefit to the property owner (irrigation or toilet flushing usage) and is generally supported by this Plan.

PLANNING CONTROLS: Planning controls including flood planning levels and flood related development control plans are discussed in a previous measure. As Council is currently undertaking a formal review of the Draft Flood Risk Management DCP and Draft Stormwater Drainage Management DCP no recommendations are provided in this Plan for updating these planning aspects.

It is noted that in many other Council areas within Sydney, flood related planning controls are being applied in overland flow areas such as the upper catchment. The inclusion of these areas needs to be considered by Council as part of any review of the current policies.

SITE SPECIFIC MEASURES: There are significant overland flow problems in the upper catchment that have occurred several times in the past. There are no cost effective measures that will eliminate these flood problem. The measures considered in the Floodplain Risk Management Study were pit and pipe upgrades, road/gutter works to divert flow and voluntary purchase of affected properties. The main issue with these measures is the high cost and the need to justify the works in terms of a reduction in flood damages in order to seek funding from the State or Federal Government. The latter requires a detailed floor level survey and drainage investigation.

Upgrading of the pit and pipe network and road/gutter works is most probably the only measure acceptable to the local residents. Voluntary house purchase will likely be rejected by the community.

It is recommended that Council continue to record instances of inundation from local drainage (refer maintenance of drainage database measure). This process will ensure that the overland flow problem is accurately identified. As a general strategy Council should continue and revise where required, the maintenance program for pits and pipes. Council may also wish to consider parking controls in areas where overland flow is significant to ensure grate inlets are clear to receive stormwater.

The following provides a summary of the recommended actions for the specific areas investigated.

Cecil Street, Cecil Lane, Hampden Street: These streets are probably the most flood affected in the catchment and works should be undertaken to reduce the frequency of inundation. The preferred works are construction of an open channel along the northern end of the streets and this is likely to have a relatively high benefit cost ratio.

Roylston Street: The preferred works are construction of an overland flowpath from Cecil Street into Trumper Park (see above).

Walker Avenue, Glenmore Road: Minor road works would assist in a small flood but there are no practical mitigation measures for large flood events.

Pit and pipe upgrades at the following areas should be further investigated:

- **George Street, Elizabeth Street,**
- **Victoria Street, Underwood Street,**
- **Hopetoun Street, Hopetoun Lane,**
- **Hargrave Street, Sutherland Street,**
- **Ocean Street, Tara Street,**
- **Harris Street,**
- **Neild Avenue, Boundary Street**.

The above investigations will all require a ground and floor level survey and a detailed drainage investigation to be undertaken to quantify the flood problem, identify potential inundated properties, assess impacts to downstream properties and estimate the potential damage and scope design requirements. Subsequently a rigorous cost benefit analysis should be undertaken to justify the works.

2.4.2. MEDIUM Priority

1. **Evacuation Planning**
    - **Cost:** minimal,
    - **Responsibility:** Council, SES
    - **Timeframe:** ongoing.

OUTCOMES

A Local Flood Plan which includes Rushcutters Bay catchment should be prepared. The SES's role in flooding in the Rushcutters Bay catchment is likely to occur before (awareness program) and after the event (clean up) due to the limited response time available and likely demand on resources from other areas flooding concurrently. The response of the community during an event is critical in reducing the flood damages and risk to life and thus, even if emphasised as a 'self help' approach, should be formulated in conjunction with/by the SES.

ACTIONS

It is recommended that Council with SES seek to adopt a local SES headquarters within the Woollahra LGA and develop a Local Flood Plan.

2. **Voluntary Purchase**
    - **Cost:** depends on property,
    - **Responsibility:** Council, DECCW, property owner,
    - **Timeframe:** ongoing.

OUTCOMES

In the lower catchment there are no properties that would be suitable for voluntary purchase but it may be appropriate in the upper catchment if no other measures are viable.

ACTIONS

To be considered for implementation in the upper catchment if no other measures are viable.

3. **Channel Modifications – Remove Pedestrian Footbridges**
    - **Cost:** $50,000,
    - **Responsibility:** Council, landowner
    - **Timeframe:** 1 year.

OUTCOMES

The pedestrian bridges along the open channel may fail and cause blockage of the downstream culverts under Craigend Street/New South Head Road during a large flood. Any blockage at this location will significantly raise flood levels upstream and the likelihood should be minimised as far as possible.

Other potential channel modifications measures include increasing the size of the channel south of Glenmore Road adjacent to Walker Avenue and/or upgrading the culvert under Craigend Street. These are more long term measure that could only be undertaken in conjunction with other development works in the area.

ACTIONS

Removal of the pedestrian bridges along the open channel or at a minimum ensuring their structural integrity in a flood should be undertaken to minimise the risk of blockage (particularly of the openings under New South Head Road).

2.4.3. LOW Priority

1. Construction of Retarding Basins

- **Cost:** depends on extent of works,
- **Responsibility:** Council,
- **Timeframe:** ongoing.

OUTCOMES

Retarding basins are unlikely to be a cost effective measure to negate overland flow problems in the upper catchment. However all basins will provide some flow mitigation and water quality benefit. The benefit that can be achieved must be balanced against the loss of use of the land and concerns about Council's liability if construction of a basin increases the flood hazard in the area.

ACTIONS

Council should further investigate the use of retarding basins as a means of providing some flow mitigation and water quality benefit.

2. Flood Proofing

- **Cost:** depends on property,
- **Responsibility:** Council, DECCW, property owner,
- **Timeframe:** ongoing.

OUTCOMES

Flood proofing for the flood affected non-residential buildings would assist in reducing the tangible damages associated with flooding in the catchment. This measure is unlikely to receive Government funding however it should still be pursued by Council and potential owners should be advised that it is an available option.

Flood proofing of residential properties in low hazard areas on a property by property basis could alleviate local inundation issues. However consideration would have to be given to the (possible) redistribution of flows to downstream properties and safety issue of isolating residents behind such protection measures should they fail. This option would not be considered for Government funding however could be pursued by individual property owners. At some locations it is the only viable measure. In Sydney it has been used to protect basement car parks.

ACTIONS

Flood proofing should be promoted as a means available to reduce flood damages for non-residential buildings and possibly in isolated places where no alternative is available for residential buildings. These types of measures are not recommended for new developments unless they are "fail safe".

2.5. Development Measures

These measures consider the management of future development from a flooding and water quality perspective.

2.5.1. Climate Change

- **Cost:** minimal for Council but will add to developer costs,
- **Responsibility:** Council, OEH, property owner,
- **Timeframe:** ongoing.

OUTCOMES

The potential impact of increased design flood levels in the catchment due to climate change is greater in the lower portion of the catchment adjacent to the open channel where both an ocean level rise and a rainfall increase have an effect. An increase in ocean levels of 0.9 m by the year 2100 would raise the 100 year ARI flood levels by approximately 0.2m upstream of Craigend Street. An increase in rainfall of 10% would raise 100 year ARI flood levels by 0.25m upstream of Craigend Street.

There are no means of lessening the increase in greenhouse gases other than a world-wide reduction in their production. Council should continue to monitor the available literature and reassess Council's Stormwater and Flooding DCPs as appropriate. At a minimum Council should obtain the most current information available from the Bureau of Meteorology, CSIRO and OEH every two years.

ACTIONS

Many Councils in NSW have raised the Flood Planning Levels to account for the expected increase in flood level. This rise would be in addition to the 0.3 m freeboard. This issue should be canvassed further by Council.

2.5.2. Development Intensification

- **Cost:** minimal for Council,
- **Responsibility:** Council,
- **Timeframe:** ongoing.

OUTCOMES

There is continuing pressure on Council to permit further subdivision of existing lots to increase the density of development or permit multi-unit development within the catchment. As a result this could increase water quality issues and/or exacerbate flooding. Council policies to manage the adverse effects of development on flooding are supported and if implemented successfully will ensure minimal adverse impact on other floodplain users. It is understood that these documents are currently being reviewed by Council.

ACTIONS

No action required at this stage.

2.5.3. Water Sensitive Urban Design

- **Cost:** minimal for Council but will add to developer costs,
- **Responsibility:** Council,
- **Timeframe:** ongoing.

OUTCOMES

Urban development can lead to changes in the catchment hydrology with the most obvious being an increase in peak flow (and resulting flood levels) and pollutants in the creek system. Traditionally floodplain risk management studies have focussed on the increase in peak flow where the principal objective is to safely and efficiently convey stormwater to the ocean. This is the reason why a concrete lined channel forms the main drainage channel in the lower part of the Rushcutters Bay catchment.

The increased public awareness of environmental issues and shortage of water resources have highlighted the importance of the environmental management of urban stormwater. An integrated stormwater management strategy to cater for multiple objectives is therefore required. This approach is termed Water Sensitive Urban Design (WSUD) and has the following broad objectives:

- reduce the potable water demand through water efficient appliances and rainwater and grey water collection and reuse,
- minimising wastewater generation,
- treat urban stormwater to meet water quality objectives and reuse if possible,
- using stormwater to maximise the visual and recreational amenity of the urban landscape.

This floodplain risk management study supports the general objectives of WSUD but it is not possible to address every aspect (e.g. water saving devices, grey water reuse, etc.) within the scope of the study. Woollahra Council has implemented several WSUD features throughout the LGA and supports the principles. The following have been considered.

Reduce Potable Water Demand: The introduction of BASIX (Building Sustainability Index) to ensure minimum energy and water use targets has ensured that all new developments minimise the potable water demand. Whilst BASIX only applies to residential developments the water use principles can also be applied to other land use activities (commercial and industrial developments).

This could also be further extended to existing Council or government structures and facilities. In some Council areas there are opportunities to construct either rainwater tanks or structures, for example on concrete netball or tennis courts. Inspection of the catchment indicates no obvious or significant facilities where this approach could be applied. However should such an opportunity arise this should be supported.

Treat Urban Stormwater: Council has already introduced water quality devices in the catchment (water quality boom at the exit of the channel to Rushcutters Bay) and the following should be considered:

Gross Pollutant Traps: Downstream of Glenmore Road the preferred siting of a GPT is as an offline structure where land is available and does not limit the use of the adjoining land. If possible it should be constructed as a wetland and so incorporate a nutrient absorption function. It would provide significant environmental benefit with no adverse hydraulic impacts and potentially some social benefits. There may be other potential sites for GPTs. These should be considered where appropriate.

Sub-Surface Devices: Where appropriate Council should install more of these devices.

Improved Water Absorption: Council should consider, as far as possible, changes to its work procedures to ensure maximum water absorption.

3. INTRODUCTION

The Rushcutters Bay catchment is located primarily within the Woollahra Municipal Council Local Government Area (LGA) and a small part is located within the City of Sydney LGA. The catchment covers an area of approximately 2.4 km^2 from Oxford Street draining into Sydney Harbour at Rushcutters Bay (Figure 1). It includes the suburbs of Paddington, Rushcutters Bay and parts of Edgecliff, Woollahra and Darlinghurst.

The catchment is characterised by an upper and a lower section. The upper section is relatively steep and fully urbanised and is drained by pit and pipe networks with surcharging flows conveyed overland along streets. The pits and pipes have largely been installed by Woollahra Municipal Council in the 1930's. The lower portion has flatter terrain and is drained to the Harbour via a large box culvert and an open channel. Features within this section include Trumper Park, the White City tennis complex, the Weigall sportsground, the waterway crossing of Craigend Street/New South Head Road and Rushcutters Park.

Flooding problems have been experienced at a number of locations within the catchment during periods of heavy rainfall. Woollahra Municipal Council has undertaken to address this issue by undertaking a Floodplain Risk Management Process that covers both the upper and lower parts of the catchment.

3.1. Floodplain Risk Management Process

As described in the Floodplain Development Manual (Reference 1), the Floodplain Risk Management Process entails four sequential stages:

Stage 1:	*Flood Study.*
Stage 2:	*Floodplain Risk Management Study.*
Stage 3:	*Floodplain Risk Management Plan.*
Stage 4:	*Implementation of the Plan.*

The Rushcutters Bay Catchment Floodplain Risk Management Study constitutes the second stage in the process. The Flood Study stage was completed in October 2007 with publication of the Rushcutters Bay Catchment Flood Study (Reference 2). A combination of hydrologic and hydraulic models was used in that study to determine design flood levels for the Rushcutters Bay catchment. This study superseded a previous Catchment Management Study (Reference 3) completed in 1991.

3.2. Drainage Features in the Lower Section of the Catchment

Table 3 provides a descriptive overview of the open channel drainage systems downstream of Glenmore Road. Details of piped systems include a 1200 mm diameter culvert under Trumper Park, a box culvert under Craigend Street draining primarily the western portion of the catchment near Boundary Street and a 4.5m wide and a 7.92m by 1.83m box culvert under Craigend Street and New South Head Road (the latter constructed in 1986 by Sydney Water). The roof of the original 4.5 m wide box culvert is constricted by pipes etc. with the height reducing to approximately 0.5 m. Thus there is a significant reduction in the waterway capacity compared to what is available at the entrance and exit. Photographs 1-10 show some features of the drainage system within this section. The extent of the lower section is shown on Figure 1 and is defined by the limit of the 2D model developed in the Flood Study.

Table 3: Open Channel Dimensions

Location	Width of Lined Channel (m)	Height to Coping (m)	Approx. Waterway Area to Coping (m^2)	Photograph
Glenmore Road	2.8	1.4	3.2	1
u/s White City footbridge #1	2.9	1.3	3.1	2
White City	3.9	1.3	4.0	3
White City footbridge #2	4.5	1.3	4.5	5
u/s of New South Head Road culverts	4.6	1.3	4.6	6
d/s of New South Head Road culverts	6.8	1.8	9.5	8
Channel outlet	13.0	2.5	30.2	10

Note: The above dimensions are approximate.
Coping is the top of bank of a lined channel.

Photo 1 Open Channel d/s of Glenmore Road

Photo 2 Looking u/s from footbridge within White City tennis complex

Photo 3 Looking d/s from footbridge within White City tennis complex

Photo 4 White City tennis complex looking u/s

Photo 5 White City tennis complex looking u/s

Photo 6 u/s of New South Head Road culverts

Photo 7 Culverts u/s of New South Head Road

Photo 8 d/s of culvert under New South Head Road

Photo 9 Rushcutters Bay Park, looking d/s

Photo 10 Mouth of Rushcutters Bay channel with water quality boom

3.3. Drainage Features in the Upper Section of the Catchment

Table 4 provides a summary of the piped networks within the upper section of the catchment (Figure 1). Photographs 11-14 show some features of the drainage system immediately upstream of the open channel.

Table 4: Pit and Pipe Drainage Network

Pit Type	Number	Pipe Diameter	Number
Kerb inlet only	48	Less than 300 mm	248
Grate inlet only	153	300 mm to 500 mm	796
Kerb and grate inlet	474	525 mm to 900 mm	139
Junction or bend or inspection - no inlet	620	1050 mm to 1800 mm	25
Outlets	27	Box culverts	100
Total	**1322**	**Total**	**1308**

Photo 11 Grate inlet in front of underground car park, Hampden Street

Photo 12 Kerb inlet in Cecil Street

Photo 13 Obstructed overland flow path in Cecil Street

Photo 14 Trumper Park looking d/s

4. STUDY AREA

4.1. Catchment Description

The catchment has been extensively developed for residential, commercial or light industrial purposes. There is only one area of natural bushland remaining and this lies to the north of Trumper Park. In the lower section of the catchment there is recreational open space including Trumper Park, the White City tennis complex, the Weigall sportsground and Rushcutters Park adjacent to the Harbour.

Much of the urbanisation occurred in the 1900s prior to the installation of drainage systems, and hence many buildings lie on overland flow paths. There are a large numbers of terraced houses with small gardens thus the proportion of impervious paved areas is large.

Drainage in the upper section of the catchment is characterised by underground pipe systems and overland flow conveyed along the roads, which are nearly entirely formed with kerbs and gutters. The lower section is characterised by an open channel system that consists of a lined channel with no natural channel remaining.

4.2. Development

The land use within the study area is predominantly urban residential development, comprising a mixture of pre-1900 terrace buildings and newer buildings including a number of medium density developments. The non-residential development includes several schools, parks, churches and community buildings. There are no significant industrial developments and few major commercial developments.

Significant catchment development occurred in the latter part of the 19th century. The 1861 census indicated a population of 2,700 which rose to 19,000 by 1890. The current catchment population is of the order of 15,000.

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, particularly as Council has an On-site Stormwater Detention Policy to ensure pre development peak flows are not increased.

The current LEP zonings for the catchment are provided on Figure 2.

4.3. Preliminary Environmental Assessment

4.3.1. Water Quality

As part of the Catchment Management Study (Reference 3) water quality sampling was undertaken. Results from this study and water quality samples indicated that the main pollutants in the study area included faecal coliforms, phosphorus and litter. All other pollutant concentrations tested (including suspended solids) were low even in rainfall events. A change in faecal coliforms concentrations may have occurred since 1991 as at the time of sampling, parts of the catchment still had a combined sewer and stormwater system. Under the Sydney Water Sewer Overflow Abatement Program it is assumed that any connections in low and high rainfall events would be significantly reduced and hopefully eliminated.

In 2006 Council completed the “Woollahra Street Sweeping and Pit Cleaning Activities Review” which considered Council’s current practices related to water quality treatment measures, assessed their effectiveness and made recommendations. Current practices in the LGA include the use of Gross Pollutant Traps (GPT), street sweeping, litter baskets, and pit cleaning. Within the Rushcutters Bay catchment Council has not installed any GPTs.

Sydney Water recently removed (circa 2008) a litter boom that was at the entrance to the Harbour as it was not collecting enough litter to justify the maintenance costs. In 2005 Sydney Water installed a GPT at the intersection of Boundary Street and Barcom Avenue in Darlinghurst.

Council actively undertakes education programs for the community to inform and engage residents in the management of water quality. For example, there is an environmental stall held once a year and Council has run a “gutter talk” program that highlighted the effectiveness of cleaning out gutters.

Council has an environmental works program that is in accordance with the Port Jackson South Management Plan (1999).

4.3.2. Flora and Fauna

As the entire natural drainage system has been replaced by either pipes or a concrete lined open channel there is little opportunity for the development of flora/fauna habitats. A detailed environmental assessment has not been undertaken as part of this study, however a preliminary review indicates that it is unlikely that there are any significant habitats along the creek system. Nevertheless every opportunity in the future should be taken to enhance the quantity and quality of the habitats. The vegetated area to the north of Trumper Park and Cecil Street is one of the few remaining areas of semi natural bushland in the catchment.

4.3.3. Visual Amenity

The visual amenity of the creek system itself would generally be described as of low quality compared to a natural system. However, apart from some graffiti, it is clean, fenced, well maintained and is typical of creek systems in heavily urban areas in Sydney that have developed in response to development pressures to use all available land when the environmental qualities of natural systems were not considered of high value and could be sacrificed.

4.3.4. Recreational Amenity

The actual channel system has no legal recreational amenity, however it does allow the use of significant areas of floodplain for active and passive recreational activities (White City and Weigall sports complexes). This is an excellent use of flood prone lands.

4.4. Previous Studies

A review of all known previous flood related studies was undertaken as part of the Flood Study (Reference 2). Of relevance for this Floodplain Risk Management Study are findings from the Flood Study (Reference 2), Rushcutters Bay Catchment Management Study (Reference 3) and Cecil and Hampden Streets, Paddington Drainage Investigation (Reference 4).

4.4.1. Rushcutters Bay Catchment Flood Study (Reference 2)

The Flood Study (Reference 2) established a rainfall and runoff model using the DRAINS software to estimate flows and assess hydraulic performance of pit and pipe systems in the upper catchment. A SOBEK hydraulic model was established for the lower portion of the catchment to convert flows into water levels. The SOBEK model was calibrated against historic flood information.

The Flood Study defined the flood behaviour for the 5 year, 10 year, 20 year, 50 year, 100 year ARI design storms and the Probable Maximum Flood (PMF). The main outcomes were:

- assessment of the adequacy and capacity of Council's existing pipe network,
- quantification of peak overland flows in the upper catchment,
- design flood levels and velocities in the lower catchment,
- preparation of flood contour, extent and preliminary hazard for the lower catchment,
- production of a modelling platform to form the basis for this Floodplain Risk Management Study and Plan.

It should be noted that design flood levels, extents and velocities were not determined in the upper catchment. Consequently the extent of flood damages (building floors inundated) is not available for this part of the catchment.

4.4.2. Rushcutters Bay Catchment Management Study (Reference 3)

This study included:

- a detailed assessment of the water quantity and quality aspects of the Rushcutters Bay catchment,
- results from a residential questionnaire,
- classification of flood hazard and hydraulic categorisation,
- flood damage estimates,
- recommendations for mitigation measures to address problem areas.

Recommendations related to stormwater drainage included:

- pipe upgrades,
- roadworks and works to footpaths,
- kerb raising and fences,
- development controls,
- on-site stormwater detention study.

4.4.3. Cecil and Hampden Streets Drainage Investigation (Reference 4)

This investigation identified options to alleviate localised flooding in these streets. A range of options were considered. Recommended works included:

- upgrade downstream trunk drainage capacity,
- local works at the entry of the car park,
- new pipe drainage outlet from the eastern end of Hampden Street,
- provide an overland flow path from the northern end of Cecil Street to Trumper Park,
- provide a pipe drainage line from the northern end of Cecil Street to the open channel downstream of Glenmore Road.

The third option listed above (replacement of a blocked line with a new line via Hampden Street and Cecil Street to the Sydney Water system) was recently completed.

5. EXISTING FLOOD ENVIRONMENT

5.1. Flooding Mechanism

Based on the available information flooding in the Rushcutters Bay catchment may occur due to:

- Elevated water levels in Rushcutters Bay due to a high tide and/or storm surge.
- Elevated water levels within the open channel section of the Rushcutters Bay catchment and along roads and through private property as a result of intense rain over the Rushcutters Bay catchment. The water levels in the channel and elsewhere may also be affected by constrictions (e.g. culverts, blockages, fences, buildings).
- Local runoff that accumulates (ponds) at low spots such as blocked overland flow paths or sags on roads. This type of flooding may be exacerbated by inadequate or blocked local drainage and restricted overland flow paths.

These factors may occur in isolation or in combination with each other. Elevated water levels in Rushcutters Bay would typically result from ocean influences (tides, storm surge) which may or may not occur in conjunction with intense rainfall that causes significant flooding in the Rushcutters Bay catchment. Typically flooding in the catchment occurs due to thunderstorms (as occurred in all previous events in the 1980's and 1990's).

Water level variations in Rushcutters Bay are associated with major storm events (low pressure systems, strong onshore winds and large waves) however flooding in the Rushcutters Bay catchment is generated by short duration (less than 2 hours) rainfall events. As a result, peak levels in Rushcutters Bay are unlikely to occur in conjunction with a flood over the Rushcutters Bay catchment. Sensitivity analysis for high water levels in Sydney Harbour (Reference 2) indicated that the backwater effects are confined to the lower reaches of the Rushcutters Bay open channel downstream of Craigend Street.

Craigend Street and New South Head Road form significant barriers to flow as all stormwater is channelled into twin culverts under the roads. One culvert connects to a sandstone lined channel which enters Rushcutters Bay, the other exits directly into Rushcutters Bay. The channel is tidal to upstream of Craigend Street.

The lower catchment has much lower relief than the upper catchment and is drained via trunk drainage pipes and culverts into an open channel downstream of Glenmore Road. Upstream of Glenmore Road flow in excess of the pipe system is conveyed across Trumper Park. The open channel and its floodplain passes through the White City tennis complex and Weigall Sportsground.

The underground piped networks throughout the catchment were found (Reference 2) to have a small capacity (generally less than the 5 year ARI). Thus flooding in the upper catchment is characterised by overland flow conveyed along roads or through private property. There have been several instances of flooding of roads and property in the past 20 years, notably at Cecil Street, Cecil Lane and Roylston Street.

5.2. Historical Flood Data

A detailed analysis of rainfall records and flood records was undertaken as part of Reference 1. Additionally as part of Reference 3 some 8900 questionnaires were distributed, this included 1300 more detailed questionnaires distributed to known flood problem areas. A summary of the key responses are provided in Table 5.

Table 5: Questionnaire Results (Reference 3)

Item	Response	Comment
Ever experienced flooding?	44%	This is a very high response but probably reflects the fact that those who have been flooded in the past have a greater desire to return the questionnaire.
Nature of flooding?		
• **Above house floor**	81 out of 303	This is a very high response for above floor inundation.
• **Under house**	34 out of 303	
• **In yard**	91 out of 303	
• **In street**	214 out of 303	This result is not unusual as flooding in the street is expected.
• **Other**	11 out of 303	

Reference 3 provided a summary of the flood problems with the majority of the flooding issues recorded in the Jersey Road, Trumper Park and White City areas. These are the areas along the natural drainage lines.

Recorded depths were up to 1 m for January 1989 (Roylston Street) and 0.6 m for January 1991 (Cecil Street). Trumper Park was inundated by up to 0.15 m depth in January 1991. The White City tennis complex grounds were inundated by approximately 1 m in November 1984 (indicative level of 3.1 mAHD), 0.6 m in January 1989 (indicative level of 2.7 mAHD) and 0.3 m in January 1991 (indicative level of 2.5 mAHD). Subsequent to the November 1984 event an additional culvert was installed under New South Head Road. Thus it is expected that flood levels would be lower for a similar rainfall event as these today.

The lack of data in other flood liable areas in the catchment means that the true extent of flooding in historical events is largely unknown. Consequently, following every future event of magnitude 10 year ARI or greater, Council should distribute a questionnaire, immediately following the event, to determine the extent of inundation and damages to private property.

5.3. Design Flood Data

The Rushcutters Bay Flood Study (Reference 2) reported design flood data for current catchment conditions. The Study recommended that the full range of storm durations should be considered if undertaking detailed investigations for drainage augmentation within the catchment. This is due to the potential redistribution of catchment flows if the drainage networks locally are upgraded.

5.3.1. Upper Catchment

Design results from DRAINS are provided on the following figures:

- **Figure 1: Existing Pipe Capacity** - this shows that for the majority of the catchment the pipe capacity is exceeded in events less than 5 year ARI. Thus it is concluded that in events smaller than a 5 year ARI overland flow will occur along streets and possibly through private property. This is exemplified by the series of frequent flooding events that have occurred during the duration of this study and reported by local residents (mainly in Cecil Lane and adjoining).
- **Figures 3 and 4: 100 year ARI and PMF Overland Flows** - this indicates the peak overland flows in m^3/s in the 100 year ARI and PMF events. Many of the streets indicate significant peak flows that would cause significant damage to property and risk to life (pedestrians and cars may be swept away).

The above scenario is typical of the majority of urban catchments in Sydney. Even in newly developed areas in Sydney the pipe capacity is never designed to accommodate the 100 year ARI capacity. Typically it is of the order of 5 to 10 year ARI with flows greater than the pipe capacity being conveyed along streets or drainage easements with minimal impact on surrounding developments.

In the Rushcutters Bay catchment and older suburbs in Sydney, past urban development (or re development) has occurred that has restricted overland flow paths or caused the diversion of overland flow into private property, thus causing inconvenience and damage to private and public property. Consequently, there is a significant overland flow problem in the upper catchment and of greater magnitude than would be expected in a newly designed urban development.

However, it should be noted that even in the more recently developed areas of NSW, rainfall events will occur that are greater than the design capacity of the overland flow system and in these rare events damage to surrounding developments will occur. An example of this is the floods of November 1996 and March 2009 at Coffs Harbour that inundated a large part of the residential and commercial areas as well as the June 2007 event in the Newcastle and Cardiff areas.

It is also of note that drainage problems have occurred many times in the past and residents have implemented their own adaptation approaches. In some places developments have been modified to minimise the resulting damages.

5.3.2. Lower Catchment

The Flood Study determined that the critical storm duration (produces the highest peak level) was 90 minutes for the 100 year ARI event. This duration was used for all other design events apart from the PMF which was determined to be the 120 minute duration.

The design tailwater level used in the Flood Study was the same as commonly adopted in similar studies in Sydney, which is to adopt a static water level of 1.0 mAHD in conjunction with flooding in the local catchment. Sensitivity analysis for a high tailwater level indicated that the backwater effects do not impact upstream of Craigend Street therefore validating the design tailwater assumptions.

The design conditions assumed 100% blockage of the smaller 4.5 m wide culvert under Craigend Street/New South Head Road as it was considered that there is a reasonable chance that in a large storm event blockage will occur (vegetative debris, cars, fencing etc.). Recent large storms in August 1998, Newcastle 2007 and Coffs Harbour in November 1996 and March 2009 have shown that blockage is a significant factor at all culverts and consequently raises flood levels upstream.

Peak height profiles for the 5, 10, 20, 50 and 100 year ARI events and the PMF are provided on Figure 5 and Figures 6 and 7 provides the extent of inundation and design flood contours in the 100 year ARI and PMF events.

5.4. Hydraulic Classification

The Floodplain Development Manual (Reference 1) defines three hydraulic categorises which can be applied to define different areas of the floodplain. The hydraulic categories of flood prone land include:

> "*Floodways* are those areas where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow or a significant increase in flood levels."
>
> "*Flood storage areas* are those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood."
>
> "*Flood fringe* is the remaining area of flood prone land after floodway and flood storage areas have been defined."

The above hydraulic classifications have been applied to the Rushcutters Bay catchment based on available hydraulic model results together with knowledge of the catchment and experience in other catchments.

Upper Catchment

- Overland flow paths, generally along roads, are classified as floodways as a significant portion of floods is conveyed along these flow paths. This is consistent with recommendations in Reference 3.
- There are no significant areas considered as flood fringe or flood storage.

Lower Catchment

- Flow through Trumper Park is classified as floodway with flood fringe areas where the flow depth is less than 0.1 m.
- The open channel downstream of Glenmore Road is classified as floodway.

- Overland flow along roads (such as Walker Avenue, Glenmore Road, Cecil Street, Roylston Street and Hampden Street) is classified as floodway.

5.5. Flood Hazard Classification

The hazard categorisation for the lower catchment was quantitatively determined using depth and velocity for each design event in accordance with the provisional hydraulic hazard categorisation. The provisional hazards were refined to consider other factors such as rate of rise of floodwaters, duration, threat to life, danger and difficulty in evacuating people and possessions and the potential for damage, social disruption and loss of production. These factors and related comments are given in Table 6. For the Rushcutters Bay catchment these factors do not significantly alter the provisional hazard classifications (Figures 8 and 9) for the 100 year ARI and PMF events.

Table 6: Hazard Classification

Criteria	Weight (1)	Comment
Rate of Rise of Floodwaters	High	The rate of rise in the channel and onset of flow along roads would be very rapid, which would not allow time for residents to prepare.
Duration of Flooding	Low	The duration is less than 2 hours and would not significantly increase the hazard.
Effective Flood Access	High	Roads within the catchment can be inundated and may restrict vehicular access during a flood but pedestrian access to high ground or a building is always available.
Size of the Flood	Low	The hazard does not significantly increase with the magnitude of the flood.
Effective Warning and Evacuation Times	High	Both in the upper and lower sections of the catchment there is very little, if any, warning time. During the day residents will be aware of the heavy rain but at night (if asleep) residential and non-residential building floors may be inundated with no prior warning.
Additional Concerns such as Bank Erosion, Debris, Wind Wave Action	High	The main concern would be debris blocking culverts or pits. This is considered to have a high probability of occurrence and will significantly increase the hazard.
Evacuation Difficulties	Low	Given the quick response of the catchment, evacuation is not considered to be necessary and therefore is not significant.
Flood Awareness of the Community	Medium	The flood awareness of the community is moderate in the lower catchment due to frequency and severity of flooding. It is considered low in the upper catchment.
Depth and Velocity of Floodwaters	Medium	In the upper catchment, roads are subject to fast flowing water. In the lower catchment the channel velocities and depth would be high. However for the majority of areas that are likely to be occupied during a flood the velocity and depth are low. However there is always a risk of a car or pedestrian being swept into the open channel downstream of Glenmore Road.

Note: (1) Relative weighting in assessing the true hazard.

5.6. Flood Damages

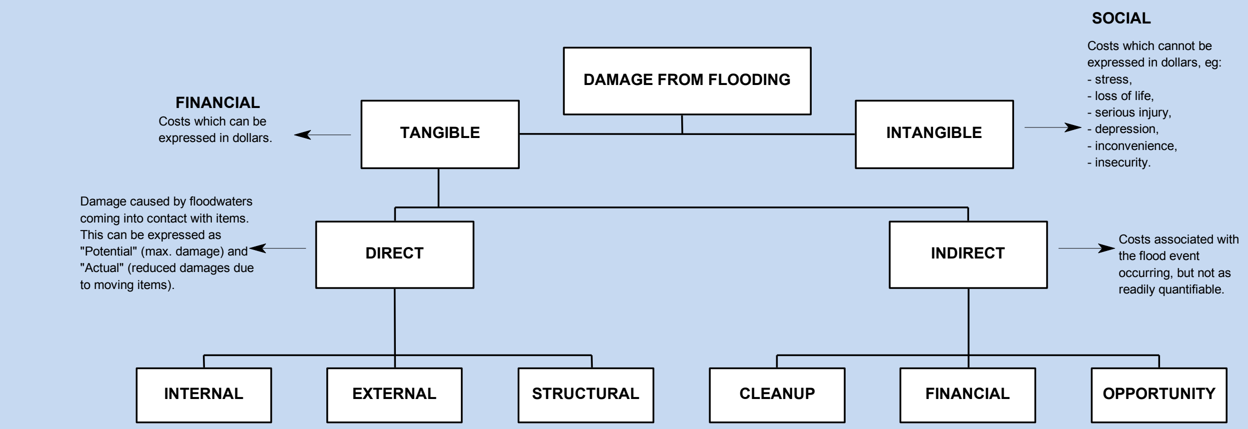
The cost of flood damages and the extent of the disruption to the community depend upon many factors including:

- the magnitude (depth, velocity and duration) of the flood,
- land usage and susceptibility to damage,
- awareness of the community to flooding,

- effective warning time,
- the availability of an evacuation plan or damage minimisation program,
- physical factors such as erosion of the river bank, flood borne debris, sedimentation.

Flood damages can be defined as being "tangible" or "intangible" (refer Table 7). Tangible damages are those for which a monetary value can be assigned, in contrast to intangible damages, which cannot easily be attributed a monetary value (stress, injury, loss to life, etc.).

Table 7: Flood Damages Categories



	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

5.6.1. Tangible Flood Damages

Tangible flood damages are comprised of two basic categories; direct and indirect damages. Direct damages are caused by floodwaters wetting goods and possessions thereby damaging them and resulting in either costs to replace or repair or a reduction in 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.

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. However, considering damages is 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 is equal to the damage caused by all floods over a period of time divided by the number of years in that period and represents the equivalent average damages that would be experienced by the community on an annual basis. This means that the smaller floods, which occur more frequently, are given a greater weighting than the rare catastrophic floods.

5.6.2. 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 above, 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 paper 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 its 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.

5.6.3. Assessment of Tangible Flood Damages

While the total likely damages in a given flood are useful to get a “feel” for the magnitude of the flood problem, it is of little value for absolute economic evaluation. When considering the economic effectiveness of a proposed mitigation measure, the key question is what are the total damages prevented over the life of the measure? This is a function not only of the high damages which occur in large floods but also of the lesser but more frequent damages which occur in small floods.

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. By this means the smaller floods, which occur more frequently, are given a greater weighting than the rare catastrophic floods.

A flood damages assessment was undertaken for existing development within the lower catchment for both residential and commercial properties, including the White City complex. This was based on a detailed floor level survey and results from the SOBEK model. The damage assessment considered multiple houses per property (units, etc.) as well as two storey houses (habitable/non-habitable ground floor) and applied an adjustment factor to represent the anticipated damages. Damages to public structures have not been assessed.

The summary of flood damages for the lower catchment is provided in Tables 8 to 10 with the building floors inundated shown on Figure 10.

Table 8: Number of Properties with above Floor Inundation

	5 year ARI	10 year ARI	20 year ARI	50 year ARI	100 year ARI	PMF
Residential	41	42	42	46	47	81
Commercial	4	4	4	4	4	7
Other *	2	2	3	3	3	3
Total	**47**	**48**	**49**	**53**	**54**	**91**

* includes grandstands and Tennis Centre for Weigall Sportsground and White City

Table 9: Number of Properties with above Ground Inundation

	5 year ARI	10 year ARI	20 year ARI	50 year ARI	100 year ARI	PMF
Residential	78	78	82	83	88	107
Commercial	5	5	5	5	5	8
Other *	3	4	4	4	4	4
Total	**86**	**87**	**91**	**92**	**97**	**119**

* includes Weigall Sportsground, White City and Trumper Park

Table 10: Summary of Flood Damages

Design Flood	Floors Inundated		Tangible Damages*
	Residential	**Non-Residential**	
5y ARI	41	6	$2.15M
10y ARI	42	6	$2.24M
20y ARI	42	7	$2.49M
50y ARI	46	7	$2.55M
100y ARI	47	7	$2.73M
PMF	81	10	$6.09M
	Average Annual Damages		**$1.34M**

Note: * Excludes all damages to public assets but includes external damages that may or may not occur with building floor inundation.

Damages in the upper catchment were not estimated due to the absence of surveyed floor levels and design flood level information. Within this area the extent of above floor inundation is difficult to accurately assess. The effect of buildings, sheds, fences and other structures can have a significant impact on the direction and depth of floodwaters. Also the exact location and level of all entry points to buildings needs to be determined based on ground survey.

According to Council records there has been some above floor inundation in the upper catchment, however the cause of inundation at each property may be due to other reasons (roof leakage) or ponding of local runoff in yards. It is also possible that the cause of the inundation has now been resolved (inadequate number of inlet pits) or the building has been renovated or re-built.

5.7. Previous Flood Mitigation Measures Considered

Flood mitigation measures were considered in the Rushcutters Bay Catchment Management Study (Reference 3) and the Cecil and Hampden Streets Drainage Investigation (Reference 4) study. The recommended options from each are noted below.

Recommendations in Reference 3 considered options to alleviate flooding for both the 20 year and 100 year ARI events. Measures included upgrading of piped drainage systems, road works and kerb raising to divert stormwater and/or protect inundated properties, channel works downstream of Glenmore Road, development controls and an on-site detention study. Voluntary purchase was considered, however was found not to be economically feasible.

Reference 4 identified options to alleviate localised flooding at Cecil Street and Hampden Street as noted previously. One aspect of the works, replacement of a blocked line with a new line via Hampden Street and Cecil Street to the Sydney Water system was recently completed.

Culvert amplification at Craigend Street was completed by Sydney Water in 1986.

5.8. Community Consultation

A rigorous public consultation program was carried out as part of this study. This included:

- A newsletter provided to local residents, stakeholders and those who previously had been involved in flood related matters as part of the Flood Study,
- follow up telephone calls to key respondents,
- meetings with residents,
- floodplain management committee meetings,
- workshop/site inspection and interviews,
- public exhibition of material.

6. FLOODPLAIN RISK MANAGEMENT MEASURES

6.1. Introduction

The NSW Government's Floodplain Development Manual (2005 – Reference 1) 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 informing 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 approach has long been used to quantify the economic worth of each measure on a relative basis enabling ranking against similar projects in other areas. The benefit/cost ratio is the ratio of the Net Present Worth of the reduction in flood damage (benefit) compared to the cost of the works. Generally the ratio expresses only the reduction in tangible damages as it is difficult to accurately include intangibles such as anxiety, risk to life, ill health and other social and environmental effects. In this study the reduction in tangible damages to public utilities as a result of implementation of a floodplain management measure has not been included.

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 classical benefit/cost approach. The public consultation program carried out as part of this study has ensured that identifiable social and environmental factors were considered in the decision making process.

Possible mitigation measures and pit and pipe upgrades evaluated in this study are shown on Figure 11.

6.2. Flood Modification Measures

Flood modification involves changing the behaviour of the flood itself, by reducing flood levels or velocities, or excluding floodwaters from areas under threat. This includes:

- dams,
- retarding basins,
- channel modifications,

- levees,
- flood gates,
- pumps.

6.2.1. Flood Mitigation Dams

Flood mitigation dams have frequently been used in rural areas of NSW to reduce peak flows downstream. Dams are rarely used as a flood mitigation measure for existing development or in urban areas on account of the:

- high cost of construction,
- high environmental damage caused by the construction,
- possible sterilisation of land within the dam area,
- high cost of land purchase,
- risk of failure on the dam wall,
- likely low benefit cost ratio,
- lack of suitable sites. A considerable volume of water needs to be impounded by the dam in order significant reduction in flood level downstream.

Based on an assessment of the catchment and taking into account the above factors flood mitigation dams were not considered further for this catchment.

6.2.2. Retarding Basins

DESCRIPTION

Retarding basins are small-scale flood mitigation dams commonly used in urban catchments for the same reasons. One of the major impediments in their use as a flood mitigation measure for existing development is the lack of suitable sites. For new "green fields" developments there is the opportunity to incorporate the retarding basins into site design which is not possible for existing development. Retarding basins can also provide significant water quality benefits, though in a heavily built up urban environment it is difficult to maintain these systems for this purpose.

DISCUSSION

Whilst retarding basins appear to be a fairly simple and effective means of controlling runoff and water quality in urban catchments there are a number of potential issues that need to be resolved. These are summarised below.

Size: In order to be effective at reducing peak flows and benefiting water quality the basin area must cover a reasonably high percentage of the upstream catchment. The larger the basin, the more effective it will be.

Cost: Whilst construction costs of the basin and wall in an urban environment will be high, additional costs are associated with any alterations to services (gas, electricity, telephone, water, sewerage, roads, etc.) that are within or close proximity to the proposed basin. Depending upon the nature of the services these costs may exceed several hundred thousand dollars. Some sites which at first glance may appear suitable are unviable due to the deposition of inappropriate fill material in the past (ex rubbish site, buried asbestos or other forms of waste). It is for these reasons that many of these sites were left as open space. The cost of removal of this material and safe deposition at another site makes construction on these sites unviable.

Benefit: Whilst any basin will provide some peak flow reduction and water quality benefit this must be balanced against the cost, and whether there are more cost effective methods. For example, it is generally acknowledged that public education and awareness and point source reduction provides the greatest benefit from a water quality perspective. The benefit for peak flow reduction is subject to the size of the basin and the outlet works. These are not easily defined at a concept stage, as detailed survey and design is required. Small basins generally provide the greatest peak flow reduction in small more frequent events, when the basin volume is a high percentage of the total flood volume. However, in these events there is often only minor above floor damage or minimal hazard to mitigate. In large events, basins (unless very big) are largely ineffectual from both a water quality and peak flow reduction perspective. Also, for multi-peaked rainfall events the basin may provide some benefit in the initial peak but very little when the second or third peak arrives.

The use of a basin for dual purposes (water quality and peak flow reduction) generally means that a compromise of the benefits for each purpose has to be reached. This is because the water quality purpose is best achieved by containing all the frequent inflows. For flood mitigation purposes, these flows are generally not contained to allow the volume in the basin to be “empty” at the time of the peak inflow.

Loss of Land Use:

In a rural area (or some urban areas) the loss of land for basin construction is acceptable. However in a dense urban area such as in the Rushcutters Bay catchment, where areas of open space are very valuable, the loss of previously useable land (parks) is significant. Basins can have multi-uses but this can be difficult to achieve.

Safety: This is one of the most important factors to be considered when constructing a basin in an urban area. Council will be changing an open space area with a low hazard potential during rainfall events to an area with a greater hazard. Apart from the risk of wall failure and consequently a sudden rush of floodwaters, there is the risk that people may drown or be swept into the basin. This can be negated by using fencing but this then precludes the use of the basin for other purposes. Generally basins deeper than say 1.2 m are unacceptable as a person cannot wade out of them. The benefit of a reduction in hazard downstream must be balanced with the potential increase in hazard at the basin site. Constructing a basin places a significant potential liability on Council should it cause harm to persons in flood (or even non-flood) times.

Signs can be placed advising of the hazard, however in a legal environment it is difficult to argue that this abrogates Council’s responsibilities. Also children, older residents and non-English speaking background residents may not understand the signs.

Availability of Land:

In an urban area the lack of a potential basin site obviously restricts the use of this mitigation measure. The most preferred sites are within golf courses (or any sports ground) where many of the above issues can be negated. Examples in Sydney are in Fox Hills (Prospect) and Muirfield (North Rocks) golf courses.

POSSIBLE MEASURES

Trumper Park: Reference 3 considered a retarding basin in Trumper Park (see below), however concluded that the costs outweighed the potential benefits. This site, whilst appearing suitable, is at the downstream end of the catchment and thus will largely only provide mitigation for the downstream sports fields in small events. In larger events it will provide a benefit to residential properties but in these events the mitigation benefit will be minor due to the large volume of floodwaters and the comparatively small size of the basin.

Trumper Park

Aerial photographic and site inspections of the catchment were undertaken to identify potential sites for retarding basins. Two other sites have been considered for basins at Moncur Reserve and Dillon Street Reserve.

Moncur Reserve ***Dillon Street Reserve***

Moncur Reserve: The topography indicates that overland flow from Morrell Street flows through Moncur Reserve and continues down Spicer Lane onto Jersey Road. Preliminary calculations were done to ascertain the effectiveness of a basin at this location. It was estimated that the available volume in the Reserve could be between 500 and 1,500 m^3 depending on if the area is maintained for public use (side slopes 6:1, maximum depth of 1 m) or the area is fenced and solely used for stormwater detention (vertical walls, depth 1.5 m). The estimated volume of overland flow at this site taken from the DRAINS model is 9,500 m^3 in a 10 year ARI event and 16,300 m^3 in a 100 year ARI. Thus the effectiveness of the Reserve as a retarding basin will be minimal as the available storage is around 10 times less than overland flow volume. Additionally any reduction of the peak flow will only benefit properties locally but have limited impact to properties downstream at Jersey Road due to inflows from other catchments. This option was therefore not pursued.

Dillon Street Reserve: The DRAINS model results indicate that overland flow between 2 to 5 m^3/s occurs down Stephen Street (on the eastern side) in a 100 year ARI event. This option considered diverting water from Stephen Street into a retarding basin facility located in the Dillon Street Reserve. Preliminary calculations were done to ascertain the effectiveness of a basin at this location. It was estimated that the available volume in the Reserve could be between 500 and 1500 m^3 depending on if the area is maintained for public use (side slopes 6:1, maximum depth of 1 m) or the area is fenced and solely used for stormwater detention (vertical walls, depth 1.5 m). The estimated volume of overland flow at this site, along Stephen Street and Neild Avenue is 3600 m^3 in a 10 year ARI event and 7000 m^3 in a 100 year ARI. The effectiveness of the area for detention may be beneficial for a 10 year ARI event if the maximum volume is achieved, however this would require high vertical retaining walls and would restrict any dual purpose recreational use. For events greater than the 10 year ARI the basin would be less effective.

There are only two reported inundation issues downstream of the reserve thus the cost benefit of a basin is expected to be small. Of greater concern is the existing use of the land for recreational purposes. Significant changes to the recreational activities would be required in order to construct a basin within the site.

OUTCOMES

Retarding basins are unlikely to be a cost effective measure to negate overland flow problems in the upper catchment. However all basins will provide some flow mitigation and water quality benefit. The benefit that can be achieved must be balanced against the loss of use of the land and concerns about Council's liability if construction of a basin increases the flood hazard in the area.

ACTIONS

Council should further investigate the use of retarding basins as a means of providing some flow mitigation and water quality benefit.

6.2.3. Channel Modifications

DESCRIPTION

Channel modifications are usually undertaken to either increase the capacity of the channel and/or improve the conveyance of floodwaters, which in turn will reduce peak flood levels. Channel modifications encompass a broad range of measures and include amplification, straightening, concrete lining, removal of structures, dredging and vegetation clearing.

DISCUSSION

Amplification

Channel amplification would increase the capacity of the creek or drainage system and reduce the frequency with which floodwaters overtop the banks.

Straightening, Concrete Lining, Dredging and Vegetation Clearing

These measures are generally undertaken in order to increase the conveyance of water through the channel system. However, as the existing open channel at Rushcutters Bay is relatively straight and concrete lined these measures are not applicable and were therefore not considered further.

Removal/Replacement of Structures & Blockage Prevention Devices

Reviews of the August 1998 North Wollongong, June 2007 Newcastle and March 2009 Coffs Harbour storms highlighted the significant effects blockage of structures can have on flood levels. Evidence from the North Wollongong event indicates that there is the potential for culvert openings less than 6 m width to be partially or fully blocked during a flood.

Blockage deflector devices (a series of bars that deflect debris over the road above a culvert) are available for natural channels. However they are not recommended for a lined channel due to the high velocities (over 5 m/s) and risk that they may increase the likelihood of blockage.

Maintenance to Reduce the Risk of Blockage

The most likely causes of blockage in the lower catchment are from:

- fallen trees,
- cars swept from roads (e.g Glenmore Road),

- adjoining fences, tennis court netting or bridge structures which are swept into the channel. An example of this is shown on Photographs 2, 3 and 5.

There is little preventative works that can be undertaken to minimise the risk from the first two causes. For the latter cause, particularly tennis court fencing or netting, there is an opportunity to undertake preventative works by ensuring that all fences are well maintained and are flood resistant or tied down. The cost of the works should be shared (where appropriate) between the landowner and the owner of the channel (Sydney Water). Such a scheme could be introduced by Council undertaking a bi-annual inspection and if necessary notifying Sydney Water or the landowner of any issues.

POSSIBLE MEASURES

Amplification

Channel amplification was considered just downstream of Glenmore Road, in the reach adjacent to Walker Avenue and White City. A preliminary hydraulic assessment of this measure was undertaken using the SOBEK model developed in the Flood Study. Modelling results indicate that increasing the channel width from 4m to 8m for a length of 100 metres downstream of Glenmore Road would decrease flood levels adjacent to Walker Avenue in the 100 year ARI event by up to 0.25 m and 0.4 m in the 10 year ARI event. However whilst this option reduces flood levels in the rear of the Walker Avenue properties it does not reduce the level at the front of the houses which face Walker Avenue. As it is the floor level taken at the front door that is adopted for the flood damages assessment this option does not therefore reduce above floor inundation and thus change the flood damages.

The main issues with this measure are the cost (several hundred thousand dollars), the loss of land and the likely low benefit cost ratio. The majority of the benefit would accrue to the adjoining sports fields which are located in this area as they are a flood compatible land use. There is some benefit to the properties along Walker Avenue but these works will not eliminate inundation of their properties and thus many residents may perceive little value in the works.

Removal/Replacement of Structures and Blockage Prevention Devices

Within the lower catchment one of the culverts under Craigend Street has potential to be partially or fully blocked during a flood as the entry is less than 6m in width, it has a reduced height under New South Head Road and there is a structure at the inlet that would potentially accumulate debris. This risk is reflected in the design conditions from the Flood Study that assumed the culvert was fully blocked. Possible mitigation options include replacing the culverts with a larger waterway opening over the complete length of the culvert or replacing the restriction at the inlet with a designed blockage deflection device.

The Flood Study assessed the case with no blockage and it was found to have a 0.27m reduction in the 100 year ARI flood levels within the White City tennis complex. This option would provide a significant hydraulic benefit to upstream floodplain users (though largely these are sports fields) and no adverse impact downstream (at many locations the potential adverse impact downstream effectively precludes this type of mitigation measure). The main issue with this measure is the likely high cost of the proposed works to reduce the restriction under New South Head Road. The costs are likely to be even greater due to the need to re locate services, these costs are unknown at this time (likely to be over $1 million) but based on experience elsewhere may make the measure unviable. This measure is supported but likely to be only undertaken (for cost reasons) when major roadworks on New South Head Road and Craigend Street are being undertaken.

There are a number of small footbridges that cross the open channel downstream of Glenmore Road. Removal of these bridges would provide minimal hydraulic benefit (largely because the culverts under Craigend Street provide limited capacity and cause a “backwater effect” upstream), however, potentially the failure of these structures during a flood and the removal of the debris downstream, may increase the likelihood of blockage of the culverts under Craigend Street. For this reason consideration should be given to either removing the bridges or ensuring that they will not fail during a flood.

OUTCOMES

Potential channel modifications measures include increasing the size of the channel south of Glenmore Road adjacent to Walker Avenue, upgrading the culvert under Craigend Street and removal of the pedestrian bridges along the open channel or at a minimum ensuring their structural integrity in a flood.

The latter is considered a cost effective management measures and should be a High priority measure as it can readily be undertaken. The former two are more long term measure that could only be undertaken in conjunction with other development works in the area.

ACTIONS

These measures should be included in the Floodplain Risk Management Plan.

6.2.4. Levees, Floodgates and Pumps

DESCRIPTION

Levees are built as a means of eliminating the inundation of floors and yards during a flood event (up to the design height of the levee together with a freeboard allowance of say 0.5 m). Flood gates can be considered as a separate modification measure or as part of a levee design. Flood gates allow local waters to be drained from an area when the level of the creek is low but prevent floodwaters from entering (or exiting) when the creek is elevated. Pumps are generally also associated with levee designs. They are installed to remove local floodwaters behind levees when flood gates are closed or there are no flood gates. They are generally only suitable for small volumes of floodwaters and have a high likelihood of failure (due to loss of power, lack of maintenance etc.).

DISCUSSION

Levees are successfully employed on large river systems (Maitland, Lismore, Grafton) where they protect a large number of properties. In an urban area they are more difficult to employ due to the nature of the topography, the high cost and significant social (aesthetics) issues. Examples of levees in urban areas are at Mackay Park (Marrickville South) on the Cooks River and at Hillcrest Avenue (Bardwell Park) on Bardwell Creek.

POSSIBLE MEASURES

Within the catchment, the application of levees is limited due to the lack of available space and the difficulty in isolating areas or being able to tie levees to high ground. For example a levee was considered for protection along the rear of properties along Walker Avenue from elevated water levels in the open channel. However ground levels indicate difficulties to tie the levee into high ground and a levee would not prevent inundation from overland flow along Glenmore Road and may actually worsen inundation due to this overland flow.

No other sites were found to be suitable therefore this option is not considered further.

OUTCOMES

Levees and flood gates are not appropriate floodplain management measures for the protection of a large number of properties within the catchment.

ACTIONS

No action required.

6.2.5. Local Drainage Issues

DESCRIPTION

Upstream of the Glenmore Road the “flood problem” is a mixture of significant overland flow (which would generally be described as a “flood”) and “local drainage”. Local drainage is due to excessive runoff which causes local problems such as ponding in low points, inundation of yards, drains blocked, runoff into garages or down driveways.

DISCUSSION

Local drainage issues will occur during most heavy rainfall events. It is important that Council monitor these issues to determine whether it is a permanent problem that requires a solution or whether it is a temporary problem (e.g. blocked pit or as a result of roadworks) that will be resolved in time (maintenance program).

During the course of this study it is apparent that local drainage issues occur say once or twice every year. However major flooding occurs less frequently. This low frequency of occurrence of major flooding is probably due to the lack of significant rainfall events over the last few years. In a wetter period (say the 1970's or mid 1980's) there is likely to be more reported problems.

OUTCOMES

Local drainage issues will arise from time to time and it is important that Council record all such instances. In order to assess their importance and determine whether a permanent solution is available the local drainage database which Council has used in the past must be maintained and where possible enhanced (include digital photographs).

ACTIONS

Council should maintain and where possible improve the existing database of reported local drainage issues and review the required actions following each major rainfall event (say an event of magnitude occurring once or twice a year). It is also important to obtain rainfall records to estimate the magnitude of the rainfall event. This can generally only be done using the pluviometer records as daily records do not identify a peak rainfall burst within a period of say 24 hours of rain.

6.2.6. Storm Surge, Wave Runup

DESCRIPTION/DISCUSSION

The Flood Study identified that the impacts due to elevated tailwater, typically from storm surge or wave runup, is not significant for the study area. Impacts are confined to the very lower reaches of the Rushcutters Bay open channel. Model results indicate that even with a relatively high tailwater, the backwater effects do not extend upstream of Craigend Street.

OUTCOMES

Storm surge and wave runup will not have a significant impact on flood liable properties upstream of Craigend Street and thus management measures are not required. However Council may wish to consider measures to protect foreshore structures.

ACTIONS

No action required.

6.3. Response Modification Measures

6.3.1. Flood Warning

DESCRIPTION

It may be necessary for some residents in the Rushcutters Bay catchment to evacuate their homes during a major flood event. Although it is unlikely that the depth of inundation will ever be such that flood depths of greater than 1m are experienced. Thus most residents would probably stay in their house and can escape the floodwaters by standing on tables etc. However some residents may wish to evacuate regardless or because they have some reason to leave the property (pick up children from school). The amount of time for evacuation depends on the available warning time. Flood warning and the implementation of evacuation procedures by the State Emergency Service (SES) are widely used throughout NSW to reduce flood damages and protect lives. The Bureau of Meteorology (BOM) is responsible for flood warnings on major river systems but does not have a system for small creeks such as Rushcutters Bay. It does issue Severe Weather Warnings (SWW).

Providing sufficient warning time has the potential to reduce the social impacts of the flood as well as reducing the strain on emergency services. Adequate flood warning gives residents time to move goods and vehicles above the reach of floodwaters and to evacuate from the immediate area. The effectiveness of a flood warning scheme 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.

DISCUSSION

Although flood warning has the potential to reduce the social and economic impacts of a flood, it is not possible to develop an effective warning system for a small catchment such as Rushcutters Bay. This is due to the relatively short response time from the start of the rain to the time of the flood peak (say less than 2 hours). This may change in the future as the BOM develops more accurate radar based warning systems that can forecast where storms and the consequent flooding will occur. However due to the imprecise nature of weather patterns it is unlikely that a highly accurate system that can provide sufficient warning will ever be possible.

OUTCOMES

Due to the short response time of the Rushcutters Bay catchment an effective flood warning system is not possible. As advancements in BOM forecasting continues this measure may become more viable.

ACTIONS

This measure has not been considered further at this stage.

6.3.2. Evacuation Planning

DESCRIPTION

A comprehensive Local Flood Plan, prepared by the SES, would assist in reducing flood damages and the risk to life. Local Flood Plans detail who is responsible for undertaking certain activities before, during and after a flood. This includes information on keeping the community and those involved prepared, how people will be evacuated/reached during a flood, what needs to be undertaken after the flood etc.

DISCUSSION

The rate of rise of the creek determines the amount of time the SES has to implement an evacuation plan. The small size of this catchment means the rate of rise in the creek is very fast (say less than 1 hour) which means that it would be unlikely the SES would arrive (the SES headquarters is located out of the catchment at Zetland) until after the peak (assuming there is no immediate risk to life). Similarly, a flood on Rushcutters Bay is likely to occur in conjunction with flooding at other nearby localities which will stretch the resources of the SES. A Local Flood Plan however does address other aspects of flooding, including preparedness and recovery, and for these reasons is still worthwhile to be developed for the catchment. Currently, there is a generic Flood Plan that covers the catchment.

OUTCOMES

A Local Flood Plan which includes Rushcutters Bay catchment should be prepared. The SES's role in flooding in the Rushcutters Bay catchment is likely to occur before (awareness program) and after the event (clean up) due to the limited response time available and likely demand on resources from other areas flooding concurrently. The response of the community during an event is critical in reducing the flood damages and risk to life and thus, even if emphasised as a 'self help' approach, should be formulated in conjunction with/by the SES.

ACTIONS

It is recommended that Council with SES seek to adopt a local SES headquarters within the Woollahra LGA and develop a Local Flood Plan.

6.3.3. Public Information and Raising Flood Awareness

DESCRIPTION

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 and 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?

The above can be improved upon through implementation of an effective Council or SES run flood awareness program. The extent of the program can vary from year to year depending upon the circumstances.

DISCUSSION

A community with high flood awareness will suffer less damage and disruption during and after a flood because people are aware of the potential risks of the situation. During a period of frequent flooding in other more flood prone areas, the residents would probably have developed an unofficial warning network to effectively respond to imminent danger by raising goods, moving cars, lifting carpets, etc. Photographs and other non-replaceable items are generally put in safe places. Often residents have developed storage facilities, buildings, etc., which are flood compatible. 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 flood 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,
- history of residence,
- whether an effective public awareness program has been implemented.

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 the information and the level of awareness diminishes as the time since the last flood increases. A major hurdle is often convincing residents large floods will occur in the future. Some residents may oppose an awareness program because they consider it reduces the value of their property. However this should not hinder the continued need to inform and receive feedback from the community.

Council has a dedicated resource for implementing community education programs. In the past there has been limited communication related to flooding with a greater emphasis on water quality. It is recommended that Council and/or the SES routinely undertake education programs related to flood issues.

Notification on the Section 149 certificate is an approach to inform residents of the potential flood risk at their property. Council are currently reviewing the information provided on properties' 149 certificates. In this process it is recommended that properties potentially flooded in the upper catchment be captured as well as those within mapped flood extents identified in the lower catchment.

OUTCOMES

Based on feedback and general discussions, the residents within the lower catchment have a medium to high flood awareness due to frequency of flooding. However in the upper catchment it is expected there is a low level of flood awareness and preparedness. This is probably due to the quick onset of flooding and that it could occur at night plus a relatively high turnover of population.

A suitable Council wide flood awareness program should be implemented by Council using appropriate elements from Table 11. The details of the program and necessary follow up should be properly documented to ensure that they do not lapse with time and to ensure the most cost effective means of communication.

Table 11: Flood Awareness Methods

Method	Comment
Letter/Pamphlet from Council	These may be sent (annually or biannually) with the rate notice or separately. A Council database of flood liable properties/addresses makes this a relatively inexpensive and effective measure. 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 water quality, estuary management, etc.
Displays at Council Offices, Library, Schools, Shopping Centres, Local Fairs	This is an inexpensive way of informing the community and may be combined with related displays.
Historical Flood Markers or Depth Indicators on Roads	Signs or marks can be prominently displayed in parks, on telegraph poles or such like to indicate the level reached in previous floods. Depth indicators on roads advise drivers of potential hazards.
Articles in Local Newspapers	Ongoing articles in the 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	A recurring problem is that new owners consider they were not adequately advised that their property was flood affected on the Section 149 Certificate during the purchase process. Council do advise interested parties, when they inquire during the property purchase process, regarding flood information currently available, how it can be obtained and the cost.
Establishment of a Flood Affectation Database	A database would provide information on (say) which houses require evacuation, which roads will be affected (or damaged) and cannot be used for rescue vehicles, which public structures will be affected (e.g. sewage pumps to be switched off, telephone or power cuts). This database should be reviewed after each flood event. It could be

	developed by various authorities (SES, Police, Council).
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 would ensure that the community is adequately prepared. The SES would take a lead role in this.
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. For example, Council should have a maintenance program to ensure that its drainage systems are regularly maintained. Residents have a responsibility to advise Council if they see a maintenance problem such as a blocked drain or a flood gate that is jammed. This process can be linked to water quality or other water related issues.

ACTIONS

A Flood Awareness Program should be implemented.

6.4. Property Modification Measures

6.4.1. House Raising

DESCRIPTION

House raising has been widely used throughout NSW to eliminate inundation from habitable floors. This approach provides more flexibility in planning, funding and implementation than voluntary purchase. However its application is limited as it is not suitable for all building types and only becomes economically viable when above floor inundation occurs frequently (say in a 10 year ARI event or less).

DISCUSSION

House raising is suitable for most non-brick single storey buildings on piers and is particularly relevant to those situated in low hazard areas on the floodplain. The benefit of house raising is that it eliminates inundation to the height of the floor and consequently reduces the flood damages. However it does not reduce the external hazard, evacuation issues or yard/garage damages.

Within the lower catchment there are no properties with suitable construction material that are inundated in a 100 year ARI event. Therefore this option is not considered further.

OUTCOMES

There are no inundated houses in the catchment suitable for house raising.

ACTIONS

No further action.

6.4.2. Voluntary House Purchase

DESCRIPTION

Voluntary purchase involves the acquisition of flood affected residential properties (particularly those frequently inundated in high hazard areas) and demolition of the residence to remove it from the floodplain. Generally the land is returned to open space, however there may be an opportunity for a new house to be built at a higher floor level, either on fill or on a higher part of the property.

DISCUSSION

Voluntary purchase is mainly implemented in high hazard areas over a long period as a means of removing isolated or remaining buildings and thus freeing both residents and potential rescuers from the danger and cost of future floods. It also helps to restore the hydraulic capacity of the floodplain (storage volume and waterway area).

Voluntary purchase has no environmental impacts although the economic cost and social impacts can be high. Many residents do not accept voluntary purchase because it would have significant impact on their community and way of life. Among these concerns are:

- it can be difficult to establish a market value that is acceptable to both the State Valuation Office and the resident,
- in many cases residents may not wish to move for a reasonable purchase price,
- progressive removal of properties may impose stress on the social fabric of an area,
- it may be difficult to find alternative equivalent priced housing in the nearby area with similar aesthetic values or features.

In the lower catchment there are no properties that are considered suitable for voluntary purchase.

In the upper catchment detailed hydraulic analysis, ground and floor level survey are not available to confirm which properties are in high hazard zones. Consideration of this option is discussed at particular locations in subsequent sections. However given the high value of properties in the catchment it is very unlikely that this measure will be cost effective and thus receive funds from the State Government's funding program.

OUTCOMES

In the lower catchment there are no properties that would be suitable for voluntary purchase.

ACTIONS

To be considered for implementation in the upper catchment (refer subsequent section).

6.4.3. Flood Proofing

DESCRIPTION

Flood proofing involves the sealing of entrances, windows, vents, etc. to prevent or limit the ingress of floodwater. It is generally only suitable for brick buildings with concrete floors and it can prevent ingress for outside water depths up to approximately one metre. Depending on the nature of construction, greater depths may cause structural problems (buoyancy) unless water is allowed to enter.

DISCUSSION

This measure is rarely (if ever) used in NSW for residential buildings and is more suitable to commercial premises where there are only one or two entrances and maintenance and operation procedures can be better enforced.

For the commercial properties within the Rushcutters Bay catchment, this would require sealing the doors and possibly windows (new frame, seal and door); sealing and re-routing of ventilation gaps in brickworks; sealing of all underfloor entrances; checking of brickwork to ensure that there are no gaps or weaknesses in the mortar and sealing of floor wastes and toilets.

Flood proofing would not reduce the flood hazard and can generally only provide protection up to one metre. There are no significant environmental or social problems.

There are sophisticated flood proofing measures available such as “pop up” flood gates and “removable gates”. However the successful application would have to be assessed for individual properties drawing on specific flood analysis. The cost of the measure can vary greatly. In the UK it is now common for temporary “expandable boarding” to be used to prevent inundation to brick houses. Unfortunately the short warning times means that such a measure is not appropriate for this catchment and a permanent measure is required.

OUTCOMES

Flood proofing for the flood affected non-residential buildings would assist in reducing the tangible damages associated with flooding in the catchment. This measure is unlikely to receive Government funding however it should still be pursued by Council. Potential owners should be advised that it is an available option.

Flood proofing of residential properties in low hazard areas on a property by property basis could alleviate local inundation issues. However consideration would have to be given to the (possible) redistribution of flows to downstream properties and safety issue of isolating residents behind such protection measures should they fail. This option would not be considered for Government funding however could be pursued by individual property owners. At some locations it is the only viable measure. In Sydney it has been used to protect basement car parks.

ACTIONS

Flood proofing should be promoted as a means available to reduce flood damages for non-residential buildings and possibly in isolated places where no alternative is available for residential buildings. These types of measures are not recommended for new developments unless they are “fail safe”.

6.4.4. Flood Planning Levels

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

Woollahra Council's LEP does not require consent for development for the purpose of drainage, however redevelopment or new development does require consent.

Woollahra Council has specified the following FPLs in their Draft Flood Risk Management DCP:

- Minimum habitable floor level for residential properties and floor levels for commercial properties – 1% AEP flood level plus 300 mm freeboard.
- Non-habitable rooms including garages or laundry, entrance to underground car parks or garage - 1% AEP flood level plus 150 mm freeboard.
- Properties not affected by mainstream flooding or local overland flooding but with an OSD structure - Minimum habitable floor level for residential properties 300mm above maximum water level of OSD storage.
- Properties not affected by mainstream flooding or local overland flooding but with an OSD structure - Non-habitable rooms including garages or laundry 150mm above maximum water level of OSD storage.

Council is currently undertaking a formal review of the Draft Flood Risk Management DCP, thus within this study no comment is provided regarding flood planning levels.

OUTCOMES

Council is currently undertaking a formal review of the Draft Flood Risk Management DCP which would include review of flood planning levels, therefore no further action is required in this study.

ACTIONS

No action required.

6.4.5. Development Control Planning

DESCRIPTION

Within the Rushcutters Bay catchment there is continuing pressures for both redevelopment of existing buildings as well as for new development. 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

Development controls for flood liable areas are not addressed in the current Local Environmental Plan (LEP) but are addressed in the Draft Flood Risk Management DCP and Draft Stormwater Drainage Management DCP. To ensure that the objectives of the DCPs are implemented it is recommended that the LEP include reference to flood development controls.

The Draft DCPs specify guidelines for flood planning levels and flood-related development controls including OSD requirements. In the absence of completion of Floodplain Risk Management Plans, the Draft Flood Risk Management DCP provides an approach for identifying properties that require controls. Council is currently undertaking a formal review of these plans. For this reason a review has not been undertaken in this study. It is recommended that the DCPs are formally accepted by Council to ensure a more consistent application of controls over developments.

The flood potential and requirements for development controls is notified to property owners on Section 149 certificates. The current practice by Council is to provide a certificate on application for properties within the 100 year ARI extent. This method does not reliably capture properties that are potentially impacted due to overland flow in the upper catchment or residential properties that have land up to the FPL (0.3 m above the 100 year ARI flood level).

OUTCOMES

It is recommended that the Draft Flood Risk Management DCP and Draft Stormwater Drainage Management DCP be reviewed and accepted by Council. This would enable Council to implement sound floodplain management and drainage strategies across the catchment.

ACTIONS

Council should include development on flood liable land in its LEP and in time formally adopt the Draft Flood Risk Management DCP and Draft Stormwater Drainage Management DCP.

6.5. Upper Catchment – Overland Flow

6.5.1. Overview

In the upper catchment the “flood problem” is a mixture of significant overland flow (which would generally be described as a “flood”) and “local drainage”. Local drainage being small scale issues (blockage of kerb pit, ponding in low spot, tree roots blocking kerb flow, minor flow diversion etc.) that causes inconvenience to local residents but no significant tangible damage. Local drainage is not considered within the framework of this study but should be reported to Council and will be addressed as appropriate.

Overland flow (caused by significant rainfall that causes runoff that exceeds the capacity of the pipe drainage system) has in the past resulted in excessive ponding that has entered properties and resulted in over floor inundation and redirection of flow into low lying properties (habitable premises and garages). The accumulation of overland flow at low points can result in inundation of property and can heighten any local drainage issues at these locations and at areas downstream.

Ponding at trapped low points is due to a significant amount of overland flow directed to a low point where there is no flowpath or the flowpath is higher than the low point. As the flows are large, provision of additional drainage (additional pits and pipes) is often not sufficient to alleviate flooding. To mitigate the flooding a suite of measures may be required, such as redirection of flow away from the low point within the upper catchment, augmentation of upstream drainage lines, construction of overland flow paths or individual property protection measures.

Large overland flows conveyed along roads potentially inundate basements, driveways or floor levels that are at road level or lower. Parked cars, debris in gutters, tree roots or similar may exacerbate the problem. These problems are generally associated with relatively small catchment areas and may occur during most heavy rainfall events (say every year). These are a result of localised runoff that in many cases may affect less than five properties.

Prior to investigating mitigation measures the existing flood behaviour need to be defined using ground survey and site specific hydraulic assessment. It is important that Council continue to monitor issues (refer subsequent sections) to determine whether it is a permanent problem that requires a solution or whether it is a temporary problem (e.g. blocked pit or as a result of roadworks) that can be resolved.

6.5.2. Visual Inspection of Upper Catchment

Whilst it is acknowledged that flooding problems have occurred in the past and Council records have documented some of the problem areas (as reported in the Flood Study), unfortunately the records are generally not detailed enough to clearly identify the cause of the problem or in some cases the exact locations. Furthermore the identified problem may have been temporary (parked car, blocked pit, debris) or have been subsequently resolved by Council or the property owner. One of the major concerns with the sole use of Council's database as the criteria for determining the flood problem is that the database only reflects where residents have contacted Council. More than likely there are a large number of problem areas but the residents have not contacted Council for one reason or another (house rented, little damage, don't wish to highlight the problem to prospective purchasers, etc.).

Initially as part of this study a detailed visual assessment to identify potential flooding/drainage problems was undertaken along every road in the upper catchment. This assessment relied upon inspection of potential problem areas noted in Council's database of flood records as well as using the results from the Flood Study. 119 sites were identified and photographs of each taken. Each problem was categorised according to the nature of the problem. The results of this assessment are provided in Appendix B (see figure titles below) and in Table 12.

Figure B1: *Plan of Flooding and Drainage Issues Identified from Field Inspection*
Figure B2: *Listing of Flooding and Drainage Issues*
Figure B3: *Photographs of Sites with Reported Issues but not Identified in Field Inspection*
Figure B4: *Site Photographs*

Table 12: Summary of Detailed Site Inspection in Upper Catchment

Category	Explanation	No*
1	Garage Below Road	14
2	Floor Below Road	23
3	Ponding	38
4	Large flow	1
5	Flow diversion	17
6	No Flow Path	9
7	Ground Floor Inundation	39
8	Other	5
	Total	146

* At some locations there are multiple issues

The results from this visual inspection do not resolve the problem but can be used by Council to:

- Define the scale of the problem and therefore an overall management strategy and prioritisation of works. This needs to be undertaken before specific management strategies can be implemented in the upper catchment.
- Compare the results with "complaints" by residents following heavy rain. In this way the nature of the problem will be more closely identified and thus management measures more appropriately targeted.
- Ensure that future development in the local area does not exacerbate the problem and hopefully can be designed to reduce the extent of the problem.

Potential localised management measures include:

- pit and pipe upgrade,
- redistribution of overland flow away from inundated sites,
- management of blockage,
- flood proofing properties,
- voluntary house raising,
- voluntary house purchase,
- on-site stormwater detention,
- planning controls.

The application of management measures at individual locations should consider both the positive impacts at each site and the likely impacts to property and infrastructure downstream. To remove the flood risk for events up to a 100 year ARI would generally require either upgrading of the pit and pipe networks or house purchase where private properties are located at low points along flow paths.

An overview of each of these management measures is provided in the following sections together with the assessment of specific mitigation measures and specific areas where problems have been reported in the past.

6.5.3. Identification of Houses Inundated

DESCRIPTION

Of major concern with overland flow in the upper catchment is the inundation of buildings (mainly houses). Whilst inundation of roads or other areas of open space are of concern and possible risk to life, the inundation of houses causes significant economic and intangible damages to residents. It is expected that if above floor inundation occurs most residents would contact Council, whilst inundation of the road is less likely to be reported. Above floor inundation has occurred many times in the past and some details are available in Council's database.

In order to provide obtain a State or Federal grant for a floodplain management measure a benefit cost analysis is generally required to justify the viability of the project. The "benefit of the works" is usually expressed in terms of the reduction in damages to above floor inundation. Thus without this information funding may not be made available.

DISCUSSION

In the lower catchment it is possible to clearly identify which buildings are affected and the event that first inundates the building floor. This is not possible in the upper catchment as the DRAINS modelling only provides the peak flows in the various events and not the exact flow paths or depths of inundation. House floors have also not been identified in the field survey undertaken as part of this study.

A significant constraint on the accuracy of hydraulic modelling within the overland flow areas in the upper catchment is the hydraulic influence of fences, buildings, parked vehicles and other structures. Whilst detailed survey could identify these constraints, experience indicates that the validity of the flood modelling would be short lived, as residents can easily change the type of fencing, location of garden sheds or garden beds, etc. All of which can have a significant impact on the depth and direction of floodwaters. Nevertheless hydraulic modelling of similar type catchments has been successfully undertaken in other residential areas of Sydney.

OUTCOMES

The number of houses inundated above floor level, over the range of flood events, has not been identified in the upper catchment, nor has the floor levels of the buildings. This information is required in order to accurately identify the problem.

ACTIONS

It is recommended that an overland flow hydraulic model study (using the existing DRAINS model flows) be undertaken for the upper catchment as well as collection of surveyed floor levels in the key areas.

6.5.4. Pit and Pipe Upgrade

DESCRIPTION

Upgrading pit and pipe networks within the upper catchment will generally assist in reducing the amount of overland flow and consequently alleviate flood issues. The main drawback of this measure is the high construction costs.

DISCUSSION

The cost of the pipe itself may be of the order of $500 to $1000/metre length but the additional cost to relocate services, obtain easements through private property, construct pipes under or around buildings may double (or more) this unit cost. The relocation of services (electricity, sewer or water) by themselves can cost more than the drainage works. A further cost is to provide sufficient inlet pits to ensure the upgraded pipes run full. Unless this is undertaken the upgraded pipe system will provide only limited benefit. There is also the practical problem of being able to site sufficient new inlet pits along existing kerbs.

For this measure to be successful often the pipe network needs to be augmented to the downstream outlet so that flooding in the downstream areas does not increase as a result of the pipe upgrades upstream. If there is a section of pipe which cannot be upgraded for some reason (narrow easement through private property) then the benefit can be severely limited.

It is recommended that the major/minor design approach be adopted. The minor system is for pits and pipes that cater for events up to Council's design standard across the LGA (say 10 year ARI), with provision for major events (up to the 100 year ARI event) along roads or open space areas.

In new subdivisions this approach is generally adopted as standard, however, in older suburbs, like Woollahra, it can be very difficult to "retro fit" due to existing constraints (easement location and size, location of buildings, local topography, services, etc.).

OUTCOMES

Subject to the findings of the proposed overland flow hydraulic model study (see above) it is expected that the upgrade of pits and pipes in many areas would be an effective management measure.

ACTIONS

The upgrade of pit and pipe networks, where applicable, will provide an effective management measure in the upper catchment and should be pursued.

6.5.5. Redirection of Overland Flow

DESCRIPTION/DISCUSSION

This measure may involve raising kerbs or regrading roads to direct water away from a known flood affected location. This measure will also need to assess the impacts to downstream properties as a result of the diversion. Reference 3 recommended this measure at some locations.

OUTCOMES

Subject to the findings of the proposed overland flow hydraulic model study (see above) it is expected that the redirection of overland flows may be an effective management measure.

ACTIONS
The redirection of overland flows, where applicable, will provide an effective management measure in the upper catchment and should be pursued.

6.5.6. Management of Blockage

DESCRIPTION
Blockage of inlet pits and pipes is unfortunately relatively common in urban areas and particularly in tree lined streets and where street parking is common.

DISCUSSION
There are three main concerns for blockage in the upper catchment namely, sedimentation in pipes, blockage at pit inlets and the presence of parked cars or debris in gutters that potentially inhibit flow conveyance along roads and into the kerb inlet pits.

In the catchment most pipe systems are old and there is a high likelihood of blockage due to sedimentation or damage to pipes. Council are pro-active in keeping pipes clean as part of a maintenance program and have undertaken CCTV in many parts.

Council's maintenance program includes regular street sweeping and encouraging the community to keep gutters clean through education programs. The street sweeping program and other water quality measures were reviewed in 2004.

Council has also introduced parking restrictions to prevent vehicle parking on inlet pits. Unfortunately despite continued efforts by Council it is unlikely that 100% success can be achieved with this measure.

OUTCOMES
It is recommended that Council:

- maintain the current street sweeping program, regularly assess its effectiveness and in light of the outcomes review the adopted approach,
- consider adopting parking controls at locations where the flow is large and regularly inundates adjacent properties,
- adopt a maintenance program to inspect and rectify sedimentation in pipes, this may mean the CCTV of all pipes.

ACTIONS
The management of blockage in the drainage system will provide a cost effective management measure in the upper catchment and should be pursued.

6.5.7. House Raising

Generally this measure is not expected to be applicable as most, if not all, housing is of brick construction which is not suitable for raising.

6.5.8. Voluntary House Purchase

Voluntary purchase should be considered at locations where private property is sited at a low point, flood depths are greater than 1m or properties are subject to high velocities and no alternative strategy is available. This measure may be the most cost effective management measure where the upgrade of pit and pipe systems requires extensive inlet pits, long lengths of pipe upgrades or extensive services relocation. It is acknowledged that voluntary purchase may not support the heritage and community objectives of the LEP and may not be supported by the relevant property owners. This measure was considered in the Reference 3 and found not to be economically feasible.

6.5.9. Flood Proofing

This measure was discussed previously. As noted, flood proofing of residential properties could be pursued by individual property owners in low hazard areas to prevent above floor inundation, however consideration would have to be given to the redistribution of flows to downstream properties and maintaining safety if the measure failed. This option would generally not be considered for Government funding.

6.5.10. On-Site Detention

All Councils in Sydney (including Woollahra) have an on-site stormwater detention (OSD) policy which ensures that there will be no increase in peak flows due to an increase in density of development. Woollahra Council's policy is in the draft Stormwater DCP which is currently under review. This measure is appropriate for ensuring that future development does not increase peak catchment flows but cannot be used as a mitigation measure to reduce existing peak flows on equity grounds (a new development should only be required to not worsen the existing flood situation and not provide some form of mitigation that would help others).

6.5.11. Planning

Planning controls including flood planning levels and flood related development control plans are discussed in the previous sections. As noted previously Council is currently undertaking a formal review of the Draft Flood Risk Management DCP and Draft Stormwater Drainage Management DCP, thus within this study no recommendations are provided for updating these planning aspects.

It is noted that in many other Council areas within Sydney, flood related planning controls are being applied in overland flow areas such as the upper catchment. The inclusion of these areas needs to be considered by Council as part of any review of the current policies.

6.5.12. Site Specific Mitigation Measures

DESCRIPTION

The following areas were identified in past studies and as a result of the present analysis as experiencing existing drainage problems:

- Cecil Street, Cecil Lane, Hampden Street,
- Roylston Street,
- Walker Avenue, Glenmore Road,
- George Street, Elizabeth Street,
- Victoria Street, Underwood Street,
- Hopetoun Street, Hopetoun Lane,
- Hargrave Street, Sutherland Street,
- Ocean Street, Tara Street,
- Harris Street,
- Neild Avenue, Boundary Street.

DISCUSSION

An overview of the drainage problems at each of the above locations is provided below based on the site inspections, the Flood Study results and any other relevant information.

CECIL STREET, CECIL LANE, AND HAMPDEN STREET

Properties in these streets have been subject to property and above floor inundation on many occasions in the past as reported in all previous studies. Figure 10 identifies that approximately 20 building floors are inundated in the 5 year ARI event in this area.

The flooding is due to a combination of factors. Cecil Street and Cecil Lane are cul-de-sacs with runoff ponding in the cul-de-sac. The terraced houses on each side prevent overland flow through the properties and the high bank at the end of the cul-de-sac (Photograph 13) prevents overland flow travelling downstream. There are pit/pipe systems in the streets but these are limited by possible pit (or pipe) blockage due to vegetation debris or vehicles parked over the inlets. However the main issue is likely to be due to the lack of capacity in the main line (1525 mm pipe with a box culvert in parts) that runs from Jersey Road along the high bank at the end of the cul-de-sacs and under Trumper Park. This line has a capacity of less than a 5 year ARI event and thus may surcharge (due to the high pressure in the pipe) into the cul-de-sacs further exacerbating the problem. In addition previous CCTV has also indicated that there is sediment and partial blockage in many of the pipes.

Council has commissioned studies to investigate the problem and find solutions (Reference 4) but it is understood that major mitigation works have not been completed. This area is probably the most significant flood problem requiring a solution in the catchment.

A summary of the conclusions from Reference 4 are:

- Duplication of the Sydney Water 1525mm pipe (and associated box culverts) will cost of the order of $2.5 million in 2009. Council was to pursue Sydney Water in this regard,
- Local works (similar to a speed bump) were proposed at the entrance to the underground car park at 4 Hampden Street (Photograph 11). It is understood that these works were completed by Council but residents “complained” that some vehicles were then scraping the underside of their vehicles,
- Provide a new pipe from the eastern end of Hampden Street (the existing pipe is

blocked and presumably cannot be unblocked) to the line in Cecil Street. The cost of these works would be approximately $200,000 in 2009. This would only provide significant benefit if undertaken in conjunction with a pipe upgrade in Cecil Street and more importantly the duplication of the Sydney Water 1525mm pipe,

- As an alternative to the 1525mm pipe duplication an overland flow path could be formed at the northern end of the cul-de-sacs. The cost of these works would be of the order of $300,000 in 2009,
- If the duplication was not undertaken a separate new line could be constructed just to drain Cecil Street and Cecil Lane. The cost of these works would be of the order of $500,000 in 2009.

In conclusion the main issue with providing a solution to the flood problem is the high cost. Minor works like minimising pit and pipe blockage or ensuring that all pipes are clean will provide only minor benefit and in say a 2 year ARI or greater event practically no benefit. The only measures providing a significant benefit are duplicating the 1525 mm pipe or providing an overland flow path.

In this study measures that were assessed in the SOBEK model were:

- increased channel downstream of Glenmore Road (refer to previous section),
- an overland flowpath from the end of Cecil Street to Trumper Park, and
- pit and pipe augmentation from Cecil Street to downstream of Glenmore Road.

It should be noted that the peak overland flows are between 5 and 10 m^3/s in the 5 year ARI and greater events. This is a considerable amount of flow for an urban street, fortunately there is an "escape route" as once runoff ponds to a depth of approximately 0.7m at the end of Cecil Street it then overtops Hampden Street and can flow in a general westerly direction towards Trumper Park. As Hampden Street is relatively wide there is no significant increase in flood level once overtopping occurs.

For these two reasons (large flow and existing escape route) it is unlikely that any mitigation measure will provide a significant reduction in flood level in large flood events (say in 10 year ARI and greater events). However the measures will have a benefit in the more frequent events which may occur up to twice a year.

Overland Flow Path

The overland flow path would be in the order of 6 m wide over a length of 35m and discharge into Trumper Park. The achievable longitudinal grade would be 5% with an invert at 7.0 m AHD. This would result in approximately 250-300m^3 of cut adjacent to existing properties and cost in the order of $300,000. There is unlikely to be any significant environmental, social or visual impact of these works, however this would need to be more fully examined and in particular obtain the comments from local residents. Some minor additional works may be required within the eastern end of Trumper Park to receive the flow from the new channel.

This option lowers flood levels in Cecil Street by only 0.1 m for the range of design events (5 year to 100 year ARI). The reason for this is that under existing conditions Hampden Street (refer previous discussion) provides an "escape route" and even with this new overland flow path a significant amount of floodwaters accumulates in Cecil Street which must pass downstream. However this option will provide a benefit in more frequent flood events (say occurring twice a year on average) and thus would provide a significant reduction in the frequent inconvenience that occurs with flooding in this street.

Preliminary results indicate that this measure would reduce flood damages by approximately 4% in the 10 year and 100 year ARI events. Based on extrapolation it is possible that this measure would have a benefit/cost ratio approaching 1. This is a relatively high value for flood mitigation works and thus may qualify for state government funding.

Pit and Pipe Augmentation

Two augmentations to the Cecil Street pipe drainage system were evaluated: a 450 mm * 300 mm and a 3000 mm * 1000 mm box culvert. Both systems were assumed to only connect to the piped drainage system in Cecil Street. If these were connected directly to the existing 1525 mm pipe the flows from upstream would surcharge into Cecil Street. It was assumed that the augmentation would include five 4m long lintel pits all connected to the extra pipe.

This option lowers flood levels in Cecil Street in the 100 year ARI event by <0.1m for the 450mm * 300mm culvert, and by 0.4m for the 3m * 1m box culvert.

The main issue with this measure will be the space requirements at the rear of Cecil Street and how the culvert will exit into either Trumper Park or downstream of Glenmore Road.

The cost of these works cannot be accurately estimated at this time until a detailed services search has been undertaken and a decision made on the exit point of the culvert. An indicative cost would be $500,000.

Conclusions

A preliminary assessment suggests that construction of an overland flow path is the preferred option based on cost and other considerations (impact on Trumper Park, inconvenience and difficulties during construction, less chance of blockage).

ROYLSTON STREET

The inundation issue at this location is predominately due to overland flow from Jersey Road and Cecil Street/Hampden Street that is unable to efficiently drain onto Trumper Park. Figure 10 indicates that approximately 10 building floors are inundated in a 5 year ARI event in this area, four of which are non residential.

Options considered in the 1991 Catchment Management Study (Reference 3) included upgrading the pit and pipe system upstream to the outlet at Glenmore Road, kerb raising and road works to direct water away from the street.

This study has investigated:

- an overland flowpath from Cecil Street into Trumper Park to reduce overland flow onto Roylston Street,

- increased channel capacity and conveyance downstream of Glenmore Road, and
- upgrade drainage system upstream of Roylston Street from Sutherland Street.

The first two options were modelled in SOBEK. The addition of an overland flowpath (referred to in Cecil Lane, Cecil Street, and Hampden Lane section) reduced peak levels in the 100 year ARI event by up to 0.1m in Roylston Street. Increasing channel capacity downstream of Glenmore Road was found to have no impact on water levels in Roylston Street.

It is considered that upgrading the upstream drainage network would require a detailed hydraulic investigation and would be associated with upgrades of pit and pipe systems at other locations. It is therefore recommended that a specific hydraulic investigation for the upstream network be undertaken that assesses options and the subsequent benefits and impacts within the catchment area.

WALKER AVENUE AND GLENMORE ROAD

This area will experience inundation from overland flow along Glenmore Road ponding at the road sag or from elevated water levels along the rear of the properties adjacent to the open channel. Figure 10 indicates six building floors inundated in a 5 year ARI event, however apart from one other building (inundated in the 50 year ARI event) the remaining buildings are only inundated in the PMF.

This study has investigated:

- increased size of channel downstream of Glenmore Road (refer to Section 6.2.3),
- upgrading the road drainage along Glenmore Road,
- regrading and lowering the kerb at the low point in Glenmore Road,
- construction of a levee.

The first option was assessed in the SOBEK model. In a 100 year ARI event, localised water level reductions of 0.25m adjacent to the channel immediately downstream of Glenmore Road were achieved. However, downstream and upstream of this point no significant impacts occurred, due to the backwater effect from the culverts under New South Head Road.

The Glenmore Road drainage and road modifications would reduce the incidence of ponding and inundation of properties in small events. A more detailed evaluation would require ground survey and a detailed drainage investigation. However these works would be of no benefit in a major flood event that causes runoff across Trumper Park and Glenmore Road.

A levee surrounding the properties was considered but was rejected due to the depth of inundation (up to 1 m in a 100 year ARI event), the likely high cost (over $300,000) and the fact that runoff would enter from Walker Avenue thus defeating the purpose of the levee. Also it is unlikely that it would be acceptable to local residents for access and visual reasons as well as the requirement for an easement over the structure. The construction would also cause significant disruption and unless all property owners agreed to it being built, it would not achieve its purpose.

GEORGE STREET AND ELIZABETH STREET

Residential properties are located in a low point that drains across these streets with the contributing catchment from Queen Street and Jersey Road. DRAINS results indicate that the pipe networks at these locations have a capacity less than a 5 year ARI event. Overland flow in a 100 year ARI is estimated to be between 1-2m^3/s at George Street and 2-5m^3/s at Elizabeth Street.

The recommended option from the 1991 Catchment Management Study (Reference 3) was to upgrade the pit and pipe system from Wentworth Street to Glenmore Road, which includes these areas. In this current study DRAINS was used to undertake a concept design to cater for a 10 year ARI event. Results indicate that two 3m long kerb inlets would be required and the pipe increased from the existing 350 mm diameter pipe to a 900mm diameter (a sixfold increase in pipe capacity) for a length of 150m from George Street to Victoria Street. From Victoria Street downstream to the trunk line two 3m long kerb inlets would be required and the pipe increased from the existing 350 mm diameter pipe to a 1650mm diameter for a length of 130m. In a 100 year ARI event water would still pond at the low points.

An indicative cost for these upgrades would be $400,000 but the final cost may be significantly greater due to construction issues (e.g services re location). The full investigation of costs and benefits requires ground and floor level survey and a detailed drainage investigation to quantify the flood problem, identify potential inundated properties, assess impacts to downstream properties and undertake a preliminary design.

Alternatively the affected properties located along the low point could be voluntary purchased and re-developed at a higher level or to a more flood compatible use. The cost for this measure would be several million dollars depending upon the properties that are purchased. Based on previous experience it is unlikely that the property owners will accept this measure or that this measure will be funded by the State Government.

VICTORIA STREET AND UNDERWOOD STREET

Private properties are located in a low point that drains through these streets. The contributing catchment is from Oxford Street near Paddington School and from George and Elizabeth Streets as noted above. DRAINS results indicate that the pipe networks at these locations have a capacity less than a 5 year ARI event. Overland flow in a 100 year ARI event is estimated to be between 2-5m^3/s at Victoria Street and 5-10m^3/s at Underwood Street.

In this current study DRAINS was used to undertake a concept design to cater for a 10 year ARI event. Results indicate that five 3m long kerb inlets would be required and the pipe size increased from a 900mm diameter pipe to a 1350mm diameter pipe for a length of 150m from Victoria Street to Underwood Street. Additionally, pipe upgrades and pit installation (two 3m long kerb inlets in Underwood Street) would be required downstream to Paddington Street. In a 100 year ARI event water would still pond at these low points.

An indicative cost for these upgrades would be $300,000 but the final cost may be significantly greater due to construction issues (e.g services re location). The full investigation of costs and benefits requires ground and floor level survey and a detailed drainage investigation to quantify the flood problem, identify potential inundated properties, assess impacts to downstream properties and undertake a preliminary design.

Alternatively the 3 properties located along the low point could be purchased and developed to a more flood compatible purpose. The cost would be approximately $4.5M derived from an average property value of $1.5M. The benefits cannot be quantified without a detailed floor level survey.

HOPETOUN STREET AND HOPETOUN LANE

There is a low point in both of these streets that drains catchments from Oxford Street and Underwood Street. DRAINS results indicate that the pipe networks at these locations have a capacity less than a 5 year ARI event. Overland flow in a 100 year ARI event is estimated to be between 1-2m^3/s at Hopetoun Street and 10-20m^3/s at Hopetoun Lane.

The recommended option from the 1991 Catchment Management Study (Reference 3) was to undertake road works at the upstream end of these streets to divert overland flow into Paddington Street and Cascade Street. This study endorses this measure and has also considered an upgrade to the drainage system.

A preliminary hydraulic assessment was undertaken using the DRAINS model for a concept design to cater for a 10 year ARI event. Results indicate that three 3m long kerb inlets would be required in Hopetoun Street and fourteen 3m long kerb inlets in Hopetoun Lane. The pipe would need to be increased from the existing 375 mm diameter pipe to a 1050mm diameter pipe for a length of 100m from Hopetoun Street to Hopetoun Lane, and from a 525 mm diameter pipe to a 1950mm diameter pipe for a length of 80m from Hopetoun Lane to Cascade Street. This pipe system is part of the Cascade Street drainage line which, to accommodate upstream flows would also need to be substantially increased.

An indicative cost for these upgrades would be $300,000 but the final cost may be significantly greater due to construction issues (e.g services re location). The full investigation of costs and benefits requires ground and floor level survey and a detailed drainage investigation to quantify the flood problem, identify potential inundated properties, assess impacts to downstream properties and undertake a preliminary design.

HARGRAVE STREET AND SUTHERLAND STREET

Private properties are located in a low point that drains across these streets. The contributing catchment is from Oxford Street and Jersey Road. DRAINS results indicate that the pipe networks at these locations have a capacity less than a 5 year ARI event. Overland flow in a 100 year ARI event is estimated to be between 10-20m^3/s at Hargrave Street and Sutherland Street.

The recommended option in the Catchment Management Study (Reference 3) was to upgrade the pit and pipe system from Wentworth Street to Glenmore Road. In this current study DRAINS was used to undertake a concept design to cater for a 10 year ARI event. Results indicate that eleven 3m long kerb inlets would be required at Hargrave Street and two at Sutherland Street. The pipe size would need to increase from a 900mm to a 2100mm diameter pipe for a length of

65m from Hargrave Street to Sutherland Street, and to a 2550mm diameter pipe for a length of 50m downstream of Sutherland Street. The trunk line downstream to Glenmore Road would consequently require a capacity upgrade to carry extra flow. In a 100 year ARI event water would still pond at these low points.

An indicative cost for these upgrades would be $300,000 but the final cost may be significantly greater due to construction issues (e.g services re location). The full investigation of costs and benefits requires ground and floor level survey and a detailed drainage investigation to quantify the flood problem, identify potential inundated properties, assess impacts to downstream properties and undertake a preliminary design.

Alternatively approximately 10 properties located along the low point could be purchased and developed to flood compatible purpose. The cost would be approximately $15M derived from an average property value of $1.5M.

OCEAN STREET AND TARA STREET

Private properties are located in a low point that drains across these streets. DRAINS results indicate that the pipe networks at these locations have a capacity less than a 5 year ARI event. Overland flow in a 100 year ARI event is estimated to be between 2-5m^3/s at both streets.

Options considered in the Catchment Management Study (Reference 3) included upgrading the pit and pipe system from Ocean Street to surcharge into Jersey Road.

In this current study DRAINS was used to undertake a concept design to cater for a 10 year ARI event. Results suggest that two 3m long kerb inlets would be required at Ocean Street and one at Tara Street. The pipe size would increase from a 375mm to a 750mm diameter pipe for a length of 60m between Ocean and Tara Street, and from a 375mm to a 750mm diameter pipe for a length of 60m between Tara Street and Jersey Road. In a 100 year ARI event water would still pond at these low points.

An indicative cost for these upgrades would be $200,000 but the final cost may be significantly greater due to construction issues (e.g services re location). The full investigation of costs and benefits requires ground and floor level survey and a detailed drainage investigation to quantify the flood problem, identify potential inundated properties, assess impacts to downstream properties and undertake a preliminary design.

Other options include:

- Voluntary purchase of 4 properties and re-develop for a more flood compatible purpose. The cost would be approximately $6M derived from an average property value of $1.5M;
- Redirect water onto Trelawney Street and Jersey Road by local roadworks or modification to the kerbs;
- Property protection measures (flood proofing of building) as appropriate.

HARRIS STREET

There is a trapped low point in the lower part of Harris Street. Flood problems have been recorded on properties on the high side of Harris Street near this low point. Observations from site indicate that inundation may be due to overland flow from Sutherland Street not Harris Street/Lane. Overland flow in this area is from the Jersey Road catchment. DRAINS results indicate that the pipe networks at these locations have a capacity less than a 5 year ARI event. Overland flow in a 100 year ARI event is estimated to be between 5-10m^3/s on Harris Street.

This study has proposed:

- Upgrade drainage at the low point on Harris Street and Sutherland Street;
- Establish overland flowpath to lower Harris Street;
- Property protection measures (flood proofing of building) as appropriate.

Estimation of costs and benefits for these options requires ground and floor level survey and a detailed drainage investigation to quantify the flood problem, identify potential inundated properties, assess impacts to downstream properties and estimate potential damages.

NEILD AVENUE AND BOUNDARY STREET

These streets convey substantial overland flow during floods at the lowest point in Neild Avenue adjacent to the Weigall Sportsground. The results from DRAINS indicate that the overland flow in a 100 year ARI event is between 10-20m^3/s along these streets.

The Catchment Management Study (Reference 3) recommended that the footpath be lowered along Neild Avenue to direct water into the open channel and that the road drainage network have increased inlet capacity to alleviate flooding along Boundary Street. These options are endorsed however should be based on a detailed drainage investigation.

OUTCOMES

There are significant overland flow problems in the upper catchment that have occurred several times in the past. There are no cost effective measures that will eliminate these flood problem. The measures considered in this study are pit and pipe upgrades, road/gutter works to divert flow and voluntary purchase of affected properties. The main issue with these measures is the high cost and the need to justify the works in terms of a reduction in flood damages in order to seek funding from the State or Federal Government. The latter requires a detailed floor level survey and drainage investigation.

Upgrading of the pit and pipe network and road/gutter works is most probably the only measure acceptable to the local residents. Voluntary house purchase will likely be rejected by the community for the reasons given previously.

ACTIONS

It is recommended that Council continue to record instances of inundation from local drainage (refer previous section). This process will ensure that the overland flow problem is accurately identified. As a general strategy Council should continue and revise where required, the maintenance program for pits and pipes. Council may also wish to consider parking controls in areas where overland flow is significant to ensure grate inlets are clear to receive stormwater.

The following provides a summary of the recommended actions.

Cecil Street, Cecil Lane, Hampden Street

These streets are probably the most flood affected streets in the catchment and works should be undertaken to reduce the frequency of inundation. The preferred works are construction of an open channel along the northern end of the streets and this is likely to have a relatively high benefit cost ratio.

Roylston Street

The preferred works are construction of an overland flowpath from Cecil Street into Trumper Park (see above).

Walker Avenue, Glenmore Road

Minor road works would assist in a small flood but there are no practical mitigation measures for large flood events.

Pit and pipe upgrades at the following areas should be further investigated:

- **George Street, Elizabeth Street,**
- **Victoria Street, Underwood Street,**
- **Hopetoun Street, Hopetoun Lane,**
- **Hargrave Street, Sutherland Street,**
- **Ocean Street, Tara Street,**
- **Harris Street,**
- **Neild Avenue, Boundary Street**.

The above investigations will all require a ground and floor level survey and a detailed drainage investigation to be undertaken to quantify the flood problem, identify potential inundated properties, assess impacts to downstream properties and estimate the potential damage and scope design requirements. Subsequently a rigorous cost benefit analysis should be undertaken to justify the works.

7. DEVELOPMENT MEASURES

This chapter discusses the management of future development from a flooding and water quality perspective.

7.1. Climate Change

DESCRIPTION

The earth's surface temperature is due to the presence of certain gases in the atmosphere which allow the sun's rays to penetrate to the earth but reduce the amount of energy being radiated back. It is this trapping of the reflected heat which has enabled life to exist on earth.

Since the early 1980's there has been concern that increasing amounts of greenhouse gases (water vapour, carbon dioxide, methane, nitrous oxide, ozone) resulting from human activity may be raising the average earth surface temperature. As a consequence, this may affect the climate and sea level. The extent of any permanent climatic or sea level change can only be established through scientific observations over several decades. Nevertheless, it is prudent to consider the possible range of impacts with regard to flooding and the level of flood protection provided by any mitigation works.

Based on the latest (2007) research by the United Nations Intergovernmental Panel on Climate Change evidence is emerging on the likelihood of climate change and sea level rise as a result of increasing "greenhouse" gasses. In this regard, the following points can be made:

- greenhouse gas concentrations continue to increase,
- the balance of evidence suggests human interference has resulted in climate change over the past century,
- global sea level has risen about 0.1 m to 0.25 m in the past century,
- many uncertainties limit the accuracy to which future climate change and sea level rises can be projected and predicted.

The best available estimate of the projected sea level rise along the NSW coast is +0.4 m by the year 2050 and +0.9m by the year 2100 (Reference 5). This information is based on the latest information from the IPCC (Inter-Governmental Panel on Climate Change).

DISCUSSION

The Bureau of Meteorology has indicated that there is no intention at present to revise design rainfalls to take account of the potential climate change, as the possible mechanisms are far from clear, and there is no certainty that the changes would in fact increase design rainfalls for major flood producing storms. Even if an increase in total annual rainfall does occur, the impact on design rainfalls may not be adverse. There is some recent literature by CSIRO that suggests rainfalls may increase by up to 30% in parts of NSW (in other places the increases are much less) however this information is not of sufficient accuracy for use as yet.

Any change in design flood rainfall intensities will increase the frequency, depth and extent of inundation across the catchment. It has also been suggested that the cyclone belt may move further southwards. The possible impacts of this on design rainfalls cannot be ascertained at this time as little is known about the mechanisms that determine the movement of cyclones under existing conditions.

Any change in the sea level will have an immediate impact but this will largely only affect the open channel flood affected areas downstream of Craigend Street. The issue of sea level rise is complicated by other long term influences on mean sea level changes. The available literature suggests that a gradual increase in sea level is likely to occur with a rise of perhaps up to 0.9 m within the next 90 years along the NSW coast.

OUTCOMES

The potential impact of increased design flood levels in the catchment due to climate change is greater in the lower portion of the catchment adjacent to the open channel where both a sea level rise and a rainfall increase have an effect. To quantify this impact, the SOBEK model was run with an ocean tailwater increased by 0.9m as well as a 10% increase in rainfall. An increase in ocean levels of 0.9 m would raise the 100 year ARI flood levels by approximately 0.2m upstream of Craigend Street. An increase in rainfall of 10% would raise 100 year ARI flood levels by 0.25m upstream of Craigend Street.

There are no means of lessening the increase in greenhouse gases other than a world-wide reduction in their production. Council should continue to monitor the available literature and reassess Council's Stormwater and Flooding DCPs as appropriate. At a minimum Council should obtain the most current information available from the Bureau of Meteorology, CSIRO and OEH every two years.

There is the potential that land below approximately 2m AHD will be intermittently inundated with a 0.9m sea level rise and thus its present use may not be possible. Fortunately the majority of low lying land is open space and thus permanent inundation as a result of sea level rise will have minimal impact on existing developments. However permanent inundation must be considered in forward planning.

ACTIONS

Some Councils in NSW have raised the Flood Planning Levels to account for the expected increase in flood level. This rise would be in addition to the 0.3 m freeboard. This issue should be canvassed with revision of the Flood and Stormwater DCPs.

7.2. Development Intensification and Council Works

DESCRIPTION

There is continuing pressure on Council to permit further subdivision of existing lots to increase the density of development or permit multi-unit development within the catchment. As a result this could increase water quality issues and/or exacerbate flooding. Council also undertakes works that has the potential to cause similar issues.

DISCUSSION

Water quality issues are becoming increasingly important and Government bodies are encouraging people to minimise pollution, recycle materials and not dispose of harmful material to our drainage systems. Whilst these impacts will have no significant impact upon flood levels, community awareness and acceptance of these issues will assist in a better appreciation of other water related and environmental matters. It is hoped that this will provoke a more pro-active solution to the problem rather than an adversarial developer versus Council position.

Council are actively involved in water quality management. They undertake regular street sweeping, have constructed gross pollutant traps, use pit inserts to capture debris, clean pits and have a community awareness and involvement program. Increased public awareness of these issues (television, radio, newspaper, Council notices) will assist in reducing the problem.

Filling of low lying land is generally undertaken for a new development to raise the level of a building pad to ensure that the floor level is above the flood planning level. If the land is within the floodplain it can result in:

- the loss of temporary floodplain storage which could cause an increase in peak flow and flood level downstream,
- the loss of available flow path which could result in an increase in flood level upstream,
- redirection of local runoff onto adjoining properties.

Downstream of Glenmore Road the only significant areas of land are within the White City sports complex or public land at the Weigall sportsground. Any public or private works including filling on the floodplain, downstream of Glenmore Road must consider flooding.

Development in these areas is controlled by Woollahra Council through the Draft Flood Risk Management DCP and the Draft Stormwater Drainage DCP.

Within the upper catchment the main issue is loss of available flow path and redirection of local runoff onto adjoining properties. The loss of temporary floodplain storage is considered of minor importance in the upper catchment.

OUTCOMES

Council policies to manage the adverse effects of development on flooding are supported and if implemented successfully will ensure minimal adverse impact on other floodplain users. It is understood that these documents (DCPs) are currently being reviewed by Council.

Any works by Council must not exacerbate flooding or introduce water quality issues.

ACTIONS

No action required at this stage.

7.3. Water Sensitive Urban Design

7.3.1. Background

Urban development can lead to changes in the catchment hydrology with the most obvious being an increase in peak flow (and resulting flood levels) and pollutants in the creek system.

Traditionally floodplain risk management studies have focussed on the increase in peak flow where the principal objective is to safely and efficiently convey stormwater to the ocean. This is the reason why a concrete lined channel forms the main drainage channel in the lower part of the Rushcutters Bay catchment.

The increased public awareness of environmental issues and shortage of water resources have highlighted the importance of the environmental management of urban stormwater. An integrated stormwater management strategy to cater for multiple objectives is therefore required. This approach is termed Water Sensitive Urban Design (WSUD) and has the following broad objectives:

- reduce the potable water demand through water efficient appliances and rainwater and grey water collection and reuse,
- minimising wastewater generation,
- treat urban stormwater to meet water quality objectives and reuse if possible,
- using stormwater to maximise the visual and recreational amenity of the urban landscape.

This floodplain risk management study supports the general objectives of WSUD but it is not possible to address every aspect (e.g. water saving devices, grey water reuse, etc.) within the scope of the study. Council supports the application of WSUD and in this regards undertakes its own research into inlet pit design.

The following sections consider those aspects that can be included within the scope of the NSW Government's Floodplain Development Manual (Reference 1).

7.3.2. Reduce Potable Water Demand

The introduction of BASIX (Building Sustainability Index) to ensure minimum energy and water use targets has ensured that all new developments minimise the potable water demand. One outcome of this is the maximisation of pervious area within a development thus reducing the volume and rate of runoff during a flood event. A major consequence will ultimately be a possible slowing down (or at least not an increase) of the rate of runoff and thus the peak flow.

Whilst BASIX only applies to residential developments the water use principles can also be applied to other land use activities (commercial and industrial developments).

This could also be further extended to existing Council or government structures and facilities. In some Council areas there are opportunities to construct either rainwater tanks or structures, for example on concrete netball or tennis courts. Inspection of the catchment indicates no obvious or significant facilities where this approach could be applied. However should such an opportunity arise this should be supported.

7.3.3. Minimise Wastewater Generation

There is no opportunity within the scope of this study to address this aspect of WSUD.

7.3.4. Treat Urban Stormwater

Council has already introduced water quality devices in the catchment (water quality boom at the exit of the channel to Rushcutters Bay). The following sections describe possible additional devices.

Gross Pollutant Traps: Upstream of Trumper Park there is little or no opportunity to install a GPT (Gross Pollutant Trap). Downstream of Glenmore Road the preferred siting of a GPT is as an offline structure where land is available and does not limit the use of the adjoining land. Offline structures similar to that constructed by Sydney Water at several locations in their network may cost up to $200,000. If possible it should be constructed as a wetland and so incorporate a nutrient absorption function. It would provide significant environmental benefit with no adverse hydraulic impacts and potentially some social benefits.

There may be other potential sites for GPTs. These should be considered where appropriate.

Sub-Surface Devices: Where appropriate Council should install more of these devices. A major consideration with these devices is the ongoing maintenance. This is costly and if not undertaken regularly means the device is largely ineffective.

Improved Water Absorption: Council should consider, as far as possible, changes to its work procedures to ensure maximum water absorption. For example this may mean grading footpaths or similar so they shed runoff onto grassed areas before entering the stormwater system. On public roads this is generally not possible but could be implemented within certain types of developments (units).

Maximisation of Visual and Recreational Amenity: Achieving the objective of enhancing the visual and recreational amenity is outside the scope of the present study.

8. ACKNOWLEDGEMENTS

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- Woollahra Council,
- Office of Environment and Heritage,
- Rushcutters Bay Floodplain Management Committee,
- residents of Rushcutters Bay catchment.

9. REFERENCES

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Floodplain Development Manual
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Webb, McKeown & Associates, October 2007.

3. Water Board
Rushcutters Bay SWC No. 84 Catchment Management Study
Water Board, 1991.

4. Woollahra Municipal Council
Cecil and Hampden Streets, Paddington – Drainage Investigation
Patterson Britton & Partners, May 2004.

5. **Flood Risk Management Guide**
Department of Environment Climate Change and Water NSW, August 2010.

Figures

Appendix A

APPENDIX A: GLOSSARY

Taken from the Floodplain Development Manual (April 2005 edition)

acid sulfate soils	Are sediments which contain sulfidic mineral pyrite which may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual published by Acid Sulfate Soil Management Advisory Committee.
Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Annual Damage (AAD)	Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
Average Recurrence Interval (ARI)	The long term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
caravan and moveable home parks	Caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the LG Act.
catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
consent authority	The Council, Government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the Council, however legislation or an EPI may specify a Minister or public authority (other than a Council), or the Director General of DIPNR, as having the function to determine an application.
development	Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act). **infill development:** refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development. **new development:** refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power. **redevelopment:** refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services.
disaster plan (DISPLAN)	A step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of

	connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.
discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
ecologically sustainable development (ESD)	Using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act 1993. The use of sustainability and sustainable in this manual relate to ESD.
effective warning time	The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.
emergency management	A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.
flash flooding	Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
flood awareness	Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.
flood education	Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves an their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.
flood fringe areas	The remaining area of flood prone land after floodway and flood storage areas have been defined.
flood liable land	Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).
flood mitigation standard	The average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.
floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
floodplain risk management options	The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
floodplain risk management plan	A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.

flood plan (local)	A sub-plan of a disaster plan that deals specifically with flooding. They can exist at State, Division and local levels. Local flood plans are prepared under the leadership of the State Emergency Service.
flood planning area	The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the “flood liable land” concept in the 1986 Manual.
Flood Planning Levels (FPLs)	FPL’s are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the “standard flood event” in the 1986 manual.
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.
flood readiness	Flood readiness is an ability to react within the effective warning time.
flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. **existing flood risk:** the risk a community is exposed to as a result of its location on the floodplain. **future flood risk:** the risk a community may be exposed to as a result of new development on the floodplain. **continuing flood risk:** the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.
flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.
freeboard	Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
habitable room	**in a residential situation:** a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom. **in an industrial or commercial situation:** an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.
hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to

	the community. Definitions of high and low hazard categories are provided in the Manual.
hydraulics	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
hydrograph	A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
hydrology	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
local drainage	Are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.
mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
major drainage	Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purpose of this manual major drainage involves: • the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or • water depths generally in excess of 0.3 m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or • major overland flow paths through developed areas outside of defined drainage reserves; and/or • the potential to affect a number of buildings along the major flow path.
mathematical/computer models	The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
merit approach	The merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well being of the State's rivers and floodplains. The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into Council plans, policy and EPIs. At a site specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local floodplain risk management policy and EPIs.
minor, moderate and major flooding	Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood: **minor flooding:** causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople

	begin to be flooded. **moderate flooding:** low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered. **major flooding:** appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.
modification measures	Measures that modify either the flood, the property or the response to flooding. Examples are indicated in Table 2.1 with further discussion in the Manual.
peak discharge	The maximum discharge occurring during a flood event.
Probable Maximum Flood (PMF)	The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.
Probable Maximum Precipitation (PMP)	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
probability	A statistical measure of the expected chance of flooding (see AEP).
risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	Equivalent to "water level". Both are measured with reference to a specified datum.
stage hydrograph	A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
survey plan	A plan prepared by a registered surveyor.
water surface profile	A graph showing the flood stage at any given location along a watercourse at a particular time.
wind fetch	The horizontal distance in the direction of wind over which wind waves are generated.

Appendix B