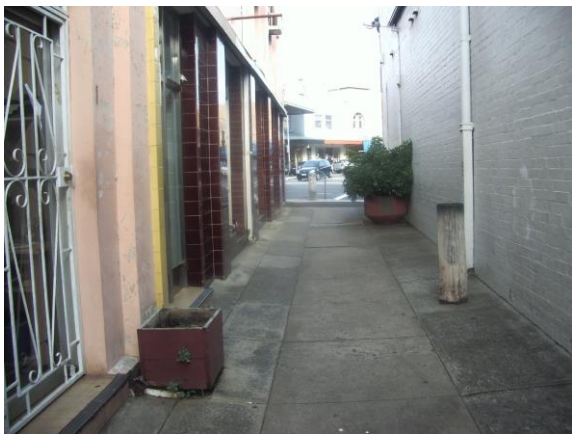
WOOLLAHRA MUNICIPAL COUNCIL

ROSE BAY FLOODPLAIN RISK MANAGEMENT STUDY AND PLAN



wma water

JANUARY 2014

Level 2, 160 Clarence Street
Sydney, NSW, 2000

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

ROSE BAY FLOODPLAIN RISK MANAGEMENT STUDY AND PLAN

JANUARY, 2014

Project **Rose Bay Floodplain Risk Management Study and Plan**	**Project Number** **111009**
Client Woollahra Municipal Council	**Client's Representative** M Casteleyn
Authors Richard Dewar Zac Richards	**Prepared by**
Date 7 January 2014	**Verified by**

Revision	Description	Date
1	1st Draft Report	March 2012
2	Public Exhibition Draft	March 2013
3	Final	7 January 2014

ROSE BAY FLOODPLAIN RISK MANAGEMENT STUDY AND PLAN

TABLE OF CONTENTS

LIST OF PHOTOGRAPHS

LIST OF TABLES

LIST OF APPENDICES

LIST OF FIGURES

LIST OF ACRONYMS

AAD	Annual Average Damages
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ARI	Average Recurrence Interval
ALS	Airborne Laser Scanning
BASIX	Building Sustainability Index
BOM	Bureau of Meteorology
CCTV	Closed Circuit Television
CFERP	Community Flood Emergency Response Plan
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCP	Development Control Plan
DECCW	Department of Environment, Climate Change and Water (now OEH)
FPL	Flood Planning Level
GPT	Gross Pollutant Trap
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 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)
WSUD	Water Sensitive Urban Design
1D	One dimensional hydraulic computer model
2D	Two dimensional hydraulic computer model

1. FOREWORD

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

1. Flood Study

- determines 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.

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 Rose Bay Floodplain Risk Management Study and Plan constitutes the second and third stages of the management process for the Rose 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 Rose Bay catchment.

2. ROSE BAY FLOODPLAIN RISK MANAGEMENT PLAN

2.1. Introduction

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

Rose Bay has a catchment area of approximately 5.2km^2. The area drains to Sydney Harbour and includes the suburbs of Bellevue Hill, Rose Bay and parts of Vaucluse within Woollahra Council LGA and Dover Heights and North Bondi suburbs in Waverley Council LGA. The catchment is characterised by an upper and a lower section.

The upper catchment comprises of steep slopes with medium density developments with few non-residential developments and little open space. The lower part of the catchment comprises flatter slopes occupied by low to medium residential development and a significant area of open space comprising Woollahra and Royal Sydney golf courses. Stormwater from the upper section is carried within an underground pipe network or when exceeded, along roads and through private property. The runoff travels through the lower section via underground pipes, and the main open stormwater channel through Woollahra and Royal Sydney golf courses. Most of the drainage infrastructure was installed in the 1930s.

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. Rose Bay Catchment Flood Study

The Rose Bay Catchment Flood Study (Reference **2**) was initiated as a result of flooding on roads and in residential areas. The largest recent event was in November 1984 which inundated the shops on New South Head Road at Rose Bay by over 1 metre depth.

The study initially included a review of available reports and data. Subsequently a hydrologic and hydraulic computer model were established, calibrated to historical data and used to determine design flood levels. The study defined flood behaviour including the flood extent and hazard mapping in the Rose Bay catchment for a range of design flood events up to the Probable Maximum Flood (PMF). Sensitivity analyses were undertaken to assess the impact of varying model parameters.

2.2.1. Existing Flood Problem

A flood damages assessment 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 regions of the catchment. The estimated number of building floors which are likely to be inundated in the 5 year ARI is 90 (54 residential, 34 commercial and 2 public lots) and 122 (75 residential, 43 commercial and 4 public lots) in the 100 year ARI. In the PMF up to 200 building floors would be inundated. The annual average damages are estimated to be $2.6 million. The flood damages information has been based on recent guidelines on the assessment of flood damages provided by DECCW (now OEH).

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 also been given for damages to public structures or utilities (bridges, roads, pumping stations) or for the complete collapse of structures due to flooding.

2.2.2. Future Development

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

2.2.3. Floodplain Risk Management Study

The specific aims of this study are 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.

The subsequent Floodplain Risk Management Plan documents the recommended strategies.

2.2.4. 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.

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 Rose Bay catchment.

2.2.5. 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.

Flooding causes significant hardship (tangible and intangible damages) to the community. The impacts will increase if sea levels and rainfall intensities rise. For this reason Woollahra Municipal Council has undertaken a program of studies to address the management of flood risks.

The present study was initiated to assess floodplain risk management measures and incorporate the sea level rise predictions by the Intergovernmental Panel on Climate Change (IPCC) and the CSIRO Technical Review for Australia, and also the potential increase in rainfall intensities, and evaluate suitable adaptation measures where appropriate. In September 2012 the NSW Government retracted its advice that councils must adopt the 2009 sea level rise benchmarks. Councils must now make their own decisions in this regard.

2.3. Risk Management Measures Considered

A matrix of possible management measures was prepared and evaluated in this Floodplain Risk Management Study taking into account a range of parameters. This process eliminated a number of flood risk management measures (refer Section 6) including:

- Flood mitigation dams and retarding basins: - on the basis of high cost, large footprint, and environmental impact,
- Catchment treatment to increase soil infiltration and storage of rainfall in the catchment: - on the basis of minimal reduction in flood levels,
- Voluntary purchase of flood affected buildings: - as it is uneconomic and has a high social impact.

The full range of measures was evaluated in Section 6 and the outcomes are summarised in Table 1. Community opinion on the full range of options was canvassed during the public exhibition period in Section 5.8. However it should be noted that these outcomes may change in time if community expectations change. The final options documented in the Rose Bay Floodplain Risk Management Plan reflect the current community input.

Table 1:Review of Floodplain Management Measures

MEASURE	REFER SECTION	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 provides water quality benefits.	To be considered as a means of mitigating the effects of urban development if suitable sites are available.
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 enables 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 in Rose Bay.	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 due to the sort available warning time.	Not applicable.	Not viable.
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	Recommended.

MEASURE	REFER SECTION	PURPOSE	COMMENT	ECONOMIC ASSESSMENT	IMPLEMENTATION VIABILITY
				reduces with time since last flooding event.	
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.	May 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 assessment 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 BLOCKAGE	Section 6.5.6	To ensure the efficient use of the available infrastructure.	A variety of means are available but it is difficult to achieve 100% success.	Not costed	Recommended.
ON-SITE DETENTION	Section 6.5.10	Expand the policy to mitigate existing flood flows.	No other Council has undertaken this expanded policy approach.	Probably not viable.	Not recommended.

Table 2: Review of Development Measures

MEASURE	REFER SECTION	PURPOSE	COMMENT	ECONOMIC ASSESSMENT	IMPLEMENTATION VIABILITY
SEA LEVEL RISE	Section 7.1	Assess possible impacts of sea level rise and include in Flood Planning Level.	The effects of sea level rise will only affect design flood levels immediately upstream of the outlets north of the Rose Bay shopping precinct and around the golf course and will not affect properties. An increase in rainfall intensity will affect the entire catchment by up to 0.1m with a 10% increase.	Unknown.	Council should consider introducing a sea level rise 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 Risk Management Measures

The proposed measures have been selected from the range of measures considered above and after an assessment of each measure's impact on flood risk as well as consideration of potential environmental, social and economic impacts. The measures have been separated into one of three categories according to their priority of implementation. The priority is a qualitative assessment based on the urgency of the measure, the likelihood of obtaining funds or obtaining approval, the ease of implementation and other relevant considerations. The actual timing will depend on Council's budgetary commitments and the availability of funding from other sources.

A variety of sources of funding are available including:

- Council;
- State government – OEH;
- Commonwealth and State funding through the Natural Disaster Resilience Program;
- Funding from other semi government (SES, Sydney Water) or private funding;
- Section 94 contributions from future development.

The total cost to implement the entire package of works cannot be accurately assessed as it will depend on the exact nature of the works. The plan should be updated as better flood information and advice become available.

2.4.1. High Priority

Issue	Management Measure	Timeframe	Cost	Authority
Local Drainage Issues	Maintain drainage database	Continuously and specifically following future major events	Nil additional cost	Council
Public Information & Flood Awareness	Provide measures to improve awareness and possibly on an LGA wide basis	Continuously with individual measures occurring periodically	Depends on individual measures implemented and approach undertaken	SES and Council
Flood Planning Levels	Ensure implementation of a rigorous approach	Continuously	Nil additional cost	Council
Development Control Planning	Ensure implementation of a rigorous approach	Continuously	Nil additional cost	Council
Overland Flow Issues in the Upper Catchment	A qualitative assessment of the flood and drainage issues is provided in the Study. This assessment will be continuously updated after each new event with inputs from the drainage database. Council will need to consider appropriate management measures as they arise. This may require identification of house floors inundated, upgrading to the pit and pipe network, minor street works, re-direction of overland flow and/or the management of blockage	Continuously and specifically following future major events	Depends on individual measures implemented and approach undertaken	Council

2.4.2. Medium Priority

Issue	Management Measure	Timeframe	Cost	Authority
Evacuation Planning	Ensure that the most up to date best practice is applied	Continuously and specifically following future major events	Nil additional cost	SES, Council, residents
Flood Proofing	Measures can be retro-fitted to existing buildings or incorporated in a new design. Generally not suited for residential buildings.	Where applicable	Depends on individual measures. No funding available.	Property owners
Flow Diversion from Albemarle Avenue	Any measure that reduces floodwaters reaching the Rose Bay shops will reduce flood levels. The most likely measure is a diversion through Royal Sydney Golf Course. Local residents and Royal Sydney Golf Course would be consulted at every stage of the design.	Depends on outcomes of future studies	Likely > $100,000	Council, OEH, Royal Sydney Golf Club

2.4.3. Low Priority

Issue	Management Measure	Timeframe	Cost	Authority
Construct Retarding Basins	Construct retarding basins to reduce peak flows downstream.	Where opportunity arises	Depends on individual measures	Council, developers
Widen Worth Arcade	Widen Worth Arcade to reduce flood levels in the Rose Bay shopping precinct.	Likely only when redevelopment occurs	Depends on approach and whether costs can be offset against other developer contributions.	Council, property owners

2.4.4. Development Measures

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

Issue	Management Measure	Timeframe	Cost	Authority
Sea Level Rise	At this time the BoM has not advised that design rainfall increases will definitely occur but it is likely that some magnitude of sea level rise will occur over the next 100 years. Suitable adaptation measures must be included to protect existing developments and incorporate in development controls.	Review best practice advise on a bi-annual basis	Likely significant cost but depends on measure employed.	Council, property owners
Development Intensification	Current policies are under review and need to be then rigorously applied to ensure minimal adverse impacts result.	Within the next two years	Nil additional cost	Council
Water Sensitive Urban Design	WSUD covers many areas including: reduction in potable water demand, treating urban stormwater, construction of surface or sub surface trash collectors and improvements to water absorption.	When re-development occurs or as appropriate.	Likely high cost but depends on measure employed.	Council, residents

3. INTRODUCTION

The Rose Bay catchment is situated between Sydney Harbour and the high ridges west of Bondi (Figure 1 and Figure 2) and is located primarily within the Woollahra Municipal Council LGA covering an area of approximately 516 hectares. Approximately 40% (200 hectares) of the catchment is located within the Waverley Council LGA. The catchment contains the suburbs of Bellevue Hill, Rose Bay and a small portion of Vaucluse within Woollahra Municipal Council LGA and North Bondi and Dover Heights within Waverley Council LGA.

The Rose Bay catchment is characterised by an upper and a lower region. 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 Sydney Harbour via a large box culvert under New South Head Road and an open channel. The lined open channel is owned by Sydney Water and the floodplain of this channel is largely contained within the Woollahra and Royal Sydney golf courses and associated open space areas.

Flooding problems have been experienced at a number of locations within the catchment during periods of heavy rainfall (Figure 3) most notably in November 1984. Woollahra Municipal Council has undertaken to address this issue through the Floodplain Risk Management Process (Reference 1).

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 Rose Bay Catchment Floodplain Risk Management Study constitutes the second stage in the process. The Flood Study stage was completed in September 2010 with publication of the Rose 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 Rose Bay catchment. This study superseded a previous Catchment Management Study (Reference 3) completed in 1991.

3.2. Rose Bay Catchment Flood Study

The key phases undertaken in the Flood Study (Reference 2) 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.

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 to convert the upstream flows obtained from DRAINS into flood levels and velocities.

Calibration to Historical Flood Levels: Due to a lack of data which is common in an urban catchment 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 for the November 1984 event was preformed. The calibrated SOBEK model was then used to quantify the design flood behaviour for a range of design events.

Determination of Design Flood Flows and Levels: Design rainfall data obtained from Woollahra Council and design temporal patterns from Australian Rainfall and Runoff (Reference 4) were obtained and used in a DRAINS model to determine design event flows. The SOBEK model was then used to determine design flood levels in the lower catchment. The downstream regions of the Rose Bay catchment were predominately influenced by catchment flows and only slightly by elevated water levels in Rose Bay. Sensitivity analyses were undertaken on the DRAINS and SOBEK model results.

3.3. Drainage System

3.3.1. Open Channel

Table 3 provides an overview of the key characteristics of the open channel drainage system downstream of Old South Head Road (i.e within Woollahra LGA). The open channel system is owned and administered by Sydney Water and exits through 4.08 m by 2.15 m twin box culverts under New South Head Road to Rose Bay.

Table 3: Open Channel Dimensions

Location * (Sydney Water designation)	Chainage (m)	Dimensions (m) (width x height)	Description	Average Upstream Slope	Invert Level (mAHD)
A	0	4.08 X 2.15	Twin Box Section	1 in 183	0.12
B	33	8.42 x 2.12	Concrete Channel	1 in 4760	0.30
	38	4.25 x 1.30	Concrete Channel		
C	271	4.50 x 1.83	Concrete Masonry Channel	1 in 73	0.35
	278	5.95 x 1.72	Masonry Channel	1 in 380	0.45
F	524	5.70 x 1.2	Masonry Channel	Horizontal	1.10
	532	4.40 x 1.26	Masonry Channel		
G	556	4.30 x 1.22 (channel)	Small Weir		1.09 *(base of weir)*
H	590	1.70 x 0.79 (gate aperture)	Large Gated Weir		2.59 *(base of weir)*
	590	6.5 x 0.80	Open Earth Channel	1 in 440	2.20 approx.
	690	7.6 x 1.46	Open Earth Channel		2.27 approx.
	750	5.9 x 0.97	Open Earth Channel		2.60 approx.
J	963	2.35 x 1.08	Box Section	1 in 132	3.05
L	1176	2.35 x 1.52	Box Section	1 in 400	
M	1200	2.64 x 1.68	Box Section	1 in 400	

* Refer Figure 1. Taken from Reference 5.

3.3.2. Piped Drainage

Table 4 provides a summary of the piped network system within the Woollahra LGA DRAINS model (Figure 4) established in Reference 2. Photographs 1 to 6 show some features of the drainage system.

Table 4: Pit and Pipe Drainage Network (taken from Reference 2)

PITS - BELLEVUE HILL SUB-CATCHMENT					
Sag Pits		**OnGrade Pits**		**Others**	
0.9 m lintel	7	0.9 m lintel	115	Outlet	1
1.2 m lintel	4	1.2 m lintel	64	Node	78
1.8 m lintel	13	1.8 m lintel	97		
2.4 m lintel	4	2.4 m lintel	48		
Grate only	1	3.0 m lintel	4		
SA1 (Type 2) - 1% grade	8	Grate only	42		
		Kerb inlet 0.85 m lintel 1% crossfall	1		
		SA1 (Type 2) - 1% grade	141		
		Unrestricted entry	1		
		SA2 (Type 5) - 1% grade	3		
TOTAL	**37**	**TOTAL**	**516**	**TOTAL**	**79**

PITS - ROSE BAY SUB-CATCHMENT					
Sag Pits		**OnGrade Pits**		**Others**	
0.9 m lintel	4	0.9 m lintel	50	Node	26
1.2 m lintel	2	1.2 m lintel	31		
1.8 m lintel	5	1.8 m lintel	63		
2.4 m lintel	1	2.4 m lintel	23		
3.0 m lintel	2	3.0 m lintel	4		
Grated pit 0.9 m x 0.45 m	1	Grate only	18		
SA1 (Type 2) - 1% grade	1	Grated Inlet Pit	13		
		Grated pit 0.9 m x 0.45 m	5		
		SA1 (Type 2) - 1% grade	131		
TOTAL	**16**	**TOTAL**	**338**	**TOTAL**	**26**

Pipe Diameter (mm)	Bellevue Hill Sub-catchment	Rose Bay Sub-catchment
<300	21	25
300	186	111
375	136	80
450	120	57
525	39	14
600	50	25
675	1	0
750	39	16
825	5	0
900	7	1
1050	0	10
1200	19	0
1350	0	3
1500	0	12
1800	0	8
Box Culverts	0	3
TOTAL	**623**	**365**

Photo 1: Open channel at Manion Avenue looking upstream

Photo 2: Open channel at Manion Avenue looking downstream

Photo 3: Worth Arcade looking south towards Rose Bay shopping area

Photo 4: Storm water outlet at Rose Bay

Photo 5: New South Head Road at Rose Bay looking west

Photo 6: Worth Arcade which provides the drainage outlet to Rose Bay

Photo 7: Mudflats and seawall looking west at Rose Bay

Photo 8: Stormwater outlet at the end of Caledonia Road

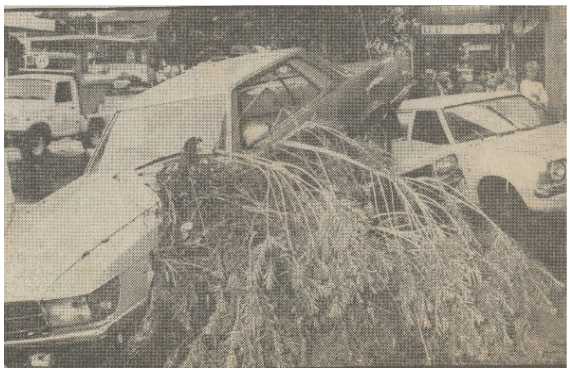


Photo 9: November 1984 – Rose Bay shops (Reference 2)

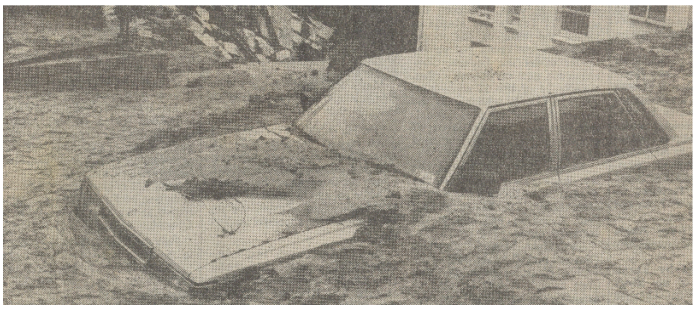


Photo 10: November 1984 – mudslide (Reference 2)

Photo 11: Overland flow - unknown street

Photo 12: Overland flow - unknown street

4. STUDY AREA

4.1. Catchment Description

The Rose Bay catchment has been developed for mostly residential or commercial purposes with the only areas of open space used as parks and golf courses. In the lower section of the catchment there are significant areas of recreational open space including Woollahra and Royal Sydney golf courses, Dangar and Woollahra ovals and Lyne Park adjacent to Sydney 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.

Drainage in the upper section of the catchment is characterised by underground pipe systems and overland flow conveyed along the roads, which are 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 small to large detached residences and medium high rise residential units with little commercial development. The non-residential development includes several schools, parks, churches and community buildings. There are no significant industrial developments and few major commercial developments.

The original stormwater channel was constructed in 1895 with additions undertaken between 1926 and 1938. Up until the 1930's market gardens and other agricultural activities were undertaken in the low lying areas. Subsequently these areas have been formed into the Royal Sydney and Woollahra golf courses and thus providing an excellent flood compatible land use. The current catchment population within the Woollahra Municipal LGA is of the order of 5,500 in 2006.

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 (OSD) to ensure pre development peak flows are not increased.

The current LEP zonings for the catchment are provided on Figure 5 together with a pie chart showing the percentage of land within the various land use zones.

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 modelling and water quality samples indicated that the main pollutants considered to have the most significant impact on the receiving water amenity of Rose Bay are suspended solids, total nitrogen, total phosphorus and in some regions faecal coliform. Litter and debris are also major contributors that are likely to reduce water quality in the event of a storm.

In 2006 Woollahra Municipal 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.

Woollahra Municipal 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). Woollahra Municipal Council has also initiated a number of water quality measures through formation of the Environmental Levy Community Reference Group.

Sydney Water recently (circa 2008) removed a litter boom that was at the entrance to Sydney Harbour as it was not collecting enough litter to justify the maintenance costs. In 2003 Sydney Water installed a Gross Pollution Trap (GPT) under Norwich Road, Rose Bay. This removed 15 tonnes of litter in the first 12 months of use.

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 although there are almost no remaining areas of semi natural bushland in the catchment.

Both golf courses provide an opportunity for further development of flora and fauna habitats.

4.3.3. Visual Amenity

The visual amenity of the "concrete lined" creek system itself would generally be described as of low quality compared to a natural system. However, apart from some graffiti, it is clean, 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 including Woollahra and Royal Sydney golf courses, Dangar and Woollahra ovals and Lyne Park. 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 Rose Bay Flood Study (Reference 2). Of relevance for this Floodplain Risk Management Study are findings from the Flood Study (Reference 2), the Rose Bay Stormwater Catchment Management Study (Reference 3) and Woollahra Drains Modelling – Draft Report (Reference 5).

4.4.1. Rose 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 the 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 1 year, 2 year, 5 year, 10 year, 20 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;
- preparation 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. Rose Bay Catchment Management Study (Reference 3)

This study included:

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

The full range of possible floodplain management measures were investigated in this study and the report considered that the focus should be on the North Bondi catchment (Waverley LGA) as the Bellevue Hill (Woollahra LGA) catchment had only isolated flooding of houses. The key recommendations were:

- **pipe and channel upgrades:** Upgrading of the crossings under Old South Head Road would be expensive and would not completely remove above floor flooding. Upgrading of the pipe drainage system would be of benefit but would involve substantial costs. Upgrading of the open channel system would provide negligible benefit. Two main options (with some sub options) were modelled but as these were east of Old South Head Road within Waverley Council LGA the results have not been discussed in this report,
- **inclusion of retarding basins:** The report acknowledged that there are limited opportunities for basins and an assessment for a basin in Barracluff Park within Waverley LGA provided minimal benefit,
- **removal of obstructions to flood flows (bridges and weirs in golf courses):** The report acknowledged that these would provide minimal benefit,
- **installation of floodways:** It was suggested that an additional or enlarged culvert could be constructed under Old South Head Road at the low point at Murriverie Road within Waverley LGA. This would reduce flood levels for upstream properties in the Waverley Council LGA but would increase flows downstream through the golf course,
- **increase infiltration and decrease runoff:** These measures would assist in small events but would generally have minimal impact in floods of say 2 year ARI and greater magnitude,
- **reduce damage susceptibility through house raising, voluntary purchase and flood warning:** It was acknowledged that there are few houses suitable for raising with most not really possible as of brick houses and voluntary purchase is cost prohibitive. A flood warning system was suggested but it is difficult to see how effective this would be given the acknowledged short possible warning time of one to two hours. An annual cost of $8,000 ($1991) was given,
- **redirect the loss burden through flood insurance and government disaster relief:** The report suggested that government disaster was unlikely. Flood insurance has evolved considerably since 1991 and since approximately 2006 is now available for many flood liable properties. Following the Brisbane River flood of January 2011 a review has been undertaken of flood insurance, including its pricing and availability,
- **low cost structural improvements:** These measures include additional drainage pits and minor pipe upgrades.

The flood damages assessment concluded that the proposed drainage improvements could not be justified based on a reduction in tangible damages but would reduce the intangible damages.

4.4.3. Woollahra DRAINS Modelling – Draft Report (Reference 5)

This investigation provided results from the DRAINS computer model developed to model the Woollahra LGA. The models were run for a number of design events and areas with drainage

problems that have the potential to flood were isolated. This report noted that the following areas were likely to experience large overland flows during heavy rainfall events:

- 11 and 13 Bundarra Road and 8, 10 and 12 Blaxland Road;
- 19, 21 and 23 Bunyula Road and 58 and 60 Boronia Road;
- 49 and 51 Boronia Road and 177 and 179 O'Sullivan Road;
- 63 and 65 Victoria Road;
- 2 Beresford Crescent and 50, 52 and 56 Beresford Road;
- 24, 26, 19 and 21 Balfour Street;
- 7 Aston Gardens;
- 9 Cranbrook Lane and 13, 15 and 17-19 Cranbrook Road;
- Cranbrook School;
- 482, 484-486 and 488-492 Old South Head Road;
- properties along Spencer Street;
- 34, 36, 51, 53 and 55 Dover Road;
- 56, 58, 71 and 73a Wilberforce Avenue;
- About half of the Rose Bay shopping centre, particularly at the intersection of Newcastle Street and New South Head Road.

5. EXISTING FLOOD ENVIRONMENT

5.1. Flooding Mechanism

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

- Elevated water levels in Rose Bay due to a high tide and/or storm surge.
- Elevated water levels within the open channel section of the Rose Bay catchment and along roads and through private property as a result of intense rain over the Rose Bay catchment. The water levels in the channel and elsewhere may also be affected by constrictions such as culverts, blockages, fences and 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 Rose 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 Rose Bay catchment. Typically flooding in the catchment occurs due to thunderstorms as occurred in all previous events in the 1970's and 1990's.

Water level variations in Rose Bay are associated with major storm events (low pressures, strong onshore winds and large waves) however flooding in the Rose Bay catchment is generated by short duration generally less than 2 hour rainfall events. As a result, peak levels in Rose Bay are unlikely to occur in conjunction with a flood over the Rose Bay catchment. Sensitivity analysis for high water levels in Sydney Harbour (Reference 2) indicated that the backwater effects are confined to the two golf courses and immediately upstream of the outlets north of the Rose Bay shopping precinct.

New South Head Road forms a significant barrier to flow in the catchment with the central and western regions channelling the majority of flood water into the Rose Bay channel. Flood waters in this channel are then required to travel through a twin box culvert under New South Head Road before exiting into Rose Bay. Flows in the north and the east of the catchment are channelled out through an opening near the intersection of New South Head Road and Newcastle Street in the Rose Bay shopping precinct. The shops form a barrier along New South Head Road with the only opening at Worth Arcade (refer Photo 9 and Photo 10).

The lower catchment has much lower relief than the upper catchment and is drained via trunk drainage pipes and culverts into the Rose Bay open channel mentioned above. This channel and its floodplain are within the Woollahra and Royal Sydney golf courses. Upstream of the golf courses, flows in excess of the pipe system are predominately conveyed along roads and gutters, with some regions affected by overland flows passing through private properties.

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

years.

Peter Poland, president of the Woollahra History and Heritage Society, provided an account of flood waters entering the study area from the Dover Heights sub-catchment and of flood behaviour in the Rose Bay sub-catchment. He stated that "*water comes down all streets from Dover Heights into Old South Head Road*", from there water flows along Hamilton Street and then down Short and Spencer Lanes to Dover Road. Flow also comes down Spencer Street and then down Spencer Lane if drainage on Hamilton Street can not cope. He noted that during the November 1984 flood event the majority of water on Dover Road flowed through properties to Wilberforce Avenue. This joined with flows coming from Old South Head Road down Wilberforce and Albemarle Avenues which combined on Newcastle Street and then flowed into the Rose Bay shopping precinct.

5.2. Historical Flood Data

A detailed analysis of rainfall records and flood records was undertaken as part of Reference 2 to gain an appreciation of the historical flood record. Additionally as part of Reference 3 some 7000 questionnaires were distributed and of this approximately 2% were returned. A summary of the key responses to the questionnaires is provided in Table 5.

Table 5: Questionnaire Results (Reference 3)

Item	Response	Comment
Ever experienced flooding?	64%	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	19%	This is a high response for above floor inundation.
Under house	10%	
In yard	32%	
In street	37%	This result is not unusual as flooding in the street is expected.

Reference 3 provided a summary of the flood problems with the majority of respondents agreeing that the November 1984 event was the worst flood they had experienced. A questionnaire distributed during the Flood Study (Reference 2) agreed with this finding and was more successful in the number of returned questionnaires. Of the 3146 sent out, 328 were returned (10%) of which 26% said they had experienced flooding in the past. This was again a high percentage which probably reflects that people who have been flooded previously are more likely to return the questionnaire. Of those who experienced flooding, 64% also reported damages due to it.

The Rose Bay Catchment Flood Study (Reference 2) details all known records of flooding and clearly the event of November 1984 was the largest since at least the 1970's which is the earliest form of record held by Council. This event caused extensive damage in the Rose Bay shopping precinct with water up to 1.5m deep, representing a significant threat to personal safety (refer Photo 9 and Photo 10). Other known events are January 1989, March 1989, December 1990 and January 1991 but all of these events were much smaller than November

1984.

The height (to mAHD) for the known historical events has not been accurately recorded within the Woollahra LGA but there are several levels to mAHD within the Waverley LGA for the November 1984 and January 1991 events.

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

5.3.1. Upper Catchment

The Rose Bay Catchment 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.

In Reference 2 a DRAINS hydrologic model was established which provided flows to the SOBEK 1D/2D hydraulic model. The DRAINS model results provides the peak flows down the roads and this information is provided on Figure 6 for the 100 year ARI and PMF events. Along many roads flows in excess of $5m^3/s$ will occur during the 100 year ARI event. However the entire flow will not be confined to roads and flow will enter private properties through driveway entrances and through/under fences. This is illustrated in Photo 11 and Photo 12 and will be typical of many properties.

This is particularly the scenario in the Bellevue Hill sub-catchment where the road system is aligned parallel to the ground contours as opposed to being perpendicular to the contours. In the former, runoff that exceeds the capacity of the gutters will flow over the kerbs on the “low side” (Photo 11 and Photo 12) and then enter the footpaths and ultimately into private property. The velocity of flow will be in excess of 1m/s and represents a significant public safety risk. In the Rose Bay sub-catchment the roads are generally perpendicular to the contours and thus there is less opportunity for flow to enter private property. However this will still occur where a road meets the downstream road at a “T” junction.

Reference 2 did not simulate the flow through private property as this would require survey of driveways and fences. Also a very detailed hydraulic model (say 1m grid size) would be required as many of the flow paths through private property are narrow (1m to 2m wide). The flow paths are also likely to be affected by garages, retaining walls, structures, swimming pools etc. within private property. At some locations residents may also have installed some form of flow diversion device if they have experienced flooding in the past. The simplest of these is to install “water proof” gates on their driveway to divert the overland flow to the downstream neighbouring property.

The Rose Bay Catchment Flood Study (Reference 2) also indicates that the piped drainage system has a capacity of less than 5 year ARI. This 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 Rose 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 piped drainage and overland flow system and in these rare events damage to surrounding developments will occur. Examples of this are the floods of November 1996 and March 2009 at Coffs Harbour that inundated a large part of the residential and commercial areas. However in Sydney in 2011 and 2012 there have been many instances of inundation of roads due to intense short duration (1 to 2 hour) storms.

It is also of note that the 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 Rose Bay Catchment Flood Study (Reference 2) 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 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 the golf course and immediately upstream of the outlets north of the Rose Bay shopping precinct.

The design conditions assumed no blockage of the twin box culverts under New South Head Road as it was considered that it is unlikely that blockage would occur in this region during a flood event. This is because the golf course upstream is well maintained, with little vegetative or other debris that could cause blockage. The assumption of 0% blockage was made after much consideration as recent large storms in 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.

Figure 7 provides the extent of inundation in the 100 year ARI event within the lower catchment. It should be noted that the extent of inundation is only accurately defined along roads and open space areas. Inundation will occur within many private properties but the actual extent has not accurately been defined as this would require specific details of structures within each property. Figure 8 provides the extent of inundation in the PMF event.

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 Rose 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 areas considered as flood storage in the upper catchment with all remaining inundated land flood classified as flood fringe.

Lower Catchment

- Flow through the Woollahra and Royal Sydney golf courses is classified as low hazard flood fringe.
- The Rose Bay open channel is classified as floodway.
- Overland flow along roads such as New South Head Road, O'Sullivan Road, Balfour Road, Salisbury Road and Beresford 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 Rose Bay catchment these factors do not significantly alter the provisional hazard classifications (Figure 9 and Figure 10) for the 100 year ARI and PMF events respectively.

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 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	Low	The main concern would be debris blocking culverts or pits. This will occur but is considered to not significantly increase the hazard.
Evacuation Difficulties	Low	Given the quick response of the catchment evacuation from a building is generally not considered to safe as there is less risk remaining in the building until the floodwaters fall.
Flood Awareness of the Community	Medium	The flood awareness of the community is moderate in the lower catchment due to the frequency and severity of flooding in the past at the Rose Bay shops. It is considered low in the upper catchment.
Depth and Velocity of Floodwaters	High	In the upper catchment, roads are subject to fast flowing water. In the lower catchment the channel velocities and depth would be high. 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 away, particularly in the Rose Bay shopping area.

Note: [1] Relative weighting in assessing the true hazard.

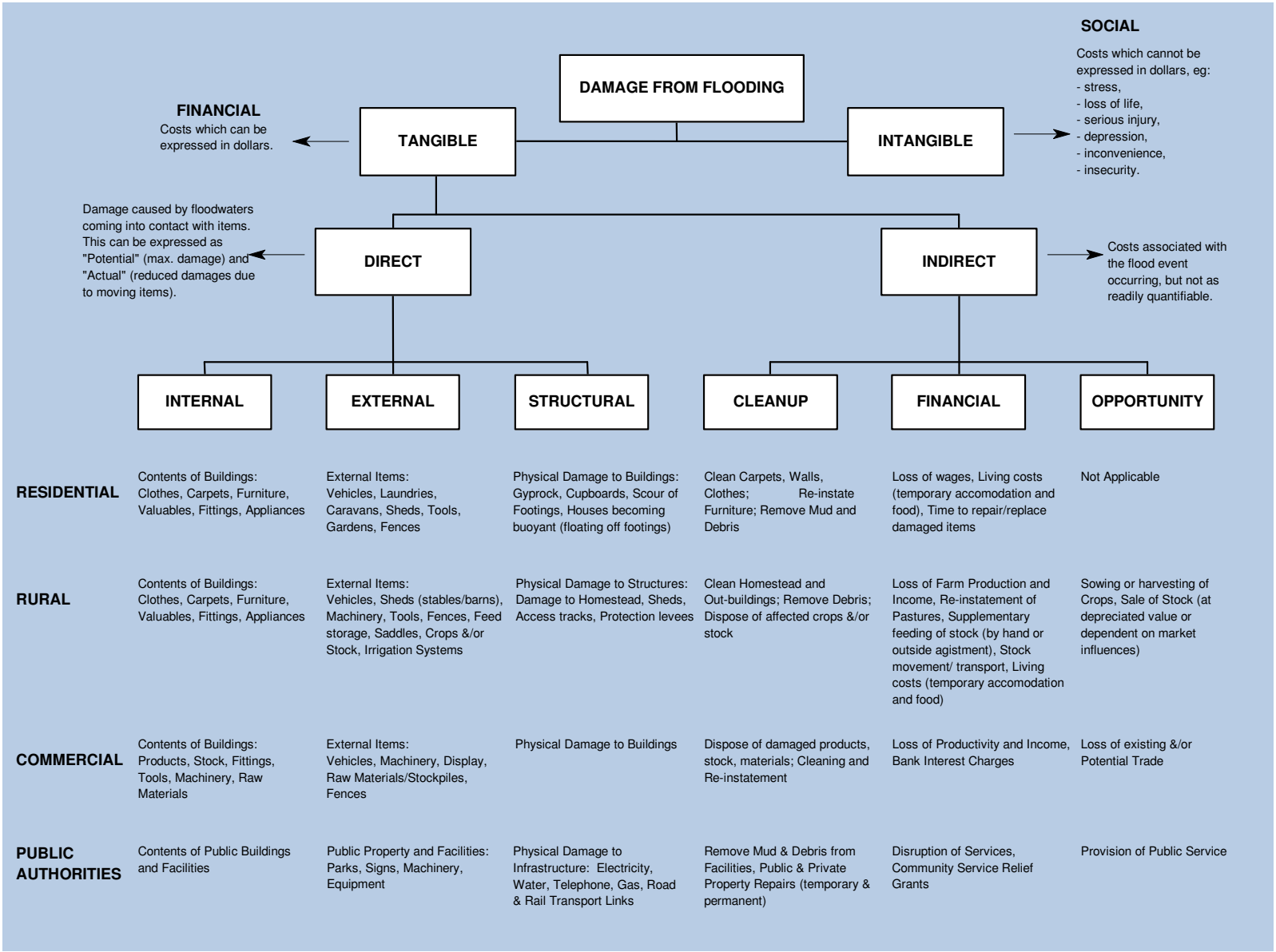
5.6. Flood Damages

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”. 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.) – refer Table 7.

Table 7: Flood Damages Categories



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, commercial and publicly owned properties. This was based on a detailed floor level survey and results from the SOBEK model. The damages 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. The summary of flood damages for the lower catchment is provided in Table 8, Table 9 and Table 10 with the building floors inundated shown on Figure 11.

It was noted that there is a high number of floors inundated in the 2 year ARI and smaller events. This was investigated and occurs due to the relatively flat terrain, shallow depths of inundation and presumably shallow low flow paths which cannot be accurately accounted for in the hydraulic model using a 2m grid (i.e gutter flow will drain a low lying area but is not reflected in the hydraulic model).

Table 8: Number of Surveyed Properties with Above Floor Inundation

	ARI						
Type	**1 year**	**2 year**	**5 year**	**10 year**	**20 year**	**100 year**	**PMF**
Residential	25	48	54	57	65	75	145
Commercial	21	29	34	38	40	43	49
Public	2	2	2	2	2	4	6
Total	**48**	**79**	**90**	**97**	**107**	**122**	**200**

Table 9: Number of Surveyed Properties with above Ground Inundation

	ARI						
Type	**1 year**	**2 year**	**5 year**	**10 year**	**20 year**	**100 year**	**PMF**
Residential	162	190	195	203	206	227	256
Commercial	40	45	49	50	51	54	56
Public	8	9	9	9	10	11	12
Total	**210**	**244**	**253**	**262**	**267**	**292**	**324**

Table 10: Summary of Flood Damages

Design Flood	Floors Inundated		Tangible Damages*
	Residential	Non-Residential	
1y ARI	25	23	$1.56 M
2y ARI	48	31	$2.50 M
5y ARI	54	36	$2.99 M
10y ARI	57	40	$3.36 M
20y ARI	65	42	$3.91 M
100y ARI	75	47	$5.00 M
PMF	145	55	$9.52 M
	Average Annual Damages		$2.59 M

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 Rose Bay Catchment Management Study (Reference 3). However the majority of these measures were within the North Bondi catchment in the Waverley LGA. Various measures were considered to increase the capacity across Old South Head Road and through Royal Sydney and Woollahra golf courses. Enlarging the piped drainage system and addition of more inlet pits was also evaluated but rejected due to the significant cost.

The recommendations relating to flooding and within the Woollahra LGA were:

- Sydney Water should consider a policy for financing structural improvements to the stormwater system within the Rose Bay catchment;
- Council should ensure that the inlet pits within flood prone areas are regularly cleaned (already undertaken by Council);
- an ongoing data collection program should be established (already undertaken by Council);
- provision of additional inlet pits.

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,
- floodplain management committee meetings,
- workshop/site inspection and interviews with some key stakeholders,
- public exhibition of material.

In March 2013, Council placed the Draft Rose Bay Floodplain Risk Management Study and Plan on public exhibition and published the exhibition by distributing approximately 7000 newsletters to the residents in Rose Bay. The newsletter summarised the flood investigations that have been undertaken in Rose Bay and contained directions on where to view the Draft Study and Plan. In response to the exhibition, Council received four submissions three written and one by phone.

The phone submission related to a former land slip that occurred in the upper catchment during a large storm event due to a blocked pit on a private property overloading a retaining wall. This incident highlights the need for proper maintenance and regular drainage asset inspections but falls outside the scope of this current study.

The first written submission questioned the statement in the draft study that *"the majority of the flow from Dover Heights flows along Albemarle Avenue"* because during the November 1984 event they observed more flow down Dover Road, which included observing cars floating down the road.

Close examination reveal that these observations are consistent with the results from the Flood Study. The results indicate that at the start of large storms the majority of water does flow down Dover Road where it ponds in low points to depths that would be deep enough to float cars. However, as the storm progresses water builds up to a level high enough to cross Old South Head Road in the vicinity of Albemarle Avenue, which then carries the majority of the flood flows. Dover Road has deeper water but lower flow rates so although it appears that there are higher flows down Dover Road there are actually higher flows in Albemarle Avenue. This is a good observation though, highlighting the potential damage that flood water in Dover Road can cause.

The second written submission by a long term resident of the area was a very detailed and interesting submission that contained lots of general observations and made a number of important points as follows.

"Careful observation of this area in heavy rains has shown that the Council stormwater drains in the gutters on the uphill road leading down to the flat area (Latimer, Balfour, Salisbury & Beresford Roads) work very well and there is little or no flow across Plumer Road or into O'Sullivan Road." The drains in this area do work well in small to medium storms but in larger

storms they are overwhelmed and are too small to significantly reduce flood levels in the area.

"What your consultants have missed is the large area in this location occupied by apartment blocks with garages at the rear and a side driveway and garage area that is covered in concrete preventing any absorption of rain water. In heavy rains this water pours out of the driveways onto the footpath and road. This overwhelms the street drains." All contributing runoff areas of the catchment have been included in the consultant's hydraulic model which includes allowances for impervious areas. However the model was developed to determine flood levels along the major flow paths and the flooding referred within individual properties is considered minor local flooding which is beyond the resolution of the current model.

"In the past all stormwater was drained by outfalls into Rose Bay. Some years ago (10+) Council rebuilt the Balfour Road drain to mitigate flooding in that road. This outlet still exists but sadly, all the others have been allowed to disintegrate." The drainage outlets referred to were made redundant when the new Rose Bay promenade works were constructed.

"Some time ago, there was discussion at Council whether to refurbish the sea wall or replace it with a fence similar to that around Circular Quay. Sadly, refurbishment won and the dam effect referred to in the report remains." The sea wall is designed to protect the Rose Bay area from storm surges but unfortunately this has a detrimental effect on flood levels in the area. It is unlikely it will be changed now as it has been refurbished, however if the seawall needs to be renewed in the future the design of the seawall will be reconsidered using all the latest flood and storm surge data.

"The importance of the golf links cannot be understated. As most of the links are lower than the surrounding land the whole area acts as a retention pond in extreme rain and has an efficient drainage into the bay." The golf course is an important link for the management of floods in Rose Bay as it contains one of the major flood flow paths.

"Following the November 1984 flood, which saw about 20cm of water in my back yard, the Water Board investigated a number of flats and houses in this area and found quite a number had there stormwater plumbed into the sewer lines. Since then these residences have all had to change their stormwater runoff into the street which adds to the volume of runoff given the large area of these roofs." Sewer pipes have minimal capacity and any water wrongly directed to is insignificant in a major event.

"South Head Road, the partial collapse of that road outside the police station and the disastrous effect when a Mercedes was washed into Wentworth Lane (Worth Arcade) creating an obstruction." It is important that Wentworth Lane *(Worth Arcade)* is not blocked as it is the only major overland flow path in this area. It is planned to enlarge this laneway in the future.

The third submission was received from the Royal Sydney Golf Club. The submission expressed concern over the proposal to divert more water into the golf course. This is understandable as the golf course suffers inundation, inconvenience and some damage in major flood events. However it is unlikely that diverting additional water through the golf course would cause significantly more damage than is currently experienced as the golf course already

contains major flood flows. However, at this stage the exact effects of diverting extra water into the golf course are unknown. The land to be used for the diversion is owned by Royal Sydney Golf Club and diversion would need the consent of the Royal Sydney Golf Club. Council therefore intends to continue consulting with the Royal Sydney Golf Club and will not proceed with any further design without their consent.

Generally, the draft was well received and it is recommended that the received comments be noted and incorporated where appropriate in to the final Management Plan.

6. FLOODPLAIN RISK MANAGEMENT MEASURES

6.1. Introduction

The NSW Government's Floodplain Development Manual (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 (roads, supply of services etc.) 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 (Section 5.8) has ensured that identifiable social and environmental factors were considered in the decision making process.

Possible mitigation measures considered in this study are shown on Figure 12.

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 (such as in western Sydney) 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 significant 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 Rose 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

Aerial photographic and site inspections of the catchment were undertaken to identify potential sites for retarding basins.

The Royal Sydney Golf Course and Woollahra Golf Course: Located in the centre of the catchment, these two golf courses offer the largest open areas of "un-developed" land necessary for construction of retarding basins. Golf courses are generally preferred sites for basins as golfers cannot play in heavy rain and as the course is fenced the safety and risk to life issues are much reduced. The basins can also be used as part dams for water storage for course irrigation. However many golf courses were once old rubbish tips and thus excavation and removal of material can be cost prohibitive. It also may not be possible to "fit" a basin into the course layout and for a prestigious course such as Royal Sydney such a change may be unacceptable.

The Royal Sydney and Woollahra golf courses

This study would generally support construction of any form of retarding basin or storage dam from either a water quantity, quality or storage viewpoint. However the benefit of a retarding basin in either golf course is of limited value as the site is at the downstream end of the catchment. This means that there are only a few structures and risk to life issues downstream that would benefit from a basin construction. These relatively minor benefits must be balanced against the construction costs and likely adverse affects on the golf courses. A preliminary assessment of all issues indicates that there are more viable floodplain management measures than construction of retarding basins in the Royal Sydney and Woollahra golf courses. However diverting additional flood waters onto the golf courses during a flood and away from roads and private properties would be beneficial and this is assessed in Section 6.2.3.

Barracluff Park

Reference 3 noted the possibility of constructing a retarding basin in Barracluff Park in the North

Bondi (Waverley LGA) sub catchment. The use of this park as a basin was modelled and results showed little or no change in flood levels. This was probably due to the fact that this is a low flow region and the park is of insufficient size. This option was therefore not pursued.

Pannerong Reserve

Pannerong Reserve is situated on the corner of Newcastle Street and Wilberforce Avenue. Both roads receive large flows during flood events making this a suitable location for placement of a retarding basin. Unfortunately, due to the small size of the reserve (approximately 0.18ha), the capacity of any such basin would be ineffective as a flood mitigation measure. The estimated overland flow at this site taken from the DRAINS model is in excess of $50m^3/s$ during a 100 year ARI event and would fill any realistically constructed basin in a few minutes, thus having minimal benefit for downstream properties in large events, although in smaller events it would provide some benefit. This option was not pursued due to the relatively minor benefits compared to the likely significant dis-benefits (refer general comments on basins above) associated with its construction.

Thornton Playground

Thornton Playground is situated near the corner of Drumalbyn and Beresford Roads. It is a small park with an area of approximately 0.21ha and thus cannot accommodate a basin of any significant size. A basin built here is thus incapable of making significant contributions to flood mitigation downstream. It also has the added disadvantage of being surrounded by houses which would prove problematic if water were routed to the basin. This option was therefore not pursued.

Natural Valley between Drumalbyn and Latimer Roads

Between Drumalbyn and Latimer Roads, near Balfour Lane lies a natural valley that is approximately 150m long with an average width of 40m and depths of up to 10m. The total estimated volume of the valley that would be able to be used as a retarding basin is approximately $20,000m^3$. A retarding basin of this volume in this area would be capable of providing significant reductions in peak flows downstream. The estimated peak overland flow at this site taken from the DRAINS model is approximately $10m^3/s$ during the 100 year ARI event. A number of issues are associated with construction of a retarding basin at this location. The valley is situated on privately owned land meaning that voluntary (or forced) purchase would be necessary for construction of the basin. There is also the need to build a dam type wall at the downstream end of the basin which has high construction costs and the added risk of dam failure. For these reasons this option was not pursued.

Barracluff Park

Pannerong Reserve

Thornton Playground

Drumalbyn and Latimer Roads Valley

OUTCOMES

Retarding basins are unlikely to be a cost effective measure to negate overland flow problems in the 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, where viable, 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 will increase the capacity of the creek or drainage system and reduce the frequency with which floodwaters overtop the banks. However increasing the open channel system within the golf courses will provide no significant benefit outside of the golf courses. For this reason channel amplification has not been considered further.

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 Rose 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 3 m/s) and risk that they may increase the likelihood of blockage. For this reason this has not been considered for the culverts under New South Head Road.

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,
- adjoining fences, golf or tennis court netting or bridge structures which are swept into the channel.

There is little preventative works that can be undertaken to minimise the risk from the first two causes. For the latter cause, particularly golf or 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.

Enlarge Culverts

Increasing the size of the culverts under New South Head Road would lower flood levels upstream but as the benefit would largely only accrue to the golf courses this measure has not been pursued.

Possible Measures

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

- Intersection of New South Head Road and Newcastle Street,
- The lower sections of Beresford, Salisbury, Balfour, O'Sullivan and Powell Roads.

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

INTERSECTION OF NEW SOUTH HEAD ROAD AND NEWCASTLE STREET

The Rose Bay shopping precinct situated along New South Head Road and south west along Newcastle Street and Dover Road contains predominately commercially zoned lots. It is an area of low to medium density commercial buildings with a wide variety of business types ranging from petrol stations to restaurants.

Properties in these streets are prone to flooding and above floor inundation with rainfall events as small as the 1 year ARI event causing ponding along these roads (Reference 2). The November 1984 event, with rainfall intensities approximately that of a 100 year ARI event, caused widespread damage across Sydney and in particular at Rose Bay, which was noted (The Sun newspaper of 16/11/1989) as being one of the worst affected suburbs. Water depths of over 1.5m occurred inside a number of properties along New South Head Road and the force of the water was reported to have smashed shop windows and stacked cars on top of each other (Photo 9 and Photo 10).

Flooding in this region is due two main factors, the culmination of significant inflows from the surrounding sub catchments and the areas predisposition to ponding due to the lack of exit flow paths along New South Head Road. The co-incidence of these two factors is responsible for the high water levels seen during the November 1984 event and the modelled design events (Reference 2).

The Rose Bay/Vaucluse (Woollahra LGA) and Dover Heights (Waverley LGA) sub-catchments cover 174ha (Figure 2), an area which is relatively steep and largely impervious and is thus capable of creating large flows during heavy rainfall. The majority of the flow from the Dover Heights catchment flows along Albemarle Avenue and then down Newcastle Street into the Rose Bay shopping precinct. The two other main flow paths to the area, both in the Rose Bay/Vaucluse catchment, run along Wilberforce Avenue and New South Head Road. During the design 100 year ARI event these flow paths are responsible for approximately 50%, 25% and 25% of the inflows to the area respectively.

All flows in the region meet at the intersection of New South Head Road, Newcastle Street and Dover Road, a low point and natural flow path for the catchments. The construction of buildings along New South Head Road impedes the routing of flow from this low point into the Bay causing the ponding that occurred during the November 1984 event.

There are therefore two possible mitigations measures that could be implemented to reduce the

likelihood and impact of flooding in the Rose Bay shopping precinct:

1. Diversion of flow elsewhere upstream from the affected area (i.e to reduce the flows along New South Head Road),
2. Increasing the flow capabilities within the affected area to reduce ponding.

1. UPSTREAM FLOW DIVERSION

Reducing the volume of water to reach the Rose Bay shopping precinct would reduce peak flood levels and therefore reduce the extent and magnitude of flood damages. Generally flow diversion in an urban area is not possible as the diversion will adversely affect others where there is an increase in flow. However at Rose Bay diversion of floodwaters into the Woollahra and Royal Sydney golf courses will only affect the golf courses and no other private property. There are a number of possible locations for a diversion, including upstream of Old South Head Road within Waverley LGA. A diversion within this area may benefit properties within the Waverley LGA as well as the Woollahra LGA. However, at this time a diversion within the Waverley LGA has not been pursued as this requires input from Waverley Council together with a review of their flooding issues which are outside the scope of this study.

Diverting flood waters from the Dover Heights catchment (within the Woollahra LGA) flowing along Albemarle Avenue into Norwich Lane and then onto the Royal Sydney golf course is likely to provide the greatest reduction to flooding in the affected area. Two options have been investigated:

1. Regrading of the road at the intersection of Newcastle Streets and Albemarle Avenue to divert flow down Norwich Lane; and
2. Regrading of roads along Old South Head Road so that the primary flow path is along Albemarle Avenue and only minor local flows travel down Wilberforce Avenue.

Option one involves road regrading to increase the road level by approximately one metre slightly downstream of the Newcastle Street / Albemarle Avenue intersection thus diverting increased into Norwich Lane (and then into Royal Sydney golf course) and away from the Rose Bay shopping precinct. Option two utilises road regrading along Old South Head Road to inhibit water from flowing down Wilberforce Avenue, Dover Road and Hamilton Street. This diverts flow so that the primary flow path runs along Albemarle Avenue.

The key problems associated with the above include:

- Regrading of the Albemarle Avenue, Newcastle Street and Norwich Lane intersection would be required to assist in the diversion of flows down Norwich Lane. This is unlikely to be expensive but would require road closures during the period of construction.
- The effects of the increase in water level at the intersection of Newcastle Street and Albemarle Avenue and along Norwich Lane will increase the likelihood and severity of flooding at 42, 43, 43A, and 45 Newcastle Street as well as 1, 2, 4, 6, and 8 Norwich Lane. Further measures (such as those mentioned in subsequent sections) may be required to reduce this risk.
- An increase in downstream flows could cause flooding along Norwich Lane and within

the Royal Sydney golf course. This could potentially be alleviated by increasing the capacity of the flow channel along Norwich Lane and the culvert under New South Head Road to cope with the increase in flow. This has not been investigated further at this time.

- If Option 2 was implemented regrading of Old South Head Road would be required at a number of intersections north of Albemarle Avenue. This would potentially lead to increases in flood levels in these regions, particularly at the Old South Head Road and Albemarle Avenue intersection. Again measures mentioned in subsequent sections could be implemented to reduce this impact.

Hydraulic modelling of this flow diversion indicates that significant reductions to peak flood levels could be achieved in the Rose Bay shopping precinct although flood problems are likely to be exacerbated in a number of upstream regions and may require additional management measures. Table 11 shows the average changes (measured at 20 m intervals) in the 100 year ARI water level in the area. A negative reading shows an average decrease in flood level whilst a positive shows an average increase in flood level. Changes of less that 0.1m have been deemed as insignificant and are noted as "No Change".

Table 11: Change in Peak Flood Height (100 year ARI) due to Flow Diversion Options

Road	Location	Option (1)	Option (1 & 2)
New South Head Road	**Upstream of Dover Road**	No Change	No Change
	Newcastle Street – Dover Road	-0.23	-0.41
	Norwich Lane - Newcastle Street	-0.17	-0.26
	Downstream of Norwich Lane	-0.17	-0.12
Newcastle Street	**New South Head Road – Wilberforce Avenue**	-0.16	-0.28
	Wilberforce Avenue – Richmond Road	-0.22	-0.20
	Richmond Road - Albemarle Avenue	-0.16	-0.10
	Upstream of Albemarle Avenue	No Change	No Change
Albemarle Avenue	**Newcastle Street - Albemarle Avenue**	No Change	+0.19
	Albemarle Avenue - Old South Head Road	No Change	No Change
Norwich Lane	**Norwich Lane**	+0.31	+0.43
Intersection	**Newcastle Street - Albemarle Avenue**	+1.08	+1.17
	Old South Head Road – Albemarle Avenue	No Change	+0.17

It can be seen that a significant reduction in flood levels will occur in the Rose Bay shopping precinct. A reduction of approximately 0.4m may be possible with the implementation of Option 2 although an increase of over 1m would be experienced at the intersection of Norwich Lane/Newcastle Street and Albemarle Avenue. Any increase in peak flood level would likely only affect the area in the immediate vicinity of the intersection with changes in flood levels tapering back to zero rapidly on nearby streets (approximately 20m upstream along Newcastle Street and 60m along Albemarle Avenue). Significant regrading of the region and the addition of large drains could help in reducing levels back to existing conditions.

Both options rely on road regrading to divert flow and this could be undertaken by Council over a period of time as part of their regular road maintenance program. However, if required additional funding could be sought from the NSW Government flood mitigation program. Further

works may be required to reduce the impact on private housing in regions affected by an increase in flood levels and this could potentially be funded under the flood mitigation program.

A summary of the impacts and reduction in flood damages is presented below:

- **Option One:** The estimated number of building floors which are likely to be inundated during the 5 year ARI event is decreased by 10 and during the 100 year ARI event a decrease of 8 is expected. Additionally, the annual average damages were estimated to decrease by approximately 12%.
- **Option One and Two:** The estimated number of building floors which are likely to be inundated during the 5 year ARI event is decreased by 17 and during the 100 year ARI event a decrease of 9 is expected. Additionally, the annual average damages were estimated to decrease by approximately 20%.

It is recommended that Council:

- Further investigate the possibility of implementing both Options One and Two,
- Liaise with Royal Sydney golf course to seek their views on this measure,
- Investigate possible mitigation measures at the intersection of Newcastle Street and Albemarle Avenue and along Norwich Lane to reduce ponding and the associated adverse flood impacts,
- Investigate flood impacts downstream of Norwich Lane and potential mitigation measures to ensure that the flood problem in this region is not exacerbated.

2. INCREASE FLOW CAPABILITIES TO REDUCE PONDING IN ROSE BAY SHOPS

An investigation into the effects of increasing the size of the outflow channel on the downstream side of New South Head Road was undertaken to determine if it would assist in the quicker removal of flood waters from the Rose Bay shopping precinct and thus reduce water levels and the extent of damages. This section of New South Head Road is densely urbanized with no availability of space to increase the existing overland flow path through Worth Arcade. Removal of buildings on one side of Worth Arcade is the only possibility to increase the overland capacity.

Problems associated with this approach include:

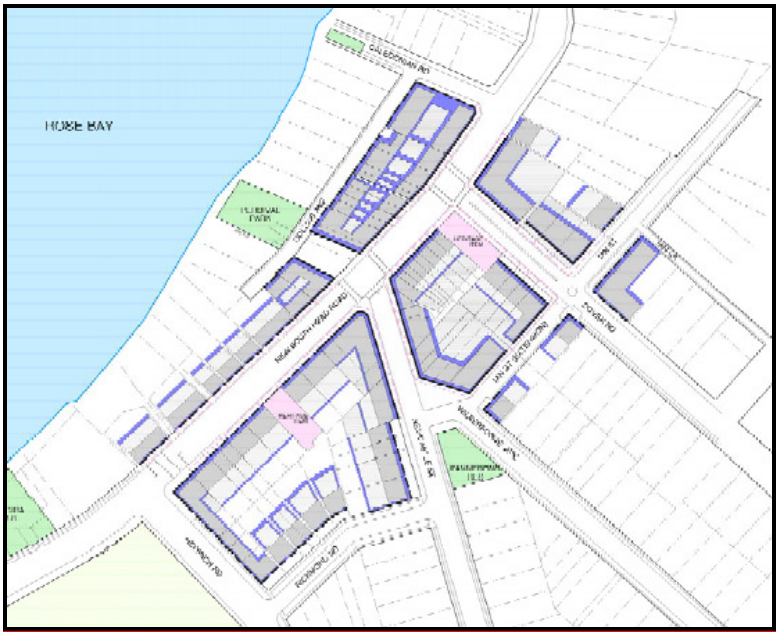
- Acquisition of land adjacent to Worth Arcade is likely to be very expensive as the median price for a unit in Rose Bay is approximately $680,000 and the median house price is $1,410,000 (Jun 2011).
- Regrading of the Newcastle Street, New South Head Road intersection (see above) may be required to assist in the removal of water from the area.

Hydraulic modelling of increasing Worth Arcade as a flood mitigation measure shows that even a three fold increase in channel diameter will not have significant impacts on peak flood levels in the region. Table 12 shows the average difference in peak flood level that can be expected along New South Head Road near the Rose Bay Shopping Precinct for a doubling and tripling of the channel width for the 100 year ARI event.

Table 12: Change in Water Level (100 year ARI event) on New South Head Road with Increase in Channel Width

Location	Double Channel Width (6 m)	Triple Channel Width (9 m)
Upstream of Dover Road	0.00	0.00
Newcastle Street – Dover Road	-0.02	-0.04
Norwich Road - Newcastle Street	-0.03	-0.11
Downstream of Norwich Road	-0.01	-0.05

Due to the flow distribution in this region (approximately half the flow flowing through the constriction and half flowing down New South Head Road) and the supercritical flow regime through the channel, any increase in channel width will have only a minor impact on flows in the 100 year ARI event. However in smaller events the benefit would be greater. This measure cannot be supported from purely a benefit/cost perspective due to the high costs to make any adjustments to Worth Arcade. However it is noted that the Rose Bay Development Control Plan (DCP) does suggest removal of some buildings on the northern side of New South Head Road (see sketch below). Any widening of the opening would provide a reduction in flood levels and is therefore supported.



THE LOWER SECTIONS OF BERESFORD, SALISBURY, BALFOUR, O'SULLIVAN AND POWELL ROADS

The lower sections of Beresford, Salisbury, Balfour, O'Sullivan and Powell Roads make up a large area of low lying flood prone land (Figure 7). This area contains predominately residential zoned lots with a small commercial hub at the intersection of Plumer and O'Sullivan Roads. It is an area of low to medium density buildings comprising of a mixture of unit developments and detached houses.

Properties in these streets are prone to flooding and above floor inundation with References 2, 3 and 4 highlighting the fact that this area has experienced flooding on a number of occasions with the most notable occurring in 1984, 1989, 1991 and 2001. Reference 2 shows water depths of

greater than 0.8 metres in the area for the 100 year ARI design event

Flooding in this region is due to a number of reasons including: the large size of the Bellevue Hill catchment (209ha), the relative minor relief in the affected region and the presence of a sea wall preventing outflow to Rose Bay.

Over half of the Bellevue Hill catchment drains to this area. Like other catchments in the area it is steep with few areas of pervious undeveloped land and is thus capable of creating large flows during heavy rainfall. Water rushes down the roads and across properties to arrive at the low lying, flat area described above. Flow into Rose Bay from Beresford, Salisbury, Balfour and O'Sullivan Roads is inhibited by a sea wall that runs along Rose Bay from Point Piper to Lyne Park. Due to the lack of openings in the sea wall, ponding occurs behind the wall and influences flood levels as far upstream as Plumer Road (Figure 7).

Many of the floor levels and garages in this region are at or below ground level, making this area susceptible to significant flood damages. Flow diversion to the Woollahra golf course was considered but was found to be impractical as the only possible route would be along Plumer Road and through the commercial areas. All buildings along Plumer Road are close to ground level and thus would be impacted by an increase in flow caused by a flow diversion. For this reason the possibility of modifying the sea wall was considered.

Modifying the Sea Wall at Rose Bay

Increasing the capacity of the openings in the sea wall would reduce the level of ponding in the affected region. Complete removal of the sea wall is not practical due to safety reasons but sections of the wall could be replaced by pervious materials such as meshing or provision of "protected outlets" that will provide an outflow point but also act as a sea wall. Heritage and aesthetic consideration also need to be considered.

Issues associated with this measure include:

- Reconstruction or modification of the wall would need to comply with current safety and aesthetic standards.
- Sections of the boardwalk would likely require closing during the construction period.
- Liaison with Council indicates that the seawall has been designed to decrease the risk of overtopping from wave actions. It therefore protects against minor inundation and damages associated with elevated water levels in Rose Bay and the wider Sydney Harbour. The sea wall must be designed to minimise damages to properties from both rainfall and sea flooding.

The complete removal of the sea wall of the sea wall was evaluated to indicate the maximum reduction in flood level that would be possible. Table 13 shows the average difference in peak water levels (100 year ARI) along New South Head Road in the vicinity of the sea wall.

Table 13: Change in Water Level (100 year ARI) on New South Head Road with Removal of Sea Wall

Road	Location	Reduction in flood level (m)
New South Head Road	**O'Sullivan Road - Iluka Street**	-0.24
	Iluka Street - Balfour Road	-0.24
	Balfour Road - Salisbury Road	-0.30
	Salisbury Road - Beresford Road	-0.42
	Beresford Road - Cranbrook Road	-0.45
	Cranbrook Road - Aston Place	-0.37

Removal of the sea wall provides reductions in flood levels for a significant distance upstream of New South Head Road. Table 14 indicates the distance along each road that a decrease in flood levels (100 year ARI) of over 100 mm would be experienced (distance taken from the centre of the intersection with New South Head Road).

Table 14: Distance along Roads that would Benefit from Removal of the Sea Wall

Road	Distance (m)
O'Sullivan Road	50
Balfour Road	60
Salisbury Road	70
Beresford Road	115
Cranbrook Road	40

Hydraulic modelling of the removal of the sea wall indicates significant reductions in flood levels would occur but as the majority of buildings in this region are elevated above ground level the impacts on reduction in home and contents damages is relatively small. For the 100 year ARI event four fewer buildings are likely to become inundated and during the PMF event the number of inundated buildings is likely to decrease by 25. The effect on the average annual damages has been determined to be a decrease of approximately 5%.

Based on the above assessment and taking into account the issues with removal or significant modifications of the sea wall it is concluded that major works to the sea wall cannot be justified. However Council should be aware that any increase in openings would provide a benefit in reducing flood levels upstream and this should be taken into account when any works (either to increase or decrease the size of the openings) are proposed on the sea wall.

Lowering of New South Head Road in Vicinity of the Open Channel

A number of properties along New South Head Road, Manion Avenue, Elanora Street, Iluka Street and O'Sullivan Road lie in close proximity to the main drainage channel within the Woollahra golf course. This area contains predominately low to medium density residential buildings comprising of a mixture of unit developments and detached houses.

New South Head Road has a damming effect on over bank flows coming down the Rose Bay open channel. By decreasing the level of the road in this region this damming effect could

potentially be minimised for larger events (100 year ARI and PMF) by allowing more water to flow over New South Head Road and into the bay. However a significant benefit can only be achieved if the road over the culverts is also lowered. This would increase the impact and risk of flooding on New South Head Road leading to potential road closures. This would prove problematic as New South Head Road is a major arterial road in the region and thus regular closures are unacceptable.

In addition, the majority of buildings in this area are not flood liable with only a small number of proximate properties being affected during the PMF (Figure 11). Reducing the road level would reduce the number of affected homes during a PMF event but the likelihood of such an event ever occurring is very low. Reconstruction of the bridge at this point along New South Head Road to allow water to flow over it during larger events would also be extremely costly. For these two reasons this measure is not supported.

OUTCOMES

A number of possible management measures are available but all require considerable more detailed investigation.

ACTIONS

Further more detailed evaluation required.

6.2.4. Levees, Floodgates and Pumps

DESCRIPTION

Levees are built as 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, Wagga Wagga) 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. Additionally, levees cause water to be diverted elsewhere across the floodplain, thus relieving the problem in one area only to worsen it in another. They also have the problem that they not only act to keep

water out but also act to keep water in. In a catchment such as Rose Bay where rainfall is relatively uniform over the catchment a levee would impede the drainage of the "dry" side of the levee.

The area between Manion Avenue and the Rose Bay channel was investigated as an area that may be likely to benefit from the construction of a levee as Reference 2 sited a number of complaints about flooding in this area. Whilst a levee could be constructed here the likely aesthetic and access issues as well as the "internal" drainage issues make this measure not viable.

No other sites were found to be suitable for construction of a levee within the catchment.

OUTCOMES

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

ACTIONS

No action required.

6.2.5. Local Drainage Issues

DESCRIPTION

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 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 every two years. However this low frequency of occurrence 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 (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 Rose Bay Catchment Flood Study Flood Study (Reference 2) identified that the impacts due to an elevated tailwater level, typically from storm surge or wave runup, is not significant for the study area. Impacts are confined to the very lower reaches of the Rose Bay open channel. Model results indicate that even with a relatively high tailwater, the backwater effects do not extend upstream of the golf course and immediately upstream of the outlets north of the Rose Bay shopping precinct.

OUTCOMES

Storm surge and wave runup will not have a significant impact on flood liable properties in the catchment 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 Rose 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 Rose Bay.

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 Rose 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 Rose 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 in Rose 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 Rose Bay catchment should be prepared. The SES's role in flooding in the Rose 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 S149 certificate is an approach to inform residents of the potential flood risk at their property. Council are currently reviewing the information provided on properties' S149 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 level of flood awareness. 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 15. 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 15: 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 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. 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 was 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. 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 Section 6.5).

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 Rose 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 State 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 existing 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 Rose Bay catchment there is continuing pressures for 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 Draft 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).

It is also essential that works undertaken by Council conform to Council's flood related development controls and in particular to the possible impact of any Council works on the floodplain affecting surrounding properties.

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, minor ponding in low spot, tree roots blocking kerb flow, minor flow diversion etc.) that causes inconvenience to local residents but no significant tangible damages. Local drainage is not considered within the framework of this study but should be reported to Council and will be addressed as appropriate (refer Section 6.2.5).

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 a result, flow is often diverted through properties causing increased risk of over floor, yard and garage inundation. 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 needs to be defined using ground survey and site specific hydraulic assessment. It is important that Council continue to monitor issues (refer Section 6.2.5) 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 these problems have occurred in the past and Council records have documented some of the problem areas (as reported in Reference 2), 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 damages, 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 Rose Bay Catchment Flood Study (Reference 2). 343 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 16.

Figure B1a and B1b: *Plan of Flooding and Drainage Issues Identified from Field Inspection*
Table B1: *Listing of Flooding and Drainage Issues*
Table B2: *Listing of Previously Reported Issues*

Figure B2: *Photographs of Sites with Reported Issues*
Figure B3: *Photographs of Sites with Issues Identified from Field Inspection*

Table 16: Summary of Detailed Site Inspection in Upper Catchment

Category	Explanation	No*
1	Floor below road	160
2	Garage below road	154
3	Flooding due to overland flow path from adjacent street	46
4	Road and footpath graded towards residence	26
5	Main flow channel bordering residence	49
6	Ponding on street	43
7	Yard flooding	11
8	High velocity flow	4
9	No flow path	6
10	Flow diversion	7
	Total	**506**

* 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;
- adjustment of drainage paths so that flood waters flows along roads;
- 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 event 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 House Floors Inundated

DESCRIPTION

Of major concern with overland flow in the upper catchment is the inundation of building floors (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 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 at capacity. 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

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. This measure has been investigated at a number of locations in the lower catchment to reduce flood levels in the Rose Bay shopping precinct (see

Section 6.2.3).

OUTCOMES

Subject to the findings of detailed hydraulic modelling 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 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 in parts pf the LGA. 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

As noted previously 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 Drainage Management 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.

7. DEVELOPMENT MEASURES

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

7.1. Sea Level Rise

DESCRIPTION

The NSW Chief Scientist has advised that the sea level rise benchmarks, measured as an increase above the 1990 mean sea levels, of 40cm by the year 2050 and 90cm by the year 2100 are adequate in light of evolving understanding of the complex issues surrounding future sea levels.

DISCUSSION

The Bureau of Meteorology has indicated that there is no intention at present to revise design rainfalls, 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 very lower reaches of the Rose Bay open channel and other stormwater outlets exiting to Rose Bay. 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 80 years along the NSW coast.

OUTCOMES

The potential impact of increased design flood levels in the catchment due to sea level rise 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 in the Rose Bay Catchment Flood Study (Reference 2) with an increase in ocean levels of 0.18m, 0.55m and 0.91m (these were the expected sea level rise increases at the time of the study) and a 10% and 20% rainfall increase.

The results are provided in detail in Reference 2. In summary the 0.18m and 0.55m increase in ocean levels produced only minor increases and even with a 0.91m increase the affectation was confined to the golf course and immediately upstream of the outlets north of the Rose Bay shopping precinct. The increase in flood level due to a 10% and 20% increase in rainfall

intensity is shown in plan form in Appendix C of Reference 2. Overall a 10% increase in rainfall produces up to a 0.1m increase in the 100 year ARI flood level and up to a 0.2m increase for a 20% increase.

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

Some Councils in NSW have raised the FPLs to account for the expected increase in flood level due to both sea level rise and rainfall increase. This rise would be in addition to the 0.3 m freeboard.

7.2. Development Intensification

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.

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.

In the lower catchment significant areas of land include the Woollahra and Royal Sydney golf courses and Lyne Park. Any public or private works including filling on the floodplain, in this region must consider flooding.

Development in these areas is controlled by Woollahra Council through the Draft Flood Risk Management DCP and the Draft Stormwater Management 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. We understand that these documents are currently being reviewed by Council.

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 Rose 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 does support WSUD and has undertaken research into various approaches in the LGA. In particular further investigation into inlet pit capacity is required.

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 (GPT at the exit of the channel to Rose Bay). There may be other potential sites for GPTs and these should be considered where appropriate. The following sections describe possible additional devices.

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

This study was carried out by WMAwater and funded by Woollahra Council and the Office of Environment and Heritage. The assistance of the following in providing data and guidance to the study is gratefully acknowledged:

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

9. REFERENCES

1. NSW Government
Floodplain Development Manual
April 2005.

2. Woollahra Municipal Council
Rose Bay Catchment Flood Study
WMAwater, September 2010.

3. Water Board
Rose Bay Stormwater Catchment Management Study
Water Board, 1991.

4. Pilgrim DH (Editor in Chief)
Australian Rainfall and Runoff – A Guide to Flood Estimation
Institution of Engineers, Australia, 1987.

5. Woollahra Municipal Council
Woollahra Drains Modelling – Draft Report
Brown Consulting, November 2006.