MARRICKVILLE council

COOKS RIVER FLOODPLAIN RISK MANAGEMENT STUDY AND PLAN

wma water

STORM_CONSULTING

February 2015

STORM_CONSULTING

Suite 3, 6 West Street
Pymble NSW 2073

Tel: (02) 9499 4333
Fax: (02) 9499 4311
Email: info@stormconsulting.com.au
Web: www.stormconsulting.com.au

wma water

Level 2, 160 Clarence Street
Sydney, NSW, 2000

Tel: (02) 9299 2855
Fax: (02) 9262 6208
Email: wma@wmawater.com.au
Web: www.wmawater.com.au

COOKS RIVER FLOODPLAIN RISK MANAGEMENT STUDY AND PLAN

FEBRUARY 2015

Project Cooks River Floodplain Risk Management Study and Plan	**Project Number** **112010**
Client Marrickville Council	**Client's Representative** Brooke Martin
Authors Richard Dewar, Laura Wallis (WMAwater) Gerard Mimmo, Tim Howe (Storm Consulting)	**Prepared by**
Date February 2015	**Verified by**

Revision	Description	Date
1	1st Draft for Review	September 2012
2	2nd Draft for Review	January 2013
3	Public Exhibition	February 2013
4	Final	February 2015

Marrickville Council has prepared this document with financial assistance from the NSW Government through its Floodplain Management Program. This document does not necessarily represent the opinions of the NSW Government or the Office of Environment and Heritage.

COOKS RIVER FLOODPLAIN RISK MANAGEMENT STUDY AND PLAN

TABLE OF CONTENTS

PAGE

FOREWORD i

1. COOKS RIVER FLOOD RISK MANAGEMENT PLAN 1

1.1. Executive Summary 1

1.1.1. Background 1

1.1.2. Climate Change 1

1.1.3. Risk Management Measures Considered 1

1.2. Introduction 5

1.3. Recommended General Measures 6

1.3.1. General High Priority 6

1.3.2. General Medium Priority 6

1.3.3. General Low Priority 7

1.4. Recommended Location Specific Measures 7

1.4.1. Riverside Crescent area 7

1.4.2. Illawarra Road area 8

1.4.3. Carrington Road area 8

1.4.4. Bay Street area 9

1.4.5. Alexandra Canal area 9

2. INTRODUCTION 10

2.1. Background 10

2.2. Objectives 10

2.3. Floodplain Risk Management Process 11

2.4. History of Flooding 11

2.5. Causes of Flooding 12

2.6. Council's Current Planning Instruments, Policy, Plans and Strategies 12

2.6.1. Local Environmental Plan 12

2.6.2. Cooks River Floodplain Development Control Plan (DCP30) 12

2.6.3. Marrickville Development Control Plan 2011 and Part 2.22 Generic Flood Provisions for Flood Management 13

2.6.4. Sub-catchment Planning Framework 14

2.6.5. Marrickville Urban Strategy 14

2.7. Previous Studies 15

2.7.1. Cooks River Flood Study (1985) 15
2.7.2. Cooks River Floodplain Management Study (1994) 16
2.7.3. Cooks River Floodplain Management Plan (1997) 16
2.7.4. Cooks River Flood Study (2009) 16
2.7.5. Cooks River Stormwater Management Plan (1999) 17
2.7.6. Marrickville Valley Flood Study (2011) 17
2.8. Implementation Audit of Previous Management Plan 17
3. STUDY AREA 21
3.1. Sub-Areas 21
3.2. Land Use 23
3.3. Environmental Summary 24
3.4. History of River Change 25
3.5. Community Consultation 27
3.5.1. Public Exhibition of Draft Flood Studies and Policy for Identifying Properties Subject to Flood Related Development Controls 27
3.5.2. Public Exhibition of Draft Floodplain Risk Management Study and Plan 27
4. EXISTING FLOOD ENVIRONMENT 28
4.1. Flood Behaviour 28
4.1.1. Revision of Assumed Botany Bay Level 28
4.2. Hydraulic Classification 30
4.3. Flood Hazard Classification 31
4.4. Implications of Climate Change 34
4.4.1. Background 34
4.4.2. Revision of Climate Change Assessment 34
4.4.3. How will Climate Change Affect Water Levels in the Cooks River? 35
4.4.4. Impacts of Climate Change to Flood Risk from the Cooks River 36
4.5. Flood Risk and the Social Impacts of Flooding 37
4.5.1. Tangible Flood Damages 38
4.5.2. Tangible Flood Damages for Climate Change 41
4.5.3. Intangible Flood Damages 42
4.6. Flood Awareness and Flood Warning 42
4.7. Impacts of Flooding on Public Infrastructure 43
4.8. Impacts of Flooding on Commercial and Industrial Activities 46
4.9. Environmental Impacts of Flooding 47

4.10. Flood Emergency Response Classification 47
4.11. Implications of Future Development 48
5. RISK MANAGEMENT MEASURES 50
5.1. Introduction 50
5.1.1. Relative Merits of Management Measures 50
5.1.2. Management Matrix 51
5.2. Measures Not Considered Further 52
5.2.1. Flood Mitigation Dams, Retarding Basins, On-Site Detention 52
5.2.2. Channel Modifications 53
5.2.3. Catchment Treatment 55
5.2.4. Voluntary Purchase of Buildings 56
5.3. Flood Modification Measures 56
5.3.1. Levees, Flood Gates and Pumps 56
5.3.2. Temporary Flood Barriers 61
5.3.3. Local Drainage Issues 61
5.4. Property Modification Measures 63
5.4.1. House Raising 63
5.4.2. Flood Proofing 64
5.5. Response Modification Measures 65
5.5.1. Flood Warning and Evacuation 65
5.5.2. Flood Emergency Management 66
5.5.3. Public Information and Raising Flood Awareness 67
5.6. Planning and Future Development Control Measures 70
5.6.1. Strategic Planning Issues 70
5.6.2. Rezoning 72
5.6.3. Flood Planning Levels 73
5.6.4. Modification to the S149 Certificates 75
5.6.5. Review and Update LEPs and DCPs 76
5.7. Other Management Measures 77
5.7.1. Flood Access 77
5.7.2. Flood Insurance 78
6. ACKNOWLEDGMENTS 79
7. REFERENCES 80

LIST OF APPENDICES

Appendix A: Glossary of Terms
Appendix B: Flood Mapping
Appendix C: Cooks River Model Validation – 8th March 2012 Flood Event

LIST OF FIGURES

Figure 1: Study Area
Figure 2: Land Use Zones (MLEP 2011)
Figure 3: Historical Aerial Photographs
Figure 4: Design Event That First Inundates The Building Floor
Figure 5: Emergency Response Classifications

APPENDIX B

Figure B1: Design Flood Extents
Figure B2: Flood Extents 1% AEP event, 2012, 2050 and 2100 – Sea Level Rise
Figure B3: Flood Extents 1% AEP event, 2012, 2050 and 2100 – Sea Level Rise and 10% Rainfall Intensity Increase
Figure B4: Flood Planning Levels (1% AEP Flood level plus 500mm)
Figure B5: Flood Hazard 50% AEP event
Figure B6: Flood Hazard 5% AEP event
Figure B7: Flood Hazard 1% AEP event
Figure B8: Hydraulic Categorisation – 1% AEP event
Figure B9: Hydraulic Categorisation – PMF event

APPENDIX C

Figure C1: Flood Photos 8th March 2012
Figure C2: Stream Gauges and Rainfall Stations
Figure C3: Rainfall Hyetographs – 7-8 March 2012
Figure C4: Burst Intensities and Frequencies - 8th March 2012
Figure C5: Peak Daily Water Levels – Automatic Gauges
Figure C6: Peak Flood Level Profiles
Figure C7: Model Validation 8th March 2012
Figure C8: Water Level Hydrographs - 8th March 2012

LIST OF TABLES

Table 1: Summary of Management Measures Investigated 2
Table 2: Proposed Management Measures 4
Table 3: Historical Floods - Peak Flood Levels (mAHD) 11
Table 4: Recommended General Strategies from the 1997 Management Plan 19
Table 5: Strategies for each Area from the 1997 Floodplain Management Plan 20
Table 6: Cooks River Catchment Values and Objectives (Reference 9) 24
Table 7: Timeline of Significant Activities along the Cooks River 26
Table 8: Effect of Varied Downstream Water Levels (1% AEP) 29
Table 9: Hazard Classification 32
Table 10: True Flood Hazard for different areas (1% AEP event) 33
Table 11: Increase in 1% AEP Flood Levels due to Climate Change 36
Table 12: Increase in Flood Affected Properties in the 1% AEP Event due to Climate Change 36
Table 13: Flood Damages Categories (including damage and losses from permanent inundation) 38
Table 14: Summary of Tangible Damages for Surveyed Properties 40
Table 15: Increase in Floor Levels Inundated due to Climate Change 41
Table 16: Tangible Flood Damages – 1% AEP event – Increases due to Sea Level Rise 41
Table 17: Sewer Pumping Station Survey Details 44
Table 18: Riverside Crescent Sewer Pumping Station (SPS45) Flood Levels 44
Table 19: Wharf Street Sewer Pumping Station (SPS68) Flood Levels 44
Table 20: Cooks River Crossings Flood Levels (m AHD) 45
Table 21: Emergency Response Classifications of Communities 48
Table 22: Flood Risk Management Measures 50
Table 23: Matrix Scoring System 52
Table 24: Community Flood Awareness Methods 69

LIST OF ACRONYMS

AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ARI	Average Recurrence Interval
ALS	Airborne Laser Scanning
BOM	Bureau of Meteorology
CFERP	Community Flood Emergency Response Plan
DA	Development Application
DECC	Department of Environment and Climate Change
DECCW	Department of Environment, Climate Change and Water (now OEH)
DCP	Development Control Plan
FPL	Flood Planning Level
GIS	Geographic Information System
IPCC	Intergovernmental Panel on Climate Change
LEP	Local Environmental Plan
LGA	Local Government Area
m	metre
m^3/s	cubic metres per second
mAHD	metres above Australian Height Datum
OEH	Office of Environment and Heritage
OSD	On Site Detention
PMF	Probable Maximum Flood
SES	State Emergency Service
SWSOOS	Southern and Western Suburbs Ocean Outfall Sewerage System
TUFLOW	one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software program (hydraulic computer model)
WBNM	Watershed Bounded Network Model (hydrologic computer model)
WSUD	Water Sensitive Urban Design
1D	One dimensional hydraulic computer model
2D	Two dimensional hydraulic computer model

FOREWORD

The State Government's Flood Prone Land Policy is directed at providing solutions to existing flooding problems in developed areas and to ensuring that new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

Under the Policy, the management of flood liable land remains the responsibility of local Government. The State Government subsidises flood mitigation works to alleviate existing problems and provides specialist technical advice to assist councils in the discharge of their floodplain management responsibilities.

The flood management process in NSW incorporates consideration of the effects of climate change, and particularly the effects of sea level rise, on mean water levels and on flood levels.

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

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

2. ***Floodplain Risk Management Study***
    - evaluates management options for the floodplain in respect of both existing and proposed development.

3. ***Floodplain Risk Management Plan***
    - involves formal adoption by Council of a plan of management for the floodplain/foreshore.

4. ***Implementation of the Plan***
    - construction of flood mitigation works to protect existing development,
    - use of Local Environmental Plans, development and building controls to ensure new development is compatible with the flood hazard.

This Cooks River Floodplain Risk Management Study and Plan constitutes the second and third stages of the floodplain management process. This study has been prepared by Storm Consulting and WMAwater for Marrickville Council and provides the basis for the future management of flood prone lands in the Cooks River area.

The study concentrates on those areas of flood prone land along the Cooks River within the boundaries of Marrickville Council. There is no investigation of land within the surrounding local government areas.

1. COOKS RIVER FLOOD RISK MANAGEMENT PLAN

1.1. Executive Summary

1.1.1. Background

The Cooks River Floodplain Risk Management Plan has been prepared to provide the basis for future management of the floodplain of the Cooks River within the Marrickville LGA. It does not include management of the flood problem within the "overland" flow areas upstream of the Cooks River flood extent and only considered the five sub areas shown on Figure 1. Initially the Plan reviewed all past flood studies and management plans for the study area.

1.1.2. Climate Change

A recent addition has been the analysis of the effects of climate change (sea level rise and rainfall increase) on design flood levels. In September 2012 the NSW Government repealed its Policy on sea level rise which now means that individual Councils will have to determine what sea level rise projections should be adopted for flood related planning and controls. Previously these were mandated as 0.4m rise by the year 2050 and 0.9m rise by the year 2100. Sea level rises of these magnitudes will impact on existing developments and in particular at properties near Riverside Crescent, Illawarra Road and Bay Street. Sea level rise will increase the peak flood levels but also the normal water and high tide levels.

1.1.3. Risk Management Measures Considered

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

- <u>Flood mitigation dams and retarding basins:</u> on the basis of high cost, large footprint, and environmental impact;
- <u>Modifying the Cooks River channel by dredging:</u> on the basis of high cost and environmental impact due to heavy metal contents in the bed of the Cooks River;
- <u>Catchment treatment, to increase soil infiltration and storage of rainfall in the catchment:</u> whilst this is beneficial, the amount of infiltration during a flood is small, particularly as the ground is saturated and as a result there is minimal reduction in flood levels; and
- <u>Voluntary purchase of all flood affected buildings:</u> as it is uneconomic and has a high social impact.

The full range of measures was evaluated and the outcomes are summarised in Table 1. It should be noted that these outcomes may change in time if community expectations change or as an outcome of further analysis or possibly climate change.

From a detailed evaluation of all possible measures (Table 1) the proposed measures (Table 2) were categorised into General (as applying to all the study area) and Specifc (as applying to one of the five sub areas shown on Figure 1).

Table 1: Summary of Management Measures Investigated

Measure	Purpose	Comment
FLOOD MODIFICATION MEASURES		
Levee banks (either earth, concrete, small brick wall) and associated flood gates, pumps	Prevent or reduce the frequency of flooding of protected areas. Prevent or delay inundation from rising sea levels.	Relatively expensive for larger structures but may be feasible for smaller structures. May cause local drainage problems and social problems. A levee in the golf course to protect the Riverside Crescent area will likely have a low cost benefit ratio and possibly adverse social impacts. Raising of the Mackey Park levee protecting the Carrington Road area would be difficult due to the presence of trees on the current embankment and would also require raising of the eastern bank of the drainage channel to be effective.
Temporary flood barriers	Installed upon a flood warning to act as a temporary levee.	Needs good flood warning time to be successful. Larger barriers would need well trained staff for installation. Smaller scale options include sandbagging homes are generally successful (see flood proofing).
Local drainage issues – works to minimise local drainage problems	To reduce the incidence of local runoff ponding in yards and streets.	Flooding in this way rarely enters building although occurs frequently and causes significant inconvenience. A community based approach is underway as part of Council's Sub-Catchment Planning Framework. The completed Marrickville Flood Study provides design flood levels resulting from local catchment runoff.
PROPERTY MODIFICATION MEASURES		
House raising	Prevent flooding of existing building floors by raising the floor above the predicted flood levels.	All flood damages will not be prevented and external damages could still occur. Only suitable for non-brick buildings on piers. As most properties in the study area are brick this measure is generally not possible.
Flood proofing usually referred to as "dry flood proofing" in shallow depth flooding like the Cooks River and "wet flood proofing" in deep flood areas such as the Hawkesbury River	Prevent flooding of existing buildings by sealing all possible water entry points. Can also be applied to new constructions.	Generally only suitable for brick, slab on ground buildings. Less viable for residential buildings but should be considered for non-residential buildings such as those in the Carrington Road area for reducing the residual risk of Mackey Park levee failure/overtopping or overland flooding. Flood proofing buildings also can include designing electrical circuits above flood levels to reduce the risk of electrocution.
RESPONSE MODIFICATION MEASURES		
Flood warning and evacuation	Enable people to prepare and evacuate, to reduce damages to property and injury to persons.	No BoM flood warning system in place. Made difficult by the quick response time of the Cooks River catchment (typically less than 6 hours from start of rainfall).
Flood emergency management	To ensure evacuation can be undertaken in a safe and efficient manner.	The Local Flood Plan, part of the Local Disaster Plan, should be updated with the latest flood information from the Flood Study (Reference 2) and this FRMS&P. Need to include which properties affected, when and where roads and access cut, and other facilities that would be affected.
Public information and raising public awareness	Educate people to prepare themselves and their properties for floods to minimise flood damages and reduce risk to people.	A cheap and effective method but requires continued effort. Can be linked with updating S149 certificates, Council rate notices, local community events, school education. Recommended also to advise residents of possible flood proofing measures, hazard at their properties and suitable evacuation routes.
PLANNING AND FUTURE DEVELOPMENT CONTROL MEASURES		
Strategic planning issues	Reduce potential hazard and losses from flooding and inundation by appropriate land use planning.	Planned retreat, additional conditions on development and changes in land zoning are possible planning responses.
Rezoning	Changing land use in LEP to remove higher risk properties from floodplain such as residential buildings.	May freeze development in flood affected areas causing degradation of an area. Generally suitable land zones are currently defined within the floodplain of the Cooks River with the most flood prone areas given over to recreation and open space.

Measure	Purpose	Comment
Flood Planning Levels	To ensure floor levels are above flood levels to provide an acceptable level of flood risk (or for less vulnerable properties such as commercial properties flood proofing to this level).	Usually set as the 1% AEP flood level plus 0.5m freeboard. Ensures that new development is built at an appropriate level. Greater restrictions can be placed on buildings more vulnerable to flooding such as hospitals, electricity sub-station, seniors housing and lower restrictions on less vulnerable uses such as commercial activities where flood proofing to the FPL can be used in place of raising floor levels.
Modification of S149 certificates	S149 certificates should clearly inform property owners and purchasers of the flood risk, planning controls and policies applicable to the subject land.	Council should review flood and permanent inundation related information on the Section 149 certificate to bring it in line with the findings of this plan. Residents in flood prone areas can also be notified by re-issue of S149 certificates. Council should make property information on flooding available on their web site.
Review and update LEPs and DCPs	To be kept up-date date with current flood mapping to reduce flood risk through planning controls.	LEPs and DCPs should be up-to-date to effectively manage flood risks for new development. These controls are used to stipulate FPLs, land use zones, flood proofing and floor level requirements
OTHER MEASURES		
Flood access, provision and maintenance of infrastructure and services	Ensuring flood free, or low flood hazard access to aid evacuation or supply delivery. Ensuring infrastructure and services can be provided and maintained for their chosen life-time.	Identifying when current access road and river crossings become impassable. Ensuring that any future development does not worsen this situation and all new development has suitable access. Planning controls in the DCP should be used to ensure critical infrastructure such as electricity sub-stations or sewerage pumps are protected up to the PMF event.
Flood Insurance	To spread the risk of individual financial loss across the whole community through incurring against flood damage.	Does not reduce damage but spreads the cost. Insurance against catchment (rainfall induced) flooding is now commercially available at a price. This is being reviewed in light of the January 2011 south east Queensland floods as well as considering universal or subsidy schemes.

Table 2: Proposed Management Measures

Measure	Purpose	Priority and Cost
GENERAL MEASURES		
Review DCP controls and mapping	Prevent or reduce the frequency of flooding for future developments	High as relatively easily undertaken by Council and minimal costs
Identify flood liable properties on S149 certificates	Prevent or reduce the frequency of flooding for future developments	High as relatively easily undertaken by Council and minimal costs
Undertake flood awareness program	Ensure residents are fully aware of the flood risk	High as relatively easily undertaken by Council and SES. The costs will depend on the extent of the program.
Complete Local Flood Plan	Ensures the SES can adequately manage during future events	High as relatively easily undertaken by the SES
Undertake sea level impact assessment Report	To inform Council and residents of the implications of sea level rise and possible adaptation measures such as levees	Medium - within the next 5 years. Cost - $30,000
Monitor local drainage issues	Ensure local drainage issues adequately addressed	Medium as relatively easily undertaken by Council and minimal costs
Flood Warning Alarm System for Marrickville Oval retarding basin	Provide warning of filling up of basin	Medium with indicative cost of $20,000 and annual cost of $3,000.
House Raising	Raise house to reduce or eliminate above floor damages	Low as likely no applicants. Cost $60,000+ per building
Flood Proofing	Provide barrier to water entering buildings – most suitable for non residential	Low as likely no applicants and funding unlikely from state government. Cost $20,000+ per building
SPECIFIC MEASURES FOR SUB AREA		
Riverside Crescent		
Further investigation of levee at Riverside Crescent	Investigate levee to prevent inundation	Low - A more detailed evaluation is required taking into account engineering and social issues. Indicative investigation costs of $30,000 by a consultant.
Investigation to improve drainage in Riverside Crescent and Dibble Avenue	Improve drainage of area	Low - A more detailed evaluation is required taking into account engineering and social issues. Indicative investigation costs of $15,000 by a consultant.
Illawarra Road		
No specific measure proposed		
Carrington Road		
Audit of Mackey Park Levee	To ensure integrity and possible upgrade of levee	Medium – around $50,000 to be undertaken by a consultant but may include some earthworks at additional cost
Bay Street		
No specific measure proposed		
Alexandra Canal		
No specific measure proposed		

1.2. Introduction

The Cooks River Floodplain Risk Management Plan has been prepared in accordance with the NSW Floodplain Development Manual (Reference 1) 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.

The Cooks River drains a catchment of approximately 100 square kilometres in the south-western suburbs of Sydney. The river originates as a small watercourse near the Chullora railway workshops and flows some 23 kilometres in a generally eastern direction to enter Botany Bay just south of Kingsford Smith Airport. Prior to discharging into Botany Bay, the Cooks River is joined by a number of tributaries, the most significant being Coxs Creek which drains the Punchbowl area, Cup and Saucer Creek which enters near Canterbury, Wolli Creek which begins in Beverly Hills and Sheas Creek which drains the Alexandria area and enters the Cooks River via Alexandra Canal.

The Cooks River catchment has been extensively developed and is home to almost 400,000 people, contains more than 130,000 dwellings and over 100,000 commercial and industrial properties. Little remains of the original landscape and vegetation. The river channel itself has been highly modified and virtually the entire length of the river has been lined with extensive straightening and realignment. Despite the heavy development of the catchment, the river has not caused severe flooding problems over the years, mainly because much of the floodplain has been isolated from development for use as recreational parkland or road reserves. There are however, some flood liable areas of residential or industrial zoned land.

Flooding causes significant hardship (tangible and intangible damages) to the community and the impacts will increase with further infill development within the catchment and if sea levels rise due to anthropomorphic climate change. For this reason Marrickville Council has undertaken a program of studies to address the management of flood risks.

The present study was initiated by Marrickville Council to reassess floodplain risk management options in light of changes within the physical environment, updated flood information in the 2009 Cooks River Flood Study (Reference 2) and in the context of recent legislative and policy changes, and also the potential increase in rainfall intensities due to anthropomorphic climate change, and evaluate suitable adaptation measures.

1.3. Recommended General Measures

1.3.1. General High Priority

Current DCP controls with regards to flood risk (DCP 2.22) recommend a 1% AEP plus 0.5m freeboard (FPL) for new residential development and raised floor levels and flood proofing for commercial and industrial development. It is recommended that these are reviewed on a regular basis as more flood information becomes available. Mapping in the LEP and DCP should be updated following this project. Any work would be undertaken by Council and has not been costed.

Council are in the process of identifying flood liable properties and therefore providing detail on S149 certificates. Although not compulsory, it is recommended that information on potential flood risk due to climate change is also included and that properties that may not be currently identified as flood liable but may become flood liable in the future be tagged as potentially climate change affected properties. Likewise, properties currently afforded protection by the Mackey Park levee should also be identified so that these occupants are aware of the risks of being within a levee protected area and thus are aware of the risk of flooding of their property. Any work would be undertaken by Council and has not been costed.

A flood awareness campaign is recommended, especially in the light of the recent March 2012 flood and while people are still alert to flooding. In raising awareness, issues including how to remain safe in a flood, what to do to reduce loss and damage as well as potential retrofitting of flood proofing measures should be considered. A flood awareness campaign should be repeated on a regular basis so as to keep awareness at a high level. In the first instance, the flood awareness campaign can be undertaken at the same time as notifying flood liable residents of their risk. This work would most likely be undertaken by the SES with possibly assistance from Council and consultants. An indicative cost for this work would be $20,000 but this depends upon the extent of the flood awareness campaign.

The Local Flood Plan should be updated with information on road closures, flood depths and timings to aid evacuation. Any work would be undertaken by the SES and has not been costed.

1.3.2. General Medium Priority

The current LEP land use zones ensure largely recreational and open space areas adjacent to the Cooks River with only limited areas of residential and commercial/industrial use located within the 1% AEP floodplain. Re-assigning land use zones for these developed areas would have social implications and therefore appropriate DCP planning controls would better mitigate the flood risk.

However, Council needs to plan for sea level rise and thus should explore the possibility of changing land use zones in flood liable areas. It is recommended that Council undertake a preliminary study to further consider the implications of sea rise within the existing land use zones and if necessary make recommendations for change.

Levees are the only viable means of protecting existing development from increased flood levels due to sea level rise. The preliminary study should include an assessment of the practicality of constructing levees in the future to mitigate the increase in flood level due to sea level rise within the study area. An outcome of this study may be to ensure that land is available and reserved for levee construction should sea level rise eventuate and no other measures are possible.

This work would probably be undertaken by an external engineering consultant with assistance from Council staff. An indicative cost for such a preliminary study would be $30,000, however this would depend upon the exact study area and nature of the work.

Local drainage issues are the most frequent source of flooding for residents. Council should continue to monitor these and address them where appropriate.

Whilst the Marrickville Oval retarding basin is upstream of the extent of flooding from the Cooks River, the possible failure of this structure has the potential to have impacts downstream and the filling up of the basin represents a potential risk to life. A flood warning alarm system for this structure should be considered.

1.3.3. General Low Priority

House raising is probably not possible in this study area as the houses (brick construction) are not suitable and owners generally prefer to rebuild a new house. However house raising will be considered for suitable applicants with costs of $60,000+ per building.

Flood proofing of existing buildings is probably not viable for houses but may be appropriate for non residential buildings. The costs will be of the order of $20,000 per building but can vary significantly depending upon the required works. Funding is generally not available for flood proofing but can be considered.

1.4. Recommended Location Specific Measures

The application of specific flood mitigation measures for each of the five sub areas (Figure 1) has been investigated. As will be noted in many of the areas no specific measures have been proposed. This is not to say that Council or the NSW Government is abandoning the flooding issues in the area. It is just that catchment wide measures are the only measures that can be provided in the area as local measures will not work. A discussion of the reasons is provided in the main body of the report.

1.4.1. Riverside Crescent area

ISSUE

Reports from residents indicate that the pavement on Riverside Crescent is inundated several times a year although this is predominantly due to local drainage (albeit with possibly an elevated water level in the Cooks River restricting outflow) rather from overtopping from the Cooks River. This issue should be addressed by Council either through upgrading of the pipe drainage system or creation of an overland flow path across the golf course. These measures would provide no benefit in a flood emanating from the Cooks River. Hazard and emergency response classification mapping of properties identifies that safe pedestrian access is not always available from some properties during a flood.

Building floors (6 of them) are potentially first inundated in the 5% AEP event.

A levee in part of Marrickville golf course would likely have a low benefit cost ratio and possibly raise social impacts. However the viability should be considered further, particularly as it may form part of possible adaptation measures for climate change (see Section 5.3.1).

Rezoning to either a less vulnerable use, such as commercial would affect the social aspects of the area and will be unacceptable. Rezoning to a higher density land use could encourage new development at a higher level. However, this would be a slow process and have implications in terms of the social make-up of the area. Appropriate development controls can be used to ensure new development is flood proofed; either by raised floor levels or other flood proofing techniques but this measure does not benefit the existing flood liable properties.

No specific measures are proposed for this area.

1.4.2. Illawarra Road area

ISSUE

Road raising in 1995 reduced the amount of time Illawarra Road was closed each year due to inundation from high tides. However, the road is still susceptible to flooding several times a year (largely from high tides and any associated rainfall) closing the vehicular access along Wharf Street and Illawarra Road. Cooks River flooding of 50% AEP and greater magnitude will also inundate the road and surrounding area, as occurred in March 2012.

Building floors (5 of them) are potentially first inundated in the 5% AEP event.

No specific measures are proposed for this area.

1.4.3. Carrington Road area

ISSUE

Although generally protected by the Mackey Park levee up to the 1% AEP event any floods greater than this or failure of the levee could cause flooding of properties (mainly commercial and industrial). Upgrading the levee is problematic due to the presence of large trees planted on the bank and to prevent back flow up the Sydney Water stormwater channel (some form of flap gate is required). Although protected, flood development controls should still apply to the area behind the levee in case of failure, overtopping and for climate change.

Building floors are only first inundated in floods greater than the 1% AEP event.

The following specific management recommendations are made regarding the existing Mackey Park levee:

- Further investigate backflow protection on the Western Channel (cost $10,000);
- Survey the east bank of the Western Channel and raise the ground to an equivalent level to the river bank levee (cost of up to $20,000);
- Undertake an audit to determine the potential for failure of the Mackey Park levee due to the presence of trees on the embankment (cost $10,000); and
- Undertake a study to evaluate the potential for raising the levee to provide additional protection due to a sea level rise increase in flood levels. This study could be undertaken to encompass the above three recommendations or following completion of these studies as a separate project. If undertaken as a separate project an indicative cost would be $20,000 but there would be significant cost savings if all four projects were undertaken together.

1.4.4. Bay Street area

ISSUE

Flooding in the future in this area will be affected by sea level rise. House raising is not considered practical considering the age and type of buildings. Re-development controls over a longer term can relieve flooding by ensuring all new development has raised floor levels and/or flood proofing as necessary.

A levee would prevent above floor inundation and mitigate against sea level rise. However construction of a levee cannot be justified at this time as building floors (four of them) are only first inundated in the 1% AEP event with none in the more frequent events. A levee for this area would be further considered in the preliminary study to consider the implications of sea rise (Section 1.3.2).

No specific measures are proposed for this area.

1.4.5. Alexandra Canal area

ISSUE

Development in this area is entirely of either large commercial or industrial premises. There are no residential properties affected in events up to the 1% AEP (and more than likely up to the PMF). No floor levels were obtained in this area for this reason and no specific measures are proposed.

2. INTRODUCTION

2.1. Background

The Cooks River catchment is located south-west of the Sydney central business district with flows discharging to Botany Bay at Tempe, adjacent to and immediately south of Sydney Airport. The Cooks River catchment area is approximately 100 km^2 and covers portions of 13 local government areas. The catchment has been extensively developed, with many reaches severely altered by developments, and the river channel constrained or diverted from its original alignment.

Virtually the entire length of the Cooks River is concrete lined or has steel revetment walls, and the channel itself has been straightened and realigned in a number of places.

The Marrickville catchment is drained by three open trunk drainage lines (Figure 1) which discharge into the Cooks River; these are known as the Eastern, Central and Western Channels. The Eastern Channel is generally a twin open channel that enters the Cooks River near Tempe railway station. A detention basin located near Sydenham railway station forms part of this system. The Central Channel is open at the upstream end, through railway land, and covered at the downstream end adjacent to Carrington Street. This system is controlled by two pumping stations which pump excess run-off to the Eastern Channel, and directly to the Cooks River. The Western drainage line comprises two systems including an open channel which enters the Cooks River at Mackey Park, and the Malakoff tunnel which drains the top end of the catchment above Sydenham and Livingstone Roads, Marrickville.

For the purpose of the investigation the study area has been sub-divided into five sub-areas as shown on Figure 1 and described later in Section 3.1.

2.2. Objectives

Marrickville Council engaged Storm Consulting and WMAwater (formerly Webb, McKeown & Associates) to review the 1994 Cooks River Floodplain Risk Management Study and 1997 Plan (References 3 and 4) and address the existing, future and continuing flood problems, taking into account the potential impacts of climate change as well as guidelines for rainfall intensity increases.

The objectives of the Study are to identify and compare various management options, including an assessment of their social, economic and environmental impacts, together with opportunities to enhance the foreshore environments. The primary aim of the Plan is to reduce the flood hazard and risk to people and property in the existing community and to ensure future development is controlled in a manner consistent with the flood hazard and risk at this time and as a result of climate change.

2.3. Floodplain Risk Management Process

As described in the 2005 NSW Government's 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.*

Mainstream flood behaviour within the Cooks River catchment has been progressively investigated and updated over the last 20 years in line with advances in floodplain management policies, analytical techniques and changes to catchment and forecast climate conditions. The 2009 Cooks River Flood Study (Reference 2) formed the first stage of the management process building on the 1985 Cooks River Flood Study (Reference 5) and subsequent 1994 Cooks River Floodplain Management Study (Reference 3) which updated the design flood levels, to more accurately simulate the existing catchment and river conditions.

This present Floodplain Risk Management Study builds upon the 1994 Cooks River Floodplain Risk Management Study (Reference 3) and 1997 Cooks River Floodplain Risk Management Plan (Reference 4) and constitutes the second and third stages in the process.

2.4. History of Flooding

A number of flood events have occurred on the Cooks River, the highest reported of which occurred in 1889. However little data is available for this event. Other events of significance, for which a reasonable amount of data are available, occurred in February 1956, March 1958, November 1961, June 1964 and March 1983. Other events may have occurred but were not been recorded. Table 3 summarises levels at key points for the historical floods for which peak heights are known.

Table 3: Historical Floods - Peak Flood Levels (mAHD)

Location	Feb 1956	Mar 1958	Nov 1961	Jun 1964	Mar 1983
Brighton Avenue	2.27	2.39	3.39	-	2.38
Canterbury Road	2.37-2.60	2.24	2.54-3.9	2.22	2.13-2.46
Church Street	2.07	1.91	-	-	2.07
Wardell Road	2.12	2.10	2.64-2.92	1.89	-
Illawarra Road	2.07	1.83	2.41	1.72	1.63-1.92
Unwins Bridge	-	-	2.63	-	1.38
Tempe Railway	1.48	1.49	-	2.08	-
Princes Highway	1.32	1.40	-	-	-

Notes: Data obtained from the 1994 Cooks River Floodplain Management Study (Reference 3). On occasions there have been considerable differences between reported levels at the same point for the same flood. This is a common occurrence with flood records and reflects the problems in accurately observing levels under unusual and often difficult conditions.

Until recently there were no water level gauges along the Cooks River. However, three gauges have since been installed at Canterbury Road (1995), Illawarra Road Bridge (2001) and Tempe Bridge (1991). In addition the SES maintains records during flood events from their gauge boards (Figure 1).

During the course of the project a small flood event occurred in March 2012 which caused a number of properties (not building floors) to be inundated. The water level reached 1.95mAHD at Illawarra Road and caused extensive flooding of the road. This flood had a recurrence interval of approximately the 50% AEP event (2-year ARI). Hydrologic and hydraulic modelling was undertaken using available rainfall data and more detail can be found as Appendix C. This event verified flooding hotspots which were identified in the 1994 Cooks River Floodplain Management Study and 1997 Plan.

2.5. Causes of Flooding

Flooding along the Cooks River and its tributaries occurs as a result of a combination of intense rainfall over the catchment and elevated tidal levels (high tide and/or storm surge). Previous residential and industrial development on the natural floodplain means that in places many developments are affected due to flooding. The natural pattern and distribution of flooding has been affected due to:

- modifications to the river channel, including concrete lining, construction of revetment walls and re-alignment;
- changes to the runoff characteristics of the catchment due to development (piping of flows, loss of vegetation cover, increase in impermeable cover, filling of low lying land etc.); and
- flow obstructions (e.g. development on the floodplain, hydraulic structures (bridges and approaches, overgrown vegetation, filling of the floodplain).

Future changes to the extent of flooding may occur due to anthropomorphic climate change, notably sea level rise but also possibly rainfall intensity increases. The nature of flooding is detailed further in Section 0.

2.6. Council's Current Planning Instruments, Policy, Plans and Strategies

2.6.1. Local Environmental Plan

The Marrickville Local Environmental Plan (MLEP) 2011 came into force by a special notification from the NSW Government on 12th December 2011. This repeals the former Marrickville Local Environmental Plan 2001.

2.6.2. Cooks River Floodplain Development Control Plan (DCP30)

The Cooks River floodplain DCP (DCP30) was adopted by Council on 15th September 1998. Preparation of the DCP was one of the recommended management measures in the 1997 Cooks River Floodplain Management Plan (Reference 4). It applied to the development of land within the 1% AEP floodplain + 0.5m freeboard band designated as flood liable land by

Council. The DCP provides controls for minimum floor levels, flood proofing, flood access, filling in the floodplain as well as requirements for extensions and change of use. It includes a draft flood proofing code. DCP30 has now been superseded by the new Marrickville Development Control Plan 2011 Part 2.22.

2.6.3. Marrickville Development Control Plan 2011 and Part 2.22 Generic Flood Provisions for Flood Management

The Marrickville Development Control Plan 2011 was adopted by Council on 12th July 2011 and came into effect on 15th December 2011. The purpose of this DCP is to supplement the provisions of Marrickville LEP 2011 and provide more detailed provisions to guide development. It is a new comprehensive Plan which consolidates all of Council's existing DCPs into one document. The DCP is to be read in conjunction with Marrickville LEP 2011. In the event of an inconsistency between the provisions of the two documents, the provisions of LEP 2011 shall prevail to the extent of the inconsistency. Part 2.22, Generic Flood Provisions for Flood Management, supersedes DCP30.

Part 2.22 sets out development controls related to both Cooks River and overland flooding and acknowledges that the DCP will be updated following new information becoming available. Therefore this Study and Plan as well as the 2011 Marrickville Valley Flood Study (Reference 6) referring to overland flooding will be incorporated and the DCP updated as required.

The DCP defines flood prone land as land being within the Flood Planning Level (FLP) of the Cooks River and/or within the FPL of an area identified as being subject to local overland flooding and also any land likely to be affected by the PMF. The FPL is defined in the plan as land likely to be affected by the 1% AEP (1 in 100-year) flood plus 0.5m freeboard from the Cooks River. This means that some land may be identified as being within the Cooks River flood prone area (i.e within the PMF extents) but not within the flood planning area (i.e land below the Cooks River 1% AEP plus 0.5m flood level area). The plan applies controls to all development within the flood planning area and some development within flood prone land that is outside of the flood planning area.

Key controls (relating to Cooks River flooding) from the policy are summarised below:

- Development is not to increase flood hazard or risk to other properties;
- Proposed building materials are to be suitable;
- Development is to be in the optimal position to avoid flood waters and allow evacuation;
- Electrical services are to be adequately flood proofed;
- Flood free access is to be provided where practicable;
- Floor levels of habitable rooms shall be a minimum of 0.5m above the standard flood level (i.e above the flood planning level) at that locality;
- Any portion of buildings classified as being flood liable shall be constructed from flood compatible materials; and
- For new non-residential development floor levels (except for access-ways) must

be at least 0.5m above the standard flood level, or the buildings must be flood-proofed to at least 0.5m above the standard flood level.

The plan also sets out controls for extensions, change of use, subdivision, basement garages and filling of flood prone land.

The plan currently specifies hazards for the five sub-areas of the Cooks River floodplain. These should be reviewed following this Plan to ensure they are as stated. Furthermore, following this Floodplain Risk Management Study flood prone properties should be identified on Council's database and this information provided to affected residents.

2.6.4. Sub-catchment Planning Framework

Marrickville Council's Waterevolution Sub-catchment Planning Framework is the outcome of the Urban Stormwater Integrated Management project. The framework is an approach to managing water use and improving water quality through working on a sub-catchment basis with local communities. Sub-catchment management plans are to be prepared and implemented for each of the 21 sub-catchments. These plans focus on the water cycle, water re-use and improving water quality but also in not increasing rainfall runoff and thereby reducing stormwater (overland) flooding by such measures as detention basins, rainwater gardens and other means. Flood mitigation options are identified and assessed together with other water cycle management options.

So far Council has applied the framework methodology to four sub-catchments within the study area of this Floodplain Risk Management Study. In 2003, Council joined with the Illawarra Road sub-catchment community in Marrickville South and other stakeholders and created Marrickville's first sub-catchment management plan in 2006. Council completed the Tennyson Street sub-catchment management plan in Dulwich Hill in 2009. The Riverside Crescent sub-catchment is the third to have a management plan. The sub-catchment plans will be reviewed annually to track progress and will have a major review every five years by Council and sub-catchment stakeholders, including the sub-catchment working groups (refer Reference 7). The Eastern Channel, East sub-catchment management plan is currently being completed by Council.

2.6.5. Marrickville Urban Strategy

The Marrickville Urban Strategy (Reference 8), adopted by Marrickville Council in April 2007, provides the planning context for future development across the Marrickville LGA. It establishes a vision and co-ordinated directions addressing a range of planning, community, and environmental issues, to guide short, medium and long term strategic planning policies. The Urban Strategy reviews current land use and zoning issues at a strategic level and incorporates the many existing Marrickville Council plans and strategies.

When preparing the strategy in 2004, Marrickville LGA had an estimated 32,600 dwellings, with some 60 percent located in and around centres. The Australian Bureau of Statistics estimated the population of Marrickville in 2004 at 75,752. The population in 2000 was estimated at 77,163. Therefore, there has been a recent decline in the population of the LGA of some 1,400 residents, or approximately 350 per year. Over the same period (2000/01 to 2004/05) approximately 240 to 550 dwellings were built each year. Of the total 1,813 new dwellings over this period, 77 percent were constructed in or around centres and 23 percent were in other infill areas. The demand for more housing in Marrickville is largely driven by demographic change and social trends leading to less people living in each household. This occurs with an older population, more people living alone, an increase in divorce rates and more established households where children are leaving home to establish their own homes. Additional dwellings are needed in Marrickville in the future to meeting housing needs and support future population growth. Of particular note, even in a situation of zero population growth, Marrickville will still require an estimated 2,400 dwellings to accommodate social and demographic change (i.e. as a result of less people living in each dwelling).

In summary, the Urban Strategy suggests that Marrickville Council should plan for 3,830 dwellings over the next 25 years, through a mix of the renewal approaches described, to provide;

- Rezoning and development controls to provide for 2,530 dwellings in the first 10 years;
- An additional 1,300 in 10 to 25 years; and
- 80 percent of new dwellings being located in or near centres, in walking distance to shops and services close to public transport.

The position against these targets will be assessed and reviewed at five-yearly intervals, with the first review in 2012/13.

The strategy highlights the risk of flooding as a constraint to the demand for future dwellings and employment in Marrickville. Despite this awareness of the risk of flooding, the pressure to accommodate additional dwellings in an already dense LGA may mean that areas at risk of flooding are considered for continued development. Any development proposals in these areas must therefore carefully consider the impacts of future flooding.

2.7. Previous Studies

A number of previous flood related studies have been undertaken on the Cooks River; many of which are relevant to this study. The following sections provide a review of these studies and identify key points relevant to this study.

2.7.1. Cooks River Flood Study (1985)

This Public Work Department’s flood study was the first comprehensive study of flooding for the Cooks River (Reference 5). Significant improvements have been made in flood modelling techniques since then and hence subsequent flood studies supersede this report.

2.7.2. Cooks River Floodplain Management Study (1994)

This study (Reference 3), commissioned jointly by Marrickville and Canterbury Councils involved both a revision of the previous Public Work Department's flood study (Reference 5) and the development and assessment of floodplain management options for the study area. Since the previous study considerable advances in computer modelling techniques and a revision of design rainfall data in the 1987 edition of Australian Rainfall and Runoff meant a re-work of the previous study was necessary. A WBNM hydrological runoff routing model was established together with a one dimensional RUBICON hydraulic model. The models were calibrated to historical flood data and then used for design flood estimation.

The study identified four key areas subject to flooding in the 1% AEP event (within the bounds of this current study); Riverside Crescent and Dulwich Hill, Illawarra Road and Wharf Street, Carrington Road and finally Bay Street (it did not consider the Alexandra Canal area). Different management options were recommended for each of these areas including rezoning land, road raising, raising the Mackey Park levee and establishing development controls. Dredging of the Cooks River was rejected as a management measure due to economic and environmental reasons as was lowering of the overbank areas. Levees were considered but in general rejected due to their visual impact and loss of amenity issues. One of the initial recommendations was to rezone areas to allow higher density development and thus remove frequently inundated buildings. This rezoning measure was not supported by the community and subsequently rejected.

2.7.3. Cooks River Floodplain Management Plan (1997)

This Plan (Reference 4) followed on from the 1994 Floodplain Management Study and provided the recommended management measures for the study area in Canterbury and Marrickville LGAs. The general floodplain risk management measures included adoption of the 1% AEP flood event as the flood standard and residential floor levels set a minimum of 0.5m above this, a review of floor level requirements for non-residential properties, provision of flood awareness educational material to residents, adoption of a prioritised list of flood mitigation strategies, continuing collection of further data and studies and flood proofing measures for individual properties. No large scale structural works were proposed in this plan.

Following completion of this Floodplain Management Plan Marrickville Council adopted their DCP30 policy setting development controls with regard to flooding and implementing the recommendations of the 1997 Plan. The effectiveness of this plan has been audited in Section 2.8.

2.7.4. Cooks River Flood Study (2009)

The 2009 Cooks River Flood Study (Reference 2) provides the most up to date information on design flood behaviour. It was conducted by Sydney Water to support investigations into the feasibility of naturalising some reaches of river bank along the Cooks River. This report updated the previous 1994 Cooks River Management Study (Reference 3). Feasibility and further modelling work on the bank naturalisation will follow in subsequent reports.

The main reasons for updating the hydraulic modelling approach were:

- Use of a two dimensional (2D) hydraulic model;
- Availability of higher quality bathymetric data to better describe the river channel rather than the cross sections used previously;
- Availability of Airborne Laser Scanning (ALS) survey that provides a very accurate definition of the overbank topography;
- A more detailed appraisal of design ocean level conditions; and
- Incorporation of predicted climate change sea level rises and rainfall increases.

The adopted approach was to establish a TUFLOW 2D hydraulic model based on the available bathymetric and ALS survey with inflows from a WBNM hydrologic model; similar but not identical model to that used in the 1994 study (Reference 3). Due to the absence of available stream flow data it was not possible to directly calibrate the hydrologic model. Thus a joint calibration of the hydrologic and hydraulic models was undertaken (identical approach to Reference 3) using data from the November 1961 and March 1983 events. The modelling approach was then used for design flood estimation with sensitivity analysis undertaken to determine the impacts of various model parameters as well as predicted climate change sea level rises and rainfall increases.

2.7.5. Cooks River Stormwater Management Plan (1999)

The Stormwater Management Plan (Reference 9) examined stormwater management issues for the whole of the Cooks River catchment and was prepared for all thirteen Councils within the catchment. It considers a large number of stormwater related issues, many relating to pollution controls for the Cooks River such as the quality of sediment in the river, amounts of litter and concentrations of pollution. The outcome was an action plan for water quality, river health and storm water management.

2.7.6. Marrickville Valley Flood Study (2011)

This study is currently in draft form (Reference 6). The study primarily examined overland flooding within the Marrickville Valley and the interaction with mainstream flooding as derived from the latest Cooks River flood modelling (Reference 2). The results from this study will ultimately be incorporated a management plan for the study area.

2.8. Implementation Audit of Previous Management Plan

Table 4 and Table 5 identify the actions recommended as a result of the 1997 Floodplain Management Plan (Reference 4) relevant to the study area of this report (note Reference 4 also included Canterbury LGA) and documents how successful these have been or comments on their implementation.

A comprehensive Public Participation Program was developed as part of the 1997 plan (Reference 4) in order to seek the views of the local residents on the proposed measures and as a result considerable changes were made to the Draft Plan. The outcome was that following a detailed consideration of the social, economic, environmental and hydraulic factors it was concluded that protection could not be provided to all buildings inundated above floor level in the 1% AEP event.

The key features of the Plan were (taken from Reference 4):

- The 1% AEP flood to continue as the Flood Standard and the Minimum Residential Floor Level established as 0.5 m above the 1% AEP flood. Both Councils are to review their policy regarding Minimum Floor Level requirements for non-residential buildings;
- Definition of the 1% AEP flood extent and identification of properties subject to Minimum Floor Level requirements;
- A priority listing of flood mitigation strategies has been adopted;
- Both Councils will provide information and education to local residents in order to ensure that flood damages in the future are minimised;
- Further data will be collected and studies conducted to increase understanding of flooding along the Cooks River and to improve the accuracy of the design flood levels;
- The available literature and advice from relevant government departments on the possible impact of the Greenhouse Effect (climate change) will be considered and works and measures undertaken if required;
- Future development within the catchment and in the floodplain will be monitored to ensure that it does not exacerbate the flood problem or water quality/sedimentation problems; and
- Both Councils support any measures by public authorities which will increase the length of flood warning time available to the residents or the efficiency of emergency services.

No large scale structural works were proposed. The two main initiatives were a comprehensive flood awareness program and flood proofing measures to prevent the ingress of floodwaters.

A priority listing of the recommended general floodplain management strategies from Reference 4 is provided in Table 4.

Table 4: Recommended General Strategies from the 1997 Management Plan

Strategy	Comment	Has the Strategy subsequently been implemented in the Marrickville LGA?
HIGH PRIORITY		
Amend S149 Planning Certificates	Councils will update the S149 Planning Certificates to include the latest information regarding flooding.	YES
Provide Information and Education	Will ensure future damages are minimised.	YES
Minimum Floor Level Policy to be documented	Floor levels of all new residential buildings to be at a minimum of 0.5m above the 1% AEP flood level. Fill levels to be 0.3m above the 1% AEP flood level. Councils to review policy for non-residential buildings.	YES
Review and Provide Additional Information on S149 Planning Certificate	The wording provided on the certificate should be reviewed to ensure that it adequately describes the flood situation and is consistent for both Councils. Councils should investigate the possibility of including a notification on the S149 Planning Certificate regarding the likely hazard in evacuating from a property during floods.	YES
Flood Warning and Evacuation	Councils support any measure which will improve the available flood warning. The Local Emergency Management Committees are to review and update their procedures based on the information provided in this study.	YES
MEDIUM PRIORITY		
Collect More Data	Install and maintain additional water level recorders. The data from future floods should be collected and analysed to increase understanding of the system behaviour and ensure accuracy of the design flood levels. Cost $5000 per annum.	YES
Alterations to the Floodplain	Councils will ensure that the effects of alterations to the floodplain (such as filling, fencing, buildings) are carefully monitored.	YES
Incorporate Floodplain Management Plan with an Integrated Planning Framework	This Plan should be adequately incorporated into Council's land use planning process.	YES
LOW PRIORITY		
Greenhouse Effect	To be monitored and the impacts assessed.	YES
Catchment Treatment	Will not reduce the existing flood problem. Advice can be provided at minimal cost to ensure that future works do not exacerbate the flood problem.	Not applicable
On-Site Detention	The use of OSD to control increases in flow on small creeks and drains, as well as limit water quality degradation, is supported.	Not applicable

The recommended floodplain management strategies for the four areas within the Marrickville LGA from Reference 4 are provided in Table 5.

Table 5: Strategies for each Area from the 1997 Floodplain Management Plan

Strategy	Priority	Has the Strategy subsequently been implemented?
Riverside Crescent, Dulwich Hill		
Flood Awareness Program and provision of advice.	High	YES
Local Emergency Management Committee to be advised of the flood hazard.	High	YES
Illawarra Road, Marrickville		
Flood Awareness Program and provision of advice.	High	YES
Local Emergency Management Committee to be advised of the flood hazard.	High	YES
Carrington Road, Marrickville		
Implement Revised Development Controls	High	YES
Local Emergency Management Committee to be advised of the flood hazard.	High	YES
Flood Awareness Program and provision of advice.	High	YES
Bay Street, Tempe		
Promote re-development.	High	YES
Flood Awareness Program and provision of advice.	High	YES

3. STUDY AREA

3.1. Sub-Areas

In considering the flood environment of the Cooks River the study area has been split into five sub-areas (see Figure 1). The magnitude of the flood event (from the Cooks River and not overland flow from the local catchment) that first inundates private property in the Riverside Crescent, Illawarra Road and Bay Street areas is of the order of a 2 year ARI (50% AEP) to 5 year ARI (20% AEP) event. As the Carrington Road area is protected by the Mackey Park levee the first event is closer to a 100 year ARI (1% AEP) event. A floor level survey indicates that no residential floors are inundated in any area in the 2 year ARI (50% AEP) event but floors in the Riverside Crescent and Illawarra Road areas are inundated in the 20 year ARI (5% AEP). However they could first become inundated in a smaller event than the 20 year ARI (say 10 year ARI) but no flood levels between these two design events are available to determine this.

Riverside Crescent and surrounds

This sub-area is defined by Garnet Street to the west which also forms the boundary of the study area. The Cooks River defines the boundary of the sub-area to the west with Bruce Street and Beauchamp Street forming the south-eastern sub-area boundary.

The Riverside Crescent and surrounds sub-area mainly includes properties on Riverside Crescent with some on Tennyson Street, Dibble Avenue, Pilgrim Avenue, Garnet Street, Ness Avenue, Ewart Street and Chadwick Avenue. A floor level survey was available for 45 properties in the area all of which were residential. The houses comprise largely brick built detached buildings with few unit developments. Many houses are single storey with residents therefore living on the ground floor.

Illawarra Road and surrounds

Located to the south-east of the Riverside Crescent sub-area, this sub-area largely includes properties at the lower end of Illawarra Road and along Wharf Street. Properties on Cahill Place and Hill Street near the junctions with Illawarra Road are also included. The south-east boundary of the sub area is approximately mid-way between Illawarra Road and Carrington Road.

The area is largely residential. Floor level data was available for 69 properties within the sub-area. The two main flood affected streets in the area are Wharf Street and Illawarra Road. Houses along both these streets comprise mainly single storey detached dwellings of brick construction.

The sub-area also includes Marrickville Golf Club, Mahoney Reserve and Steel Park all adjacent to the Cooks River.

Carrington Road and surrounds

This area comprises mainly commercial and light industrial developments centred around

Carrington Road. The railway line and Eastern Drainage Channel which outfalls to the Cooks River near Tempe Railway Station, bounds the east of the sub-area. Properties in this sub-area include those on Carrington Road, as well as Cary and Renwick Streets which run perpendicular to Carrington Road.

Floor level survey data was available for 21 buildings including 8 residential properties in Cary Street. These residential buildings are all brick built and single storey. Some of the commercial properties on Carrington Road are brick built with others being of mixed construction. Floor levels of the commercial properties tend to sit closer to ground levels than for the residential properties.

Mackey Park is located between Carrington Road and the Cooks River. A levee in this park affords some flood protection to properties in this sub-area (up to approximately the 1% AEP event).

This area is different compared to the other areas in that it is affected by both overbank flooding from the Cooks River as well as runoff from the local catchment (Reference 6). In recent times the flooding has all been caused by local catchment runoff. The flood planning levels for this area are therefore the higher of the local catchment runoff levels (Reference 6) and those from the 2009 Cooks River Flood Study (Reference 2). The Mackey Park levee provides an unusual situation in that it provides protection to the 1% AEP level (approximately) but is overtopped in larger events. However levees can fail and are considered to be constructed to protect existing development and not as a means of providing a lowering of the FPL for new developments. On this basis the FPL levels for the Carrington Road area for Cooks River flooding were taken as the 1% AEP flood level in the Cooks River adjoining the Mackey Park levee plus 0.5m. The FPLs have been provided to Council as part of a separate project.

Bay Street and surrounds

This area to the south of the Eastern Drainage Channel includes the Princes Highway and properties on Station, Young, Old and Bay Streets. The Tempe golf driving range is located to the east. The area is predominantly residential with a couple of commercial properties located on Holbeach Avenue adjacent to the Cooks River.

Floor level data were available for 33 properties. Most residential buildings are brick built, single storey and detached. Kendrick Park and Tempe Recreation Reserve area, both public open spaces, are located between most of the development and the Cooks River.

Alexandra Canal and surrounds

This area comprises the large commercial and industrial properties on the western bank of Alexandra Canal as well as a small part of Kingsford Smith airport and was not identified in previous studies. This land is only inundated by floodwaters in events greater than the 1% AEP event. For the above reasons floor level data or other details of this area were not obtained and no specific mitigation measures were considered for this area in this study.

3.2. Land Use

This study is focused on the Cooks River catchment within the Marrickville Council LGA which represents approximately 12% of the entire catchment which is the third highest contributing Council out of thirteen in terms of catchment size (Reference 9).

Some key features of the Marrickville LGA (www.marrickville.nsw.gov.au) are:

- The Marrickville local government area was originally owned by the Cadigal-Wangal people of the Eora nation.
- Today the area encompasses the suburbs of Dulwich Hill, Lewisham, Petersham, Marrickville (Marrickville North and Marrickville South), Stanmore, St Peters, Sydenham, Tempe, Enmore and parts of Newtown and Camperdown.
- It has a population of approximately 76,000 residents.
- The whole of the LGA lies between 4 and 10km from the centre of the city and is located in Sydney's inner west.
- Marrickville exhibits features typical of older inner city suburbs, and contains many items of heritage and of cultural significance, including sites of Aboriginal significance.
- While its native bushland has almost completely disappeared, there has been a significant enhancement of Marrickville's natural environment over recent years. The Cooks River remains one of the area's most outstanding and defining features.

Further history of the Cooks River can also be found on Canterbury Council's web site (www.canterbury.nsw.gov.au).

The land use, mapped as Figure 2, in the areas surrounding the river comprises the full range of planning zones listed in the Marrickville LEP 2011 namely;

- General Residential (R1), Low Density Residential (R2), Medium Density Residential (R3), High Density Residential (R4),
- Neighborhood Centre (B1), Local Centre (B2), Mixed Use (B4), Business Development (B5), Enterprise Corridor (B6), Business Park (B7),
- General Industrial (IN1), Light Industrial (IN2),
- Special Activities (SP1), Infrastructure (SP2),
- Public Recreation (RE1), Private Recreation (RE2),
- Natural Waterways (W1), Recreational Waterways (W2).

The Cooks River is a focal point of the LGA and is a significant commercial, environmental, recreational and scenic asset. The terrain adjacent to the northern bank of Cooks River is generally vulnerable to inundation and comprises relatively flat and low lying, recreational land including the Marrickville Golf Course and the public parks. The exception is where residential properties front the river and the land rises relatively steeply. For a large part of the river perimeter public land (Public Recreation zone RE1) separates the river from the residential (or other) use.

The main areas affected by flooding from the Alexandra Canal and the trunk drainage lines are predominantly industrial (General Industrial zone IN1) and Light Industrial (zone IN2).

There are few vacant residential, commercial or industrial zoned properties surrounding the river area. The majority of future activities will be the re-development or extension of existing land use activities with practically nil development on vacant land. In recent years there has been a small amount of subdivision within urban zoned land for residential dual occupancies and other higher density usage.

3.3. Environmental Summary

The 1999 Cooks River Stormwater Management Plan (Reference 9) described the environmental qualities of Cooks River in detail. The values include ecological, recreational, amenity, health and economic values. These values and management objectives are provided in Table 6.

Table 6: Cooks River Catchment Values and Objectives (Reference 9)

Catchment Values	Long-Term Stormwater Management Objectives	Short-Term Stormwater Management Objective
Ecological Values:		
Remnants of the original vegetation and creek lines of the river The presence of native water birds, fish and aquatic flora and fauna Visually attractive riparian vegetation along the river banks (weed free) The existing wetland areas and intertidal zone which attract large numbers of waterbirds Remnant vegetation and native animals of special conservation value such as the endangered Cooks River Clay Plain Scrub Forest, and birds protected by international treaties Natural creek banks as opposed to concrete walls and sheet piling	1. Protect and enhance remnant foreshore vegetation and natural waterways.	Protect all remnant vegetation of ecological significance and natural waterways from the impacts of stormwater from future developments.
	2. Protect and enhance existing wetlands and intertidal zones from the impacts of stormwater.	Protect all remnant wetlands of ecological significance, remaining floodplain and intertidal areas from the impacts of stormwater from future developments.
	3. Recreate aquatic habitats suitable for native waterbirds and fish.	Replace sections of concrete channel with more natural waterway in five areas.
	4. Recreate natural riparian and bushland habitats to act as a buffer zone for stormwater.	Restore the natural riparian zone in three sections along existing natural channels.
	5. Achieve water quality which meets the requirements for protection of aquatic ecosystems in all tidal areas and natural channels.	Achieve water quality which meets the guidelines for protection of aquatic ecosystems in tidal areas and natural channel at least 50% of the time.
Social Values:		
Boating and secondary contact recreation throughout the catchment Swimming in the tidal mouth of the River Fishing and the safe consumption of fish caught in the River Recreational areas with water features which are visually pleasing and safe Walking and bike tracks following the River with no visual pollution (that is, no murky water or floating litter) Facilities and use of waterways with environmental education and awareness themes.	6. Achieve water quality which meets the requirements for primary contact recreation in tidal sections of the river and the requirements for secondary contact recreation in all waterways.	Achieve water quality which meets the requirements for secondary contact recreation in all waterways more than 75% of the time.
	7. Maximise the visual amenity of waterways by achieving clear rather than murky water.	Achieve reduction in suspended solid levels in all waterways and control of bank erosion in a sustainable manner.
	8. Maximise the visual amenity of waterways by achieving no floating litter	Ensure that no significant litter is visible in waterways during dry weather and the total volume of litter collected in the five key SWC trash racks/GPTs is reduced by 20%.
	9. Achieve water quality which meets	Achieve water quality which meets

Catchment Values	Long-Term Stormwater Management Objectives	Short-Term Stormwater Management Objective
	requirements for consumption of fish	requirements for consumption of fish in the lower Cooks River more than 50% of the time.
	10. Ensure that the stormwater system is of minimal risk to public health and maximise opportunities for environmental education.	Ensure that public safety and education is considered in the design of all structural stormwater management works.
Economic Values:		
Improved property values due to improved waterway values. Stormwater suitable for reuse	11. Promote reuse of stormwater for irrigation.	Maximise opportunities for stormwater reuse on golf courses and all new developments considered.

3.4. History of River Change

Prior to European settlement, it has been estimated that approximately 1,500 aborigines inhabited the Port Jackson/Botany Bay area (reference: Governor Phillip to Lord Sydney, 9 July 1788. Historical Records of New South Wales, Volume 1, Part 2, p. 153). The Aboriginal population fished, gathered shellfish, hunted and undertook subsistence cropping along the Cooks River. Captain Cook was the first recorded non-native to enter the Cooks River. In 1770, Captain Cook reported on “a fine stream of fresh water” entering the Bay and suggested that the lands within the river catchment offered fertile lands that were appropriate for agriculture. Colonisation went ahead and the Cooks River catchment was initially used for farming.

The Cooks River is now considered one of the most polluted river systems in Sydney and has undergone significant anthropogenic change over the past 200 years causing much degradation. Since European settlement, the Cooks River has been altered and degraded by a wide variety of activities including;

- vegetation clearing;
- draining of wetlands;
- diversion of natural drainage;
- concrete lining of channels and banks;
- dredging;
- industrial activities;
- roads and transport routes;
- development of residential areas;
- dumping of wastes;
- land filling; and
- sewage contamination.

Over time works have been undertaken to control flows, reduce flood risk, reduce pollution levels and generally attempt to improve the river. However, some of these improvements such as channelisation and large extents of sheet piling on the river bank have not had positive effects. There has also been substantial land reclamation mainly for Sydney Airport. Figure 3, a series of photographs from Adastra Aerial Surveys (Reference 10), shows how the mouth of the Cooks River was largely engineered between 1947 and 1955 to allow for land reclamation and enlarge Sydney Airport. The engineering works included diverting and straightening the watercourse as well as considerable land reclamation.

The timeline (Table 7) below describes how increased use of the river and urbanisation has caused the river to be in its current degraded state (information largely from Reference 9).

Table 7: Timeline of Significant Activities along the Cooks River

Pre-1770	The Darug Aboriginal People populate the areas and use the river for gathering shellfish, other fishing and subsistence cropping
1770	Captain Cook enters the river
1788	Colonists begin to arrive - catchment used for farming, timber gathering, fishing and recreational pursuits.
1839	Dam constructed at Tempe to supply freshwater to Sydney but not used as water remained saline. Had impacts on tidal flushing and sedimentation and dam subsequently removed.
1840s	Dam built in Canterbury to service the Australian Sugar Company refinery
1850s	Wool washers, tanneries, rendering works become established along Cup and Saucer Creek and Alexandra Canal providing a continuous source of pollution.
Mid 1800s	Several thousand people settled in an industrial village causing waste from overflowing septic tanks, household waste, effluent from industries including slaughter houses, soap factories, sewerage farms, chemical manufacturing.
1886	Alexandra Canal dredged and channelised to allow boat navigation. Following this sewerage and storm infrastructure was first constructed in the Sydney region.
1920s	Bank erosion noted as a major source of sediment causing siltation. Training walls and concrete channels were installed to reduce this but have had significant negative effects reducing dry weather flows and flushing ability but increasing wet weather flows and flood risk.
1925	The Cooks River Improvement League lobbied to improve the environmental conditions of the Cooks River.
1930	Concrete block embankment works constructed.
1946	Cooks River Improvement Act passed. This aimed to prevent degradation of the river banks and involved a program of dredging and construction of concrete channels. The NSW Public Works Department were given control of the lower reaches of the river to make improvements for flood mitigation and river diversion works. This included dredging of the river, reclaiming swamp areas and sheet piling the banks of the lower river reaches.
1947–1955	Alexandra Canal and lower reaches of the river diverted by up to 1.6km to allow for land reclamation to enlarge the airport.
1950s	Upstream banks sealed with concrete.
1963	Carrington Road drainage pumping station and detention pit constructed.
1950s-2012	Further development within the Cooks River catchment causes continued pressure on the river in terms of water quality, flood risks etc. However over the last 20+ years there has been an increased awareness of pollution and the general degradation of the Cooks River, as a result some measure have been introduced to slow the rate of degradation and in places enhance the water quality and visual amenity.
2011	Three areas of the river bank were 'naturalised' under the Estuary Management Program by cutting the sheet piling at bed level and replacing this with vegetated banks.

3.5. Community Consultation

3.5.1. Public Exhibition of Draft Flood Studies and Policy for Identifying Properties Subject to Flood Related Development Controls

As part of this Floodplain Risk Management Study letters were sent out to residents advising them that Marrickville Council was in the process of updating its database of properties that will be subject to flood-related development controls. The technical basis for identifying the properties was provided in the following reports which were placed on public exhibition in May 2012:

- Cooks River Flood Study – 2009 (Reference 2);
- Eastern Channel East Flood Study – 2010 (Reference 11);
- Marrickville Valley Flood Study – 2011 (Reference 6); and
- Policy for Identifying Properties Subject to Flood Related Development Controls (Reference 12).

In addition two public meetings were held in Council Offices in May 2012. Some feedback was obtained directly from the meetings and subsequently from telephone calls and a completed questionnaire.

3.5.2. Public Exhibition of Draft Floodplain Risk Management Study and Plan

Council resolved to place the Draft Cooks River Floodplain Risk Management Study and Plan on public exhibition at their April 2013 meeting. The plan was placed on public exhibition during August and September 2014. No submissions were made in direct response to the Cooks River Floodplain Risk Management Study and Plan during this exhibition process. The Cooks River Floodplain Risk Management Study and Plan was subsequently adopted by Council in February 2015.

4. EXISTING FLOOD ENVIRONMENT

4.1. Flood Behaviour

Flooding from the Cooks River may occur as a result of a combination of factors including fluvial flooding from the river itself and tidal influences. One of the key considerations in modelling tidally influenced systems is the probability of occurrence of a combined ocean and rainfall event and the relative magnitude of both. It is considered to be overly conservative to assume a 1% AEP ocean event will occur concurrently with a 1% AEP rainfall event; the joint probability of these two events occurring at the same time will be significantly rarer than the events occurring in isolation of each other. For this reason, two scenarios were analysed for the 1% AEP event; a rainfall dominated scenario which assumes the design rainfall over the catchment in conjunction with a design ocean event of equal or smaller magnitude (taken as the High Water Spring Solstice peak of 1.1m AHD - a static water level boundary was assumed rather than a tide) and an ocean dominated scenario which assumes the design ocean event in conjunction with the design rainfall (50% AEP event) of equal or smaller magnitude (Reference 2).

Hydraulic modelling was undertaken as part of the 2009 Cooks River Flood Study (Reference 2). This study produced flood estimates for the PMF and 50%, 5% and 1% AEP events. Flood extent and hazard mapping using the models from the Flood Study are included in Appendix B.

4.1.1. Revision of Assumed Botany Bay Level

As noted above the 2009 Cooks River Flood Study (Reference 2) assumed two scenarios for the 1% AEP event:

- A 1% AEP rainfall scenario with a constant downstream boundary of the High Water Spring Solstice peak of 1.1 m AHD; and
- A 1% AEP ocean scenario of a tide with a 1.7m AHD peak (assumed 1% AEP peak of 1.45m AHD plus 0.25m increase due to storm related effects at the mouth of the Cooks River).

Since publication of the 2009 study more recent NSW government guidance is now available on the joint probability of rainfall and ocean events (Reference 14). This guideline indicates that the following two scenarios should be investigated with an envelope of the peak levels adopted:

- 1% AEP ocean flooding with 5% AEP catchment flooding assuming coincident peaks; and
- 5% AEP ocean flooding (peak level assumed as approximately 1.35 mAHD rather than the previously adopted peak level of 1.1 mAHD) with 1% AEP catchment flooding assuming coincident peaks.

A rigorous review of the above scenarios was outside the scope of this project and for this reason only a limited assessment was undertaken. The approach adopted was to determine the change in peak level (Table 8) within the study area for the following scenarios:

1. 1% AEP rainfall plus constant 1.1m ocean level (1% AEP rainfall event in Reference 2). This was the 'base' scenario which other scenarios were compared to,
2. 1% AEP rainfall plus constant 1.2m ocean level,
3. 1% AEP rainfall plus constant 1.3m ocean level,
4. 1% AEP rainfall plus constant 1.4m ocean level,
5. 1% AEP rainfall plus constant 1.5m ocean level,
6. 1% AEP rainfall plus constant 2.0m ocean level,
7. 50% AEP rainfall plus 1.7m tide as provided in Reference 2 (1% AEP ocean event in Reference 2),
8. 5% AEP rainfall plus 1.7m tide as provided in Reference 2,
9. 50% AEP rainfall plus 1.7m tide as provided in Reference 2 increased by 0.4m (peak of 2.1m AHD),
10. 50% AEP rainfall plus 1.7m tide as provided in Reference 2 increased by 0.9m (peak of 2.5m AHD),
11. 1% AEP rainfall plus 1.7m tide as provided in Reference 2 decreased by 0.3m (peak of 1.4m AHD).

Table 8: Effect of Varied Downstream Water Levels (1% AEP)

Scenario	mAHD	Change in Peak Flood Level (m)									
	1	2	3	4	5	6	7	8	9	10	11
General Holmes Drive	**1.7**	0.1	0.2	0.2	0.3	0.6	0.1	0.3	0.5	0.9	0.2
Marsh Street	**2.0**	0.1	0.1	0.2	0.2	0.5	-0.1	0.2	0.3	0.7	0.2
Princes Highway	**2.2**	0.1	0.1	0.2	0.2	0.5	-0.2	0.1	0.2	0.6	0.1
Tempe Rail Bridge	**2.3**	0.0	0.1	0.1	0.2	0.4	-0.3	0.1	0.1	0.5	0.1
Bayview Ave	**2.4**	0.0	0.1	0.1	0.2	0.5	-0.4	0.0	0.0	0.4	0.1
Illawarra Road	**2.9**	0.1	0.1	0.1	0.2	0.5	-0.7	-0.2	-0.4	0.0	0.1
Flinders Rd Bridge	**3.1**	0.1	0.2	0.2	0.2	0.5	-0.7	-0.2	-0.4	-0.1	0.2
Wardell Road	**3.3**	0.0	0.1	0.2	0.2	0.4	-0.9	-0.2	-0.6	-0.2	0.1
Lang Road Bridge	**3.4**	0.0	0.1	0.1	0.2	0.4	-0.9	-0.3	-0.7	-0.3	0.1
Foord Ave Bridge	**3.7**	0.0	0.1	0.1	0.1	0.3	-1.1	-0.3	-0.9	-0.5	0.1
Karool Ave Bridge	**3.8**	0.0	0.1	0.1	0.1	0.3	-1.2	-0.4	-0.9	-0.6	0.1
Canterbury Road	**4.1**	0.0	0.1	0.1	0.1	0.3	-1.4	-0.4	-1.2	-0.8	0.1
Canterbury Rail Bridge	**4.4**	0.0	0.0	0.1	0.1	0.2	-1.6	-0.5	-1.4	-1.0	0.0
Brighton Avenue	**4.9**	0.0	0.0	0.0	0.1	0.2	-2.0	-0.7	-1.7	-1.3	0.0

The results of varying the downstream water level for the rainfall induced scenarios (Runs 1 to 6) indicate that the effect diminishes with distance from Botany Bay. Up to a 1.4m AHD level produces only up to a 0.2m increase within the study area. Thus if the analysis was undertaken strictly in accordance with Reference 14 (i.e 1% AEP rainfall coincident with 5% AEP ocean – between Runs 3 and 4 – highlighted in Table 8) then the 1% AEP flood levels would increase by approximately 0.2m at the Princes Highway and 0.1m at Illawarra Road. However this increase is somewhat offset as assuming a constant tailwater is a more conservative approach that adopting a tidal varying level which is assumed for Reference 14. Run 11 indicates the relative change of using a tide in Botany Bay and the 1% AEP rainfall coincident with the 5% AEP ocean peak (taken as 1.4m AHD). This produces slightly lower peak levels than Run 4 (constant tailwater of 1.4m AHD).

Based on the above assessment and in conjunction with advice from the OEH the flood levels in the 2009 Cooks River Flood Study (Reference 2) have not been updated.

Run 7 is the ocean flooding scenario adopted in Reference 2. This indicates that apart from at the mouth (General Holmes Drive) the 1% AEP rainfall scenario produces higher flood levels. Run 8 is the ocean scenario but in accordance with Reference 14 (i.e 5% AEP rainfall coincident with 1% AEP ocean). This scenario produces slightly higher (by generally only 0.1m) levels than Run 1. Runs 9 and 10 indicate the impact of sea level rise on the ocean scenario (Run 7).

4.2. Hydraulic Classification

The 2005 NSW Government's Floodplain Development Manual (Reference 1) defines three hydraulic categories which can be applied to define different areas of the floodplain; namely floodway, flood storage or flood fringe.

Floodways

"those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels."

Flood Storage Areas

"those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas."

Flood Fringe

"the remaining area of flood prone land after floodway and flood storage areas have been defined".

There is no precise definition of flood storage and flood fringe or accepted approach to differentiate between the two areas and the delineation of these areas is somewhat subjective based on knowledge of an area, hydraulic modelling and previous experiences.

In reviewing the hydraulic modelling results presented in the Flood Study (Reference 2) no hydraulic classification of flood liable lands was undertaken. It is likely that some of the open space areas adjacent to the river are used for flood storage such as the flooded area of Marrickville golf club. However much of the flood extents, where properties are affected, are likely to be considered flood fringe. It should be noted that different design flood events will result in different areas of the floodplain being defined as flood storages areas or flood fringe due to differences in flood depths and velocities.

For this study hydraulic categorisation for the 1% AEP and PMF events was defined according to the following approach, namely:

Floodway = *Velocity * Depth > 0.25m*^{2}*/s AND Velocity > 0.25m/s OR Velocity > 1m/s*

The remainder of the floodplain outside the Floodway becomes either Flood Storage or Flood Fringe. In this study Flood Storage was defined as the land outside the Floodway if the depth is greater than 0.5m and Flood Fringe if the depth is less than 0.5m. As noted in the Floodplain Development Manual (Reference 1) *"it is impossible to provide explicitly quantitative criteria for defining floodways and flood storage areas, as the significance of such areas is site specific"*. The resulting maps are provided in Appendix B.

4.3. Flood Hazard Classification

Flood hazard is a measure of the overall adverse effects of flooding and the risks they pose. The 2005 NSW Government's Floodplain Development Manual (Reference 1) describes two *provisional flood hazard* categories; High and Low, based on the product of the depth and velocity of floodwaters. The provisional (hydraulic) hazard categories are only based on depth and velocity and do not take into account any other factors which may influence the flood hazard (Figure L2 of the Floodplain Development Manual). The boundary of the provisional High and Low hazard classification will change according to the magnitude of the flood. Mapping of flood hazard for the Cooks River is included in Appendix B.

To assess the full flood hazard all adverse effects of flooding have to be considered. As well as considering the provisional (hydraulic) hazard it also incorporates threat to life, danger and difficulty in evacuating people and possessions and the potential for damage, social disruption and loss of production. As with provisional (hydraulic) hazard, land is classified as either *Low* or *High* hazard for a range of flood events. A high hazard is defined as an area or situation where there is possible danger to personal safety, evacuation by trucks is difficult and able-bodies adults would have difficulty in wading to safety. There could also be potential for significant structural damage to buildings. In a low hazard situation people and possessions could still be evacuated by trucks if necessary and able-bodied adults would have little difficulty wading to safety.

An additional consideration is now required for areas that become permanently inundated as a result of sea level rise. While this is not a catastrophic event, it presents a high hazard to property and infrastructure over time.

The classification of flood hazard is a qualitative assessment based on a number of factors as listed in Table 9.

Table 9: Hazard Classification

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

(1) Relative weighting in assessing the hazard.

Due to the relatively steep nature of the sides of the river channel there is not a significant difference in flood extents between different sizes of floods except near Carrington Road, however the magnitude of the flood will affect the flood depths and velocities.

The rise of the Cooks River is dependent on the prevailing flood mechanism; fluvial or tidal. For fluvial events the Cooks River is known to rise within 4 to 6 hours and therefore little flood warning time is available. With tidal events there is greater warning as the heights of high tides are accurately known and storm surge (increase in water level above the astronomic level) effects occur over a period of days.

Flood awareness of the community is generally low to medium as there have been few significant events in recent times affecting properties in the area. This is partly due to the large open space land use corridor surrounding the Cooks River which means few are affected. The resulting depth of inundation in a larger, less frequent event will be much greater than what the community is expecting as it is likely that none of the current residents will have experienced this magnitude of flooding before.

For the majority of residents, as the floodplain extents are not vast, there should be relatively easily available vehicular access to dry higher ground. The vehicular and pedestrian access routes are all along sealed roads and present no unexpected hazards if the roads have been adequately maintained. An exception to this may be along Illawarra Road sub-area where the depth and distance of travel through floodwaters may be large. For the more frequent smaller flood events wading could be possible but is not recommended except as a last resort.

Hazard mapping for the 1% AEP event shows the hazard on Illawarra Road to be high, and also at the intersection of Riverside Crescent and Dibble Avenue. A number of bridges are below the 1% AEP flood level and would become unusable (see Section 4.7). However, in this instance although river crossing will not be possible, there is sufficient surrounding high ground to be able to remain safe from floodwaters.

The impact of debris is unlikely to be a major factor due to the lower flood depths/velocities in the more frequent smaller magnitude events. However for the larger flood events, particularly within the inundated residential areas, vehicles or other objects in streets or yards could float and cause structural damage to properties and even danger to life if people are in the water.

Due to the steep nature of the catchment it is likely that any rainfall event causing flooding of the Cooks River will also cause surface water flooding due to the pressure on the capacity of the piped drainage systems. Additionally, any surface water drainage systems that outfalls to the Cooks River will be unable to discharge during high river levels and thus reduce the capacity of the drainage system. This overland flooding has been considered as part of the Marrickville Valley Flood Study (Reference 6).

The true flood hazard for the study area varies by location according to the relative depths, velocities and effective flood access. True flood hazards for different areas, taking into account the provisional flood hazard and the criteria discussed above, are summarised in Table 10.

Table 10: True Flood Hazard for different areas (1% AEP event)

Location	True Flood Hazard	Comment
Riverside Crescent	High	High provisional hazard at junction of Riverside Crescent and Dibble Avenue
Illawarra Road	High	Bridge access cut. High provisional hazard on Wharf Street and Illawarra Road
Carrington Road	Low	The 1% AEP event is restricted by the Mackey Park levee
Bay Street	Low	Low velocities and shallow depths. Access available

These general hazard classifications will have to be reviewed against specific local conditions, and may increase in areas where the general depth of floodwaters exceeds 1 m, there are high flow velocities, and/or there is a risk of isolation and difficulties for evacuation.

In floods greater than the 1% AEP the hazard will increase as the depth increases. For the majority of areas, the flood level will increase gradually, and as such, residents will still be able to evacuate to higher ground.

4.4. Implications of Climate Change

4.4.1. Background

Climate change is predicted to cause an increase in sea level and possibly changes to design rainfall intensities. The likely impacts of this climate change include an increase in the intensity and frequency of tidal storm surges, an increase in rainfall intensity and storm activity, with accompanying damage to and destruction of human assets and settlements.

In developed urban areas which have a tidally influence river system, a rise in sea level is likely to influence the future building design, standards and performance as well as land zone and resources planning such as placement of vulnerable key residential service infrastructure such as power and water supply.

The 2005 Floodplain Development Manual (Reference 1) and 2010 Flood Risk Management Guide (Reference 14) requires that Flood Studies and Risk Management Studies consider the impacts of climate change on flood behaviour. Rising sea levels and increased rainfall intensities will affect construction and reconstruction of structures, such as embankments, river crossings and public access in the future.

In September 2012 the NSW Government repealed its 2009 Sea Level Policy which mandated that all coastal Councils in NSW must assume a 0.4m sea level rise by the year 2050 and 0.9m by the year 2100. However this announcement does not mean that the NSW Government considers sea level rise will not occur, rather it requires that each council must make their own interpretation of the available information and thus potentially adjoining councils will assume different levels. For councils which have already adopted a sea level rise policy then no change is required. Also, councils can still adopt the same benchmarks as outlined in the 2010 Flood Risk Management Guide (Reference 14).

4.4.2. Revision of Climate Change Assessment

The 2009 Flood Study considered climate change by increasing rainfall intensity by 20% and increasing the downstream boundary of the High Water Spring Solstice peak of 1.1 m AHD by 0.55m to account for sea level rise. Since publication of the 2009 study more recent NSW government guidance is now available of climate change (References 13 and 14). Therefore, for the purpose of this FRMS the hydraulic models were re-run using a sea level increase of 0.4m and 0.9m expected to be reached by 2050 (1.5m AHD boundary) and 2100 (2.0m AHD boundary) respectively. In addition the effect of a 10% rainfall intensity increase for the year 2050 and 2100 sea level rise scenarios were modelled. Figures showing flood levels, depths and velocities for these scenarios are provided in Appendix B.

4.4.3. How will Climate Change Affect Water Levels in the Cooks River?

Climate change has the potential to alter the water level in both non-flood and flood times.

During Non-Flood Times

Given that flooding in the lower reaches of the Cooks River is influenced by tide levels, the main impact in non-flood times will be in the increase in the general water level of the Cooks River due to elevated sea levels (0.4m in the year 2050 and by 0.9m in the year 2100 as determined by the NSW State Government's 2010 Flood Risk Management Guide - Reference 14). This rise in water levels will increase the permanently inundated area and effectively widen the river corridor.

The increase in the normal water level in the Cooks River during non-flood times may result in increased maintenance costs and/or modifications costs for existing developments and infrastructure (golf course) due to more frequent inundation in non-flood times. The increased cost for residents and Marrickville Council to maintain the existing developments and infrastructure is unknown. A separate study is required to quantify the effect in non-flood times but it is likely that at some time in the future the existing services in particularly low lying areas for example river crossings, will become unable to be maintained and it will have to be relocated or re-built. This may affect service standards to existing developments.

The increase in water levels during non-flood times may also see some areas of land that are currently dry become flooded most of the time. Currently much of the floodplain area is zoned for recreational use and inundation of this area will therefore not have significant adverse effects on developed areas. However, an increase in permanent inundation will still affect the current use of that land and strategic planning is necessary to reduce the economic impact resulting from this flooding.

Any change in the normal water level regime could also impact on the ecology of the Cooks River. The implications of this are largely outside the scope of this Floodplain Risk Management Study though may want to be considered when considering land use zoning.

During Flood Events

Climate change may affect the behaviour of flood events in several ways and flooding mechanisms and the flood regime will change in the future due to this. An increase in peak rainfall intensity and storm volume will increase design flood levels during a fluvial flood event. In addition the increase in ocean level will raise the normal water level in the Cooks River as well as the assumed ocean level adopted for design flood estimation. For the 1% AEP event an increase of up to 0.3m will occur due to a 10% increase in rainfall alone. When this is combined with a rise in ocean levels flood levels will increase significantly as indicated in Table 11.

Table 11: Increase in 1% AEP Flood Levels due to Climate Change

	Existing Flood Level (mAHD)	Revised Flood Level (m AHD)					
		+10%RF	+ 30%RF	SL+0.4m	SL+0.9m	SL+0.4m + 19% RF	SL +0.9m +10%RF
Riverside Cres	**3.15**	3.39	3.72	3.37	3.60	3.52	3.73
Illawarra Road	**2.95**	3.12	3.49	3.13	3.40	3.26	3.52
Carrington Rd	**1.39***	1.54	2.98	1.86	3.00	2.16	3.11
Bay Street	**2.14**	2.22	2.52	2.35	2.60	2.41	2.64

NOTE - RF = Rainfall Increase; **SL** = Sea level rise
*most properties in this area are protected by the Mackey Park levee.

4.4.4. Impacts of Climate Change to Flood Risk from the Cooks River

Given that the Cooks River is tidally influenced, future development and redevelopment of riverside areas will need to factor how future sea level rise will impact on the existing and proposed developments. For a 1% AEP event occurring in the year 2050 (0.4m sea level rise) and 2100 (0.9m sea level rise) a further 17 and 41 buildings respectively will be inundated above floor level based on the floor level survey (see Table 15, Section 4.5.2).

The impacts of increased flood levels due to climate changed was considered with reference to the flood planning level (FPL); taken as the 1% AEP flood level plus 0.5m. The number of properties affected by the FPL in the year 2012, 2050 and 2100 flood scenarios was undertaken by simply counting the number of cadastre properties within the FPL extents. This analysis (Table 12) identified properties which are within the FPL extents, however it should be noted that although flood waters may encroach onto a property, this does not take into account whether or not a building is flooded above floor level.

Table 12: Increase in Flood Affected Properties in the 1% AEP Event due to Climate Change

Year	No. Properties Tagged As At Or Below the FPL	Increase in Number of Properties from 2012 FPL
2012	514	**-**
2050 (+0.4m)	555	41
2100 (+0.9m)	579	65

A total of 65 additional properties would be affected by the FPL in 2100 based on current sea level rise predictions. Although a significant number of residential properties would become affected by flooding in the future, there is a greater increase in the number of non-residential properties affected by flooding in the climate change scenarios. Extent mapping shows that a particularly high increase in the number of flooded properties will occur in the Carrington Road industrial area (Figure B2) where sea level rise concurrent with a 1% AEP event would cause overtopping of the Mackey Park levee which currently affords protection to many industrial and commercial properties.

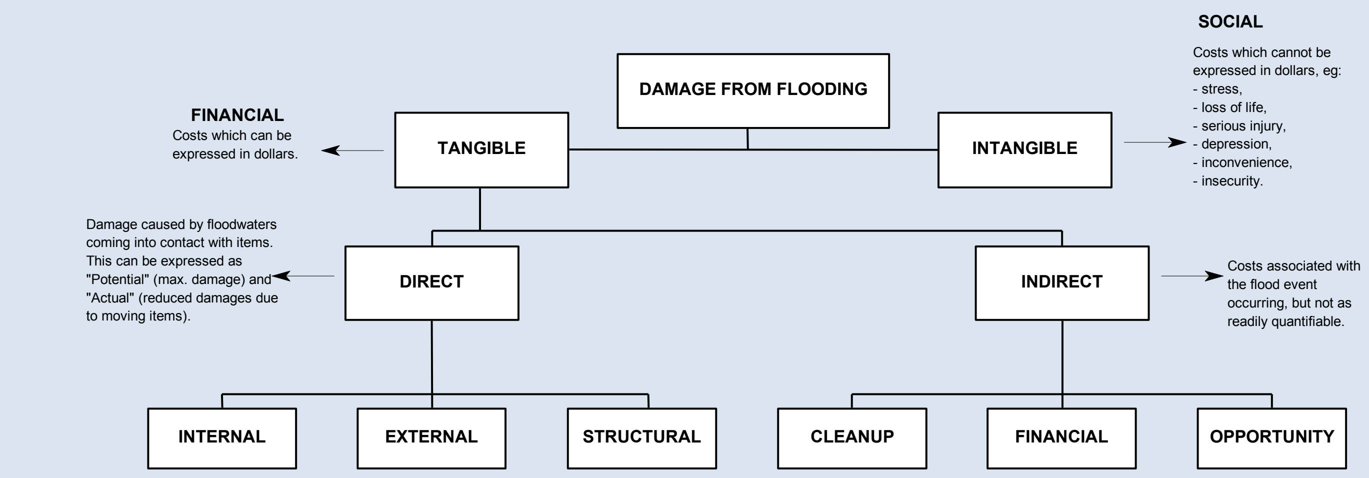
4.5. Flood Risk and the Social Impacts of Flooding

For impacts to which a monetary value can be assigned, the social impacts of flooding can be estimated by calculating a value of flood damages. The quantification of flood damages is an important part of the floodplain risk management process. By quantifying flood damage for a range of design events, appropriate cost effective management measures can be analysed in terms of their benefits (reduction in damages) versus the cost. The costs 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 use and susceptibility to damages;
- awareness of the community to flooding;
- effective warning time;
- the availability of an evacuation plan or damage minimisation program;
- physical factors such failure of services (sewerage), flood borne debris, sedimentation; and
- the types of asset and infrastructure affected.

The estimation of flood damages tends to focus on the physical impact for the human environment but there is also a need to consider the ecological cost and benefits associated with flooding. Flood damages can be defined as being “tangible” or intangible”. Tangible damages are those for which a monetary value can be assigned, in contrast to intangible damages, which cannot easily be attributed a monetary value. A summary of the types of flood damages is shown on Table 13.

Table 13: Flood Damages Categories (including damage and losses from permanent inundation)



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

4.5.1. Tangible Flood Damages

Tangible flood damages comprise two basic categories; direct and indirect damages. Direct damages are caused by floodwaters wetting goods and possessions thereby damaging them and resulting in either costs to replace or repair or a reduction in their value. Direct damages are further classified as either internal (damage to the contents of a building including carpets, furniture), structural (referring to the structural fabric of a building such as foundations, walls, floors, windows) or external (damage to all items outside the building such as cars, garages). Indirect damages are the additional financial losses caused by the flood for example the cost of temporary accommodation and loss of wages by employees involved in clearing up after the event.

Given the variability of flooding and property and content values, the total likely damages figure in any given flood event is useful to get a "feel" for the magnitude of the flood problem, however it is of little value for absolute economic evaluation required when studying the economic effectiveness of proposed mitigation options. Understanding the total damages prevented over the life of the option in relation to current damages, or to an alternative option, can assist in the decision making process.

The standard way of expressing flood damages is in terms of average annual damages (AAD). AAD is equal to the damage caused by all floods over a period of time divided by the number of years in that period and represents the equivalent average damages that would be experienced by the community on an annual basis. This means that the smaller floods, which occur more frequently, are given a greater weighting than the rarer catastrophic floods.

A flood damages assessment was undertaken for existing development along the floodplain of the Cooks River in accordance with the DECC (now OEH) guideline (Reference 15) and Floodplain Development Manual (Reference 1). In order to quantify the damages caused by inundation of existing development, the floor level database from the 1994 Flood Study (Reference 3) was used and additional floor level survey was undertaken by Peter Bolan & Associates Registered Surveyors (as part of this present study) where necessary to supplement this. It should be noted damage calculations have been based on those residential properties identified as being located within the 1% AEP flood extent. It is possible that some buildings beyond this extent may be inundated in larger events.

The damages were calculated with use of a number of height/damage curves which relate the depth of water above the floor with tangible damages. These have been developed based on guidelines provided by DECC (now OEH). Each component of tangible damages is allocated a maximum value and a maximum depth at which this value occurs. Any flood depths greater than this allocated value do not incur additional damages as it is assumed that, by this level, all damages have already occurred.

For the Cooks River (Table 14) assessment external damages (damages caused by flooding below the floor level) were set at $8,375 and additional costs for clean-up as $5,000. For additional accommodation costs or loss of rent a value of $825 was allowed assuming that the property would have to be unoccupied for up to three weeks. Internal (contents) damages were allocated a maximum value of $60,000 occurring at a depth of 2m above the building floor level (and linearly proportioned between the depths of 0 to 2 m). Structural damages vary on whether the property is slab/low set or high set. For the purpose of this study, any property with a floor level of 0.5m or more above ground level was assumed to be high set. For two storey houses, damages (apart from external damages) are reduced by a factor of 70% where only the ground floor is flooded as it is assumed some contents will be on the upper floor and unaffected and that structural damage costs will be less.

This flood damages estimate does not include the cost of restoring or maintaining services and infrastructure. In some instances external damage may occur even where the property is not inundated above floor level and therefore tangible damages include external damages which may occur with or without building floor inundation.

Figure 4 indicates the design flood event which first inundates the building floor on the property.

Table 14: Summary of Tangible Damages for Surveyed Properties

Event	No. Flooded Above Floor Level	Properties Affected	Tangible Flood Damages	Average Tangible Damages Per Damaged Property
RIVERSIDE CRESCENT AREA				
2-year (50% AEP)	0	3	$25,125	$8,375
20-year (5% AEP)	6	9	$336,901	$37,433
100-year (1% AEP)	9	14	$581,289	$41,521
200-year (0.5% AEP)	13	20	$959,799	$47,990
PMF	43	44	$3,861,925	$87,771
Riverside Crescent area - Average Annual Damages			**$109,422**	**$2,487**
ILLAWARRA ROAD AREA				
2-year (50% AEP)	0	0	$0	$0
20-year (5% AEP)	5	24	$440,762	$18,365
100-year (1% AEP)	21	31	$1,187,387	$38,303
200-year (0.5% AEP)	27	50	$1,876,242	$37,525
PMF	68	69	$6,977,803	$101,128
Illawarra Road area - Average Annual Damages			**$161,484**	**$2,340**
CARRINGTON ROAD AREA				
2-year (50% AEP)	0	0	$0	$0
20-year (5% AEP)	0	0	$0	$0
100-year (1% AEP)	0	6	$64,236	$10,706
200-year (0.5% AEP)	7	19	$613,620	$32,296
PMF	21	21	$2,265,727	$107,892
Carrington Road area - Average Annual Damages			**$10,163**	**$484**
BAY STREET AREA				
2-year (50% AEP)	0	0	$0	$0
20-year (5% AEP)	0	10	$126,969	$12,697
100-year (1% AEP)	4	11	$326,427	$29,675
200-year (0.5% AEP)	10	17	$588,039	$34,591
PMF	23	25	$1,623,535	$64,941
Bay Street area - Average Annual Damages			**$45,440**	**$1,818**
TOTALS FOR STUDY AREA				
2-year (50% AEP)	0	3	$25,125	$8,375
20-year (5% AEP)	11	43	$904,633	$21,038
100-year (1% AEP)	34	62	$2,159,339	$34,828
200-year (0.5% AEP)	57	106	$4,037,700	$38,092
PMF	155	159	$14,728,990	$92,635
Average Annual Damages			**$326,509**	**$2,054**

Note: No floor levels obtained in the Alexandra Canal area

The damages assessment shows that within the Carrington Road area there is a significant rise is damages between the 1% AEP and 0.5% AEP event. This is due to the properties afforded protection by the Mackey Street levee, however at the 0.5% AEP event the levee is overtopped. Average annual damages per property are fairly consistent between the areas with the Carrington Road average annual damages low due to the area being protected in the smaller flood events. The Bay Street area also has lower average annual damages due to the lower damage value per property in the PMF event. This is due to a smaller difference between the range flood levels at this location compared to elsewhere.

4.5.2. Tangible Flood Damages for Climate Change

The increase in tangible flood damages has been used to consider the potential increase in flood impact for a 1% AEP event due to predicted climate change effects. No adjustments have been made to the future damages figure to allow for increases in average weekly earnings or other indexes and therefore represent a relative cost in real terms.

The NSW Government's Guidance on climate change (Reference 14) predicts an expected sea level rise of 0.4m by the year 2050 and 0.9m by 2100. As well as sea level rise, climate change is likely to increase rainfall intensity. Table 15 highlights the potential increase in buildings inundated flooded during a 1% AEP event now and in the years 2050, 2100 and with an increase in rainfall depth of 10% applied. Mapping of the 1% AEP events for 2050 and 2100 is also included as Figure B2.

Table 15: Increase in Floor Levels Inundated due to Climate Change

	Existing 1% AEP event	Sea Level Rise by 0.4m Year 2050	Sea Level Rise by 0.9m Year 2100	Rainfall Increase 10%
Buildings inundated above Floor Level	34	51	75	42
Increase	-	17	41	8
Increase (%)	-	+50%	+121%	+24%

NOTE - only includes properties where floor levels were surveyed for this Study. Therefore potentially more properties could be flooded above floor level but were not included in the survey.

Based on the above, the tangible flood damages for a 1% AEP event are shown in Table 16. The increase in flood damages due to sea level rise alone (i.e. no increase in rainfall), for a 1% AEP event, is significant. An increase in the total cost of damages of 53% and 146% could be seen by the year 2050 and 2100 respectively. The area most affected is Carrington Road. This area is currently protected by Mackey Park levee to approximately the 1% AEP standard. However, during any event of greater magnitude the levee, if it remains at its current level, will be overtopped.

Table 16: Tangible Flood Damages – 1% AEP event – Increases due to Sea Level Rise

Area	Existing 2011	+0.4m Sea Level Rise Year 2050	+0.9m Sea Level Rise Year 2100
Riverside Crescent	$ 581,289	$ 738,279 (27%)	$ 925,683 (59%)
Illawarra Road	$ 1,187,387	$ 1,470,177 (24%)	$ 2,118,045 (78%)
Carrington Road	$ 64,236	$ 502,404 (682%)	$ 1,508,481 (2248%)
Bay Street	$ 326,427	$ 588,039 (80%)	$ 757,679 (132%)
Total:	**$ 2,159,339**	**$ 3,298,899 (53% increase)**	**$ 5,309,887 (146% increase)**

NOTE - (% increase in brackets)

4.5.3. Intangible Flood Damages

The intangible damages associated with flooding, by their nature, are inherently more difficult to estimate in monetary terms. In addition to the tangible damages discussed above, additional costs/damages are incurred by residents affected by flooding, such as stress, risk/loss to life, injury, loss of sentimental items etc. It is not possible to put a monetary value on the intangible damages as they are likely to vary dramatically between each flood (from a negligible amount to several hundred times greater than the tangible damages) and depend on a range of factors such as the size of flood, the individuals affected, and community preparedness. However, it is still important that the consideration of intangible damages is included when considering the impacts of flooding on a community.

Post flood damages surveys have linked flooding to stress, ill-health and trauma for the residents. For example the loss of memorabilia, pets, insurance paper and other items without fixed costs and of sentimental value may cause stress and subsequent ill-health. Flooding may affect personal relationships and lead to stress in domestic and work situations. In addition to the stress caused during an event (from concern over property damage, risk to life for the individuals or their family, clean up etc.,) many residents who have experienced a major flood are fearful of the occurrence of another flood event and its associated damages. The extent of the stress depends on the individual and although the majority of flood victims recover, these effects can lead to a reduction in quality of life for the flood victims.

During any flood event there is the potential for injury as well as loss of life due to causes such as drowning, floating debris or illness from polluted water. Generally, the higher the flood velocities and depths the higher the risk of loss of life. The Cooks River floodplain has a combination of high and low hazard areas within the built up residential areas. However, there will always be local high risk (high hazard) areas where flows may be concentrated around buildings or other structures within low hazard areas.

4.6. Flood Awareness and Flood Warning

The flood awareness of the community and the available flood warning time are important factors in reducing the likely flood damages. Based on experience in other areas it is likely that the flood awareness of the community is relatively low, although the recent March 2012 event would have increased awareness somewhat. The 1997 Cooks River Floodplain Management Plan (Reference 4) gave a high priority for the provision of flood awareness programs and flood hazard notification.

The available flood warning time is relatively low as the river rises relatively quickly; the physical modifications to the river over the years including it being predominantly concrete lined and many straightened reaches means that the Cooks River functions more like a stormwater drainage system than a river system. In addition, overland flooding which occurs when the drainage network is overwhelmed is difficult to predict and produces its own flooding issues.

The extent or success of damage mitigation measures employed by the residents during the March 2012 event is unknown. However as a number of vehicles were stranded during the flood event this suggests that the inundation happened relatively quickly and the flood warning time was low (the peak of the event was early to mid-morning on a weekday).

Although the BoM may issue severe weather warnings for the Cooks River area there is no official flood warning system in place due to the rapid response time of the catchment. The BoM can sometimes provide advance warning of heavy rain but once the rain occurs there is no time to interrogate rainfall and water level gauges and make a prediction of the magnitude or time of the river peak along its length.

As no flood warning exists the onus falls on residents to realise when flood waters are rising near their property and to prepare for the onset of flooding. However, the SES has door-knocked during past events such as March 2012, to evacuate residents when water levels are rising. The success of this will depend on the nature of each event; it may be associated with preceding rain or high winds that mean the SES are otherwise engaged and therefore may not have resources to warn and evacuate. A high level of flood awareness will obviously mean that residents can act in an efficient manner to protect their lives and property.

4.7. Impacts of Flooding on Public Infrastructure

Public sector (non-building) damages include; recreational/tourist facilities, water and sewerage supply, gas supply, telephone supply, electricity supply including transmission poles/lines, sub-stations and underground cables, roads and bridges including traffic lights/signs, and costs to employ the emergency services and assist in cleaning up. Damages to the public sector can contribute a significant proportion of the total flood costs but are difficult to accurately calculate or predict.

Fixed infrastructure such as roads and sewer (refer below) are particularly vulnerable to permanent inundation as sea levels rise. This will increase maintenance and service costs, and may lead to long-term failure of some assets unless they are re-designed or relocated.

Cooks River Sewerage Aqueduct

The Cooks River Sewerage Aqueduct crosses the Cooks River between Wanstead Reserve in Undercliffe, Canterbury to Thorley Street, Marrickville. This aqueduct, completed in 1895, is now part of the Southern and Western Suburbs Ocean Outfall Sewerage System (SWSOOS).

Sewer Pumping Stations

The sites of two sewer pumping stations at Wharf Street and Riverside Crescent are located within the 1% AEP flood extent. These were both included in the recent floor level survey, although not included in the damages assessment, with details summarised in Table 17.

Table 17: Sewer Pumping Station Survey Details

Location	Indicative Ground Level* (mAHD)	Lowest Floor Level (maHD)	Approx. Floor Area (m^2)	Floor Construction	Wall Construction
Wharf Street (SPS 68)	2.41	3.46	40	slab	brick
Riverside Crescent (SPS 45)	3.88	4.28	40	slab	brick

NOTE - ground level across the site varies, indicative ground level taken at building location

Should these become flooded then infrastructure failure could have significant impacts. However, at both sites the floor levels are raised above the surrounding ground. An assessment of the floor level relative to the design flood levels, including climate change scenarios, shows that it is only in the PMF event that both stations will be flooded above floor level. With their current floor levels they are afforded protection until the year 2100 based on current climate change predictions (Table 18 and Table 19).

Table 18: Riverside Crescent Sewer Pumping Station (SPS45) Flood Levels

Event	Flood Level (mAHD)	Depth Above Ground (m)	Depth Above Floor (m)	Floor Flooded?
DESIGN EVENTS				
50% AEP	2.16	-1.72	-2.12	no
5% AEP	2.88	-1.00	-1.40	no
1% AEP	3.32	-0.56	-0.96	no
0.5% AEP	3.80	-0.08	-0.48	no
Probable Maximum Flood	6.43	**2.55**	**2.15**	**yes**
CLIMATE CHANGE SCENARIOS				
1% AEP +RF10%	3.56	-0.32	-0.72	no
2050 – 1% AEP	3.52	-0.36	-0.76	no
2050 – 1% AEP +RF10%	3.68	-0.20	-0.60	no
2100 - 1% AEP	3.73	-0.15	-0.55	no
2100 - 1% AEP +RF10%	3.87	-0.01	-0.41	no

Table 19: Wharf Street Sewer Pumping Station (SPS68) Flood Levels

Event	Flood Level (mAHD)	Depth Above Ground (m)	Depth Above Floor (m)	Floor Flooded?
DESIGN EVENTS				
50% AEP	-	-2.41	-3.46	no
5% AEP	2.48	0.07	-0.98	no
1% AEP	2.90	0.49	-0.56	no
0.5% AEP	3.27	0.86	-0.19	no
Probable Maximum Flood	6.22	**3.81**	**2.76**	**yes**
CLIMATE CHANGE SCENARIOS				
1% AEP +RF10%	3.05	0.64	-0.41	no
2050 - 1% AEP	3.07	0.66	-0.39	no
2050 - 1% AEP +RF10%	3.19	0.78	-0.27	no
2100 - 1% AEP	3.35	0.94	-0.11	no
2100 - 1% AEP +RF10%	3.47	**1.06**	**0.01**	**yes**

River Crossings

Within the study area, six river crossings traverse the Cooks River (not including the SWSOOS). From west to east these are;

- Wardell Road bridge;
- Footbridge near the golf course;
- Illawarra Road bridge;
- Unwins bridge (Bayview Avenue);
- The rail line crossing; and
- The Princes Highway.

During a flood event, should these structures become inundated there could be difficulties with access. A coarse assessment was undertaken to assess when these structures, or access to them, would become inundated. The level of each structure or the access to it was approximated from the ALS data. As ALS is smoothed over watercourses, and bridges tend to rise slightly as they cross a river, levels of the ground either side were used where these were lower. When the path to the bridge is cut off effectively this also cuts the bridge access.

Table 20 highlights the expected design flood levels at each of the structures and identifies when these first become flooded. Access to the pedestrian bridge at the golf course is likely to be cut off first while the Princes Highway is likely to be the last road crossing in the study area to become impassable.

Table 20: Cooks River Crossings Flood Levels (m AHD)

Location	Access Level	50% AE)	5% AEP	1% AEP	0.5% AEP	PMF	Access Flooded?
Wardell Road bridge	**1.75**	2.14	2.81	3.25	3.72	6.43	50% AEP
Footbridge	**1.40**	2.05	2.64	3.08	3.56	6.36	50% AEP
Illawarra Road bridge	**1.60**	1.92	2.47	2.89	3.26	6.22	50% AEP
Unwins bridge (Bayview Ave)	**1.40**	1.63	2.20	2.48	2.74	5.41	50% AEP
Rail line crossing	**4.00**	1.54	1.98	2.27	2.49	5.06	PMF
Princes Highway	**2 to 5**	1.48	1.89	2.15	2.35	3.43	1% AEP

Although Wardell Road bridge may be above the flood level, an area of Wardell Road approximately 100m to the west of the bridge (in Canterbury LGA) is flooded in the 50% AEP event by flood waters spilling from the river at the upstream meander.

Access to the footbridge by the golf course becomes inundated in the 50% AEP event to depths of 0.4m and therefore, despite the fact that the bridge itself is raised over 1m above the ground, this would not be a suitable evacuation or flood access route.

At Illawarra Road the levels on the road are low and subject to flooding. On occasions this area is also known to be subject to flooding from high tides. Flood modelling shows the road to become flooded to a depth of 0.3m in the 50% AEP event. The road was flooded to a depth of approximately 0.3m in the recent March 2012 event (flood level of 1.99 mAHD). At this depth flood waters are still passable in a vehicle although not recommended, however at a depth of 0.9m (likely to occur in the 5% AEP event), traversing flood waters is dangerous and normal vehicles cannot pass through.

Bayview Avenue is at a level of approximately 1.4 mAHD as it heads east towards Unwins Bridge. The road here could become inundated to a depth of 0.6m in the 5% AEP event at which the hazard is considered high and dry access to the bridge is cut from either direction. An event between the 50% AEP and 5% AEP was not modelled, however it is likely that this access route will be flooded more frequently than the 5% AEP event.

The railway line is not overtopped in the 0.5% AEP event although it is inundated in the PMF by depths of over 1m. Although not shown to flood from an event on Cooks River, the Marrickville Valley Flood Study (Reference 6) shows that the rail lines could be potentially affected by overland flow in a much smaller event than this near Sydenham Station.

Although the Princes Highway bridge itself does not become inundated, there is a depression in ground levels approximately 90m to the north of the crossing which modelling shows to be subject to flood depths of 0.1m in the 1% AEP event. This is unlikely to make the bridge impassable and emergency trucks should still easily pass at these depths. The flood depth increases to 0.25m for the 0.5% AEP event when traversing flood water can become more difficult. Flood mapping also shows an area of the highway 500-600m south of the crossing, at the junction of Gertrude Street is flood prone in the 1% AEP event although alternate access is likely around the back streets.

4.8. Impacts of Flooding on Commercial and Industrial Activities

Commercial and industrial activities will also be adversely affected by flooding and vulnerable to permanent inundation as sea levels rise due to climate change. The damages to a commercial or industrial property are much more variable than for residential properties, as they are heavily influenced by the type of business being carried out and the amount of stock being carried. A damages assessment for these properties is therefore of limited value unless information is obtained about the use of the buildings. A damages assessment was not undertaken for these properties but clearly flooding will cause both direct and indirect damages.

Within the 1% AEP flood extent, the number of non-residential properties (not necessarily building floors) subject to flooding will increase from 185 to 244 by the year 2050 and to 283 by the year 2100 under current developed conditions (see Section 4.4.4 and Table 13). Although currently afforded some protection by the Mackey Park levee, Carrington Road lies in a natural valley line and the climate change scenarios indicate a significant increase in flooding to the area in the future unless this is managed.

As re-development occurs in the area, it likely that measures to mitigate the impacts of flooding and climate change can be incorporated into the building design of new developments. This issue would need to be examined on a case by case basis.

4.9. Environmental Impacts of Flooding

Flooding is a natural phenomenon that has been a critical element in the formation of the present topography. Thus erosion, sedimentation and other effects from flooding should be viewed as part of the natural ecosystem. It is only when these impact on man-made elements that they are of concern, and similarly, when development impacts or exacerbates these processes.

There is little natural environment remaining on the Cooks River and much of the area is heavily urbanised with the river corridor subject to unsympathetic hard engineering. The character of the river banks has been gradually improved over recent years with landscaping and beautification of Council parklands as well as the current scheme (undertaken under the Estuary Management Program) to naturalise areas of the Cooks River bank by cutting the existing sheet piling at bed level and creating ‘natural’ vegetated banks.

4.10. Flood Emergency Response Classification

To assist in the planning and implementation of response strategies, the SES in conjunction with DECCW (now OEH) have developed guidelines to classify communities according to the impact that flooding has upon them (Reference 16). Flood affected communities are considered to be those in which the normal functioning of services is altered, either directly or indirectly, because a flood results in the need for external assistance. This impact relates directly to the operational issues of evacuation, resupply and rescue. Based on the guidelines, communities are classified as either; Flood Islands; Road Access Areas; Overland Access Areas; Trapped Perimeter Areas or Indirectly Affected Areas (refer Table 21). From this classification an indication of the emergency response required can be determined. Key considerations for flood emergency response planning in these areas include;

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

Table 21: Emergency Response Classifications of Communities

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

The guideline was applied for the community living alongside the Cooks River as shown on Figure 5 for the PMF event. Generally many residential properties fall within the classification of an area with rising road access. These are areas where people can be progressively evacuated from low-lying areas as the level of inundation increases. Rescue is unlikely to be needed unless people have delayed evacuation from their homes or have reason that they cannot wade or take their own vehicular access through floodwaters (entering floodwaters is not recommended by the SES).

In the Riverside Crescent area most residential properties are in the area of rising road access. However, a few properties in the cul-de-sac of Pilgrim Avenue could be considered to be within a low trapped perimeter area where the land is lower than the PMF and during a flood can become isolated as access is cut. The properties may become inundated if floodwaters continue to rise after it is isolated.

Within the Illawarra Road area the Marrickville golf club falls within an area with an overland escape route as people can easily walk over open land out of the flood extent. Properties to the east of Illawarra Road within the PMF flood extents fall under the classification of an area with rising road access. A few properties on Cahill Place can be considered to be within a high trapped perimeter area. Although out of the PMF flood extents access to these properties would require traversing through the floodplain and hence the area could become isolated. Other properties on Illawarra Road and Wharf Street could fall within low trapped perimeter areas.

Within the Carrington Road area most properties have rising road access. However, some properties around Renwick Street could be considered to be in a low trapped perimeter area. The Bay Street area properties all fall within a rising road access classification.

4.11. Implications of Future Development

Future development can cause hydrological impacts such as increased runoff due to increased land cover. However, the Cooks River catchment is already extensively urbanised and therefore it is unlikely increased building construction within the catchment will have any significant impact on the flood regime by increased runoff volumes or the rate of runoff.

Development along the river bank areas can reduce the available floodplain storage capacity and affect overland flow paths hence locally increase levels. However, at present much of the land use along the Cooks River corridor is given over to public recreation areas and therefore will remain undeveloped. This land use activity is considered an appropriate use for a flood storage or flood fringe area.

5. RISK MANAGEMENT MEASURES

5.1. Introduction

This floodplain risk management study aims to identify and assess risk management measures which could be put in place to mitigate flooding impacts and reduce flood damages. The risk management measures should be assessed against the legal, structural, environmental, social and economic conditions or constraints of the local area. The 2005 NSW Government's Floodplain Development Manual (Reference 1) separates risk management measures into three broad categories.

Flood modification measures modify the physical behaviour of a flood including depth, velocity and redirection of flow paths. Typical measures include flood mitigation dams, retarding basins, on-site detention, channel improvements, levees or floodways.

Property modification measures modify the existing land use and development controls for future development. This is generally accomplished through such means as flood proofing such as house raising or sealing entrances, strategic planning such as land use zoning, building regulations such as flood-related development controls, or voluntary purchase.

Response modification measures modify the response of the community to flood hazard by educating flood affected property owners about the nature of flooding so that they can make better 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.

Table 22 below provides a summary of floodplain risk management measures that could be considered for the Cooks River floodplain, though many are clearly not viable.

Table 22: Flood Risk Management Measures

Flood Modification	Property Modification	Response Modification
Flood mitigation dams	Land zoning	Community awareness/preparedness
Retarding basins	Voluntary purchase	Flood warning
Bypass floodways	Building & development controls	Evacuation planning
Channel modifications	Flood proofing	Evacuation access
Levees	House raising	Flood plan / recovery plan
Temporary defences	Flood access	Flood insurance

5.1.1. Relative Merits of Management Measures

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 option enabling the ranking against similar projects in other areas. The benefit/cost ratio is the ratio of the net present worth (the total present value of a time series of cash flows) and the cost of implementation. It is a standard method for using the time value of money to appraise long-term projects of the reduction in flood damages (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 intangible damages.

The potential environmental or social impacts of any proposed flood mitigation measure must be considered in the assessment of any management measure and these cannot be evaluated using the classical benefit/cost approach. For this reason a matrix type assessment has been used which enables a value (including non-economic worth) to be assigned to each measure.

Due to the limited number of options available this matrix was not rigorously used for each option and was used only as a guideline for assessing options. It is a recommendation of this report that multi-variate decision matrices be developed for specific sub areas when considering measures to adapt to climate change (if required), allowing detailed benefit/cost estimates, community involvement in determining social and other intangible values, and local assessment of environmental impacts.

5.1.2. Management Matrix

The criteria assigned a value in the management matrix are;

- impact on flood behaviour (reduction in flood level, hazard or hydraulic categorisation) over the range of flood events;
- number of properties benefited by measure;
- technical feasibility (design considerations, construction constraints, long-term performance);
- community acceptance and social impacts;
- economic merits (capital and recurring costs versus reduction in flood damages);
- financial feasibility to fund the measure;
- environmental and ecological benefits;
- impacts on the State Emergency Services;
- political and/or administrative issues;
- long-term performance given the likely impacts of climate change and ocean/sea level rises; and
- risk to life.

The scoring system for the above criteria is provided in Table 23 and largely relates to the impacts in a 1% AEP event. The matrix below is designed to set out a general scheme to illustrate how a local matrix might be developed. These criteria and their relative weighting may be adjusted in the light of community consultations and local conditions.

Table 23: Matrix Scoring System

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

5.2. Measures Not Considered Further

It was apparent that after a preliminary assessment that a number of risk management measures were not worthy of further consideration. These are summarised below.

5.2.1. Flood Mitigation Dams, Retarding Basins, On-Site Detention

Large flood mitigation dams within the catchment are not viable on economic, social and environmental grounds. They are rarely used as a flood mitigation measure for existing development or in urban areas on the account of the likely low benefit cost ratio due to high construction costs, significant land demand, environmental damage and risk of failure. Often a considerable volume of water needs to be impounded in order to create a reduction in flood level downstream.

Construction of retarding basins and the use of on-site stormwater detention (OSD) or retention systems are increasingly being used in developing catchments and Marrickville Council (as well as all other LGAs contributing to the Cooks River catchment) has an OSD policy which is applied within its LGA. These measures are appropriate for use in controlling flooding in small catchments or to mitigate the effects of increased runoff caused by development within the local catchments. However, due to the significant urban nature of the Cooks River catchment they will have negligible impact in reducing flood levels in the Cooks

River.

Detention basins are currently used at Marrickville Oval and the Sydenham storage pit to provide for temporary storage of overland flow floodwaters. The Marrickville Oval was formalised in 1996 as a flood retarding basin after a combination of a concrete reinforced masonry wall and an earthen bund were constructed around the oval. The Oval is the only retarding basin in the catchment where flows are not pumped out (as occurs at the Sydenham storage pit).

Although there are a few retarding basins within the catchment, these are for overland flooding and whilst they would provide a benefit in this respect would provide little benefit in terms of reduced Cooks River flood levels. Given the lack of open space on which communal retarding basins could be located, due to the highly urbanised nature of the catchment, these methods are not prioritised. However, where possible opportunities to incorporate basins into parklands exist they should be explored.

5.2.2. Channel Modifications

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 levels. Channel modification includes a range of measures from straightening, concrete lining, removal of structures limiting the hydraulic capacity of the river, dredging and vegetation clearing. In some instances 'naturalising' the channel upstream can reduce peak levels downstream by slowing flows (but likely increasing flood levels upstream). The Cooks River has been subject to much concrete lining and piping, with the channel also being straightened and realigned that there are few further opportunities for improving its capacity.

Naturalising Banks

The Cooks River has already undergone significant amounts of straightening and clearing over the years and much of the river bank is formed with sheet piling. A recently completed project has been to cut the sheet piling at bed level and replacing this with vegetated banks. This is an ongoing project which seeks to restore the 'natural' river bank at several locations along the Cooks River between the freshwater sections at Centenary Drive, Strathfield, to the tidal saltwater sections of the river leading into Alexandra Canal at Sydney Airport.

The existing sheet piling with say a golf course adjoining is a hydraulically efficient bank profile. Naturalisation will introduce denser vegetation and thus reduce the overbank hydraulic efficiency and so increase flood levels upstream. This can be compensated for by shaving the overbank to increase the waterway area but will mean loss of useability of the overbank from its existing purpose. Experience indicates that it can be very difficult to achieve no adverse impact on flood levels with a naturalisation project.

Bank naturalisation is not undertaken as a flood mitigation measure but rather as an environmental or aesthetic measure. As such the naturalisation works will not receive funding under the flood mitigation program. For this reason the feasibility of these naturalisation works has not been considered further.

In conclusion these projects are supported as long as the works do not increase flood levels for existing developments.

Dredging

Historically dredging has been considered in some details by the Cooks River Advisory Committee (Reference 17). This concluded that although dredging of approximately 500,000m^3 of material below Unwins Bridge could reduce flood levels (by up to as much as 0.5m at Illawarra Road – this reduction in level is indicative and not verified by hydraulic modelling) disposal of dredged material would be a difficult issue. The 1994 Floodplain Management Study (Reference 3) modelled a similar scheme removing 190,000m^3 of material between the Princes Highway and Church Street. The reduction in flood levels was an average of 0.15m (1% AEP). However, both studies concluded that dredging was not a feasible option for floodplain risk management in this area due to the significant disposal issue.

The 1994 Floodplain Management Study (Reference 3) also considered removal of Fatima Island, a small island in the river just downstream of the railway crossing that was originally a dredge spoil island (formed in 1901 when the Cooks River was dredged). It was noted in a comparison of cross-sections, between the Illawarra railway line and the Princes Highway, that the river has compensated for the presence of Fatima Island by widening and deepening. Therefore removing the island is likely to have a negligible impact on the flood levels in the immediate area with no impact in locations where significant flood damages occur. The island was apparently also much larger in the past and has been heavily eroded when expansions to Kingsford Smith Airport and the realignment of the Cooks River were undertaken. It is likely to be significantly eroded following a major flood.

Further to the 1994 Floodplain Management Study, the 1997 Floodplain Management Plan (Reference 4) also rejected dredging as a risk management measure on the ground of economic and environmental issues. It concluded that disturbing and disposing of the polluted sediment from the river bed could not be justified based solely on flood mitigation grounds.

The major issue with dredging is dealing with the material removed from the river. The Cooks River has a history of industrial use and pollution dating back as far as 1830s (see Section 3.4) and there is sufficient information available to indicate that the Cooks River catchment has experienced high levels of pollutants over long period of time. The Cooks River Stormwater Management Plan (Reference 9) looks in some detail at the contamination of the river; both water quality and the pollutants present in the river bed. Much of the original low lying mangrove and mudflat areas adjacent to the river have been drained and reclaimed leading to pollution problems. Contamination from garbage and other polluted fill materials have continued to leach into the river. Furthermore, elevated levels of toxicants, including heavy metals, have been recorded in the sediments of the Cooks River (Reference 9). The bottom sediments of all the tidally influenced areas of the Cooks River have acid sulphate soils (Reference 9). These soils, if exposed to oxygen, pose a severe environmental risk.

In addition, elevated levels of chemicals have been recorded up to 9m below the surface (Reference 9). Dredging or excavating of the river would disturb these soils and could cause a major environmental problem. Like acid sulphate soils, these chemically polluted soils do not pose a significant risk while they are immobile below the surface, although when disturbed can release contaminants into the water. It is not advisable to regularly move soils with such concentrations of pollutants. If dredging was to occur there would be high costs associated with appropriate location and treatment of any removed material.

In addition to the risk of mobilising polluted particulate, it can take up to ten years for dredged silt which has been covered with clay based material to sufficiently subside to the point at where it is able to carry vehicular traffic (Reference 9). Therefore the final use of the fill material is limited.

Probably the most significant issue with any form of dredging is that it is not sustainable. Rivers are dynamic systems and are continually responding to tides and runoff. In time any dredged area will fill in and require on-going dredging. For navigation or other essential use purpose dredging can be supported. In the past dredging for flood mitigation was acceptable but this viewpoint has changed and the philosophy today is that it is unsustainable and thus not acceptable.

In conclusion dredging for flood mitigation purposes is not acceptable due to:

- the high cost of dredging,
- the likely environmental impacts due to exposing contaminants both in the Cooks River and at the disposal site,
- this measure is not sustainable,
- the high cost of disposal,
- limited hydraulic benefit (i.e reduction in flood levels).

5.2.3. Catchment Treatment

Catchment treatment modifies the runoff characteristics of the catchment to reduce inflows to the river. For an urban catchment, this involves planning to maximise the amount of pervious area and maintaining natural channels where practical. This approach is now called Water Sensitive Urban Design or WSUD. These measures can reduce the volumes of storm water run-off in relatively small, frequent events, typically up to about the 20% AEP (5-year ARI) events but they have little effect in larger, less frequent events. Thus these measures can be effective on small catchments but have a negligible impact on large catchments such as the Cooks River.

As a general concept, catchment treatment techniques and WSUD should be encouraged. On-site detention, limit area of imperviousness for new developments, controls on land use, along with water quality and other environmental controls are effective approaches for minimising local drainage and overland surface water flooding, as well as providing some water quality benefits. However, as a management measure to significantly reduce flood impacts from the Cooks River they are not considered viable, though their application is supported.

5.2.4. Voluntary Purchase of Buildings

Of those residential buildings surveyed, 34 are inundated above floor level in the 1% AEP event of which 23 experience depths of only 0.25m. Eleven residential buildings are inundated above floor level in the 5% AEP event and none in the 20% AEP event. Of the surveyed non-residential buildings, only one is inundated above floor level in the 20% AEP event. This building is currently an industrial warehouse but it is understood a DA has been approved for development of a multistorey residential property. Generally, Government funding is only available for voluntary purchase of residential buildings that are frequently flooded in a high hazard area. At an assumed cost of $800,000 per property this would cost in the order of $9 million to purchase all residential properties inundated above floor level in the 5% AEP event.

An indicative benefit cost ratio of 0.3 was determined for the building inundated in the most frequent flood event in the study area (at Illawarra Road) and assuming a 50 year further life of the building and a purchase cost of $800,000. As the flood depth is relatively shallow alternative means such as flood proofing (say $20,000 per building) would be more beneficial in terms of a benefit/cost ratio. Flood proofing for several houses, though generally not funded under the flood mitigation program, would be far more financially beneficial than spending $800,000 on purchasing a single house.

Voluntary purchase may also introduce a number of social problems (residents are unwilling to sell, or are unable to find alternative accommodation with similar attributes) which can be difficult to resolve. There is also the issue of whether knowledge of a house in a voluntary purchase scheme should be disclosed on the Section 149 certificate or to a prospective purchaser by the real estate agent. If there is disclosure this may mean that the owner will find it much harder (or achieve a lower price) to sell unless sold within the scheme.

In some flood liable areas individual buildings may be suitable for voluntary purchase due to their particular circumstances (isolation, high hazard, regularly flooded). In the Cooks River study area extents, no individual building has been identified as being suitable for voluntary purchase.

5.3. 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.

5.3.1. Levees, Flood Gates and Pumps

DESCRIPTION

Levees involve the construction of raised embankments between the river and flood affected area so as to prevent the ingress of floodwater up to a design height. Levees usually take the form of earth embankments but concrete walls can be constructed where there is limited space or other constraints. They are commonly used on large river systems (Hunter, Macleay, Clarence) but can also be found on smaller systems in urban areas. One example is the earthen levee at Mackey Park and there are several others in the Sydney basin.

Flood gates can be considered as a separate modification measure or as part of a levee design. They are commonly installed on drainage systems within a levee area and allow local runoff to be drained but prevent water from entering when river levels are elevated.

Pumps are generally also associated with levee designs. They are installed to remove local runoff behind levees when the flood gates are closed or if there are no flood gates.

Unless designed for the PMF, levees will be overtopped. When levees are overtopped it is generally acknowledged that the residents will be less well prepared than if no levee was constructed (residents assume that the levee will never be overtopped and thus hold a false sense of protection). Thus a situation of greater hazard may occur than exists without a levee. A good example of this is Hurricane Katrina in New Orleans (August 2005) where over 1800 people lost their lives and the city was devastated.

DISCUSSION

An advantage of levee systems (this includes the levee and any drains, gates or pumps associated with its function) is a relatively low on-going maintenance cost compared to other measures such as dredging, although the levee system needs to be inspected on a regular basis for erosion or failure. In addition there needs to be some maintenance for grass cutting and vegetation trimming though generally these works are undertaken for aesthetic reasons. The annual cost of inspections for erosion or failure will generally be small (often less than $5,000 per annum per levee). However this amount can vary considerably depending upon the complexity and size of the structure.

Whilst the levee system may protect a large number of buildings from being inundated in a less frequent and more rare event, many levees have a low to medium benefit cost ratio as there are few buildings floors inundated (and so being able to be protected) in the more frequent floods. However with sea level rise the benefit cost ratio will increase and levees may become more economically viable or even become the only means of protecting existing developments.

Constructing a levee can cause additional flooding behind the levee due to local runoff within the protected area being unable to drain. In addition, as the levee causes a displacement of water from one area of the floodplain to another they should be carefully modelled and designed using hydraulic modelling techniques so as to ensure the construction does not increase the flood risk to an adjacent area.

Unless the levee system is constructed to above the PMF level it will be overtopped. When this occurs the damages are likely to be higher as the population will be much less flood aware. Many residents consider that following construction of a levee the existing flood related planning controls (minimum floor level, structural integrity certificate) should be relaxed. However, many experts consider that this should not be the case unless the levee is built to the PMF level and the risk of failure is close to nil (there is always a small risk of failure). The general opinion is that a levee should reduce flood damages to existing development but should not be used as a means of protecting new buildings through a reduction in existing standards.

Riverside Crescent area

The 1994 Floodplain Management Study (Reference 3) considered a levee in Riverside Park which is part of Marrickville golf course. This levee would be tied into high ground at both ends and there would be no need to reconstruct the road along Riverside Crescent. This levee would protect 9 residential building floors from being inundated in the 1% AEP event (of which 6 are inundated in the 5% AEP event and none in the 50% AEP event).

The hinterland is relatively steeply sloping land and therefore it is technically feasible to provide pressure drainage from most of the catchment; disposing of water through pressure pipes from higher areas of the catchment. However, the number of underground services involved could make this an expensive option and, the previous floodplain management plan (Reference 4) rejected this idea due to the high costs, low benefit cost ratio and problems with drainage behind the levee. Minor brick levees around properties were considered to be more economically attractive, however these were also decided against being socially and practically unacceptable with walls up to 2m high, properties having no flood free access and maintenance and operation of gates (in private ownership) being an ongoing issue.

Constructing the levee bank along the river bank and using the golf course as a temporary storage basin was also considered. However, this would require major excavation of the golf course and construction of the levee would also cause adverse effects on the opposite side of the river which would need to be addressed. Therefore due to high costs and a very low benefit cost ratio this option (building floors only first inundated in a 5% AEP event) was rejected in the previous study.

A review as part of this present study reached similar conclusions to Reference 3, however consider that further investigation is required to assess its viability. No floors have been inundated in this area in the last 20 or more years (there are no records when floors were last inundated). Construction of the earthen levee within the golf course may cost of the order of $300,000+ (depending upon the construction method – earth or concrete wall), however the cost to resolve the internal drainage issues are impossible to estimate but may be up to $500,000+. Thus a levee is feasible but the internal drainage issues and likely social issues (from residents and the golf course) make this a low priority measure. Based on the low flood hazard, availability of an escape route to high ground and a likely low benefit cost ratio (high cost relative to the number of houses protected) it is unlikely that funding from the floodplain management program will be made available in the short term.

Illawarra Road area
In this area there are 21 houses inundated above their building floor in the 1% AEP event, 5 in the 5% AEP and none in the 50% AEP. The options for levees in Steel Park and Mahoney Reserve were also considered in the previous 1997 Floodplain Management Plan (Reference 4). Construction of levees could be achieved in conjunction with road raising or as a stand-alone option. However the amenity value of the recreation areas and issues with draining the land behind the levee meant this option was considered no further.

A levee is feasible at this location. At this stage it is not possible to accurately assess the construction costs but an indicative cost will be $400,000 and upwards depending upon services and the extent of road works and any landtake costs. Internal drainage will be less of an issue due to the relatively small upstream catchment. This measure is a low priority measure due to the likely social issues, easy escape route to high ground and likely low benefit cost ratio means that this measure is unlikely to receive funding from the state government. There are no records of above floor inundation in the last 20+ years in this area.

For this area the most viable measure is redevelopment of the existing residential buildings with habitable floors above the required flood planning level.

Carrington Road area
The Carrington Road area is currently protected by a levee in Mackey Park. The crest of the levee is at approximately 2.8mAHD (Reference 6) which is above the estimated 1% AEP flood level of 2.5mAHD. The levee therefore provides little freeboard above the predicted 1% AEP flood level. Events greater than the 1% AEP, including any climate change scenarios will overtop the levee, hence the percentage increase in damages from the existing 1% AEP flood to future year 2050 and 2100 flood events is high (refer Section 4.5.2).

Two Sydney Water drains (Figure 1), one on each side of the Carrington Road low point transport much of the local runoff directly to the river. The remaining runoff is directed to a pumping station in Mackey Park. This pumping station would also be used to reduce flood levels should the levee overtop, and once the Cooks River level subsides.

It is noted that there are a number of large trees growing on the Mackey Park levee. Ideally a levee should not be tree planted so that it can be easily be maintained and raised if necessary. In addition trees can cause a potential source of failure of the levee if the root/earth mound becomes saturated and the tree falls taking with it a large portion of the embankment. Although the presence of the trees limits the possibility of raising the levee and increases the risk of breach, due to the levee being located in a public recreational area means that removal of the trees could be a contentious issue. A geotechnical audit should be carried to determine the potential for failure.

A well designed earth embankment can have minimal environmental impact whilst protecting properties from flooding. As much of the Cooks River bank area through Marrickville LGA is designated as public recreation areas, issues such as existing or potential development restricting the placement of levees should not be significant. However, raising levees to protect to a PMF standard (for example raising Mackey Park levee by at least 3m to over 5.4mAHD) would involve considerable land fill and cost and have significant implications for the aesthetics of the waterfront. Raising the levee by 0.5m to provide a freeboard above 1% AEP event could be an option considered; this would also raise the levee height above the predicated year 2100 flood level of approximately 3mAHD. However, maintaining the existing trees may hinder this option.

Furthermore, the Western Channel, which runs alongside Mackey Park and outfalls to the Cooks River, appears not to be protected from Cooks River backflows as it has no flap gate or non-return system. This may or may not be a significant issue but requires further more detailed investigation to ensure that the levee system will function effectively.

From ALS survey of the top of the eastern bank of the Western Channel the ground appears to be between 2.3mAHD and 3.5mAHD and therefore in places lower than the river bank levee. However, ALS has an accuracy of +\- 0.15m and is also smoothed to remove the influence of trees and buildings which means that the true level of the bank may not be represented accurately by the ALS.

The following recommendations are made:

- Further investigate backflow protection on the Western Channel (cost $10,000);
- Survey the east bank of the Western Channel and raise the ground to an equivalent level to the river bank levee (cost of up to $20,000);
- Undertake an audit to determine the potential for failure of the Mackey Park levee due to the presence of trees on the embankment (cost $10,000); and
- Undertake a study to evaluate the potential for raising the levee to provide additional protection due to a sea level rise increase in flood levels. This study could be undertaken to encompass the above three recommendations or following completion of these studies as a separate project. If undertaken as a separate project an indicative cost would be $20,000 but there would be significant cost savings if all four projects were undertaken together.

Bay Street area

The possibility of raising Holbeach Avenue to act as a levee was discussed briefly in the 1997 Floodplain Management Plan (Reference 4). However, in doing so this would cause access difficulties for properties along Holbeach Avenue and internal drainage would present a significant problem as flood affected properties are in a distinct depression with no local flood storage space.

A levee in this area cannot be economically justified as only 4 buildings are inundated above floor level in the 1% AEP event with none in the 5% AEP event.

SUMMARY

Construction of new levees or upgrading of the existing Mackey Park levee is one of the only means of protecting existing buildings from sea level rise and therefore must be considered further as an adaptation measure to protect existing developments. Initially a preliminary concept design should be undertaken (cost $20,000) and this may foreshadow areas where land might have to be "protected" to ensure that the required levees could be constructed. A more detailed design of the system would be undertaken by 2020 when it is likely more precise knowledge is obtained about climate change.

5.3.2. Temporary Flood Barriers

DESCRIPTION

Temporary flood barriers include demountable defences, wall systems and sandbagging which are deployed before the onset of flooding.

DISCUSSION

Demountable defences can be used to protect large areas and are often used as a means to assist in current mitigation measures rather than being the sole protection measure; for example in filling in gaps in levees or raising them at the risk of levee overtopping. The effectiveness of these measures relies on sufficient warning time being available to install them (several hours). It is important that temporary barriers, particularly demountable defences which can be used to protect large areas, are not put up without prior planning and investigation as they tend to raise flood levels elsewhere as a levee would; so whilst aiding one area might cause increased flooding in another. However, as discussed in Section 4.1 the Cooks River has a quick response to catchment rainfall and therefore demountable defences would not be the ideal solution due to time constraints. This situation may change as the BoM improves its forecasting.

Sandbagging can be a more appropriate solution for dealing with flooding in smaller areas and individual properties. However, again this relies on warning time and availability of sandbags and people to place them.

SUMMARY

Although large temporary demountable barriers would not be an effective method for the Cooks River (due to the short warning time available) the use of sandbagging to protect individual areas or properties is an option to consider. This is not a permanent method and therefore works best as a secondary option.

5.3.3. Local Drainage Issues

DESCRIPTION

Overland flooding is usually caused by the incapacity of the local drainage system to deal with heavy rainfall. Historically drainage infrastructure was built to cope with smaller flood events and a smaller scale of development. Local flooding often occurs when the capacity of these systems become exceeded, or where the outflow is restricted, for example from high river levels. Generally it only occurs after several hours of rain and will not cause above floor inundation.

The Cooks River catchment is highly urbanised and therefore local drainage also poses a significant flood risk. This is considered in the Marrickville Valley Flood Study (Reference 6). Three drainage systems (Figure 1) operate in the Marrickville and wider area; the Eastern Channel, Central Channel and Western Channel with the Malakoff Tunnel.

The Eastern Channel is generally a twin open channel that enters the Cooks River near Tempe railway station. The storage detention basin near Sydenham railway station forms part of this system. The Central Channel begins as an open channel but is covered at the downstream end adjacent to Carrington Road. Two pumping stations pump excess runoff to the Eastern Channel and directly to the Cooks River. The Western Channel is an open channel that enters the Cooks River at Mackey Park and the Malakoff Tunnel drains the top end of the catchment entirely as an underground conduit.

Local stormwater flooding is likely to occur when drainage systems are over capacity or outfalls are blocked, either by high water levels in the instance of an outfall to the river or by debris and siltation.

DISCUSSION

The Marrickville Valley Flood Study (Reference 6) provides mapping of the overland flooding and discusses the overland issues with flooding. The study identifies that a number of properties would suffer flooding in a significant storm event including those in the Marrickville industrial area, Malakoff Street and generally the area downstream of Marrickville Oval and on the southern side of Sydenham Road (Livingstone Road), Marrickville railway station and Sydenham railway station. The Carrington Road area would also be significantly affected.

The study showed that the Eastern Channel has sufficient capacity to convey flows of up to the 1% AEP event magnitude. However, the Central Channel has insufficient capacity during all design events modelled. Additionally the tailwater conditions in the Cooks River affect its capacity. Whilst the Malakoff Tunnel was shown to be at almost full capacity during the 1% AEP event its inlet pits do not have sufficient capacity to convey all overland flows into the tunnel. The Western Channel only shows capacity to transfer the 50% AEP event along almost its entire reach without overtopping. It was noted in the study that there was little difference in the peak outflow from the channels for the 50% AEP event and 1% AEP event signifying a lack of capacity in the channels for larger events.

The Riverside Crescent/Dibble Avenue is regularly inundated from local runoff ponding at the intersection. An upgraded pipe system or creation of an overland flow path across the golf course would alleviate this problem.

SUMMARY

Although local drainage issues are not within the scope of this study they will have a large effect on flooding in the Carrington Road area. On-site stormwater detention or other WSUD measures are recommended for new development so as not to increase runoff from new sites and thus exacerbate the problem.

5.4. Property Modification Measures

5.4.1. House Raising

DESCRIPTION

House raising has been widely used throughout NSW to eliminate or significantly reduce flooding of habitable floors, particularly in low hazard areas of the floodplain. However it has limited application as it is not suitable for all building types being more suitable for non-brick single storey buildings. Raising a house allows creation of an underfloor garage or non-habitable area though it is essential that this underfloor area and its contents will not incur flood damages, as if subsequently used as such this may negate the benefits of house raising.

House raising is not a suitable option for properties that are affected by permanent inundation (due to sea level rise) as, while the building may be above flood levels, the land and infrastructure will be affected by the rising waters.

DISCUSSION

The benefit of house raising is that it eliminates flooding to the height of the floor and consequently reduces the flood damages. It should be noted that larger floods than the design flood which was used to establish the floor level will inundate the house floor. It also provides a safe refuge during a flood, assuming that the building is suitably designed for the water and debris loading. However, the potential risk to life is still present if residents choose to enter floodwaters or are unable to leave the house during a medical emergency, or larger floods than the design flood occurs.

Funding is available for house raising in NSW and has been widely undertaken in rural areas (Macleay River floodplain) and urban areas (Fairfield and Liverpool). An indicative cost to raise a house is $60,000 though this can vary considerably depending on the specific details of the house. House raising was the traditional method of eliminating tangible flood damages but is less prevalent today in NSW as;

- the majority of suitable buildings have already been raised;
- the houses that can be raised are nearing the end of their useful life;
- house styles and requirements (ensuites, cabling, air conditioning) means that the timber piered homes are less attractive than in the past;
- most households indicate that they would prefer to use the funding to construct a new house; and
- re-building rather than renovations are becoming more cost effective. In many suburbs in Sydney 30 year old brick homes are being demolished as the cost per m^2 to renovate is up to twice the per m^2 cost of re-building. Thus if 50% of the house is to be renovated it is cheaper to re-build.

However, the majority of properties subject to flooding from the Cooks River are of brick structure, some are two storey and raising would therefore not be possible.

SUMMARY

House raising is a viable means for those houses that can be raised but as nearly all the residential flood affected buildings are of brick construction there are few opportunities available in the study area. For those houses that are suitable this could be considered but it is likely that many of these residents would prefer to rebuild.

5.4.2. Flood Proofing

DESCRIPTION

An alternative to house raising for buildings that are not suitable is flood proofing or sealing off the entry points to the building. This measure has the advantage that it is generally less expensive than house raising and causes less social disruption. Flood proofing requires sealing of doors and possibly windows (new frame, seal and door); sealing and re-routing of ventilation gaps in brick work; sealing of all underfloor entrances and checking of brickwork to ensure there are no gaps or weaknesses in mortar. It is generally only suitable for brick buildings with concrete floors and it can prevent ingress from outside depths of up to one metre. Greater depths may cause structural problems unless water is allowed to enter. Generally an existing house can be sealed for approximately $20,000. New development and extensions allow the inclusion of flood appropriate materials and designs meaning the actual cost of flood proofing can be less when compared to buildings requiring retro-fitting of flood proofing measures.

Flood proofing should also consider suitable electrical installation so as to avoid the risk of electrocution during a flood. A minimum aim should be to have all properties in the flood planning area, at least, be fitted with a circuit breaker although ideally for all new development all unsealed electrical circuits should be above the Flood Planning Level.

Additionally, flood proofing can involve the raising of easily damaged/high cost items such as commercial stock, equipment and machinery.

Alternatively, temporary flood proofing can also be achieved by the use of sandbags or private flood gates which fit over doors, windows and vents and are deployed by the occupant before the onset of flooding.

DISCUSSION

This measure is really only suitable for commercial and industrial buildings where there are only limited entry points and aesthetic considerations are less of an issue. Also there are issues of compliance and maintenance. However flood compatible building or renovating techniques should be employed for extensions or renovations where appropriate. Guidelines are provided in a booklet *"Reducing Vulnerability to Flood Damage"* prepared in 2006 for the Hawkesbury-Nepean Floodplain Management Steering Committee (Reference 18).

The use of temporary measures such as flood gates which occupants fit over their doors and other possible water inlets can be useful in areas where there is frequent shallow flooding. These methods are better used when flooding is of short duration otherwise people may become stranded in their homes. Alternatively they can be used to make a property more flood resistant before evacuation.

In some frequently inundated areas of Sydney private businesses have installed water proof doors, raised flood barriers and other such devices. These should be considered by properties in the Carrington Road area but will probably only be adopted if businesses regularly lose a significant amount of stock. Once problem with such devices is that a lack of maintenance or "testing" means that when required the devices fail.

Minimising the chance of electrocution by turning of the electricity supply during a flood should be 'standard practice' for residents and commercial owners during floods. The risk of electrocution can also be reduced by installing electrical circuits above, at least, the flood planning level.

SUMMARY

Flood proofing is a good solution for reducing flood risk to commercial and industrial properties. Flood proofing techniques, be they permanent or temporary, could be utilised for the properties in the Carrington Road area however they would have to be installed at the owner's expense as they are not eligible for state government grant funding. An important issue with this measure is that generally some manual intervention is required to implement the measure, if this is not undertaken then it will likely fail.

5.5. Response Modification Measures

5.5.1. Flood Warning and Evacuation

DESCRIPTION

Flood warning can significantly reduce damages and risk to life and studies have shown that flood warning systems generally have a high benefit/cost ratio if sufficient warning time is provided.

Flood warning and the implementation of evacuation procedures by the 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 and the SES disseminates these warning to the local community. Adequate warning gives residents time to move goods and cars above the reach of floodwaters and to evacuate from the immediate area to high ground. 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; and
- the flood awareness of the community responding to a warning.

DISCUSSION

The Cooks River Flood Study (Reference 2) found that the critical duration for the 1% AEP event was approximately 2 hours. Due to the flashy nature of the Cooks River flooding, there is no SES flood warning system in operation, although gauge boards (Figure 1) are read to inform the SES of water levels (as occurred in the March 2012 event).

In the past no river gauges were available for flood warning. However three automatic gauges have been installed (Figure 1) on the Cooks River at Canterbury Road (1995), Illawarra Road Bridge (2001) and Tempe Bridge (1991). These are currently not used in a flood warning system although this could possibly be established. However, the flashy nature of the catchment makes predicting flood levels and timing very difficult and gives little time for accurate warning or evacuation.

As much of the floodplain is undeveloped land and designated as public recreation, it will be subject to flooding before the onset of any river flooding to developed properties. Therefore, an alternate to a flood warning system would be an education program to raise public awareness of flooding on the Cooks River so residents can minimise flood damages.

Mention is made in Section 5.2.1 of the Marrickville Oval retarding basin. Whilst this is upstream of the extent of flooding from the Cooks River, the possible failure of this structure has the potential to have impacts downstream and the filling up of the basin represents a potential risk to life. The cost of such a system would depend upon the level of sophistication but an indicative cost would be $20,000 with an annual maintenance cost of $3,000. The benefit cost ratio of this system cannot be accurately evaluated but is likely to be high. A flood warning alarm system for this structure should be considered.

SUMMARY

The greatest improvement in the accuracy of any flood warning predictions generally only occurs following major flood events. It is imperative therefore that a post flood assessment report be prepared by the SES following each future flood event with particular emphasis on the adequacy and accuracy of the flood warning system and evacuation. In the instance where no flood warning is available, a report on the flooding and subsequent management of it should be prepared to look at the option for providing flood warning in the future and to assess if any improvements can be made to evacuation, management and clean-up procedures.

A flood warning alarm system for the Marrickville Oval retarding basin should be considered.

5.5.2. Flood Emergency Management

DESCRIPTION

As mentioned above, it may be necessary for some residents to evacuate their homes in a major flood. This would usually be undertaken under the direction of the lead agency under the Displan, the SES. Some residents may choose to leave on their own accord based on flood information from the radio or other warnings, and may be assisted by local residents. The main problems with all flood evacuations are;

- they must be carried out quickly and efficiently;

- there can be confusion about 'ordering' evacuations, with rumours and well-meaning advice taking precedence over official directions which can only come from the lead agency, the SES;
- they are hazardous for both rescuers and the evacuees;
- residents are generally reluctant to leave their homes, causing delays and placing more stress on the rescuers, and
- people (residents and visitors) do not appreciate the dangers of crossing floodwaters.

For this reason, the preparation of a Community Flood Emergency Response Plan (CFERP) helps to minimise the risk associated with evacuations by providing information regarding evacuation routes, refuge areas, what to do/not to do during floods etc. It is the role of the SES to develop a CFERP for vulnerable communities.

DISCUSSION

Updating the flood emergency plan with information from this Floodplain Risk Management Study and Plan will be highly beneficial.

Although flood warning is limited, a Local Disaster Plan should be prepared and updated to include the latest information on design flood levels and details on roads, properties, and other facilities which would be flood affected. In discussions with the SES this is currently underway.

SUMMARY

The SES should ensure that a Local Flood Plan (there is already a draft plan) is prepared for areas within flood prone land from the Cooks River. This Flood Plan should be regularly kept up to date and should include feedback from the March 2012 event and the recommendations of this Floodplain Risk Management Study and Plan once finalised.

5.5.3. 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? How aware is the community to the threat from sea level rise?;
- *Flood Preparedness*: How prepared is the community to react to the threat of flooding? Do they (or the SES) have damage minimisation strategies (such as sand bags, raising possessions) which can be implemented?; and
- *Flood Evacuation*: How prepared are the authorities and the residents to evacuate households to minimise damages and the potential risk to life during a flood? How will the evacuation be done, where will the evacuees be moved to?

Public information and the level of public awareness are key contributors to reduce flood damages and losses.

DISCUSSION

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 the frequency and impact of previous floods, the history of residence, and whether an effective community awareness program has been implemented.

Families (notably in rural areas) who have owned properties for a long time will have established a considerable depth of knowledge regarding flooding and a high level of flood awareness. A community which consists predominantly of short lease rental homes will have a low level of flood awareness. It would appear that the majority of the residents have lived in the area for several years and have therefore some knowledge of flooding. Also it is very likely that new residents will be aware from advice at the time of their property purchase (Section 149 certificate) or from neighbours after they move in or by viewing the river, or even viewing the March 2012 event that flooding may occur in the area.

A community with high flood awareness will suffer less damage and disruption during and after a flood because people are aware of the potential of the situation. On river systems which regularly flood, there is often a large, local, unofficial warning network which has developed over the years and residents know how to effectively respond to warnings by raising goods, moving cars, lifting carpets, etc. Photographs and other sentimental or non-replaceable items are generally put in safe places. In more frequently flooded areas, some residents may have developed storage facilities which are flood compatible. However, apart from the recent flooding of March 2012 which caused evacuation of properties and traffic disruption, there has been little property flooding from the Cooks River in the last 20 or more years. This has been due to the undeveloped nature of the floodplain; it being largely designated as recreation and the absence of large floods. Therefore, the level of community awareness is likely to be low. Generally community awareness will decline as the time since the last flood increases and maybe increase as a result of community flood or climate change awareness programs.

A major hurdle is often convincing residents that major floods will occur in the future. Many residents hold the false view that once they have experienced a large flood then another will not occur for a long time thereafter. This viewpoint is incorrect as a 1% AEP event has the same chance of occurring next year, regardless of the magnitude of the event that may have recently occurred.

SUMMARY

For risk management to be effective it must become the responsibility of the whole community. It is difficult to accurately assess the benefits of an awareness program but it is generally considered that the benefits far outweigh the costs. The perceived value of the information and level of awareness diminishes as the time since the last flood increases.

As time passes since the last significant flood, the direct experience of the community with historical floods will diminish. It is important that a high level of awareness is maintained through implementation of a suitable Flood Awareness Program that would include Floodsafe brochures as well as advice provided on the Council and SES websites. These need to be updated on regular basis.

Table 24 provide examples of possible further education methods that may be developed and supported by Council or other public authorities. Rockdale City Council implemented such a program for Wolli Creek and Bardwell Creek several years ago.

Table 24: Community 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 ongoing implementation of the Risk Management Plan, changes to flood levels, climate change or any other relevant information.
Council website	Council should continue to update and expand their website to provide both technical information on flood levels as well as qualitative information on how residents can make themselves flood aware. This would provide an excellent source of knowledge on flooding as well as on issues such as climate change. It is recommended that Council's website continue to be updated as and when required.
Community Working Group	Council should initiate a Community Working Group framework which will provide a valuable two way conduit between the local residents and Council.
School project or local historical society	This provides an excellent means of informing the younger generation about flooding and climate change. It may involve talks from various authorities and can be combined with topics relating to water quality, estuary management, etc.
Historical flood markers and flood depth markers	Signs or marks can be prominently displayed on telegraph poles or such like to indicate the level reached in previous floods. Depth indicators advise of potential hazards, particularly to drivers. These are inexpensive and effective but in some flood communities not well accepted as it is considered that they are considered by some to affect property values.
Articles in local newspapers	Ongoing articles in the newspapers will ensure that the flood and climate change issues are not forgotten. Historical features and remembrance of the anniversary of past events are interesting for local residents.
Collection of data from future floods	Collection of data (including photographs and recorded flood levels) 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 may wish to advise interested parties, when they inquire during the property purchase process, regarding flood information currently available, how it can be obtained and the cost. This information also needs to be provided to all visitors who may rent for a period. Some Councils have conducted "briefing" sessions with real estate agents and conveyancers.
Establishment of a flood effects database and post flood data collection program	A database would provide information on a number of issues such as which houses require evacuation, which public structures will be affected (eg. telephone or power cuts). This database should be updated following each flood with input from the community.
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.
Develop approaches to 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. The development of approaches that promote community ownership should therefore be encouraged. For example residents should be advised that they have a responsibility to advise Council if they see a problem such as blockage of drains or such like. This process can be linked to water quality or other water related issues including estuary management. The specific approach can only be developed in consultation with the community.

The specific flood awareness measures that are implemented will need to be developed by Council taking into account the views of the local community, funding considerations and other awareness programs within the LGA. The details of the exact measures would then need to be developed in consultation with affected communities.

5.6. Planning and Future Development Control Measures

5.6.1. Strategic Planning Issues

DESCRIPTION

The division of flood prone land into appropriate land use zones can be an effective and long term means of limiting danger to personal safety and flood damage to future developments. Zoning of flood prone land should be based on an objective assessment of land suitability and capability, flood risk, environmental and other factors. In many cases, it is possible to develop flood prone lands without resulting in undue risk to life and property.

The strategic assessment of flood risk (as part of the present study) can prevent new 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 developments likely to be affected by flooding to acceptable levels. Development control planning includes both zoning and development controls.

DISCUSSION

Flood extent mapping (Appendix B) from this study should be used by Council to identify properties subject to flood related development controls and as a result of sea level rise. However, as always, as further advances in flood modelling technologies and better information becomes available it should be updated.

It may be that some existing developed areas are not appropriate to be protected by adaptation (house raising) or defence (levees) mechanisms. For these areas Council and the community will need to establish some form of land zoning, retreat or re-development strategy. For those properties only affected when taking into account future climate change, such measures will not be necessary for many years. However, planning should start now to allow sufficient time to develop suitable adaptation plans, funding models, and market mechanisms to make the transition as easy and equitable as possible.

Filling

Filling can raise ground levels to above predicted flood levels thereby reducing flood damages. However, on riverine floodplains filling can raise flood levels by eliminating temporary floodplain storage and, in some cases, reducing the hydraulic conveyance. It also may have an environmental impact in terms of habitat, visual aesthetics and natural environment. Along the Cooks River corridor much land is zoned as public open space and therefore filling of this land is unlikely to occur under current controls. This should be maintained. In addition, filling of the floodplain in other locations should be considered in terms of its impact on the flood behaviour and also in terms of increased flood risk.

In flood fringe areas, where raising ground levels will not have a significant adverse impact on flood behaviour, managed filling could also be adopted for infill development as long as care is taken to ensure local drainage issues are not exacerbated and services (roads, sewer, water) can be accommodated. Possibly a staged approach can be undertaken where the new buildings and garages are constructed on elevated pads and in time the remainder of the property and the roads are raised. However, this piece-meal approach can lead to disharmony within the community when there are some filled and some non-filled properties.

Planned Retreat

Permanent inundation and increased flooding as a result of predicted impacts of future climate change may make some land unsuitable for future development or re-development. Within the study area, flood mapping (Appendix B) has shown that this would not affect significant areas of already developed land and other risk management measures could be used.

Limit the Extent of Development

Development could be restricted in that no new development would be allowed within a flood prone area, for example up to the 1% AEP event. However, where areas are already developed this can lead to degeneration in an area and has social implications for current property owners. More reasonably, future residential development in flood prone areas could be restricted through planning controls so that there would be no increase in residential density and therefore no increase in the number of people at risk. Thus dual occupancy, sub division or increasing the site coverage (increasing the size of the building) would not be permitted.

Ensuring Adequate Evacuation

Most flood affected residents will already have access to high ground although river crossings may not be possible. Evacuation can be improved on the basis of issuing flood warnings and preparing flood plans. However, as discussed previously there is no current warning system in place for the Cooks River and it is unlikely that a warning system will be established in the near future due to the flashy nature of the catchment and the relatively low risk of flooding compared to other areas of NSW. Although there is no warning system in place, a disaster plan should identify routes to higher ground.

SUMMARY

Strategic planning is the main approach for reducing flood damages to future developments and in particular to adapt to the implications of climate change. A range of options can be considered and are often used in conjunction with other structural methods. Different approaches may be applied as necessary for the five sub areas (Figure 1).

No detailed assessment of each area has been undertaken or the necessary public consultation to determine which strategy should be employed, through local area adaptation plans, for example. It is recommended that this process be undertaken to develop an appropriate approach for each sub area (Figure 1).

5.6.2. Rezoning

DESCRIPTION

Rezoning involves changing current land uses as defined in the LEP to remove higher risk properties from the floodplain such as residential accommodation and to prevent further development which could be at flood risk.

DISCUSSION

While it seems common sense to prevent additional development in flood prone areas this could, in effect, freeze new development in all flood affected areas leading to areas of degradation where a few properties remain surrounded by derelict areas. This could also have implications for the aesthetics and perceived security of the open public space areas. The NSW Government's 2005 Floodplain Development Manual (Reference 1) seeks to permit new development in flood affected areas, provided the risk is adequately assessed and managed.

In general, if more buildings, infrastructure and people are located in flood hazard areas it is likely to increase the risk to people and property. Therefore land should not be rezoned if it allows increases in development intensity. Individual developments that increase development intensity within current zonings, should be assessed against the increased risk to persons and property as a result of the development to ensure there is no nett increase in risk.

Nonetheless, in some specific circumstances, rezoning of flood liable land for higher density development could encourage people to purchase and demolish existing flood liable property and redevelop the area in accordance with Council's floor level policy. This strategy is difficult to implement, as generally the surrounding residents, who are not flood affected, may consider that the quality of the area would be adversely affected by the increased building density. Furthermore the high cost to purchase the existing land and buildings is unlikely to make this measure financially attractive to developers. Additional concerns include adequate flood access and increasing the number of people within the floodplain and therefore this measure should only be allowed where there is good flood access and ideally sufficient warning time so that all people can leave before the onset of flooding.

Alternatively the option of rezoning currently residential flood prone areas to commercial or industrial development where there is less risk to human life can be considered. However this can have significant implications for Council in changing the social aspects of the community. Current residents will not favour their community becoming an industrial area. Alternatively Council could consider increasing the current zone of public open space along the river corridor, although such a measure would have to take into account potential voluntary purchase or a land swap scheme to prevent derelict residential areas.

The wholesale rezoning of all flood liable lands is not appropriate, but this measure could be used on a local scale as a means of removing or improving flood liable buildings.

SUMMARY

Current Council land use zones (Figure 2) are largely appropriate with regards to flood risk. The majority of the floodplain falls within land assigned as public recreation and open space. Where the floodplain extends past this land use is either light industrial or low density residential except for a small area in the Bay Street area zoned as general residential. It is therefore considered that current land uses are largely appropriate although they may wish to be considered in the future in the light of climate change.

5.6.3. Flood Planning Levels

DESCRIPTION

Flood Planning Levels (FPLs) are an important control in floodplain risk management. The Floodplain Development Manual (Reference 1) provides a comprehensive guide to the purpose and determination of FPLs. The FPL provides a development control measure for managing the future flood risk and is derived from a combination of a design flood event and freeboard. In determining a suitable FPL Council should consider the impacts of restricted development in a flood prone area with the benefits of a reduction in damage, frequency and danger to life caused by flooding.

Flood related development controls are the most constructive measure for reducing flood damages to new residential dwellings. The Floodplain Development Manual (Reference 1) states that in general the FPL for a standard residential development would be the 1% AEP event plus a freeboard, typically 0.5m.

Developments more vulnerable to flooding (hospitals, electricity sub-stations, senior's housing) must consider rarer events greater than the 1% AEP when determining their FPL. With predicted sea level rise the FPL is increased to account for climate change for the life of the development. However, the FPL does not address the full range of issues when considering flood and permanent inundation risk such as access and failure of essential services.

DISCUSSION

According to the Floodplain Development Manual (Reference 1) the purpose of the freeboard is to provide reasonable certainty that the reduced flood risk exposure provided by selection of a particular flood as the basis of a FPL is actually achieved given the following factors;

- uncertainties in estimates of flood levels;
- differences in water level because of local factors;
- increases due to wave action;
- the cumulative effect of subsequent infill development on existing zoned land; and
- climate change.

Defining the appropriate FPL involves trading off the social and economic benefits of a reduction in the frequency, inconvenience, damage and risk to life caused by flooding against the social, economic and environmental costs of restricting land use and development in flood prone areas and of implementing management measures. FPLs are generally required to be defined or applied for the following broad use land categories;

- residential (1% AEP + 0.5m);
- commercial and industrial (suggested to be determined at the time on the basis of the nature of the development);
- community services such as schools, community halls (suggested 1% AEP + 0.5m);
- critical services such as hospitals, nursing homes, police stations, council offices (suggested PMF);
- recreation facilities (suggested to be determined at the time on the basis of the nature of the development);
- caravan parks (preferred to be at 1% AEP + 0.5 but this may not be practical in all circumstances);
- additions or extensions to existing structures (preferred to be at 1% AEP + 0.5m but this may not be practical in all circumstances); and
- public utilities such as electricity, water, sewer, telephone (suggested PMF).

Although generally a FPL of the 1% AEP flood level plus a 0.5m freeboard is set, the FPL can be varied depending on the use, and the vulnerability of the building/development to flooding. For example residential development could be considered more vulnerable due to people being present whilst commercial development could be considered less vulnerable. Likewise, critical services such as hospitals, fire stations and other services which would need to operate during a flood event would be considered more vulnerable to flood damage and could be stipulated to have higher FPLs; or even better to be situated outside of the floodplain where possible.

Flood proofing a property can be considered where raising floor levels is not an option or feasible and can be appropriate for the less vulnerable commercial and industrial developments. Whilst raising the floor levels will ensure that the floors are not flooded in the design event there is still the issue of whether adequate services (sewer, roads) can be provided and that the private land will be suitable for habitation (i.e not permanently or regularly inundated so as to make the land unsuitable).

The FPL can also be used to set requirements for flood proofing a building. New developments and re-developments should have requirements to locate unsealed electrical circuits at least 0.5m above the 1% AEP flood level to reduce the risk of electrocution.

For new residential development Council currently specifies in the DCP habitable rooms should have a minimum floor level of the 1% AEP flood level plus 0.5m freeboard. For new non-residential development Council’s DCP also stipulates a minimum floor level of the 1% AEP flood level plus 0.5m freeboard or that buildings must be at least flood proofed to this level.

SUMMARY

A FPL is a good means of reducing flood risk to any new development and Council should review its current policies in this regard in either an updated LEP or DCP. Council is currently in the process of reviewing its procedure for identifying flood liable properties (Reference 12) affected by Cooks River flooding and local overland flooding.

5.6.4. Modification to the S149 Certificates

DESCRIPTION

Councils issue planning certificates to potential purchasers under Section 149 of the Environmental Planning and Assessment Act of 1979. The function of these certificates is to inform purchasers of planning controls and policies that apply to the subject land. Planning certificates are an important source of information for prospective purchasers on whether there are flood related development controls on the land. They need to rely upon the information under both Section 149(2) and 149(5) in order to make an informed decision about the property. It should be noted that only Part 2 is compulsory when a house is purchased and thus detail in Part 5 may not be made known to the purchaser unless it is specifically requested. Under Part 2 Council is required to advise if it is aware of the flood risk as it is of any other known risk (bush fire, land slip etc.).

DISCUSSION

Because of the wide range of different flood conditions across NSW, there is no standard way of conveying flood related information. As such, Councils are encouraged to determine the most appropriate way to convey information for their areas of responsibility. This will depend on the type of flooding, whether from major rivers or local overland flooding, and the extent of flooding (whether widespread or relatively confined). It should be noted that the Section 149 certificate only relates to the subject land and not any building on the property. This can be confusing or misleading to some.

The information provided under Part 2 of the certificate is determined by the legislation and unless specifically included by the Council provides no indication of the extent of flood inundation. Under Part 5 there is scope for providing this additional type of information. There is a general perception that insurance companies, lending authorities or other organisations may disadvantage flood liable properties that have only a very small part of their property inundated by floodwaters. Some Councils have addressed this concern by adding information onto Part 5 to show the percentage of the property inundated as well as floor levels and other flood related information. In addition the hazard category could be provided and also advice regarding climate change increases in flood level.

SUMMARY

As Council information for 149 Certificates is obtained mainly from computerised databases and maps, Council should investigate ways to make property-based flooding information more accessible via its web-site.

Data from the 2009 Flood Study (Reference 2) is in the process of being incorporated into

Council's Section 149 planning controls (Reference 12). All residents should be advised by personalised mail from Council if their land is affected. Additionally Council may want to notify residents who are not currently affected by flooding but could be for the modelled climate change scenarios or in the least, note on S149 certificates that these properties may become flood prone in the year 2050 or by the year 2100.

5.6.5. Review and Update LEPs and DCPs

DESCRIPTION

Clear and up-to-date planning controls are an essential part of the floodplain management process. They ensure that all members of the community are fully aware of what development or land use is allowed on flood prone land. The LEP usually specifies the nature of development allowable on any area of land and whether Council consent is required. A DCP usually applies to a particular issue such as flood risk management, or locality where specific development controls are imposed.

DISCUSSION

The primary objective of the NSW Government's Flood Policy is "*to reduce the impact of flooding and flood liability on individual owners and occupiers, and to reduce private and public losses resulting from flooding, utilising ecologically positive methods wherever possible*".

Appropriate development controls involve consideration of the social, economic, environmental and risk to life of consequences associated with the occurrence and management of floods. This involves trading off various benefits of reducing the impacts of flooding on development against the costs of restricting land use in flood prone areas and of implementing appropriate management measures.

The Floodplain Management Plan will provide recommended planning and management controls that will form the basis of development or planning documents in relation to flooding regarding produced by Council. These recommendations can be incorporated into existing planning instruments and management controls or, alternatively, the existing documents can simply refer to the Management Plan itself.

The Marrickville Council LEP was adopted in late 2011 and included a property tagging policy (Reference 12) to be undertaken following this Floodplain Management Study. Within the DCP, current development controls include specific provisions for flood management (see Section 2.6).

SUMMARY

A review of the available documentation was undertaken as part of the Floodplain Risk Management Study. Council currently has appropriately zoned land within the LEP and good flood management development controls covered in Part 2.22 of their DCP. The flood prone land and flood planning area maps within the DCP should be updated following this study. Flood tagging should be undertaken for properties within the flood planning area of the Cooks

River (1% AEP flood level plus 0.5m freeboard) and might be considered for properties liable to flooding due to the impacts of future climate change.

5.7. Other Management Measures

5.7.1. Flood Access

DESCRIPTION

The key methods for improving evacuation is to ensure that there are adequate evacuation routes available and appropriate warnings for when these routes will become impassable. For example, roads and river crossings can be raised, or low areas of ground filled to allow continuous dry or safe access.

Maintaining appropriate access to or from affected areas during times of flood is important to ensure;

- people have the chance to evacuate themselves and valuables/belongings before becoming inundated or trapped by rising flood waters;
- emergency services (SES, ambulance, police etc) are not restricted or exposed to unnecessary hazards in carrying out their duties; and
- areas are not isolated for extended periods of time preventing people from going about their normal routines or business or restricting essential services.

DESCRIPTION

There are a number of issues to be considered in raising roads and bridges, but largely the relatively high cost for the benefit provided is significant. A number of bridges (Figure 1) become inundated during flooding of the Cooks River (as discussed in Section 4.7). However, there is still access to high ground without having to cross the river. Importantly, emergency services can still reach affected areas without having to cross the Cooks River.

Raising access and bridges can also have implications for flood levels and unless designed with detailed hydraulic investigation could cause increased flood levels and velocities.

In particular the Illawarra Road bridge is frequently affected by flooding. The road and bridge could be raised to above the 1% AEP flood level to give dry access during a flood event. However, some 700m of road would need to be raised on the north side to reach the required level which in turn would not only be an expensive option, but would also create difficult or in some cases impossible access to some properties. Alternatively, consideration could be given to re-aligning Illawarra Road into the public open space area in Steel Park. However, although this option would not affect access into properties, there would be major disruptions to Steel Park and it is likely the route of the road would affect the public amenity building and play park which was only recently improved in 2010.

SUMMARY

Due to the nature of the Cooks River floodplain and easy access to high ground it is unlikely that improving flood access by ground raising would be a suitable option. The raising of bridges and infrastructure for flood access cannot be justified at this time but may need to be considered in the future due to increased flood levels (and frequency of overtopping) due to climate change.

5.7.2. Flood Insurance

Flood insurance does not reduce flood damages but transforms the random sequence of losses into a regular series of payments. It is only in the last five years or so that flood insurance has become readily available for houses, although it was always available for some very large commercial and industrial properties. There are many issues with the premium for this type of insurance and how insurance companies evaluate the risk. For example; whether it is based on the house floor being inundated or the ground within the property or the risk is spread across a number of properties. These issues are outside the scope of this present study and are currently being re-assessed as an outcome of the South East Queensland floods of January 2011.

Flood insurance at an individual property level is encouraged for affected land owners, but is not an appropriate risk management measure as it does not reduce flood damages.

6. ACKNOWLEDGMENTS

This study was carried out by Storm Consulting and WMAwater and funded by Marrickville Council and the NSW State Government. The assistance of the following in providing data and guidance to the study is gratefully acknowledged:

- residents of the Cooks River floodplain,
- Marrickville Council,
- NSW Office of Environment and Heritage.

7. REFERENCES

1. **Floodplain Development Manual**
NSW Government, April 2005
Sydney Water Corporation

2. **Cooks River Flood Study**
MWH and PB Joint Venture, February 2009
Marrickville Council and Canterbury City Council

3. **Cooks River Floodplain Management Study**
Webb, McKeown & Associates, August 1994
Marrickville Council and Canterbury City Council

4. **Cooks River Floodplain Management Plan**
Webb, McKeown & Associates, 1997

5. **Cooks River Flood Study 1985**
Public Works Department, 1985
Marrickville Council

6. **Marrickville Valley Flood Study**
WMAwater & Storm Consulting, May 2011
Marrickville Council

7. **Marrickville Sub-catchment Planning Framework**
http://www.marrickville.nsw.gov.au/environment/in_your_community/water_and_subcatchments/subcatchmentplanning.html [accessed June 2012]

8. **Marrickville Urban Strategy**
Marrickville Council, April 2007
Cooks River Catchment Association of Councils

9. **Cooks River Stormwater Management Plan**
PPK Environmental & Infrastructure Pty & Webb, McKeown & Associates, September 1999

10. **Adastra Aerial Surveys Sydney Airport 1947 - 1975**
http://www.adastra.adastron.com/projects/sydney-airport-1947-1975.htm [accessed May 2012]

11. **Eastern Channel East Flood Study**
Golder Associates, March 2010
Marrickville Council

12. **Development of a Policy for Identifying Properties Subject to Flood Related Development Controls**
WMAwater, July 2011
Marrickville Council

13. **Floodplain Risk Management Guideline; Practical Consideration of Climate Change**
Department of Environment and Climate Change (DECC), October 2007

14. **Flood Risk Management Guide**
Incorporating sea level rise benchmarks in flood risk assessments
NSW Department of Environment, Climate Change and Water (DECCW), August 2010

15. **Flood Risk Management Guideline: Residential Damages**
NSW Department of Environment and Climate Change (DECC), October 2007

16. **FRM Guideline: Flood Emergency Response Planning Classification of Communities**
NSW Department of Environment and Climate Change (DECC), October 2007

17. **Report of the Cooks River Advisory Committee**
Cooks River Advisory Committee, May 1978

18. **Reducing Vulnerability of Buildings to Flood Damage**
Hawksbury-Nepean Floodplain Management Steering Committee, June 2006

Figures

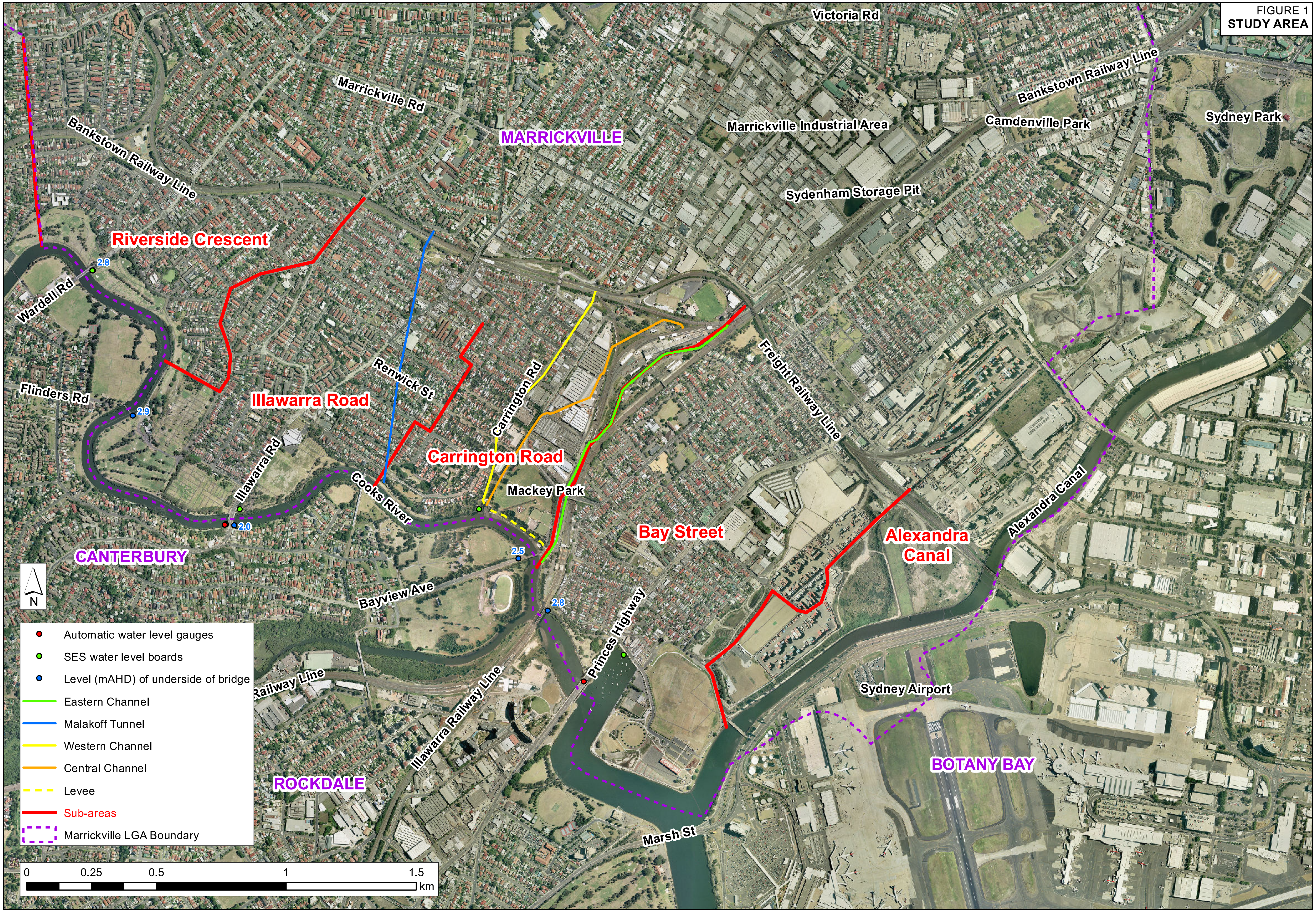
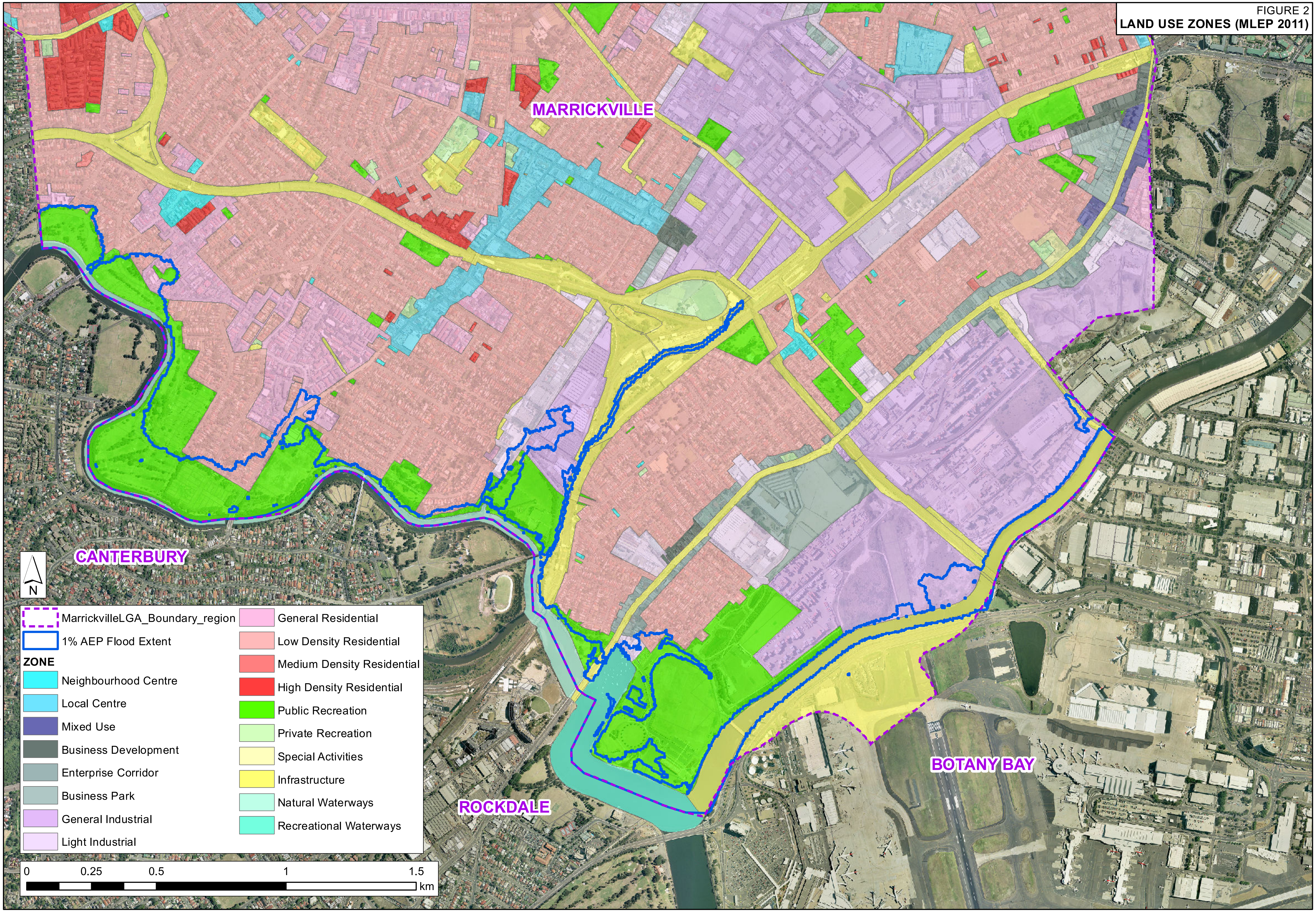


FIGURE 1
STUDY AREA

J:\Jobs\112010\ArcView\ArcMaps\ReportFigures\Figure01_StudyArea.mxd



J:\Jobs\112010\ArcView\ArcMaps\ReportFigures\Figure02_LandUseZones.mxd

FIGURE 3
HISTORICAL AERIAL PHOTOGRAPHS

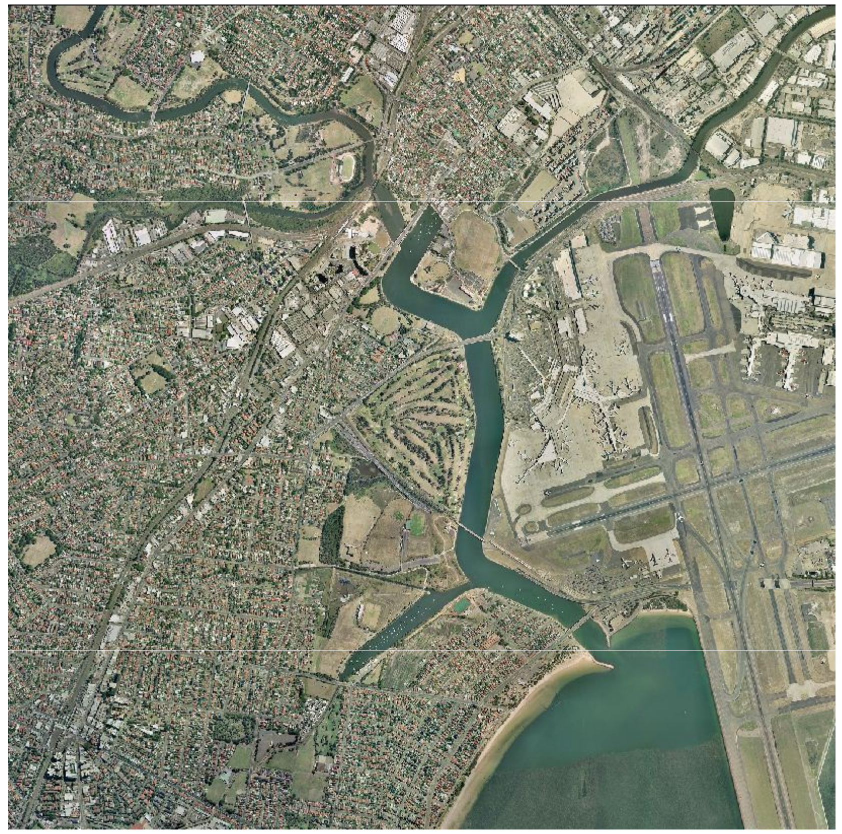
1948

1949

1951

1952

1953



2011

Images from: Madeline and Warren Ide Collection
ADASTRA AERIAL SURVEYS www.adastra.adastron.com

J:\Jobs\112010\Working\Figure03_HistoricAerial.pptx

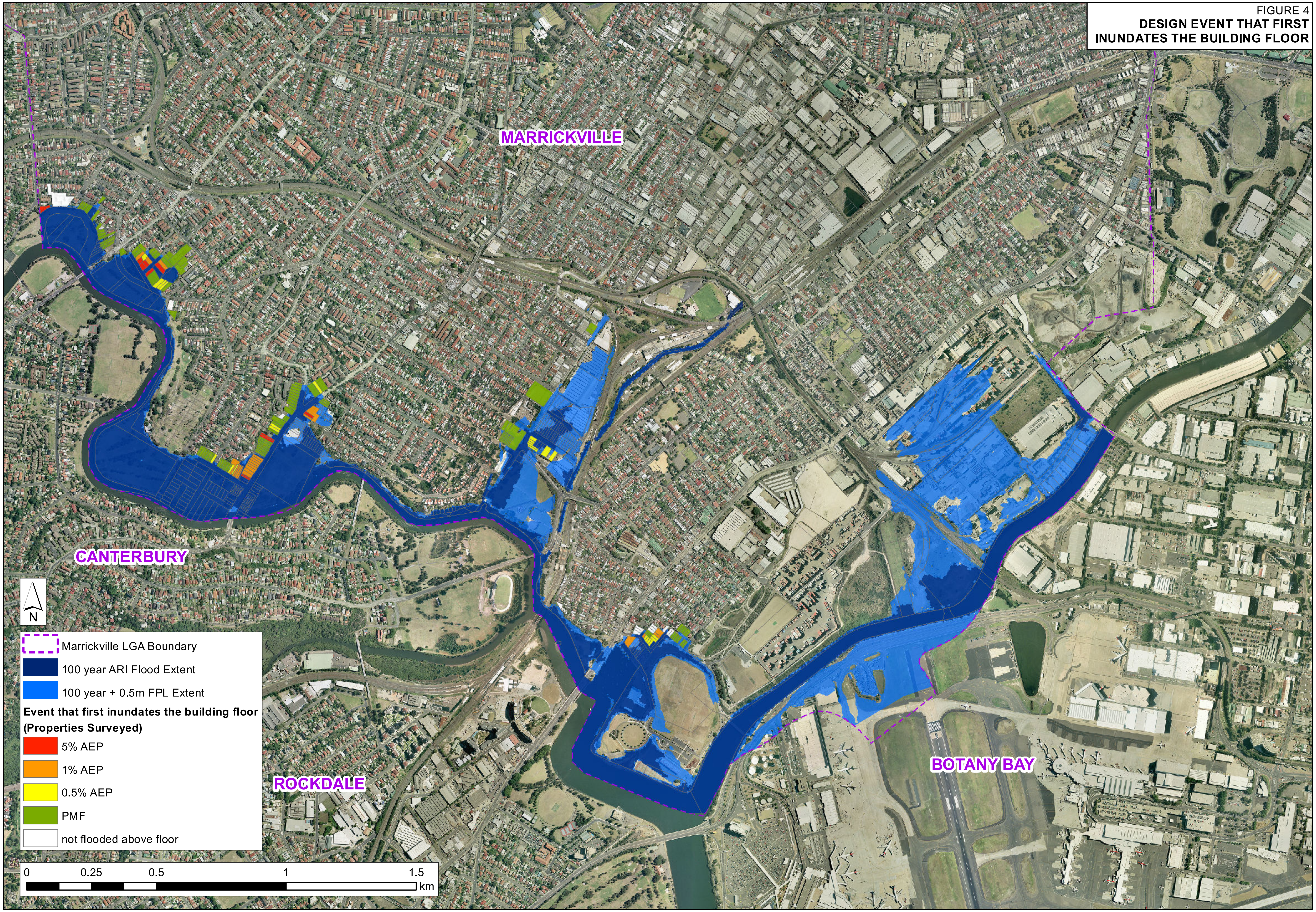
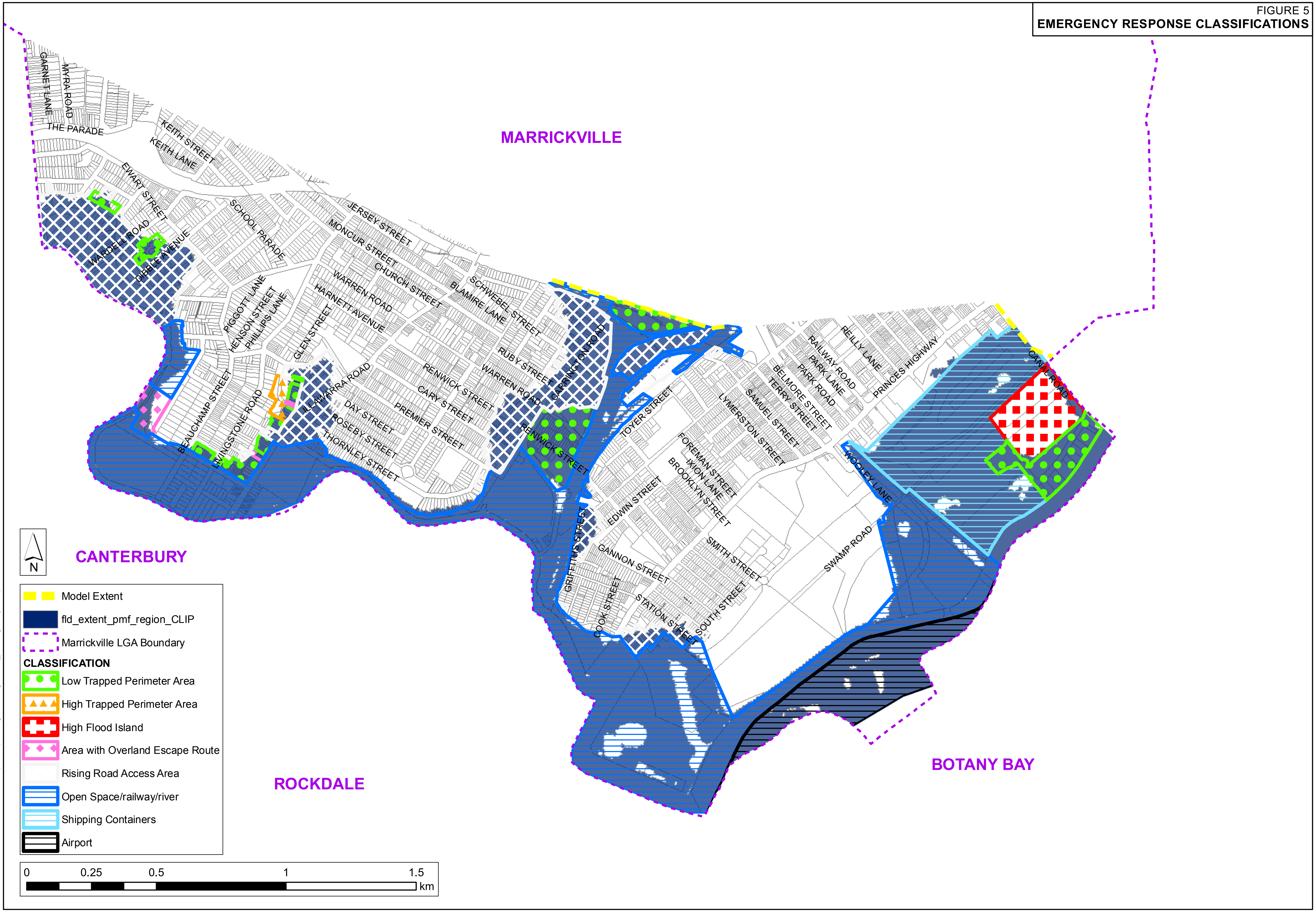


FIGURE 4
DESIGN EVENT THAT FIRST INUNDATES THE BUILDING FLOOR
MARRICKVILLE
CANTERBURY
ROCKDALE
BOTANY BAY
N
Marrickville LGA Boundary
100 year ARI Flood Extent
100 year + 0.5m FPL Extent
Event that first inundates the building floor (Properties Surveyed)
5% AEP
1% AEP
0.5% AEP
PMF
not flooded above floor
0 0.25 0.5 1 1.5 km
J:\Jobs\112010\ArcView\ArcMaps\ReportFigures\Figure04_Properties_First_Flooded.mxd

FIGURE 5
EMERGENCY RESPONSE CLASSIFICATIONS



J:\Jobs\112010\ArcView\ArcMaps\ReportFigures\Figure05_EmergencyResponseClassifications.mxd

Appendix A

APPENDIX A: GLOSSARY OF TERMS

Taken from the Floodplain Development Manual (April 2005 edition)

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

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

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

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

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

Appendix B

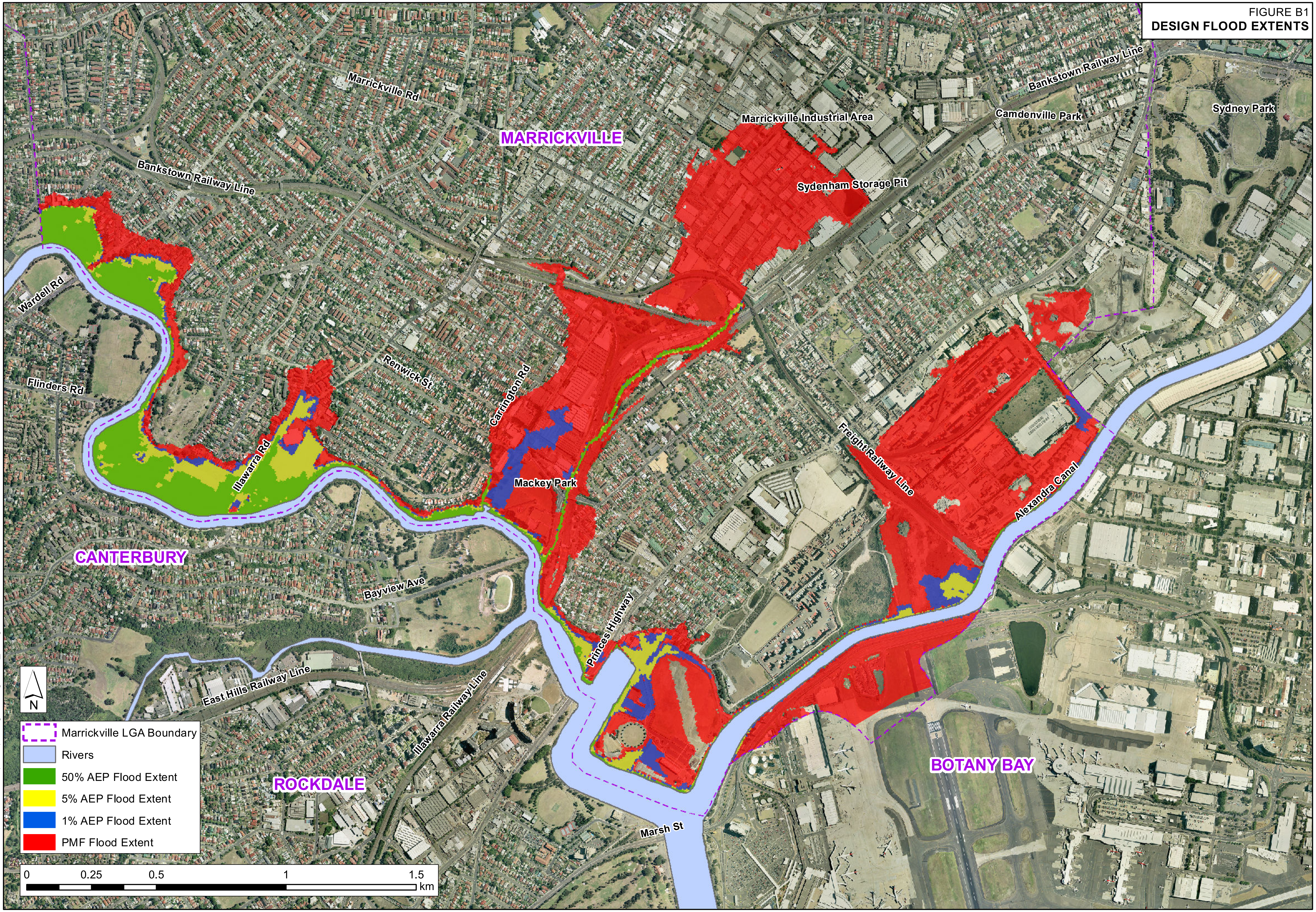


FIGURE B1
DESIGN FLOOD EXTENTS

J:\Jobs\112010\ArcView\ArcMaps\Report\Figures\FigureB1_DesignFloodExtents.mxd

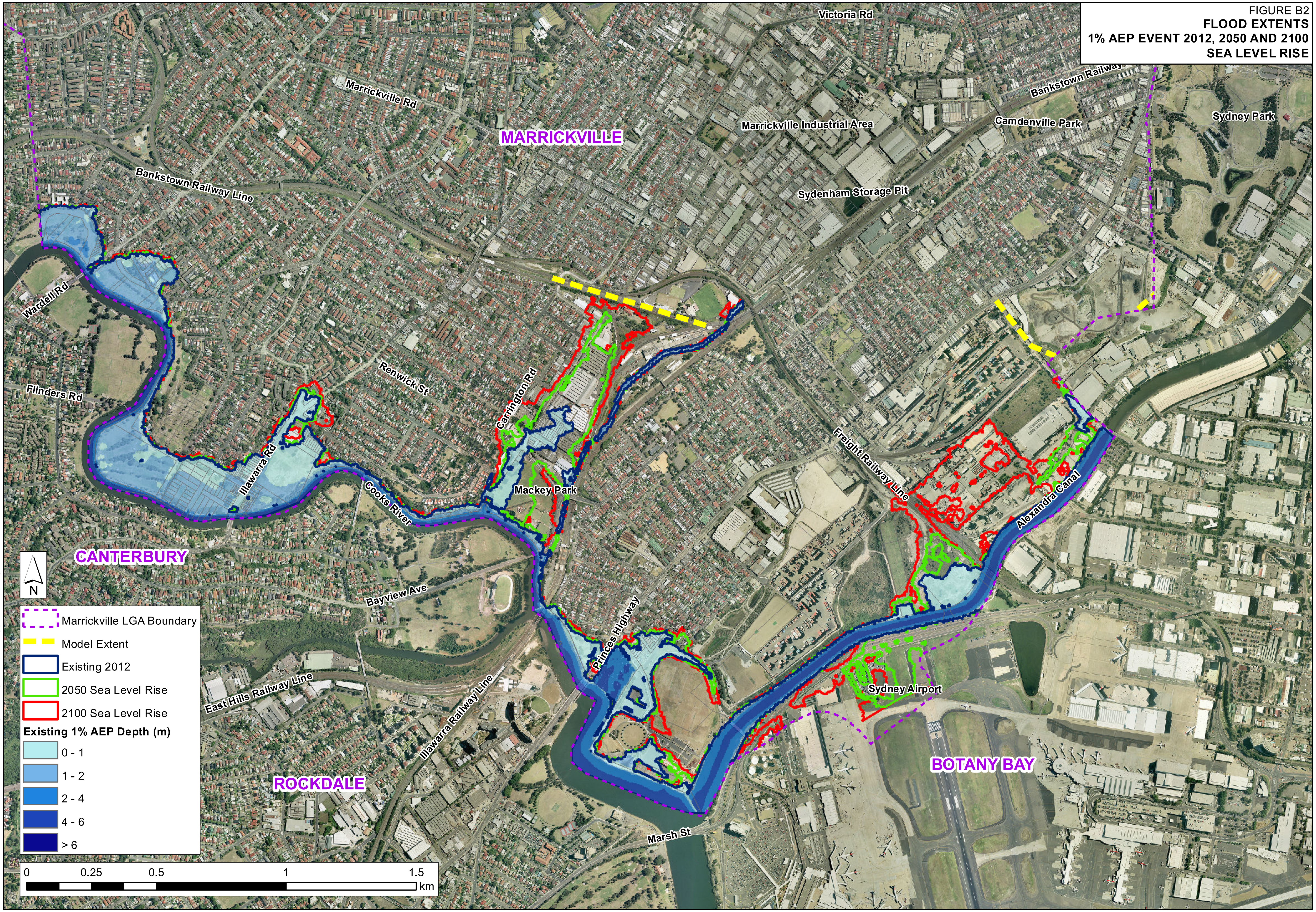
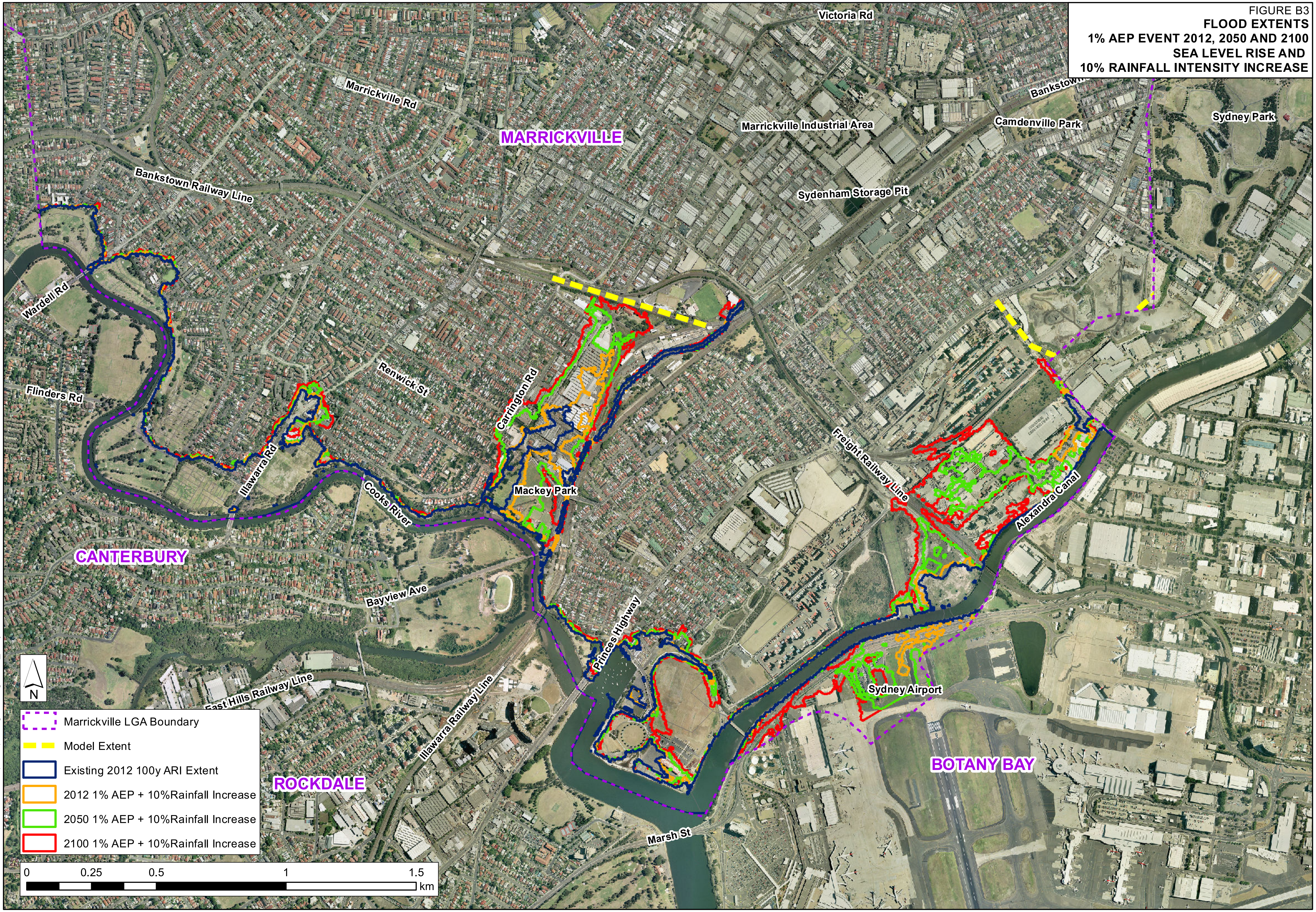


FIGURE B2
FLOOD EXTENTS
1% AEP EVENT 2012, 2050 AND 2100
SEA LEVEL RISE
MARRICKVILLE
CANTERBURY
ROCKDALE
BOTANY BAY
Victoria Rd
Marrickville Rd
Bankstown Railway Line
Marrickville Industrial Area
Camdenville Park
Sydney Park
Sydenham Storage Pit
Wardell Rd
Renwick St
Flinders Rd
Carrington Rd
Illawarra Rd
Cooks River
Mackey Park
Freight Railway Line
Alexandra Canal
Bayview Ave
Princes Highway
East Hills Railway Line
Illawarra Railway Line
Sydney Airport
Marsh St
N
Marrickville LGA Boundary
Model Extent
Existing 2012
2050 Sea Level Rise
2100 Sea Level Rise
Existing 1% AEP Depth (m)
0 - 1
1 - 2
2 - 4
4 - 6
> 6
0 0.25 0.5 1 1.5
km
J:\Jobs\112010\ArcView\ArcMaps\Report\Figures\FigureB2_Flood_Extents_100yARI.mxd

FIGURE B3
FLOOD EXTENTS
1% AEP EVENT 2012, 2050 AND 2100
SEA LEVEL RISE AND
10% RAINFALL INTENSITY INCREASE



J:\Jobs\112010\ArcView\ArcMaps\ReportFigures\FigureB3_100yARI+10%Rainfall.mxd

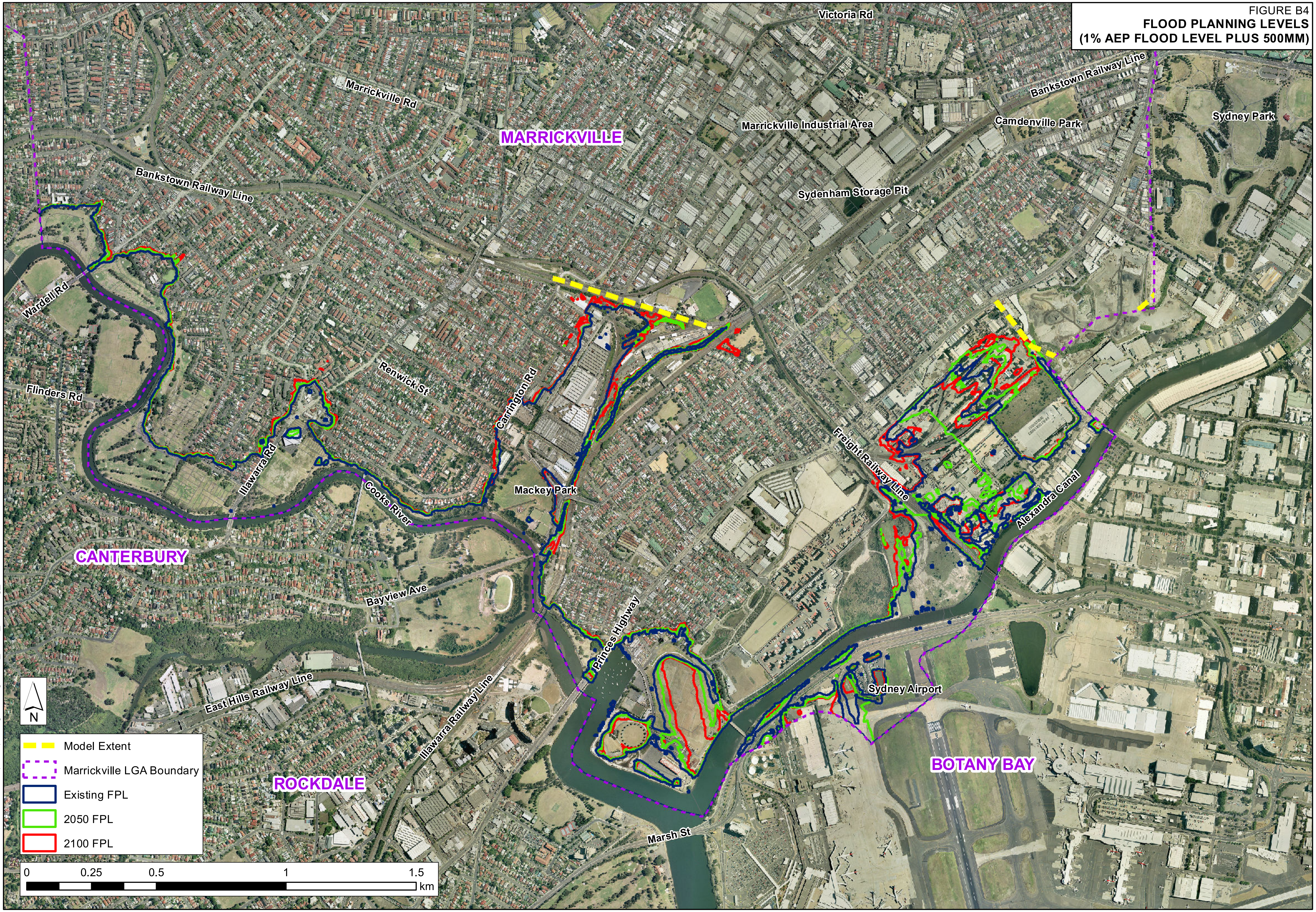
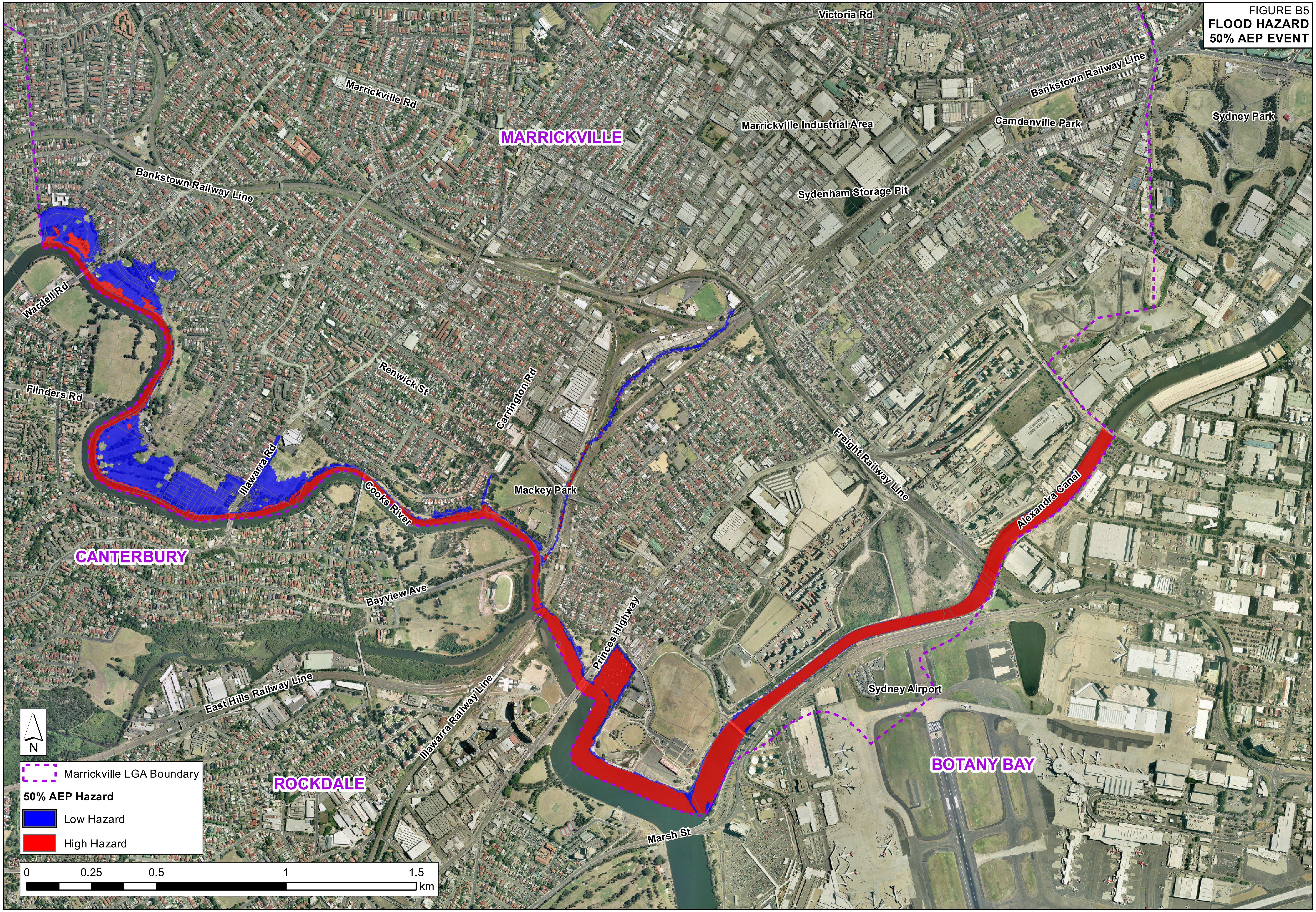


FIGURE B4
FLOOD PLANNING LEVELS
(1% AEP FLOOD LEVEL PLUS 500MM)
Victoria Rd
Marrickville Rd
MARRICKVILLE
Marrickville Industrial Area
Bankstown Railway Line
Camdenville Park
Sydney Park
Sydenham Storage Pit
Bankstown Railway Line
Wardell Rd
Renwick St
Flinders Rd
Carrington Rd
Freight Railway Line
Illawarra Rd
Mackey Park
Cooks River
Alexandra Canal
CANTERBURY
Bayview Ave
Princes Highway
East Hills Railway Line
Illawarra Railway Line
Sydney Airport
BOTANY BAY
ROCKDALE
Marsh St
N
Model Extent
Marrickville LGA Boundary
Existing FPL
2050 FPL
2100 FPL
0
0.25
0.5
1
1.5
km
J:\Jobs\112010\ArcView\ArcMaps\ReportFigures\FigureB4_Flood_Planning_Levels.mxd



J:\Jobs\112010\ArcView\ArcMaps\ReportFigures\FigureB5_2y_Hazard.mxd

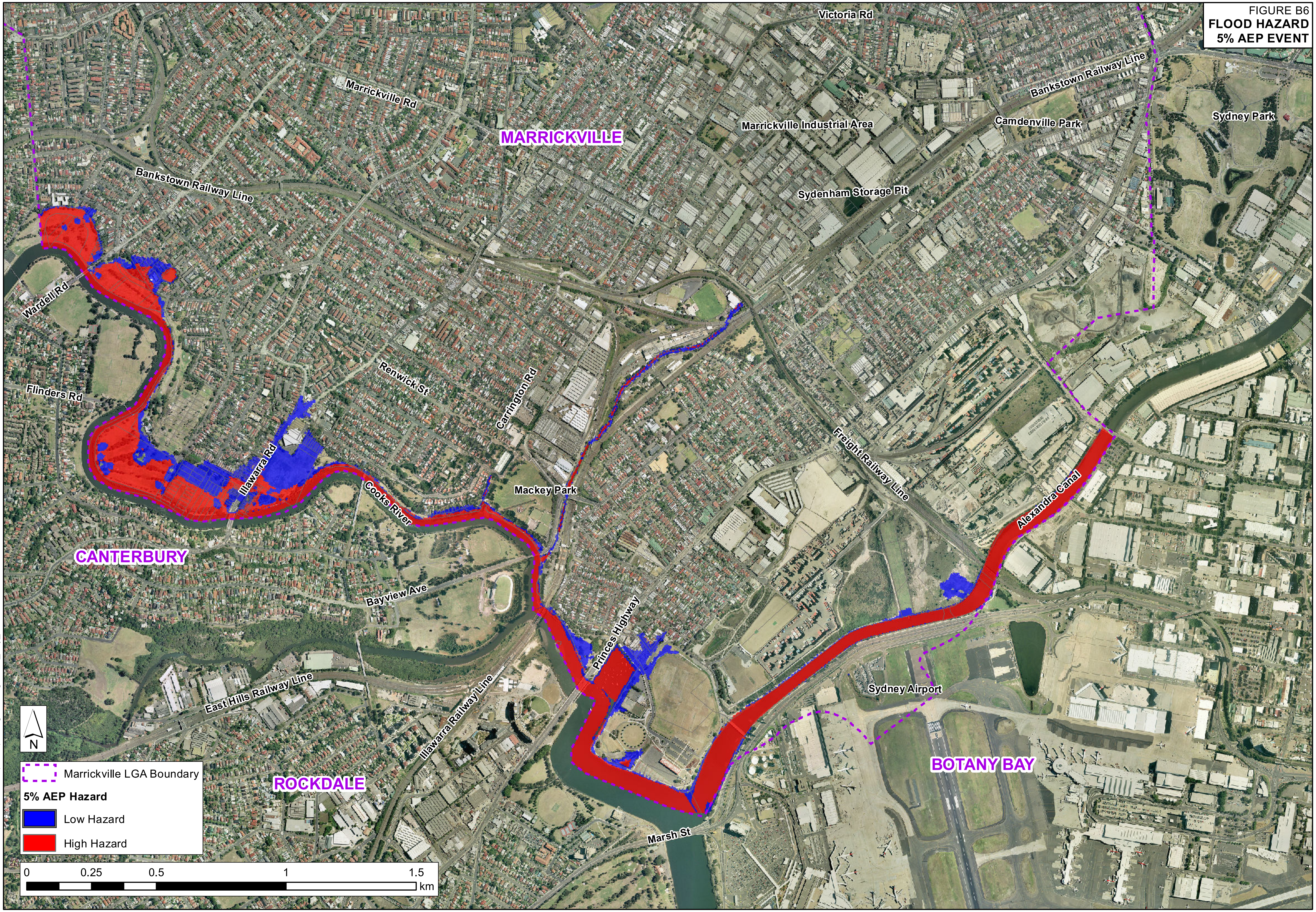


FIGURE B6
FLOOD HAZARD
5% AEP EVENT
Victoria Rd
Marrickville Rd
MARRICKVILLE
Bankstown Railway Line
Camdenville Park
Sydney Park
Marrickville Industrial Area
Sydenham Storage Pit
Wardell Rd
Flinders Rd
Renwick St
Carrington Rd
Illawarra Rd
Cooks River
Mackey Park
Freight Railway Line
Alexandra Canal
CANTERBURY
Bayview Ave
Princes Highway
East Hills Railway Line
Illawarra Railway Line
Sydney Airport
BOTANY BAY
ROCKDALE
Marsh St
N
Marrickville LGA Boundary
5% AEP Hazard
Low Hazard
High Hazard
0
0.25
0.5
1
1.5
km
J:\Jobs\112010\ArcView\ArcMaps\Report Figures\FigureB6_20y_Hazard.mxd

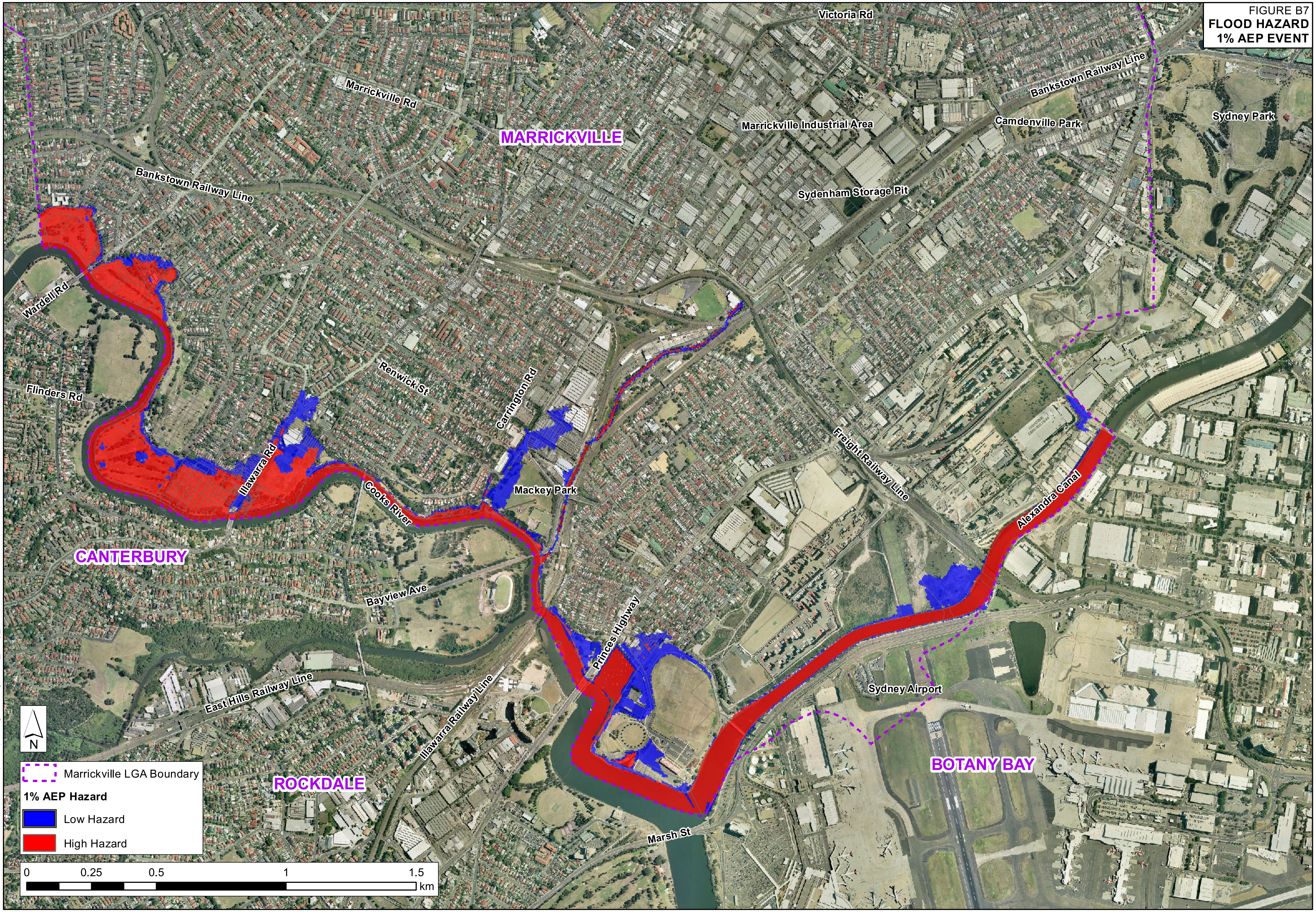


FIGURE B7
FLOOD HAZARD
1% AEP EVENT

J:\Jobs\112010\ArcView\ArcMaps\ReportFigures\FigureB7_100y_Hazard.mxd

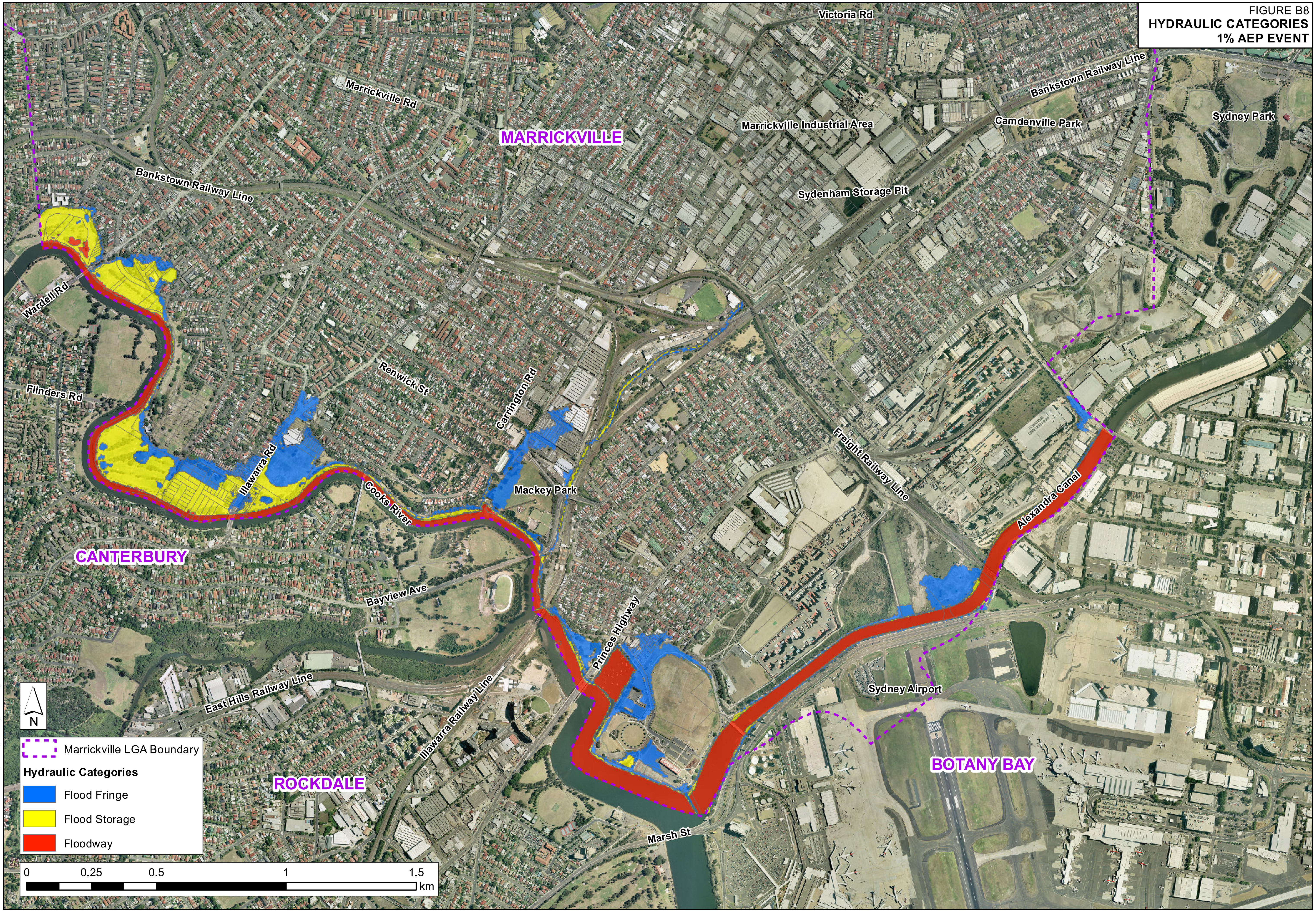


FIGURE B8
HYDRAULIC CATEGORIES
1% AEP EVENT

J:\Jobs\112010\ArcView\ArcMaps\ReportFigures\FigureB8_100y_HydCat.mxd

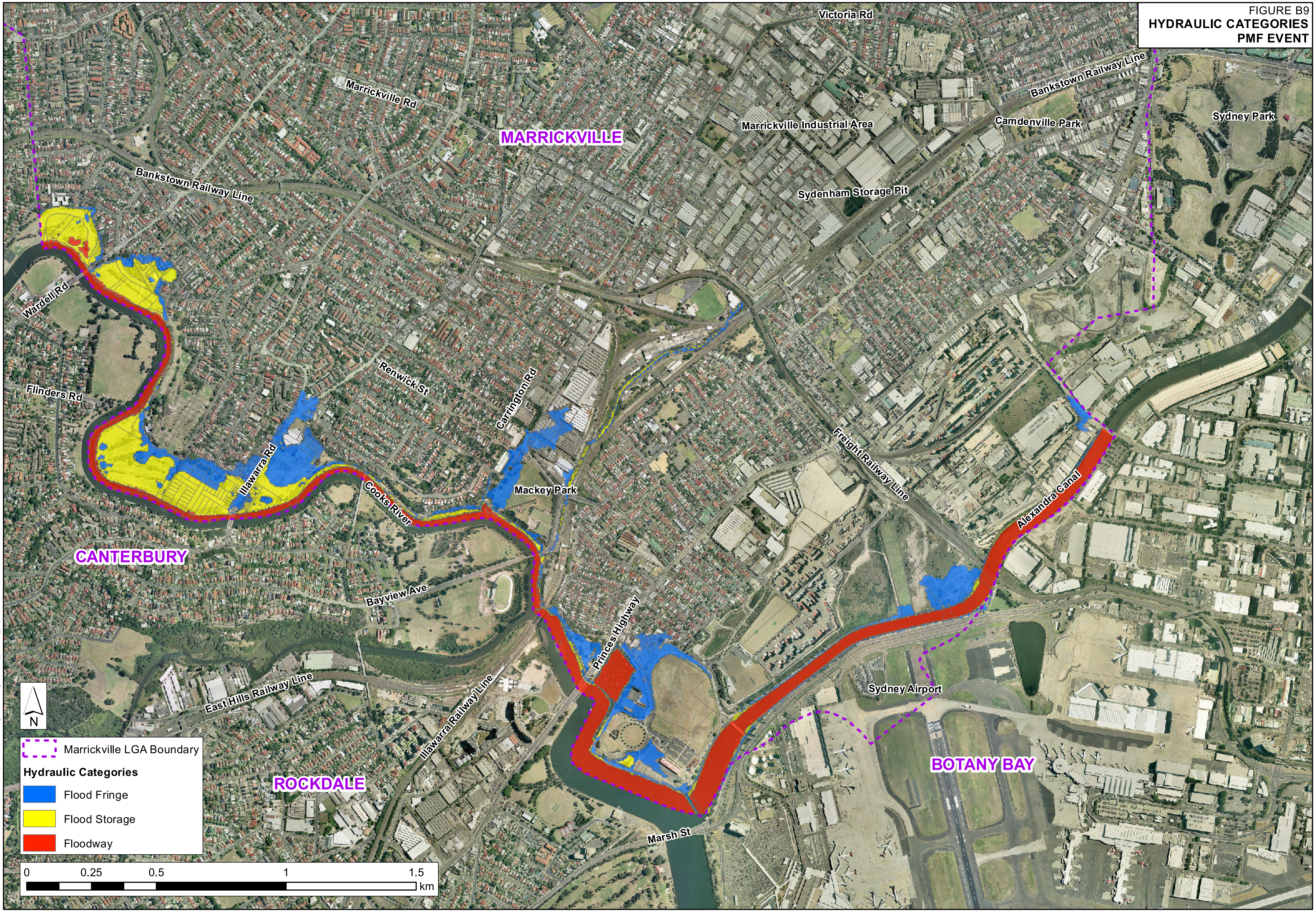


FIGURE B9
HYDRAULIC CATEGORIES
PMF EVENT

J:\Jobs\112010\ArcView\ArcMaps\Report\Figures\FigureB9_PMF_HydCat.mxd

Appendix C

APPENDIX C: Cooks River Model Validation – 8th March 2012 Flood Event

C1. INTRODUCTION

C1.1 General

Rainfall in March 2012 caused widespread flooding throughout Sydney and within the Cooks River catchment resulting in overbank flooding, including overtopping of the Illawarra railway line along Wolli Creek as seen on Figure C1.

C1.2 Objectives

As part of the Cooks River Floodplain Risk Management Study, this 8th March 2012 event has been investigated and modelled using the 2009 Cooks River Flood Study (Reference 2) hydrologic and hydraulic models. Comparisons of modelled behaviour versus recorded flood behaviour are made for the 8th March 2012 event and evaluated against rainfall records and design flood levels from the 2009 Cooks River Flood Study.

C2. AVAILABLE DATA

The first stage in the investigation of flooding matters is to establish the nature, size and frequency of the problem. On large river systems there are generally stream height and historical records dating back to the early 1900's or in some cases even further. On the Cooks River there are no stream flow records, however there are stream height and continuously read rainfall gauges in the catchment.

C2.1 Rainfall Data

C2.1.1 Rainfall Stations

There are a number of pluviometer rainfall stations within the catchment and surrounding area. These gauges are operated either by Sydney Water (SWC) or the Bureau of Meteorology (BoM). There may also be other private gauges in the area (bowling clubs, schools) but data from these have not been collected as there is no public record of their existence. Table C1 lists available pluviometer rainfall data and Figure C2 shows the locations of the gauges. Daily read data were not collected as these 24hour records are of much lesser value in assessing an event of less than 24h duration and which crosses the 9:00am reading time (i.e records will be split into a two day record).

Table C1: Pluviometers within the Cooks River Catchment

Station No	Owner	Station	Elevation (mAHD)	Date Opened (daily read gauge)
66037	BoM	Sydney Airport	6.0	1960
566020	SWC	Enfield (Composite Site)	10.0	14/4/1959
566026	SWC	Marrickville	5.0	1/5/1904
566028	SWC	Mascot Bowling Club	5.0	28/8/1973
566036	SWC	Potts Hill Reservoir	55.0	1/12/1945
566047	SWC	Mortdale Bowling Club	40.0	28/10/1971

C2.1.2 Analysis of Pluviometer Data

Data from the entire period of record of the Enfield pluviometer (566020) and the Marrickville pluviometer (566026) have been analysed and the major storm events listed in Table C2 and C3. It should be noted that pluviometer data have only been collected since approximately the early 1970's.

A comparison of these pluviometer data (Figure C3) suggests that there is significant variability in rainfall throughout the catchment for the various historical events.

Table C2: Rainfall (mm) and Rainfall Intensity (mm/h) for major rainfall events at Enfield (566020) rainfall station

Rainfall Event	5 min	10 min	30 min	60 min	2 hour	3 hour	6 hour	12 hour	24 hour
5/8/1986	9	16	36	50	64	77	147	228	316
	(108)	(96)	(72)	(50)	(32)	(26)	(25)	(19)	(13)
2/1/1996	16	24	57	81	8	95	97	97	99
	(186)	(141)	(113)	(81)	(44)	(32)	(16)	(8)	(4)
10/4/1998	7	14	25	43	67	78	97	132	143
	(84)	(81)	(49)	(43)	(33)	(26)	(16)	(11)	(6)
31/1/2001	7	12	28	35	61	72	111	133	173
	(84)	(72)	(55)	(35)	(30)	(24)	(18)	(11)	(7)
30/4/1988	8	10	23	35	50	58	102	161	215
	(90)	(57)	(46)	(35)	(25)	(19)	(17)	(13)	(9)
8/3/2012	*5*	10	17	25	43	62	66	95	105
	(60)	(57)	(34)	(25)	(21)	(17)	(11)	(8)	(4)

Table C3: Rainfall (mm) and Rainfall Intensity (mm/h) for major rainfall events at Marrickville (566026) rainfall station

Rainfall Event	5 min	10 min	30 min	60 min	2 hour	3 hour	6 hour	12 hour	24 hour
13/5/2003	12 *(138)*	22 *(129)*	51 *(101)*	65 *(65)*	66 *(33)*	70 *(23)*	84 *(14)*	108 *(8)*	126 *(5)*
17/2/1993	12 *(138)*	18 *(108)*	47 *(94)*	64 *(64)*	81 *(41)*	88 *(29)*	98 *(16)*	98 *(8)*	98 *(4)*
10/4/1998	11 *(132)*	17 *(102)*	45 *(89)*	64 *(64)*	77 *(38)*	79 *(26)*	84 *(14)*	116 *(10)*	116 *(5)*
5/8/1986	*7* *(78)*	*11* *(66)*	*23* *(45)*	*30* *(30)*	*40* *(20)*	*54* *(18)*	*103* *(17)*	*178* *(15)*	*264* *(11)*
13/2/1988	8 *(96)*	12 *(72)*	27 *(54)*	47 *(47)*	75 *(37)*	82 *(27)*	96 *(16)*	111 *(9)*	111 *(8)*
8/3/2012	6 *(72)*	9 *(54)*	24 *(47)*	31 *(31)*	42 *(21)*	54 *(18)*	72 *(12)*	98 *(9)*	112 *(5)*

C2.1.3 8th March 2012 Event

Table C4 and Figure C4 indicate the peak rainfall intensity at each rainfall station during the 8th March 2012 rainfall event for various durations.

Table C4: Peak Burst Rainfall Intensity (mm/h) – 8th March 2012

Duration	Sydney Airport (66037)	Enfield (566020)	Marrickville (566026)	Mascot (566028)	Potts Hill (566036)	Mortdale (566047)
5 min	50.4	60.0	72.0	66.0	30.0	84.0
10 min	45.6	57.0	54.0	60.0	21.0	72.0
20 min	38.4	46.5	41.0	45.0	21.0	46.5
30 min	33.2	34.0	47.0	38.0	21.0	36.0
1 hour	21.6	25.0	30.5	26.0	16.0	25.5
1.5 hours	17.2	23.7	24.3	20.0	13.7	21.0
2 hours	15.3	21.3	21.0	17.3	13.3	19.8
3 hours	13.3	17.3	18.0	17.7	11.7	16.2
4 hours	11.0	14.1	15.1	15.1	10.8	13.9
5 hours	10.1	12.8	13.6	13.3	10.0	12.4
6 hours	8.7	11.0	11.9	11.9	8.6	10.5
8 hours	7.0	9.1	9.4	9.3	7.8	9.1
10 hours	6.9	8.9	9.2	8.7	7.6	8.7
12 hours	6.0	7.9	8.2	8.2	7.1	7.8
15 hours	5.5	6.8	7.2	7.1	6.2	6.8
18 hours	4.7	5.8	6.2	6.1	5.2	6.0
24 hours	3.6	4.4	4.7	4.6	4.0	4.5
36 hours	2.4	2.9	3.1	3.1	2.7	3.0
48 hours	1.8	2.2	2.3	2.3	2.0	2.3

Rainfall data at each station was compared against all historical data at the station and ranked in order of intensity in Table C5. Note that data were only obtained at the Sydney Airport gauge (66037) for the past two years; therefore as the period of record is not substantial it has not been included in this analysis.

Table C5: Rainfall Ranking – 8th March 2012

Station Number	(566020)	(566026)	(566028)	(566036)	(566047)
Data Length	29 years	32 years	39 years	30 years	34 years
5 min	>200	>200	132	>200	29
10 min	83	>200	87	>200	27
20 min	86	43	79	>200	40
30 min	76	31	66	>200	42
1 hour	62	33	61	89	30
1.5 hours	54	26	57	73	22
2 hours	27	24	56	53	15
3 hours	25	17	20	34	15
4 hours	27	19	23	25	14
5 hours	17	18	22	21	15
6 hours	17	19	20	24	16
8 hours	22	21	26	20	16
10 hours	11	15	20	13	12
12 hours	14	16	17	10	11
15 hours	13	15	19	12	12
18 hours	16	18	24	12	14
24 hours	25	28	33	21	19
36 hours	42	50	64	43	38
48 hours	59	80	100	68	54

The above data indicates that the storm was approximately a 50% AEP (approximately 2-year ARI) event for a 9 to 18 hour duration period at the Mortdale, Marrickville, Mascot and Enfield pluviometers and less for other durations. At the Sydney Airport gauge the intensity of rainfall only approximated a 1 year ARI (99.99% AEP) event for these durations. It should be noted that there is not necessarily a direct correlation between the ARI of the rainfall intensities and the resulting water level ARI in the Cooks River. This occurs due to variability in the rainfall temporal patterns across the catchment.

C2.2 Flood Height Data

C2.2.1 Automatic Water Level Gauges

The lower Cooks River catchment includes three river gauging stations at Canterbury Road, Illawarra Road Bridge and Tempe Road as shown on Figure C1. A summary of peak daily height data is shown in Figure C5 which indicates that the 8th March 2012 event is the largest recorded event since installation of these gauges in the early 1990's. At Tempe Bridge on the Princes Highway there are events in the period 1998 to 2001 that are close to the level of the 8th March 2012 event. However it is likely that these events at the Tempe Bridge gauge would be strongly influenced by elevated ocean levels due to it being the most downstream gauge.

The peak flood levels for the 8th March 2012 are shown in Table C6 and on Figure C6. Comparisons are made to the November 1961 and March 1983 events (from 2009 Cooks River Flood Study), with the 8th March 2012 event exhibiting much lower flood levels.

Table C6: Automatic Water Level Gauges – Cooks River

Location	Gauge Started	8th March 2012 (mAHD)	November 1961*	March 1983*	50% AEP (2yrARI)	5% AEP (20yrARI)	1% AEP (100yrARI)
Canterbury Road	1995	2.44	3.1, 4.6	3.4	2.53	3.46	4.14
Illawarra Rd Bridge	2001	1.99	3.1, 3.4	1.9, 2.3	1.92	2.49	2.94
Tempe Bridge	1992	1.50	-	-	1.56	1.99	2.28

Note: * Recorded levels for November 1961, March 1983 and design flood levels from 2009 Cooks River Flood Study. There is a wide variation in level at Canterbury Road for November 1961.

A comparison of historic flood levels at the automatic gauges against design flood levels from the 2009 Cooks River Flood Study are shown in Table C6 which indicates that the 8th March 2012 has a flood level coinciding with a design recurrence interval of approximately 50% AEP (2 year ARI).

C2.2.2 Additional Flood Height Survey

In addition to the water level gauges a survey of flood levels was undertaken by Marrickville Council immediately following the 8th March 2012 event. Table C7 summarises the information with the locations shown on Figure C7.

Table C7: Recorded Flood Level Data

ID	Location	Description	Flood Level (mAHD)	Easting (m)	Northing (m)
1	Riverside Cres	Telegraph pole outside 47 Riverside Cres	2.2	327968.965	6245826.887
2	Riverside Cres	Telegraph pole outside 10 Dibble Avenue	2.235	328002.969	6245844.129
3	Riverside Cres	Telegraph pole opposite 12 Dibble Ave	2.22	328000.317	6245829.677
4	Steel Park	BBQ Park Area	1.955	328409.400	6244941.252
5	Steel Park	Light pole near bike path	1.91	328415.474	6244923.670
6	Steel Park	Dwarf wall park area	1.935	328455.073	6244922.464
7	Mackey Park	Canoe club building corner	1.745	329508.957	6244760.801
8	Kendrick Park	Bike underpass fence	1.525	329531.53	6244519.823
9	Kendrick Park	Bike underpass wall	1.555	329535.607	6244521.447

Recorded flood levels in Table C7 appear to be relatively consistent with the water level gauge recordings in Table C6.

C2.2.3 Tidal Data

Predicted peak tidal levels at Sydney (Fort Denison) were obtained with tidal ranges shown in Table C8. Tidal peaks were matched to flood stage hydrographs at Tempe Bridge in order to account for the change in timing between high tide at Fort Denison and along the Cooks River which discharges into Botany Bay.

Table C8: Predicted Tides at Fort Denison

Date and Time		Tidal Level (mAHD)	Description
7/3/2012	7:45 PM	0.65	High Tide
8/3/2012	1:41 AM	-0.59	Low Tide
8/3/2012	7:58 AM	0.91	High Tide
8/3/2012	2:19 PM	-0.7	Low Tide
8/3/2012	8:28 PM	0.76	High Tide
9/3/2012	2:29 AM	-0.65	Low Tide
9/3/2012	8:44 AM	0.9	High Tide

C3. RESULTS

C3.1 General

Two hydrologic scenarios were considered for the 8th March 2012 event. Firstly, using all six pluviometers with the spatial and temporal patterns assigned using a Thiessen weighting method and secondly using only the Marrickville pluviometer (566026) as this produced the highest intensity rainfall burst for the event.

C3.2 Comparison to Design Flows

Peak flows are compared against design flows from the 2009 Cooks River Flood Study in Table C9 with peak flows from the 8th March 2012 event generally less than the 50% AEP design event.

Table C9: Modelled Peak Flows (m^3/s) – 8th March 2012

Location	All Gauges	Marrickville Pluviometer	50% AEP (2 yr ARI)	5% AEP (20yr ARI)
General Holmes Drive	464	451	496	803
Marsh Street	395	415	436	709
Princes Highway	341	392	359	573
Tempe – Wolli Creek Railway	309	359	357	572
Illawarra Road	180	215	216	327
Wardell Road	172	205	200	282
Lang Road	174	205	191	279
Foord Avenue	181	219	209	322
Canterbury Road	158	202	193	298
Brighton Avenue	148	195	188	301
Burwood Road	130	181	172	307
Punchbowl Road	99	154	146	275
Water Street	100	158	147	271
Hume Highway	35	76	75	134
Morgan Place	35	74	71	98

C3.3 Comparison to Flood Data

Peak flood level profiles along the Cooks River are shown in Figure C6, with a comparison of modelled and recorded 8th March 2012 peak flood levels against peak design flood levels from the 2009 Cooks River Flood Study.

Modelled peak flood levels are compared against recorded levels in Table C10 and Figure C7, with water level hydrograph comparisons provided in Figure C8 at the Canterbury Road, Illawarra Road and Tempe Bridge gauges.

Table C10: Comparison of Recorded and Modelled Peak Flood Levels

		Modelled (All Gauges)		Modelled (Marrickville pluviometer)	
Location	Recorded Level (mAHD)	Level (mAHD)	Difference (m)	Level (mAHD)	Difference (m)
Canterbury Road	2.44	2.2	-0.3	2.4	-0.03
Riverside Crescent	2.2	1.8	-0.37	2.0	-0.16
Riverside Crescent	2.235	1.8	-0.40	2.0	-0.19
Riverside Crescent	2.22	1.8	-0.39	2.0	-0.18
Illawarra Road	1.99	1.7	-0.27	1.8	-0.14
Steel Park	1.955	1.6	-0.35	1.8	-0.15
Steel Park	1.91	1.6	-0.28	1.8	-0.11
Steel Park	1.935	1.6	-0.31	1.8	-0.14
Mackey Park	1.745	-	-	1.6	-0.20
Kendrick Park	1.525	1.3	-0.18	1.5	-0.07
Kendrick Park	1.555	-	-	-	-
Tempe Bridge	1.50	1.3	-0.20	1.4	-0.09

Generally the Flood Study model underestimates flood levels by up to -0.4 m (Table C10).

C3.4 Comparison to Observed Flood Behaviour

Modelled results did not match observed flooding behaviour in the Wolli Creek catchment where overtopping of the Illawarra railway line was observed near the Bexley North and Bardwell Park stations (Photo C1) with modelled flood levels more than 1m lower than observed.

This is the largest area of discrepancy and may potentially be attributed to the sparse distribution of pluviometer data. It is likely that the hydrologic modelling underestimates rainfall within the Wolli Creek catchment during the 8th March 2012 event, as there is no nearby rainfall gauge and therefore no available data within the catchment. Also no calibration data was available in this reach for the events used in calibration in the 2009 Cooks River Flood Study.

Photo C1: Flooded rail lines between Bexley North and Bardwell Park stations on Wolli Creek. Photo: *Alan Lee*

C3.5 Conclusions

The 8th March 2012 flood event is estimated to have an average recurrence interval of the order of a 50% AEP event.

The hydraulic model established for the 2009 Cooks River Flood Study model was calibrated to the November 1961 and March 1983 events which were significantly larger flood events, although they had a lesser quality and quantity of flood height data than for the 8th March 2012 flood.

The 8th March 2012 event was simulated using the same hydraulic model and the results under estimated the recorded peak flood levels by up to 0.4 m. The most significant feature of these results is that the model results are consistently below the recorded levels, rather than there being some model points above and below the recorded levels. Potentially these results indicate that the model results are therefore underestimating design flood levels.

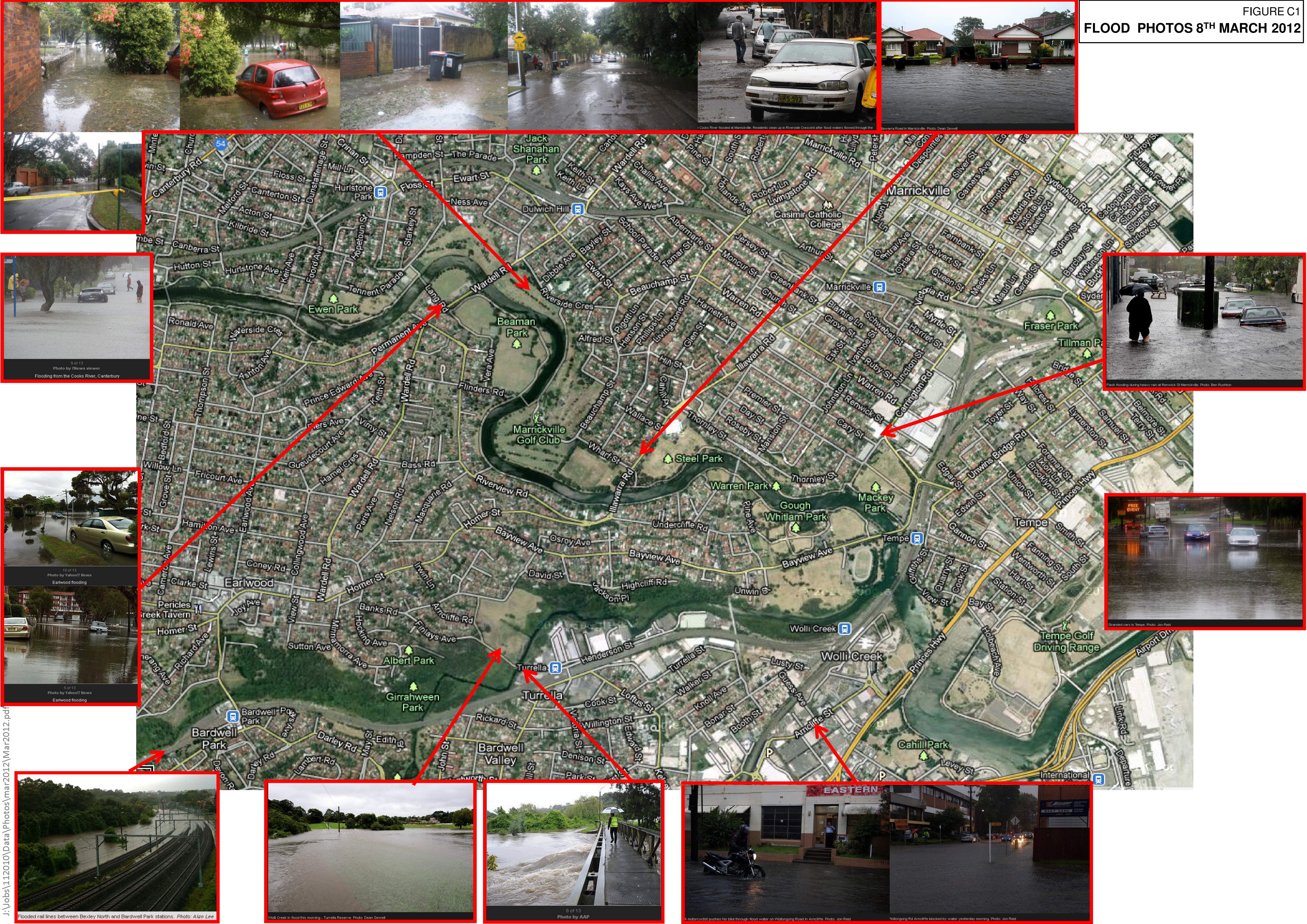
Adjusting the model calibration to more closely replicate the 8th March 2012 flood height data could be undertaken but this is not warranted given that the November 1961 and March 1983 events were much larger and thus more relevant for determining design flood levels for the 1% AEP and larger events.

A recommendation is that the hydraulic model should be used to “test” the calibration for all future flood events.

Figures

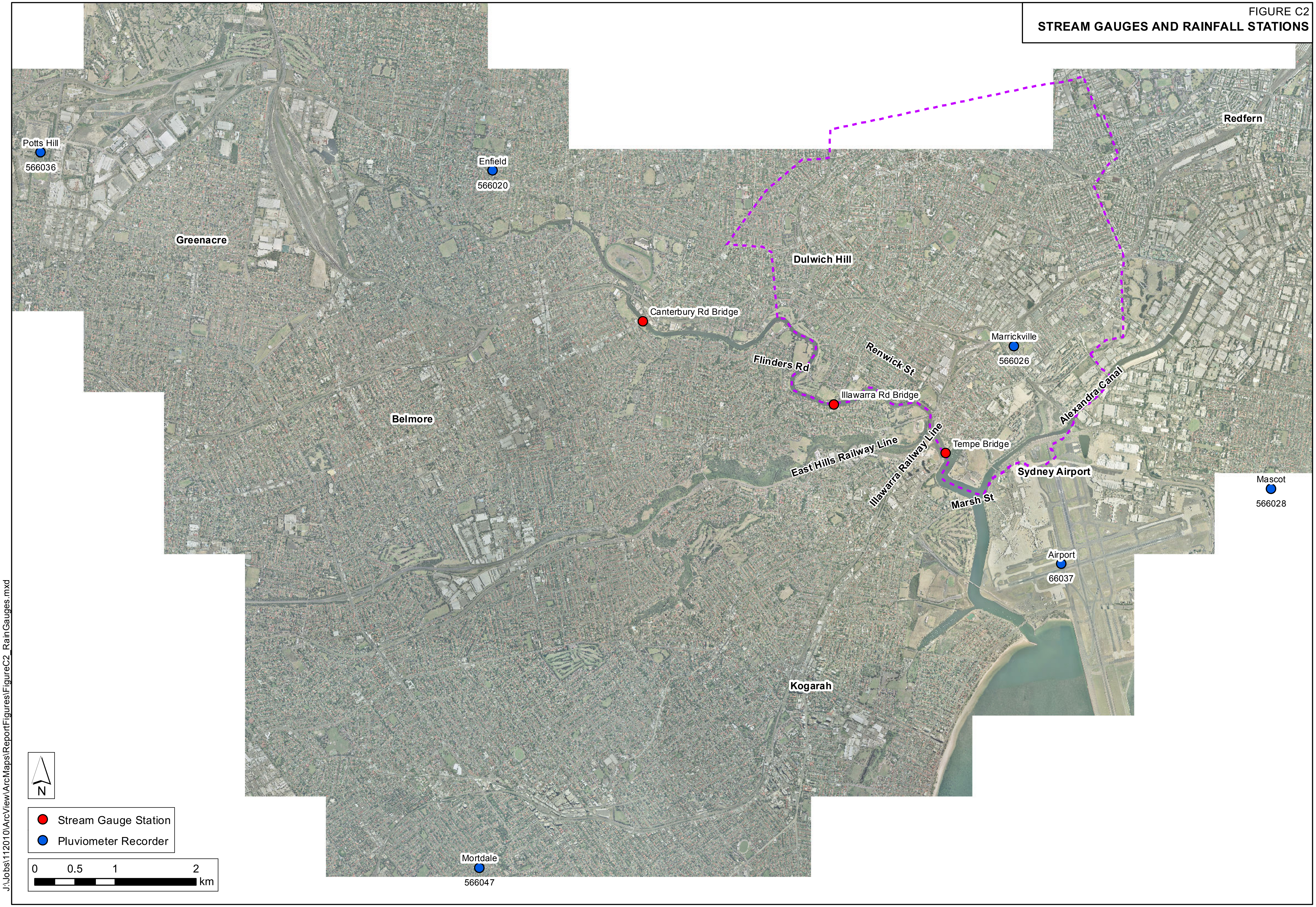
FIGURE C1

FLOOD PHOTOS 8TH MARCH 2012



J:\Jobs\112010\Data\Photos\mar2012\Mar2012.pdf

FIGURE C2
STREAM GAUGES AND RAINFALL STATIONS



J:\Jobs\112010\ArcView\ArcMaps\ReportFigures\FigureC2_RainGauges.mxd

FIGURE C3
RAINFALL HYETOGRAPHS
7-8 MARCH 2012

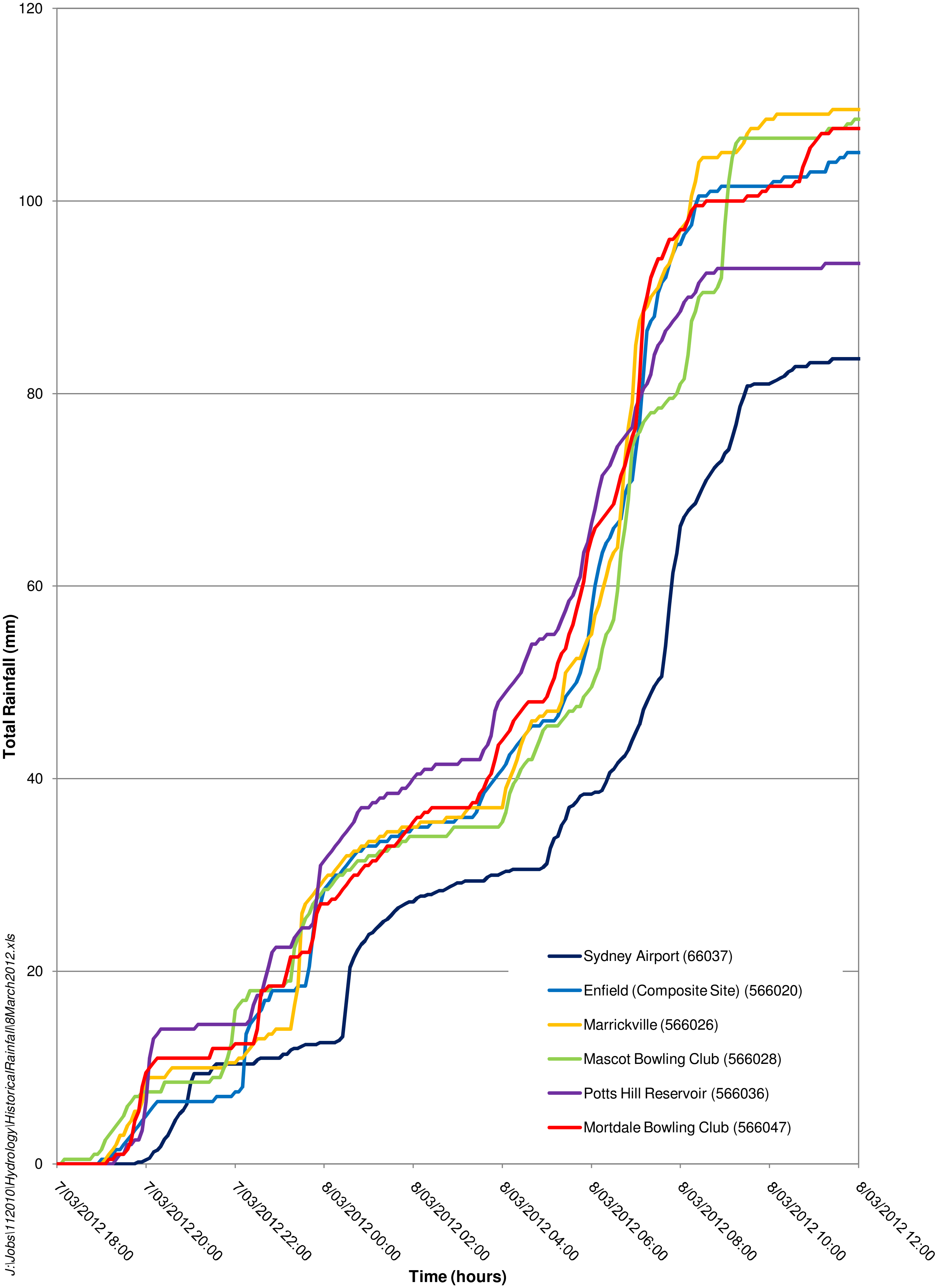
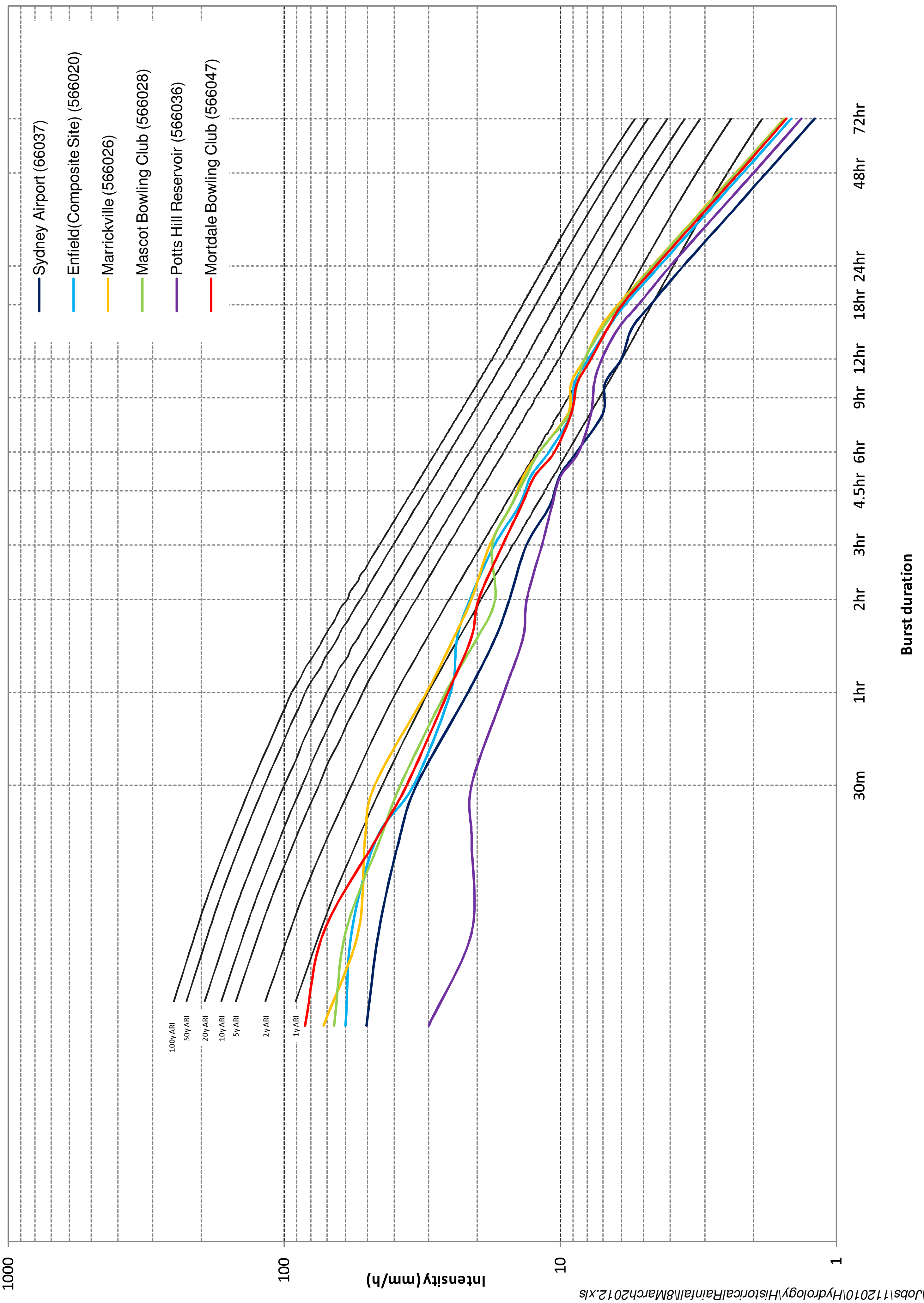
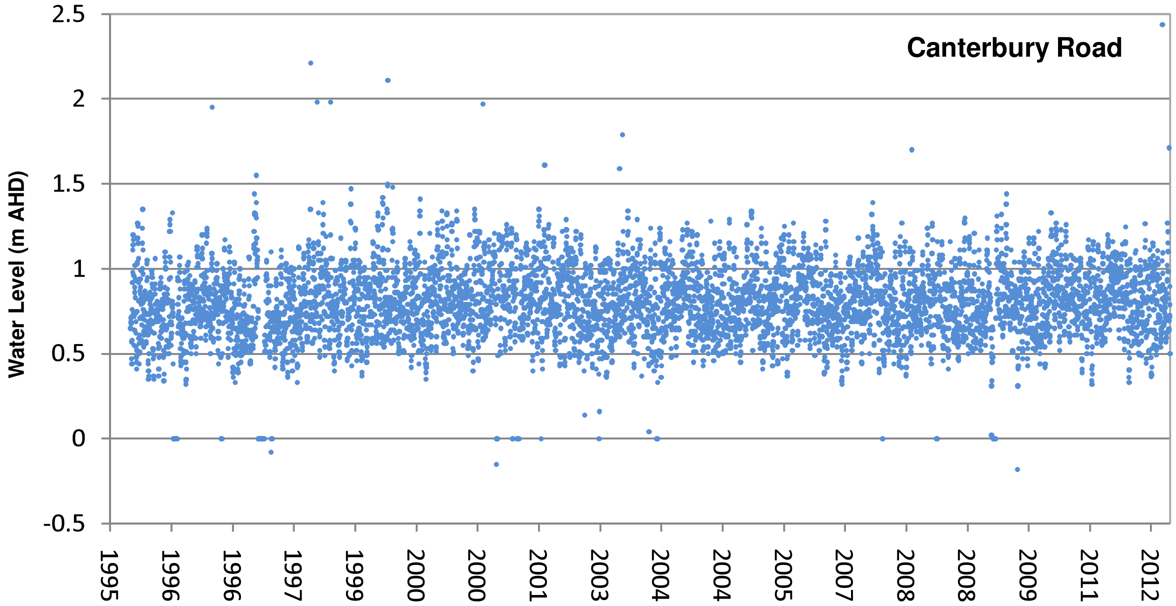


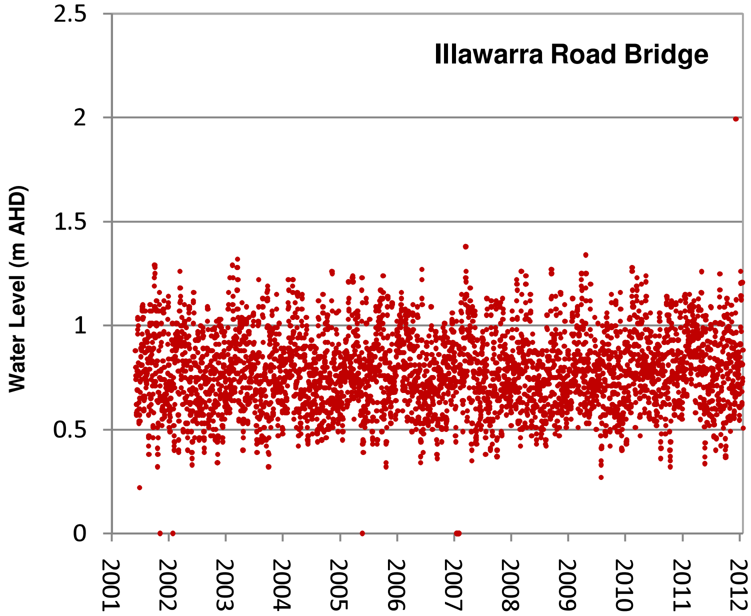
FIGURE C4
BURST INTENSITIES AND FREQUENCIES 8th MARCH 2012

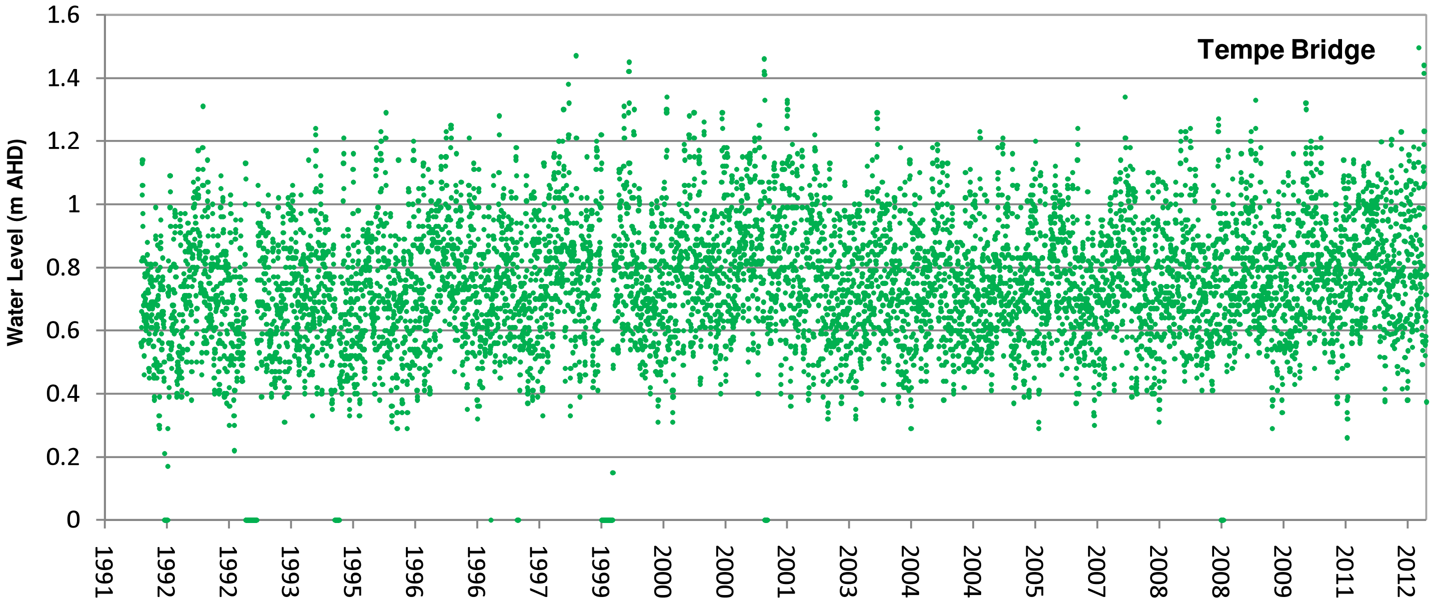


J:\Jobs\112010\Hydrology\HistoricalRainfall\8March2012.xls

FIGURE C5
PEAK DAILY WATER LEVELS
AUTOMATIC GAUGES

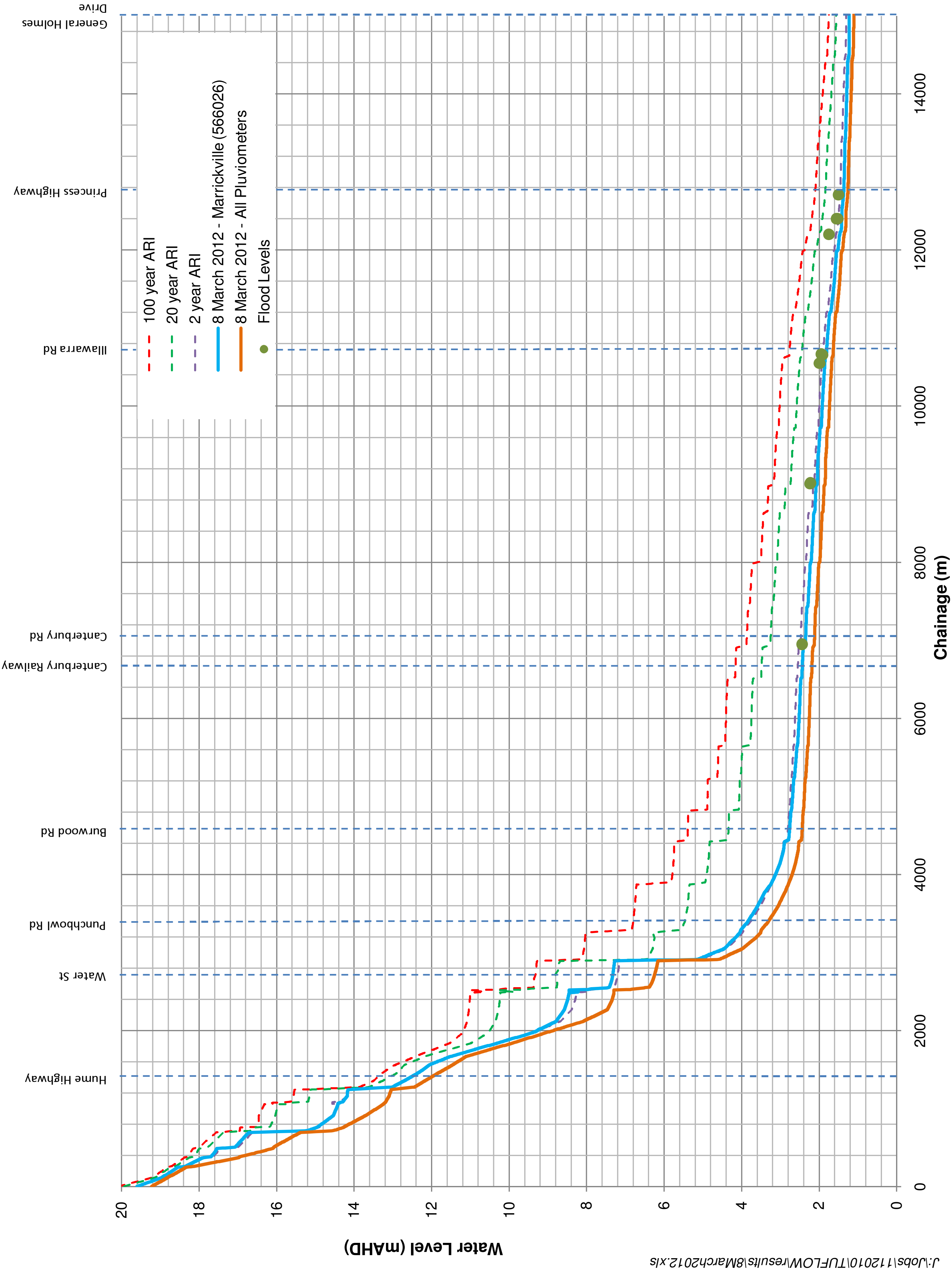






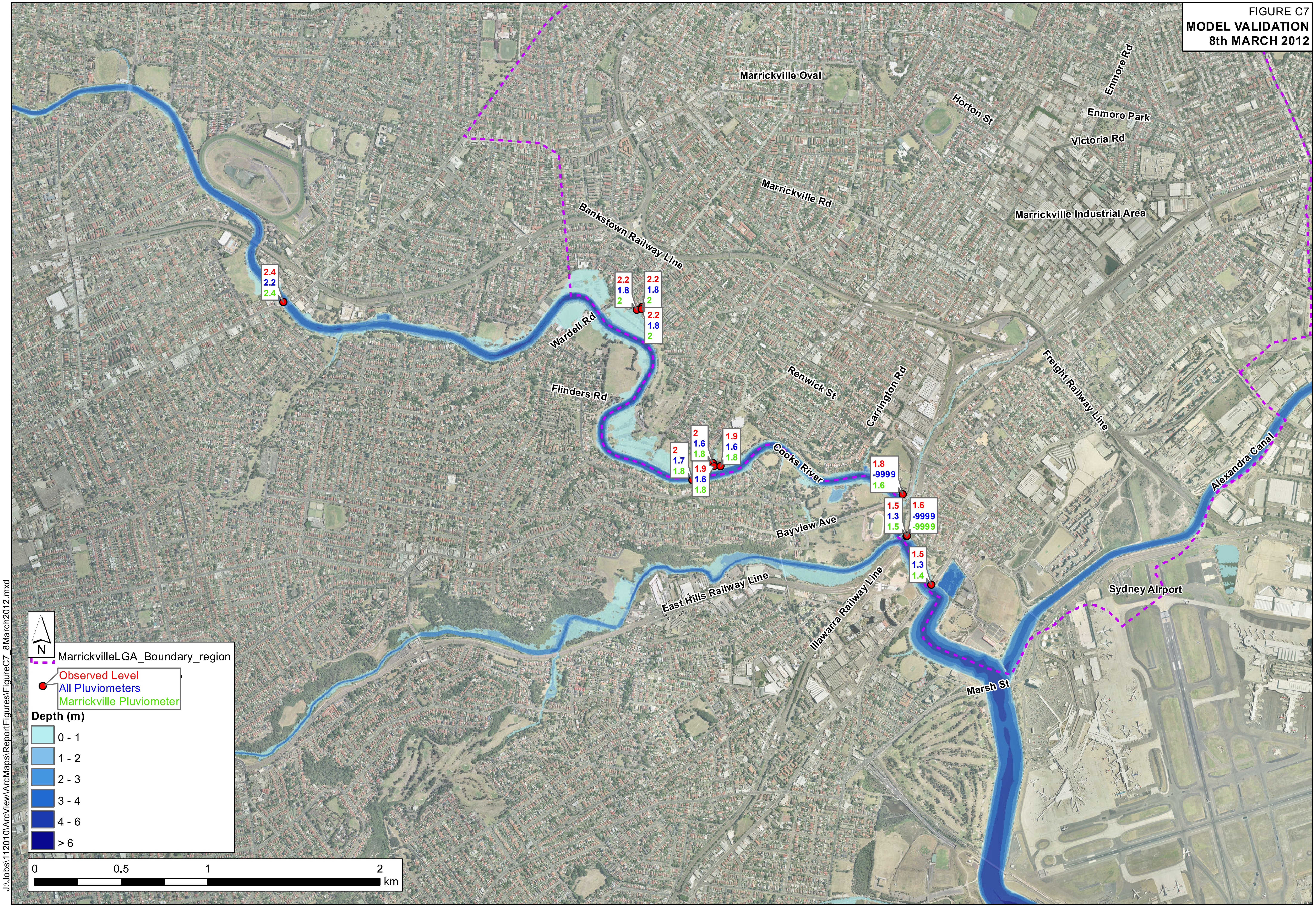
J:\Jobs\112010\Working\WaterLevelStations\GraphsWaterLevelStations.

FIGURE C6
PEAK FLOOD LEVEL PROFILES



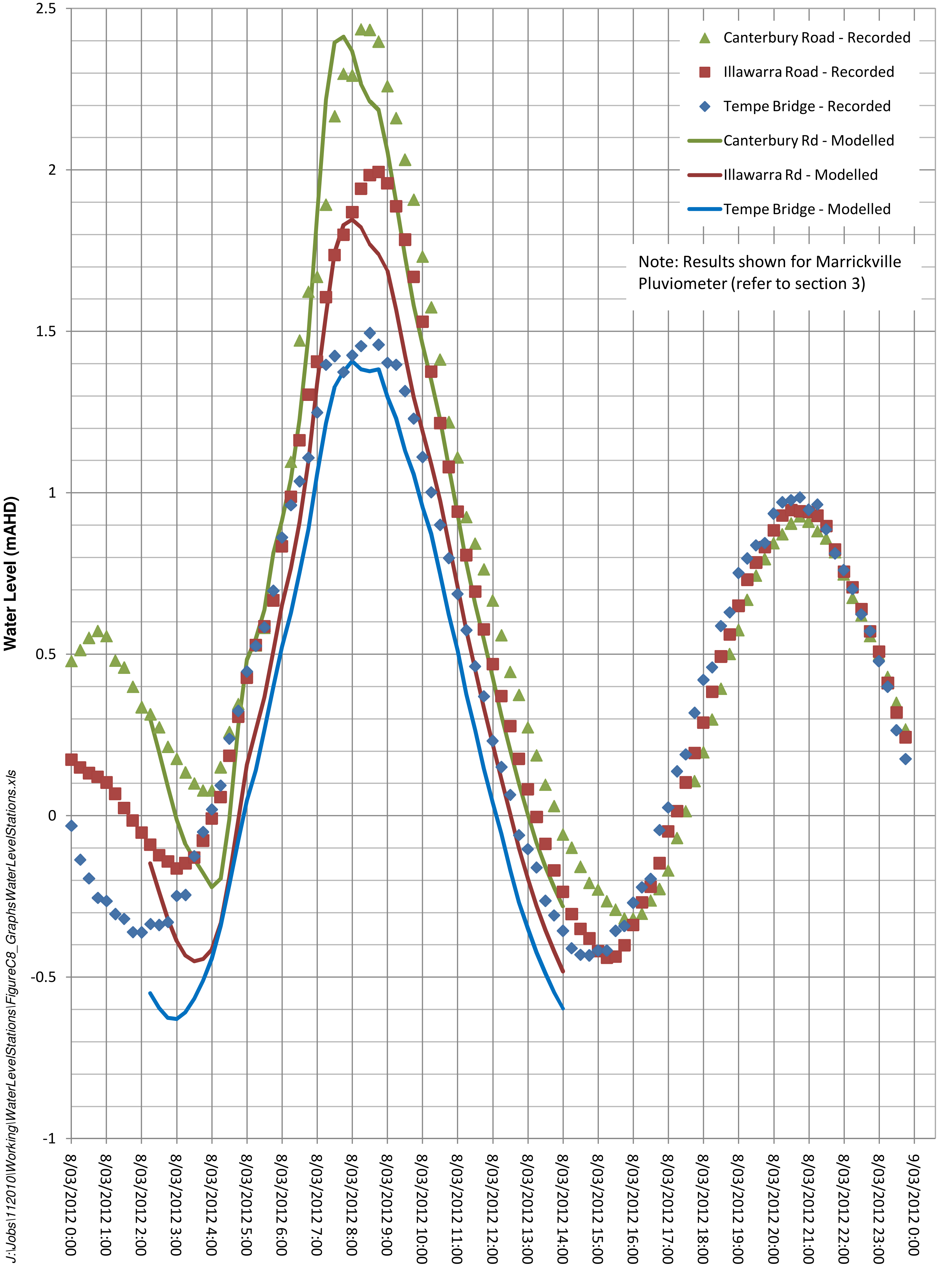
J:\Jobs\112010\TUFLOW\results\8March2012.xls

FIGURE C7
MODEL VALIDATION
8th MARCH 2012



J:\Jobs\112010\ArcView\ArcMaps\ReportFigures\FigureC7_8March2012.mxd

WATER LEVEL HYDROGRAPHS
8th MARCH 2012



J:\Jobs\112010\Working\WaterLevelStations\FigureC8_GraphsWaterLevelStations.xls