GREEN SQUARE - WEST KENSINGTON
FLOODPLAIN RISK MANAGEMENT STUDY
RANDWICK CITY COUNCIL REPORT

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Level 2, 160 Clarence Street
Sydney, NSW, 2000

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

GREEN SQUARE – WEST KENSINGTON FLOODPLAIN RISK MANAGEMENT STUDY

FINAL – RANDWICK CITY COUNCIL

Project **Green Square – West Kensington Floodplain Risk Management Study**	**Project Number** **28041**
Client **City of Sydney (CoS)** **Randwick City Council (RCC)**	**Client's Representative** Myl Senthilvasan (CoS) Terry Kefalianos (RCC)
Authors **Bowen Hicks** **Matthew Chadwick** **Richard Dewar**	**Prepared by**
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FOREWORD

The NSW State Government's Flood Policy provides a framework to ensure the sustainable use of floodplain environments. The Policy is specifically structured to provide solutions to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

Under the Policy, the management of flood liable land remains the responsibility of local government. The State Government supports Councils in the discharge of their floodplain management responsibilities with provision of specialist technical advice and access to funding assistance for flood mitigation works.

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

1. ***Flood Study***
   - Determine the nature and extent of the flood problem.
2. ***Floodplain Risk Management***
   - Evaluates management options for the floodplain in respect of both existing and proposed development.
3. ***Floodplain Risk Management Plan***
   - Involves formal adoption by Council of a plan of management for the floodplain.
4. ***Implementation of the Plan***
   - Construction of flood mitigation works to protect existing development, use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

The Green Square – West Kensington Floodplain Risk Management Study constitutes the second stage of the management process for the Green Square – West Kensington catchment. WMAwater has been commissioned to undertake this study by Randwick City Council (RCC) and the City of Sydney (CoS). Funding assistance and specialist technical advice has also been provided by the NSW Department of Environment, Climate Change and Water (DECCW) (now Office of Environment and Heritage). The outcomes are to support the future management of flood liable lands in the Green Square – West Kensington catchment.

EXECUTIVE SUMMARY

GREEN SQUARE – WEST KENSINGTON CATCHMENT

The Green Square and West Kensington (GSWK) study catchment covers approximately 2.5 km^2 and drains predominantly from east to west. The upper reaches (east of South Dowling Street) are predominantly zoned for residential usage. The area immediately west of South Dowling Street was once dominated by industrial premises. Significant redevelopment of this area in the form of medium and high density housing as well as commercial premises has been undertaken in recent years (since the year 2000). The study area extends west to Botany Road and O'Riordan Street downstream of the proposed Green Square Town Centre (GSTC) precinct.

Urbanisation has dramatically altered the nature of available drainage within the catchment. Flood problems within the West Kensington portion of the catchment typically result from ponding in trapped low-points such as those found in Milroy Avenue, McDougall Street and the Lenthall Street underpass below South Dowling Street. Ponding also occurs at various locations along the eastern side of South Dowling Street. Within the City of Sydney portion of the catchment, similar ponding behaviour also occurs at South Dowling Street (opposite the Supacentre), at Lachlan Street and in Botany Road (adjacent to the Green Square railway station plaza). The most significant trapped low point is located within Joynton Avenue which receives runoff from a significant portion of the study catchment. A number of the trapped low points in West Kensington and the Joynton Avenue low-point are known to have experienced severe flooding in early November 1984.

In the floodplain west of South Dowling Street, overland flow paths typically follow the existing road network. However in the southern portion of the floodplain between Link Road and Joynton Avenue, a number of uncontrolled overland flow paths form when the capacity of the trunk drainage system is exceeded. Significant overland flow paths also form between Portman Street and Botany Road when ponding in Joynton Avenue causes flood waters to overtop Portman Street. Overtopping of the Botany Road trapped low point also results in overland flow along the Green Square railway station plaza.

The NSW Government's Flood Policy provides for:

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

Implementation of the Policy requires a four stage approach, the first of which is preparation of a Flood Study to determine the nature and extent of the flood problem.

GREEN SQUARE – WEST KENSINGTON FLOOD STUDY

The Green Square – West Kensington (GSWK) Flood Study was initiated as a joint project between City of Sydney and Randwick City Council to establish flood behaviour for existing conditions across the catchment. The specific aims of the (GSWK) Flood Study were to:

- define flood behaviour across the catchment in both Local Government Areas (LGAs),
- prepare flood hazard and flood extent mapping,
- prepare suitable models of the catchment and floodplain for use in a subsequent Floodplain Risk Management Study (FPRMS) and Plan.

Hydrologic and hydraulic investigations were undertaken to determine the response of the drainage system to 50% AEP (1 in 2 year), 20% (1 in 5 year), 5% AEP (1 in 20 year), 2% AEP (1 in 50 year), 1% AEP (1 in 100 year) and 0.2% AEP (1 in 500 year) events and the Probable Maximum Flood (PMF). The results of these investigations were quantified as peak pipe capacities and peak overland flows throughout the study area. Peak flood levels were also estimated for each of the major trapped low points in the West Kensington area. For the lower reaches of the catchment (generally west of South Dowling Street) the study provides estimates of peak flood levels, flows and velocities along the overland flow paths. The key Flood Study phases undertaken were:

Review all available data: namely,

- reports, photographs, Council records,
- newsletter and questionnaire responses,
- review of rainfall and historical flood level data, and
- acquisition of drainage assets and aerial topographic survey data for both LGAs within the catchment.

Determine Approach: A rainfall-runoff approach was adopted due to the absence of long term historical flood data. This approach involved setting up a MIKEStorm hydrologic model for the entire catchment. The results from this model were used to provide inflow boundary conditions for two hydraulic models (MIKEStorm and SOBEK). The one-dimensional MIKEStorm hydraulic model represented the major trapped low points in West Kensington in addition to the sub-surface drainage system. An integrated one-dimensional/two-dimensional (1D/2D) SOBEK computer model was established of the lower reaches (from just east of South Dowling Street to the Green Square railway station plaza). The SOBEK hydraulic model represented both the sub-surface drainage system and overland flowpaths in this area. The 2D overland flow model provided detailed information on the nature and extent of flooding throughout the lower reaches.

Validation to Historical Flood Levels: Due to the lack of suitable data a rigorous calibration of the various flood models could not be undertaken. However, a limited validation of the models to historical flood height data was undertaken based on records of past flooding during the November 1984 floods. This generally indicated that the models were performing satisfactorily.

Determination of Design Flood Flows and Levels: Design rainfall data and design temporal patterns from Australian Rainfall and Runoff (1987) were obtained and used to generate embedded design storms based on a 60 minute duration peak burst embedded within a 6 hour duration storm. These patterns were input to the MIKEStorm hydrologic model to determine design flood flows. These flows were then used as inflow boundary conditions to the SOBEK hydraulic model to determine design flood levels (and other behaviour).

Sensitivity analyses were undertaken on the various hydrologic and hydraulic model results.

EXISTING FLOOD PROBLEM

As part of the current GSWK FPRM Study, the flood models established for the Flood Study where refined and updated where necessary to account for more recent development within the catchment and the availability of new survey data in other areas. These updated models were then re-run for all design events assessed for the original Flood Study.

A flood damages assessment for existing development has been undertaken based on a detailed survey of building floor levels and the latest design flood level estimates across the full range of events.

No consideration has been given for damages to public structures or utilities (bridges, roads, pumping stations) or for the complete collapse of structures due to flooding. This information has been based on recent guidelines on the assessment of flood damages provided by the then Department of Environment and Climate Change (DECC now Office of Environment and Heritage - OEH).

FUTURE DEVELOPMENT

The majority of the upper catchment has been fully developed for residential usage but there is continuing pressure to renew and re-develop large amounts of land in the lower reaches that were once used for predominantly commercial/industrial uses. Examples of significant urban renewal projects within the catchment include Victoria Park and the proposed Green Square Town Centre Precinct.

FLOODPLAIN RISK MANAGEMENT STUDY

The specific aims of this study are to:

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

The subsequent Floodplain Risk Management Plan will document the recommended strategies.

FLOODPLAIN RISK MANAGEMENT MEASURES

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

A summary of the various floodplain management measures considered during the course of the study is presented in Table (i) together with a brief assessment of their viability for implementation as part of the Floodplain Risk Management Plan for the Green Square – West Kensington catchment.

RANDWICK CITY COUNCIL FINALISATION - October 13, 2011
It is necessary to note that the City Of Sydney is currently investigating floodplain management measures for the Green Square Town Centre. This location is significantly downstream from the Randwick City Council local government area and any resulting amendments will not have any impacts on the Randwick City Council portion of the catchment.

As such, this study is now finalised as it relates to the Randwick City Council local government area. Details for the City of Sydney local government area are still in draft form and should not be relied upon until finalised.

Table i): Review of Floodplain Management Measures

MEASURE	REFER SECTION	PURPOSE	COMMENT	ECONOMIC ASSESSMENT	IMPLEMENTATION VIABILITY
FLOOD MODIFICATION MEASURES:					
FLOOD MITIGATION DAMS	Section 5.2.1	Reduce flows from upper catchment areas, water storage.	Major dams are not practical. Many issues (cost, social, environmental) would need to be resolved in order to justify construction of major dams and any land acquisition process.	Generally not viable for small urban catchments.	Not viable.
RETARDING (DETENTION) BASINS	Section 5.2.2	Reduce flows from upper catchment areas.	A number of basins already exist within the catchment. Opportunities for new basins within the catchment are constrained by land availability. Several locations currently being considered for larger basins include upstream of Joynton Avenue lowpoint (Precinct E) and the Moore Park golf course.	Generally not viable from a purely flooding perspective but more attractive if has water quality and stormwater harvesting benefits.	To be considered as a means of mitigating the effects of urban development.
PIT/PIPE and TRUNK SYSTEM UPGRADE	Section 5.2.3	To minimise overland flooding, particularly for smaller, more frequent events	Upgrades of trunk capacity are being considered at a number of locations, particularly where associated with re-development activities. Regional upgrades being considered as part of major urban renewal (e.g. Mid-Block and GSTC precincts), local improvements considered for established areas (e.g. Duke Street).	Urban renewal activities provide opportunity to account for typically high costs as part of overall re-development. However, costs can be significant where there are conflicts with existing services infrastructure.	To be considered as part of any urban re-development activities. Must ensure that any improvements in upstream pipe capacity results in no adverse impacts downstream.
LEVEES, FLOOD GATES AND PUMPS	Section 5.2.4	Prevents or reduces the frequency of inundation of protected areas, assists in reducing problems with local runoff issues.	No appropriate sites.	Not undertaken.	Not applicable.
MANAGEMENT OF BLOCKAGE	Section 5.2.5	Minimise opportunity for blockage to ensure that the drainage system operates effectively during an event.	Blockage of inlets and culverts is a major problem in urban catchments, can significantly affect local flood levels. Measures can include street sweeping, inlet works etc.	Relatively low cost to implement although benefits are difficult to quantify due to uncertainties in blockage behaviour.	Measures to manage blockage within the system are relatively easy to implement and should be actively supported.
PROPERTY MODIFICATION MEASURES:					
HOUSE RAISING	Section 5.3.1	Prevent flooding of existing buildings by raising habitable floor levels.	No suitable buildings found within the study area.	High cost per property. May introduce social problems.	Not considered suitable.

VOLUNTARY HOUSE PURCHASE	Section 5.3.2	To remove flood liable houses from the floodplain.	May be limited opportunities within West Kensington catchment	Nil.	Do nothing.
FLOOD PROOFING	Section 5.3.3	Prevents inundation of floodwaters.	Generally only suitable for non-residential buildings.	Depends upon building. Not funded by the State Government.	To be promoted where applicable.
FLOOD PLANNING LEVELS	Section 5.3.4	To minimise flood damages to new developments.	Existing controls have been reviewed for both Councils and potential improvements have been suggested.	Negligible cost.	Amendments/improvements to be considered.
DEVELOPMENT CONTROL PLANNING	Section 5.3.5	To ensure new development reduces the flooding and drainage impacts on downstream properties, the pollutant loads and conserves potable water supplies.	Existing guidelines have been reviewed and possible improvements have been suggested. All Development Applications in the floodplain must be supported by a Flood Study.	Negligible cost.	Amendments to be considered.
CLIMATE CHANGE	Section 5.3.6	Assess possible impacts of climate change and include in Flood Planning Level	Potential increases in rainfall intensity will affect the entire catchment.	Unknown.	To be considered.
WATER SENSITIVE URBAN DESIGN	Section 5.3.7	To minimise runoff volume, rate of runoff and to improve runoff quality.	Should be employed where opportunities arise.	Variable.	To be promoted.
RESPONSE MODIFICATION MEASURES:					
FLOOD WARNING	Section 5.4.1	Enable people to evacuate and take measures to reduce flood damages.	An effective flood warning system is not possible due to the short response time of the Green Square – West Kensington catchment.	Not applicable.	Not viable.
EVACUATION PLANNING	Section 5.4.2	To ensure that evacuation can be undertaken in a safe and efficient manner.	The SES should prepare a Local Flood Plan.	Relatively low cost.	Recommended.
PUBLIC INFORMATION AND RAISING FLOOD AWARENESS	Section 5.4.3	Educate people on flood risk and community preparedness to minimise flood damages and reduce the flood risk.	A cheap and effective method but requires continued effort. Examples of methods are provided.	Benefits likely to be significant for relatively low cost. Effectiveness reduces with time since last flood.	Recommended.

1. INTRODUCTION

1.1. Background

The Green Square and West Kensington study catchment has an area of approximately 2.5 km^2 and drains predominantly from east to west (refer Figure 1). South Dowling Street runs north-south through the middle of the catchment dividing the City of Sydney and Randwick City Local Government Areas (LGAs). 57% of the study catchment lies within the City of Sydney LGA, with 43% being within the Randwick City Council LGA. The catchment includes parts of the suburbs of Zetland, West Kensington, Waterloo, Alexandria and Rosebery.

The upper reaches of the catchment (east of South Dowling Street) are predominantly zoned for residential usage. This area also includes The Australian golf course and the Moore Park Supacentre. The area immediately west of South Dowling Street within the City of Sydney LGA was once dominated by industrial premises. Significant redevelopment of this area in the form of medium and high density housing as well as commercial premises has been undertaken in recent years (since 2000). This includes the Victoria Park and ACI site redevelopments. The study area extends west to Botany Road and O'Riordan Street which represents the downstream limit below the proposed Green Square Town Centre (GSTC) area. The GSTC is defined as the land between Joynton Avenue and Botany Road which is the subject of a proposed urban renewal project as at 2011.

Flooding problems have been experienced at a number of locations within the catchment during periods of heavy rainfall. Recognising the importance of a consistent approach across the catchment the City of Sydney and Randwick City Council have jointly undertaken to address these issues via a Floodplain Risk Management Process that extends through both LGAs.

1.2. Floodplain Risk Management Process

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

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

The Green Square - West Kensington Floodplain Risk Management Study constitutes the second stage in the process. The Flood Study stage was completed in April 2008 with publication of the Green Square - West Kensington Flood Study (Reference 2). A combination of hydrologic and hydraulic models was used in that study to determine design flood levels for the Green Square - West Kensington catchment. This study supersedes a number of local site specific studies and several broader flood studies of the area including the 1985 Public Works Department study of West Kensington (Reference 3) and the South Sydney Stormwater Quality and Quantity Study (SQQS) undertaken in 2003 (Reference 4).

A Glossary of technical terms is provided as Appendix A.

1.3. Finalisation of Randwick Local Government Area Study as at 13 October 2011

It is necessary to note that the City Of Sydney is currently investigating floodplain management measures for the Green Square Town Centre. This location is significantly downstream from the Randwick City Council local government area and any resulting amendments will not have any impacts on the Randwick City Council portion of the catchment.

As such, this study is now finalised as it relates to the Randwick City Council local government area. Details for the City of Sydney local government area are still in draft form and should not be relied upon until finalised.

2. STUDY AREA

2.1. Catchment Description

The upper reaches of West Kensington are drained by pit and pipe networks with surcharging flows conveyed mainly along the road network. This portion of the catchment contains a number of major trapped low points which are known to be susceptible to ponding in large events.

Photo 1: Inlet Pits near South Dowling and Myrtle Streets West Kensington.

Located at the downstream end of West Kensington, the Eastern Distributor (noisewalls to the right of the photo) forms a barrier to overland flow in some locations. Drainage in these areas relies upon sub-surface drainage through to CoS LGA.

Photo 2: Minor Flooding (0.3 m depth) observed in Joynton Avenue trapped low point following a small storm in February 2001.

By comparison, depths within the low point during the major November 1984 storms were estimated to be in the order of 1.2m.

Overland flow paths in the lower reaches of the floodplain (west of South Dowling Street) typically follow the existing road network. There are several major trapped low points in this area including Joynton Avenue and Botany Road.

Photo 3: Sydney Water trunk drainage line from West Kensington.

This reach is an open channel that is sometimes covered by development. This section of the channel is located downstream of Link Road (looking downstream).

Photo 4: Sydney Water channel upstream of CoS Epsom Road works depot.

Photo of channel shown in Photo 3 further downstream. The presence of development in and around the trunk lines exacerbates flood problems when capacity of the formal system is exceeded.

In the southern portion of the floodplain between Link Road and Joynton Avenue, a number of uncontrolled overland flow paths form when the capacity of the trunk drainage system is exceeded. Significant overland flow paths also form between Portman Street and Botany Road when ponding in Joynton Avenue causes flood waters to overtop Portman Street. Overtopping of the Botany Road trapped low point also results in overland flow along the Green Square railway station plaza.

Urbanisation has dramatically altered the nature of available drainage within the catchment. Consideration of the natural drainage systems prior to development provides the context for many of the flood problems known to exist in the area today. For example, many of the trapped low points noted above were once natural depressions within swampy areas or were utilised as reservoirs.

In addition, the removal of the swamps and dams that once dominated the lower reaches of the catchment has reduced the provision for natural storage of stormwater thereby increasing flows to downstream areas. This has been exacerbated over time by a major increase in the proportion of paved area and consequent reduction in pervious areas, resulting in corresponding increases in runoff (in terms of both peak flows and volumes).

2.2. Land Use and Development

Much of the West Kensington portion of the catchment was developed between 1912 and 1920 and was fully developed by the 1940’s. Much of the subsurface drainage system in the West Kensington area is thought to have been constructed prior to the 1930s (Reference 3). Major changes since 1980 have included the re-development of industrial premises at Raleigh Park into a medium density residential estate and drainage works associated with the Eastern

Distributor.

The area immediately west of South Dowling Street was once dominated by industrial premises although much of the area has been re-developed in recent years. Examples of re-developed sites include Victoria Park and the ACI site which consist of high density housing as well as commercial premises. Significant portions of the Green Square area are also planned to be re-developed within the next 20 years including the GSTC development to be located between Portman Street and Botany Road. The study area extends west to Botany Road and O'Riordan Street which represents the downstream limit below the proposed GSTC area.

2.3. Preliminary Environmental Assessment

2.3.1. Water Quality

Apart from site-specific studies commissioned as part of re-development within the catchment (e.g. to examine groundwater contamination at an industrial site) water quality issues for the Green Square – West Kensington catchment have generally been examined as part of investigations of the broader catchments of Sheas Creek, Alexandra Canal and the Cooks River. Examples of these studies include the 2003South Sydney Stormwater Quantity and Quality Study (SQQS) (Reference 4), the 1999 Cooks River Stormwater Management Plan (Reference 5) and Alexandra Canal Masterplan (2000) (no precise reference details of the Masterplan).

Although there is a general lack of recorded water level data for the Sheas Creek catchment, available information for Alexandra Canal and Cooks River indicate that major sources of pollutants include faecal coliforms and other contaminants (such as metals, petro-chemicals etc.) associated with the various land use activities found within the catchment.

The sewer system throughout the Green Square-West Kensington area is noted by the SQQS as one of the oldest in Sydney and was once operated as a combined stormwater/sewer system leading to significant loadings of faecal coliforms into the waterways. However, a Sydney Water abatement program has since allowed the separation of the sewer/stormwater systems to a large degree. Continuing problems with faecal coliforms present in downstream waterways have been attributed to a sewer overflow point in Alexandra Canal and leakage from the sewer system into the stormwater system.

Being a largely urbanised catchment with a long history of industrial activities, previous studies identified a wide range of pollutants from diffuse sources that can be expected to be present in runoff from the GSWK catchment including:

- a range of metals and chemical (including nutrient) contaminants from current and past activities within the catchment,
- suspended solids, oils and grease etc. generated from traffic movements within the catchment, and
- chemical contamination of the underlying aquifer arising from infiltration across contaminated sites.

In terms of specific water quality management approaches Reference 4 reviews a range of stormwater options including treatment (e.g. constructed wetlands) and re-use. The review identifies various constraints facing the introduction of these types of measures including land availability and potential mobilisation of sub-soil contaminants into the Botany Sands aquifer. CoS have advised that there is at least one Gross Pollutant Trap (GPT) installed within the GSWK catchment (located in Victoria Park). Reference 4 also discusses options for the installation of GPT devices although it is noted that GPTs do not address issues associated with dissolved pollutants and pathogens.

2.3.2. Flora and Fauna

As the entire natural drainage system has been replaced by either pipes or a concrete lined open channel there is little opportunity for the development of natural flora/fauna habitats. Hence a detailed environmental assessment has not been undertaken as part of this study. However, there are a small number of locations in some areas that have recently been re-developed where Water Sensitive Urban Design (WSUD) principles have been applied to incorporate wetland style devices as part of the drainage system (e.g. Victoria Park). It may be conceivable that these types of features can provide a source of flora/fauna habitat. It is recommended that every opportunity in the future should be taken to enhance the quantity and quality of the potential habitats as part of future urban renewal projects.

2.3.3. Visual Amenity

For the upper reaches of the catchment, the drainage system within the series of major trapped low points offers no particular visual amenity as it generally blends in as part of the urban landscape. The predominant visible evidence of the drainage system is in the form of kerb inlets within the low points. Some street locations, particularly those on the upstream side of the Eastern Distributor have an extensive amount of inlets visible within the road reserve.

The visual amenity of the main trunk system from West Kensington through to the lower reaches (in the vicinity of Link Road and Epsom Road) would generally be described as of low quality compared to a natural system. However, apart from some graffiti, it is clean, fenced and well-maintained. The constructed channel is typical of creek systems in heavily urban areas in Sydney that have been formalised in response to development pressures to use all available land at a time when the environmental qualities of natural systems were not considered of high value and could be sacrificed. In some respects, the amenity of the open channel system is further compromised by the presence of buildings constructed over the channel easement. This open channel then drains to a sub-surface system upstream of Joynton Avenue.

As part of more recent urban renewal projects, consideration has been given to enhancing the visual amenity of major drainage features within the urban landscape. These include open space landscaping within formal detention basins such as those in Victoria Park and Raleigh Park (refer Figure 1) and the incorporation of wetland style features as part of water quality control systems.

The Victoria Park detention basin and surrounds provides a significant example of the ability of stormwater systems to enhance the visual amenity of the landscape. The basin incorporates a public art feature in the form of cascading waterfalls within the basin. These waterfalls also form part of an overall water treatment and recycling scheme for the Victoria Park estate. In addition to being a functional part of an overall stormwater management system these types of features also highlight the role of water within the urban environment. They therefore play an important part in fostering awareness of water-related issues in the local community.

2.3.4. Recreational Amenity

At present much of the formal drainage system has no legal recreational amenity. However, there are exceptions to this including:

- publicly accessible open space areas within constructed detention basins (such as those found in Victoria Park and Raleigh Park) and
- parts of the floodplain that lie within public parklands and golf courses (e.g. portions of Moore Park and The Australian golf courses).

Providing due consideration is given to personal safety and risk to life then the use of the floodplain for the above activities is an excellent use of flood prone lands.

2.4. Previous Studies

A review of all known previous flood related studies then available was undertaken as part of the GSWK Flood Study (Reference 2). Of particular relevance for this Floodplain Risk Management Study are findings from the recent GSWK Flood Study (Reference 2) and West Kensington Flood Study (Appendix B of this present report), the South Sydney Stormwater Quality and Quantity Study (SQQS) (Reference 4) and the West Kensington Flooding Drainage Works Investigation (Reference 3).

2.4.1. Green Square - West Kensington Flood Study (Reference 2)

The Flood Study (Reference 2) established a rainfall and runoff model using the MIKEStorm software to estimate flows throughout the study catchment. The MIKEStorm model was also used to assess the hydraulic performance of sub-surface and overland flow systems in the West Kensington catchment. A SOBEK hydraulic model was established for the area west of South Dowling Street to define the nature and extent of design flood behaviour in the lower reaches of the catchment. The various models were validated against historic flood information available for the two events in early November 1984.

The Flood Study defined the flood behaviour for a range of events including the 1% AEP (1 in 100 year) design storm and the Probable Maximum Flood (PMF). The main outcomes were:

- determination of the capacity of Council's existing sub-surface drainage network;
- quantification of peak overland flows and design flood levels in each of the major trapped low points in the West Kensington catchment;

- estimates of design flood levels, flows and velocities in the lower reaches of the catchment (generally west of South Dowling Street);
- preparation of peak flood level contours, extents and provisional hydraulic hazard for the major trapped low points in West Kensington and within the hydraulic model domain for the lower catchment;
- provision of a modelling platform to form the basis for this Floodplain Risk Management Study and Plan.

2.4.2. West Kensington Flood Study (Appendix B)

Design flood behaviour within the West Kensington catchment was previously analysed as part of Reference 2. Due to limitations in the data then available, the model representation of flowpaths and other hydraulic features within the West Kensington area was limited in detail. However, RCC has since acquired more detailed topographic data within the West Kensington area. Hence RCC requested that WMAwater refine the hydraulic modelling from Reference 2 based on the more detailed topographic datasets of the West Kensington area. The outcomes of this work are presented in Appendix B of this report.

The specific aims of the West Kensington Flood Study were to establish a more refined hydraulic model and to then:

- define flood behaviour across the West Kensington area,
- prepare flood hazard and flood extent mapping,
- prepare suitable models of the catchment and floodplain for use in current GSWK Floodplain Risk Management Study and Plan.

Similar to the analysis undertaken in Reference 2, hydrologic and hydraulic investigations have been undertaken to determine the response of the West Kensington catchment and drainage system to 50% AEP (1 in 2 year), 20% (1 in 5 year), 5% AEP (1 in 20 year), 2% AEP (1 in 50 year), 1% AEP (1 in 100 year) and 0.2% AEP (1 in 500 year) events and the Probable Maximum Flood (PMF). The results of these investigations are quantified as peak pipe capacities and peak overland flows throughout the study area. Peak flood levels, depths and provisional hydraulic hazard categories have also been determined.

2.4.3. South Sydney Stormwater Quality and Quantity Study (Reference 4)

The 2003 South Sydney Stormwater Quality and Quantity Study (SQQS) was a broad study examining stormwater management for the overall Sheas Creek catchment (for which the Green Square – West Kensington study area is a contributing catchment). The study investigated flood-related and water quality aspects, defined catchment behaviour under existing conditions and identified opportunities for regional works to manage stormwater.

Although the flood modelling undertaken was less detailed than that used for the 2008 Flood Study (Reference 2), the approach adopted is consistent with the objectives of the SQQS to broadly characterise key aspects of flood behaviour across the catchment and to identify potential mitigation measures at a regional level.

Many flood-related problems for the catchment were attributed to insufficient capacity in the minor stormwater drainage system. However, large scale upgrades of the trunk system to address this were not considered feasible due to a number of constraints:

- much of the trunk drainage system lies underneath existing properties and roads. As a consequence any major upgrades are constrained by limitations in the available corridor space and would create significant disruptions to traffic, residents and businesses,
- Sydney Water is the responsible authority for most of the trunk infrastructure that requires upgrading. During the course of the SQQS Sydney Water advised that large scale works were not feasible and did not intend on proceeding with large scale upgrades to the trunk network, and
- staging upstream works in a manner that does not adversely impact downstream reaches is difficult to achieve, and an 'all or nothing' approach would be required.

In view of the above, the SQQS recommended a series of measures involving large scale regional works (such as community-based detention) in conjunction with localised pipe upgrades. The options were targeted to take advantage of potential funding sources associated with the Green Square re-development area. Recommendations aimed at supporting the development of more detailed development control policies in the future were also presented covering stormwater quantity, quality and re-use.

2.4.4. West Kensington Flooding Drainage Works Investigation (Reference 3)

The West Kensington area forms the upper reaches of the study catchment. This area experienced severe flooding during the early part of November 1984 with numerous properties and houses being inundated within the trapped low points of Milroy Avenue, McDougall Street, Balfour Road and Lenthall Street. Commissioned in the wake of the November 1984 events, the primary objectives of the 1985 West Kensington Flooding Drainage Works Investigation were to assess the impacts of the floods, determine the design flood behaviour of the existing system and to devise a program of works to mitigate flood damages.

The report includes the outcomes of extensive community consultation following the November 1984 floods including:

- documentation of observed flood behaviour (e.g. flowpaths, flood levels, locations of inundated properties/houses including corresponding floor levels) and
- details of flood damages including consideration of both tangible costs associated with property damage and less tangible items associated with social disruption following the floods.

The hydrological/hydraulic models established to quantify flood behaviour were based on the ILSAX package which at the time was a leading platform for the analysis of urban drainage systems. The ILSAX model was validated against the November 1984 events before being used to determine the design flood behaviour of the existing system (in accordance with the 1977 version of Australian Rainfall and Runoff - this document has since been superseded). The validated models were used to assess the performance of various mitigation schemes by comparison to existing conditions using specified design criteria.

Due to a number of physical constraints (including the amount of existing development within the catchment) the sub-surface drainage options considered were based on the amplification of existing drainage lines and/or the installation of new pipes as part of a bypass system. The potential to amplify existing drainage infrastructure was noted as being complicated for those reaches not located within existing drainage easements or road reserves. When developing the various schemes, the authors also took into consideration additional downstream constraints. For example, any increase in system capacity to alleviate flooding in the West Kensington catchment would exacerbate flooding in the lower reaches should the loading exceed the current capacity of the downstream system.

The preferred option used a staged approach to increase system capacity within West Kensington in a controlled manner and to take advantage of other works to improve the downstream capacity of the system in the future (refer to Figure 2). The key components of the preferred scheme included:

- amplification of existing local drainage within West Kensington (although the inlet capacity was initially limited so as not to exceed the current capacity of downstream infrastructure),
- provision of detention capacity in Raleigh Park and on the grounds of The Australian golf course (the detention capacity within the golf course also included improved sub-surface drainage to this area from the Balfour Road trapped low point), and
- amplification of the Sydney Water (then known as the Metropolitan Water, Sewer and Drainage Board - MWS&DB) channel downstream to provide additional downstream capacity.

The main advantages of the preferred scheme were noted as being:

- a flexible approach that was staged so as not to adversely impact downstream areas until sufficient downstream capacity was available, and
- the proposed amplification and augmentation of the sub-surface drainage system was to be confined to existing drainage and road reserves and did not require any land acquisition. Land acquisitions were noted as being necessary for the additional works involving the implementation of detention basins for Raleigh Park and The Australian golf course.

Information provided by Randwick City Council during this present study indicates that the proposed scheme has been partially implemented including:

- provision of detention capacity at Raleigh Park (refer to Photo 5),
- drainage upgrade works completed in the 1990's along Baker Street (new system along the northern side) and the Balfour Road system (increased pipe capacity through amplification and duplication).

From the available survey it appears that the new Baker Road system drains directly west to South Dowling Street rather than Virginia Street as was originally intended. RCC has also indicated that the pipe sizes nominated in the 1985 study could not be achieved in some portions of the system due to utility services constraints.

Photo 5: Raleigh Park detention basin, West Kensington.

3. EXISTING FLOOD ENVIRONMENT

3.1. Flooding Mechanism

Flooding in the catchment typically occurs due to intense rainfall that may be experienced during thunderstorms (as occurred in all previous events in the 1980's and 1990's). As discussed in Reference 2, urbanisation has dramatically altered the nature of available drainage within the catchment and has led to:

- a major increase in the proportion of paved area and consequent reduction in pervious areas, resulting in corresponding increases in runoff (in terms of both peak flows and volumes),
- the removal of the swamps and dams that once dominated the lower reaches of the catchment reducing the provision for storage of stormwater thereby increasing flows to downstream areas,
- development within the trapped depressions that were once swamps or dams, resulting in flood problems in these areas. Examples include the Joynton Avenue trapped depression and other locations within the West Kensington catchment (such as Milroy Avenue and McDougall Street). Damages have been incurred at these locations during past floods such as the November 1984 events.

In view of the above, flood problems within the catchment are generally the result of insufficient capacity within the trunk drainage system and the general lack of a formal overland flow system to provide controlled capacity in large events. Based on evidence from past floods (Reference 4) flooding can be exacerbated by blocked local drainage and restricted overland flow paths. Whilst recent re-development in parts of the middle catchment has addressed some issues, there are many locations in which there is a significant degree of existing floodplain risk.

3.2. Historical Flood Data

A detailed analysis of rainfall records and flood records was undertaken as part of Reference 2. Although a survey questionnaire was distributed to the local community as part of Reference 2, much of the information on past flooding within the catchment was sourced from existing references.

Most records relate to the significant flooding that occurred during the November 1984 events and document extensive flooding within trapped low points throughout the catchment. This includes the inundation of 56 properties (including 27 houses) within West Kensington (Reference 3) and significant ponding (> 1m) within the Joynton Avenue low point that flooded the ex-South Sydney Community Health Centre (Reference 4). There is also anecdotal evidence of flood problems occurring within other areas of the catchment such as Botany Road (near the present Green Square railway station plaza) and South Dowling Street (opposite Moore Park Supacentre).

The lack of data in other flood liable areas in the catchment means that the true extent of flooding in historical events is largely unknown. When flooding occurs within the catchment in the future, it is recommended that Council undertake to collect any available information (photos, rainfall data, flood heights, extent of inundation and damages to private property etc.) as soon as practicable after the event including after smaller, more frequent flooding such as would be expected in the 50% AEP (1 in 2 year) event.

3.3. Design Flood Data

3.3.1. Overview

The Green Square - West Kensington Flood Study (Reference 2) documents design flood data across the catchment for a range of events. The Study recommended that the full range of storm durations should be considered if undertaking detailed investigations for drainage augmentation within the catchment. This is due to the potential redistribution of catchment flows if the drainage networks locally are upgraded.

Since the publication of the GSWK Flood Study, additional topographic survey information has been acquired and there have been a number of developments approved within the City of Sydney LGA. As part of this project, the various hydraulic models established for Reference 2 were revised and updated to take these aspects into account. In comparison to the model layouts and assumptions adopted for the previous Green Square – West Kensington Flood Study the key changes made for the current Floodplain Risk Management Study include:

- refinement of the Balfour Road trapped low point in West Kensington (including available storage volume and outlet control for overland flow) based on Airborne Laser Scanning (ALS) survey provided by Randwick City Council,
- an allowance for inflows into the Balfour Road trapped low point from the adjacent Kensington catchment (via Todman Avenue) was made based on preliminary results from Reference 6 (refer Table 1),
- various refinements to represent development layouts within Victoria Park approved subsequent to the publication of the GSWK Flood Study including the ARV site, the Audi site and the WeLive development,
- refinements in the vicinity of the South Dowling Street low point on the basis of detail survey and a layout for proposed re-development of the site bounded by O'Dea Avenue, South Dowling Street and the southern end of Ameila Street (refer to Figure 3a). This includes the provision of an overland flow path from the South Dowling Street low point into a new 3,000m^3 detention basin on-site, together with supporting upgrades to the trunk system from the low point through the development (note that following completion of the modelling work, CoS have since advised that the Development Application for this site has been withdrawn – the proposed works have therefore been included as potential mitigation options for this Study),
- an upgrade of the sub-surface drainage in the vicinity of O'Dea Avenue including a 0.9m diameter pipe from South Dowling Street to just upstream of Ameila Street and a 1.2m diameter pipe from this point down to Joynton Avenue. The City of Sydney is proposing to undertake these works ahead of planned development of the Mid-block Precinct bounded by Lachlan Street and O'Dea Avenue.

It should be noted that the various developments within the CoS LGA noted above have been assessed as part of corresponding Development Applications for the City of Sydney. These assessments have demonstrated that none of these developments generate adverse flood impacts within the West Kensington portion of the catchment.

Table 1: Estimated inflows to West Kensington from adjacent catchment via Todman Avenue

Event	Peak Flow Estimate (m^3/s)	Comments
5% AEP (1 in 20 year)	-	see note
2% AEP (1 in 50 year)	< 0.1	see note
1% AEP (1 in 100 year)	3.6	see note
0.2% AEP (1 in 500 year)	5.4	Approximated as 1.5 x Q_{100}
Probable Maximum Flood (PMF)	11.1	Approximated as 3 x Q_{100}

Note: Peak flows from Reference 6 and are preliminary estimates only and may be subject to change

The revised hydraulic models were run for the full range of design storms and the Probable Maximum Flood (PMF) used in the GSWK Flood Study (Reference 2). For the 1% AEP (1 in 100 year) event, a comparison of the more recent results against those reported in Reference 2 shows that new results are generally slightly lower (typically within 0.05m) in the middle reaches of the catchment (upstream of Joynton Avenue). There are significant reductions in flood level at two trapped low points:

- Lenthall Street – peak flood levels have been reduced by around 0.1m due to the improved representation of flood storage in the Balfour Road depression,
- South Dowling Street – peak flood levels in this location have been reduced by around 0.6m due to the provision of improved drainage and an overland flowpath as part of the re-development of the property on the corner of O'Dea Avenue and South Dowling Street.

There were found to be no changes to flood levels within Epsom Road (downstream of Link Road) and in areas downstream of the Joynton Avenue trapped low point (including the trapped low point itself). On this basis, the revised models were considered fit-for-purpose and were used in all later phases of the present FPRM Study (including flood damages assessment and climate change analyses).

3.3.2. Key Outcomes

Design Flood Information

Peak flood level estimates for the full range of design events are tabulated in the following sections for each of the major trapped low points. Within the 2D model domain, the model results have been presented in terms of peak flood height and depth for the 1% AEP (1 in 100 year) and PMF events (refer to Figures 3 and 4). For those low points in the West Kensington area, additional maps showing peak flood levels and depths for the 1% AEP (1 in 100 year) and PMF events are also shown in Figures 5 and 6.

West Kensington Area (Randwick City Council LGA)

Given the natural topography of this area most of the flood problems occur in the known low points where there is insufficient drainage capacity to convey runoff during periods of intense rainfall. Peak flood levels in the major trapped low points for the various design storm events are shown in Table 2.

Table 2: Peak Flood Levels and Depths – Major Trapped Low Points West Kensington

Location	Minimum Level At Low Point (mAHD)	50% AEP Design Flood		20% AEP Design Flood		10% AEP Design Flood		5% AEP Design Flood	
		Level (mAHD)	**Depth (m)**	**Level (mAHD)**	**Depth (m)**	**Level (mAHD)**	**Depth (m)**	**Level (mAHD)**	**Depth (m)**
Balfour Road	24.0	24.7	0.7	24.9	0.9	25.0	1.0	25.1	1.1
McDougall Street	23.2	23.9	0.7	24.0	0.8	24.2	1.0	24.3	1.1
Milroy Avenue	24.3	24.7	0.4	24.9	0.6	24.9	0.6	25.0	0.7
Virginia Street	23.8	24.0	0.2	24.1	0.3	24.1	0.3	24.1	0.3
Lenthall Street	20.4	21.9	1.5	22.0	1.6	22.0	1.6	22.1	1.7

Note: Estimated ponding depths are approximate only (based on ALS data)

Location	Minimum Level At Low Point (mAHD)	2% AEP Design Flood		November 8-9 1984 Flood Observations		1% AEP Design Flood		0.2% AEP Design Flood		Probable Maximum Flood	
		Level (mAHD)	**Depth (m)**	**Level (mAHD)**	**Depth (m)**	**Level (mAHD)**	**Depth (m)**	**Level (mAHD)**	**Depth (m)**	**Level (mAHD)**	**Depth (m)**
Balfour Road	24.0	25.3	1.3	25.23	1.23	25.5	1.5	25.8	1.8	26.5	2.5
McDougall Street	23.2	24.5	1.3	24.8	1.60	24.6	1.4	24.6	1.4	25.0	1.8
Milroy Avenue	24.3	25.0	0.7	25.2	0.90	25.1	0.8	25.1	0.8	25.5	1.2
Virginia Street	23.8	24.1	0.3	n/a	n/a	24.1	0.3	24.2	0.4	24.4	0.6
Lenthall Street	20.4	22.1	1.7	21.44	1.04	22.1	1.7	22.2	1.8	22.4	2.0

Note: Estimated ponding depths are approximate only (based on ALS data)

The results for smaller events are consistent with local observations that ponding within the roadway occurs relatively frequently (Reference 3). For larger events the design flood levels compare well with observed levels from the 8-9 November 1984 event (refer to Table 2). This outcome lends confidence to the modelling results and highlights the severity of the flood problem in these areas.

In addition to the above locations the modelling results indicate that ponding occurs at the western (downstream) end of Ingram Street, again due to insufficient drainage capacity. Ponding depths in this area exceed 1 m for the 1% AEP (1 in 100 year) event. For the area of South Dowling Street between Myrtle Street and Todman Avenue, peak depths along the roadway are typically within 0.2 m. A minor area of ponding occurs along this street between Cooper Place and Winkurra Street where peak depths exceed 0.5 m for the 1% AEP (1 in 100 year) event. This minor low point is due to the natural topography of the area.

Green Square Area (City of Sydney LGA)

Flood problems occur in a number of major trapped low points within the CoS LGA that reflect the natural underlying topography and a corresponding lack of available capacity in the sub-surface drainage network. Examples include Lachlan Street, South Dowling Street (opposite Moore Park SupaCentre), Botany Road (near Green Square railway station plaza) and Joynton Avenue. A summary of the peak flood levels at these locations for the design events is provided in Table 3 and Table 4.

Table 3: Peak Flood Levels and Depths – Major Trapped Low Points CoS LGA

Location	Minimum Level At Low Point (mAHD)	50% AEP Design Flood		20% AEP Design Flood		10% AEP Design Flood		5% AEP Design Flood	
		Level (mAHD)	**Depth (m)**	**Level (mAHD)**	**Depth (m)**	**Level (mAHD)**	**Depth (m)**	**Level (mAHD)**	**Depth (m)**
South Dowling Street Low Point opp. SupaCentre	25.7	26.1	0.4	26.2	0.5	26.2	0.5	26.3	0.6
Lachlan Avenue	25.9	26.0	0.1	26.3	0.4	26.3	0.4	26.4	0.5
Joynton Avenue	16.7	18.3	1.6	18.6	1.9	18.7	2.0	18.8	2.1
Botany Road	13.3	13.8	0.5	13.9	0.6	13.9	0.6	14.1	0.8

Table 4: Peak Flood Levels and Depths – Major Trapped Low Points CoS LGA (Continued)

Location	Minimum Level At Low Point (mAHD)	2% AEP Design Flood		1% AEP Design Flood		0.2% AEP Design Flood		Probable Maximum Flood	
		Level (mAHD)	**Depth (m)**	**Level (mAHD)**	**Depth (m)**	**Level (mAHD)**	**Depth (m)**	**Level (mAHD)**	**Depth (m)**
South Dowling Street Low Point opp. SupaCentre*	25.7	26.3*	0.6*	26.4*	0.7*	26.5*	0.8*	26.8*	1.1*
Lachlan Avenue	25.9	26.5	0.6	26.5	0.6	26.6	0.7	26.9	1.0
Joynton Avenue	16.7	18.9	2.2	19.0	2.3	19.1	2.4	19.7	3.0
Botany Road	13.3	14.2	0.9	14.3	1.0	14.5	1.2	15.4	2.1

Note: These flood levels assume the provision of an overland flowpath between South Dowling Street and a proposed extension of Amelia Street. Hence the peak levels at the South Dowling Street trapped low point reported above have been reduced by approximately 0.6 m compared to the results previously reported in Reference 2. However, subsequent to this modelling work for this study CoS advised that the DA for works in this area had not been approved.

Due to the natural topography and the large area of contributing catchment upstream, the Joynton Avenue trapped low point is one of the most significant flood-affected areas within the catchment.

At the Botany Road trapped low point peak flood depths are in the order of 1 m for the 1% AEP (1 in 100 year) event. Overland flow from this low point occurs across the plaza adjacent to the western entrance of Green Square railway station. The depth and velocity of floodwaters within this flowpath present a significant hazard in a 1% AEP (1 in 100 year) event and water will enter the underground railway station under current conditions even minor events.

3.4. Hydraulic Classification

3.4.1. Overview

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

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

The above hydraulic classifications have been applied to the Green Square - West Kensington catchment based on available hydraulic model results together with our knowledge of the catchment and experience in other catchments. The outcomes are shown in Figure 7.

3.4.2. Major Trapped Low Points – West Kensington

- Overland flow paths, generally along roads are classified as floodway given that a significant portion of flow is conveyed via the road network.
- Within each of the major trapped low points, the areas contained by the road reserve are considered as floodways as floodwaters typically enter these low points via the road network. The remaining inundated area adjacent to each of the low points is regarded as being flood storage.

3.4.3. Other Areas

The areas considered to operate as floodways within the catchment are indicated in Figure 7. Key features to be noted include:

- Overland flow paths form along many roadways within the lower catchment, these have been classified as floodway.
- Formal detention basins and overland flow paths to and from these basins have been classified as floodways. Examples include Nuffield Park, Joynton Park and the proposed basin located on the re-developed site at the corner of South Dowling Street and O'Dea Avenue.
- The easement between Lenthall Street and Ingram Street in West Kensington conveys overland flow from the Virginia Street trapped low point and is classified as floodway.
- Major trapped low points including those in Joynton Avenue, Lachlan Street, Botany

Road and Lenthall Street and South Dowling Street are classified as floodways.

The area generally located between Link Road and Joynton Avenue is currently the subject of detailed assessment by the City of Sydney. For the purposes of this project, the areas of floodway indicated in Figure 7 have been made on the basis of existing conditions with the understanding that the CoS is currently preparing options to formalise flow paths in this area in the manner that suitably addresses floodplain risk in accordance with Reference 1.

3.5. Flood Hazard Classification

The hazard categorisation for the lower catchment was quantitatively determined using depth and velocity for each design event in accordance with the provisional hydraulic hazard categorisation. The provisional hazards were refined to consider other factors such as rate of rise of floodwaters, duration, threat to life, danger and difficulty in evacuating people and possessions and the potential for damage, social disruption and loss of production. These factors and related comments are given in Table 5. For the Green Square - West Kensington catchment these factors do not significantly alter the provisional hazard classifications shown on Figures 8 and 9 for the 1% AEP (1 in 100 year) and PMF events respectively.

Table 5: Hazard Classification

Criteria	Weight [1]	Comment
Rate of Rise of Floodwaters	High	The rate of rise in the channel and onset of flow along roads would be very rapid, which would not allow time for residents to prepare.
Duration of Flooding	Low	The duration is less than 2 hours and would not significantly increase the hazard.
Effective Flood Access	High	Roads within the catchment can be inundated and may restrict vehicular access during a flood but pedestrian access to high ground is generally available. However, there are some isolated locations where pedestrian access to low hazard land above the floodplain is not available (Figure 8).
Size of the Flood	Low	The hazard does not significantly increase with the magnitude of the flood.
Effective Warning and Evacuation Times	High	Both in the upper and lower sections of the catchment there is very little, if any, warning time. During the day residents will be aware of the heavy rain but at night (if asleep) residential and non-residential building floors may be inundated with no prior warning.
Additional Concerns such as Bank Erosion, Debris, Wind Wave Action	High	The main concern would be debris blocking culverts or pits. This is considered to have a high probability of occurrence and will significantly increase the hazard.
Evacuation Difficulties	Low	Given the quick response of the catchment evacuation is not considered to be necessary and therefore is not significant.
Flood Awareness of the Community	Low - Medium	Flood awareness within the West Kensington portion of the catchment is considered to be low to moderate given that past flooding in the major trapped low points is noted by long-term residents. However, in the lower reaches about Green Square, the level of flood awareness is considered to be low given the rapid rate of urban renewal and influx of new residents.
Depth and Velocity of Floodwaters	Medium	In the West Kensington portion of the catchment, flowpaths along roadways are subject to fast flowing water, although the depths are reasonably shallow. However, significant depths will occur in each of the major trapped low points. Similarly in the Green Square portion of the catchment much of the road network will convey fast flowing yet shallow (<0.4m) floodwaters. Depths along some roads can be higher increasing the hazard

	(e.g. Epsom Road and northern sections of Joynton Avenue). Significant flood depths occur within the major trapped low points and formal detention basins. Areas adjacent to (and including) the open channel portion of the trunk system downstream of Link Road create high hazard areas between Link Road and Joynton Avenue. Cross-site flows between Joynton Avenue and Botany Road also create localised areas of high hazard.

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

3.6. Flood Damages

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

- the magnitude (depth, velocity and duration) of the flood,
- land usage and susceptibility to damage,
- awareness of the community to flooding,
- effective warning time,
- the availability of an evacuation plan or damage minimisation program,
- physical factors such as erosion of the river bank, flood borne debris, sedimentation.

Flood damages can be defined as being “tangible” or “intangible”. Tangible damages are those for which a monetary value can be assigned, in contrast to intangible damages, which cannot easily be attributed a monetary value (stress, injury, loss to life, etc.). Several post flood damages surveys indicate that the intangible losses are likely to equal or exceed the tangible losses.

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

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

A flood damages assessment was undertaken for existing development within the Green Square- West Kensington catchment. The assessment was based on:

- revised hydraulic model results prepared for this study,
- floor level survey of selected West Kensington residential properties, and
- floor level survey of commercial and residential properties in the Green Square area.

The properties included in this assessment are shown in Figure 10. The assessment used the tangible damage calculation methods outlined in Reference 7 allowing for CPI adjustments. The damage assessment considered residential and commercial properties, multiple houses per property (units etc.) as well as two storey houses (habitable/non-habitable ground floor) and applied an adjustment figure to represent the anticipated damages. Damages to public infrastructure have not been assessed as they are difficult to accurately estimate and can vary greatly from one event to another. A summary of flood damages for the portion of the catchment within the RCC LGA is provided in Table 6 and Table 7. Similar information for the Green Square (CoS) portion of the catchment is shown in Table 8. The locations of inundated building floors are shown in Figure 10.

Table 6: Summary of Flood Damage Estimates for West Kensington Catchment (RCC LGA)

Event	West Kensington Major Trapped Low Points				All Properties Within RCC LGA
	Virginia Street	**Milroy Avenue**	**McDougall Street**	**Balfour Road**	
50% AEP (1 in 2y)*	$7K	$14K	$1K	$26K	$320K
20 % AEP (1 in 5y)*	$10K	$59K	$2K	$134K	$840K
10 % AEP (1 in 10y)*	$10K	$59K	$10K	$220K	$1,000K
5% AEP (1 in 20y)*	$10K	$80K	$20K	$340K	$1,200K
2% AEP (1 in 50y)*	$10K	$81K	$80K	$640K	$1,620K
1% AEP (1 in 100y)*	$10K	$120K	$150K	$1,030K	$2,160K
0.2% AEP (1 in 500y)*	$23K	$120K	$150K	$1,870K	$3,100K
PMF*	$72K	$696K	$669K	$4,250K	$7,900K
Avg. Annual Damages	**$6K**	**$29K**	**$6K**	**$103K**	**$496K**

*Tangible Damages.
^Average Annual Damages are Tangible Damages weighted according to probability of occurrence.

Table 7: Above Floor and Property Inundation – West Kensington (RCC LGA)

Event	West Kensington Major Trapped Low Points								All Properties Within	
	Virginia Street		**Milroy Avenue**		**McDougall Street**		**Balfour Road**		**RCC LGA**	
	Ground	**Floor**	**Ground**	**Floor**	**Ground**	**Floor**	**Ground**	**Floor**	**Ground**	**Floor**
50% AEP (1 in 2y)*	3	0	2	1	1	0	12	0	30	8
20 % AEP (1 in 5y)*	4	0	5	2	1	0	16	8	53	25
10 % AEP (1 in 10y)*	4	0	5	2	7	0	20	9	64	28
5% AEP (1 in 20y)*	4	0	14	2	11	1	22	12	82	33
2% AEP (1 in 50y)*	4	0	14	2	19	3	32	20	103	44
1% AEP (1 in 100y)*	4	0	14	4	22	6	42	26	118	55
0.2% AEP (1 in 500y)*	5	2	14	4	22	6	60	46	141	78
PMF	8	3	29	23	30	20	73	67	196	154

Table 8: Summary of Green Square Flood Damages (City of Sydney LGA)

Event	Commercial Properties		Residential Properties		All Properties	
	Above Floor Flooding	Tangible Damages	Above Floor Flooding	Tangible Damages	Above Floor Flooding	Tangible Damages
50% AEP (1 in 2y)*	22	$0.63M	8	$0.46M	30	$1.08M
20 % AEP (1 in 5y)*	27	$0.92M	8	$0.47M	35	$1.39M
10 % AEP (1 in 10y)*	37	$1.32M	9	$0.55M	46	$1.87M
5% AEP (1 in 20y)*	42	$1.51M	11	$0.62M	53	$2.14M
2% AEP (1 in 50y)*	51	$1.72M	13	$0.65M	64	$2.37M
1% AEP (1 in 100y)*	56	$1.93M	17	$0.71M	73	$2.63M
0.2% AEP (1 in 500y)*	62	$2.50M	26	$0.90M	88	$3.40M
PMF*	95	$5.80M	35	$1.94M	130	$7.74M
Avg. Annual Damages		**$0.66M**		**$0.37M**		**$1.03M**

*Tangible Damages.
^AAD's are Tangible Damages weighted according to probability of occurrence.

3.7. Community Consultation

The Draft Green Square - West Kensington Floodplain Risk Management Study and the Draft West Kensington Catchment Floodplain Risk Management Plan were placed on public exhibition from Monday 16th May 2011 to Friday 24th June 2011.

Public displays were placed at the following locations:

- Bowen Library, 669-673 Anzac Parade, Maroubra,
- Randwick Library, Level 1 Royal Randwick Shopping Centre, Randwick,
- Council's administration centre, 30 Frances Street, Randwick.

Exhibition material at the public displays included:

- Copies of the draft reports,
- Poster,
- Fact sheets,
- Comment sheets,
- Comment box.

Newspaper advertisements were placed in the Southern Courier on 17th May and 7th June providing details of the public exhibition.

The public exhibition was also advertised on Council's website. Information was placed on the web site as follows

- Copies of the draft reports,
- Details of the public exhibition,
- Fact sheet,

- Comment sheet.

A community drop in session was held at Bowen Library, 669-673 Anzac Parade, Maroubra on Wednesday 8th June between 4pm and 7pm. Staff from Council, WMAwater and the Office of Environment and Heritage were available for the community to come along and find out about the study or ask questions.

A letter was sent to all property owners, within Randwick City Council's portion of the catchment, identified as being below the 1% AEP flood plus freeboard or below the Probable Maximum Flood. A total of 1049 letters were sent to property owners providing details of the public exhibition and the community drop in session.

4. REVIEW OF PLANNING CONTROLS AND POLICIES

4.1. City of Sydney

4.1.1. Planning Instruments

The main CoS planning instrument containing flood related provisions is the South Sydney Local Environmental Plan 1998 (hereafter referred to as the SSLEP) and subsequent amendments including Amendment No. 17 – Green Square Town Centre. The SSLEP applies across the whole study area within the CoS LGA and contains general conditions applicable to flood prone land based on the opinion of Council regarding the location of the proposed development (refer to Clause 38). More recently the SSLEP has been amended to specifically address stormwater and floodplain risk management issues within the GSTC precinct (refer to Clauses 27KH (1) and 27KH (2)).

In contrast to the general provisions of Clause 38, the conditions defined in Clause 27KH cover specific floodplain risk management aspects relating to the future GSTC precinct. These include conditions to mitigate adverse impacts resulting from development in addition to managing floodplain risk within the development site (in terms of property damage and risk to life). Clause 27KH (2) specifically recognises the existing overland flowpath that operates across the plaza adjacent to the Green Square railway station entrance (immediately downstream of the Botany Road trapped low point). The latter clause places additional conditions on development in this location aimed at reducing the future floodplain risk post-development.

Importantly, the conditions in the GSTC LEP amendment make reference to the Floodplain Development Manual (Reference 1) and require the use of relevant floodplain risk management policies as appropriate.

The SSLEP also directs that any new development within the Green Square portion of the catchment (i.e. that portion of the catchment generally west of South Dowling Street) requires the preparation of a masterplan to demonstrate that the proposal is consistent with CoS planning objectives (refer to Clause 27D). This clause also directs that the masterplans address any relevant CoS Development Control Plans (DCPs). These are discussed in the following sections.

4.1.2. Development Control Plans

A review of available information indicates that there are three parts of the South Sydney Development Control Plan 1997 (DCP) covering flood-related conditions for the CoS portion of the study catchment, including:

- South Sydney Development Control Plan 1997 – Part B: Urban Design Principles (SSDCP Part B),
- South Sydney Development Control Plan 1997: Urban Design – Part G: Special Precinct No. 9 Green Square (SSDCP Part G), and

- South Sydney Development Control Plan 1997 Amendment Part H: Green Square Town Centre (SSDCP Part H).

The SSDCP Part B document broadly covers stormwater management principles, acknowledging the need for development to manage drainage issues in a "responsible and sustainable manner". This plan promotes the use of on-site detention and water sensitive urban design (WSUD) to manage stormwater consistent with ecologically sustainable development (ESD). Sites where stormwater detention is to be integrated with development and/or open space are indicated. For the study catchment, these sites include the ACI development precinct, the Midblock precinct, Victoria Park and portions of Rosebery adjacent to Epson Road and South Dowling Street.

Whilst also promoting the principles of ESD and WSUD in relation to best practice stormwater management, Part G of the SSDCP contains specific floodplain risk management provisions that require due consideration be given to:

- any relevant Council approved flood studies and the principles of the NSW Floodplain Development Manual (Reference 1),
- minimising flood damages through the use of the appropriate Flood Planning Levels (FPLs), flooding proofing measures etc.,
- the development of flood management systems that minimise risk to personal safety and do not adversely impact existing floodplain risk for a range of design storm events.

Part H of the SSDCP contains similar provisions to those documented in Part G although the former contains site specific conditions integrating stormwater design and floodplain risk management into the overall design of the Town Centre precinct (including the public domain space).

Both Parts G & H of the SSDCP contain a tabulated listing of Flood Planning Levels (FPLs) to be adopted within the Green Square portion of the catchment (refer to Appendix C). These FPLs are considered to be appropriate to the study catchment.

4.1.3. Other Relevant Policies and Codes

- Stormwater Drainage Connection Information (Revision 02 July 2006).
- Stormwater – Development Sites over 50,000 m^2 (11 November 1998).

The first document above contains guidelines for private connections into the City of Sydney's stormwater drainage system. This document conditions on-site detention (OSD) requirements for sites greater than 250 m^2 such that the 1% AEP (1 in 100 year) post-development site runoff must be limited to the 20% AEP (1 in 5 year) pre-development runoff.

For sites less than 1,000 m^2, exemptions may apply depending on consideration of the size and nature of the development and proximity to receiving waters. For sites having an area of greater than 50,000 m^2, Council allows developers to reduce their OSD conditions in exchange for private lands being dedicated as being public open space with an integrated stormwater management capacity.

In addition, for connections to a Sydney Water (or other public utility authority) drainage system the above documents direct developers to comply with any OSD requirements that may be imposed by the owner of the drainage system. Sydney Water has established OSD requirements for developments with the Green Square area in the past (e.g. Reference 8 and 9). Although contacted as part of this study, no written advice from Sydney Water was received in this regard.

4.1.4. Existing Floodplain Risk Management Plans

CoS and Landcom commissioned the Floodplain Risk Management Plan for the GSTC precinct in 2008 (Reference 10). The GSTC FPRM Plan was provided by the CoS for direct use in this report. The outcomes of the GSTC FPRM Plan are supported by previous technical analysis commissioned by the CoS and Landcom (Reference 11).

The GSTC FPRM Plan was prepared to address flood risk management issues and manage impacts associated with re-development of the GSTC precinct between Joynton Avenue and Botany Road. The outcomes include a combination of structural flood mitigation measures, property modification measures (e.g. development controls) and emergency response modification measures (e.g. community awareness, emergency response plans). Full details of the measures can be found in Reference 10.

It should be noted that the GSTC FPRM Plan assumes that the preferred option for structural works (referred to as "Option 1a – Limited Works Option") are implemented. These works are described further in Section 5.2.3.

4.2. Randwick City Council

4.2.1. Planning Instruments – Randwick Local Environmental Plan (LEP) 1998

The Randwick LEP 1998 contains several clauses relating to drainage and water management issues including Clauses 22, 40, 40A and 42E. These conditions are broadly defined and cover drainage in general e.g. works associated with excavation or filling of land must consider potential implications with regards to impacts on existing drainage. Proposed development in or adjacent to watercourses and/or wetlands is covered with specific provisions related to environmental management features, conserving natural remnant vegetation and habitat corridors.

For large developments (i.e. for sites > 4000m^2), masterplans are to be prepared that address issues associated with the management of riparian lands and the application of "integrated natural water cycle designs".

However, there appears to be no reference to specific floodplain risk management objectives e.g. risk to life and property within the current LEP.

4.2.2. Development Control Plans (DCPs)

RCC has a number of existing DCPs that contain provisions relevant to stormwater and floodplain risk management. The particular DCPs examined for the present study included:

- Dwelling Houses and Attached Dual Occupancies DCP amended 26 November 2000 (LGA wide),
- Multi-Unit Housing DCP (LGA wide),
- Randwick Racecourse Development Control Plan 8 May 2007 (site specific),
- Kensington Town Centre DCP 2002 (site specific), and
- Campos 2000 – UNSW Kensington Campus DCP 27 March 2007 (site specific).

Of these, the two DCPs which are applicable across the LGA contain only general references to stormwater management objectives e.g. "to control stormwater quality and quantity and eliminate discharge impacts on adjoining properties". No specific reference to flooding or floodplain risk management is made. However, conditions relating to floodplain risk are referred to in several site specific DCPs although the level of consistency and detail varies between individual documents.

It is acknowledged that none of the site specific DCPs reviewed herein apply to the West Kensington area. However, they do represent instances where RCC's existing floodplain risk management approach is documented.

Most of the DCPs make reference to the use of Flood Planning Levels either defining them explicitly (e.g. minimum flood level of habitable or storage areas is to be at least 0.3 m above the 1% AEP (1 in 100 year) level) or requiring suitable FPLs to be determined as part of a Stormwater Management Plan (SMP) prepared for the proposed development. FPLs defined in this manner are to be developed in consultation with Council and are to consider the Floodplain Development Manual (Reference 1). FPLs known to have been specified by RCC within the LGA include:

- Carparking areas to be a minimum of 0.15 m above the 1% AEP (1in 100 year) level (this freeboard increases to 0.3 m where the velocity is greater than 2 m/s).
- Minimum floor level of habitable and storage areas are to be set at least 0.3 m above the 1% AEP flood level (this is increased to 0.5 m in areas where the velocity is greater than 2 m/s).

The Kensington Town Centre DCP acknowledges the potential risk to life and safety posed by underground carparks in relation to flooding. The Kensington Town Centre and Randwick Racecourse DCPs also make direct reference to the Floodplain Development Manual (Reference 1), particularly with respect to the management of floodplain risk including issues of risk to personal safety and risk to life. However, other DCPs that also have flood related conditions do not contain any reference to this document (or principles thereof).

4.2.3. Other Relevant Policies and Codes

Randwick City Council also has a Private Stormwater Code, the objective of which is to prevent damage and reduce public nuisance/risk associated with the collection and disposal of stormwater runoff from private lots.

The Code defines on-site detention (OSD) conditions across the LGA. For the West Kensington catchment, these conditions require the on-site detention of private runoff from the 1 in 5 year event up to and including the 1 in 100 year flow. To cater for extreme storms or system failure, provision must be made for an overland flow route from the OSD system. The capacity is to be sufficient to provide 0.3 m freeboard above the 1 in 100 year level to any adjacent habitable and storage areas.

For works within Council easements, proposed developments should ensure that the 1% AEP flow is wholly contained within the easement and that no changes are made that may exacerbate the floodplain risk to existing properties. Proposed developments that drain to infrastructure owned by other agencies must seek approval in writing from the responsible authority (e.g. Sydney Water).

4.3. Discussion of Current Floodplain Risk Management Approaches

4.3.1. City of Sydney

Potential areas where issues arise based on the City of Sydney's current approach relate to:

- limitations in the information and procedures available to assessing officers to identify whether or not a particular property is subject to flood-related controls, and
- conditions covering the quality of site-specific flood studies submitted in support of a Development Application (DA).

When assessing DAs the City of Sydney currently relies upon several methods to identify properties at which flood-related development controls may apply. These include:

- the direct use of completed catchment-wide Flood Studies that have been adopted by Council (e.g. Reference 2). These types of studies provide suitable information although they have not yet been undertaken for all catchments within the LGA. Whilst the CoS is currently undertaking and will also commission other studies in the future (e.g. the Alexandria Canal Flood Study is currently being prepared in 2011), it will likely take time to cover all the catchments within the LGA (CoS are working on a five to six year timeframe). Hence there is a need to provide the means to undertake site-specific flood studies for individual DAs in the interim (as an aside, we would also recommend that the completed studies are reviewed and updated on a regular basis e.g. to take advantage of new information or to maintain consistency with changes in planning and development layouts etc).
- corporate knowledge within the CoS based on past flooding known to have occurred within an area. This knowledge comes from a range of sources including reports from local residents and historical knowledge held by experienced members with the

organisation.

However, there is no clear guidance regarding the application of flood related controls for properties that fall outside of the above approaches. It may be that interim overview studies of catchments within the LGA could be undertaken to identify potential properties using a conservative approach. For each identified property, a site-specific flood study would then be required as part of future DAs for that site. Whilst this approach does not eliminate the need for site-specific flood studies, it will reduce the number of properties potentially needing this type of assessment within the LGA and ensure that a more technically rigorous approach is adopted than at present.

It is acknowledged that the need for individual property owners to prepare site-specific flood studies can be onerous. However, in areas where catchment wide flood studies exist, site-specific studies can be readily undertaken. In these cases, the site-specific study can provide an improved description of flood behaviour to better inform floodplain risk management outcomes (e.g. through the use of detailed survey data).

In other areas where the absence of approved catchment flood studies means that a site-specific study will be the main source of flood information for the development assessment, it may be possible for Council to implement a tiered approach as indicated in Table 9.

Table 9: Options for Site Specific Flood Studies

Tier	Description of Approach	Advantages	Disadvantages
1	Site visit and basic desktop analysis consistent with AR&R (e.g. Urban Rational Method and Manning's calculation), limited survey required.	Only limited amount of data & engineering effort required, standard parameters can be defined by Council. A more conservative approach with freeboard should be adopted with this type of assessment.	The accuracy of the outcomes will be lower than that of more detailed methods. Applicable for small catchments less than 5ha in size (say). Only suited to those areas where simplistic overland flow assumptions can be made (e.g. the influence of trunk drainage and complex overland flowpaths can be ignored).
2	Site visit and more sophisticated design flow estimation (e.g. rainfall-runoff modelling) in combination with desktop or steady state hydraulic calculations. Ground survey by a Registered Surveyor required.	Moderate amount of data and engineering effort required, types of data required should be readily available, this style of approach can take into account major trunk systems and well defined hydraulic features (e.g. detention basins), outcomes are more reliable than Tier One studies.	Time, cost and data requirements are higher relative to Tier One assessments, not suited to areas where complex hydraulic behaviour (e.g. informal overland flowpaths) is important.
3	Detailed rainfall-runoff modelling in conjunction with detailed hydraulic modeling based on a comprehensive survey.	Makes best use of available information to provide a flood level estimate that is more reliable than other methods, can provide detailed information on flood behaviour to better inform floodplain risk management outcomes.	Significant amounts of data and engineering effort required, complexity of models and assumptions will mean that some form of validation/calibration* will be required (sensitivity analysis at a minimum), relatively expensive to prepare (in terms of time and costs).

* This will be enhanced if flood heights are available from Council records.

For areas where the outcomes of a site-specific study supersedes those from a Council approved catchment-wide flood study and the outcomes are significantly different (e.g. greater ± 20% variation in flow or ± 0.2 m variation in flood level) then the reasons for these discrepancies should be clearly justified to Council's satisfaction.

It is recommended that any site-specific flood study be undertaken by a suitably qualified water engineer having credentials and demonstrated experience in floodplain risk management. This requirement should form part of the DCP conditions an example of which could be (based on similar conditions in Reference 12):

"Assessments are to be certified by a Chartered Professional engineer specialised in the field of hydrology and hydraulics as it applies to floodplain risk management".

It will be up to the engineer to detail his/her credentials and experience as part of the assessment. This approach will allow CoS assessing officers to have confidence in the study outcomes submitted as part of DAs. A key of advantage of this approach is that engineers with CPEng status have a recognised level of competence and their continuing professional development is subject to audit.

However, it is acknowledged that there may need to be some clarification as this requirement may be too restrictive. For example, it is reasonable to consider that such qualifications are not needed to design/certify local, on-site drainage works that address local runoff/OSD etc. However, for flood risk assessments involving the estimation of Flood Planning Levels and/or hazard management issues then the CPEng status (together with demonstrated practical experience) provides evidence to Council officers that the engineer is sufficiently qualified to undertake the flood risk assessment.

4.3.2. Randwick City Council

At present Randwick City Council does not have a consistent documented code, policy or DCP relating to floodplain risk management issues across the Council's LGA. There are currently no documented controls relating to the West Kensington catchment apart from generic drainage and OSD provisions in the LEP 1998 and in the Private Stormwater Code. However, there are provisions relating to floodplain risk management for other areas in the LGA as part of several site-specific DCPs (e.g. flood planning levels, references to risk to life and evacuation). Whilst the use of site-specific DCPs is advantageous for precincts having unique features, it is recommended that RCC consider developing a DCP (or equivalent) that documents floodplain risk management provisions for the entire LGA. These catchment wide conditions can then be refined for future site-specific DCPs as needed. This approach would:

- ensure that floodplain risk management is addressed in a consistent manner across the LGA and,
- would improve the ability of Council to efficiently fulfil its obligations regarding the management of flood prone land in an open and transparent manner (in practice this will benefit Council's internal operations and also its constituents).

Similar to the City of Sydney, Randwick City Council also faces difficulties when identifying which properties may be subject to flood related planning and development controls. Assessing officers currently rely on a range of information including:

- existing catchment wide flood studies, and
- reference to historical flood reports and known flood prone areas based on corporate knowledge and Council's internal database of reported problems (e.g. as notified by local residents).

Unfortunately, the current approach has the potential to miss affected properties due to the lack of sufficient information. Whilst RCC is currently in the process of preparing formal flood studies for all catchments within the LGA, this will take some time to complete. Hence, some type of overview method to provide a broad indication of affected properties (as suggested in Section 4.3.1) may be of benefit to Council staff in the interim. The overview study would not provide flood levels at properties. Rather, this type of study would conservatively identify those properties at which site-specific flood studies need to be undertaken as part of the DA process. It will provide Council officers with a consistent approach for identifying properties across the LGA in those catchments where formal flood studies have not yet been undertaken.

For those properties identified as being subject to flood related development controls, RCC officers also face difficulties in determining the scale of flood assessment required (similar to issues already discussed in Section 4.3.1). Officers currently consider a number of factors with regards to this aspect including (but not limited to):

- the scale of the proposed development e.g. single lot private residence vs. higher density mixed development,
- the location of the development with respect to past flooding issues,
- the size of the contributing catchment upstream.

To provide clear and consistent guidance for Council officers, it is recommended that RCC develop a documented system of tiered flood assessments similar to that proposed in Section 4.3.1. The system can account for criteria already informally used by Council officers (as described above) and can leverage available outputs from formal flood studies and overview studies.

Given the significant time since Randwick City Council's On-Site Detention policy was first implemented it is appropriate that a review be undertaken in light of current practice and in particular the adoption of the principles of WSUD. WSUD encourages retention and infiltration and possibly this approach may lead to changes in the OSD requirements. A review of OSD should be undertaken as part of formulating development controls.

4.3.3. Other Considerations

In addition to the various aspects covered in Section 4.3.1 there are a range of issues pertinent to both Councils relating to floodplain risk, planning controls and the management/dissemination of flood-related information. These aspects are outlined briefly below. Given that the manner in which these factors are addressed is dependant upon the needs of each individual Council, the following is intended to serve as a starting point to promote initial discussion.

Council Issued Planning Certificates under Section 149 Environmental Planning and Assessment Act 1979

A section 149 certificate is a planning tool to notify that land is affected by a Council Policy with development controls. For flood-related risks, issues arise regarding the existence of a corresponding Council Policy, the nature of information to be included and the internal processes used to manage this aspect.

Identification of Flood Prone Properties

Even when suitable flood information is available, the approach used to identify flood prone properties is still very much a subjective process. The approach will need to be determined by individual Councils following consideration of a number of aspects including:

- legislative constraints (e.g. Department of Planning may restrict tagging of residential development to the nominated Flood Planning Level unless it is demonstrated that exceptional circumstances apply),
- the nature of flooding within an area (e.g. overland flow vs. mainstream flooding from a defined watercourse),
- the availability and quality of available datasets (e.g. ground survey, design flood levels),
- localised features common to urban areas and their potential impact on flooding (e.g. blockage of overland flow paths due to fences of other uncontrolled development).

It is acknowledged that any method used to identify flood prone properties at a catchment scale will be less than perfect due to inherent complexities. However, these complexities can be mitigated through the implementation of generic development controls applied across the catchment e.g. all house floors and garages must be a minimum of 0.3 m above the surrounding terrain.

Importantly, the use of a documented approach allows Council to identify properties in a consistent and transparent manner. It also allows an opportunity for the identification of properties to be refined in the future on the basis of site-specific assessments.

Accessibility and Management of Information

Both Councils will need to implement quality control procedures for managing and disseminating the flood related information to:

- ensure that current information is being used (as flood studies are revised in time and/or site-specific studies become available),
- control both internal and external access to flood-related information, and
- ensure that a rigorous process is adopted for the provision of information to the public.

These aspects will largely depend upon accepted Council policies, planning and development control processes and internal data management procedures.

5. FLOODPLAIN RISK MANAGEMENT MEASURES

5.1. Introduction

The NSW Government's Floodplain Development Manual (Reference 1) separates floodplain management measures into three broad categories:

Flood modification measures modify the flood's physical behaviour (depth, velocity) and include flood mitigation dams, retarding basins and levees.

Property modification measures modify land use including development controls. This is generally accomplished through such means as flood proofing (house raising or sealing entrances), planning and building regulations (zoning) or voluntary purchase.

Response modification measures modify the community's response to flood hazard by informing flood affected property owners about the nature of flooding so that they can make informed decisions. Examples of such measures include provision of flood warning and emergency services, improved information, awareness and education of the community and provision of flood insurance.

A number of methods are available for judging the relative merits of competing measures. The benefit/cost approach has long been used to quantify the economic worth of each measure on a relative basis enabling ranking against similar projects in other areas. The benefit/cost ratio is the ratio of the present worth of the reduction in flood damage (benefit) compared to the cost of the works. Generally the ratio expresses only the reduction in tangible damages as it is difficult to accurately include intangibles such as anxiety, risk to life, ill health and other social and environmental effects. In this study the reduction in tangible damages to public utilities as a result of implementation of a floodplain management measure have not been included due to the absence of data on the likely impacts of flooding.

The potential environmental or social impacts of any proposed flood mitigation measure are of great concern to society and these cannot be evaluated using the classical benefit/cost approach. The public consultation program carried out as part of this study (Section 3.7) has ensured that identifiable social and environmental factors were considered in the decision making process.

5.2. Flood Modification Measures

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

- dams,
- retarding basins,
- channel modifications,
- levees,

- flood gates,
- pumps.

5.2.1. Flood Mitigation Dams

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

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

Based on the natural topography and existing development in the catchment, there is no opportunity to accommodate a flood mitigation dam within the catchment. This type of measure was not considered further for this catchment.

5.2.2. Retarding Basins

DESCRIPTION

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

DISCUSSION

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

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

Cost: Whilst construction costs of the basin and wall in an urban environment will be high, additional costs are associated with any alterations to services (gas, electricity, telephone, water, sewerage, roads, etc.) that are within or close proximity to the proposed basin. Depending upon the nature of the services these costs may exceed several hundred thousand dollars. Some sites which at first glance may appear suitable, may be less so due to the deposition of inappropriate fill material in the past (e.g. rubbish site, buried asbestos or other forms of waste). This aspect is of particular significance given the industrial activities previously undertaken within the catchment. Also of concern are the potential inter-actions with the groundwater table, particularly in areas where there is a shallow depth to ground water and/or potential to mobilise/exacerbate groundwater contaminants. Any basin option should therefore give due consideration to site remediation costs (including the cost to manage contaminated materials) and clearly define the funding source(s) for these costs.

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

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

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

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

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

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

POSSIBLE MEASURES

Previous studies have considered opportunities for regional basins within the catchment (e.g. References 3 and 4). This study also examined other locations within the upper reaches of the study area in and around the Moore Park Golf Course.

Lower Catchment (West of South Dowling Street)

Within the lower portion of the catchment (e.g. west of South Dowling Street), a number of these basins have been constructed (or are planned for construction) as part of ongoing urban renewal activities (see Figures 11 and 13). The City of Sydney has also advised that detention basins are also being designed as part of the GSTC development and the Precinct E area immediately upstream of Joynton Avenue (References 10 and 11). Beyond these, opportunities for additional basins in the Green Square area are limited.

The largest of the proposed basins is to be located in the Council owned area located upstream of the trapped low point in Joynton Avenue (referred to as Precinct E). Under existing conditions, the Joynton Avenue lowpoint provides a significant amount of flood storage that attenuates overland flows from the upper catchment. This lowpoint experiences nuisance flooding in smaller, more frequent events and is subject to significant ponding (flood depths greater than 0.8m) in larger events. To reduce the flood hazard across Joynton Avenue, CoS proposes to eliminate the Joynton Avenue lowpoint (i.e. raise the roadway) and construct a new detention basin within the Precinct E area. The basin concept and approach has been provided by CoS as part of investigations documented in Reference 11. A concept plan of the proposed basin is provided in Figure 14. Key features include:

- raising of Joynton Avenue (the current concept suggests raising the minimum road level to 18.25 mAHD),
- provision of related infrastructure to direct overland flow from the upper catchments into the basin (including inlets, culverts, channels and overland flowpaths), and
- outlet provisions to manage outflows through to the GSTC precinct.

It should be noted that the implementation of the Precinct E basin assumes that proposed trunk drainage upgrades within the GSTC precinct would be in place (the GSTC works are discussed further in Section 5.2.3). The current concept is only intended to reduce flooding on Joynton Avenue and does not provide any benefits to downstream sites (Reference 11).

Upper Catchment (East of South Dowling Street)

Similarly, land constraints in the West Kensington limit the opportunities for new basins to open space areas within The Australian and/or Moore Park golf courses. Of these, The Australian golf course site offers the most benefit as it recovers runoff from urbanised portions of the upper catchment. This option has been examined previously (Reference 3) and works to implement the basin in some form appear to have been undertaken (based on a review of Council ALS data and hydraulic model results).

Similar approaches may also be feasible for south-western portions of the Moore Park golf course although these locations drain non-urban catchments (Figure 11). This option may involve several smaller basins serving local catchments within the Moore Park Golf course site. Hydraulic modelling of this option indicates that approximately 16,100m^3 of storage (comprising 24% existing storage and 76% of additional storage) would be sufficient to contain runoff from this area for the 1% AEP (1 in 100 year event). The potential locations of this storage identified for this assessment are shown in Figure 11. For the 1% AEP (1 in 100 year) event, the implementation of these basin was found to produce localised reductions in flood levels in the order of 0.1m - 0.2m in Todman Avenue (adjacent to the Supacentre development) and within the Raleigh Park development. However, due to differences in the relative timing of runoff received from other parts of the catchment, these basins were not found to reduce flood levels in other areas of the catchment west of the Todman Avenue intersection with South Dowling Street.

Formalised basins within the Moore Park golf course would also provide stormwater harvesting opportunities for the golf club.

In a review of other potential detention basin sites in West Kensington, the feasibility of constructing a basin within the existing Lenthall Street lowpoint was also considered. Identified by Council, this location offers an alternative site should any proposed works at The Australian golf course be found to be not feasible. Although the Lenthall Street location takes advantage of the existing natural lowpoint in this part of the catchment, the construction of a basin is considered impractical for a number of reasons including:

- the social and economic costs associated with acquisition of existing properties surrounding the site (RCC estimate that the economic costs alone could be in the order of $15M);
- the implications in terms of changed traffic conditions resulting from the closure of Lenthall Street, and
- the likelihood that the flooding benefits in upstream reaches of the catchment (gained for example due to pipe capacity upgrades) would be relatively minor and are unlikely to be of consequence for larger events (say greater than the 5% AEP event). Notwithstanding the obvious economic considerations, it would be difficult to justify the social impact of this option on this basis. For these reasons, this particular option was not investigated further.

The park at the Ingram Street low point was rejected as a potential basin site as the existing drainage from the low point is shallow and there is very little scope to lower ground levels in the park. Furthermore, there is little scope to lower the drainage network from the Ingram Street low point. The storage volume gained by undertaking these works is minor compared to even the 50% AEP storage volume in the low point. Therefore, these works will have negligible impact on flooding in the trapped low point

The laneway between Ingram Street and Lenthal Street was rejected as a potential basin site as this location also provided a negligible increase in available storage volume.

The park at the intersection of Virginia Street and Baker Street was rejected as a potential basin site as it is isolated from the floodplain and the natural topography is not conducive to construction of a basin. The park is located on higher ground and there are no floodwaters in the vicinity that can be diverted to the park. Furthermore, the park is not of sufficient area to accommodate a significant flood storage volume.

The low points in Samuel Terry Avenue already act as flood storages and flooding in this area is already generally confined to the road reserve. The site was rejected as a potential basin site as there is little scope to obtain additional storage volume. Any benefits of a basin are likely to be highly localised and, given that flooding is already generally confined to the road reserve in this area, would not provide any significant benefits for adjoining properties.

OUTCOMES

The proposed Precinct E basin will reduce flooding within the trapped lowpoint at Joynton Avenue (Reference 11). The concept plan for this basin does not include additional storage to provide downstream benefits.

Retarding basins in Moore Park golf course would provide localised reductions in flood levels within the West Kensington catchment and may also provide some water quality and re-use potential.

The construction of basins in these locations is supported.

ACTIONS

To liaise further with Moore Park (public course) golf club regarding the construction of retarding basins.

5.2.3. Pit/Pipe and Trunk System Upgrade

DESCRIPTION

Upgrading of pit/pipe and trunk networks within the GSWK catchment will generally assist in reducing the amount of overland flow and consequently alleviate flood issues. The main drawbacks to such schemes include:

- potentially high construction costs, especially where upgrades are to go through private property and/or existing services need to be relocated, and

- potential adverse impacts downstream resulting from the improved efficiency of the upgraded system.

There are several areas within the catchment where pit and pipe upgrades have been (or are currently being) considered by Council including:

- upgrades to the trunk system along O'Dea Avenue (Reference 13),
- redevelopment of the Mid-block precinct between Lachlan Street and O'Dea Avenue, including provision of local drainage to 10% AEP capacity (Reference 14),
- provision of new trunk drainage and overland flowpaths adjacent to the major trapped lowpoint in South Dowling Street,
- augmentations of existing pit and pipe drainage in the Milroy Avenue catchment in West Kensington (details outlined in Reference 3 – note that portions of this system have since been upgraded (refer to Section 2.4.4),
- augmentation of existing drainage along Samuel Terry Avenue in West Kensington adjacent to the noisewalls along South Dowling Street,
- upgrade of existing drainage capacity in the Duke Street area, upstream of the trapped low point in Balfour Road,
- upgrade of existing Sydney Water Trunk system from South Dowling Street through to Precinct E,
- augmentation of the existing trunk drainage system within the GSTC precinct as part of the GSTC urban renewal project.

DISCUSSION

There is potential for the works described above to improve the local flood behaviour in each area.

City of Sydney LGA

For the Mid-block precinct and surrounding area these types of upgrades are currently being investigated as part of a number of major urban re-development projects occurring (or planned to occur) within this area. It is understood the CoS is currently investigating the feasibility of upgrading the trunk system within O'Dea Avenue, into which much of the Mid-block precinct will drain. This option is being addressed with a view to providing regional improvements to trunk drainage throughout O'Dea Avenue and Joynton Avenue.

As noted previously in Section 3.3.1, the CoS has investigated improvements within the vicinity of the South Dowling Street low point as part of proposed re-development of the site bounded by O'Dea Avenue, South Dowling Street and the southern end of Ameila Street. This includes the provision of an overland flow path from the South Dowling Street low point into a new 3,000m^3 detention basin on-site, together with supporting upgrades to the trunk system from the low point through the development. The creation of a managed overland flowpath from the current lowpoint together with upgraded trunk drainage capacity can significantly reduce peak flood levels within the South Dowling Street lowpoint. Comparison with results documented in Reference 2 indicates that these works can reduce ponding levels at this lowpoint by up to 0.6m in the 1% AEP (1 in 100 year) event. However, care should be taken that such works do not adversely impact downstream areas. Although the Development Application for these works has since been withdrawn, it is understood that CoS are still considering the potential for these works to be integrated into the future re-development of the Mid-block precinct.

Technical investigations to assess the performance of proposed trunk drainage upgrades within the GSTC precinct have already been undertaken on behalf of the CoS and Landcom (Reference 11). The CoS has therefore provided the outcomes of this work for direct use in this study. The nominated works are referred to as "Option 1a – Limited Works option" in References 10 and 11 (refer to Figure 15). From Reference 11, key features of the scheme include:

- surface inlets located just east of Portman Street to discharge into Boulevard Park (within the GSTC),
- a 1.5m diameter pipe to convey flow from Boulevard Park to Botany Road, and
- raising of the railway plaza frontage along Botany Road by 0.8m to mitigate overland flow to O'Riordan Street, and
- inlets located in Botany Road draining flow underneath the railway plaza to new pipe systems that discharge in O'Riordan Street and Bourke Road.

A hydraulic assessment of the proposed system for the 1% AEP (1 in 100 year) event (documented in Reference 11) concluded that:

- peak water levels upstream of the GSTC in the Joynton Avenue were not adversely impacted,
- flood behaviour within the GSTC precinct could be suitably managed in combination with a GSTC-specific Floodplain Risk Management Plan (this Plan is documented as Reference 10),
- flood hazard across the railway plaza was reduced to low hazard,
- peak water levels in certain areas downstream of the system were increased. For example, peak flood levels downstream of Bowden Street were found to have increased by 0.02 m to 0.06 m. Localised increases of up to 0.15 m were noted as being insignificant. Larger increases (in the order of 1 m) found to occur in the vicinity of the O'Riordan Street and Botany Road intersection were attributed to corresponding changes in road levels associated with modifications to the intersection.

The adverse impacts noted above are acknowledged as part of the assessment and it is conceivable that localised impacts could be addressed as part of future detailed design. Re-development of significant portions of the lower catchment is also planned to occur in the future. This will also provide many opportunities to mitigate the broader adverse impacts noted above. It is understood that the CoS will be undertaking further investigations as more detailed models of the catchment become available (e.g. as part of the Alexandra Canal Flood Study and subsequent Floodplain Risk Management Study and Plan).

In terms of provisional flood hazard, the proposed works were found to cause localised increases in high hazard areas downstream of the GSTC site although the increase was noted as being insignificant (Reference 11). Due to the proposed road works at the Botany Road/O'Riordan Street intersection, a high hazard area was found to exist north-west of the railway plaza along Bourke Road. Reference 11 notes that the hazard in this location was primarily created by high velocities and suggested that these could be mitigated during detailed design stage. No comment on the effects of these measures in terms of changes in flood levels is provided although it is anticipated that this would also be addressed during the detailed design phase.

The performance of the proposed scheme in terms of changes in flood risk to existing properties for design events other than the 1% AEP (1 in 100 year) event is not documented.

Randwick City Council LGA

A number of major trunk drainage upgrades have already been implemented within the West Kensington catchment based on technical assessments undertaken following the major flooding that occurred in November 1984 (as discussed previously in Section 2.4.4).

For the Milroy Avenue catchment, the feasibility of any further augmentations to existing drainage to reduce the flooding potential in both the Milroy Avenue and McDougall Street low points is very much limited by downstream capacity constraints. Opportunities for any further upgrades within the area are limited due to land ownership and existing development constraints. However, consideration is given to potential upgrades associated with the Sydney Water infrastructure draining the broader Milroy Avenue catchment and local works in the vicinity of Duke Street. These are discussed below.

For the upper part of the catchment draining to the Balfour Road trapped low point, RCC expressed an interest in upgrading local drainage capacity within the Duke Street precinct to address local flooding issues. Typically, the topography of this area is relatively flat and the current kerb and guttering system has been adversely affected by tree roots (refer to Photo 6). As a result this area experiences localised ponding and nuisance flooding even after relatively minor rainfall events e.g. less than 1 in 1 year ARI (refer to Photo 7 and Photo 8).

Photo 6: Existing kerb and guttering within Duke Street area is affected by tree roots.

Photo 7: Localised ponding in Duke Street following minor rainfall.

Photo 8: Ponding in front of Duke Street property access following minor rainfall.

The local drainage system within the Duke Street area drains to the Balfour Road system. Components of the Balfour Road system extending downstream to The Australian golf course were updated following recommendations documented in Reference 3. To mitigate local flood problems in Duke Street, RCC are currently considering upgrading the local drainage in the vicinity of Duke Street.

This option was assessed using the hydraulic model for a range of design flood events. However, the outcomes indicated that:

- upgrading the local system resulted in minimal reductions in flood levels for design events in Duke Street and,
- such upgrades would result in negligible adverse impacts in downstream areas.

These outcomes reflect the fact that the local system reaches capacity even in smaller events. However, given the condition of the existing system kerb and gutter system in Duke Street, the planned upgrade will result in localised improvements for minor rainfall events and hence reduce the occurrence of nuisance flooding similar to that shown in Photo 7 and Photo 8.

The existing Sydney Water stormwater channel that services much of the southern portion of upper West Kensington catchment is of limited capacity and acts as a constraint for any proposed drainage augmentation in the upper catchment. This portion of the trunk system drains through to the existing CoS works depot site on Epsom Road.

It is recommended that the feasibility of increasing the Sydney Water channel capacity be further investigated on the basis that any potential adverse downstream impacts resulting from such works could potentially be mitigated by:

- additional detention capacity within Precinct E,
- provision of detention capacity within The Australian golf course, or
- a combination of the above.

There are several trapped low points that lie immediately east of the noisewalls along South Dowling Street in West Kensington. The presence of the noisewalls and associated road infrastructure means that there is no effective overland flowpath from these areas and the ponding behaviour is dependent on the capacity of the existing sub-surface drainage. However due to the significant physical constraints posed by the noisewalls, South Dowling Street and the Eastern Distributor, any options to improve the existing sub-surface capacity would be difficult to implement. Due to the complexity of the public infrastructure in this area, it is recommended that joint investigations between Council and the Roads and Traffic Authority (RTA) be undertaken to further assess this aspect.

OUTCOMES

Several options are available that will provide some reduction in overland flow and thus reductions in peak levels and damages.

ACTIONS

It is recommended that consideration be given to upgrading the Duke Street drainage. Further consideration should also be given to investigating the potential to upgrade the Sydney Water infrastructure at the downstream end of the West Kensington catchment. This latter option would be subject to further discussions with both RCC and CoS and would depend upon the feasibility of mitigation works to address downstream impacts within the CoS LGA.

It is recommended that joint investigations between Council and the RTA be undertaken to investigate the feasibility of options to manage the impacts of sound walls on South Dowling Street.

No further consideration should be given to other trunk drainage upgrades in the West Kensington portion of the catchment.

5.2.4. Levees, Floodgates and Pumps

DESCRIPTION

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

DISCUSSION

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

Note that the use of a levee (or similar) for the protection of an individual property is considered a property protection measure rather than a catchment based mitigation measure.

POSSIBLE MEASURES

Levees are typically used to address mainstream flooding behaviour associated with overtopping of an open drainage line. This type of flood behaviour is not apparent within those areas of West Kensington susceptible to flood damages. Furthermore, the application of levees is limited due to the lack of available space and the difficulty in isolating areas or being able to tie levees to high ground.

As noted previously in Section 3.3.1, portions of the West Kensington catchment receive overland flow from the adjacent Centennial Park – Kensington catchment via Todman Avenue. Although some form of diversion measure(s) may be considered to prevent this cross-flow, it is recommended that these types of works not be implemented. Whilst this type of approach may mitigate some of the flood risk for residents within West Kensington, these works will also result in a corresponding increase in flood risk for residential and commercial properties in the Centennial Park catchment.

In view of the above, it is recommended that no further consideration be given to the construction of levees by either Council within the study catchment.

OUTCOMES

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

ACTIONS

No further consideration be given to the construction of levees and flood gates.

5.2.5. Management of Blockage

DESCRIPTION

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

DISCUSSION

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

In most of the catchment the pipe systems are old and there is a likelihood of blockage due to sedimentation or damage to pipes. A pro-active maintenance program including regular street sweeping and education programs to encourage the community to keep gutters clean can assist in this regard.

Some Councils in urban catchments (Woollahra) have introduced parking restrictions to prevent vehicle parking on inlet pits. Unfortunately despite these types of measures it is unlikely that 100% success can be achieved.

OUTCOMES

It is recommended that Council:

- regularly assess the effectiveness of current street sweeping programs and in light of the outcomes refine/improve the adopted approach,
- consider adopting parking controls at locations where the flow is large and regularly inundates adjacent properties,
- review current inlet pits and consider potential modifications to reduce the likelihood of blockage where practical,
- explore opportunities to replace pipes with WSUD in conjunction with other Council works,
- consider the implementation of blockage protection at major trapped low points where feasible,
- adopt a maintenance program to inspect and rectify sedimentation in pipes, this may mean closed circuit TV inspection of pipes in critical locations.

ACTIONS

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

5.3. Property Modification and Development Measures

5.3.1. House Raising

DESCRIPTION

House raising has been widely used throughout NSW to eliminate inundation from habitable floors. This approach provides more flexibility in planning, funding and implementation than voluntary purchase. However its application is limited as it is not suitable for all building types and only becomes economically viable when above floor inundation occurs frequently (say in a 10% AEP (1 in 10 year) event or less).

DISCUSSION

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

OUTCOMES

A review of the flood damages database indicates that there are no properties on piers in West Kensington that are inundated in a 20% AEP (1 in 5 year) to 10% AEP (1 in 10 year) event and hence may have been suitable for consideration in terms of house raising. There is one property on piers in Milroy Avenue but it is not inundated until the 5% AEP (1 in 20 year event) and as a result is not considered a suitable candidate for house-raising.

For other areas within the catchment there are no other properties with suitable construction material that are in inundated in a 1% AEP (1 in 100 year) event.

ACTIONS

No properties appear suitable for this type of option within the catchment. No further consideration should be given to house raising schemes.

5.3.2. Voluntary House Purchase

DESCRIPTION

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

DISCUSSION

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

Voluntary purchase has no environmental impacts although the economic cost and social impacts can be high. Within the study area, it is extremely difficult for Councils to afford to purchase properties even with grant funding assistance. It would be difficult for either the State or Federal Governments to financially sustain such schemes. Further, many residents do not accept voluntary purchase because it would have significant impact on their community and way of life. Among these concerns are:

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

Voluntary purchase schemes in well established urban areas are unlikely to be successful for the above reasons.

Voluntary purchase should be considered at locations where private property is sited at low points, flood depths are greater than 1 m or properties subject to high velocities. This approach may be the most cost effective measure in situations where alternative measures based on the upgrade of pit and pipe systems are less practical and/or expensive to implement.

OUTCOMES

A review of the West Kensington catchment undertaken in consultation with RCC staff indicates that there are no feasible sites.

This type of approach is considered to be less suited to the Green Square area given that much of the affected area is subject to re-development as part of an ongoing urban renewal process. CoS have indicated that floodplain risk will be addressed and managed as part of this renewal process. Examples include the Mid-block precinct (bound by Lachlan Street and O'Dea Avenue), and the Precinct E area (including areas to east up to and including Link Road).

ACTIONS

No further consideration should be given to voluntary purchasing of houses.

5.3.3. Flood Proofing

DESCRIPTION

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

DISCUSSION

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

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

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

There are sophisticated flood proofing measures available such as “pop up” flood gates and “removable gates”. However the successful application would have to be assessed for individual properties drawing on specific flood analysis.

OUTCOMES

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

Flood proofing of residential properties in low hazard areas on a property by property basis could alleviate local inundation issues however consideration would have to be given to the (possible) redistribution of flows to downstream properties and safety issue of isolating residents behind such protection measures. This option would not be considered for Government funding however could be pursued by individual property owners.

ACTIONS

Flood proofing should be promoted as a means available to reduce flood damages for existing non-residential buildings.

5.3.4. Flood Planning Levels

DESCRIPTION

Flood Planning Levels (FPLs) serve two purposes. Firstly, a FPL is used to define land subject to flood related development controls. Secondly, FPLs are adopted as the minimum level to which floor levels of different types of development in the flood affected areas must be built (e.g. residential floor level, car park level etc.).

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

DISCUSSION

An outline of FPLs currently being used by both Councils is provided in Section 4.

The CoS documents FPLs for the Green Square area as part of relevant DCPs. These FPLs are consistent with the principles of the Floodplain Development Manual and are considered appropriate.

Although site-specific DCPs for other areas within the RCC LGA define a range of FPLs, there is no existing documentation of FPLs that are directly applicable to the West Kensington catchment. Hence, it is recommended that RCC review existing practice and develop appropriate FPLs for use in West Kensington. These FPLs should reflect the principles of the Floodplain Development Manual (Reference 1), and should be broadly consistent with FPLs that might be applicable to the broader catchment.

OUTCOMES

FPLs are essential for implementing flood related development controls. CoS have documented their FPLs. RCC is to prepare suitable FPLs as part of this Study.

ACTIONS

It is recommended that Randwick City Council develop suitable FPLs for use in West Kensington. RCC has since undertaken this task as part of this Study, the outcomes of which are presented in Appendix C.

5.3.5. Development Control Planning

DESCRIPTION

Within the Green Square - West Kensington catchment there is continuing pressures for both redevelopment of existing buildings as well as for new development and urban renewal. The strategic assessment of floodplain risk can prevent development occurring in areas with a high hazard and/or with the potential to have significant impacts upon flood behaviour in other areas. It can also reduce the potential damage to new or redeveloped properties likely to be affected by flooding to acceptable levels.

DISCUSSION

Issues relating to Development Control Planning have been discussed previously in Section 4 and are briefly outlined below for each Council.

City of Sydney

Development controls for flood liable areas in general are not addressed in the current Local Environmental Plan (LEP) except for specific areas of the catchment (such as GSTC precinct). Rather these types of controls are documented in corresponding DCPs. To ensure that the objectives of these DCPs are implemented it is recommended that the LEP include reference to flood development controls in context of the broader catchment.

In terms of the DCPs themselves, it is recommended that these be amended to ensure that flood assessments are always undertaken by suitably qualified engineers.

Randwick City Council

As previous, it is recommended that RCC make reference to flood liability and controls in the LEP to ensure that floodplain risk management objectives are addressed and controls can be enforced.

As discussed in Section 4, RCC currently has no formal DCP documenting flood development controls for the broader West Kensington catchment (or wider LGA). It is recommended that

Council act to address this with suitable amendments to the LEP and through the development of a corresponding DCP (or equivalent). This approach will ensure the consistent application of flood development controls across the LGA and does not preclude the use of more refined, site-specific controls where needed.

Other Issues Relevant to Both Councils

The flood potential and requirements for development controls is notified to property owners on Section 149 Certificates. To achieve this it will be necessary for each Council to consider:

- the development and acceptance of a formal Flood Policy,
- the means by which properties are identified for Section 149 notations including compulsory Section 149(2) notations and optional 149(5) information,
- the management and on-going maintenance procedures relating to flood related information within the catchment.

In terms of addressing the cumulative impacts of development within the catchment, it is recommended that Councils not allow the filling of land within the floodplain as a general principle. A reasonable exception to this would be for the construction of a building pad within a property. However, the filling of an entire property would ultimately disadvantage others within the floodplain as the cumulative loss of floodplain occurs. Further, the gradual loss of floodplain will unfairly distribute the benefits and adverse impacts to other floodplain users. For example, whilst the filling of one property may benefit an individual property owner, the adverse impacts will have to be borne by others within the floodplain. As a result it is difficult to distribute the benefits and impacts in an equitable manner.

OUTCOMES

Both Councils have some form of flood-related development control planning measures however these should be improved upon. Such measures should be consistent with the principles of the NSW Floodplain Development Manual (Reference 1) thereby addressing aspects including (but not limited to):

- the use of appropriate Flood Planning Levels,
- ensuring that there are no adverse impacts on flooding (including conveyance of flood waters and floodplain storage volume) and that the potential for cumulative impacts is suitably managed,
- ensuring the safety of persons and emergency access during flooding for all floods up to and including the PMF, and
- ensuring that new development suitably manages the risk to personal safety and (as a minimum) does not adversely impact flood damages. New developments/re-development should reduce the risk to life and property where possible.

ACTIONS

It is recommended that both Councils amend current planning instruments to take into account the aspects identified above. Importantly both Councils should refer to flood liability and controls in the LEP to ensure that controls can be enforced consistently across the broader catchment and/or LGA.

5.3.6. Climate Change

DESCRIPTION

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

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

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

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

DISCUSSION

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

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

The issue of sea level rise is complicated by other long term influences on mean sea level changes. The available literature suggests that a gradual increase in sea level is likely to occur with a rise of perhaps up to 0.9 m by the year 2100 along the NSW coast. However, any change in the sea level is unlikely to affect flooding within the study catchment.

OUTCOMES

The potential impact of increased design flood levels in the catchment due to climate change is examined for the 1% AEP (1 in 100 year) event in Section 6. The results show that increases in rainfall from climate change could significantly impact on the number of buildings inundated above floor level and the amount of property damage incurred.

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

ACTIONS

Some Councils in NSW have raised Flood Planning Levels to account for the expected increase in flood level. For example, this rise would be in addition to the 0.5 m freeboard for residential properties. Council should consider the provision of appropriate freeboard for flood planning levels to account for uncertainties associated with climate change. This issue should be canvassed at the Floodplain Risk Management Plan stage.

5.3.7. Water Sensitive Urban Design

DESCRIPTION

Urban development can lead to changes in the catchment hydrology with the most obvious being an increase in peak flow (and resulting flood levels) and pollutants in the creek system. Traditionally floodplain risk management studies have focussed on the increase in peak flow where the principal objective is to safely and efficiently convey stormwater to the ocean. This is the reason extensive trunk drainage infrastructure drains runoff from the GSWK to the lower Alexandra Canal area.

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

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

This floodplain risk management study supports the general objectives of WSUD but it is not possible to address every aspect (e.g. water saving devices, grey water reuse, etc.) within the scope of the study. The following sections consider those aspects that can be included within the scope of the NSW Government's Floodplain Development Manual (Reference 1).

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

Whilst BASIX only applies to residential developments the water use principles can also be applied to other land use activities (commercial and industrial developments). This could also be further extended to existing Council or government structures and facilities, particularly in open space areas.

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

Treat Urban Stormwater
The following sections describe possible additional devices.

- **Gross Pollutant Traps:** Within the established residential areas of the West Kensington catchment there is little opportunity to install a GPT (Gross Pollutant Trap). However, Reference 4 identifies that these types of devices can be implemented as part of urban re-development of individual precincts. If possible it should be constructed as a wetland and so incorporate a nutrient absorption function. It would provide significant environmental benefit with no adverse hydraulic impacts and potentially some social benefits. There may be other potential sites of GPTs. These should be considered where appropriate.

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

- **Improved Water Absorption:** Council should consider, as far as possible, changes to its work procedures to ensure maximum water absorption. For example this may mean grading footpaths or similar so they shed runoff onto grassed areas or swales before entering the stormwater system. On existing public roads this is generally not possible but could be implemented within certain types of developments (units) or in new development precincts. The study has wide streets and in time these could be modified to incorporate WSUD.

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

5.4. Response Modification Measures

5.4.1. Flood Warning

DESCRIPTION

It may be necessary that some residents in the Green Square - West Kensington catchment will evacuate their homes or need to reach safety during a major flood event. The amount of time for evacuation depends on the available warning time. Flood warning and the implementation of evacuation procedures by the State Emergency Service (SES), are widely used throughout NSW to reduce flood damages and protect lives. The Bureau of Meteorology (BOM) is responsible for flood warnings on major river systems but does not have a system for smaller urban catchments such as Green Square - West Kensington.

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

- the maximum potential warning time before the onset of flooding,
- the actual warning time provided before the onset of flooding. This depends on the adequacy of the information gathering network and the skill and knowledge of the operators,
- the flood awareness of the community responding to a warning.

DISCUSSION

Although flood warning has the potential to reduce the social and economic impacts of a flood, it is not possible to develop an effective warning system for a small catchment such as Green Square - West Kensington. This is due to the relatively short response time from the start of the rain to the time of the flood peak (say less than 2 hours). This aspect is compounded as the actual flood event may occur at night while people are sleeping or in the day while people are at work and cannot get home in time to take action.

This may change in the future as the BOM develops more accurate radar based warning systems that can forecast where storms and the consequent flooding will occur. However due to the complex nature of dynamic weather patterns it is unlikely that a highly accurate system capable of providing sufficient warning will ever be possible. Hence even if an accurate flood warning system is developed the short time between rainfall and flooding provides little opportunity to take protective measures.

OUTCOMES

Due to the short response time of the Green Square - West Kensington catchment an effective flood warning system is not currently possible and is therefore not recommended for further consideration as part of this study.

ACTIONS

This measure has not been considered further at this stage.

5.4.2. Evacuation Planning

DESCRIPTION

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

DISCUSSION

The rate of rise of the floodwaters determines the amount of time the SES has to implement an evacuation plan. The small size of this catchment means the rate of rise is very fast (say less than 2 hours) which means that it would be unlikely the SES could effectively deploy until after the peak (assuming there is no immediate risk to life). Similarly, a flood in the Green Square - West Kensington area is likely to occur in conjunction with flooding at other nearby localities (as was the case with the November 1984 floods) which will stretch the resources of the SES. A Local Flood Plan however does address other aspects of flooding, including preparedness and recovery, and for these reasons is still worthwhile to be developed for the catchment.

OUTCOMES

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

ACTIONS

It is recommended that both Councils with the SES seek to develop a local Flood Plan.

5.4.3. Public Information and Raising Flood Awareness/Preparedness

DESCRIPTION

The success of any flood warning system and the evacuation process depends on:

- ***Flood Awareness:*** How aware is the community to the threat of flooding? Has it been adequately informed and educated?
- ***Flood Preparedness:*** How prepared is the community to react to the threat? Do they (or the SES) have damage minimisation strategies (such as sand bags, raising possessions) which can be implemented?

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

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

DISCUSSION

A community with high flood awareness/preparedness will suffer less damage and disruption during and after a flood because people are aware of the potential risks of the situation. During a period of frequent flooding in other more flood prone areas, the residents would probably have developed an unofficial warning network to effectively respond to imminent danger by raising goods, moving cars, lifting carpets, etc. Photographs and other non-replaceable items are generally put in safe places. Often residents have developed storage facilities, buildings, etc., which are flood compatible. The level of trauma or anxiety may be reduced as people have "survived" previous floods and know how to handle both the immediate emergency and the post flood rehabilitation phase in a calm and efficient manner.

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

- frequency and impact of previous floods,
- history of residence,
- whether an effective public awareness/preparedness program has been implemented.

It is difficult to accurately assess the benefits of an awareness/preparedness program but it is generally considered that the benefits far outweigh the costs. The perceived value of the information and the level of awareness diminishes as the time since the last flood increases. A major hurdle is often convincing residents large floods will occur in the future. Some residents may oppose an awareness/preparedness program because they consider it reduces the value of their property. However this should not hinder the continued effort to inform and receive feedback from the community.

Council has a dedicated resource for implementing community education programs. In the past there has been limited communication related to flooding with a greater emphasis on water quality. It is recommended that both Councils routinely undertake education programs related to flood issues. Notification on the Section 149 certificate can inform residents of the potential floodplain risk at their property.

OUTCOMES

The existing level of flood awareness/preparedness can be better gauged following public consultation. However, it is expected there is a low level of flood awareness and preparedness. This is probably due to the quick onset of flooding and that it could occur at night and the relatively new population in the Green Square area.

A suitable Council wide flood awareness/preparedness program should be implemented by Council using appropriate elements from
Table 10. The details of the program and necessary follow up should be properly documented to ensure that they do not lapse with time and to ensure the most cost effective means of communication.

Table 10: Flood Awareness/Preparedness Methods

Method	Comment
Letter/Pamphlet from Council	These may be sent (annually or biannually) with the rate notice or separately. A Council database of flood liable properties/addresses makes this a relatively inexpensive and effective measure. The pamphlet can inform residents of subsidies, changes to flood levels or any other relevant information.
School Project or Local Historical Society	This provides an excellent means of informing the younger generation about flooding. It may involve talks from various authorities and can be combined with topics relating to water quality, estuary management, etc.
Displays at Council Offices, Library, Schools, Shopping Centres, Local Fairs	This is an inexpensive way of informing the community and may be combined with related displays.
Historical Flood Markers or Depth Indicators on Roads	Signs or marks can be prominently displayed in parks, on telegraph poles or such like to indicate the level reached in previous floods. Depth indicators on roads advise drivers of potential hazards.
Articles in Local Newspapers	Ongoing articles in the newspapers will ensure that the problem is not forgotten. Historical features and remembrance of the anniversary of past events make good copy.
Collection of Data from Future Floods	Collection of data assists in reinforcing to the residents that Council is aware of the problem and ensures that the design flood levels are as accurate as possible.
Types of Information Available	A recurring problem is that new owners consider they were not adequately advised that their property was flood affected on the 149 Certificate during the purchase process. Council do advise interested parties, when they inquire during the property purchase process, regarding flood information currently available, how it can be obtained and the cost.
Establishment/upgrading of a Flood Affectation Database	A database would provide information on (say) which houses require evacuation, which roads will be affected (or damaged) and cannot be used for rescue vehicles, which public structures will be affected (e.g. sewage pumps to be switched off, telephone or power cuts). This database should be reviewed after each flood event. It could be developed by various authorities (SES, Police, Council).
Flood Preparedness Program	Providing information to the community regarding flooding helps to inform it of the problem and associated implications. However, it does not necessarily adequately prepare people to react effectively to the problem. A Flood Preparedness Program would ensure that the community is adequately prepared. The SES would take a lead role in this.
Foster Community Ownership of the Problem	Flood damages in future events can be minimised if the community is aware of the problem and takes steps to find solutions. For example, Council should have a maintenance program to ensure that its drainage systems are regularly maintained. Residents have a responsibility to advise Council if they see a maintenance problem such as a blocked drain or a flood gate that is jammed. This process can be linked to water quality or other water related issues.
Provide open access to Flood Studies, Floodplain Risk Management Studies and Plans	These studies provide information on the nature of flooding in the catchment, flooding issues and the basis for Councils actions. Open access to this information can be facilitated by making the study documents available on the Council web site. This option can include a specific web page dedicated to providing information on flooding issues and access to studies

ACTIONS

A Flood Awareness/preparedness should be implemented.

6. CLIMATE CHANGE ASSESSMENT

6.1. Overview

The 2005 Floodplain Development Manual (Reference 1) requires that Flood Studies and Floodplain Risk Management Studies consider the impacts of climate change on flood behaviour. Hence the sensitivity of the model results to various climate change scenarios was assessed as part of this study.

Within the last five years current best practice for considering the impacts of climate change (in terms of ocean level rise and rainfall increase) has been evolving rapidly. Key developments have included:

- the release of the Fourth Assessment Report by the Inter-governmental Panel on Climate Change (IPCC) in February 2007 (Climate Change 2007), which updated the Third IPCC Assessment Report of 2001;
- the preparation of Climate Change Adaptation Actions for Local Government by SMEC Australia for the Australian Greenhouse Office in mid 2007;
- the preparation of Climate Change in Australia by CSIRO in late 2007, which provides an Australian focus on Climate Change 2007;
- the release of the Floodplain Risk Management Guideline Practical Consideration of Climate Change by the NSW Department of Environment and Climate Change in October 2007 (referred to herein as the DECC Guideline 2007 – Reference 15).

In accordance with the DECC Guideline 2007, the following climate change scenarios (by the year 2100) are considered:

Increase in peak rainfall and storm volume:

- low level rainfall increase = 10%,
- medium level rainfall increase = 20%,
- high level rainfall increase = 30%.

From Reference 15, the maximum projected sea level rise climate change scenario for 2100 is 0.9m above a (say) peak 1% AEP (1 in 100 year) level of 2.5 mAHD in Alexandra Canal. The peak indicative level of 3.4 mAHD is far below the lowest elevation point of the study area and hence beyond the influence of ocean tailwater effects. Therefore, the effect of sea level rise was not considered.

To assess the effects of an increase in peak rainfall and storm volume each ordinate design rainfall hyetograph was increased by the nominated DECC 2007 value. External catchment inflows were similarly increased by the nominated DECC 2007 value.

A high degree of uncertainty surrounds the likely impact of climate change upon rainfall. Hence, a range of increased rainfalls have been assessed for this study. It is understood that work currently being undertaken by CSIRO and the Sydney Catchment Authority should provide better direction on the possible impacts to rainfall.

6.2. Results and Discussions

The models were run for the 1% AEP 60 minute duration design storm for the rainfall scenarios described in Section 6.1.

A relative comparison of the changes in peak flows and flood heights for different climate changes scenarios is shown in Table 11 and Table 12. Changes in peak flood level across the study area for each scenario are shown in Figures 16 to 18. Corresponding impacts in terms of the number of properties inundated are also provided for each of the major trapped low points in West Kensington and for properties within the CoS LGA (refer to Table 13 and Table 14).

Table 11: Climate Change – Peak Flow Comparison 1% AEP (1 in 100 year) Event

Location	Existing Flow (m^3/s)	Climate Change Scenario					
		+10% Rainfall Increase in Flow		+20% Rainfall Increase in Flow		+30% Rainfall Increase in Flow	
		(m^3/s)	%	(m^3/s)	%	(m^3/s)	%
Portman Street Outflows	23.5	4.4	19%	8.9	38%	13.7	59%
Epsom Road Outflows	5.5	0.6	10%	1.1	20%	1.7	31%
Joynton Avenue (South)	3.2	0.2	7%	0.4	13%	0.5	16%
Joynton Avenue (East)	8.8	0.6	7%	1.2	14%	1.9	22%
Joynton Avenue (North)	18.2	2.5	14%	5.2	29%	8.3	46%
Lachlan Street Low Point	5.9	0.9	15%	1.8	31%	2.9	49%
O'Dea Avenue (from South Dowling Street)*	7.6	1.4	18%	3.4	45%	5.1	67%
Todman Avenue (Sobek Inflow)	0.6	0.1	17%	0.2	30%	0.3	45%
Lenthall Street (u/s of low point)	1.1	0.2	18%	0.3	27%	0.5	45%
Flow from The Australian golf course	6.8	0.7	10%	1.3	19%	1.9	28%
Sydney Water Stormwater Channel near Link Road	14.3	0.7	5%	1.2	8%	1.6	11%
Victoria Park Central Outflows	3.7	0.6	17%	1.5	39%	2.3	62%
Todman Ave & Balfour Road	2.4	0.1	4%	0.2	8%	0.4	17%
Todman Ave & Baker Street	3.2	0.2	6%	0.4	13%	0.6	19%

* NOTE: Assumes drainage works in place between Ameila Street Extension, O'Dea Avenue and South Dowling Street (including trunk drainage upgrade, detention basin and overfland flowpaths).

Table 12: Climate Change – Increase in Peak Flood Level 1% AEP (1 in 100 year) Event (m)

LOCATION	Climate Change Scenario		
	+10% Rainfall	**+20% Rainfall**	**+30% Rainfall**
Joynton Avenue Low Point	0.06	0.11	0.16
Botany Road Low Point	0.08	0.16	0.23
Lenthall Street Low Point	0.03	0.05	0.07
Victoria Park Central Basin	0.09	0.16	0.21
Lachlan Avenue Low Point	0.04	0.08	0.12
South Dowling Street Low Point (opp. SupaCentre)*	0.05	0.10	0.14
Cnr O'Dea Avenue and Joynton Avenue	0.02	0.04	0.05
Winkurra Street (West Kensington)	0.07	0.14	0.20
Epsom Road (adjacent to CoS Works Depot)	0.04	0.09	0.13
Balfour Road Trapped Low Point	0.14	0.34	0.38
McDougall Street Trapped Low Point	0.04	0.07	0.09
Milroy Avenue Trapped Low Point	0.03	0.05	0.08
Virginia Street Trapped Low Point	0.02	0.03	0.05

Notes: Change in flood level calculated relative to existing conditions.
Assumes overland flow path to Amelia Street in place.

Overall the outcomes show that peak flood levels throughout much of the catchment are relatively insensitive to increases in rainfall, particularly within the major overland flowpaths that form within the road network. For example, increases in flood levels along Epsom Road, O'Dea Avenue and South Dowling Street (opposite the SupaCentre) are within 0.15 m for the 30% rainfall scenario. This outcome reflects the relatively high conveyance capacity available within these portions of the road network.

In contrast, peak flood levels within the major trapped low points were found to be more sensitive to changes in rainfall. Examples of this include the low points in Botany Road, Balfour Road and Milroy Avenue (refer to Table 12). The effect of increased rainfall on the peak flood level in these locations reflects limitations in the available storage and/or capacity of the overland flowpaths draining these low points. The change in peak flood level within the Joynton Avenue trapped low point was found to be +0.16 m for the 30% rainfall scenario, due in part to the relatively large amount of flood storage available in this area.

The effects of different rainfall scenarios in terms of property inundation are shown in Table 13 to 15.

Table 13: Climate Change – Damages for Major Trapped Low Points in West Kensington

Climate Change Scenario	Trapped Low Point			
	Virginia Street	**Milroy Ave**	**McDougall Street**	**Balfour Rd**
	1% AEP Damages	**1% AEP Damages**	**1% AEP Damages**	**1% AEP Damages**
Existing Conditions	$10 K	$118 K	$153 K	$1,031 K
+10% Rainfall	$10 K (0%)	$118 K (0%)	$153 K (0%)	$1,549 K (50%)
+20% Rainfall	$23 K (137%)	$118 K (0%)	$153 K (0%)	$2,225 K (116%)
+30% Rainfall	$23 K (137%)	$118 K (0%)	$153 K (0%)	$2,225 K (116%)

Notes : Estimates based on tangible damages.
: % increase relative to existing conditions

Table 14: Climate Change – Inundation for Major Trapped Low Points in West Kensington

Climate Change Scenario	Trapped Low Point							
	Virginia Street		**Milroy Ave**		**McDougall Street**		**Balfour Rd**	
	Ground[1]	**Floor**[2]	**Ground**[1]	**Floor**[2]	**Ground**[1]	**Floor**[2]	**Ground**[1]	**Floor**[2]
Existing Conditions	4	0	14	4	22	6	42	26
+10% Rainfall	4 (+0)	0 (0)	14 (+0)	4 (+0)	22 (+0)	6 (+0)	54 (+12)	38 (+12)
+20% Rainfall	5 (+1)	2 (+2)	14 (+0)	4 (+0)	22 (+0)	6 (+0)	63 (+21)	52 (+26)
+30% Rainfall	5(+1)	2 (+2)	14 (+0)	4 (+0)	22 (+0)	6 (+0)	63 (+21)	52 (+26)

Notes: 1 – Number of properties flooded above ground level
2 – Number of properties flooded above floor level

Table 15: Climate Change – Inundation in Green Square Area (CoS LGA)

Climate Change Scenario	Commercial Properties		Residential Properties	
	Flooded Above Floor Level	**1% AEP Damage**	**Flooded Above Floor Level**	**Damage**
Existing Conditions	56	$1.93 M	17	$0.71 M
+10% Rainfall	57 (+1)	$2.06 M (7%)	21 (+4)	$0.78 M (11%)
+20% Rainfall	60 (+4)	$2.31 M (20%)	25 (+8)	$0.86 M (21%)
+30% Rainfall	63 (+7)	$2.63 M (37%)	26 (+9)	$0.92 M (30%)

Notes : Estimates based on tangible damages.
: % increase relative to existing conditions

From Table 13 and Table 15 it is worth noting that the relative increase in 1% AEP (1 in 100 year) damages across different change scenarios is typically higher for some of the trapped low points in West Kensington compared to properties in other locations, even though similar numbers of properties are inundated. This is due to the sensitivity of peak flood levels to changes in rainfall.

7. ACKNOWLEDGEMENTS

This study was carried out by WMAwater and funded by Randwick City Council, the City of Sydney and the Department of Environment, Climate Change and Water (now Office of Environment and Heritage). The assistance of the following in providing data and guidance to the study is gratefully acknowledged:

- Randwick City Council and the City of Sydney,
- Department of Environment, Climate Change and Water, (now Office of Environment and Heritage),
- Green Square - West Kensington Floodplain Management Committee,
- Residents of Green Square - West Kensington catchment.

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Figures

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List of Figures


FIGURE 1
LOCALITY MAP
Study Area
Midblock Precinct
ACI site
Lachlan St
Amelia St
Dacey Ave
Moore Park Supacentre
Moore Park Golf Course
O'Dea Ave
VICTORIA PARK
Tote Park
Joynton Park
Cooper Pl
Todman Ave
Raleigh Park
Gadigal Ave
Nuffield Park
South Dowling St
Winkurra St
Baker St
Balfour Rd
Kensington Rd
Duke St
Mirroy Ave
McDougall St
Myrtle St
Virginia St
Ingram St
Lenthall St
Link Rd
Epsom Rd
The Australian Golf Course
City of Sydney Epsom Road Depot
Royal South Sydney Community Health Complex
Portman St
Joynton Ave
Tilford St
Waverley Council Works Depot
NSW Police
Green Square Railway Station
Bourke St
George St
Elizabeth St
Powell St
Hunter St
Wyndham St
Mandible St
Botany Rd
Bowden St
O'Riordan St
0 125 250 m
N
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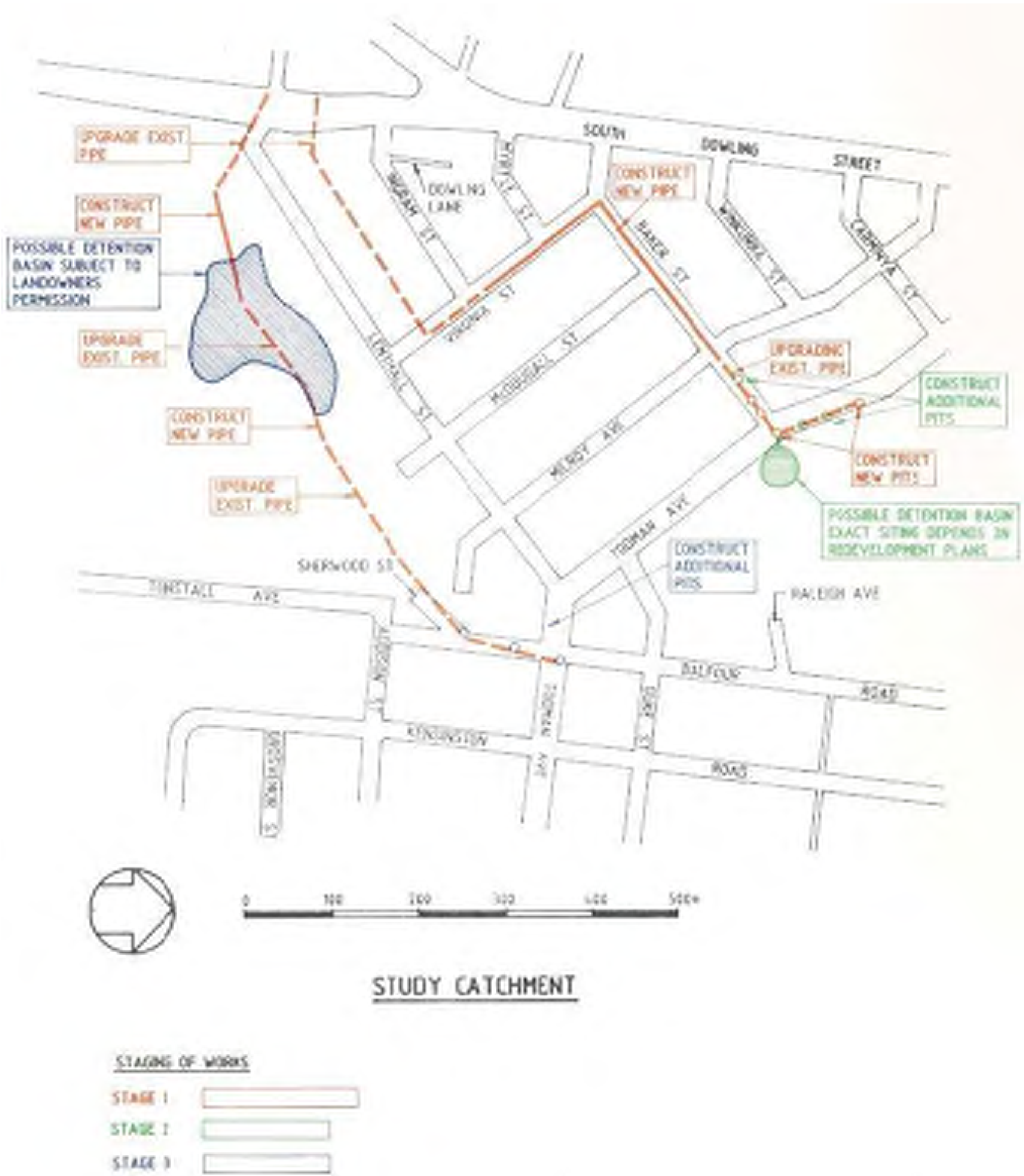
FIGURE 2
1985 WEST KENSINGTON DRAINAGE STUDY
PREFERRED MANAGEMENT OPTIONS



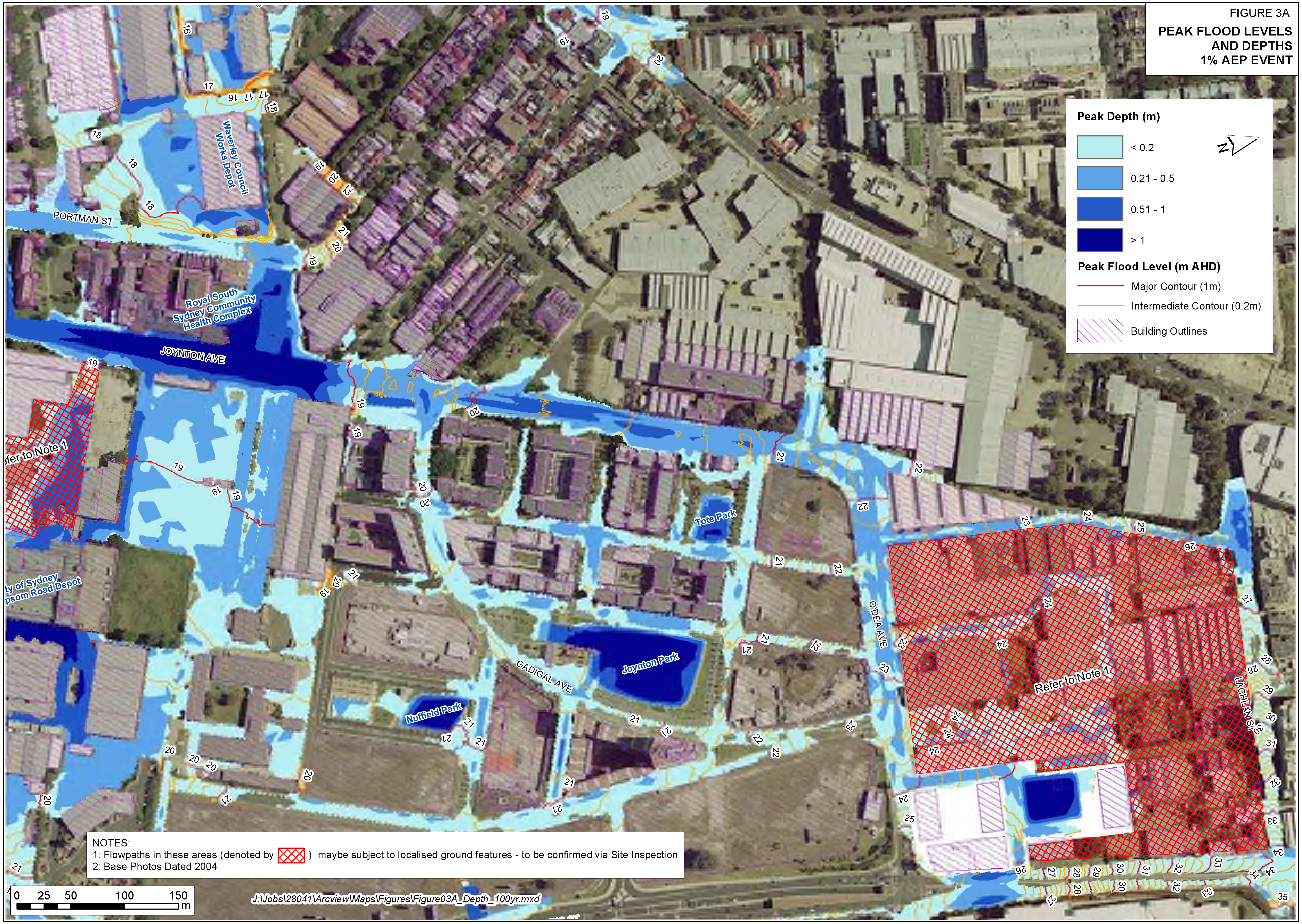


FIGURE 3A
PEAK FLOOD LEVELS
AND DEPTHS
1% AEP EVENT
Peak Depth (m)
< 0.2
0.21 - 0.5
0.51 - 1
> 1
Peak Flood Level (m AHD)
Major Contour (1m)
Intermediate Contour (0.2m)
Building Outlines
N
Waverley Council Works Depot
PORTMAN ST
Royal South Sydney Community Health Complex
JOYNTON AVE
Refer to Note 1
City of Sydney Epsom Road Depot
Tote Park
Joynton Park
Nuffield Park
GADIGAL AVE
ODEA AVE
LACHLAN ST
Refer to Note 1
NOTES:
1: Flowpaths in these areas (denoted by) maybe subject to localised ground features - to be confirmed via Site Inspection
2: Base Photos Dated 2004
0 25 50 100 150 m
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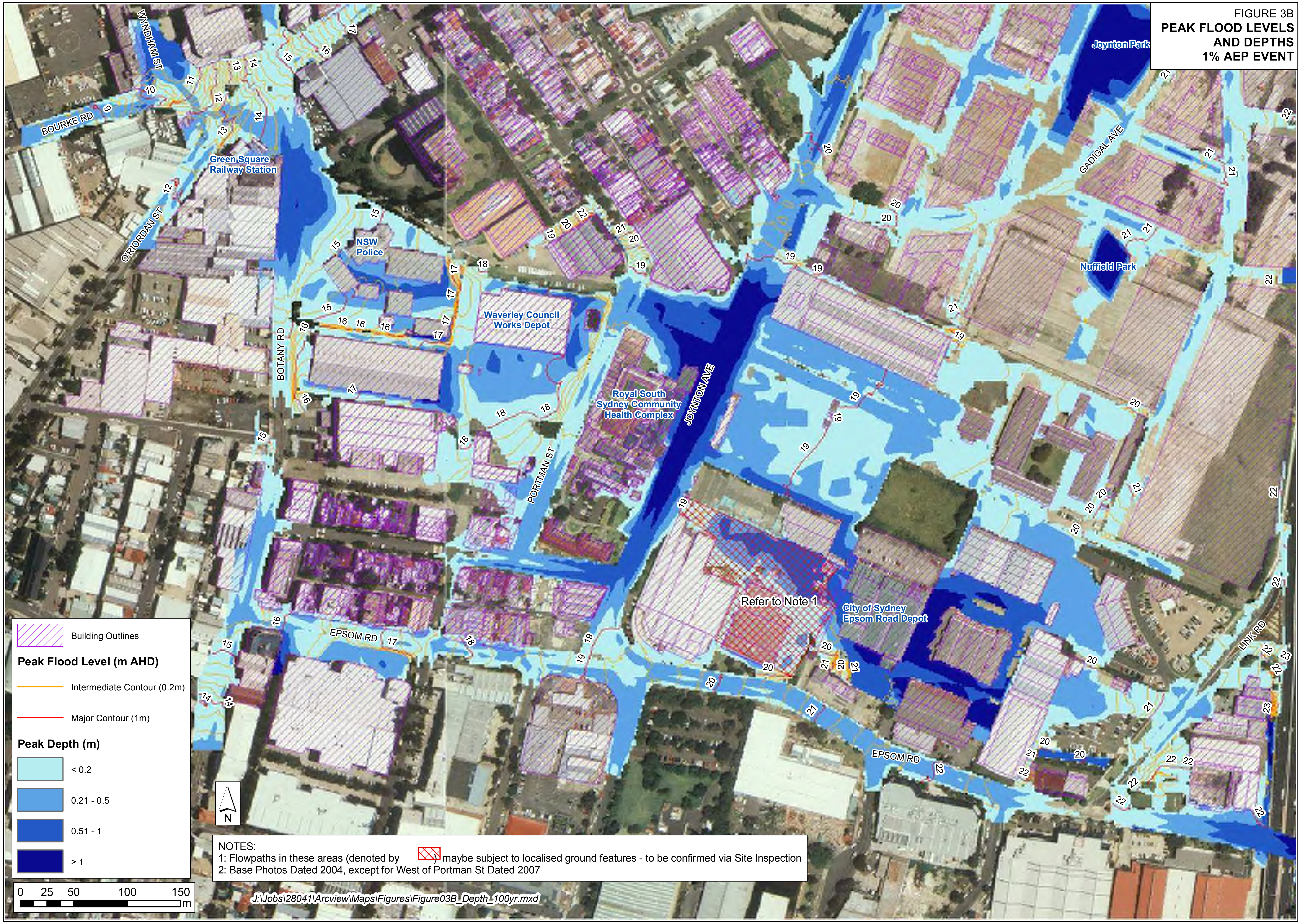
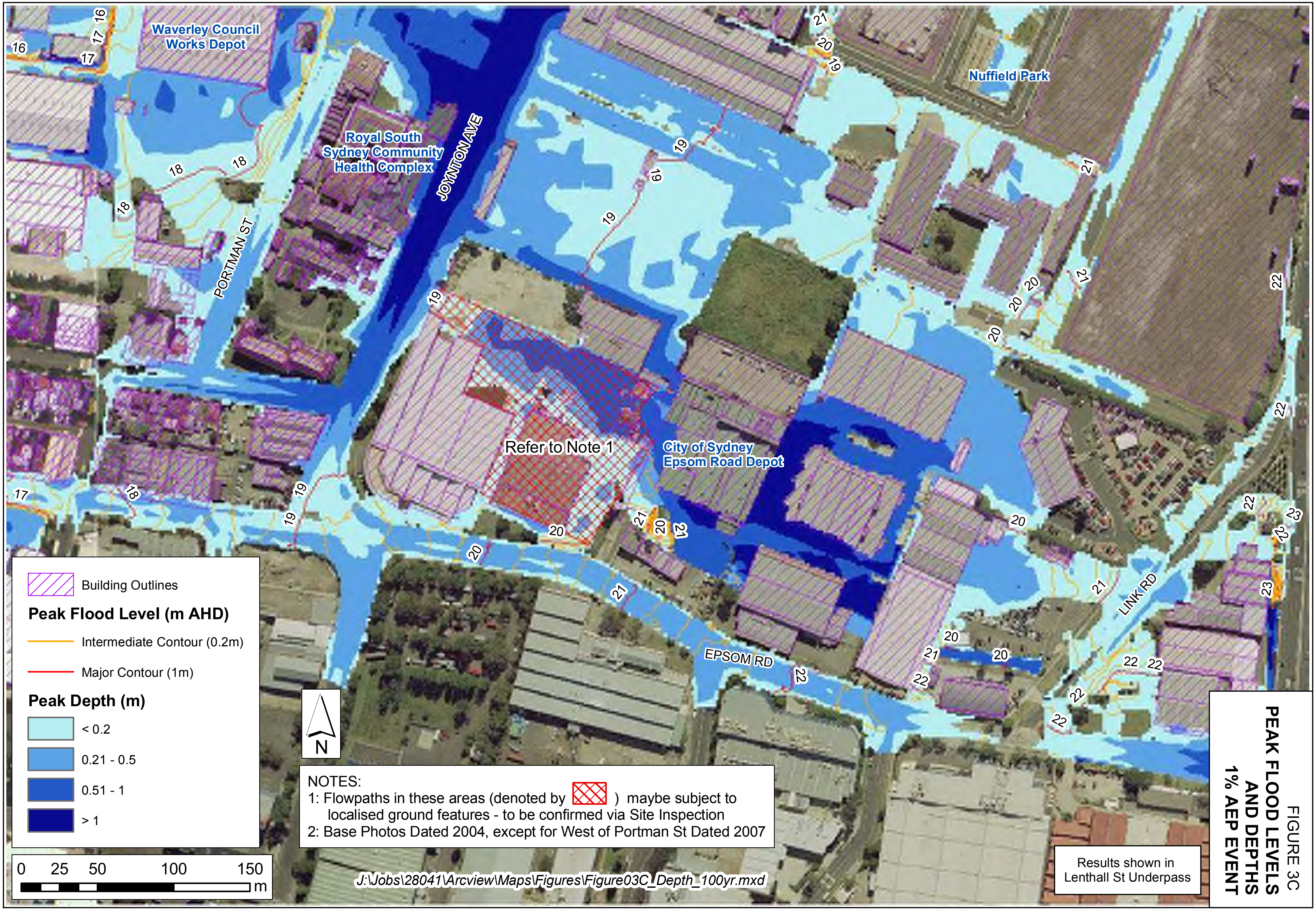


FIGURE 3B
PEAK FLOOD LEVELS AND DEPTHS 1% AEP EVENT
Building Outlines
Peak Flood Level (m AHD)
Intermediate Contour (0.2m)
Major Contour (1m)
Peak Depth (m)
< 0.2
0.21 - 0.5
0.51 - 1
> 1
0 25 50 100 150 m
N
NOTES:
1: Flowpaths in these areas (denoted by) maybe subject to localised ground features - to be confirmed via Site Inspection
2: Base Photos Dated 2004, except for West of Portman St Dated 2007
J:\Jobs\28041\Arcview\Maps\Figures\Figure03B_Depth_100yr.mxd
WYNDHAM ST
BOURKE RD
Green Square Railway Station
O'RIORDAN ST
NSW Police
BOTANY RD
Waverley Council Works Depot
Royal South Sydney Community Health Complex
JOYNTON AVE
PORTMAN ST
Joynton Park
GADIGAL AVE
Nuffield Park
Refer to Note 1
City of Sydney Epsom Road Depot
EPSOM RD
LINK RD



NOTES:
1: Flowpaths in these areas (denoted by) maybe subject to localised ground features - to be confirmed via Site Inspection
2: Base Photos Dated 2004, except for West of Portman St Dated 2007

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FIGURE 3C
PEAK FLOOD LEVELS AND DEPTHS
1% AEP EVENT

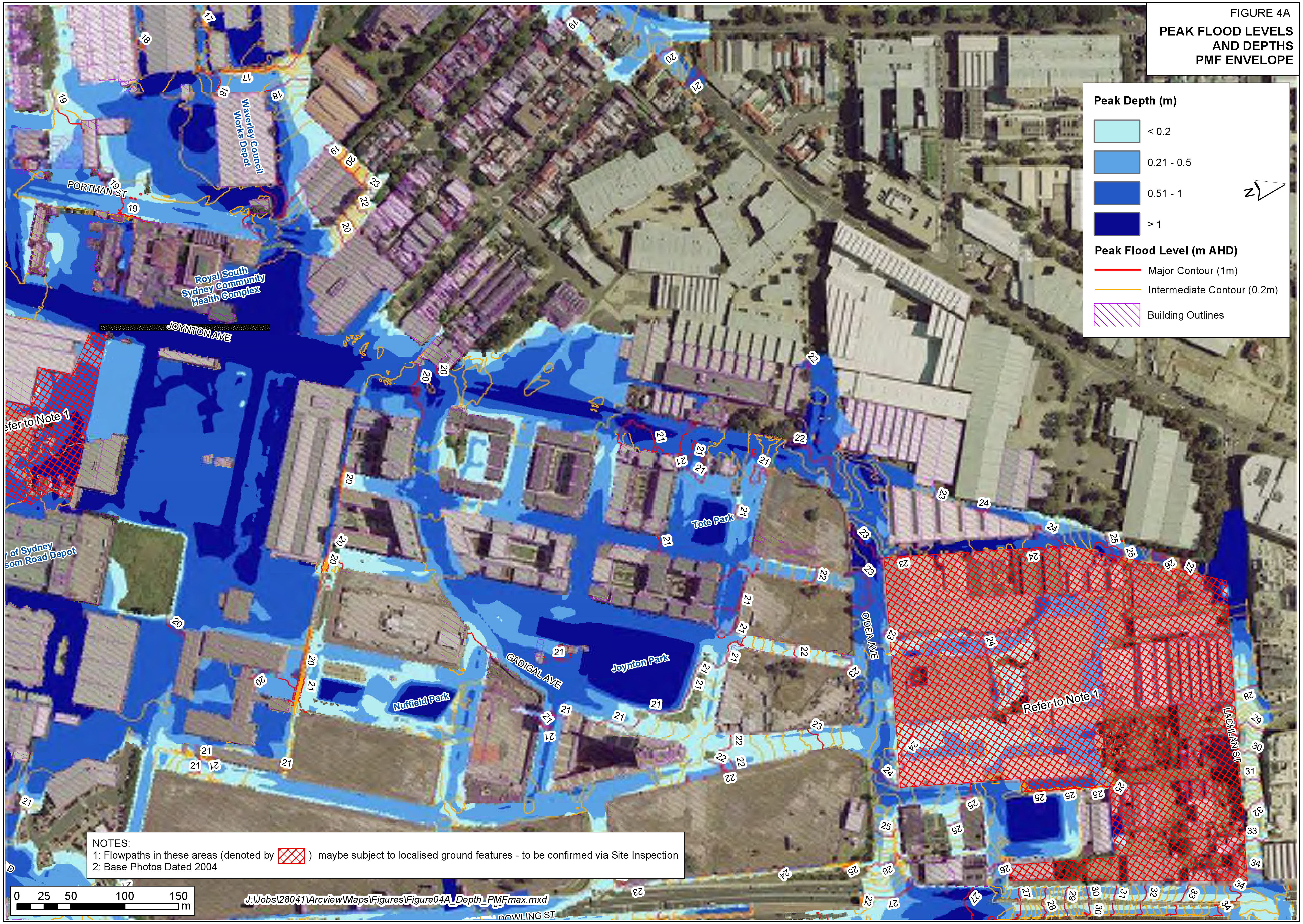
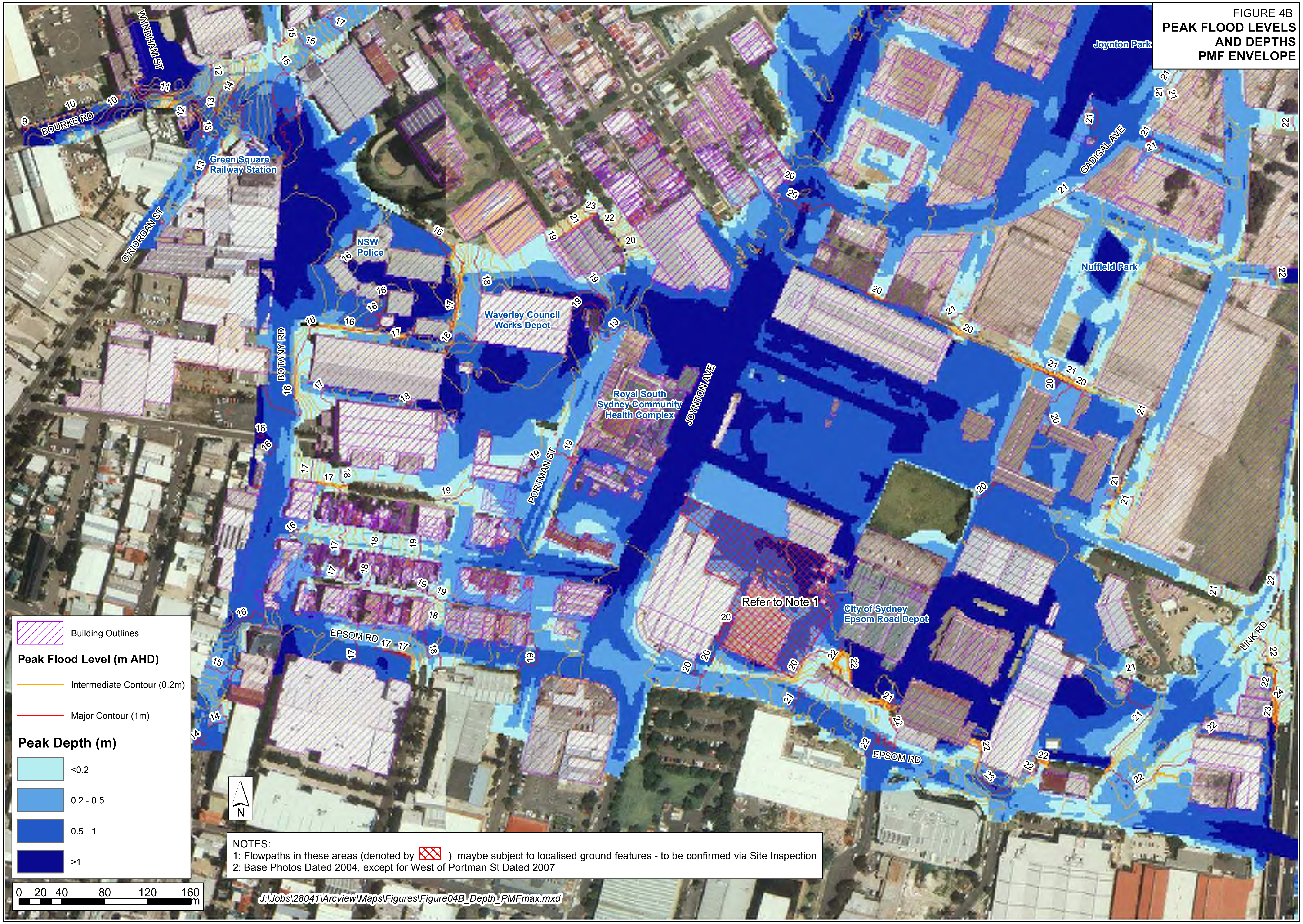
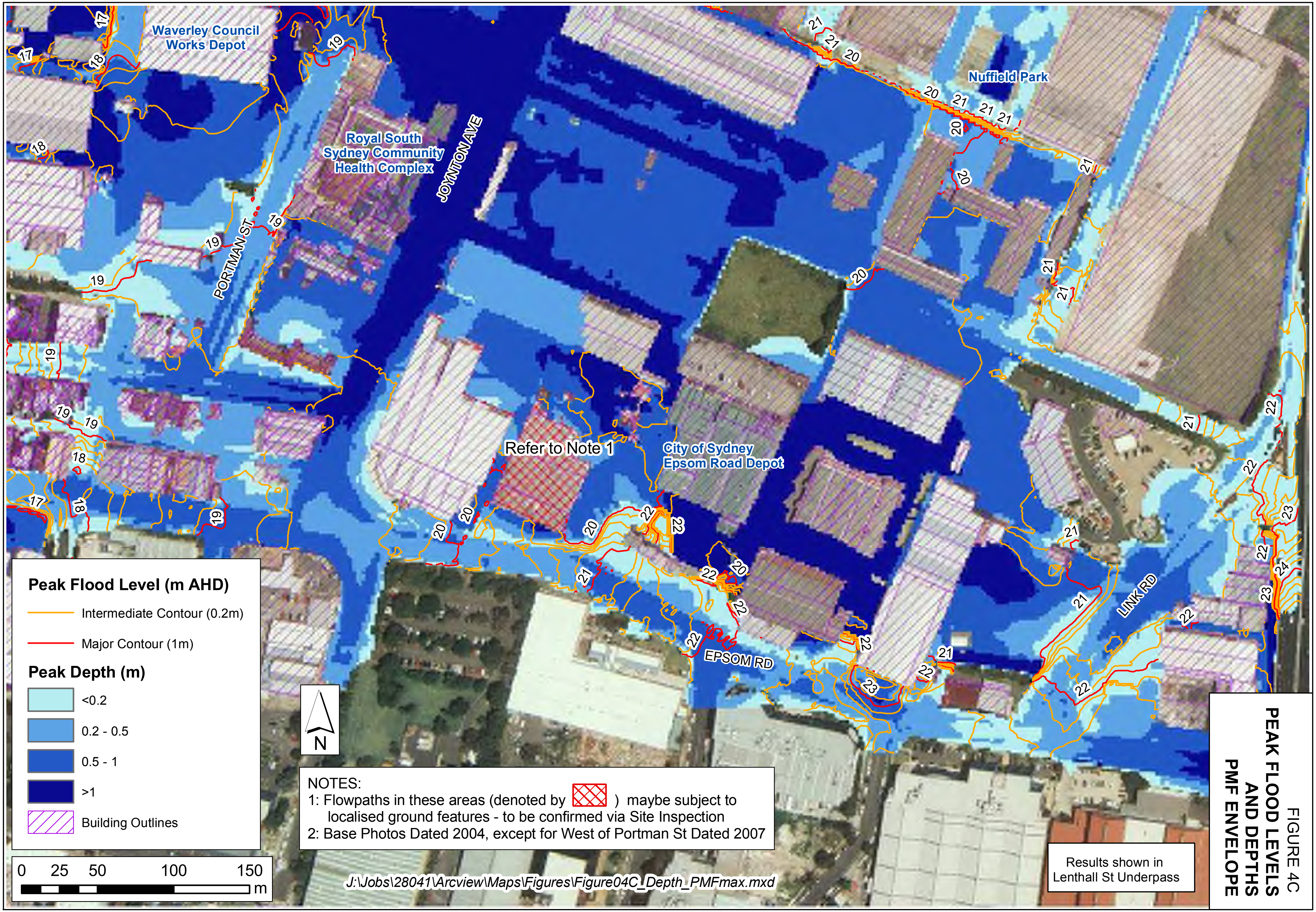


FIGURE 4A
PEAK FLOOD LEVELS AND DEPTHS PMF ENVELOPE
Peak Depth (m)
< 0.2
0.21 - 0.5
0.51 - 1
> 1
Peak Flood Level (m AHD)
Major Contour (1m)
Intermediate Contour (0.2m)
Building Outlines
N
Waverley Council Works Depot
PORTMAN ST
Royal South Sydney Community Health Complex
JOYNTON AVE
Refer to Note 1
Tote Park
Joynton Park
Nuffield Park
CADIGAL AVE
ODEA AVE
LACHLAN ST
DOWLING ST
NOTES:
1: Flowpaths in these areas (denoted by) maybe subject to localised ground features - to be confirmed via Site Inspection
2: Base Photos Dated 2004
0 25 50 100 150 m
J:\Jobs\28041\Arcview\Maps\Figures\Figure04A_Depth_PMFmax.mxd

FIGURE 4B
PEAK FLOOD LEVELS AND DEPTHS PMF ENVELOPE



NOTES:
1: Flowpaths in these areas (denoted by [red cross-hatch symbol]) maybe subject to localised ground features - to be confirmed via Site Inspection
2: Base Photos Dated 2004, except for West of Portman St Dated 2007

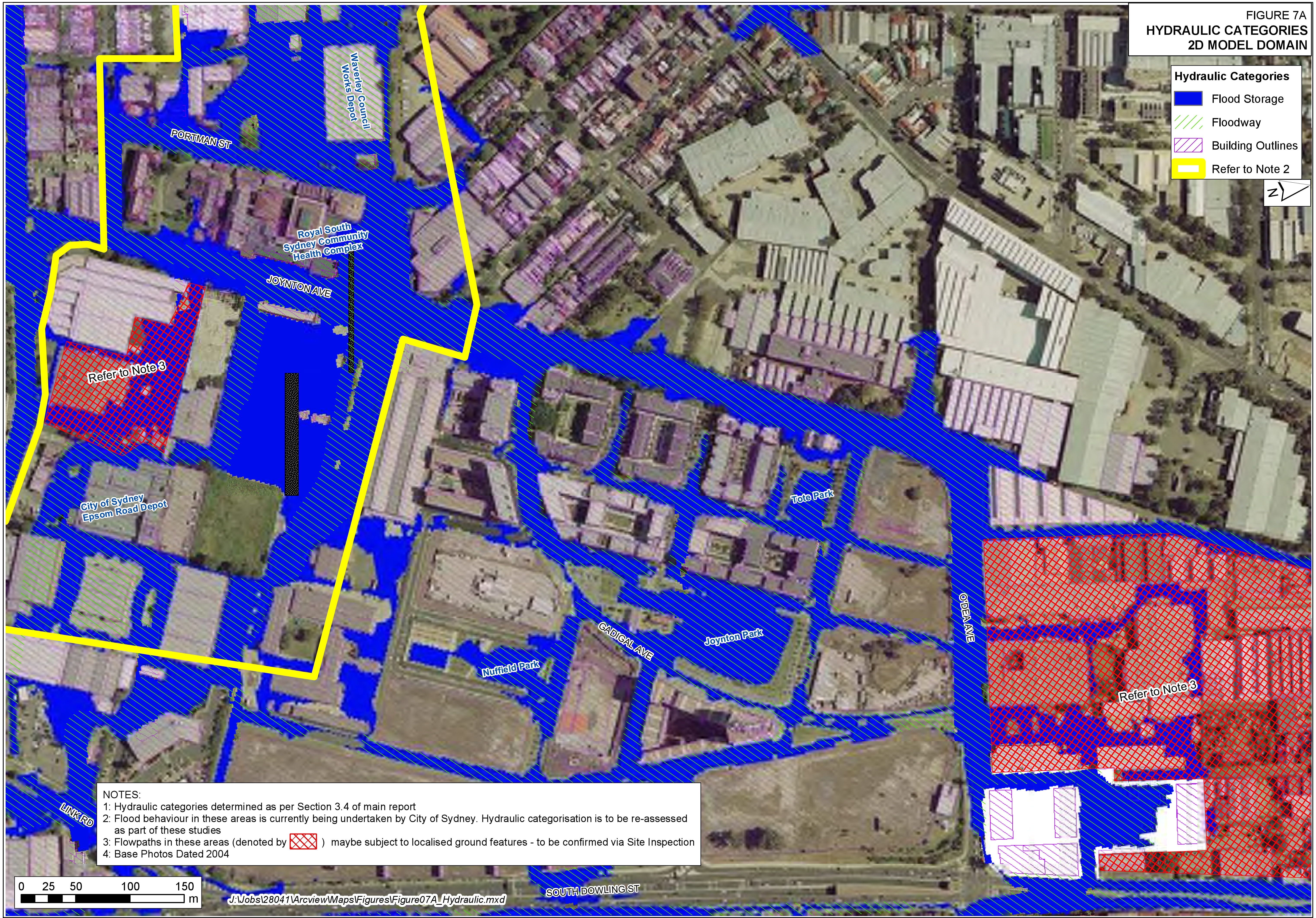


Waverley Council Works Depot
Royal South Sydney Community Health Complex
JOYNTON AVE
PORTMAN ST
Nuffield Park
Refer to Note 1
City of Sydney Epsom Road Depot
EPSOM RD
LINK RD
Peak Flood Level (m AHD)
Intermediate Contour (0.2m)
Major Contour (1m)
Peak Depth (m)
<0.2
0.2 - 0.5
0.5 - 1
>1
Building Outlines
0 25 50 100 150 m
N
NOTES:
1: Flowpaths in these areas (denoted by) maybe subject to localised ground features - to be confirmed via Site Inspection
2: Base Photos Dated 2004, except for West of Portman St Dated 2007
J:\Jobs\28041\Arcview\Maps\Figures\Figure04C_Depth_PMFmax.mxd
Results shown in Lenthall St Underpass
FIGURE 4C
PEAK FLOOD LEVELS AND DEPTHS
PMF ENVELOPE

FIGURE 5
PEAK FLOOD LEVELS AND DEPTHS
WEST KENSINGTON
1% AEP EVENT
100Y: 26.9mAHD
100Y + 0.5m: 27.4mAHD
Raleigh Park
Todman Ave
Cooper Pl
Winkurra St
100Y: 22.6mAHD
100Y + 0.5m: 23.1mAHD
Balfour Rd
Baker St
100Y: 25.1mAHD
100Y + 0.5m: 25.6mAHD
Duke St
South Dowling St
100Y: 24.6mAHD
100Y + 0.5m: 25.1mAHD
Milroy Ave
Myrtle St
Virginia St
McDougall St
100Y: 25.5mAHD
100Y + 0.5m: 26mAHD
100Y: 24.1mAHD
100Y + 0.5m: 24.6mAHD
Ingram St
100Y: 22.2mAHD
100Y + 0.5m: 22.7mAHD
Lenthal St
N
100Y: 22.1mAHD
100Y + 0.5m: 22.6mAHD
Ponding Location
Peak Depth (m)
< 0.2
0.2 - 0.5
0.5 - 1
> 1
Mapping Extent
The Australian
Golf Course
100Y: 23.6mAHD
100Y + 0.5m: 24.1mAHD
NOTE:
Base Photos dated 2004
0 50 100 200
m
J:\Jobs\28041-01\Arcview\Maps\Figures\Figure05New_WKFloodLevelsDepths_100y.mxd


FIGURE 6
PEAK FLOOD LEVELS AND DEPTHS
WEST KENSINGTON
PMF EVENT
PMF Level: 28.3mAHD
Raleigh Park
Todman Ave
Cooper Pl
Winkurra St
PMF Level: 23.8mAHD
Baker St
Balfour Rd
PMF Level: 25.5mAHD
Duke St
South Dowling St
PMF Level: 25mAHD
Milroy Ave
Myrtle St
Virginia St
McDougall St
PMF Level: 26.5mAHD
Ingram St
PMF Level: 24.4mAHD
PMF Level: 23mAHD
Lenthal St
PMF Level: 22.4mAHD
The Australian Golf Course
PMF Level: 24.6mAHD
NOTE:
Base Photos dated 2004
0 50 100 200 m
N
Peak Depth (m)
< 0.2
0.2 - 0.5
0.5 - 1
> 1
Ponding Location
Mapping Extent
J:\Jobs\28041-01\Arcview\Maps\Figures\Figure06New_WKFloodLevelsDepths_PMF.mxd

FIGURE 7A
HYDRAULIC CATEGORIES
2D MODEL DOMAIN



NOTES:
1: Hydraulic categories determined as per Section 3.4 of main report
2: Flood behaviour in these areas is currently being undertaken by City of Sydney. Hydraulic categorisation is to be re-assessed as part of these studies
3: Flowpaths in these areas (denoted by [red cross-hatch symbol]) maybe subject to localised ground features - to be confirmed via Site Inspection
4: Base Photos Dated 2004

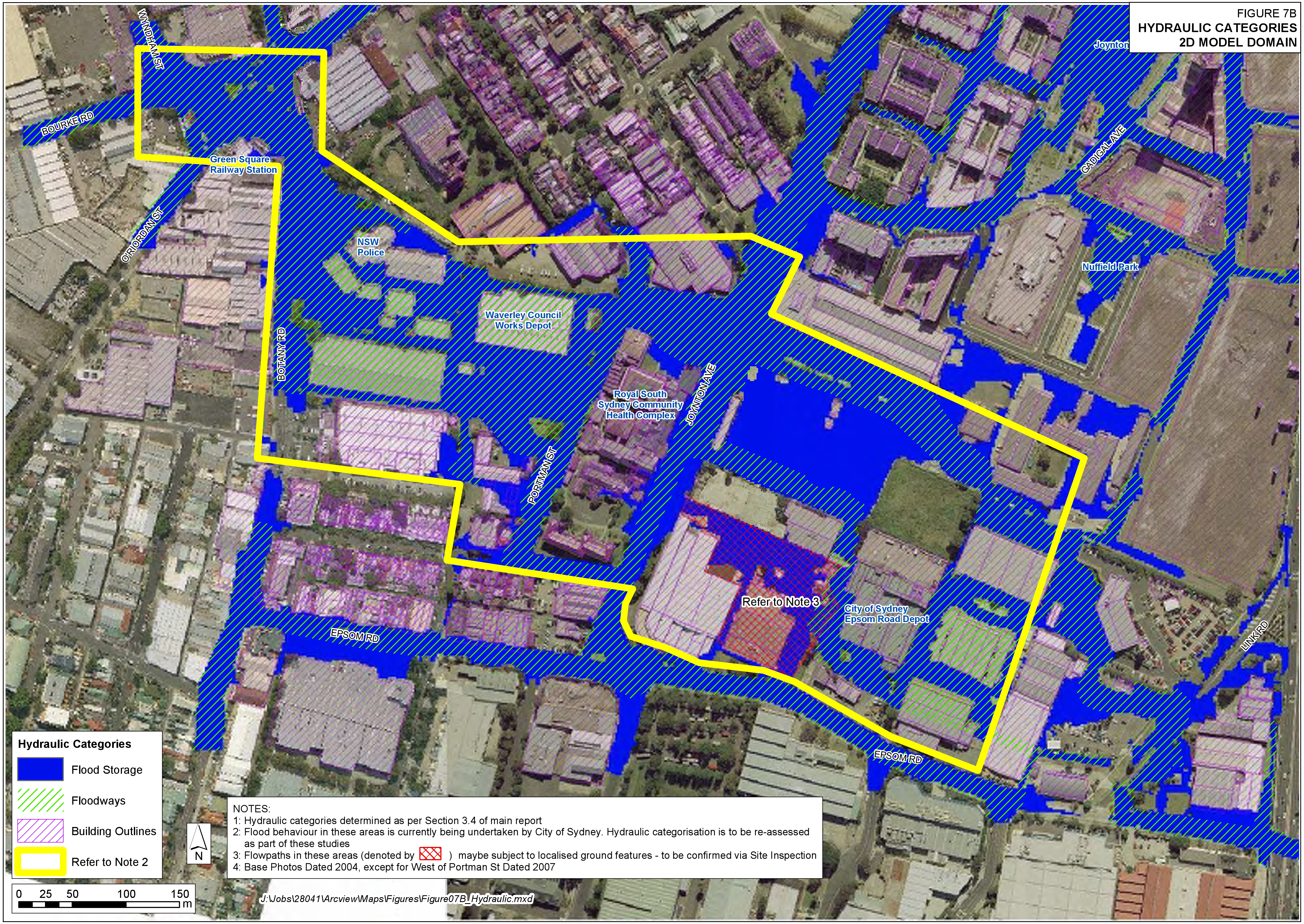


FIGURE 7B
HYDRAULIC CATEGORIES
2D MODEL DOMAIN
WYNDHAM ST
BOURKE RD
Green Square Railway Station
O'RIORDAN ST
NSW Police
Waverley Council Works Depot
BOTANY RD
Royal South Sydney Community Health Complex
JOYNTON AVE
PORTMAN ST
Joynton
GADIGAL AVE
Nuffield Park
Refer to Note 3
City of Sydney Epsom Road Depot
EPSOM RD
EPSOM RD
LINK RD
Hydraulic Categories
Flood Storage
Floodways
Building Outlines
Refer to Note 2
N
0 25 50 100 150 m
NOTES:
1: Hydraulic categories determined as per Section 3.4 of main report
2: Flood behaviour in these areas is currently being undertaken by City of Sydney. Hydraulic categorisation is to be re-assessed as part of these studies
3: Flowpaths in these areas (denoted by) maybe subject to localised ground features - to be confirmed via Site Inspection
4: Base Photos Dated 2004, except for West of Portman St Dated 2007
J:\Jobs\28041\Arcview\Maps\Figures\Figure07B_Hydraulic.mxd

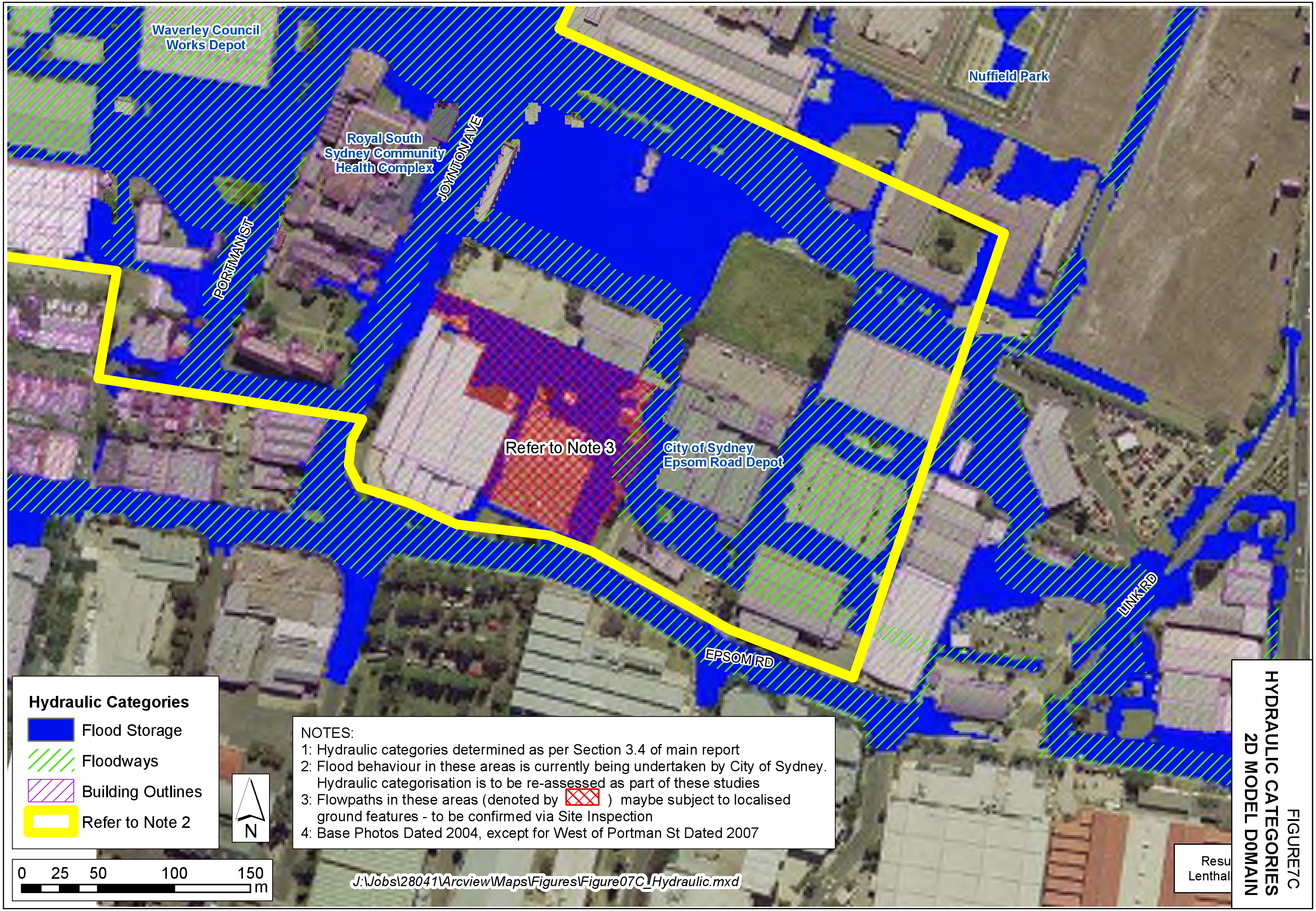
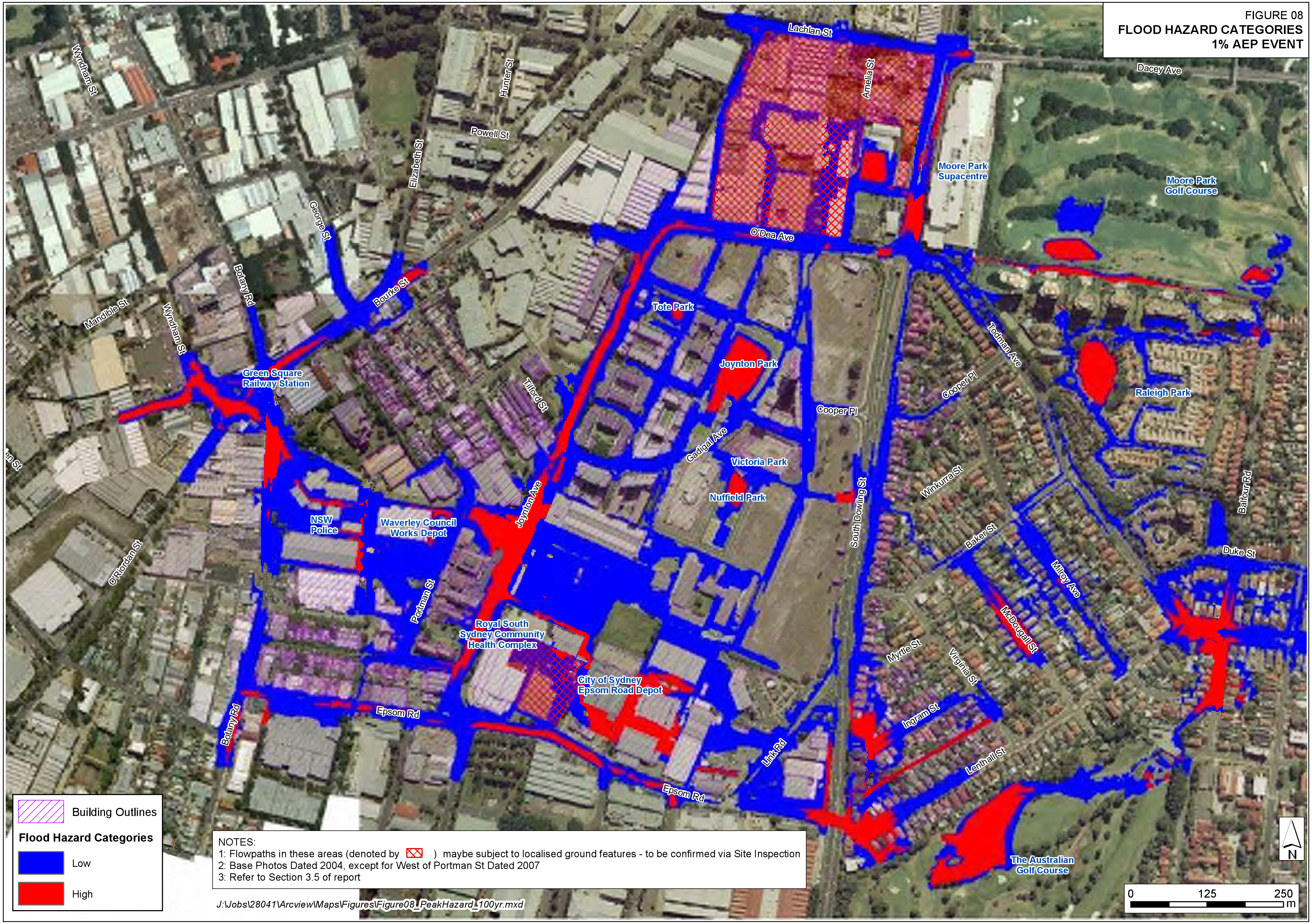

Waverley Council Works Depot
Nuffield Park
Royal South Sydney Community Health Complex
JOYNTON AVE
PORTMAN ST
Refer to Note 3
City of Sydney Epsom Road Depot
LINK RD
EPSOM RD
Hydraulic Categories
Flood Storage
Floodways
Building Outlines
Refer to Note 2
N
0 25 50 100 150 m
NOTES:
1: Hydraulic categories determined as per Section 3.4 of main report
2: Flood behaviour in these areas is currently being undertaken by City of Sydney. Hydraulic categorisation is to be re-assessed as part of these studies
3: Flowpaths in these areas (denoted by) maybe subject to localised ground features - to be confirmed via Site Inspection
4: Base Photos Dated 2004, except for West of Portman St Dated 2007
J:\Jobs\28041\Arcview\Maps\Figures\Figure07C_Hydraulic.mxd
FIGURE7C
HYDRAULIC CATEGORIES
2D MODEL DOMAIN

FIGURE 7D
HYDRAULIC CATEGORIES
1% AEP EVENT

J:\Jobs\28041-01\Arcview\Maps\Figures\Figure07D_Hydraulic.mxd

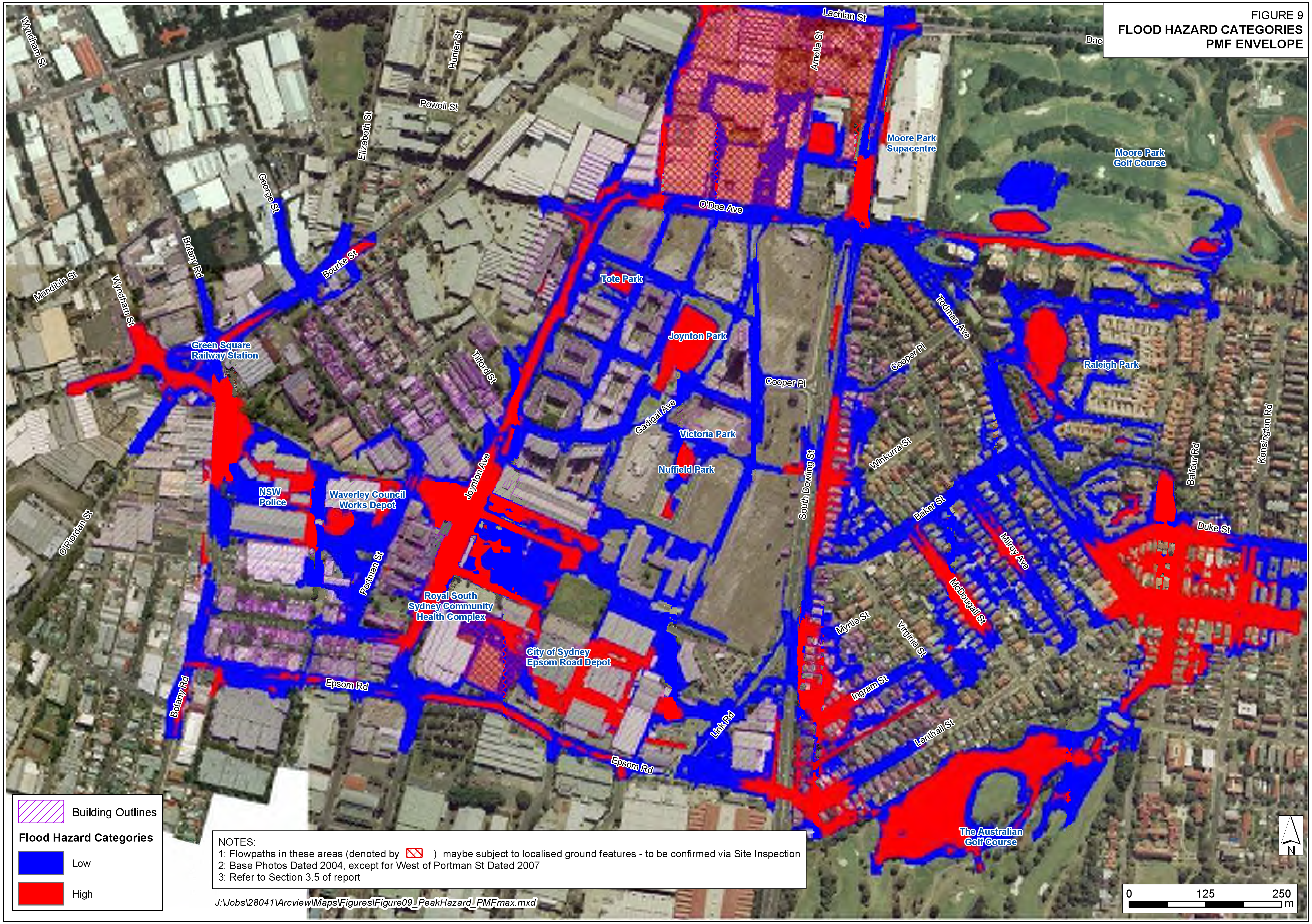
FIGURE 08
FLOOD HAZARD CATEGORIES
1% AEP EVENT



NOTES:
1: Flowpaths in these areas (denoted by [hatched symbol]) maybe subject to localised ground features - to be confirmed via Site Inspection
2: Base Photos Dated 2004, except for West of Portman St Dated 2007
3: Refer to Section 3.5 of report

J:\Jobs\28041\Arcview\Maps\Figures\Figure08_PeakHazard_100yr.mxd

FIGURE 9
FLOOD HAZARD CATEGORIES
PMF ENVELOPE



NOTES:
1: Flowpaths in these areas (denoted by [hatched symbol]) maybe subject to localised ground features - to be confirmed via Site Inspection
2: Base Photos Dated 2004, except for West of Portman St Dated 2007
3: Refer to Section 3.5 of report

J:\Jobs\28041\Arcview\Maps\Figures\Figure09_PeakHazard_PMFmax.mxd

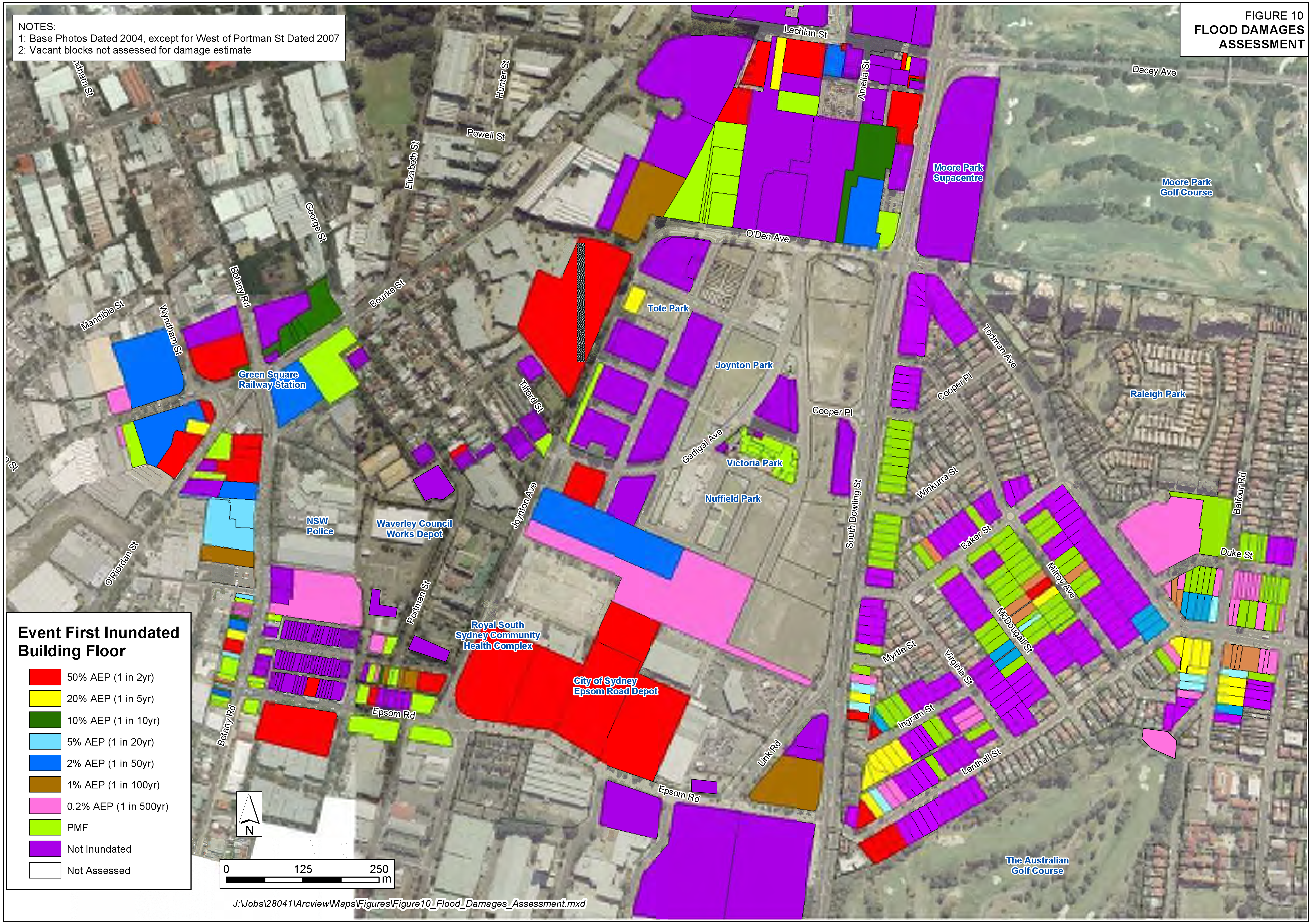


FIGURE 10
FLOOD DAMAGES ASSESSMENT
NOTES:
1: Base Photos Dated 2004, except for West of Portman St Dated 2007
2: Vacant blocks not assessed for damage estimate
Event First Inundated Building Floor
50% AEP (1 in 2yr)
20% AEP (1 in 5yr)
10% AEP (1 in 10yr)
5% AEP (1 in 20yr)
2% AEP (1 in 50yr)
1% AEP (1 in 100yr)
0.2% AEP (1 in 500yr)
PMF
Not Inundated
Not Assessed
0
125
250
m
N
Lachlan St
Dacey Ave
Amelia St
Hunter St
Powell St
Elizabeth St
George St
Botany Rd
Bourke St
O'Dea Ave
Moore Park Supacentre
Moore Park Golf Course
Mandible St
Wyndham St
Green Square Railway Station
Tote Park
Joynton Park
Todman Ave
Cooper Pl
Raleigh Park
Tilford St
Gadigal Ave
Victoria Park
Nuffield Park
Winkurra St
South Dowling St
Balfour Rd
Baker St
Duke St
Joynton Ave
NSW Police
Waverley Council Works Depot
O'Riordan St
Portman St
Mirloy Ave
McDougall St
Royal South Sydney Community Health Complex
Myrtle St
Virginia St
City of Sydney Epsom Road Depot
Ingram St
Epsom Rd
Link Rd
Lenthall St
The Australian Golf Course
J:\Jobs\28041\Arcview\Maps\Figures\Figure10_Flood_Damages_Assessment.mxd

FIGURE 11
POTENTIAL BASIN LOCATIONS
MOORE PARK GOLF COURSE

NOTE:
Base Photos dated 2004

J:\Jobs\28041-04\Arcview\Maps\Report\Figure12_Duke_Street_Upgrade.mxd

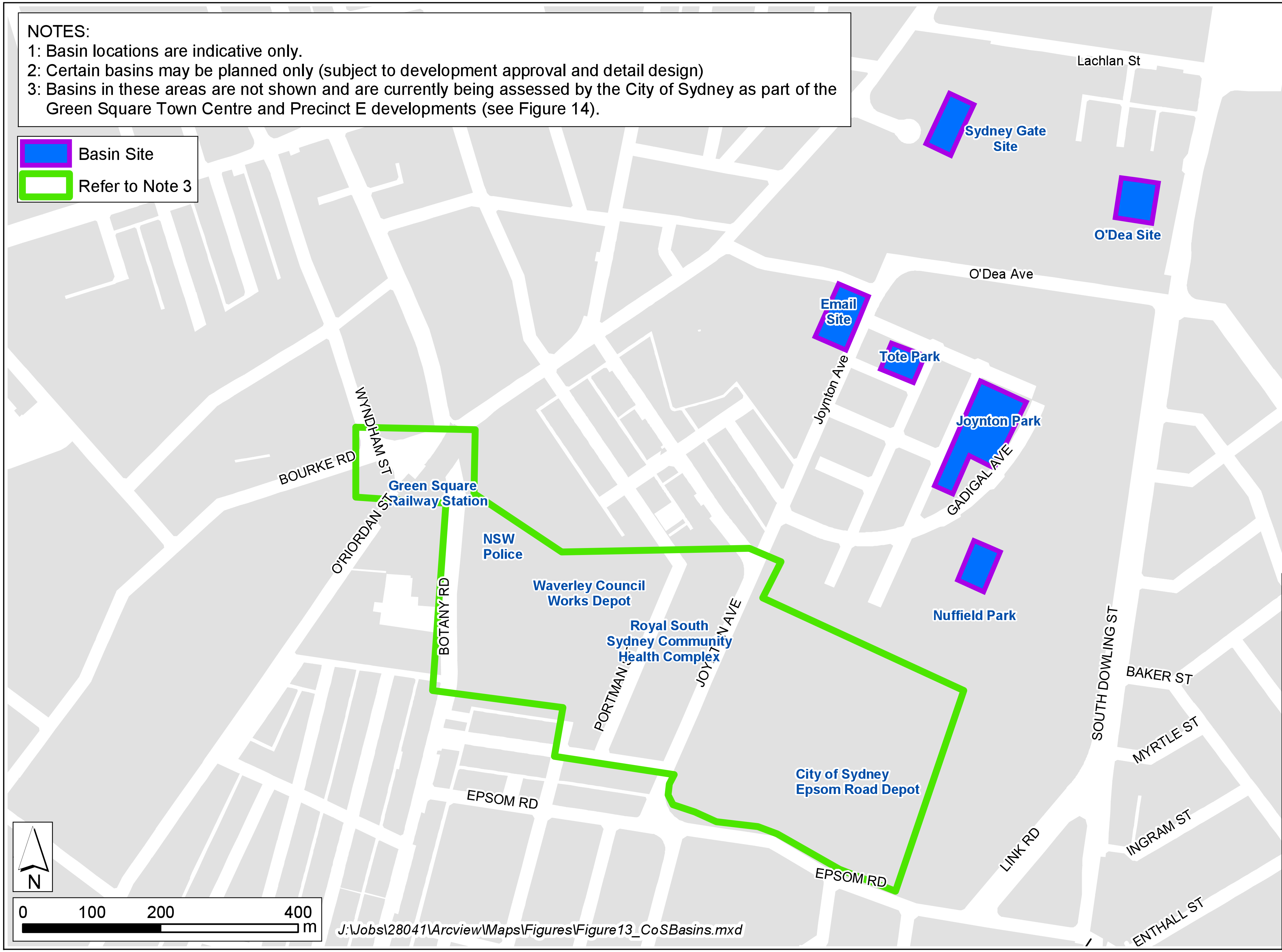
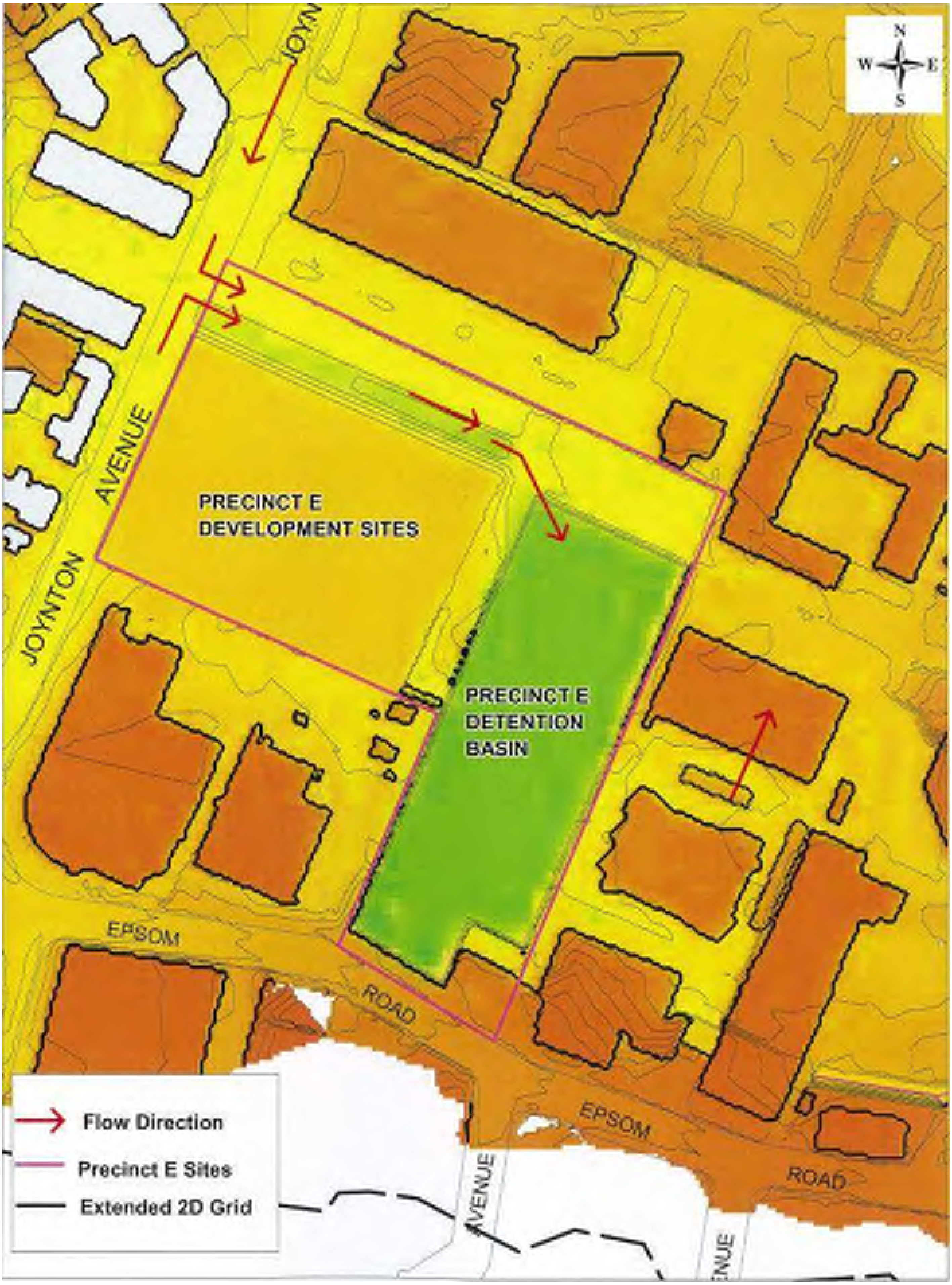


FIGURE 13
CONSTRUCTED AND PLANNED BASINS
GREEN SQUARE AREA

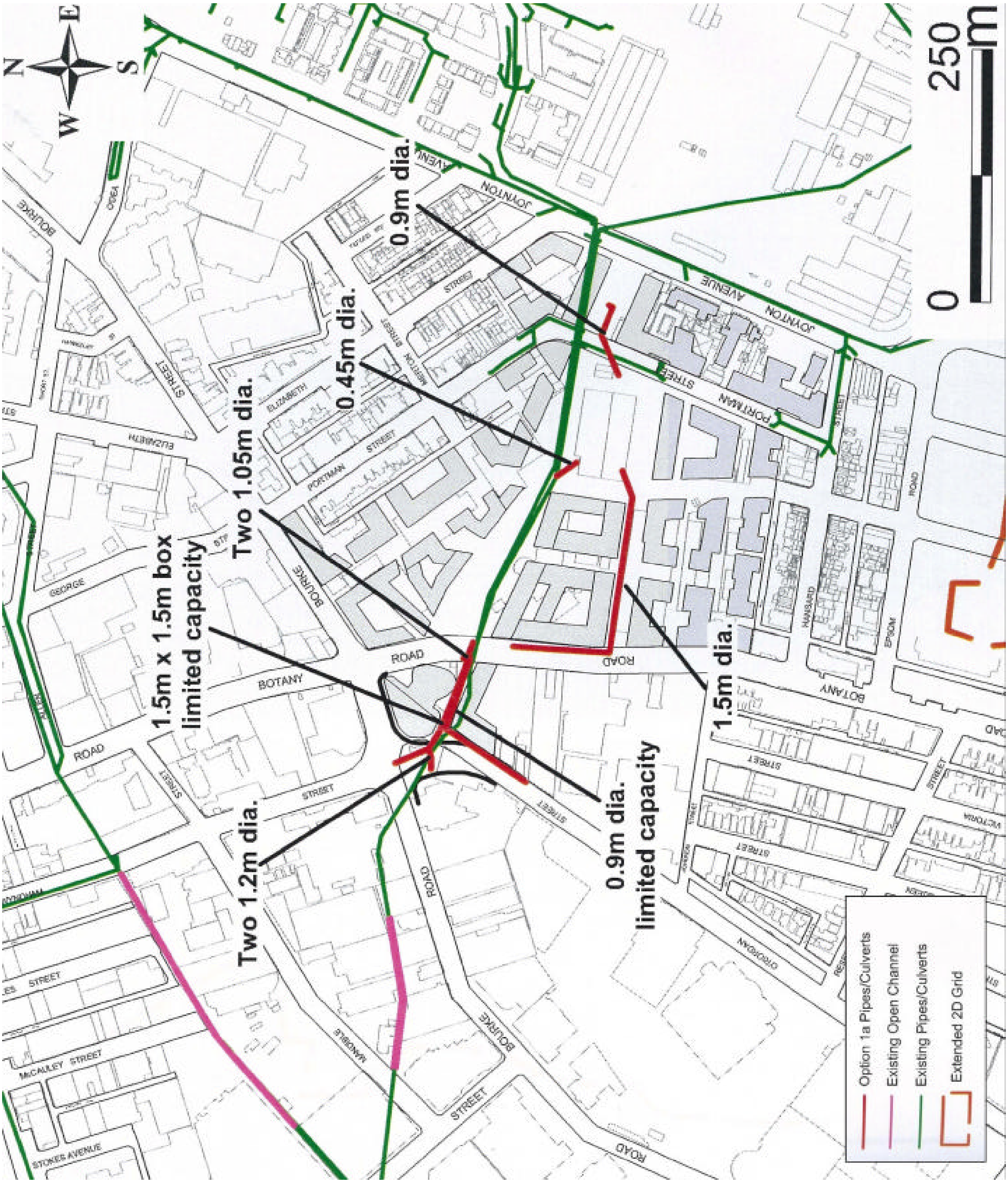
FIGURE 14
PRECINCT E DETENTION BASIN CONCEPT



Source: Flood Mitigation Options Report Green Square Town Centre
16 July 2008

J:\Jobs\28041\Admin\Report\DraftReport\Figures\Figure14_PrecinctE_DetentionBasin.cdr

FIGURE 15
PROPOSED TRUNK DRAINAGE WORKS
GSTC PRECINCT



Source: Flood Mitigation Options Report Green Square Town Centre
16 July 2008 Option 1a:Limited Works Option

J:\Jobs\28041\AdminReport\DraftReport\Figures\Figure15_GSTCPrecinct.cdr

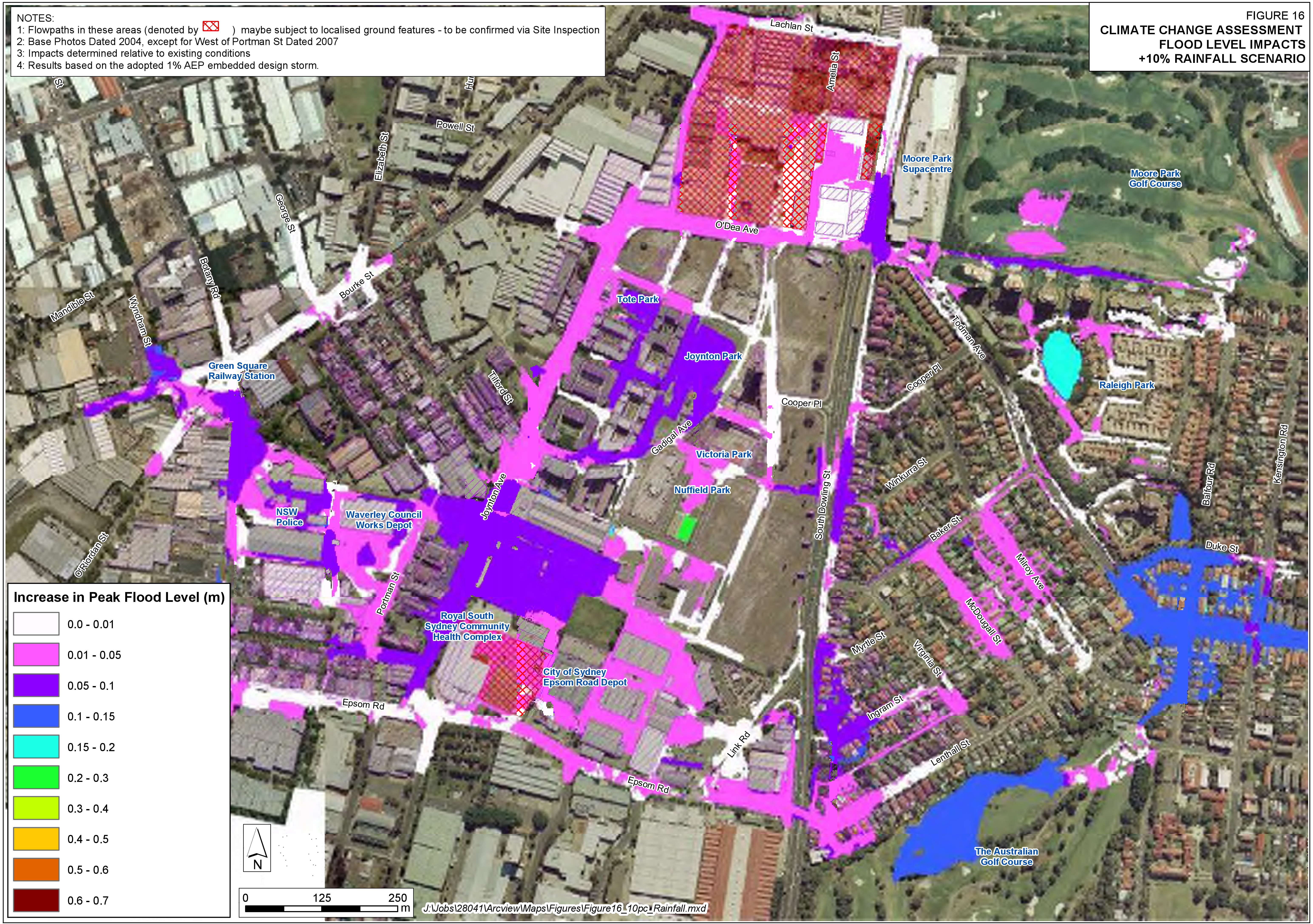


FIGURE 16
CLIMATE CHANGE ASSESSMENT
FLOOD LEVEL IMPACTS
+10% RAINFALL SCENARIO
NOTES:
1: Flowpaths in these areas (denoted by) maybe subject to localised ground features - to be confirmed via Site Inspection
2: Base Photos Dated 2004, except for West of Portman St Dated 2007
3: Impacts determined relative to existing conditions
4: Results based on the adopted 1% AEP embedded design storm.
Increase in Peak Flood Level (m)
0.0 - 0.01
0.01 - 0.05
0.05 - 0.1
0.1 - 0.15
0.15 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
0.6 - 0.7
Lachlan St
Amelia St
Powell St
Elizabeth St
George St
Bourke St
Botany Rd
Mandible St
Wyndham St
O'Dea Ave
Moore Park Supacentre
Moore Park Golf Course
Tote Park
Joynton Park
Green Square Railway Station
Tilford St
Todman Ave
Cooper Pl
Raleigh Park
Gadigal Ave
Victoria Park
Nuffield Park
South Dowling St
Winkurra St
Kensington Rd
Balfour Rd
NSW Police
Waverley Council Works Depot
Joynton Ave
Baker St
Duke St
Milroy Ave
O'Riordan St
Portman St
Royal South Sydney Community Health Complex
McDougall St
Myrtle St
Virginia St
City of Sydney Epsom Road Depot
Epsom Rd
Ingram St
Link Rd
Lenthall St
The Australian Golf Course
N
0 125 250 m
J:\Jobs\28041\Arcview\Maps\Figures\Figure16_10pc_Rainfall.mxd

NOTES:
1: Flowpaths in these areas (denoted by [hatched symbol]) maybe subject to localised ground features - to be confirmed via Site Inspection
2: Base Photos Dated 2004, except for West of Portman St Dated 2007
3: Impacts determined relative to existing conditions
4: Results based on the adopted 1% AEP embedded design storm

FIGURE 17
CLIMATE CHANGE ASSESSMENT
FLOOD LEVEL IMPACTS
+20% RAINFALL SCENARIO

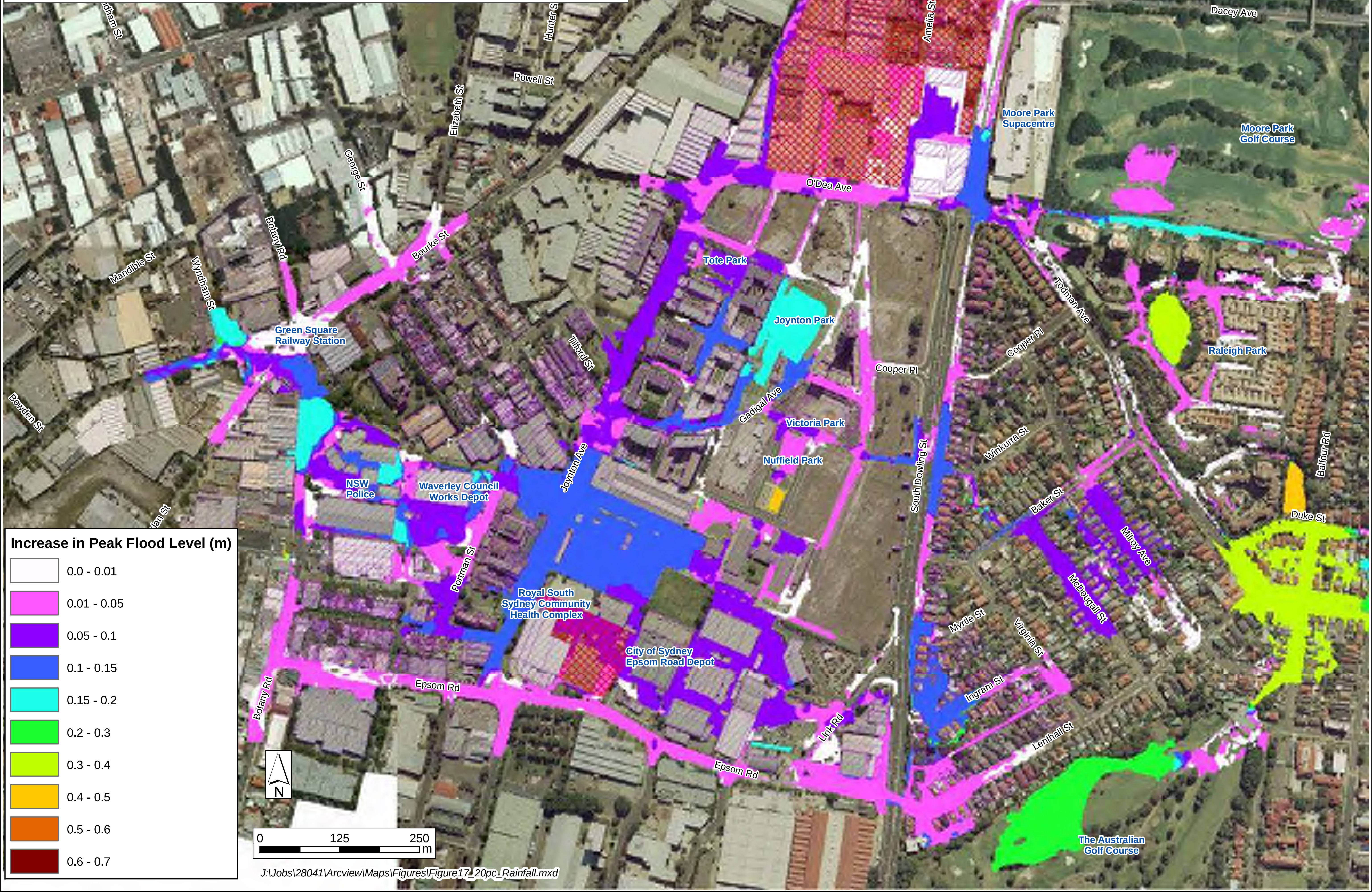
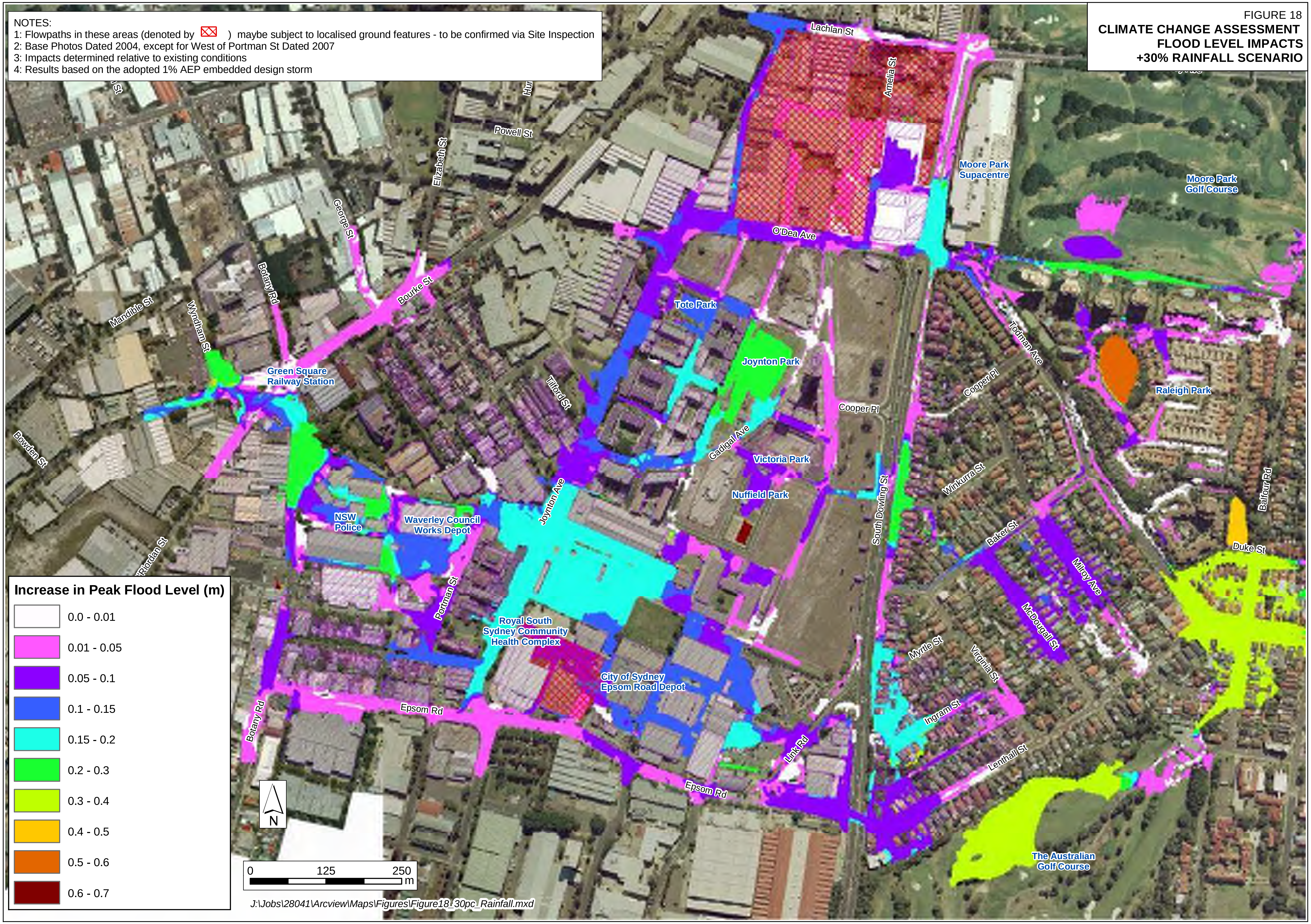


FIGURE 18
CLIMATE CHANGE ASSESSMENT
FLOOD LEVEL IMPACTS
+30% RAINFALL SCENARIO

NOTES:
1: Flowpaths in these areas (denoted by [hatched symbol]) maybe subject to localised ground features - to be confirmed via Site Inspection
2: Base Photos Dated 2004, except for West of Portman St Dated 2007
3: Impacts determined relative to existing conditions
4: Results based on the adopted 1% AEP embedded design storm



J:\Jobs\28041\Arcview\Maps\Figures\Figure18_30pc_Rainfall.mxd

Appendix A

APPENDIX A: GLOSSARY

Taken from the Floodplain Development Manual (April 2005 edition)

acid sulfate soils	Are sediments which contain sulfidic mineral pyrite which may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual published by Acid Sulfate Soil Management Advisory Committee.
Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Annual Damage (AAD)	Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
Average Recurrence Interval (ARI)	The long term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
caravan and moveable home parks	Caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the LG Act.
catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
consent authority	The Council, government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the Council, however legislation or an EPI may specify a Minister or public authority (other than a Council), or the Director General of DIPNR, as having the function to determine an application.
development	Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act). **infill development:** refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development. **new development:** refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power. **redevelopment:** refers to rebuilding in an area. For example, as urban areas

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

floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
floodplain risk management options	The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
floodplain risk management plan	A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammetic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
flood plan (local)	A sub-plan of a disaster plan that deals specifically with flooding. They can exist at State, Division and local levels. Local flood plans are prepared under the leadership of the State Emergency Service.
flood planning area	The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the "flood liable land" concept in the 1986 Manual.
Flood Planning Levels (FPLs)	FPL's are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the "standard flood event" in the 1986 manual.
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.
flood readiness	Flood readiness is an ability to react within the effective warning time.
floodplain 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. Floodplain risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. **existing floodplain risk:** the risk a community is exposed to as a result of its location on the floodplain. **future floodplain risk:** the risk a community may be exposed to as a result of new development on the floodplain. **continuing floodplain risk:** the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing floodplain risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing floodplain 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 floodplain 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.

FIGURE B17
PEAK FLOOD LEVELS AND DEPTHS
2% AEP EVENT
Moore Park Supacentre
Moore Park Golf Course
26.9
26.7
Raleigh Park
Todman Ave
Cooper Pl
Winkurra St
22.6
Baker St
Balfour Rd
Kensington Rd
Duke St
25
24.5
South Dowling St
Milroy Ave
McDougall St
Myrtle St
Virginia St
25.3
Ingram St
24.1
22.1
Lenthal St
Links Rd
22.1
23.4
The Australian Golf Course
N
Peak Flood Level (m AHD)
Mapping Extent
Peak Depth (m)
< 0.2
0.2 - 0.5
0.5 - 1
> 1
NOTE:
Base Photos dated 2004
0 50 100 200 m
J:\Jobs\28041-04\ArcviewMaps\Report\Figure17_PeakFloodLevelsandDepths_050y.mxd


FIGURE B18
PEAK FLOOD LEVELS
AND DEPTHS
1% AEP EVENT
Moore Park
Supacentre
Moore Park
Golf Course
Raleigh Park
The Australian
Golf Course
27
26.9
22.6
25.1
24.6
25.5
24.1
22.2
22.1
23.6
Todman Ave
Cooper Pl
Winkurra St
Baker St
Balfour Rd
Kensington Rd
Duke St
South Dowling St
Milroy Ave
McDougall St
Myrtle St
Virginia St
Ingram St
Lenthal St
Links Rd
N
Peak Flood Level (m AHD)
Mapping Extent
Peak Depth (m)
< 0.2
0.2 - 0.5
0.5 - 1
> 1
NOTE:
Base Photos dated 2004
0 50 100 200
m
J:\Jobs\28041-04\ArcviewMaps\Report\Figure18_PeakFloodLevelsandDepths_100y.mxd


FIGURE B19
PEAK FLOOD LEVELS AND DEPTHS 0.2% AEP EVENT
Moore Park Supacentre
27.2
Moore Park Golf Course
27.4
Raleigh Park
Todman Ave
Cooper Pl
Winkurra St
22.8
Baker St
25.1
24.6
Balfour Rd
Kensington Rd
Duke St
South Dowling St
Milroy Ave
Myrtle St
Virginia St
McDougall St
25.8
24.2
22.3
Ingram St
Lenthal St
Links Rd
22.2
23.8
The Australian Golf Course
N
Peak Flood Level (m AHD)
Mapping Extent
Peak Depth (m)
< 0.2
0.2 - 0.5
0.5 - 1
> 1
NOTE:
Base Photos dated 2004
0 50 100 200
m
J:\Jobs\28041-04\ArcviewMaps\Report\Figure19_PeakFloodLevelsandDepths_500y.mxd

FIGURE B20
PEAK FLOOD LEVELS AND DEPTHS PMF EVENT

FIGURE B21
PROVISIONAL HYDRAULIC HAZARD CATEGORIES 1% AEP EVENT

NOTE:
Hazard calculated in accordance with Figure L2 of the Floodplain Development Manual 2005

J:\Jobs\28041-04\ArcviewMaps\Report\Figure21_ProvisionalHydraulicHazardCategories_100y.mxd

FIGURE B22
PROVISIONAL HYDRAULIC HAZARD CATEGORIES PMF EVENT

NOTE:
1: Hazard calculated in ac cordance with Figure L2 of the Floodplain Development Manual 2005.
2: Base Photos dated 2004.
3:Indicated PMF Flood Level and Depths Estimates based on Peak Envelope from a range of storm durations.

J:\Jobs\28041-04\Arcview\Maps\Report\Figure22_ProvisionalHydraulicHazardCategories_PMF.mxd

Appendix C

APPENDIX C:

CITY OF SYDNEY FLOOD PLANNING LEVELS

Flood Planning Levels – Green Square Area DCP

Item	Flood Planning Level
Residential Properties	
Habitable Room Floor Level	
• inundated by mainstream flooding	1% AEP + 0.5 m
• inundated by local drainage flooding	1% AEP + 0.5 m or if the depth of flow in the 1% AEP is < 0.25 m then 2 x the depth of flow with a minimum of 0.3 m above the surrounding surface
• all other properties	0.3 m above surrounding ground
Non Habitable Floor Level such as a garage (excluding underground garages) or laundry for which development approval is required	
• inundated by mainstream or local drainage flooding	1% AEP
Underground Garage or Car Park	
For this purpose an underground garage or car park is where the floor of the car park is more than 1 m below the surrounding natural ground	
Single property owner with not more than 2 car spaces	
• inundated by mainstream or local overland flooding	1% AEP + 0.5 m
• car park outside floodplain	0.3 m above the surrounding surface
All others	
• inundated by mainstream or local overland flooding	1% AEP + 0.5 m (as a minimum) or a level that is determined based on a review of the PMF, whichever is the higher
• car park outside floodplain	0.3 m above the surrounding surface
Industrial/Commercial Properties	
It is assumed that all properties will be advised of the flood risk, either from existing studies or investigations by the proponent	
• floor level of a small business	1% AEP
• floor level of a large business,	merits approach presented by the applicant
• floor level of schools and child care facilities,	merits approach presented by the applicant
• residential floors within tourist establishments,	1% AEP + 0.5 m
• housing for older people or people with disabilities,	1% AEP + 0.5 m (as a minimum) or a level that is determined based on a review of the PMF, whichever is the higher
• above ground car park,	1% AEP
Critical Facilities	
These include: hospitals and ancillary service, communication centres, police, fire and SES stations, major transport facilities, sewerage and electricity plants, any installations containing infrastructure control equipment, any operational centres for use in a flood	
• floor level	1% AEP + 0.5 m (as a minimum) or a level that is determined based on a review of the PMF, whichever is the higher
• access to and from	1% AEP + 0.5 m (as a minimum) or a level that is determined based on a review of the PMF, whichever is the higher
Note: The Flood Planning Level (FPL) refers to the minimum building floor levels. For underground parking or other forms of underground development, the FPL refers to the minimum level at each access point. The higher of any FPL shall prevail.	

Source: South Sydney Development Control Plan 1997: Urban Design - Part G: Special Precinct No.9 Green Square

RANDWICK CITY COUNCIL: PROPOSED FLOOD PLANNING LEVELS

Item	**Flood Planning Level**
Residential Properties	
Habitable Floor Level	
• Inundated by mainstream flooding	1% AEP + 0.5m freeboard
• Inundated by local drainage flooding	1% AEP + 0.5m freeboard or if the depth of flow in the 1% AEP is less than or equal to 0.25m then 2 x the depth of flow with a minimum of 0.3m above the surrounding surface
• All other properties	0.3m above surrounding ground
Non habitable floor levels, such as laundry or shed but excluding garages, with a total floor area less than 10m^2.	
• Inundated by main stream or local drainage flooding	1% AEP but not less than 0.15m above surrounding ground level
Open car parking, car ports and garages, excluding underground garage or car park	
• Open car parking spaces and car ports	5% AEP flood
• Enclosed residential parking for up to two spaces	1% AEP but not less than 0.15m above surrounding ground level
• Enclosed residential parking with more than two spaces	Applicable residential habitable floor level requirement
• Enclosed Industrial/Commercial parking spaces	Applicable industrial/commercial floor level requirement
Underground garage or car park	
For this purpose an underground garage or car park is where the floor of the car park is more than 0.8m below the surrounding natural ground	
• Inundated by main stream or local drainage flooding	All openings to be sealed up to 1% AEP + 0.5m freeboard with a minimum of 0.3m above the surrounding surface
• All others areas	All openings to be sealed up to 0.3m above the surrounding surface
• All emergency exits	All underground garages and car parks to have emergency exits protected from inundation up to the 1% AEP flood plus 0.7m freeboard with a minimum of 0.2m freeboard from vehicle entry point.
Industrial/commercial properties	
Habitable floor level	
This includes floor levels such as; office space, show rooms, child care facilities, residential floor levels for hotels and tourist establishments	
• Inundated by mainstream flooding	1% AEP + 0.5m freeboard
• Inundated by local drainage	1% AEP + 0.5m freeboard or if the depth

flooding	of flow in the 1% AEP is less than or equal to 0.25m then 2 x the depth of flow with a minimum of 0.3m above the surrounding surface
• All other properties	0.3m above surrounding ground
Non habitable floor level	
• Inundated by main stream or local drainage flooding	1% AEP but not less than 0.15m above surrounding ground level
• All other properties	0.15m above surrounding ground
Critical facilities	
These include; hospitals, police, fire, ambulance, SES stations, major transport facilities, major sewage or water supply or electricity or telecommunication plants, schools, nursing homes and retirement villages.	
• Floor level mainstream flooding	PMF + 0.5m freeboard
• Floor level local drainage flooding	PMF + 0.5m freeboard or if the depth of flow in the PMF is less than or equal to 0.25m then 2 x the depth of flow with a minimum of 0.3m above the surrounding surface
• Floor level all other locations	0.3m above surrounding surface
• Site access	1% AEP + 0.5m freeboard or PMF, whichever is higher
Material storage location	
• Materials sensitive to flood damage	1% AEP + 0.5m freeboard
• Materials which may cause pollution or be potentially hazardous during flooding	% AEP + 0.5m freeboard
Note: The flood planning level refers to the minimum required building floor levels. For underground car parking or other forms of underground development, the flood planning level refers to minimum level at each access point.	

Appendix B

Level 2, 160 Clarence Street
Sydney, NSW, 2000

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

APPENDIX B WEST KENSINGTON FLOOD STUDY

FINAL REPORT

Project Appendix B West Kensington Flood Study		Project Number 28041-04
Client **Randwick City Council (RCC)**		**Client's Representative** Terry Kefalianos (RCC)
Authors **Michael Wyk** **Matthew Chadwick**		**Prepared by**
Date **13 OCTOBER 2011**		**Verified by**
Revision	**Description**	**Date**
2	Final	13/10/2011
1	Preliminary Draft Report	19/3/2010

APPENDIX B WEST KENSINGTON FLOOD STUDY

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FOREWORD

The NSW State Government's Flood Policy provides a framework to ensure the sustainable use of floodplain environments. The Policy is specifically structured to provide solutions to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

Under the Policy, the management of flood liable land remains the responsibility of local government. The State Government supports Councils in the discharge of their floodplain management responsibilities with provision of specialist technical advice and access to funding assistance for flood mitigation works.

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

1. ***Flood Study***
   - Determine the nature and extent of the flood problem.
2. ***Floodplain Risk Management***
   - Evaluates management options for the floodplain in respect of both existing and proposed development.
3. ***Floodplain Risk Management Plan***
   - Involves formal adoption by Council of a plan of management for the floodplain.
4. ***Implementation of the Plan***
   - Construction of flood mitigation works to protect existing development, use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

The West Kensington Flood Study constitutes the first stage of the management process for the West Kensington catchment. WMAwater have been commissioned to undertake this study by Randwick City Council (RCC). Funding assistance and specialist technical advice has also been provided by the NSW Department of Environment, Climate Change and Water (DECCW) (now Office of Environment and Heritage). The outcomes are to support the future management of flood liable lands in the West Kensington catchment.

EXECUTIVE SUMMARY

The West Kensington study catchment covers approximately 0.9 km^2 and drains predominantly from east to west. It is bounded by Moore Park Golf Course to the north; The Australian golf course to the south, South Dowling Street to the west and is predominantly zoned for residential usage.

Urbanisation has dramatically altered the nature of available drainage within the catchment. Flood problems typically result from ponding in trapped low-points such as those found in Milroy Avenue, McDougall Street and at the Lenthall Street underpass below the Eastern Distributor. Ponding also occurs at various locations along the eastern side of South Dowling Street. A number of the trapped low points in West Kensington are known to have experienced severe flooding during the November 1984 events.

The NSW Government's Flood Policy provides for:

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

Implementation of the Policy requires a four stage approach, the first of which is preparation of a Flood Study to determine the nature and extent of the flood problem.

Design flood behaviour within the study catchment was previously analysed as part of the 2008 Green Square – West Kensington (GSWK) Flood Study (Reference B1). Due to limitations in the data then available, the model representation of flowpaths and other hydraulic features within the West Kensington area was limited in detail. Since the 2008 study was completed however, Randwick City Council (RCC) has made available more detailed topographic data within the West Kensington area. Hence RCC requested that WMAwater refine the existing hydraulic modelling based on the more detailed topographic datasets of the West Kensington area. The outcomes of this work are presented in this report. The specific aims of this West Kensington Flood Study are to establish a more refined hydraulic model and to then:

- define flood behaviour across the West Kensington area,
- prepare flood hazard and flood extent mapping,
- prepare suitable models of the catchment and floodplain for use in current GSWK Floodplain Risk Management Study (FPRMS) and Plan.

Hydrologic and hydraulic investigations have been undertaken to determine the response of the catchment and drainage system to 50% AEP (1 in 2 year), 20% AEP (1 in 5 year), 5% AEP (1 in 20 year), 2% AEP (1 in 50 year), 1% AEP (1 in 100 year) and 0.2% AEP (1 in 500 year) events and the Probable Maximum Flood (PMF). The results of these investigations are quantified as peak pipe capacities and peak overland flows throughout the study area. Peak flood levels, depths and provisional hydraulic hazard categories have also been determined.

1. INTRODUCTION

1.1. Background

The West Kensington study catchment has an area of approximately 0.9 km^2 and drains predominantly from east to west (refer Figure B1). The area is predominantly located within the Randwick City Council (RCC) Local Government Area (LGA), although portions of the catchment also lie within the City of Sydney (CoS) LGA.

Flooding problems have been experienced at a number of locations within the West Kensington area during periods of heavy rainfall. Recognising the importance of having a consistent approach across the catchment RCC and the CoS have initiated a floodplain risk management program for the broader Green Square - West Kensington (GSWK) catchment (Figure B1). As part of this process, a Flood Study covering the entire GSWK catchment was produced in April 2008 (Reference B1) in accordance with the NSW Floodplain Development Manual (Reference 2). A subsequent Floodplain Risk Management Study and Plan (FPRMS&P) is currently being prepared for the overall GSWK catchment, of which this report is Appendix B.

The 2008 Flood Study defined design flood behaviour throughout the catchment for a range of events including the 1% AEP (1 in 100 year) event and the Probable Maximum Flood (PMF). Due to limitations in the data then available, the model representation of flowpaths and other hydraulic features within the West Kensington area was limited in detail. However, since the 2008 study was completed, RCC have made available more detailed topographic data within the West Kensington area. Hence as part of the current FPRMS&P, RCC requested that WMAwater refine the hydraulic modelling for the West Kensington area based on the more detailed topographic datasets. The outcomes of this work are presented in this report.

1.2. Objectives

As described in the Floodplain Development Manual (Reference B2), 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.

In effect, the West Kensington Flood Study constitutes the first stage in the process. A combination of hydrologic and hydraulic models was used in this study to determine design flood behaviour for the West Kensington catchment. Design flood behaviour was determined for a range of design flood events from the 50% AEP (~1 in 2 year) event to the 1% AEP (1 in 100 year) event through to the Probable Maximum Flood (PMF).

2. BACKGROUND

2.1. Catchment Description

The upper reaches of West Kensington are drained by pit and pipe networks with surcharging flows conveyed mainly along the road network. This portion of the catchment contains a number of major trapped low points which are known to be susceptible to ponding in large events.

Photo B1: Inlet Pits near South Dowling and Myrtle Streets West Kensington.

Located at the downstream end of West Kensington, the Eastern Distributor (noise walls to the right of the photo) forms a barrier to overland flow in some locations. Drainage in these areas relies upon sub-surface drainage through to CoS LGA.

Photo B2: Trapped low point in Milroy Avenue.

A number of major trapped lowpoints such as the one shown above exist throughout the West Kensington catchment.

2.2. Causes of Flooding

Flooding in the catchment typically occurs due to intense rainfall that may be experienced during thunderstorms (as occurred in all previous events in the 1980's and 1990's). As discussed in Reference B1, urbanisation has dramatically altered the nature of available drainage within the catchment and has led to:

- a major increase in the proportion of paved area and consequent reduction in pervious areas, resulting in corresponding increases in runoff (in terms of both peak flows and volumes), and
- development within the trapped depressions that were once swamps or dams, resulting in flood problems in these areas. Examples include the Milroy Avenue and McDougall Street trapped depression and other locations within the West

Kensington catchment. Damages have been incurred at these locations during past floods such as the November 1984 events.

In view of the above, flood problems within the catchment are generally the result of insufficient capacity within the trunk drainage system and the general lack of a formal overland flow system to provide controlled capacity in large events. Based on evidence from past floods (Council records and anecdotal resident evidence) flooding can be exacerbated by blocked local drainage and restricted overland flow paths. Whilst recent re-development in parts of the middle catchment has addressed some issues, there are many locations in which there is a significant degree of existing floodplain risk.

2.3. Previous Studies

This Flood Study builds directly upon the most recent 2008 GSWK Flood Study (Reference B1). In addition there are a number of prior studies relevant to the study area - a review of all known previous flood related studies is documented in Reference B1.

3. AVAILABLE DATA

3.1. Drainage Information

As part of the 2008 GSWK Flood Study (Reference B1) a comprehensive drainage assets database was developed for the drainage network located within the RCC LGA. This data was collected by AWT Survey and included details of all drainage inlet pits and pipes for the Randwick catchment.

3.2. Aerial Laser Scanning (ALS) Survey

RCC commissioned AAMHATCH Pty. Ltd. to undertake an Aerial Laser Scanning (ALS) survey within the extents of the Randwick LGA (refer Figure B2). The survey was flown in December 2005 at a 1:2000 scale flying height. The resultant mapping was provided to Council in March 2006. In terms of ground level information the ALS survey provides numerous ground level spot heights (approximately at 1m spacing in open areas), from which a Digital Terrain Model (DTM) can be constructed.

For well defined points mapped in clear areas, the expected nominal point accuracies (based on a 68% confidence interval) are in the order of:

- Vertical Accuracy: ±0.15 m
- Horizontal Accuracy: ±0.57 m

When interpreting the above, it should be noted that the accuracy of the ground definition can be adversely affected by the nature and density of vegetation and/or the presence of steeply varying terrain.

3.3. Rainfall Data

3.3.1. Overview

The first stage in the investigation of flooding matters is to establish the nature, size and frequency of the problem. On large river systems such as the Hawkesbury River there are generally stream height and historical records dating back to the early 1900's, or in some cases even further. However, in smaller urban catchments such as the GSWK study area there are often no stream gauges or official historical records available. A picture of flooding must therefore be obtained from an examination of rainfall records and local knowledge.

Rainfall data is recorded either daily (24hr rainfall totals to 9:00am) or continuously (pluviometers measuring rainfall in 0.5 m rainfall increments). Daily rainfall data have been recorded for over 100 years at many locations within the Sydney basin, including at Observatory Hill since 1858. In general, pluviometers have only been installed since the 1970's. Together these records provide a picture of when and how often large rainfall events have occurred in the past.

However, care must be taken when interpreting historical rainfall measurements. Rainfall records may not provide an accurate representation of past events due to a combination of factors including local site conditions, human error or limitations inherent to the type of recording instrument used. Examples of limitations that may impact the quality of data used for the present study are highlighted in the following:

- Rainfall gauges frequently fail to accurately record the total amount of rainfall. This can occur for a range of reasons including operator error, instrument failure, overtopping and vandalism. In particular, many gauges fail during periods of heavy rainfall and records of large events are often lost or misrepresented.
- Daily read information is usually obtained at 9:00am in the morning. Thus if the storm encompasses this period it becomes “split” between two days of record and a large single day total cannot be identified.
- In the past, rainfall over weekends was often erroneously accumulated and recorded as a combined Monday 9:00am reading.
- The duration of intense rainfall required to produce flooding in the Green Square-West Kensington catchment is typically less than two hours. This is termed the “critical storm duration”. For a much larger catchment (such as the Parramatta River) the critical storm duration may be from 24 to 36 hours. For the Green Square-West Kensington catchment a short intense period of rainfall can produce flooding but if the rain stops quickly (as would be typical of a thunderstorm), the daily rainfall total may not necessarily reflect the magnitude of the intensity and subsequent flooding. Alternatively the rainfall may be relatively consistent throughout the day, producing a large total but only minor flooding.
- Rainfall records can frequently have “gaps” ranging from a few days to several weeks or even years.
- Pluviometer (continuous) records provide a much greater insight into the intensity (depth vs time) of rainfall events and have the advantage that the data can generally be analysed electronically. These data have much fewer limitations than daily read data. The main drawback is that many of the relevant gauges have only been installed since 1990 and hence have a very short period of record compared to the daily read data. The Sydney Observatory and Sydney Water Board Head Office gauges were installed in 1970 but unfortunately are located too far away to provide a representative indication of rainfalls occurring over the Sheas Creek catchment. Pluviometers can also fail during storm events due to the extreme weather conditions.
- Rainfall bursts likely to cause flooding in the Green Square-West Kensington catchment are expected to be relatively localised and as such only accurately “registered” by a nearby gauge. Gauges sited only a few kilometres away can show very different intensities and total rainfall depths.

3.3.2. Available Rainfall Data

There are no official rain gauges located within the study area of the broader Sheas Creek catchment. However, there are several gauges in adjacent catchments. Table B1 presents a summary of official rainfall gauges located close to, or within the catchment. These gauges are (or have been) operated either by Sydney Water or the Bureau of Meteorology. Of the 45 gauges listed in Table B1 over 58% (26) have now closed. The gauge with the longest record is Observatory Hill, operating from 1858 to the present.

Table B1: Listing of Rainfall Stations

Station No	Owner	Station	Elevation (mAHD)	Date Opened	Date Closed	Type
66139	BOM	Paddington	5	Jan_68	Jan_76	Daily
566041	SW	Crown St Reservoir	40	Feb_1882	Dec_60	Daily
566032	SW	Paddington (Composite Site)	45	Apr_61		Continuous
566032	SW	Paddington (Composite Site)	45	Apr_61		Daily
566009	SW	Rushcutters Bay Tennis Club	0	May_98		Continuous
566042	SW	Sydney H.O. Pitt St	15	Aug_49	Feb_65	Continuous
66015	BOM	Crown St Reservoir		Feb_1882	Dec_60	Daily
66006	BOM	Sydney Botanic Gardens	15	Jan_1885		Daily
66160	BOM	Centennial Park	38	Jun_00		Daily
566011	SW	Victoria Park @ Camperdown	0	May_98		Continuous
66097	BOM	Randwick Bunnerong Rd		Jan_04	Jan_24	Daily
66062	BOM	Sydney (Observatory Hill)	39	??		Continuous
66062	BOM	Sydney (Observatory Hill)	39	Jul_1858	Aug_90	Daily
66033	BOM	Alexandria (Henderson Rd)	15	May_62	Dec_63	Daily
66033	BOM	Alexandria (Henderson Rd)	15	Apr_99	Mar_02	Daily
66073	BOM	Randwick Racecourse	25	Jan_37		Daily
566110	SW	Erskineville Bowling Club	10	Jun_93	Feb_01	Continuous
566010	SW	Cranbrook School @ Bellevue Hill	0	May_98		Continuous
566015	SW	Alexandria	5	May_04	Aug_89	Daily
66066	BOM	Waverley Shire Council		Sep_32	Dec_64	Daily
66149	BOM	Glebe Point Syd. Water Supply	15	Jun_07	Dec_14	Daily
566099	SW	Randwick Racecourse	30	Nov_91		Continuous
66052	BOM	Randwick Bowling Club	75	Jan_1888		Daily
566141	SW	SP0057 Cremorne Point	0			Continuous
66021	BOM	Erskineville	6	May_04	Dec_73	Daily
	SW	Gladstone Park Bowling Club	0	Jan_01		Continuous
566114	SW	Waverley Bowling Club	0	Jan_95		Continuous
566043	SW	Randwick (Army)	30	Dec_56	Sep_70	Continuous
566077	SW	Bondi (Dickson Park)	60	Dec_89	Feb_01	Continuous
566065	SW	Annandale	20	Dec_88		Continuous
66098	BOM	Royal Sydney Golf Club	8	Mar_28		Daily
66005	BOM	Bondi Bowling Club	15	Jul_39	Dec_82	Daily
66178	BOM	Birchgrove School	10	May_04	Dec_10	Daily
66075	BOM	Waverton Bowling Club	21	Dec_55	Jan_01	Daily
66187	BOM	Tamarama (Carlisle St)	30	Jul_91	Mar_99	Daily

66179	BOM	Bronte Surf Club	15	Jan_18	Jan_22	Daily
566130	SW	Mosman (Reid Park)	0	Jan_98	Jun_98	Continuous
566030	SW	North Sydney Bowling Club	80	Apr_50	Sep_95	Daily
66007	BOM	Botany No.1 Dam	6	Jan_1870	Jan_78	Daily
66067	BOM	Wollstonecraft	53	Jan_15	Jan_75	Daily
66061	BOM	Sydney North Bowling Club	75	Apr_50	Dec_74	Daily
566027	SW	Mosman (Bradleys Head)	85	Jun_04		Continuous
566027	SW	Mosman (Bradleys Head)	85	Jun_04		Daily
566006	BOM	Bondi (Sydney Water)	10	Jun_97		Operational
66175	BOM	Schnapper Island	5	Mar_32	Dec_39	Daily
BOM = Bureau of Meteorology **SW = Sydney Water**						

3.3.3. Analysis of Recent Storms

As noted previously, pluviometer records provide a more detailed description of temporal variations in rainfall. Table B2 lists the maximum storm intensities for several recent rainfall events from both the pluviometers and daily read gauges in proximity of the Green Square-West Kensington catchment.

Table B2: 5 November 1984, 8/9 November 1984, January 1989, and January 1994 Maximum Recorded Storm Depths (in mm)

Station Location	5 Nov 1984		8/9 Nov 1984		6 Jan 1989		26 Jan 1991	
	30 min	60 min	30 min	60 min	30 min	60 min	30 min	60 min
Paddington	36	51	54	91	53	54	52	53
Observatory Hill	20	32	90	119	42	42	60	65
Sydney Airport	-	-	85	100	6	6	11	12
Marrickville	28	31	26	38	1	1	37	38
Mascot Bowling Club	43	48	34	47	36	37	17	18
UNSW (Avoca St)(1)	65	112	41	58	-	-	-	-
UNSW (Storey St)(1)	65	90	33	46	-	-	-	-

Station Location	24 hour Totals to 0900 hrs				
	5 Nov 1984	8 Nov 1984 (2)	9 Nov 1984 (2)	6 Jan 1989	26 Jan 1991
Royal Botanic Gardens	-	37	248	49	59
Sydney Airport	121	20	132	85	53
Observatory Hill	98	44	234	47	65
Paddington	108	71	208	63	54

Notes:

(1) Data manually interpreted from Reference B3.
(2)The November 1984 event consisted of two separate rainfall bursts (between 6:00am and 10:00am and 9:00pm and midnight). Both produced flooding but the second burst was the most intense. One possible reason why there are so few recorded flood levels is that the second burst occurred at night and thus few would have been outside to view the flood extent or record levels.

The above data indicate that for January 1989 and January 1991 the peak 30 minute rainfall comprised the majority of the daily rainfall. However for the two major events in November 1984 the 30 minute peak was part of a much larger rainfall event.

Comparison with design rainfall intensities indicate that the January 1989 and January 1991 events were less than a 5% AEP (20 year ARI) design intensity for the 30 minute and 60 minute intensities, except at Observatory Hill in January 1991 which approached a 40 year ARI for the 30 minute intensity.

The 8th-9th November 1984 storm was a significant rainfall event across the Sydney and Wollongong region and is well documented in References B3 and B4. Table B3 shows that this storm had an approximate ARI of 100 years across several locations in Sydney. The storm was separated into two distinct bursts (6:00am to 10:00am and 9:00pm to midnight). The latter was the most intense period and flooding was reported throughout the catchment, though the actual timing of the flooding is unknown.

Table B3: ARI Estimates of the 8th November 1984 Rainfall (Reference B4)

Station	Rainfall Duration				
	0.5 hour	1 hour	2 hour	3 hour	6 hour
Sydney - Observatory Hill	100y	100y	100y	100y	100y
Mosman	20y	50y	100y	20y	10y
Vaucluse	100y	100y	50y	20y	10y

3.4. Historical Flood Records

A detailed analysis of rainfall records and flood records and distribution of a community survey was undertaken as part of Reference B1. However, much of the information on past flooding within the catchment was sourced from existing reports and references (e.g. References B3 to B5).

Most records relate to the significant flooding that occurred during the November 1984 events and document extensive flooding within trapped low points throughout the catchment. This includes the inundation of 56 properties (including 27 houses) within West Kensington (Reference B4). There is also anecdotal evidence of flood problems occurring within other nearby areas of the catchment within the CoS LGA such as South Dowling Street (opposite Moore Park Supacentre).

The lack of data in other flood liable areas in the catchment means that the true extent of flooding in historical events is largely unknown. When flooding occurs within the catchment in the future, it is recommended that Council undertake to collect any available information (photos, rainfall data, flood heights, extent of inundation and damages to private property etc.) as soon as practicable after the event including after smaller, more frequent flooding such as would be expected in the 50% AEP (1 in 2 year) event.

An allowance for inflows into the Balfour Road trapped low point from the adjacent Kensington catchment (via Todman Avenue) was made based on preliminary results from Reference B5 (refer to Table B4).

Table B4: Estimated inflows to West Kensington from adjacent catchment via Todman Avenue

Event	Peak Flow Estimate (m^3/s)	Comments
5% AEP (1 in 20 year)	-	see note
2% AEP (1 in 50 year)	< 0.1	see note
1% AEP (1 in 100 year)	3.6	see note
0.2% AEP (1 in 500 year)	5.4	Approximated as 1.5 x Q_{100}
Probable Maximum Flood (PMF)	11.1	Approximated as 3 x Q_{100}

Notes: Peak flows from Reference B5 are preliminary estimates only and may be subject to change

4. APPROACH ADOPTED

4.1. General

The approach adopted by this study has been influenced by the study objectives and the quality and quantity of available data. The urbanised nature of the study area with its mix of pervious and impervious surfaces, and existing piped and overland flow drainage systems has created a complex hydrologic and hydraulic flow regime. The analysis is further complicated by:

- the need to identify flow generated from numerous sub-catchment areas,
- surcharging within the pipe system,
- a need to ascertain the proportion of the total flow which travels overland,
- a need to estimate the nature of overland flows at critical locations in the catchment in terms of flood levels, flows and velocities.
- the complexity of the overland flow paths in some parts of the catchment.

In an urban drainage catchment, there is rarely a historical flood record available and the use of a flood frequency approach for the estimation of design floods is not possible. A rainfall/runoff approach linking hydrologic and hydraulic models followed by a process of calibration and verification was not appropriate due to insufficient historical information (flood flows and/or level data). This situation is typical of the majority of urban drainage catchments.

For the present study, an existing hydrological (MIKE-Storm) model (prepared as part of Reference B1) was used to generate runoff hydrographs for sub-areas within the West Kensington catchment. These runoff hydrographs were used as inflow boundary conditions for input to a two-dimensional unsteady flow hydraulic (TUFLOW) model. The TUFLOW model simulates the dynamic behaviour of flow through the stormwater network and overland flow paths. The outcomes include flood levels, flowrates and velocities across the floodplain.

With the limited amount of flood height data and other historical flood information, the parameters adopted in the model were based on a limited model validation and experience in similar catchments. A sensitivity analysis was also undertaken to assess the impacts of the adopted assumptions modelling assumptions. The hydrologic and hydraulic models were then used to quantify the design flood behaviour for a range of design storm events up to and including the PMF.

5. HYDROLOGIC MODEL (MIKE-Storm)

5.1. Overview

Techniques suitable for design flood estimation in an urban environment are described in ARR87 (Reference B6). These techniques range from simple procedures to estimate peak flows (e.g. Probabilistic Rational Method calculations), to more complex rainfall-runoff routing models that estimate complete flow hydrographs and can be calibrated to recorded flow data.

For the present study, the DHI software package MIKE-Storm has been used to estimate the catchment hydrology (Reference B7). The MIKE-Storm model has been configured to utilise a runoff routing formulation that is based on methodology contained in the ILSAX/DRAINS models (References B8 and B9). The ILSAX/DRAINS type method has been widely adopted in Australia for use in urban catchments, similar to that of the present study.

5.2. Sub-catchment Layout

This study used the detailed MIKE-Storm hydrological model of the study catchment (established for Reference B1). The hydrological model covers a total catchment area of 90 hectares and comprises over 255 sub-catchments. The layout of the hydrological model sub-areas and corresponding drainage network is shown in Figure B3 and Figure B4.

A sub-catchment area was specified at each pit or node accepting inflow into the system. This meant that every inlet pit, pipe inlet and channel junction in the model had an associated sub-catchment surface area producing inflow into the drainage system. Sub-catchment boundaries were manually delineated based on interpolation of the available topographic data, aerial photography and other similar information. For each sub-catchment, the portion of impervious area for each sub-catchment was determined from an inspection of aerial photographs and land use types from GIS information supplied by Council. The adopted amount of impervious area (percentage paved) for each land use type are tabulated in Table B4 It should be noted that these are only generic and were sometimes varied for particular sub-catchments where appropriate.

Table B5: Land Use Paved Pertentage

Land Use	Percentage Paved
General Residential	70
Road Reserve	75
Parkland and Open Space	10
Commercial and Industrial	85-95
Medium to High Density Residential	40-95

Note: Commercial and industrial and medium to high density residential were assessed on an individual basis as they tended to vary considerably. The percentages shown indicate the range in values determined.

5.3. Rainfall Losses and Soil Type

Losses from paved areas are considered to comprise only of an initial loss (an amount sufficient to wet the pavement and fill minor surface depressions). Losses from grassed areas are more complex. They are made up of both an initial loss and a continuing loss. The continuing loss was calculated within the model using Horton's infiltration relationship which is based on the estimated representative soil type and antecedent moisture condition. Being an event-based model, it is necessary to define an antecedent moisture condition to reflect the level of saturation of the soils within the pervious portions of the catchment at the start of the event.

For consistency with previous studies undertaken within the Sheas Creek catchment, it was assumed that the soil in the sub-catchments has a moderate rate of infiltration potential and the antecedent moisture condition was considered to be saturated (i.e. a soil type of 2 and an Antecedent Moisture Condition of 4 was adopted). The latter was justified by the fact that the peak rainfall burst can typically occur within a longer storm event that possibly has a duration of a few days. The adopted parameters are summarised in Table B6.

Table B6: Adopted MIKE-Storm Hydrologic Model Parameters

RAINFALL LOSSES	
Paved Area Depression Storage (Initial Loss)	1 mm
Grassed Area Depression Storage (Initial Loss)	5 mm
SOIL TYPE	2
Moderate infiltration rates and moderately well-drained. This parameter, in conjunction with the Antecedent Moisture Condition, determines the continuing loss (defined by Horton's infiltration equation).	
ANTECEDENT MOISTURE CONDITIONS (AMC)	4
Description	Saturated
Total Rainfall in 5 Days Preceding the Storm	Over 25 mm

5.4. Time of Concentration

Overland travel times for surface runoff within a sub-catchment were calculated using the kinematic wave equation. This relationship is based on the nature of the sub-catchment and accounts for different travel times with varying rainfall intensities.

6. HYDRAULIC MODEL

6.1. TUFLOW Background

The TUFLOW modelling package includes a finite difference numerical model for the solution of the depth averaged shallow water flow equations in two dimensions (2D). The TUFLOW software has been widely used for a range of similar floodplain projects both internationally and within Australia. The model is capable of dynamically simulating complex overland flow regimes. It is especially applicable to the hydraulic analysis of flooding in urban areas which is typically characterised by short duration events and a combination of supercritical and subcritical flow behaviour. Further details of the TUFLOW software can be found in Reference B10.

For the hydraulic analysis of overland flow paths, a two-dimensional (2D) model such as TUFLOW provides several key advantages when compared to a traditional one-dimensional (1D) model. For example, in comparison to a 1D approach, a 2D model can:

- provide localised detail of any topographic and/or structural features that may influence flood behaviour,
- better facilitate the identification of the potential overland flow paths and flood problem areas,
- inherently represent the available floodplain storage within the 2D model geometry.

Importantly, a 2D hydraulic model can better define the spatial variations in flood behaviour across the study area. Information such as flow velocity, flood levels and hydraulic hazard can be readily mapped in detail across the model extent. This information can then be easily integrated into a GIS based environment enabling the outcomes to be incorporated into Council's planning activities.

6.2. Model Extents

The 2D model extends from upstream of Kensington Road into the West Kensington catchment to downstream of South Dowling Street (refer to Figure B5).

6.3. Drainage System Elements

The drainage network and sub-catchment areas were defined utilising the asset data and detail survey collected by AWT, existing plans and reports (documented in Section 3) and topographic map information. Figure B5 shows the location and extent of branches within the study catchment which have been included in the TUFLOW model. The drainage system has been defined in the TUFLOW model using 1D elements that are dynamically coupled to the 2D model domain. The drainage system included in the model comprises:

- 484 pits and nodes, including surface inlets, junctions and outlets.

- 503 links representing underground conduits (circular pipe or box) or channel lengths between nodes.

The TUFLOW drainage system model extends west of South Dowling Street with downstream boundary conditions being defined sufficiently outside the immediate study area so that they have little influence on the results presented in this study.

There are some cases where pits within the surveyed drainage network have buried lids or lids that could not be removed and hence the invert levels of these pits and pipes could not be surveyed. In these instances an estimation of the pit/pipe invert level was made based on an assumption of a cover of 500 mm to the top of the pipe. An additional check was made to ensure that pipe reach graded downstream.

6.4. Definition of Overland Flow Paths

Overland flow paths were represented in the TUFLOW model using a 2D digital elevation model. The 2D component of the model was established based upon a digital terrain model (DTM) compiled from available survey information. The extents of the TUFLOW model grid are shown in Figure B5. The model topography was derived using a regular grid of 2 m x 2 m cells across the model extent. This fine spatial resolution was adopted to better resolve significant localised ground details and other hydraulic control features.

6.4.1. Manning's Roughness (TUFLOW)

The hydraulic efficiency of the flow paths within the TUFLOW model is represented in part by the hydraulic roughness or friction factor formulated as Manning's 'n'. This factor describes the net influence of bed roughness and incorporates the effects of vegetation and other features which may affect the hydraulic performance of the particular flow path.

The Manning's 'n' values adopted for overland flowpaths are shown in Table B7. A Manning's 'n' value of 0.015 was adopted for all pipes and culvert structures.

Table B7: Floodplain Manning's 'n' values

Catchment description	Manning's 'n'
Grassed Areas	0.030
Roads	0.022
Residential	0.020

The sensitivity of the model results to the assumed roughness factors is assessed later in Section 10.

6.5. Hydraulic Structures

Buildings have been excluded from the model as it is assumed that there is very little flow through the structures. In areas where there was large overland flow and significant obstructions by fences and other flow restrictions these were modelled in higher detail within TUFLOW.

Large buildings and other significant features likely to act as flow obstructions were also incorporated into the model network based on surveyed building footprints and available aerial photography. These types of features were modelled as impermeable obstructions to the flood waters. In areas where there was large overland flow and significant obstructions by fences and other flow restrictions these were modelled in higher detail within TUFLOW. For example, the fence downstream and parallel to Milroy Ave was included in the model and sensitivity of the results to the inclusion of the fence is assessed in Section 10.

7. MODEL VALIDATION

7.1. Overview

Ideally once the various models have been established; it is preferable to calibrate the model parameters using a suitable historical event. The performance of the calibrated model can then be verified against one or more other historical events. To calibrate/verify the models requires a sufficient amount of flood data for each historical event within the modelling extent.

For the present study, the November 1984 storms are the largest of recent events for which there is a limited amount of flood height data available. Due to the relative lack of detailed flood data in addition to the significant catchment changes that have taken place since these events, the following is a limited model validation only. However the outcomes are still useful as they provide an indication of the ability of the models to perform within reasonable limits.

When flooding occurs within the catchment in future, it is recommended that Council (or the relevant authority) undertake to collect any available information (rainfall data, flood heights, etc.) as soon as practicable after the event (including after smaller, more frequent flooding such as would be expected in the 50% AEP event).

7.2. Approach

The various models were validated using the storm events of 5th November 1984 and 8th and 9th November 1984. Compared to existing conditions, there have been a number of significant changes within the catchment since this time. In the absence of detailed information to accurately define historical conditions, key changes were identified using 1986 aerial photography and in consultation with Council/DECC (now OEH) officers. Key changes made to the "existing conditions" model configuration within the West Kensington area include:

- The removal of flood storage provided by the Raleigh Park detention basin which was constructed since 1984 and
- removal of known post-1984 upgrades to the pipe system including the pipe system from Raleigh Park down through Baker Street and the upgrades/augmentation in the Balfour Road system extending through The Australian golf course.

As there is no continuous rainfall recording device within the study catchment, pluviometer records from several nearby stations were used to define the hydrology for the November 1984 events. Given the spatial variation in both the timing and total depth of recorded rainfall, separate runs were undertaken in which the storm pattern was defined by individual station records. Following a review of the available data, rainfall records from pluviometers at Avoca Street (UNSW) and Paddington (BoM) were selected for use as they provide a reasonable representation of variability of rainfall for these events (refer to Figure B6). The model runs of each event (5th November and 8th/9th November) were undertaken using the rainfall records from each pluviometer for a total of four validation runs.

7.3. Results and Discussion

The re-configured TUFLOW model was run for both the November 5-6 and November 8-9 events using the same methodology as documented in Reference B1.

The corresponding model results are compared to reported instances of flooding in Table B8. The outcomes demonstrate that the TUFLOW model reproduces observed ponding within the Milroy Avenue, McDougall Street and Virginia Street lowpoints reasonably well. The modelled ponding level within the Balfour Road trapped lowpoint was found to be more sensitive to the assumed rainfall pattern although reasonable matches were achieved using the Paddington station for the 5-6 November event and the Avoca Street pattern for the 8-9 November event.

Note that the observed flood heights are associated with the event of 8th-9th November 1984 (the model results for the 5th of November event have been included for completeness).

Table B8: Model Validation Results – November 1984 Storms

Location	Observed Levels (mAHD)	Model Results (mAHD) 5-6th November 1984		Model Results (mAHD) 8-9th November 1984	
		RUN A: Avoca St. Pluvi.	RUN B: Paddington Pluvi.	RUN A: Avoca St. Pluvi.	RUN B: Paddington Pluvi.
Milroy Avenue	25.2 - 25.5	25.2	25.0	25.1	25.2
McDougall Street	24.6 - 24.9			24.5	24.7
Lenthall Street	21.3 - 21.7			21.6	21.8
Balfour Road	25.1 - 25.3	25.7	25.2	25.4	25.8

Based on the above the TUFLOW model is considered validated and suitable for design flood purposes. As highlighted in the GSWK FS, it is recommended that the model performance be re-assessed against flood data obtained from any future floods in the catchment.

8. DESIGN EVENT MODELLING

8.1. Approach

The MIKE-Storm and TUFLOW models were used to estimate the design flood behaviour across the study catchment under existing conditions. A number of design storm events were analysed from the 50% AEP event to the 1% AEP (1 in 100 year) event through to the PMF. Design rainfalls and Probable Maximum Precipitation estimates were based on References B6 and B12.

The traditional AR&R approach (Reference B6) to design storm hydrology is based on a peak flow generated by a critical duration peak burst rainfall pattern. The method assumes that antecedent rainfall prior to the critical duration burst does not impact upon the peak flow estimates (Reference B13). Several other studies indicate that a failure to incorporate antecedent conditions prior to the critical duration peak burst may result in the underestimation of peak flows for some catchments (Reference B13 and B14). As noted in Reference B11, this is particularly the case for catchments where the ARR critical burst durations are much shorter than the duration of historic flood-producing storms. For the West Kensington catchment, there is a significant chance that high-intensity short duration storm bursts likely to cause major flooding will occur during a broader low intensity, longer duration storm.

To address these issues, this study adopts an alternative approach to design flood estimation whereby a critical duration design storm burst is embedded within a longer duration storm of the same ARI. This approach was originally presented in Reference B13 and has been further documented in Reference B14. Initially, the critical burst is embedded to coincide with the peak of the larger duration event. To ensure that the average intensities reflect the original ARIs the intensities of the longer duration storm are adjusted such that the total rainfall depth is consistent with that of the longer duration storm. Further details regarding the procedure can be found in References B5 and B11.

For the present study, the duration of the longer storm was selected based upon recorded rainfall patterns from the November 1984 events given that these storms were known to have caused significant flooding throughout the study catchment. Pluviometer records from the Paddington and Avoca Street (Randwick) stations indicate that the majority of rainfall fell within a period of between three to six hours in duration (refer Figure B6). On this basis a 6 hour duration storm was selected as the longer duration storm within which a shorter duration design burst was embedded.

8.2. Boundary Conditions

8.2.1. Inflow Hydrographs

To link the MIKE-Storm and TUFLOW overland flow models and provide a consistent description of the design flood behaviour within the overall study area, the main inflow boundary conditions for the TUFLOW model were derived from the MIKE-Storm model results.

For each of the local sub-catchments draining within the TUFLOW model domain, local runoff hydrographs were extracted from the MIKE-Storm model and specified as inflow sources to the corresponding inlet pits in the TUFLOW model.

8.2.2. Downstream Boundaries

A range of downstream boundary conditions were adopted in the TUFLOW model as shown on Figure B5. The locations of these boundaries were defined so as to minimize the influence of any boundary condition assumptions on the flood behaviour within the immediate study area.

For overland flow boundaries, boundary conditions were specified as a constant level as appropriate based on peak flood levels from Reference B1.

In terms of the drainage network defined in the TUFLOW model the downstream boundaries are located west of South Dowling Street along known overland flowpaths through O'Dea Avenue, Cooper Place and immediately downstream of Cooper Place and Epsom Road.

In all cases the downstream boundaries are located at a sufficient distance downstream to ensure the assumed boundary locations would have minimal influence on the modelled flow regime within the study area.

9. DESIGN FLOOD RESULTS

9.1. Overview

The numerical model was run for a number of design events and the results used to provide a description of the design flood behaviour of the study area. Information such as peak flood levels and flows were extracted and have been documented as part of this report. In addition, the model results have also been produced in a digital format that can be readily imported into Council's GIS systems.

9.2. Critical Storm Duration

The determination of the critical storm duration for an urban catchment is more complex than for a rural catchment. Consideration must be taken of:

- the peak flow from the sub-catchment surface,
- the peak flow arriving at a surface inlet pit from upstream (conduit and overland flows),
- the peak flow in the pit,
- the volume temporarily collected in ponding areas,
- the location within the catchment.

Standard ARR (Reference 6) storm burst durations ranging from 10 minutes to 3 hours embedded in a 6 hour storm were run for the 1% AEP event. The corresponding peak flow and water level estimates were then compared. The critical burst duration was found to vary across the catchment ranging from 15 to 120 minutes. However a detailed review of the results showed that the relative differences between these storm durations were only minor within the main study area (within 0.025m). In addition, the 60 minute storm was found to be the critical storm burst duration in terms of peak flows and water levels at several key locations within the study area. The 60 minute embedded in the 360 minute storm was therefore adopted as the representative critical duration for the study area to ensure consistency in results and reporting. **However, it is recommended that the full range of storm durations are considered if undertaking detailed investigations for drainage works within the catchment.**

For the PMF, flow hydrographs were also derived for various storm durations up to six hours in accordance with current BoM procedures. The PMF results reported herein (peak flows and flood levels) represent maximums from the envelope of storm durations assessed for the PMF.

9.3. Model Results

Peak flows both within the drainage network and along overland flow paths in the West Kensington catchment are provided in Table B9. A corresponding summary of peak flood heights at selected locations throughout the catchment is provided in Table B10.

In addition, maps of peak flows within the drainage network are shown in Figures B7Figure B7 to B13Figure B13. For each design event, maps of peak depths together with peak flood levels in each of the major trapped low points are provided in Figures B14 to B20.

For the purposes of floodplain risk management in NSW, the floodplain is broadly divided into provisional hazard categories. Maps of the provisional hydraulic hazard (peak velocity x peak depth product) for the 1% AEP and the PMF have been produced (refer to Figures B21 and B22). These values have been categorised in terms of provisional hydraulic hazard in accordance with Reference B2.

Table B9: Summary of Flows at Key Locations (m^3/s)

Location	50% AEP			20% AEP			5% AEP			2% AEP			1% AEP			0.2% AEP			PMF		
	Piped	Overland	Total	Piped	Overland	Total	Piped	Overland	Total	Piped	Overland	Total	Piped	Overland	Total	Piped	Overland	Total	Piped	Overland	Total
O'Dea Avenue (from South Dowling Street)	0.0	2.2	2.2	0.0	2.7	2.7	0.0	4.9	5.0	0.1	6.5	6.5	0.0	7.5	7.5	0.0	7.5	7.5	0.1	33.5	33.5
Todman Avenue (Sobek Inflow)	-	0.2	0.2	-	0.3	0.3	-	0.5	0.5	-	0.6	0.6	-	0.6	0.6	-	0.6	0.6	-	2.3	2.3
Lenthall Street (U/S of low point)	0.1	0.4	0.5	0.1	0.6	0.7	0.2	0.9	1.1	0.2	1.0	1.1	0.2	1.2	1.3	0.2	1.2	1.3	0.2	4.4	4.6
Flow from The Australian golf course	1.5	0.0	1.5	1.7	0.0	1.7	1.9	0.0	1.9	2.0	0.0	2.0	2.2	0.0	2.2	2.2	0.0	2.2	2.6	9.8	12.4
Todman Ave & Balfour Street	1.3	0.1	1.3	2.1	0.1	2.1	2.2	0.2	2.3	2.2	0.2	2.3	2.3	0.2	2.5	2.3	0.2	2.5	3.0	1.2	4.2
Todman Ave & Baker Street	2.3	0.3	2.5	2.1	0.5	2.5	2.3	0.7	2.9	2.3	0.8	3.1	2.5	1.0	3.4	2.5	1.0	3.4	2.9	11.6	14.5

Table B10: Peak Flood Levels and Depths at Key Locations

Location	Minimum Level at Low Point (mAHD)	50% AEP Event		20% AEP Event		5% AEP Event		2% AEP Event		1% AEP Event		0.2% AEP Event		PMF Event	
		Level (mAHD)	Depth (m)	Level (mAHD)	Depth (m)	Level (mAHD)	Depth (m)	Level (mAHD)	Depth (m)	Level (mAHD)	Depth (m)	Level (mAHD)	Depth (m)	Level (mAHD)	Depth (m)
Balfour Road	24.0	24.7	0.7	24.9	0.9	25.1	1.1	25.3	1.3	25.5	1.5	25.8	1.8	26.5	2.5
Raleigh Park Basin	25.5	25.9	0.4	26.1	0.6	26.5	1.0	26.7	1.2	26.9	1.4	27.4	1.9	28.3	2.8
South Dowling Street Low Point opp.	25.7	26.3	0.6	26.6	0.9	26.9	1.2	26.9	1.2	27.0	1.3	27.2	1.5	27.5	1.8
McDougall Street	23.2	23.9	0.7	24.0	0.8	24.3	1.1	24.5	1.3	24.6	1.4	24.6	1.4	25.0	1.8
Milroy Avenue	24.3	24.7	0.4	24.9	0.6	25.0	0.7	25.0	0.7	25.1	0.8	25.1	0.8	25.5	1.2
Virginia Street	23.8	24.0	0.2	24.1	0.3	24.1	0.3	24.1	0.3	24.1	0.3	24.2	0.4	24.4	0.6
Lenthall Street	20.4	21.9	1.5	22.0	1.6	22.1	1.7	22.1	1.7	22.1	1.7	22.2	1.8	22.4	2.0
Ingram Street	refer note	21.8	refer note	21.9	refer note	22.1	refer note	22.1	refer note	22.2	refer note	22.3	refer note	23.0	refer note
Australian Golf Course	refer note	22.8	refer note	23.0	refer note	23.2	refer note	23.4	refer note	23.6	refer note	23.8	refer note	24.6	refer note
South Dowling Street	refer note	22.3	refer note	22.4	refer note	22.5	refer note	22.6	refer note	22.6	refer note	22.8	refer note	23.8	refer note
NOTES: Depths calculated at trapped low points only.															
Key Locations shown in Figure 1															

10. SENSITIVITY ANALYSES

10.1. Overview

The model established for the present study relies on a number of assumed parameters, the values of which are considered to be the most appropriate for urban catchments based on previous use and experience in other studies of similar catchments. Although a limited model validation has been performed, a range of sensitivity analyses was also undertaken to quantify the potential variation in the model results due to different assumptions in the key modelling parameters adopted.

The following scenarios were considered to represent the envelope of likely parameters values:

- - 20% and +20% change in design rainfall,
- increase amount of rainfall loss (low runoff potential) Initial Loss: Paved = 2mm, grassed = 10 mm, AMC = 1,
- decrease amount of rainfall losses (high runoff potential) Initial Loss: paved = 0 mm, grassed = 0 mm, AMC 4 (unchanged),
- ±20% change in Manning's 'n' value for overland flow paths.

When interpreting results, it should be noted that undertaking sensitivity analyses for the drainage system may not always result in a change in peak flow attained downstream if for instance, the size of the pipe or pit is the control and there is no change in the flow conveyed in the pipe. There may be a change in the overland flow but the effect further downstream will depend on the particular characteristics of the pit and pipe network. At some locations the change in upstream flow may not be reflected downstream due to the effects of ponding at sag pits or the relative timing of overland flows.

10.2. Results

For each of the above scenarios, the models were run for the 1% AEP embedded 60 minute duration design storm. A relative comparison of the resultant changes in peak flows and flood heights at various locations is provided in Table B11 and Table B12 respectively.

Table B11: Sensitivity Analyses – Change in Peak Flow for 1% AEP Design Event (%)

Location	Manning's 'n' - 20%			Manning's 'n' + 20%			Rainfall - 20%			Rainfall +20%			Rainfall loss low			Rainfall loss high		
	Piped	O'land	Total	Piped	O'land	Total	Piped	O'land	Total	Piped	O'land	Total	Piped	O'land	Total	Piped	O'land	Total
O'Dea Avenue (from South Dowling Street)	-7%	1%	1%	3%	-2%	2%	-29%	-29%	-29%	30%	45%	45%	4%	6%	6%	-11%	-11%	-11%
Todman Avenue (Sobek Inflow)	-	1%	1%	-	-2%	-2%	-	-24%	-24%	-	30%	30%	-	3%	3%	-	0%	0%
Lenthall Street (U/S of low point)	-1%	1%	1%	0%	3%	3%	3%	-16%	-14%	-5%	29%	25%	-3%	3%	2%	1%	7%	6%
Flow from The Australian Golf Course	-2%	0%	-2%	0%	0%	0%	-11%	0%	-11%	6%	0%	6%	1%	0%	1%	-2%	0%	-2%
Todman Ave & Balfour Street	-3%	11%	-2%	0%	7%	1%	-8%	-23%	-5%	7%	-1%	11%	0%	5%	0%	-1%	0%	-1%
Todman Ave & Baker Street	0%	2%	1%	0%	-5%	-1%	-4%	-26%	-10%	4%	33%	13%	0%	4%	1%	-1%	0%	-1%

Table B12: Sensitivity Analyses – Change in Peak Flood Height for 1% AEP Design Event (m)

Location	Manning's 'n' - 20%	Manning's 'n' + 20%	Rainfall - 20%	Rainfall +20%	Rainfall loss low	Rainfall loss high
Raleigh Park Basin	0.00	0.00	-0.41	0.40	-0.12	0.03
South Dowling St (opp. Supacenta)	0.00	0.01	-0.10	0.13	-0.04	0.02
Balfour Road Lowpoint	-0.10	0.01	-0.38	0.34	-0.05	-0.01
McDougall St Lowpoint	0.00	0.00	-0.21	0.07	-0.05	0.01
Australian Golf Course	-0.04	0.00	-0.31	0.23	-0.06	0.02
Lenthall Street Lowpoint	0.01	0.01	-0.05	0.05	-0.01	0.01
Milroy Ave Lowpoint	0.00	0.00	-0.07	0.05	-0.01	0.00
South Dowling Street Lowpoint	0.00	0.00	-0.11	0.14	0.00	0.02
Virginia St	0.00	0.00	-0.03	0.03	0.00	0.00

The results from the sensitivity analyses can be summarised as follows:

- A +20% change in the rainfall produces a corresponding 30% to 45 % (approximately) increase in peak overland flow.
- Increasing the amount of rainfall losses and changing the AMC to 1 has reduced the peak overland flows by up to 11%.
- Decreasing the amount of rainfall losses and maintaining the AMC at 4 typically has resulted in little change.
- Changing the Manning's 'n' value for overland flow paths has very little effect on peak flows.

In terms of the corresponding impacts on flood height estimates, the greatest variations were caused by variations in the applied rainfall. For an increase in rainfall of +20%, flood levels were found to increase by up to 0.4 m compared to the base case. The estimated flood levels were much less sensitive to variations in other model parameters with results for other scenarios being typically within ±0.1 m of the base case results.

In terms of assumed infiltration rate, the results show that the adopted parameters are reasonably robust and do not have a notable impact on estimated 1% AEP flood levels for this catchment. However, given the relatively sandy nature of the soils typically found in this and adjacent catchments it is recommended that opportunities for testing of soil infiltration and/or the monitoring of runoff behaviour in pervious open space areas be pursued in the future (in coordination with relevant agencies).

10.3. Accuracy of Estimated Flood Levels

Due to the limited quantity and quality of the calibration data available and in view of the sensitivity analyses, it is estimated that the order of accuracy of the design flood levels is in the order of accuracy will be ±0.3m. The accuracy of the flood extent largely depends on the slope of the land and may vary from of the order of 1m to 10m (say). These orders of accuracy are typical of such studies and can only be improved upon with additional observed flood data to refine the model calibration and more detailed and accurate definition of the terrain.

For site specific studies, it is recommended that the flood extent be confirmed using local detailed ground survey.

11. CONCLUSIONS

Detailed numerical models to quantify the hydrology and hydraulics of the West Kensington catchment have been established making best use of the data currently available. These models have been used to define the design flood behaviour for existing conditions.

The current models are significantly more detailed and refined compared to others prepared for previous studies. Given the level of detail used in the present study and the improved topographic datasets, the more recent results can be interpreted with a greater level of confidence than those published previously.

These models are therefore suitable for use in the Floodplain Risk Management Study.

12. ACKNOWLEDGEMENTS

This study was carried out by WMAwater and funded by Randwick City Council, and the Department of Environment and Climate Change and Water (now Office of Environment and Heritage). The assistance of the following in providing data and guidance to the study is gratefully acknowledged:

- Randwick City Council,
- City of Sydney,
- Department of Environment and Climate Change and Water (now Office of Environment and Heritage),
- West Kensington Floodplain Management Committee,
- residents of West Kensington catchment.

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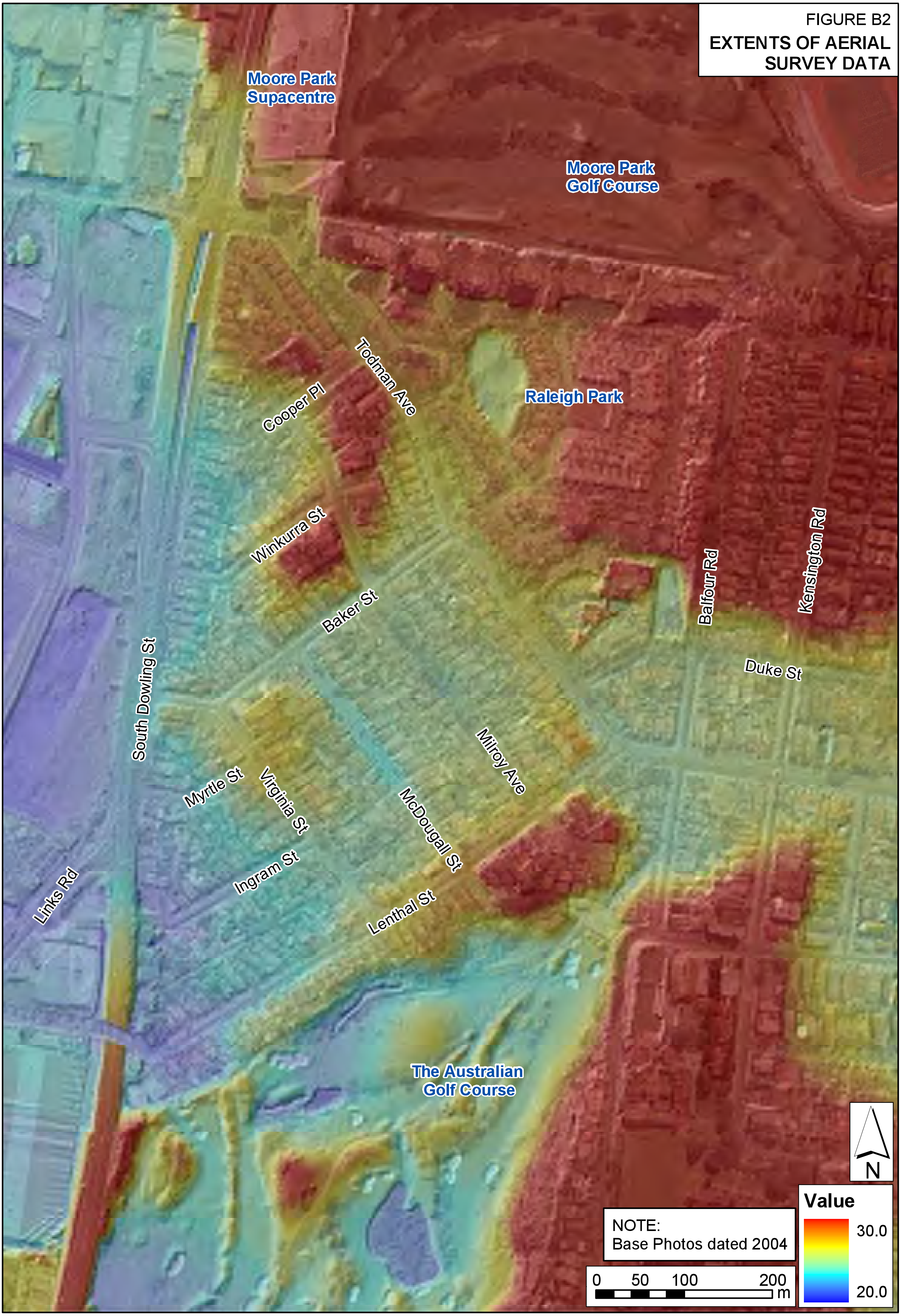
Figures

FIGURE B1
STUDY AREA

J:\Jobs\28041-04\Arcview\Maps\Report\Figure1_StudyArea.mxd

FIGURE B2
EXTENTS OF AERIAL SURVEY DATA



NOTE:
Base Photos dated 2004

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FIGURE B3
HYDROLOGICAL MODEL
SUBCATCHMENT LAYOUT

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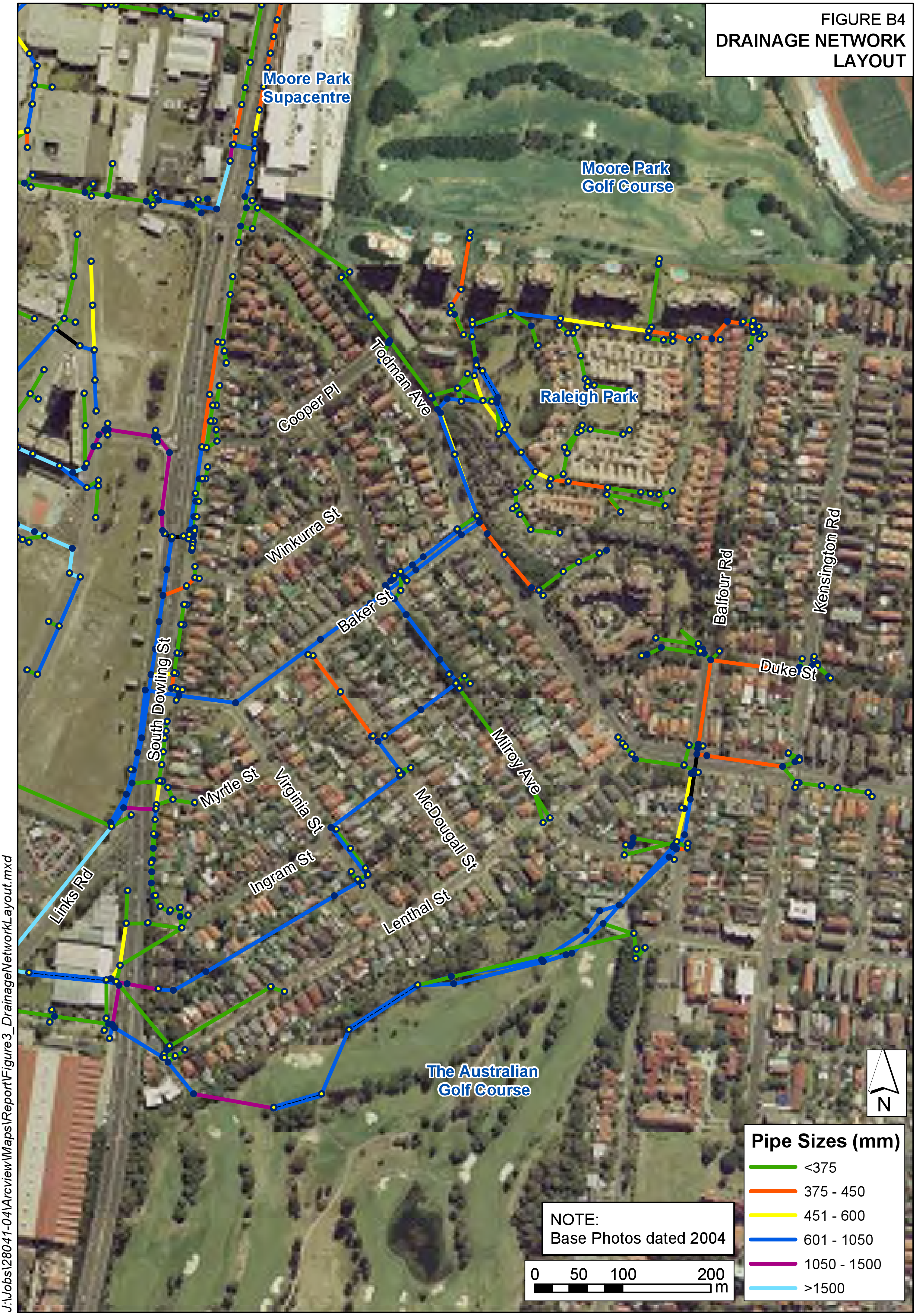
FIGURE B4
DRAINAGE NETWORK LAYOUT
Moore Park Supacentre
Moore Park Golf Course
Raleigh Park
Todman Ave
Cooper Pl
Winkurra St
Baker St
South Dowling St
Balfour Rd
Kensington Rd
Duke St
Milroy Ave
Myrtle St
Virginia St
McDougall St
Ingram St
Lenthal St
Links Rd
The Australian Golf Course
Pipe Sizes (mm)
<375
375 - 450
451 - 600
601 - 1050
1050 - 1500
>1500
NOTE:
Base Photos dated 2004
0 50 100 200 m
N
J:\Jobs\28041-04\Arcview\Maps\Report\Figure3_DrainageNetworkLayout.mxd

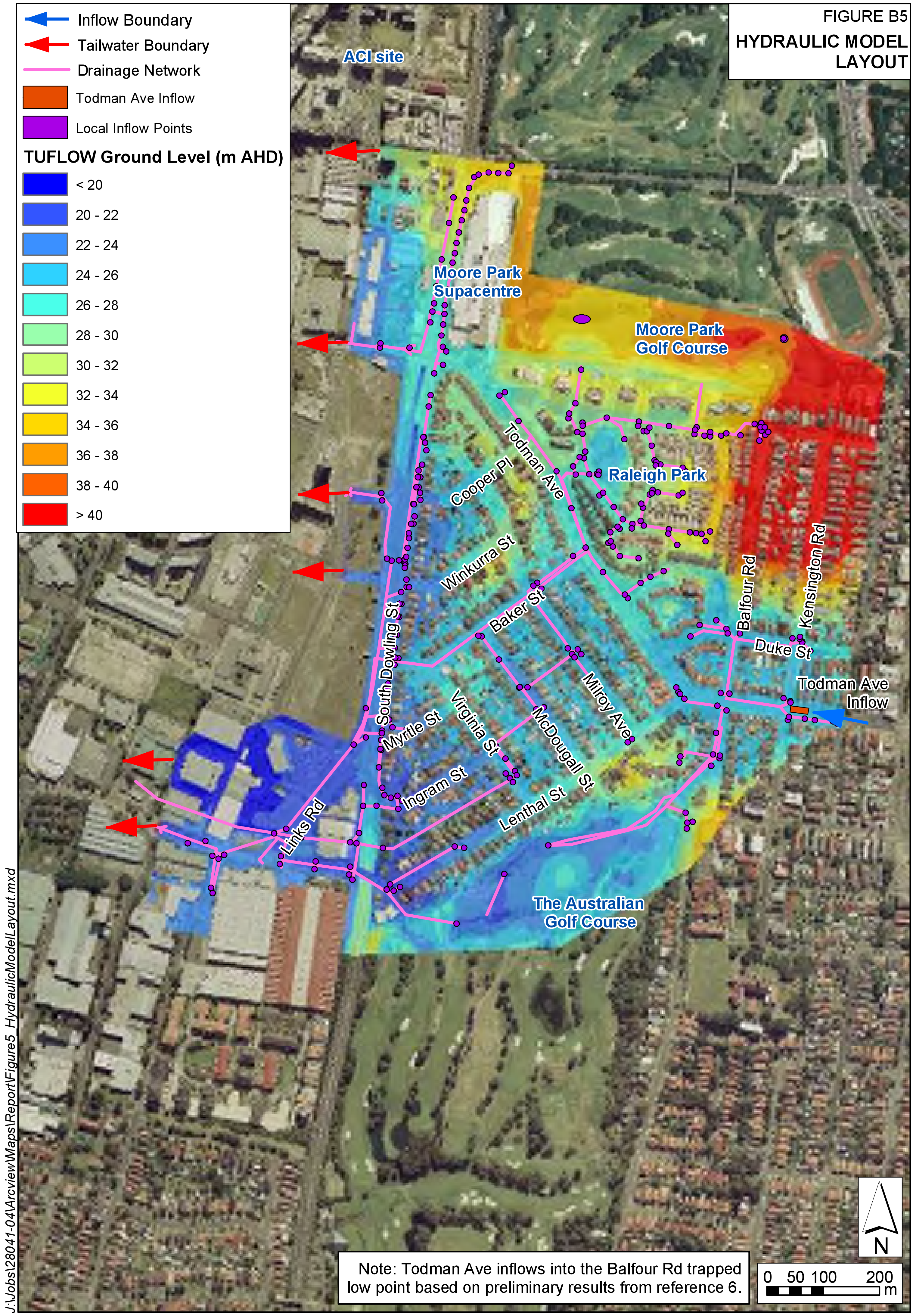

FIGURE B5
HYDRAULIC MODEL LAYOUT
Inflow Boundary
Tailwater Boundary
Drainage Network
Todman Ave Inflow
Local Inflow Points
TUFLOW Ground Level (m AHD)
< 20
20 - 22
22 - 24
24 - 26
26 - 28
28 - 30
30 - 32
32 - 34
34 - 36
36 - 38
38 - 40
> 40
ACI site
Moore Park Supacentre
Moore Park Golf Course
Raleigh Park
Todman Ave
Cooper Pl
Winkurra St
Baker St
South Dowling St
Balfour Rd
Kensington Rd
Duke St
Todman Ave Inflow
Milroy Ave
McDougall St
Virginia St
Myrtle St
Ingram St
Lenthal St
Links Rd
The Australian Golf Course
N
0 50 100 200 m
Note: Todman Ave inflows into the Balfour Rd trapped low point based on preliminary results from reference 6.
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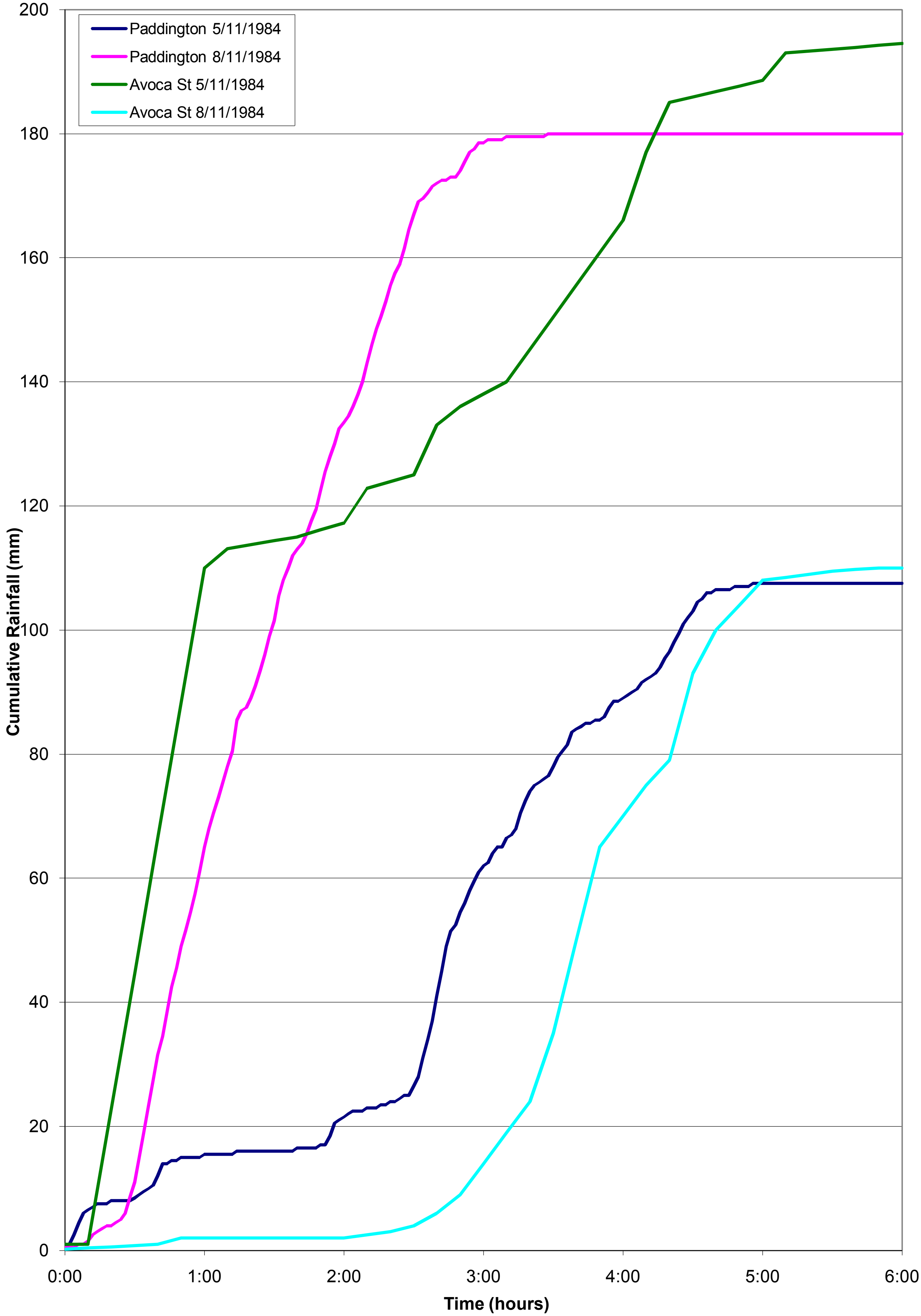
Figure B6

RAINFALL PATTERNS
NOVEMBER 1984 STORM EVENTS



Note: only peak flows in pipe network shown
FIGURE B7
DRAINAGE NETWORK
PEAK FLOWS
50% AEP EVENT
Moore Park Supacentre
Moore Park Golf Course
Raleigh Park
Todman Ave
Cooper Pl
Winkurra St
Baker St
South Dowling St
Myrtle St
Virginia St
Ingram St
McDougall St
Milroy Ave
Lenthal St
Balfour Rd
Kensington Rd
Duke St
The Australian Golf Course
NOTE:
Base Photos dated 2004
0 50 100 200 m
N
Flow (m3/s)
< 0.5
0.5 - 1
1 - 2
> 2
J:\Jobs\28041-04\Arcview\Maps\Report\Figure7_DrainageNetworkPeakFlow_002y.mxd


Note: only peak flows in pipe network shown
FIGURE B8
DRAINAGE NETWORK
PEAK FLOWS
20% AEP EVENT
Moore Park
Supacentre
Moore Park
Golf Course
Raleigh Park
Todman Ave
Cooper Pl
Winkurra St
Baker St
South Dowling St
Myrtle St
Virginia St
Ingram St
McDougall St
Lenthal St
Milroy Ave
Balfour Rd
Kensington Rd
Duke St
Rd
The Australian
Golf Course
NOTE:
Base Photos dated 2004
0 50 100 200
m
N
Flow (m3/s)
< 0.5
0.5 - 1
1 - 2
> 2
J:\Jobs\28041-04\Arcview\Maps\Report\Figure8_DrainageNetworkPeakFlow_005y.mxd

Note: only peak flows in pipe network shown
FIGURE B9
DRAINAGE NETWORK
PEAK FLOWS
5% AEP EVENT
Moore Park
Supacentre
Moore Park
Golf Course
Raleigh Park
Todman Ave
Cooper Pl
Winkurra St
Baker St
South Dowling St
Myrtle St
Virginia St
Ingram St
McDougall St
Milroy Ave
Lenthal St
Balfour Rd
Kensington Rd
Duke St
The Australian
Golf Course
NOTE:
Base Photos dated 2004
0 50 100
m
N
Flow (m3/s)
< 0.5
0.5 - 1
1 - 2
> 2
J:\Jobs\28041-04\Arcview\Maps\Report\Figure9_DrainageNetworkPeakFlow_020y.mxd

FIGURE B10
DRAINAGE NETWORK
PEAK FLOWS
2% AEP EVENT
Note: only peak flows in pipe network shown
Moore Park
Supacentre
Moore Park
Golf Course
Raleigh Park
Todman Ave
Cooper Pl
Winkurra St
Baker St
South Dowling St
Myrtle St
Virginia St
Ingram St
McDougall St
Milroy Ave
Lenthal St
Balfour Rd
Kensington Rd
Duke St
The Australian
Golf Course
NOTE:
Base Photos dated 2004
0 50 100
m
N
Flow (m3/s)
< 0.5
0.5 - 1
1 - 2
> 2
J:\Jobs\28041-04\Arcview\Maps\Report\Figure10_DrainageNetworkPeakFlow_050y.mxd

J:\Jobs\28041-04\Arcview\Maps\Report\Figure11_DrainageNetworkPeakFlow_100y.mxd


FIGURE B12
DRAINAGE NETWORK
PEAK FLOWS
0.2% AEP EVENT
Note: only peak flows in pipe network shown
Moore Park Supacentre
Moore Park Golf Course
Todman Ave
Cooper Pl
Raleigh Park
Winkurra St
Baker St
Balfour Rd
Kensington Rd
Duke St
South Dowling St
Milroy Ave
Myrtle St
Virginia St
McDougall St
Ingram St
Lenthal St
The Australian Golf Course
N
Flow (m3/s)
< 0.5
0.5 - 1
1 - 2
> 2
NOTE:
Base Photos dated 2004
0 50 100
m
J:\Jobs\28041-04\Arcview\Maps\Report\Figure12_DrainageNetworkPeakFlow_500y.mxd

FIGURE B13
DRAINAGE NETWORK PEAK FLOWS PMF EVENT

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FIGURE B14
PEAK FLOOD LEVELS AND DEPTHS
50% AEP EVENT
Moore Park Supacentre
Moore Park Golf Course
Raleigh Park
The Australian Golf Course
26.3
25.9
22.3
24.7
23.9
24.7
24
21.8
21.9
22.8
Todman Ave
Cooper Pl
Winkurra St
Baker St
Milroy Ave
McDougall St
Virginia St
Myrtle St
Ingram St
Lenthal St
South Dowling St
Links Rd
Balfour Rd
Kensington Rd
Duke St
N
Mapping Extent
Peak Flood Level (m AHD)
Peak Depth (m)
< 0.2
0.2 - 0.5
0.5 - 1
> 1
NOTE:
Base Photos dated 2004
0 50 100 200
m
J:\Jobs\28041-04\ArcviewMaps\Report\Figure14_PeakFloodLevelsandDepths_002y.mxd


FIGURE B15
PEAK FLOOD LEVELS
AND DEPTHS
20% AEP EVENT
Moore Park
Supacentre
26.6
Moore Park
Golf Course
Todman Ave
Cooper Pl
26.1
Raleigh Park
Winkura St
22.4
Baker St
Balfour Rd
Kensington Rd
24.9
Duke St
South Dowling St
24
Milroy Ave
Myrtle St
Virginia St
McDougall St
24.9
Links Rd
24.1
Ingram St
21.9
Lenthal St
22
23
The Australian
Golf Course
N
Peak Flood Level (m AHD)
Mapping Extent
Peak Depth (m)
< 0.2
0.2 - 0.5
0.5 - 1
> 1
NOTE:
Base Photos dated 2004
0 50 100 200
m
J:\Jobs\28041-04\ArcviewMaps\Report\Figure15_PeakFloodLevelsandDepths_005y.mxd

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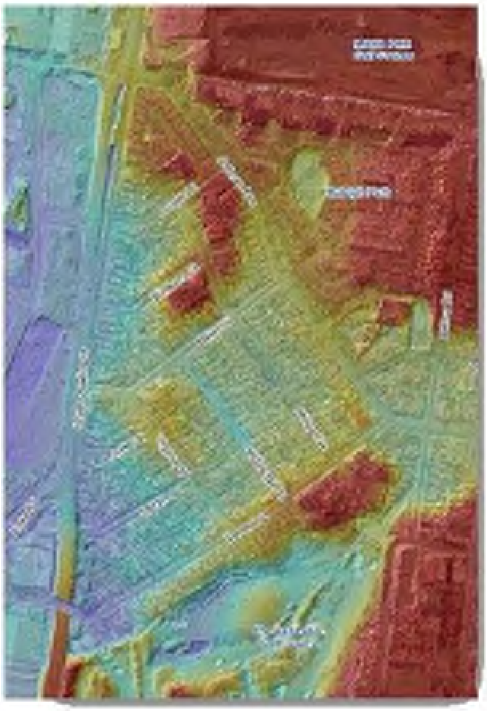
WEST KENSINGTON CATCHMENT

FLOODPLAIN RISK MANAGEMENT PLAN

OCTOBER 2011



Randwick City Council
a sense of community

Level 2, 160 Clarence Street
Sydney, NSW, 2000

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

WEST KENSINGTON FLOODPLAIN RISK MANAGEMENT PLAN

FINAL – RANDWICK CITY COUNCIL

Project **West Kensington Floodplain Risk Management Plan**	**Project Number** **28041-01**
Client **Randwick City Council**	**Client's Representative** Terry Kefalianos
Authors **Matt Chadwick** **Richard Dewar**	**Prepared by**
Date **October 11**	**Verified by**

Revision	Description	Date
4	Randwick City Council Final	13 October 2011
3	Draft Report For Public Exhibition	9/2/2011
2	Revised Draft Report For Committee Review	23/12/2010
1	Draft Report For Internal Council Review	23/11/2010

WEST KENSINGTON FLOODPLAIN RISK MANAGEMENT PLAN

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FOREWORD

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

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

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

1. Flood Study
- 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.

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

The West Kensington Floodplain Risk Management Plan constitutes the third stage of the management process for the West Kensington catchment. WMAwater has been commissioned to undertake this study by Randwick City Council (RCC) and the City of Sydney (CoS). Funding assistance and specialist technical advice has also been provided by the NSW Department of Environment, Climate Change and Water (DECCW) (now Office of Environment and Heritage). The outcomes are to support the future management of flood liable lands in the West Kensington catchment.

EXECUTIVE SUMMARY

WEST KENSINGTON CATCHMENT

The West Kensington catchment covers approximately 0.9 km^2 and drains predominantly from east to west. It is bounded by Moore Park golf course to the north; The Australian golf course to the south, South Dowling Street to the west and is predominantly zoned for residential usage. The study area lies within the upper reaches of the broader (2.5 km^2) Green Square – West Kensington (GSWK) catchment.

Urbanisation has dramatically altered the nature of available drainage within the catchment. Flood problems typically result from ponding in trapped low-points such as those found in Milroy Avenue, McDougall Street and at the Lenthall Street underpass below the Eastern Distributor. Ponding also occurs at various locations along the eastern side of South Dowling Street. A number of the trapped low points in West Kensington are known to have experienced severe flooding during the November 1984 events.

The NSW Government's Flood Policy provides for:

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

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

WEST KENSINGTON FLOOD STUDY

The GSWK catchment is known to have experienced flooding of roads, residential properties and commercial areas. The most recent significant floods occurred in November 1984.

The GSWK Flood Study (Reference 1) was jointly undertaken by both City Of Sydney (CoS) and Randwick City Council (RCC) to quantity existing flood behaviour and identify flood risk management issues within the area. As part of the subsequent GSWK Floodplain Risk Management Study (Reference 2), the models of the West Kensington area were refined to take advantage of more detailed topographic data made available by RCC. The specific objectives of the Flood Study components were to:

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

Hydrologic and hydraulic investigations have been undertaken to determine the response of the catchment and drainage system to 50% AEP (1 in 2 year), 20% (1 in 5 year), 5% AEP (1 in 20 year), 2% AEP (1 in 50 year), 1% AEP (1 in 100 year) and 0.2% AEP (1 in 500 year) events and the Probable Maximum Flood (PMF). The results of these investigations are documented in the two studies and included peak pipe capacities in addition to peak flood levels, flows and velocities within the floodplain.

EXISTING FLOOD PROBLEM

A flood damages assessment for existing development was undertaken for a range of design events. This assessment was based on a detailed survey of building floor levels in the West Kensington area. The estimated number of residential building floors which are likely to be inundated in the 5 year ARI is 25 and 55 in the 100 year ARI. In the PMF up to 154 building floors would be inundated. The annual average damages were estimated to be close to $0.5million. No consideration has been given for damages to public structures or utilities (bridges, roads, pumping stations) or for the complete collapse of structures due to flooding.

FUTURE DEVELOPMENT

The majority of the catchment has been developed for residential usage and there is limited pressure to re-develop existing properties on the floodplain.

WEST KENSINGTON CATCHMENT FLOODPLAIN RISK MANAGEMENT STUDY

The specific aims of this study were to:

- refine the existing Flood Study models of the West Kensington area to take advantage of more detailed topographic data,
- analyse the Flood Study results to determine flood damages and flood hazard for existing conditions,
- identify development and planning controls to regulate redevelopment in the flood affected properties and to ensure that future redevelopment does not significantly add to the overall potential damage,
- make recommendations to adopt Flood Planning Levels (FPL) appropriate for the catchment,
- investigate available floodplain risk management measures along with prioritisation, and staging of works.

FLOODPLAIN RISK MANAGEMENT MEASURES

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

A summary of the various floodplain management measures considered during the course of the Floodplain Risk Management Study is presented in Table i) and Figure A, including a brief assessment of their viability for implementation as part of the Floodplain Risk Management Plan for the West Kensington catchment.

Table i): Review of Floodplain Management Measures

MEASURE	PURPOSE	COMMENTS	ECONOMIC ASSESSMENT	IMPLEMENTATIO N VIABILITY	ACTION	PRIORITY
FLOOD MODIFICATION MEASURES:						
FLOOD MITIGATION DAMS	Reduce flows from upper catchment areas, water storage.	Major dams are not practical. Many issues (cost, social, environmental) would need to be resolved in order to justify construction of major dams and any land acquisition process.	Generally not viable for small urban catchments.	Not viable.	No further consideration to be given.	-
RETARDING (DETENTION) BASINS	Reduce flows from upper catchment areas.	A number of basins already exist within the catchment. Opportunities for new basins within the catchment are constrained by land availability. Several locations currently being considered for larger basins include upstream of Joynton Avenue lowpoint (Precinct E) and the Moore Park golf course.	Generally not viable from a purely flooding perspective but more attractive if has water quality and stormwater harvesting benefits.	To be considered as a means of mitigating the effects of urban development.	Potential for detention basin / stormwater harvesting basin within Moore Park golf course to be further investigated. Council to discuss options with Moore Park golf club.	Medium
PIT/PIPE and TRUNK SYSTEM UPGRADE	To minimise overland flooding, particularly for smaller, more frequent events	Upgrades of trunk capacity are being considered at a number of locations, particularly where associated with re-development activities. Regional upgrades being considered as part of major urban renewal (e.g. Mid-Block and GSTC precincts), local improvements considered for established areas (e.g. Duke St).	Urban renewal activities provide opportunity to account for typically high costs as part of overall re-development. However, costs can be significant where there are conflicts with existing services infrastructure.	To be considered as part of any urban re-development activities. Must ensure that any improvements in upstream pipe capacity results in no adverse impacts downstream.	Upgrade pipe network in vicinity of Duke Street & Balfour Road. Undertake discussions with City of Sydney (CoS) & Sydney Water regarding potential upgrades to downstream trunk system as part of re-development activities within CoS LGA. Investigate options jointly with the RTA, to manage impacts of the sound walls on South Dowling Street. Apart from these options no further consideration to be given to trunk drainage upgrades.	Medium
LEVEES, FLOOD	Prevents or reduces	No appropriate sites.	Not undertaken.	Not applicable.	No further consideration	-

GATES AND PUMPS	the frequency of inundation of protected areas, assists in reducing problems with local runoff issues.				to be given.	
MANAGEMENT OF BLOCKAGE	Minimise opportunity for blockage to ensure that drainage system operates effectively during an event.	Blockage of inlets and culverts is a major problem in urban catchments, can significantly affect local flood levels. Measures can include street sweeping, inlet works etc.	Relatively low cost to implement although benefits are difficult to quantify due to uncertainties in blockage behaviour.	Measures to manage blockage within the system are relatively easy to implement and should be actively supported.	Council to consider blockage protection works at major trapped low points and undertake works as appropriate.	High
PROPERTY MODIFICATION MEASURES:						
HOUSE RAISING	Prevent flooding of existing buildings by raising habitable floor levels.	No suitable buildings found within the study catchment.	High cost per property. May introduce social problems.	Not considered suitable.	No further consideration to be given.	-
VOLUNTARY HOUSE PURCHASE	To remove flood liable houses from the floodplain.	May be limited opportunities within West Kensington catchment	Not financially viable due to the high cost of acquisition.	Do nothing.	No further consideration to be given.	-
FLOOD PROOFING	Prevents inundation of floodwaters.	Generally only suitable for non-residential buildings.	Depends upon building. Not funded by the State Government.	To be promoted where applicable.	Only suitable for retrofitting of existing development by property owner. No further consideration to be given for the use of flood proofing for new development.	Low
FLOOD PLANNING LEVELS	To minimise flood damages to new developments.	Existing controls have been reviewed for both Councils and potential improvements have been suggested.	Negligible cost.	Amendments and improvements to be prepared by Council.	Council to consider adoption of consistent FPLs. To be implemented via creation of appropriate planning instruments (see below).	High
DEVELOPMENT CONTROL PLANNING	To ensure new development reduces the flooding and drainage impacts on downstream properties, the pollutant loads and conserves potable water supplies.	Existing guidelines have been reviewed and possible improvements have been suggested. All Development Applications in the floodplain must be supported by a Flood Study.	Negligible cost.	Amendments to be considered.	Council to implement suitable development controls through the creation of appropriate planning instruments. Provide appropriate flood-related information on planning certificates.	High
CLIMATE CHANGE	Assess possible impacts of climate change and include in	Potential increases in rainfall intensity will affect the entire catchment.	Unknown.	To be considered.	Incorporate climate change risk into Flood Planning Levels.	Medium

	Flood Planning Level				Monitor future scientific research and review management measures as required	
WATER SENSITIVE URBAN DESIGN (WSUD)	To minimise runoff volume, rate of runoff and to improve runoff quality.	Should be employed where opportunities arise.	Variable.	To be promoted.	Incorporate WSUD in planning controls and future Council works as appropriate	Medium
RESPONSE MODIFICATION MEASURES:						
FLOOD WARNING	Enable people to evacuate and take measures to reduce flood damages.	An effective flood warning system is not possible due to the short response time of the Green Square – West Kensington catchment.	Not applicable.	Not viable.	No further action by Council required.	-
EMERGENCY RESPONSE PLANNING	To ensure that evacuation can be undertaken in a safe and efficient manner.	The SES should prepare a Local Flood Plan.	Relatively low cost.	Recommended.	Provide SES with flood information and work together to prepare Local Flood Plan	High
PUBLIC INFORMATION COMMUNITY AWARENESS AND RESPONSE	Educate people on flood risk and community preparedness to minimise flood damages and reduce the flood risk.	A cheap and effective method but requires continued effort. Examples of methods are provided.	Benefits likely to be significant for relatively low cost. Effectiveness reduces with time since last flood.	Recommended.	Develop and implement suitable flood awareness program. Maintain flooding database. Provide access to flood studies, floodplain risk management studies and plans via Council's website.	High

FIGURE A

OVERVIEW OF WEST KENSINGTON FLOODPLAIN RISK MANAGEMENT PLAN

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OUTCOMES FOR SITE SPECIFIC WORKS IN WEST KENSINGTON AREA

(refer to Adjacent Map)

HIGH PRIORITY ACTIONS:

Management of Blockage

- Consider works to minimise blockage at major trapped low points and undertake works as appropriate

MEDIUM PRIORITY ACTIONS:

Pit/Pipe and Trunk System Upgrades

- Upgrade pipe network in vicinity of Duke Street and Balfour Road.
- Undertake discussions with City of Sydney (CoS) & Sydney Water regarding potential upgrades to downstream trunk system as part of re-development activities within CoS LGA.
- Apart from these options no further consideration to be given to trunk drainage upgrades.

Detention Basins

- Potential for detention basin/stormwater harvesting basin within Moore Park Golf Course to be further investigated.
- Council to discuss options with Moore Park Golf Club.

OUTCOMES FOR BROADER WEST KENSINGTON AREA

HIGH PRIORITY ACTIONS:

Planning Instruments and Development Controls

- Implement suitable development controls through creation of appropriate planning instruments.
- Provide appropriate flood-related information on planning certificates.

Flood Planning Levels (FPLs)

- Consider adoption of consistent Flood Planning Levels.
- FPLs to be implemented via creation of appropriate planning instruments.

Public Information, Community Flood Awareness and Response

- Develop and implement flood awareness program.
- Formalise and maintain flooding database.
- Provide free access to flood related information such as flood studies, floodplain risk management studies and plans (e.g. via Council web-site).

Emergency Response Planning

- Council to provide SES with flood information and work together to prepare Local Flood Plan.

MEDIUM PRIORITY ACTIONS:

Climate Change

- Incorporate climate change risk into Flood Planning Levels.
- Monitor future scientific research and review management measures.

Water Sensitive Urban Design

- Incorporate Water Sensitive Urban Design into planning controls and future Council works as appropriate.

LOW PRIORITY ACTIONS:

Flood Proofing

- Only suitable for retrofitting of existing development by property owner.
- No further consideration to be given for the use of flood proofing for new development.

1. INTRODUCTION

1.1. Background

The West Kensington study catchment has an area of approximately 0.9 km^2 and drains predominantly from east to west (refer Figure 1). The study area lies within the upper reaches of the broader (2.5km^2) Green Square – West Kensington (GSWK) catchment. The area is predominantly located within the Randwick City Council (RCC) Local Government Area (LGA), although portions of the contributing catchment also lie within the City of Sydney (CoS) LGA.

Flooding problems have been experienced at a number of locations within the West Kensington area during periods of heavy rainfall. The catchment is fully urbanised and consists predominantly of established residential areas together with some open space. Drainage within the catchment is mainly by pit and pipe networks with surcharging flows conveyed overland along streets. Flood problems typically result from ponding in trapped low-points such as those found in Milroy Avenue, McDougall Street and at the Lenthall Street underpass below the Eastern Distributor. Ponding also occurs at various locations along the eastern side of South Dowling Street. A number of the trapped low points in West Kensington are known to have experienced severe flooding during the November 1984 events.

Recognising the importance of having a consistent approach across the catchment RCC and the CoS have initiated a floodplain risk management program for the broader GSWK catchment. This current document has been prepared based on the results of the previous catchment-wide studies prepared as part of the overall GSWK floodplain risk management process.

1.2. Floodplain Risk Management Process

As described in the Floodplain Development Manual (Reference 3), the Floodplain Risk Management Process entails four sequential stages:

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

The West Kensington Floodplain Risk Management Plan constitutes the third stage of the management process for the West Kensington catchment. The Flood Study stage was completed in April 2010 with the draft publication of the West Kensington Flood Study (Reference 4). (Note that the latter document has since being incorporated as an Appendix to Reference 2). A combination of hydrologic and hydraulic models was used in the Flood Study to determine design flood levels for the West Kensington catchment. This study made use of more recent information and superseded a previous Flood Study completed in April 2008 (Reference 5). The Floodplain Risk Management Study was completed in November 2011 (Reference 2).

2. STUDY AREA

2.1. Catchment Description

The land use within the study area is predominantly urban residential development, comprising mainly free standing dwellings although there is a limited amount of medium and high density complexes. There are no significant industrial developments and few major commercial developments.

The upper reaches of the catchment are flanked by open space areas within the Moore Park and The Australian golf courses. There are also a number of smaller parks and private open space areas throughout the catchment.

Drainage throughout much of the catchment is characterised by underground pipe systems and overland flow conveyed along the roads, which are nearly entirely formed with kerbs and gutters. An overland flowpath also forms along the property easement between Ingram Street and Lenthall Street (refer to Photo 1).

Photo 1: Easement between Ingram Street and Lenthall Street (view towards Virginia Street)

Overland flow from the Virginia Street trapped lowpoint flows along this easement in large events.

Photo 2: Inlet pits near Dowling Street adjacent to the noise walls on South Dowling Street/Eastern Distributor

Located at the downstream end of West Kensington, the Eastern Distributor (noise walls to the right of the photo) forms a barrier to overland flow in some locations. Drainage in these areas relies upon sub-surface drainage through to CoS LGA.

Much of the West Kensington catchment was developed between 1912-1920 and was fully developed by the 1940's with most of the subsurface drainage system in the West Kensington area estimated to have been constructed prior to the 1930s (Reference 5). Major changes since 1980 have included the re-development of industrial premises at Raleigh Park into medium density residential estate and drainage works associated with the Eastern Distributor (refer to Photo 2).

2.2. Existing Flood Environment

Flooding in the catchment typically occurs due to intense rainfall that may be experienced during thunderstorms (as occurred in all previous events in the 1980's and 1990's). As discussed in Reference 1, urbanisation has dramatically altered the nature of available drainage within the catchment and has led to:

- a major increase in the proportion of paved area and consequent reduction in pervious areas, resulting in corresponding increases in runoff (in terms of both peak flows and volumes), and
- development within the trapped depressions that were once swamps or dams, resulting in flood problems in these areas. Examples within the West Kensington catchment include Milroy Avenue and McDougall Street. Damages have been incurred at these locations during past floods such as the November 1984 events.

In view of the above, flood problems within the catchment are generally the result of insufficient capacity within the trunk drainage system and the general lack of a formal overland flow system to provide controlled capacity in large events. Based on evidence from past floods flooding can be exacerbated by blocked local drainage and restricted overland flow paths (Reference 4).

Given the natural topography of this area most of the flood problems occur in the known low points where there is insufficient drainage capacity to convey runoff during periods of intense rainfall. This includes locations such as Milroy Avenue, Balfour Road, McDougall Street and Duke Street (refer to Photos 3 and 4). Results from the Flood Study for the smaller design events are consistent with local observations that ponding within the roadway for these areas occurs relatively frequently. For larger events the design flood levels compare well with observed levels from the event of 8-9 November 1984. This outcome lends confidence to the modelling results and highlights the severity of the flood problem in these areas.

Photo 3: Trapped low point in Milroy Avenue

A number of major trapped lowpoints such as the one shown above exist throughout the West Kensington catchment.

Photo 4: Localised ponding in Duke Street following minor rainfall

This area has limited grade and existing kerb and guttering is disrupted by tree roots.

In addition to the above locations the modelling results indicate that ponding will occur at the western (downstream) end of Ingram Street again due to insufficient drainage capacity. Ponding depths in this area exceed 1 m for the 1% AEP (1 in 100 year) event. For the area of South Dowling Street between Myrtle Street and Todman Avenue, peak depths along the roadway are typically within 0.2 m. A minor area of ponding occurs along this street between Cooper Place and Winkurra Street where peak depths exceed 0.5 m for the 1% AEP (1 in 100 year) event. This minor low point is due to the natural topography of the area.

2.3. Preliminary Environmental Assessment

The current LEP zoning for the catchment is provided on Figure 2 and a preliminary environmental assessment of the catchment is included within the Floodplain Risk Management Study (Reference 2). Water quality studies of the broader Sheas Creek catchment (of which the West Kensington catchment is part of) have been undertaken previously, although there is little detailed information relating specifically to the local area. These studies suggest that the water quality exhibits pollutants which are typical of most urban catchments in Sydney. As most of the natural drainage system has effectively been replaced by either pipes or modified flowpaths there is little opportunity for the development of flora/fauna habitats. The visual amenity of most of the drainage system would generally be described as of low quality compared to a natural system. The drainage system within the series of major trapped low points offers no particular visual amenity as it generally blends in as part of the urban landscape. Drainage features within the Moore Park and The Australian golf courses mitigate this to some degree whilst, landscaping of some constructed features (e.g. the Raleigh Park detention basin) also addresses this aspect.

At present much of the formal drainage system has no legal recreational amenity. However, there are exceptions to this including parts of the floodplain that lie within public parklands and several golf courses (e.g. portions of Moore Park and The Australian golf courses). Providing due consideration is given to personal safety and risk to life then the use of the floodplain for these activities are an excellent use of flood prone lands.

A number of previous flood related studies have been undertaken in the catchment and these are discussed in Reference 1.

3. KEY DATASETS

3.1. Historical Flood Data

A detailed analysis of rainfall records and flood records was undertaken as part of Reference 1. Although a survey questionnaire was distributed to the local community as part of that study, much of the information on past flooding within the catchment was sourced from existing reports and references.

Most records relate to the significant flooding that occurred during the November 1984 events and document extensive flooding within trapped low points. This includes the inundation of 56 properties (including 27 houses) within West Kensington (Reference 5).

When flooding occurs within the catchment in future, it is recommended that Council undertake to collect any available information (photos, rainfall data, flood heights, extent of inundation and damages to private property etc.) as soon as practicable after the event including after smaller, more frequent flooding such as would be expected in the 50% AEP (1 in 2 year) event.

3.2. Design Flood Data

3.2.1. Peak Flows and Flood Levels

The West Kensington Flood Study (Reference 4) reported design flood data for current catchment conditions. The Study recommended that the full range of storm durations should be considered if undertaking detailed investigations for drainage augmentation within the catchment. This is due to the potential redistribution of catchment flows if the drainage networks locally are upgraded.

Maps of peak depths together with peak flood levels in each of the major trapped low points for the 1% AEP (1 in 100 year) and Probable Maximum Flood (PMF) events are provided in Figure 3 and Figure 4 respectively. A summary of peak flood levels and depths at major trapped low points within the West Kensington area is shown in Table 1. Further details regarding peak flows in the pipe network and in terms of overland flows can be found in Reference 4.

Table 1: Peak Flood Levels and Depths – Major Trapped Low Points West Kensington

Location	Minimum Level At Low Point (mAHD)	50% AEP Design Flood		20% AEP Design Flood		10% AEP Design Flood		5% AEP Design Flood	
		Level (mAHD)	Depth (m)	Level (mAHD)	Depth (m)	Level (mAHD)	Depth (m)	Level (mAHD)	Depth (m)
Balfour Road	24.0	24.7	0.7	24.9	0.9	25.0	1.0	25.1	1.1
McDougall Street	23.2	23.9	0.7	24.0	0.8	24.2	1.0	24.3	1.1
Milroy Avenue	24.3	24.7	0.4	24.9	0.6	24.9	0.6	25.0	0.7
Virginia Street	23.8	24.0	0.2	24.1	0.3	24.1	0.3	24.1	0.3
Lenthall Street	20.4	21.9	1.5	22.0	1.6	22.0	1.6	22.1	1.7

Note: Estimated ponding depths are approximate only (based on ALS data)

Location	Minimum Level At Low Point (mAHD)	2% AEP Design Flood		November 8-9 1984 Flood Observations		1% AEP Design Flood		0.2% AEP Design Flood		Probable Maximum Flood	
		Level (mAHD)	Depth (m)	Level (mAHD)	Depth (m)	Level (mAHD)	Depth (m)	Level (mAHD)	Depth (m)	Level (mAHD)	Depth (m)
Balfour Road	24.0	25.3	1.3	25.23	1.23	25.5	1.5	25.8	1.8	26.5	2.5
McDougall Street	23.2	24.5	1.3	24.8	1.60	24.6	1.4	24.6	1.4	25.0	1.8
Milroy Avenue	24.3	25.0	0.7	25.2	0.90	25.1	0.8	25.1	0.8	25.5	1.2
Virginia Street	23.8	24.1	0.3	n/a	n/a	24.1	0.3	24.2	0.4	24.4	0.6
Lenthall Street	20.4	22.1	1.7	21.44	1.04	22.1	1.7	22.2	1.8	22.4	2.0

Note: Estimated ponding depths are approximate only (based on ALS data)

3.2.2. Hydraulic Classification

Hydraulic classification of the floodplain was undertaken as part of Reference 2. A number of roadways within the West Kensington area act as overland flow paths. Hence, these are to be considered as floodway given that a significant portion of flow is conveyed via the road network. Within each of the major trapped low points (including the Lenthall Street lowpoint at the underpass), the areas contained by road reserve are considered to be floodways as floodwaters typically enter these low points via the road network. The remaining inundated area adjacent to each of the low points is regarded as being flood storage.

The easement between Lenthall Street and Ingram Street in West Kensington conveys overland flow from the Virginia Street trapped low point and is classified as floodway.

Hydraulic categories for the West Kensington area as determined from this study are shown in Figure 5.

3.2.3. Flood Hazard Classification

The hazard categorisation for the catchment was quantitatively determined using depth and velocity for each design event in accordance with the provisional hydraulic hazard categorisation. The provisional hazards were then refined to consider other factors such as rate of rise of floodwaters, duration, threat to life, danger and difficulty in evacuating people and possessions and the potential for damage, social disruption and loss of production. For the West Kensington catchment these factors do not significantly alter the provisional hazard classifications for the 100 year ARI and PMF events although some allowance was made to identify key flowpaths likely to act as floodways (e.g. along the easement between Ingram Street and Lenthall Street).

Flood hazard categories for the West Kensington area as determined from this study are shown in Figure 6 and Figure 7 for the 1% AEP (1 in 100 year) and PMF events respectively.

3.2.4. Flood Damages

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

- the magnitude (depth, velocity and duration) of the flood,
- land usage and susceptibility to damage,
- awareness of the community to flooding,
- effective warning time,
- the availability of an evacuation plan or damage minimisation program,
- physical factors such as erosion of the river bank, flood borne debris, sedimentation.

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

A flood damages assessment was undertaken for existing residential properties within the West Kensington catchment (refer to Table 2 and Figure 8). The assessment was based on a detailed floor level survey and results from the Flood Study (Reference 4).

Table 2: Summary of Flood Damage Estimates for West Kensington Catchment

Event	West Kensington Major Trapped Low Points				All Properties Within RCC LGA
	Virginia Street	Milroy Avenue	McDougall Street	Balfour Road	
50% AEP (1 in 2y)*	$7K	$14K	$1K	$26K	$320K
20 % AEP (1 in 5y)*	$10K	$59K	$2K	$134K	$840K
10 % AEP (1 in 10y)*	$10K	$59K	$10K	$220K	$1,000K
5% AEP (1 in 20y)*	$10K	$80K	$20K	$340K	$1,200K
2% AEP (1 in 50y)*	$10K	$81K	$80K	$640K	$1,620K
1% AEP (1 in 100y)*	$10K	$120K	$150K	$1,030K	$2,160K
0.2% AEP (1 in 500y)*	$23K	$120K	$150K	$1,870K	$3,100K
PMF*	$72K	$696K	$669K	$4,250K	$7,900K
Avg. Annual Damages	**$6K**	**$29K**	**$6K**	**$103K**	**$496K**

*Tangible Damages.

^Average Annual Damages are Tangible Damages weighted according to probability of occurrence.

Table 3: Above Floor and Property Inundation – West Kensington

Event	West Kensington Major Trapped Low Points								All Properties Within RCC LGA	
	Virginia Street		Milroy Avenue		McDougall Street		Balfour Road			
	Ground	Floor	Ground	Floor	Ground	Floor	Ground	Floor	Ground	Floor
50% AEP (1 in 2y)*	3	0	2	1	1	0	12	0	30	8
20 % AEP (1 in 5y)*	4	0	5	2	1	0	16	8	53	25
10 % AEP (1 in 10y)*	4	0	5	2	7	0	20	9	64	28
5% AEP (1 in 20y)*	4	0	14	2	11	1	22	12	82	33
2% AEP (1 in 50y)*	4	0	14	2	19	3	32	20	103	44
1% AEP (1 in 100y)*	4	0	14	4	22	6	42	26	118	55
0.2% AEP (1 in 500y)*	5	2	14	4	22	6	60	46	141	78
PMF	8	3	29	23	30	20	73	67	196	154

3.3. Previous Flood Mitigation Measures Considered

Flood mitigation measures for the catchment have been considered previously as part of investigations undertaken following the November 1984 floods (Reference 5). Due to a number of physical constraints (including the amount of existing development within the catchment) the sub-surface drainage options considered were based on the amplification of existing drainage lines and/or the installation of new pipes as part of a bypass system. The potential to amplify existing drainage infrastructure was noted as being complicated for those reaches not located within existing drainage easements or road reserves.

These potential options are also subject to downstream capacity constraints. Any increase in system capacity to alleviate flooding in the West Kensington catchment has the potential to exacerbate flooding in the lower reaches due to the additional loading on the downstream system.

The key components of the preferred scheme are shown in Figure 9 and included:

- amplification of existing local drainage within West Kensington (although the inlet capacity was initially limited so as not to exceed the current capacity of downstream infrastructure),
- provision of detention capacity in Raleigh Park and on the grounds of The Australian golf course (the detention capacity within the golf course also included improved sub-surface drainage to this area from the Balfour Road trapped low point), and
- amplification of the Sydney Water (then known as the Metropolitan Water, Sewer and Drainage Board (MWS&DB)) channel downstream to provide additional downstream capacity.

Information provided by Randwick City Council confirms that the scheme has been partially implemented including:

- provision of detention capacity at Raleigh Park (refer to Figure 9),
- drainage upgrade works completed in the 1990's along Baker Street (new system

along the northern side) and the Balfour Road system (increased pipe capacity through amplification and duplication).

From the available survey it appears that the new Baker Road system drains directly west to South Dowling Street rather than Virginia Street as was originally intended. RCC has also indicated that the pipe sizes nominated in the 1985 study could not be achieved in some portions of the system due to utility services constraints.

3.4. Community Consultation

The Draft Green Square - West Kensington Floodplain Risk Management Study and the Draft West Kensington Catchment Floodplain Risk Management Plan were placed on public exhibition from Monday 16th May 2011 to Friday 24th June 2011.

Public displays were placed at the following locations:

- Bowen Library, 669-673 Anzac Parade, Maroubra,
- Randwick Library, Level 1 Royal Randwick Shopping Centre, Randwick,
- Council's administration centre, 30 Frances Street, Randwick.

Exhibition material at the public displays included:

- Copies of the draft reports,
- Poster,
- Fact sheets,
- Comment sheets,
- Comment box.

Newspaper advertisements were placed in the Southern Courier on 17th May and 7th June providing details of the public exhibition.

The public exhibition was also advertised on Council's website. Information was placed on the web site as follows

- Copies of the draft reports,
- Details of the public exhibition,
- Fact sheet,
- Comment sheet.

A community drop in session was held at Bowen Library, 669-673 Anzac Parade, Maroubra on Wednesday 8th June between 4pm and 7pm. Staff from Council, WMAwater and the Office of Environment and Heritage were available for the community to come along and find out about the study or ask questions. A letter was sent to all property owners, within Randwick City Council's portion of the catchment, identified as being below the 1% AEP flood plus freeboard or below the Probable Maximum Flood. A total of 1049 letters were sent to property owners providing details of the public exhibition and the community drop in session.

4. FLOODPLAIN RISK MANAGEMENT PLAN

4.1. Introduction

The West Kensington Floodplain Risk Management Plan has been prepared in accordance with the NSW Floodplain Development Manual (Reference 3) and:

- *Is based on a comprehensive and detailed evaluation of all 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;*
- *Provides a long-term path for the future development of the community.*

4.2. Floodplain Risk Management Measures Considered

All possible management measures were evaluated in the Floodplain Risk Management Study (Reference 2) taking into account a range of parameters. This process eliminated a number of measures including:

- Flood mitigation dams (no available space in catchment),
- Channel modification works (dredging, straightening, concrete lining, removal of vegetation etc are not possible),
- Levees, flood gates and pumps,
- Flood warning (available warning time too short),
- House raising (no suitable buildings),
- Flood proofing of buildings (not suitable for residential buildings).

The evaluation process for assessing each measure involved interaction with the Floodplain Management Committee technical committee, the Floodplain Management Committee itself and meetings with Council officers. The proposed measures identified as part of the present study are described in Sections 4.3 to 4.5. Note that the various measures are presented in no particular order within each priority group.

4.3. HIGH Priority Floodplain Management Measures

4.3.1. Maintain Flood and Drainage Database

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

OUTCOMES

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

ACTIONS

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

4.3.2. Public Information, Community Awareness and Response

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

OUTCOMES

Based on feedback received from earlier public consultation phases and general discussions, the residents within the West Kensington catchment generally have a low to moderate level of flood awareness and it is expected that there is a correspondingly low level of preparedness and ability to effectively respond to flooding impacts. This can be attributed to the quick onset of flooding, the influx/turnover of residents (particularly since the last major flooding that occurred in November 1984) within the area, a general low awareness of flooding in an urban area (as opposed to say a rural area such as Maitland) and the possibility of flooding occurring at night.

A suitable Council wide flood awareness and response program should be implemented by Council using appropriate elements (as outlined in Reference 2). The details of the program and necessary follow up should be properly documented to ensure that they do not lapse with time and to ensure the most cost effective means of communication.

Council should also consider making flood related information such as flood studies, floodplain risk management studies and plans freely available (e.g. via Council's website). These studies provide information regarding the nature of flooding in the catchment, flood issues and form the basis for Council's actions in managing the floodplain.

ACTIONS

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

Council should make flood-related information such as flood studies, floodplain risk management studies and plans freely available via the Council website.

4.3.3. Planning Instruments and Development Control Planning

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

OUTCOMES

The Randwick LEP 1998 contains several clauses relating to drainage and water management issues. These conditions are broadly defined covering drainage and environmental management. There are no references to specific floodplain risk management objectives (e.g. risk to life and property) within the LEP.

Council has a number Development Control Plans (DCPs) that contain flood-related conditions, although there are no site specific DCPs relevant to the West Kensington area. The two applicable LGA-wide DCPs contain general references to stormwater management and do not contain specific details regarding flooding and/or floodplain risk management.

ACTIONS

Council should consider including a reference to the Floodplain Development Manual (Reference 3) and/or relevant floodplain risk management principles in the LEP with regards to development on flood prone land.

It is recommended that Council review and consolidate existing flood-related DCPs incorporating specific floodplain risk management provisions, and in time formally adopt a Flood Risk Management DCP applicable for the broader LGA. This would enable Council to implement sound floodplain management and drainage strategies across all catchments in a consistent manner. Note that this does not preclude the use of more refined, site specific control conditions where needed.

Flooding related development controls should ensure that the following principles are incorporated into new developments:

- use of appropriate flood planning levels,
- no adverse impact on flooding including conveyance of flood waters and floodplain storage volume for floods up to and including the 1% AEP flood,
- ensure that there is no adverse cumulative impact of permitting similar types of development within the floodplain,
- ensure the safety of persons and emergency access during flooding for all floods up to and including the PMF,
- ensure appropriate protection, warning and safe evacuation from basement car parking,
- ensure structural soundness and flood compatibility of building components up to the applicable flood planning level,
- minimise the likelihood of cars or other objects becoming floating debris during a flood,
- ensure that adequate flood protection is provided for materials sensitive to flood

damage, materials that may cause pollution or be potentially hazardous during a flood,
- ensure that fencing does not obstruct the flow of flood waters, become unsafe during times of flood or become moving debris, and
- ensure that existing inappropriate structures and uses are redeveloped with no increase in floor area and in a manner that reduces the risk to human life and property damage.

4.3.4. Flood Planning Levels

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

OUTCOMES
Although site-specific DCPs for other areas within the RCC LGA define a range of Flood Planning Levels, there is no existing documentation of FPLs that are directly applicable to the West Kensington catchment. Hence, it is recommended that RCC review existing practice and develop appropriate FPLs for use in West Kensington. These FPLs should be developed in accordance with the principles of the Floodplain Development Manual (Reference 3) and should be applicable across the RCC LGA.

ACTIONS
It is recommended that Council undertake to review existing site-specific Flood Planning Level conditions in combination with the Floodplain Development Manual to produce a consistent set of Flood Planning Levels applicable across the RCC LGA. Note that this does not preclude the use of more refined, site specific controls as needed.

4.3.5. Notations to the Section 149 Certificate

- **Cost:** internally within Council,
- **Responsibility:** Council,
- **Timeframe:** proposed commencement in 2011–2012.

OUTCOMES
A Section 149 certificate is a planning tool to notify that land is affected by a Council Policy with development controls. It provides an important source of information for a prospective property purchaser in determining the flood risk. Thus it is essential that this information is as accurate and up-to-date as possible. Property owners may also wish to use this information to obtain (or not to obtain) flood insurance which has recently been introduced by major insurance companies.

ACTIONS
RCC currently has no formal Flood Policy or requirements regarding flood-risk notations on the

s149 certificate. To address it is recommended that Council give consideration to:

- the development of a formal RCC Flood Policy,
- providing flood related s149(2) notations that comply with current planning regulations,
- providing additional flood related information for s149(5) notations. Such information could include flood levels (say for the 5% and 1% AEP and the PMF events) and/or provide corresponding depths for shallower overland flowpaths. Information for smaller events (e.g. <20% AEP) is not required as these small floods can potentially be impacted by localised features, and
- Council's internal processes used to manage the provision of s149 notations.

4.3.6. Management of Blockage

- **Cost:** internally within Council,
- **Responsibility:** Council,
- **Timeframe:** on-going.

OUTCOMES

It is recommended that Council:

- regularly assess the effectiveness of current street sweeping programs and in light of the outcomes refine/improve the adopted approach,
- investigate options for blockage protection works at key trapped low points including Milroy Avenue, McDougall Street, Virginia Street and Balfour Road,
- review current configuration of pit inlets and consider potential options to minimise risk of blockage,
- consider adopting parking controls at locations where the flow is large and regularly inundates adjacent properties,
- adopt a maintenance program to inspect and rectify sedimentation in pipes, this may mean CCTV inspection of pipes in critical locations.

ACTIONS

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

4.3.7. Local Flood Plan and Emergency Response Planning

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

OUTCOMES

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

ACTIONS
It is recommended that Council provide flood related information to the SES and work with the SES to develop and adopt a Local Flood Plan.

4.4. MEDIUM Priority Floodplain Management Measures

4.4.1. Pipe/Pipe and Trunk Drainage Upgrades

- **Cost:** Significant - typically in the order of $0.5M to > $1.0M (subject to extent of works and site constraints (e.g. conflicts with existing services)),
- **Responsibility:** Council,
- **Timeframe:** Ongoing, to be incorporated as funding opportunities arise.

OUTCOMES
Opportunities to implement pit/pipe and trunk drainage upgrades to address major flooding within the West Kensington area were found to be limited as:

- a number of extensive upgrades proposed following the November 1984 floods have been implemented,
- a number of branches are limited by downstream capacity constraints. For example, the existing Sydney Water stormwater channel that services much of the southern portion of the upper West Kensington catchment is of limited capacity and acts as a constraint for any proposed drainage augmentation in the upper catchment, and
- there are significant physical constraints associated with major transport infrastructure along South Dowling Street (e.g. sound walls).

To mitigate localised flood problems in Duke Street, the impact of upgrading local drainage in the vicinity of Duke Street was examined and showed that:

- upgrading the local system resulted in minimal reductions in flood levels for design events in Duke Street and,
- such upgrades would result in negligible adverse impacts in downstream areas.

These outcomes reflect the fact that the local system reaches capacity even in smaller events and is affected by flooding within the Balfour Road system during larger events. However, given the condition of the existing kerb and gutter system in Duke Street, the planned upgrade will result in localised improvements for minor rainfall events and hence reduce the occurrence of nuisance flooding.

In terms of flooding along South Dowling Street adjacent to the existing sound walls, the potential options in terms of feasible physical drainage works are limited. There are significant complications posed by the presence of infrastructure associated with South Dowling Street and the Eastern Distributor. Joint investigations between Council and the Roads and Traffic Authority (RTA) would be needed to further assess this aspect.

ACTIONS
Although the works proposed for the Duke Street area are unlikely to reduce flood damages, there is the potential to improve the local flood behaviour and in view of this these works are recommended.

It is recommended that Council investigate options jointly with the RTA to manage impacts of the sound walls on South Dowling Street.

4.4.2. Implement Climate Change Policy

- **Cost:** minimal for Council but will add to developer costs,
- **Responsibility:** Council, Office of Environment and Heritage, property owners,
- **Timeframe:** ongoing.

OUTCOMES
The potential impact of increased design flood levels in the catchment due to climate change has been examined for the 1% AEP (1 in 100 year) event for existing conditions as part of the GSWK Floodplain Risk Management Study (Reference 2). As the lowest elevation within the West Kensington area is in the order of 20 mAHD, flood levels within the study catchment are not affected by potential changes in sea-level rise.

Within West Kensington, the potential increase in peak flood level resulting from a +30% increase in rainfall was generally found to be less than 0.25 m although localised increases of between 0.4 m to 0.6 m do occur. The largest increases were found to occur in trapped low points and in areas where flow was concentrated, such as the Raleigh Park detention basin, the Balfour Road trapped lowpoint and The Australian golf course detention basin. Corresponding increases along unobstructed overland flowpaths (e.g. within roadways and through property) were typically less than 0.15 m. Impacts of this magnitude can be readily accommodated through the use of appropriate freeboards in excess of the Flood Planning Level, particularly for residential development and critical infrastructure. For other areas where significant impacts were noted, these may be addressed through this or other means. It is expected that these aspects would be confirmed as part of Council's review of Flood Planning Levels (refer to Section 4.3.4).

ACTIONS
For existing conditions the potential impacts of increased rainfall due to climate change can be accommodated through the use of appropriate freeboards specified as part of Flood Planning Level conditions yet to be determined by Council.

For any future development that involves the modification of flood behaviour, the resulting impacts due to climate change should be accounted for as part of a site specific flood assessment.

Council should continue to monitor the available literature and reassess Council's flood-related DCPs as appropriate. At a minimum Council should obtain the most current information available from the Bureau of Meteorology, CSIRO and OEH every two years.

4.4.3. Detention Basins

- **Cost:** Significant - typically in the order of $0.4M (subject to capacity and site constraints),
- **Responsibility:** Council, property owners,
- **Timeframe:** Ongoing, subject to future negotiation with property owners,

OUTCOMES
Within the West Kensington portion of the catchment a number of detention basins have already been constructed and opportunities for new basins are limited by a lack of suitable sites (these aspects are discussed in further detail in Reference 2). However, there is the potential to construct some form of detention capacity within the Moore Park golf course site. Hydraulic assessments indicated that approximately 16,100m^3 of storage would be sufficient to contain runoff from the area in the 1% AEP (1 in 100 year) event. The provision of such capacity would result in localised reductions in flood levels of between 0.1 m to 0.2 m in Todman Avenue, adjacent to the Supacentre and Raleigh Park sites.

The layout of this option is flexible and it may involve the construction of several smaller basins serving local catchments within the Moore Park golf course site. These basins would also provide stormwater harvesting opportunities for the golf course operators.

ACTIONS
Retarding basins in Moore Park golf course would provide localised reductions in flood levels within the West Kensington catchment and may also provide some water quality and re-use potential.

The construction of basins in these locations is supported and it is recommended that Council liaise with the Moore Park (public course) golf club.

4.4.4. Water Sensitive Urban Design (WSUD)

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

OUTCOMES
Whilst the floodplain risk management process supports the general objectives of WSUD it is not possible to address every aspect (e.g. water saving devices, grey water reuse, etc.) within

the scope of the overall process. However there are specific WSUD aspects that are relevant to the scope of the NSW Government's Floodplain Development Manual (Reference 3) including:

- Opportunities to maximise the pervious area in developments (as part of BASIX requirements) should be encouraged to reduce potable water demand. These principles can also be applied to other current measures (e.g. on-site detention) or land use activities (commercial and industrial developments and/or to existing Council or government structures and facilities, particularly in open space areas),
- Treatment of urban stormwater through the installation of gross pollutant traps and/or maximising opportunities for the absorption of runoff (e.g. shedding of local runoff onto swales or grassed areas before entering the formal stormwater drainage system). In all cases, care should be taken to ensure no adverse hydraulic impacts are created and that costs associated with ongoing maintenance are accounted for.

ACTIONS
The implementation of WSUD should be generally encouraged. WSUD opportunities that also provide flood amenity should be actively pursued.

4.5. LOW Priority Floodplain Management Measures

4.5.1. Flood Proofing

- **Cost:** Site specific, to be borne by property owner,
- **Responsibility:** Council, individual property owner,
- **Timeframe:** ongoing.

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

Flood proofing of existing residential properties in low hazard areas on a property by property basis could alleviate local inundation issues however consideration would have to be given to the (possible) redistribution of flows to downstream properties and safety issue of isolating residents behind such protection measures. This option would not be considered for government funding however could be pursued by individual property owners.

ACTIONS
Flood proofing should be promoted as a means available to reduce flood damages for existing non-residential buildings. It is not recommended for use as part of any new development (or re-development).

5. ACKNOWLEDGEMENTS

This study was carried out by WMAwater and funded by Randwick City Council, City of Sydney and the Department of Environment, Climate Change and Water (now Office of Environment and Heritage). The assistance of the following in providing data and guidance to the study is gratefully acknowledged:

- Randwick City Council,
- City of Sydney,
- Department of Environment, Climate Change and Water (now Office of Environment and Heritage),
- members of the Green Square - West Kensington Floodplain Management Committee,
- residents of the West Kensington catchment.

6. REFERENCES

1. Webb McKeown and Associates
   Green Square – West Kensington (Sheas Creek Victoria Branch) Flood Study
   April 2008.

2. WMAwater
   Green Square-West Kensington Floodplain Risk Management Study
   November 2011

3. NSW Government
   Floodplain Development Manual
   April 2005.

4. WMAwater
   West Kensington (DRAFT) Flood Study
   Prepared on behalf of Randwick City Council, April 2010.

5. Public Works Department NSW
   West Kensington Flooding Drainage Works Investigation
   Technical Report No. 85037, December 1985

Figures

West Kensington Catchment, Floodplain Risk Management Plan, October 2011

List of Figures

FIGURE 1
STUDY AREA

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Zoning Description
No. 2A (Residential A Zone)
No. 2B (Residential B Zone)
No. 2C (Residential C Zone)
No. 5 (Special Uses Zone)
No. 6A (Open Spaces Zone)
No. 6B(Private open Space Zone)
FIGURE 2
LAND USE ZONINGS
WEST KENSINGTON (RCC LGA)
Moore Park
Golf Course
Raleigh Park
Tudman Ave
Cooper Pl
Winkurra St
Baker St
Balfour Rd
Kensington Rd
Duke St
South Dowling St
Milroy Ave
Myrtle St
Virginia St
McDougall St
Ingram St
Lenthal St
Links Rd
The Australian
Golf Course
N
0 50 100 200 m
NOTE: Base Photos dated 2004
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FIGURE 3
PEAK FLOOD LEVELS AND DEPTHS 1% AEP EVENT

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FIGURE 4
PEAK FLOOD LEVELS AND DEPTHS
PMF EVENT

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FIGURE 5
HYDRAULIC CATEGORIES
WEST KENSINGTON AREA

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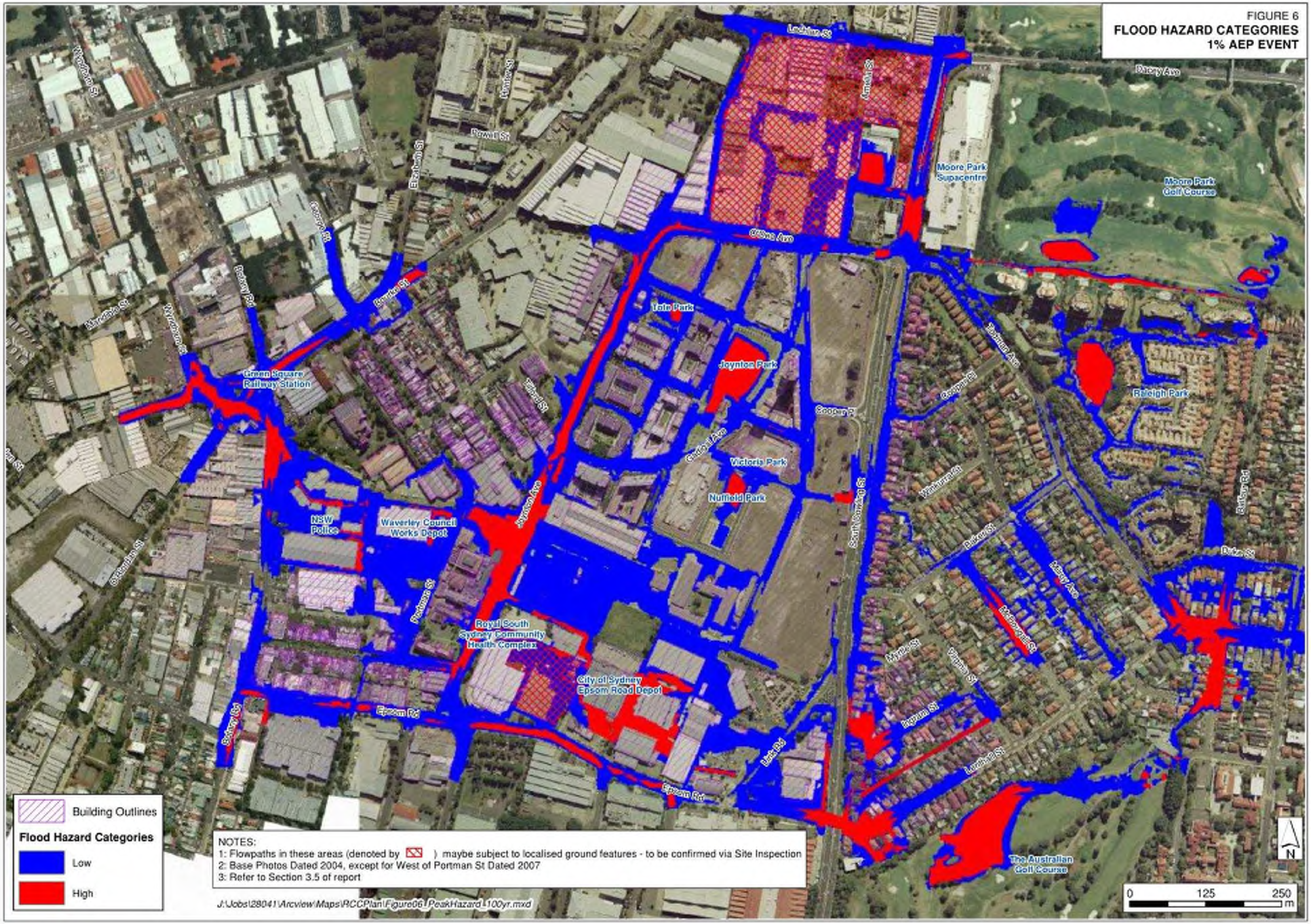
FIGURE 6
FLOOD HAZARD CATEGORIES
1% AEP EVENT



NOTES:
1: Flowpaths in these areas (denoted by ▨) maybe subject to localised ground features - to be confirmed via Site Inspection
2: Base Photos Dated 2004, except for West of Portman St Dated 2007
3: Refer to Section 3.5 of report

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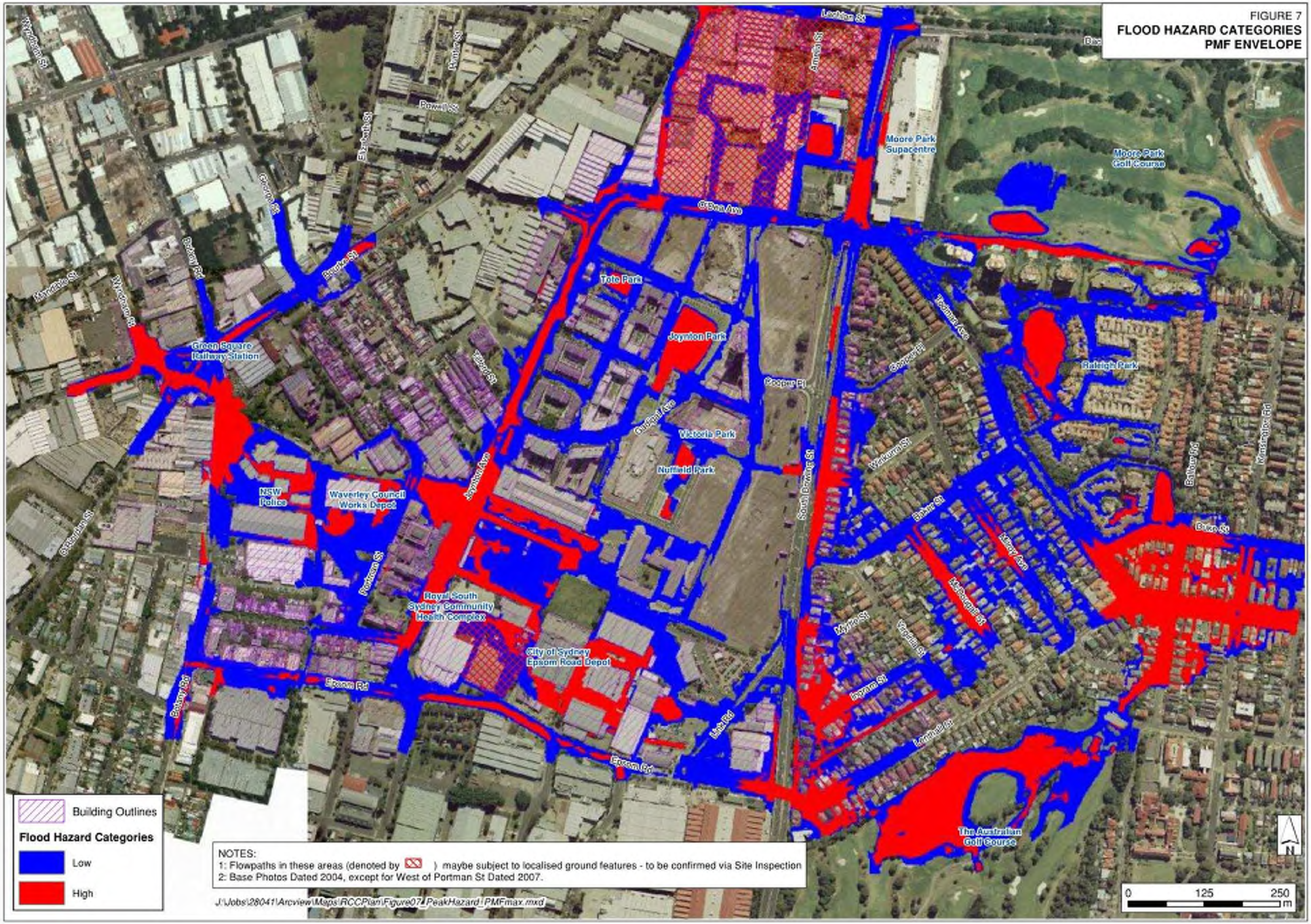
FIGURE 7
FLOOD HAZARD CATEGORIES
PMF ENVELOPE



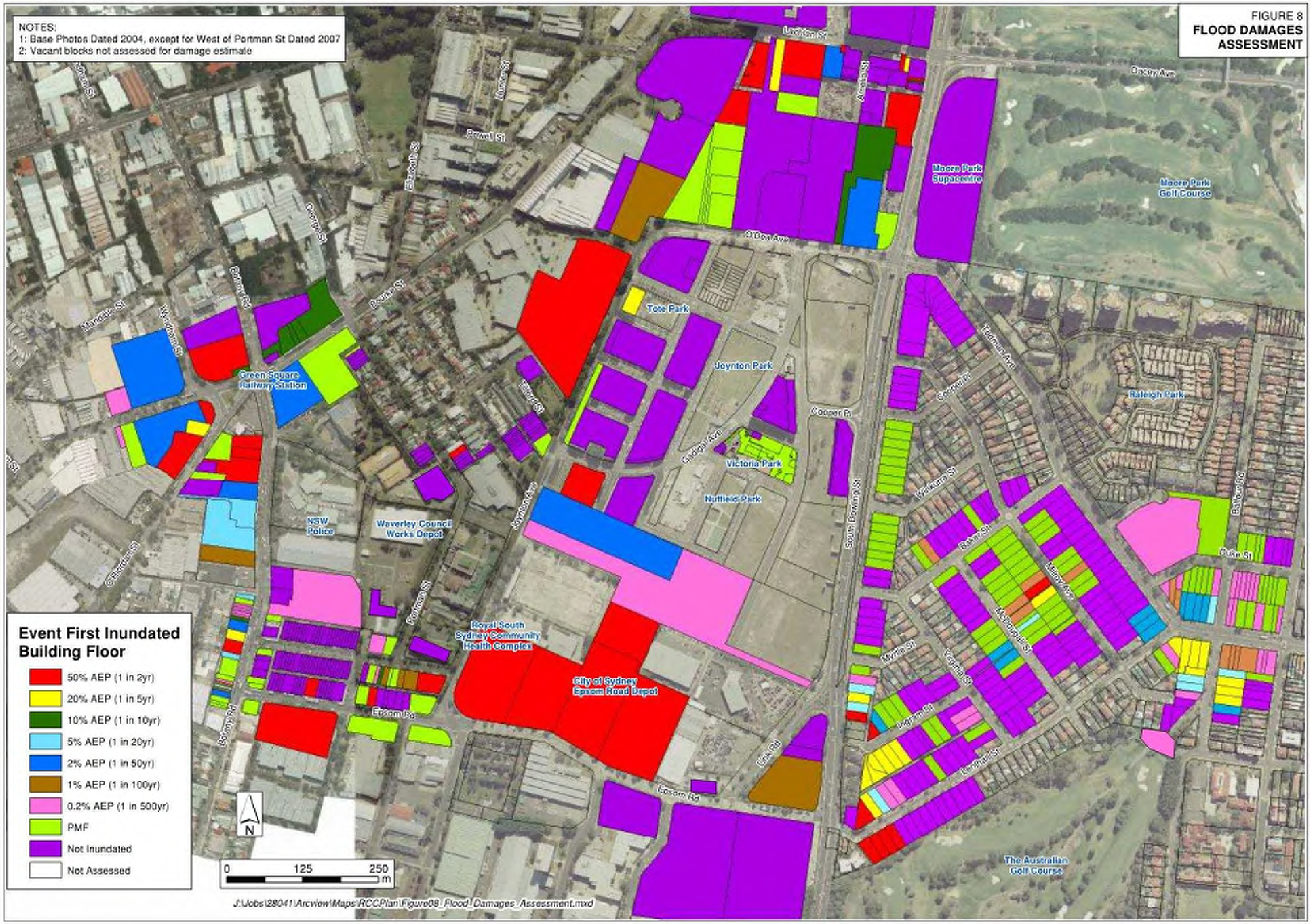


FIGURE 8
FLOOD DAMAGES ASSESSMENT
NOTES:
1: Base Photos Dated 2004, except for West of Portman St Dated 2007
2: Vacant blocks not assessed for damage estimate
Event First Inundated Building Floor
50% AEP (1 in 2yr)
20% AEP (1 in 5yr)
10% AEP (1 in 10yr)
5% AEP (1 in 20yr)
2% AEP (1 in 50yr)
1% AEP (1 in 100yr)
0.2% AEP (1 in 500yr)
PMF
Not Inundated
Not Assessed
0
125
250
m
N
Green Square Railway Station
NSW Police
Waverley Council Works Depot
Royal South Sydney Community Health Complex
City of Sydney Epsom Road Depot
Tote Park
Joynton Park
Victoria Park
Nuffield Park
Moore Park Supacentre
Moore Park Golf Course
Raleigh Park
The Australian Golf Course
Lachlan St
Dacey Ave
O'Dea Ave
Powell St
Bourke St
Botany Rd
Epsom Rd
Joynton Ave
Portman St
South Dowling St
Cooper St
Link Rd
Duke St
Baker St
Myrtle St
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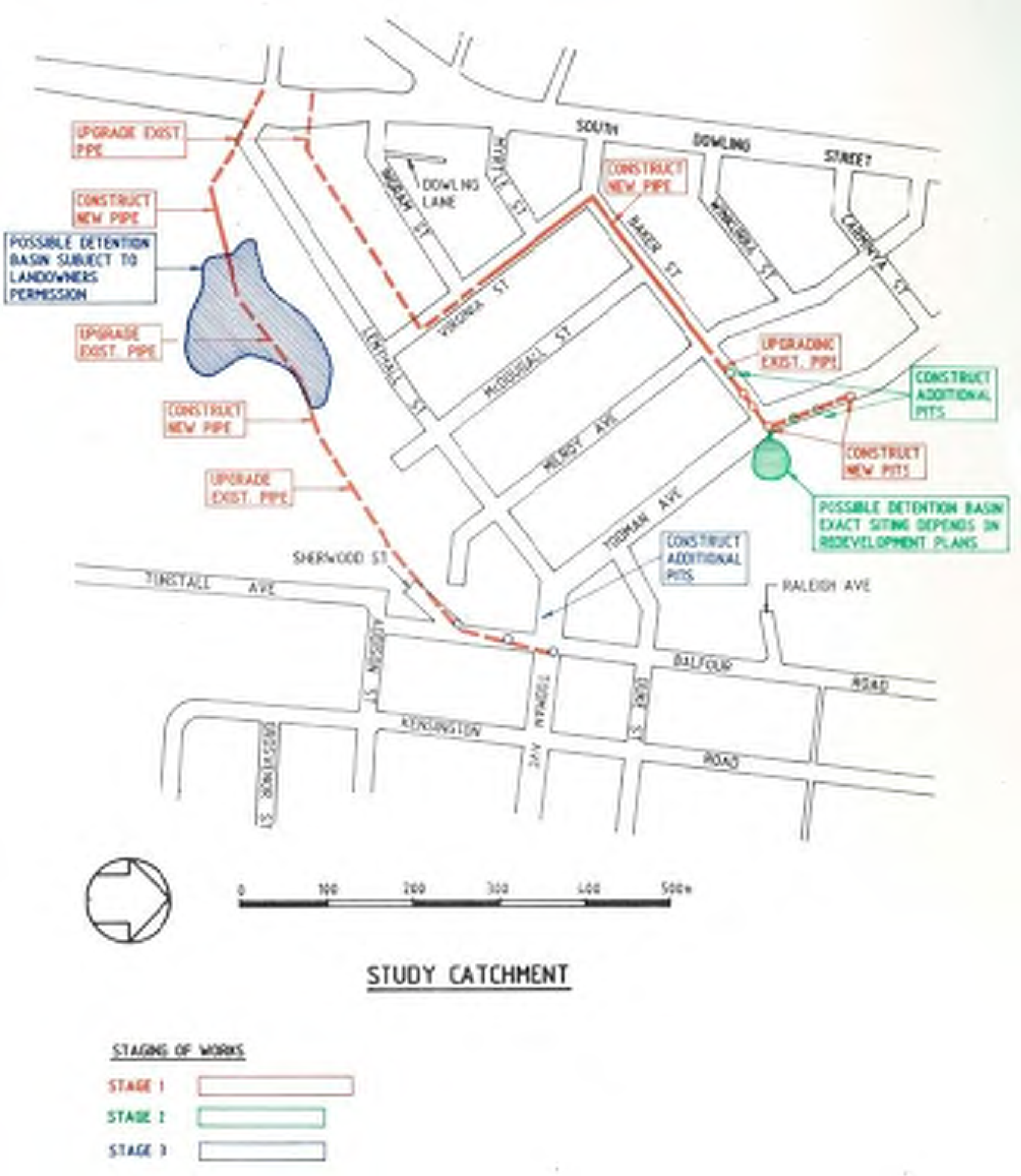
FIGURE 9
1985 WEST KENSINGTON DRAINAGE STUDY
PREFERRED MANAGEMENT OPTIONS



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Appendix A

APPENDIX A: GLOSSARY

Taken from the Floodplain Development Manual (April 2005 edition)

acid sulfate soils	Are sediments which contain sulfidic mineral pyrite which may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual published by Acid Sulfate Soil Management Advisory Committee.
Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Annual Damage (AAD)	Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
Average Recurrence Interval (ARI)	The long term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
caravan and moveable home parks	Caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the LG Act.
catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
consent authority	The Council, government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the Council, however legislation or an EPI may specify a Minister or public authority (other than a Council), or the Director General of DIPNR, as having the function to determine an application.
development	Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act). **infill development:** refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development. **new development:** refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power. **redevelopment:** refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a

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

floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
floodplain risk management options	The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
floodplain risk management plan	A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammetic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
flood plan (local)	A sub-plan of a disaster plan that deals specifically with flooding. They can exist at State, Division and local levels. Local flood plans are prepared under the leadership of the State Emergency Service.
flood planning area	The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the "flood liable land" concept in the 1986 Manual.
Flood Planning Levels (FPLs)	FPL's are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the "standard flood event" in the 1986 manual.
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.
flood readiness	Flood readiness is an ability to react within the effective warning time.
floodplain 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. Floodplain risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. **existing floodplain risk:** the risk a community is exposed to as a result of its location on the floodplain. **future floodplain risk:** the risk a community may be exposed to as a result of new development on the floodplain. **continuing floodplain risk:** the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing floodplain risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing floodplain 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 floodplain 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.