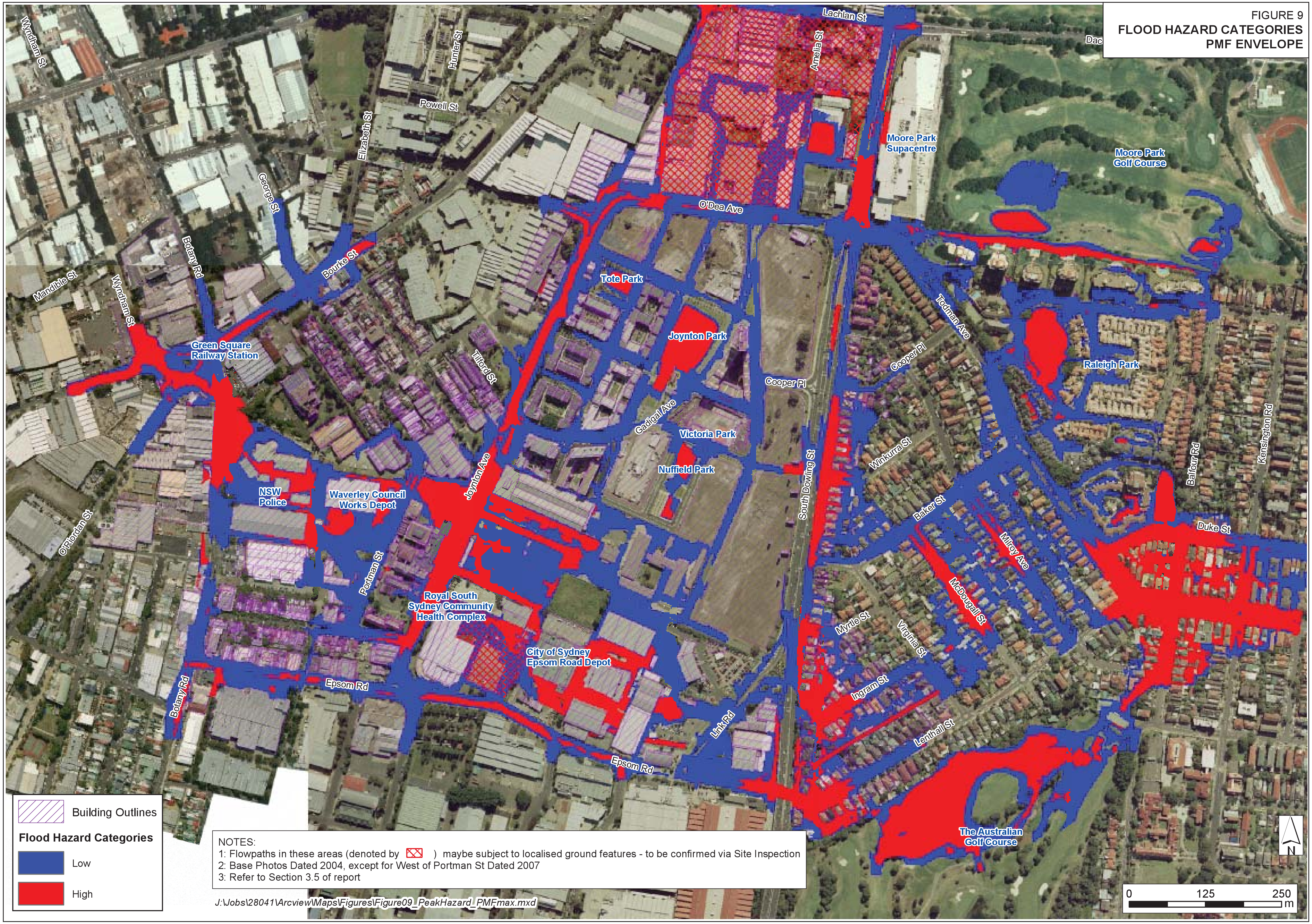

FIGURE 9
FLOOD HAZARD CATEGORIES
PMF ENVELOPE

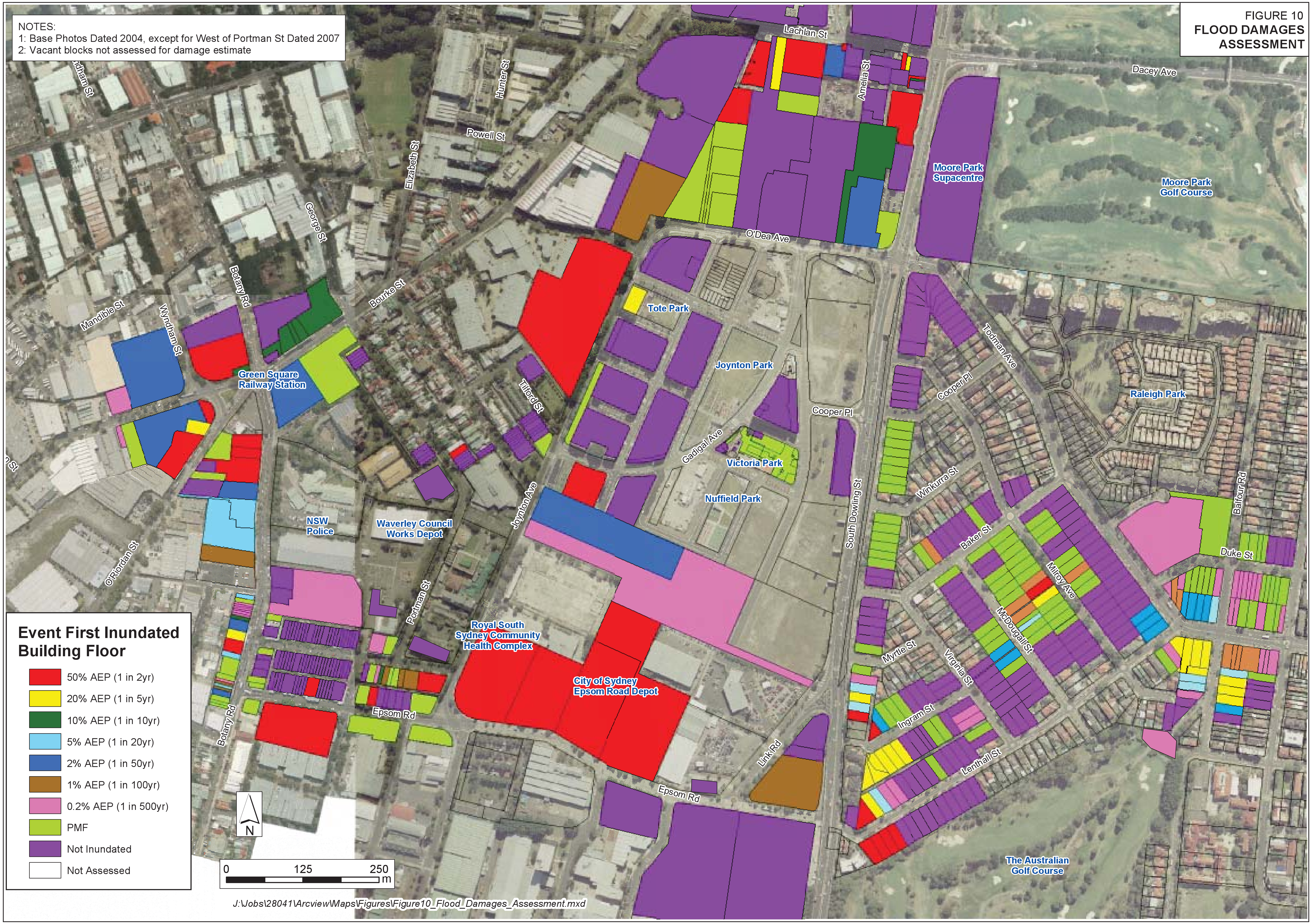

FIGURE 10
FLOOD DAMAGES ASSESSMENT

FIGURE 11

POTENTIAL BASIN LOCATIONS MOORE PARK GOLF COURSE

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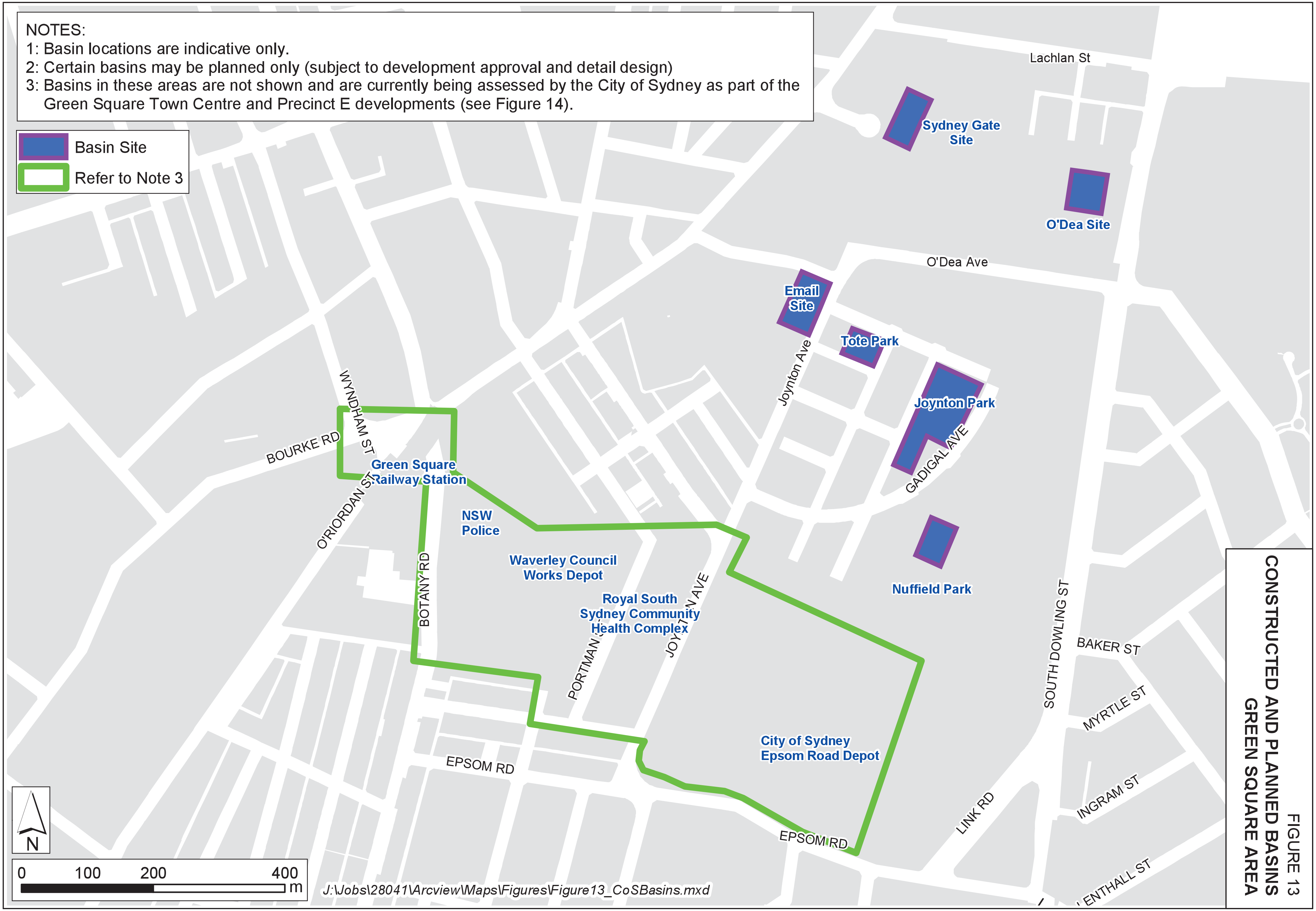
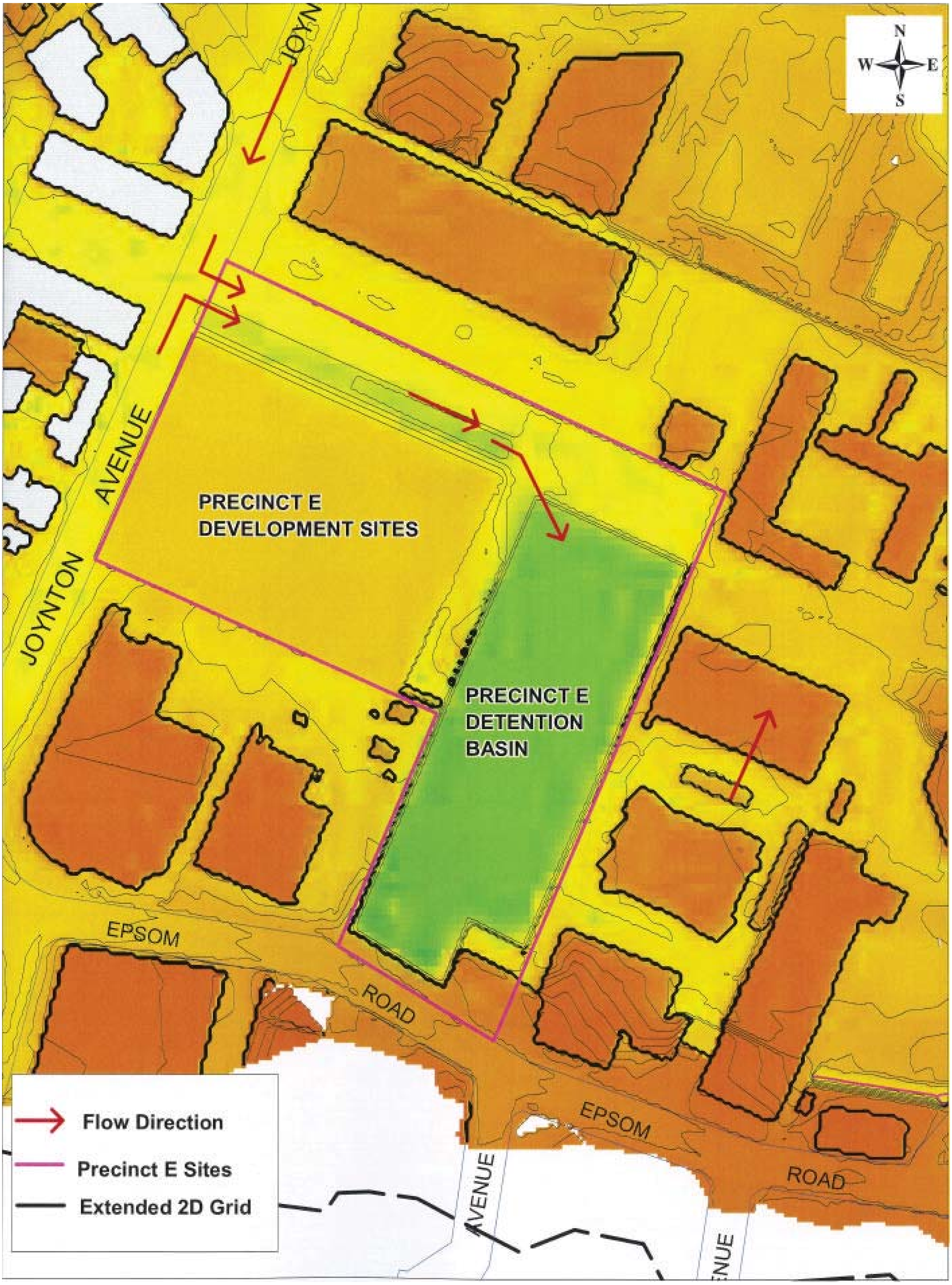


FIGURE 13
CONSTRUCTED AND PLANNED BASINS
GREEN SQUARE AREA

FIGURE 14

PRECINCT E DETENTION BASIN CONCEPT



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

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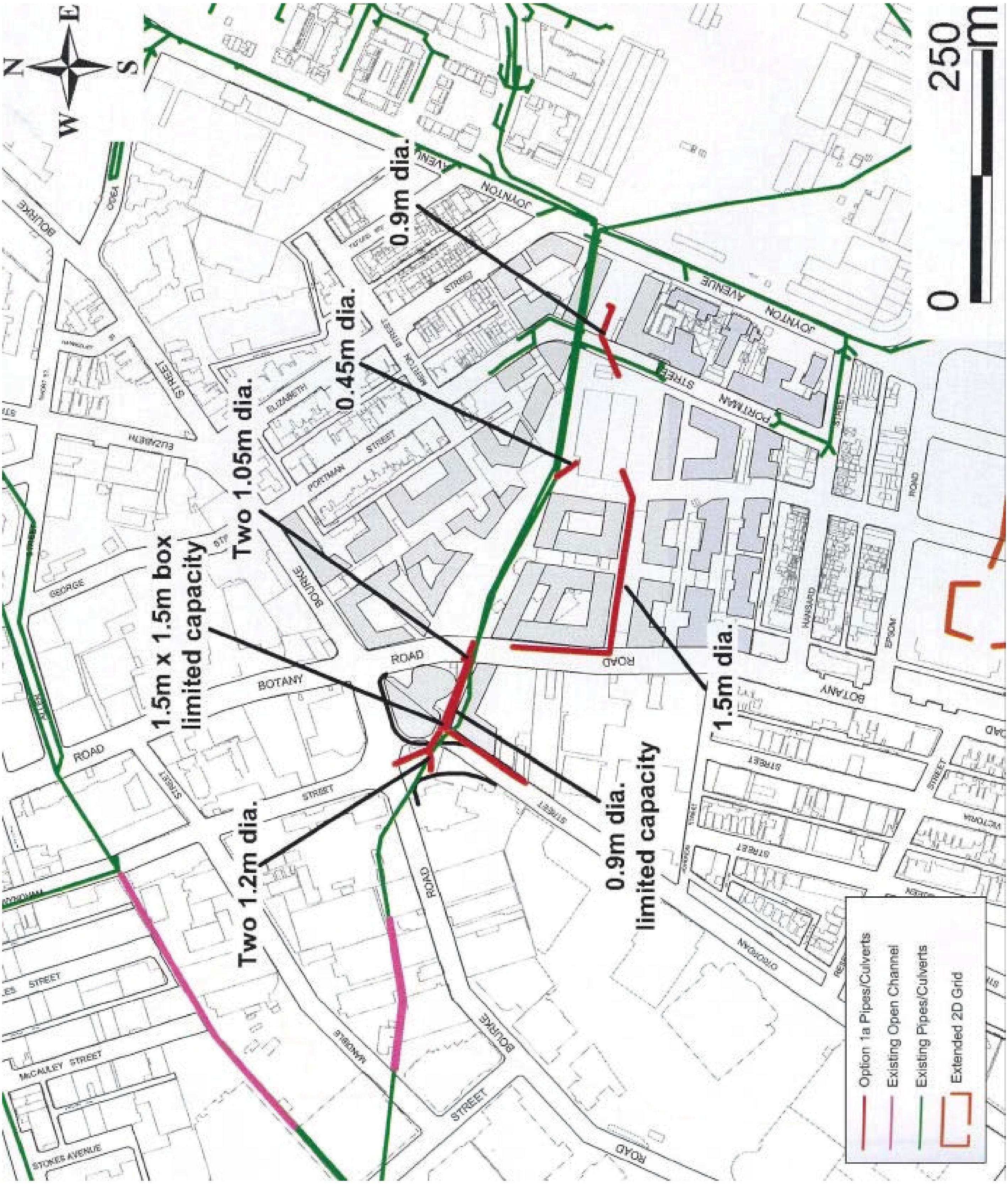
FIGURE 15

PROPOSED TRUNK DRAINAGE WORKS

GSTC PRECINCT



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

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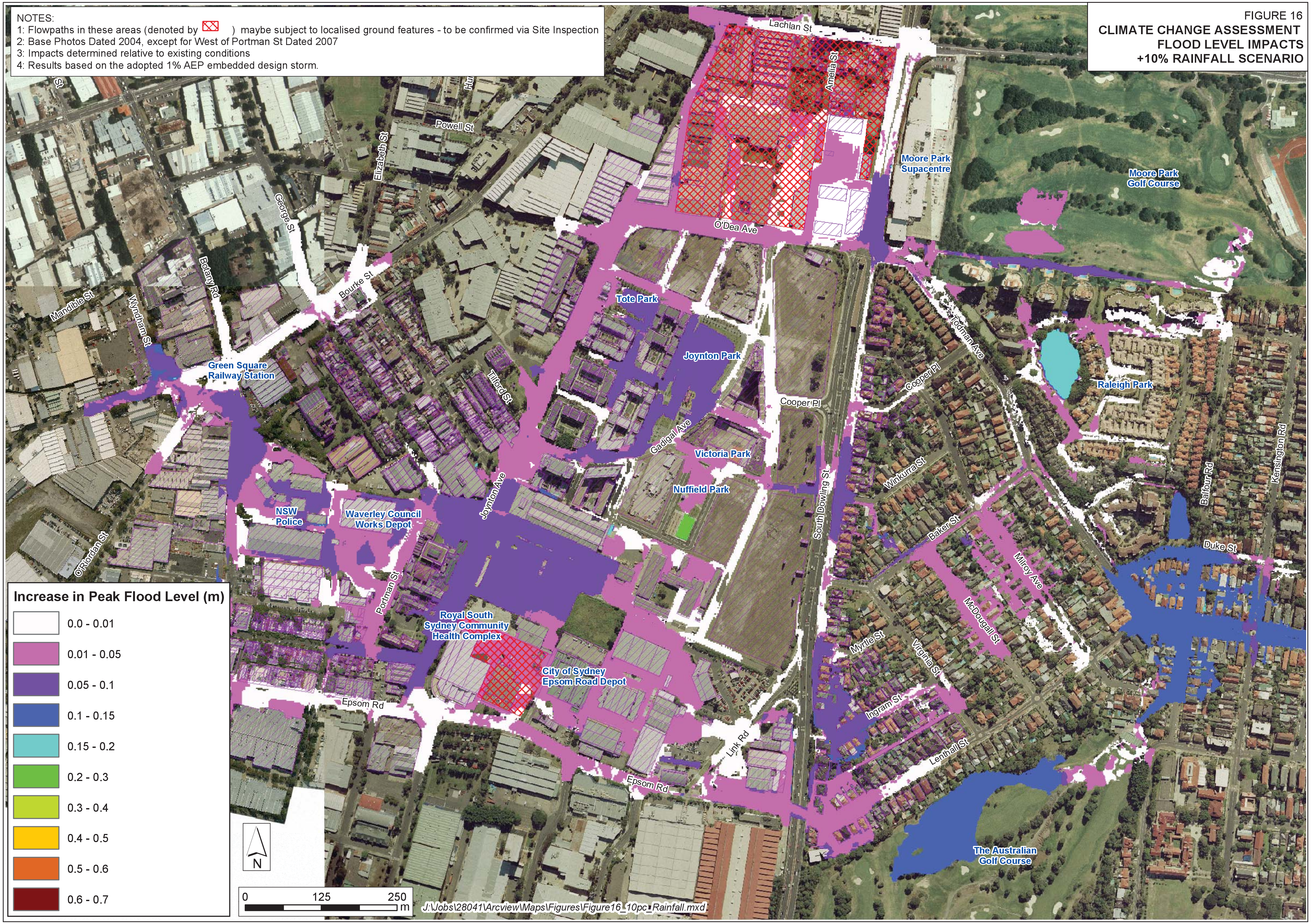
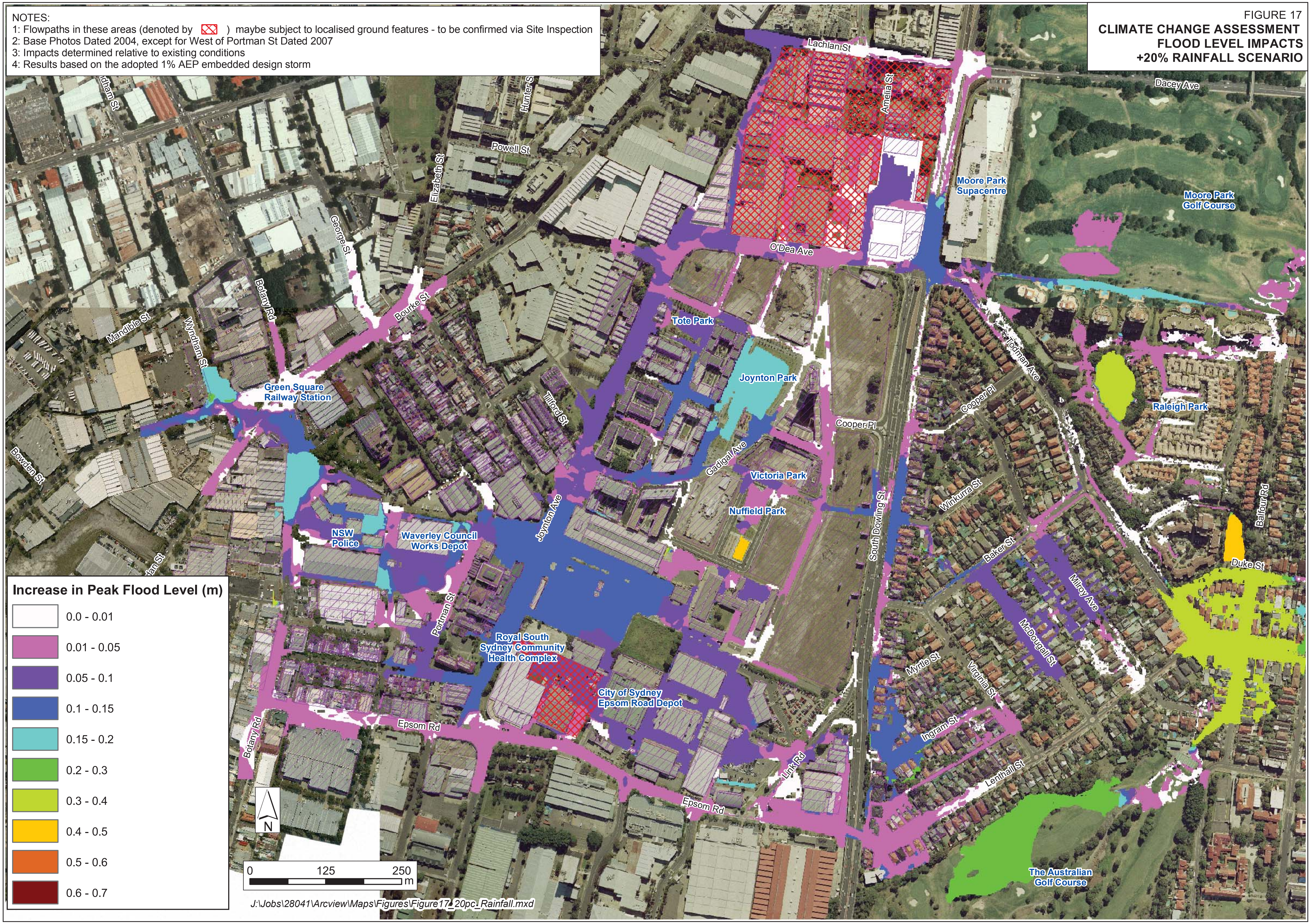


FIGURE 16
CLIMATE CHANGE ASSESSMENT
FLOOD LEVEL IMPACTS
+10% RAINFALL SCENARIO
NOTES:
1: Flowpaths in these areas (denoted by) maybe subject to localised ground features - to be confirmed via Site Inspection
2: Base Photos Dated 2004, except for West of Portman St Dated 2007
3: Impacts determined relative 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
Botany Rd
Bourke St
Mandible St
Wyndham St
O'Dea Ave
Moore Park Supacentre
Moore Park Golf Course
Tote Park
Joynton Park
Green Square Railway Station
Tilford St
Cooper Pl
Todman Ave
Raleigh Park
Gadigal Ave
Victoria Park
Nuffield Park
Joynton Ave
Winkurra St
South Dowling St
Balfour Rd
Kensington Rd
NSW Police
Waverley Council Works Depot
O'Riordan St
Baker St
Milroy Ave
Duke St
Portman St
McDougall St
Royal South Sydney Community Health Complex
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

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

NOTES:
1: Flowpaths in these areas (denoted by [hatched box]) 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\Figure17_20pc_Rainfall.mxd

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

NOTES:
1: Flowpaths in these areas (denoted by [hatched red 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

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.

Appendix B

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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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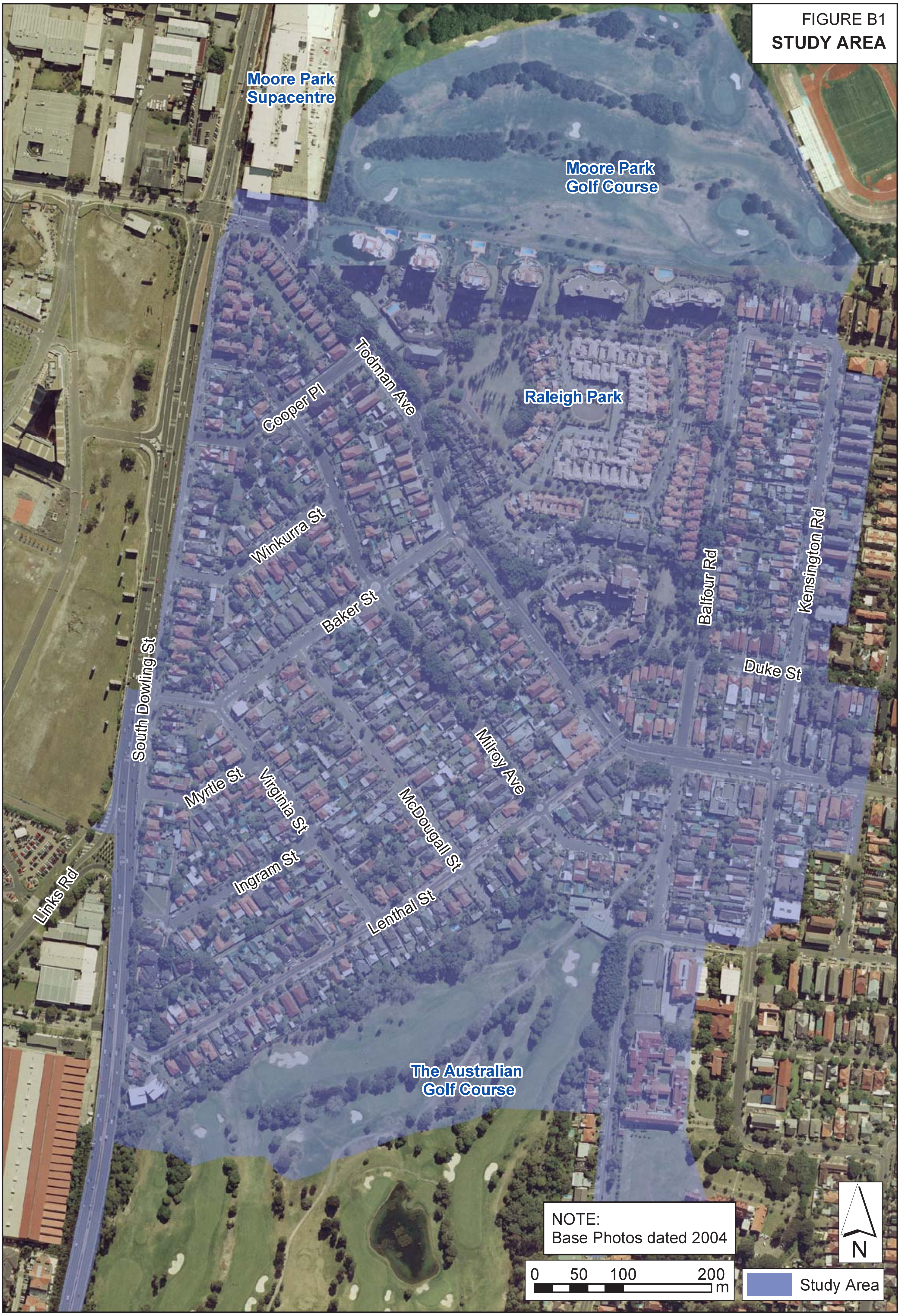
Figures

FIGURE B1
STUDY AREA



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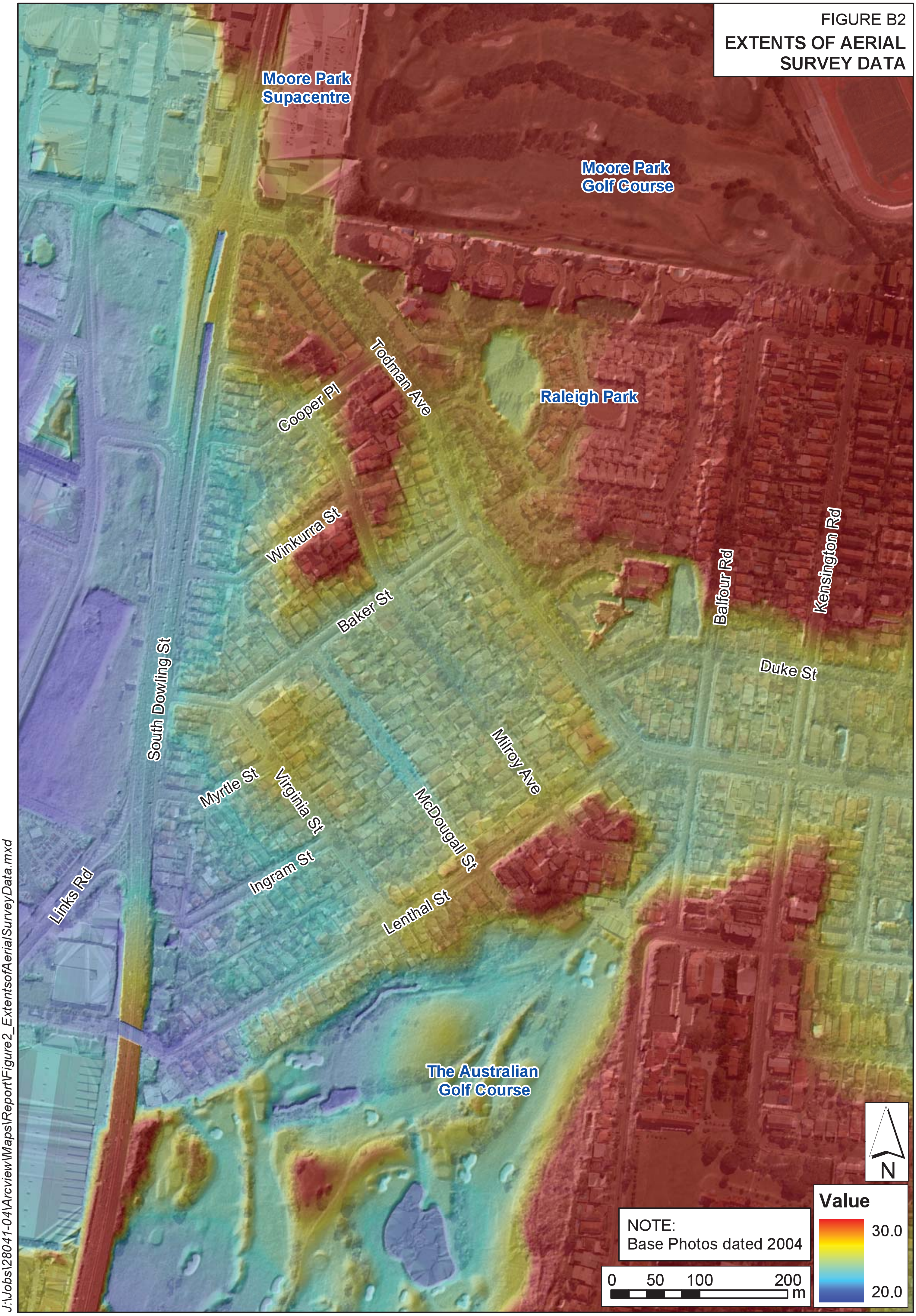
FIGURE B2
EXTENTS OF AERIAL SURVEY DATA
Moore Park Supacentre
Moore Park Golf Course
Todman Ave
Cooper Pl
Raleigh Park
Winkurra St
Baker St
Balfour Rd
Kensington Rd
Duke St
South Dowling St
Milroy Ave
Myrtle St
Virginia St
McDougall St
Ingram St
Links Rd
Lenthal St
The Australian Golf Course
N
Value
30.0
20.0
NOTE:
Base Photos dated 2004
0
50
100
200
m
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FIGURE B3
HYDROLOGICAL MODEL SUBCATCHMENT LAYOUT

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FIGURE B4
DRAINAGE NETWORK LAYOUT

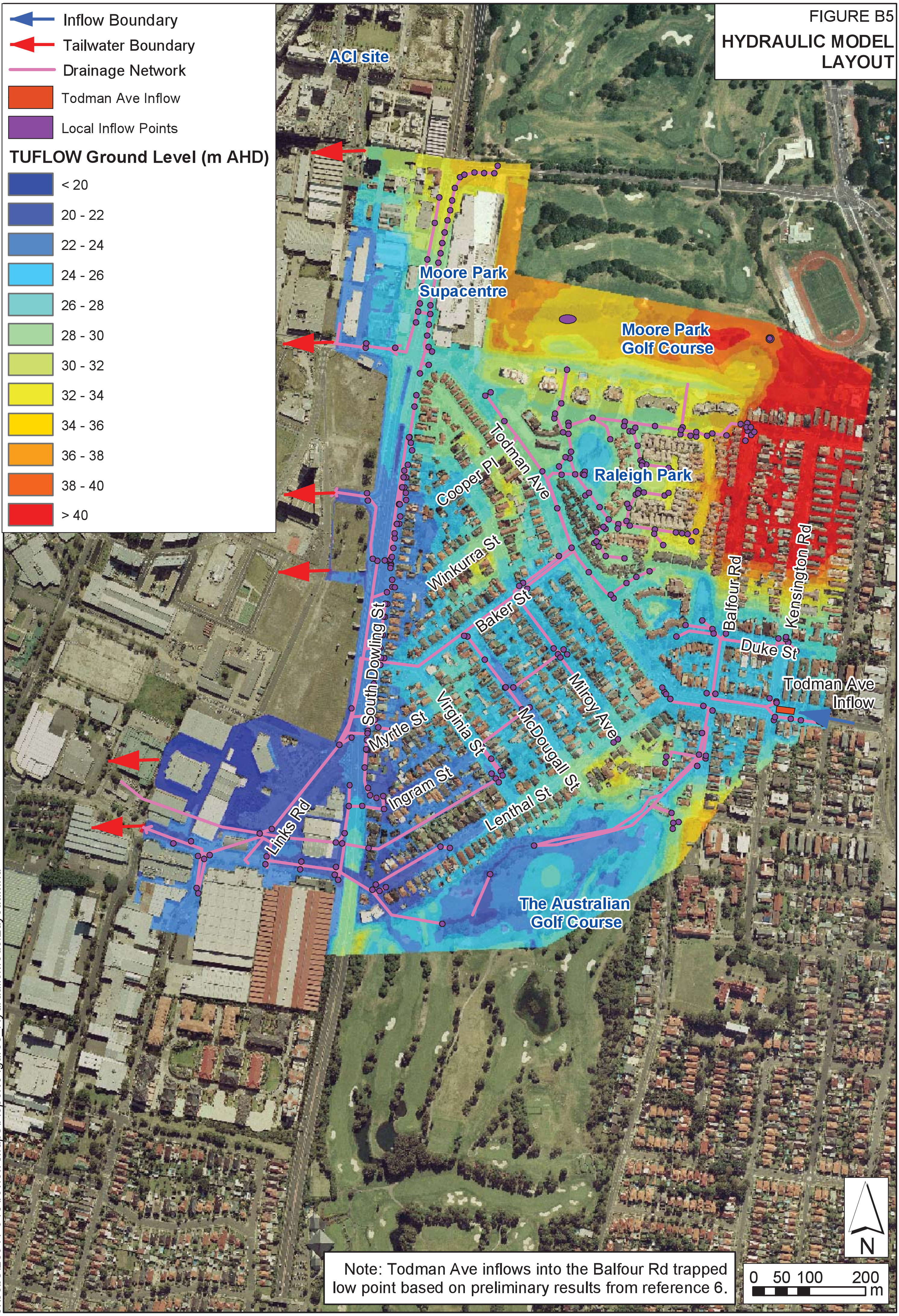
FIGURE B5
HYDRAULIC MODEL LAYOUT
Inflow Boundary
Tailwater Boundary
Drainage Network
Todman Ave Inflow
Local Inflow Points
TUFLOW Ground Level (m AHD)
< 20
20 - 22
22 - 24
24 - 26
26 - 28
28 - 30
30 - 32
32 - 34
34 - 36
36 - 38
38 - 40
> 40
ACI site
Moore Park Supacentre
Moore Park Golf Course
Raleigh Park
Todman Ave
Cooper Pl
Winkurra St
Baker St
South Dowling St
Balfour Rd
Kensington Rd
Duke St
Todman Ave Inflow
Milroy Ave
Myrtle St
Virginia St
McDougall 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

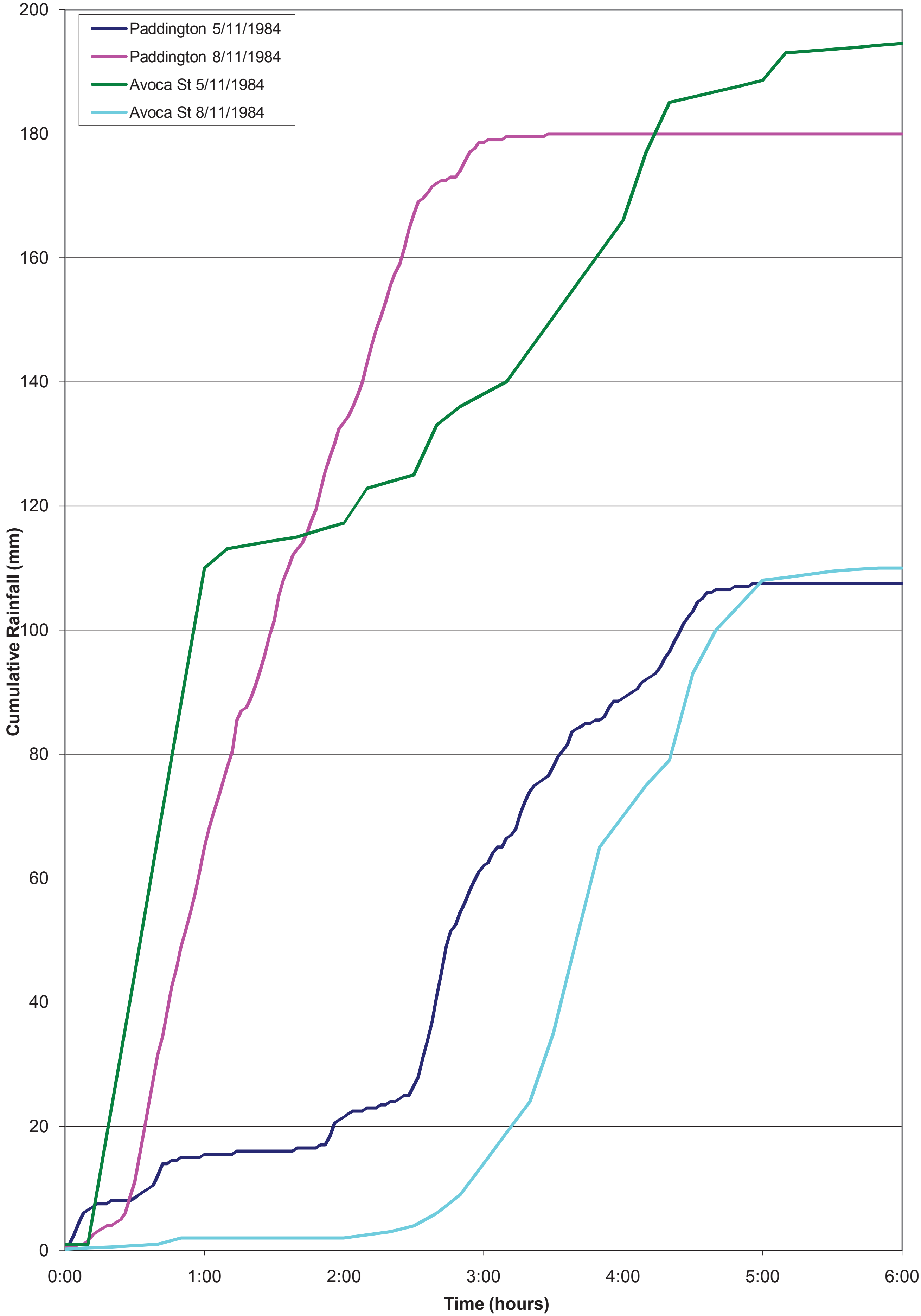

FIGURE B7
DRAINAGE NETWORK PEAK FLOWS 50% AEP EVENT

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