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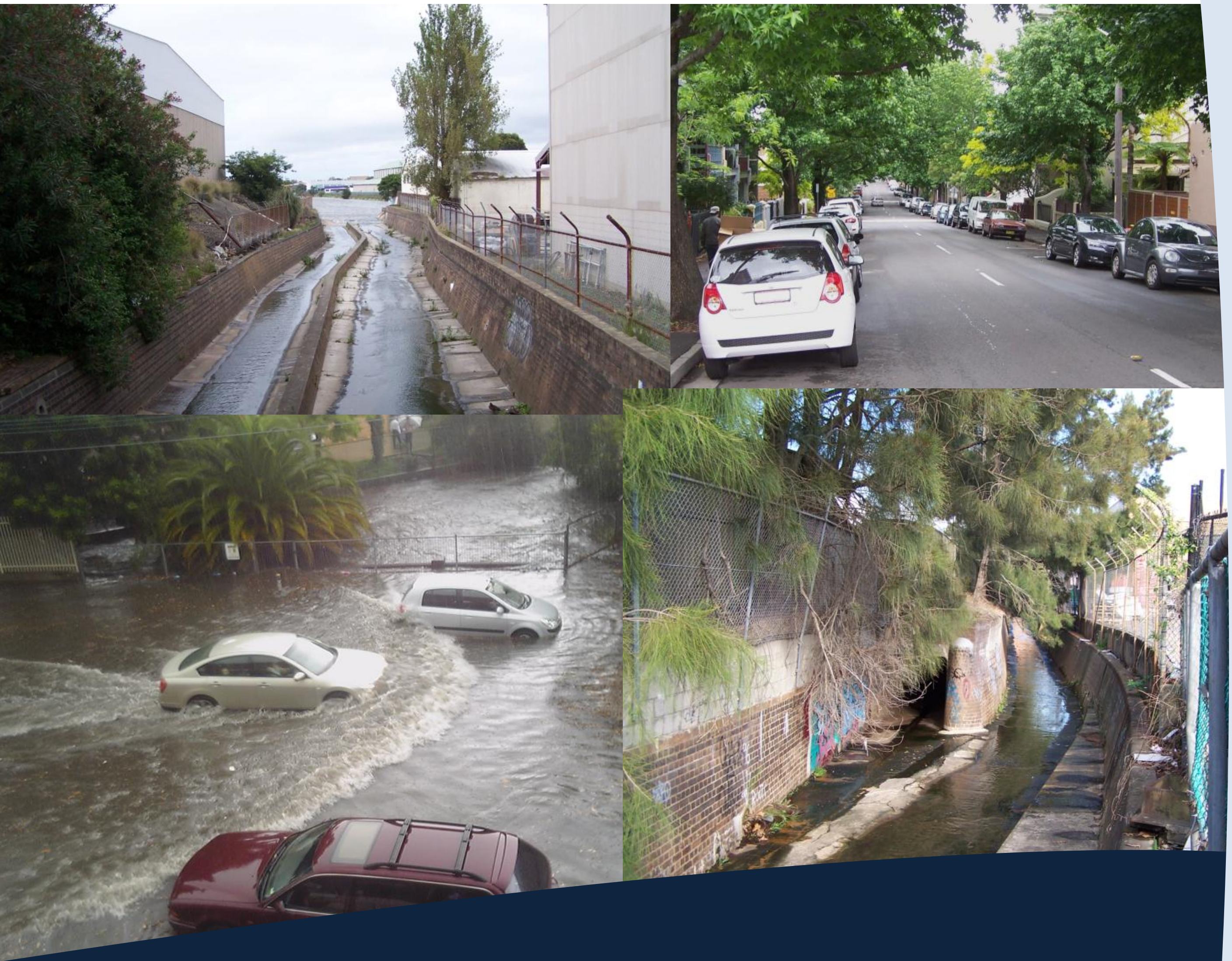

Alexandra Canal Catchment Flood Study

Report – Final

Project W4785
Prepared for City of Sydney
20 May 2014

NSW Government | Office of Environment & Heritage

CITY OF SYDNEY

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Foreword

The NSW Government Flood Prone Land Policy is directed towards providing solutions to existing flood problems in developed areas and 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 prone land is the responsibility of Local Government. The State Government subsidises flood management measures to alleviate existing flooding problems and provides specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities. The Commonwealth Government also assists with the subsidy of floodplain modification measures.

The Policy identifies the following floodplain management 'process' for the identification and management of flood risks:

1. Formation of a Committee -

   Established by a Local Government Body (Local Council) and includes community group representatives and State agency specialists.

2. Data Collection -

   The collection of data such as historical flood levels, rainfall records, land use, soil types etc.

3. Flood Study -

   Determines the nature and extent of the flood problem.

4. Floodplain Risk Management Study –

   Evaluates floodplain management measures in respect of both existing and proposed development.

5. Floodplain Risk Management Plan –

   Involves formal adoption by Council of a management plan for the floodplain.

6. Implementation of the Plan –

   Implementation of actions to manage flood risks for existing and new development.

This Alexandra Canal Catchment Flood Study represents the first stage of the management process for the catchment. The study, which has been prepared for City of Sydney Council by Cardno, defines flood behaviour for existing conditions in the catchment.

Acknowledgement

This Study was funded by the City of Sydney, the New South Wales Government, and the Commonwealth Government (under the Natural Disaster Mitigation Program).

The City of Sydney has established a Floodplain Risk Management Committee in accordance with the Floodplain Development Manual of the NSW Government to assist in the development of Flood Studies and Floodplain Risk Management Plans. Members of the Committee include councillors, representatives of the Department of Environment Climate Change and Water, the NSW SES, Sydney Water, the local community and staff members of the City of Sydney. The committee has provided guidance and oversight in the preparation of this report.

Executive Summary

Cardno were commissioned by the City of Sydney to undertake a flood study for the Alexandra Canal Catchment. The primary objective of this study is to define the flood behaviour in the study area, including both mainstream and overland flooding. While a number of previous studies have been undertaken on isolated areas of the catchment, the City of Sydney wanted to undertake a holistic view of the overall catchment.

Alexandra Canal Catchment includes the suburbs of Alexandria, Rosebery, Erskineville, Beaconsfield, Zetland, Waterloo, Redfern, Newtown, Eveleigh, Surry Hills and Moore Park. The study area is shown in **Figure 1.1**. It is roughly bounded by the Eastern Distributor and Moore Park in the east, Gardeners Road in the south, Sydney Park and Newton in the west and Albion Street in the north-east. The majority of the trunk drainage system is owned by Sydney Water Corporation, and the feeding drainage systems are primarily owned by Council.

The majority of the catchment is fully developed and consists predominantly of medium to high-density housing, commercial and industrial development with some large open spaces.

An extensive data compilation and review was undertaken for the study. This included a review of a number of previous studies which had previously been undertaken, together with collection of available rainfall records and survey data.

The study incorporates community consultation throughout. The first stage was the dissemination of a resident survey and brochure to 7000 properties in the catchment, and the collection of information from that survey on experiences of historical flooding in the catchment. The second stage was through the Floodplain Risk Management Committee, which contains community representatives and stakeholder organisations that provided guidance and review throughout the project. The final stage was the exhibition of the draft version of this report to the community for review and comment.

A key outcome from the resident survey is that approximately 70% of the community have resided in the catchment for less than 10 years. As the majority of recent large events occurred prior to 2000, this suggests that the community has limited experience of large flood events.

A detailed 1D/2D flood model was established to describe the flooding behaviour throughout the study area. This model incorporates all pits and pipes from data provided by the City of Sydney and has a 4 metre grid resolution. Hydrological modelling was undertaken through the application of the Direct Rainfall methodology.

The models were calibrated and verified against four historical storms; November 1984, January 1991, April 1998 and February 2001. November 1984 was approximately larger than a 100 year ARI event, while April 1998 was in the order of a 10 year ARI event. The other two events were smaller, with January 1991 roughly a 5 – 10 year ARI event, and February 2001 less than a 1 year ARI event. The calibration events were chosen through a combination of both their magnitude, together with the quantity of flood observations from the storm.

The results of the calibration and verification showed that the model was capable of reproducing the observations from those events, providing confidence in the overall modelling results. The models were further verified against the previous studies that have been undertaken within the catchment.

Using the established models, the study has determined the flood behaviour for the 100 year ARI, 20 year, 10 year, 5 year, 2 year and 1 year ARI events together with the Probable Maximum Flood (PMF). The primary flood characteristics reported for the design events considered include depths, levels, velocities and flow rates. The study has also defined the Provisional Flood Hazard for flood-affected areas.

An assessment of the impact of blockages of culverts and pits has also been undertaken. This analysis suggests that the catchment is particularly sensitive to these factors, and this should be considered further in the Floodplain Risk Management Study for evaluation of flood planning levels.

Climate change, including an impact of sea level rise and rainfall intensity increases, has been assessed and the likely increase in peak water levels observed. The analysis demonstrates that the model is generally more sensitive to pit and culvert blockages than to climate change.

The outcomes of this study can also be used for future studies to investigate various management and flood mitigation options for the existing catchment conditions and will assist in evaluating long term flood management strategies now that existing flood risks have been defined in this study.

This Draft Flood Study has been prepared to facilitate the Floodplain Risk Management Study (FRMS) for the Alexandra Canal Catchment.

The Draft Flood Study, Draft Floodplain Risk Management Study and Draft Floodplain Risk Management Plan were placed on public exhibition for a period of four weeks from 28 October 2013 to 25 November 2013 to allow input from the community and interested parties to the Study and its outcomes. Exhibition documents were available for review at several community locations and on Council's website.

Details of the exhibition were included in newspapers, mailed/emailed to previous contributors of flood surveys, and emailed to community groups. A community drop-in session was held on Wednesday 20 November 2013 at the Alexandria Town Hall, 73 Garden Street, Alexandria. Officers from Council, Office of Environment and Heritage and Cardno were present and available to answer community questions.

One telephone enquiry was received, three people attended the drop-in session, and one written submission was received. All these were responded to by Council and no further action is required for the Alexandra Canal Floodplain Risk Management Study and Plan.

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Glossary

Terminology in this Glossary has been derived or adapted from the NSW Government *Floodplain Development Manual*, 2005, where available.

Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
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.
Cadastre, cadastral base	Information in map or digital form showing the extent and usage of land, including streets, lot boundaries, water courses etc.
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.
Creek Rehabilitation	Rehabilitating the natural 'biophysical' (i.e. geomorphic and ecological) functions of the creek.
Creek Modification	Widening or altering the creek channel in an environmentally compatible manner (i.e. including weed removal and stabilisation with suitable native endemic vegetation) to allow for additional conveyance.
Design flood	A significant event to be considered in the design process; various works within the floodplain may have different design events, e.g. some roads may be designed to be overtopped in the 1 year ARI flood event.

Development	Is defined in Part 4 of the EPA 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. Eg, the urban subdivision of an area previously used for rural purposes. New developments involve re-zoning 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. Eg, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either re-zoning or major extensions to urban services.
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).
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 fringe	The remaining area of flood-prone land after floodway and flood storage areas have been defined.
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 provisional hazard categories are provided in Appendix L of the Floodplain Development Manual (NSW Government, 2005).

Flood-prone land	Land susceptible to inundation by the probable maximum flood (PMF) event, i.e. the maximum extent of flood liable land.
Floodplain	Area of land which is subject to inundation by floods up to the probable maximum flood event, i.e. 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.
Flood planning area	The area of land below the FPL and thus subject to flood related development controls.
Flood planning levels	Are the combinations of flood levels (derived from significant historical flood events or floods of specific ARIs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans.
Flood Risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in the Floodplain Development Manual (Appendix G) is divided into 3 types, existing, future and continuing risks. They are described below: ▪ Existing flood risk: the risk a community is exposed to as a result of its location on the floodplain. ▪ Future flood risk: the risk a community may be exposed to as a result of new development on the floodplain. ▪ Continuing flood risk: the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.

Flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas. See Section L3 of the Floodplain Development Manual.
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 flow, or a significant increase in flood levels. See Section L3 of the Floodplain Development Manual.
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. (See Section K5 of Floodplain Development Manual). Freeboard is included in the flood planning level.
Geographic information systems (GIS)	A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data.
High hazard	Flood conditions that pose a possible danger to personal safety; evacuation by trucks difficult; able-bodied adults would have difficulty wading to safety; potential for significant structural damage to buildings. See Section L5 of the Floodplain Development Manual.
Hydraulics	The term given to the study of water flow in a river, channel or pipe, in particular, the evaluation of flow parameters such as stage and velocity.
Hydrograph	A graph that shows how the discharge changes with time at any particular location.
Hydrology	The term given to the study of the rainfall and runoff process as it relates to the derivation of hydrographs for given floods.
Local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.

Low hazard	Flood conditions such that should it be necessary, people and their possessions could be evacuated by trucks; able-bodied adults would have little difficulty wading to safety. See Section L5 of the Floodplain Development Manual.
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 purposes of the Floodplain Development Manual (Appendix C) 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 0.3m (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 flowpaths through developed areas outside of defined drainage reserves; and or ▪ The potential to affect a number of buildings along the major flow path.
Management plan	A document including, as appropriate, both written and diagrammatic information describing how a particular area of land is to be used and managed to achieve defined objectives. With regard to flooding, the objective of the management plan is to minimise and mitigate the risk of flooding to the community. It may also include description and discussion of various issues, special features and values of the area, the specific management measures which are to apply and the means and timing by which the plan will be implemented.
Mathematical computer models	The mathematical representation of the physical processes involved in runoff and stream flow. These models are often run on computers due to the complexity of the mathematical relationships. In this report, the models referred to are mainly involved with rainfall, runoff, pipe and overland stream flow.

NPER	National Professional Engineers Register. Maintained by the Institution of Engineers, Australia.
Peak discharge	The maximum discharge occurring during a flood event.
Probable maximum flood	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	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 frequency or occurrence of flooding.
Risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. For this study, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
Runoff	The amount of rainfall that actually ends up as stream or pipe flow, 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 changes with time. It must be referenced to a particular location and datum.
Stormwater flooding	Inundation by local runoff. Stormwater flooding can be caused by local runoff exceeding the capacity of an urban stormwater drainage system or by the backwater effects of mainstream flooding causing the urban stormwater drainage system to overflow.
Topography	A surface which defines the ground level of a chosen area.

Abbreviations

1D	One Dimensional
2D	Two Dimensional
AAD	Average Annual Damage
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ARI	Average Recurrence Interval
AWE	Average Weekly Earnings
BoM	Bureau of Meteorology
CoS	City of Sydney Council
CPI	Consumer Price Index
DCP	Development Control Plan
FPL	Flood Planning Level
FRMC	Floodplain Risk Management Committee
FRMP	Floodplain Risk Management Plan
FRMS	Floodplain Risk Management Study
GIS	Geographic Information System
GSDM	Generalised Short Duration Method
ha	hectare
IEAust	Institution of Engineers, Australia
IFD	Intensity Frequency Duration
km	kilometres
km^2	Square kilometres
LEP	Local Environment Plan
LGA	Local Government Area
m	metre
m^2	Square metres

m^3	Cubic metres
m^3/s	Cubic metres per second
mAHD	Metres to Australian Height Datum
MHL	Manly Hydraulics Laboratory
MHWL	Mean High Water Level
mm	millimetre
m/s	metres per second
MSL	Mean Sea Level
NSW	New South Wales
OEH	NSW Government Office of Environment and Heritage (formerly the Department of Environment, Climate Change and Water (DECCW))
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
RTA	Roads and Traffic Authority
SEPP	State Environmental Planning Policy
SES	State Emergency Service
XP-RAFTS	XP-RAFTS proprietary software package

1 Introduction

Cardno Lawson Treloar was commissioned by City of Sydney to undertake a flood study for the entire Alexandra Canal Catchment. The primary objective of the study is to define the flood behaviour in the Catchment. The study has been undertaken to determine flood behaviour for a range of storm events. The primary flood characteristics reported for the design events considered include depths, levels and velocities. The study has also defined the provisional flood hazard for flood-affected areas.

The assessment of flooding in this report includes both:

- 'mainstream' flooding - flooding associated with catchment rainfall flowing to a creek, open channel or open canal and the capacity of the channel is generally exceeded; and,
- 'overland' flooding – including where catchment rainfall cannot enter the stormwater drainage system and flows 'overland', which can be through properties or down streets.

The method of assessment used for this study allows for both types of catchment flooding to be considered at the same time. The terms flooding, catchment flooding or overland flows can be used interchangeably in this report.

The study will form the basis for a subsequent floodplain risk management study for the detailed assessment of flood mitigation options and management measures.

1.1 Study Process

The primary tasks of this flood study comprise four main stages, with community consultation undertaken throughout.

1. All available data was compiled and reviewed for the study;
2. A hydrologic and hydraulic computer model was established for the study area;
3. The model was subsequently calibrated and verified;
4. The model was then used to determine flood depths, velocities and extents for a range of design storms.

These models can also be used for future studies to investigate various management and flood mitigation options for the existing catchment conditions and will assist in evaluating long term flood management strategies now that existing flood risks have been defined in this study.

1.2 Study Area

Alexandra Canal Catchment includes the suburbs of Alexandria, Rosebery, Erskineville, Beaconsfield, Zetland, Waterloo, Redfern, Newtown, Eveleigh, Surry Hills and Moore Park. The major sub-catchments are Sheas Creek (775 ha), Rosebery (207 ha), Munni Street-Erskineville (213.6 ha) and Alexandra Canal (184.2 ha).

The study area is shown in **Figure 1.1**. It represents the portion of the catchment which lies within the City of Sydney LGA, comprising approximately 93% of the total catchment. It is roughly bounded by the Eastern Distributor and Moore Park in the east, Gardeners Road in the south, Sydney Park and Newton in the west and Albion Street in the north-east.

Drainage systems consisting of open channels, covered channels, in-ground pipes, culverts and pits convey runoff from the catchment to Alexandra Canal which discharges into the Cooks River. The majority of the trunk drainage system is owned by Sydney Water Corporation and the feeding drainage systems are primarily owned by Council.

The majority of the catchment is fully developed and consists predominantly of medium to high-density housing, commercial and industrial development with some large open spaces that include Moore Park Playing Fields, Moore Park Golf Course, The Australian Golf Course, Sydney Park, Redfern Park, Waterloo Park and Alexandria Park.

1.3 Background

Previous studies undertaken within the catchment include:

- Green Square Town Centre Flood Mitigation Options Report (2009) by Cardno and Connell Wagner
- Green Square and West Kensington Flood Study (2008) by Webb McKeown
- Ashmore Street Masterplan Flood Analysis (2008) by Cardno
- South Sydney Stormwater Quality and Quantity Study (2003) by Hughes Trueman and Perrens Consulting
    - Munni Street Catchment;
    - Sheas Creek Subcatchment;
    - Botany Road – Doody Street and Gardeners Road Catchments
- Sheas Creek Flood Study (1991) by Webb McKeown

These studies have each investigated a smaller sub-section of the overall catchment. As a part of their planning and flood risk mitigation process, the City of Sydney undertook to investigate the catchment as a whole. This would draw from the previous studies to establish a holistic model of the catchment.

1.4 Objectives

The objective of the Alexandra Canal Catchment Flood Study is to define the flood behaviour in the study area. The study will produce information on flood levels, velocities and flow for the following Average Recurrence Interval (ARI) events – 1 year, 2 year, 5 year, 10 year, 20 year, and 100 year together with the Probable Maximum Flood (PMF) event. Results of the flood modelling will be output as electronic files suitable for incorporation into Council's Geographic Information System (GIS).

Detailed objectives of this study include:

- Review previous studies and available data (**Section 2**).
- Consult with the community to collect historical flood information (**Section 3**).
- Establish a hydrologic-hydraulic to model flows in the catchment (**Sections 4 and 5**).
- Define the flood behaviour for the 100 year, 20 year, 10 year, 5 year, 2 year and 1 year ARI events and Probable Maximum Flood (PMF) (**Section 6**).
- Define Provisional Flood Hazard for flood-affected areas (**Section 7**).
- Investigate potential flood impacts due to climate change (**Section 8**).

2 Review and Compilation of Data

Catchment data has been obtained from a number of sources to establish and verify the flood model, including:

- Previous reports prepared for related studies in the catchment,
- General GIS information (such as cadastre and aerial photographs) from City of Sydney Council,
- Ground survey and aerial survey information,
- Site inspections.

2.1 Previous Studies and Reports

A number of flood studies have been previously been undertaken within the study area. These studies have each investigated a smaller sub-section of the overall catchment and were reviewed for application to the Alexandra Canal Catchment Flood Study as discussed below.

2.1.1 Cooks River Flood Study (February 2009) by Parsons Brinckerhoff

The Cooks River Catchment is located in south-west Sydney with flows discharging to Botany Bay at Tempe, near Sydney Airport. The catchment is approximately 102 km^2 in area and covers portions of 13 local government areas. The Cooks River has two major tributaries, Alexandra Canal and Wolli Creek.

The study objectives included:

- Develop a hydrologic model for the Cooks River catchment.
- Develop a hydraulic model for the Cooks River and its significant tributaries (Alexandra Canal and Wolli Creek).
- Develop an understanding of existing flood behaviour within the catchment during the 2 year, 20 year, 100 year average recurrence interval (ARI) and probable maximum flood (PMF) design events.
- Use the model to estimate potential climate change flood impacts within the catchment.

Peak water levels in Alexandra Canal determined in this study were adopted as the downstream tailwater levels for the Alexandra Canal Catchment Flood Study model.

2.1.2 Green Square Town Centre Flood Mitigation Options Report (2009) by Cardno and Connell Wagner

Green Square Town Centre (GSTC) is a major urban renewal project in the area between Green Square Railway Station and Joynton Avenue. The study area is within the Sheas Creek catchment shown on **Figure 1.1.** New residential and commercial buildings and open space areas are proposed on existing industrial sites. Historically, the GSTC site has been flood-affected and certain parts of the GSTC are subjected under the current conditions to provisional high flood hazard in rare and extreme rainfall events.

The study objectives included:

- Resolve the strategy and design for stormwater and flood management measures within the Green Square Town Centre site, to ensure no additional adverse impacts are created upstream or downstream of the GSTC site, and to satisfy the requirements of the South Sydney Local Environment Plan (LEP), 1998.
- Ensure the final design for stormwater and flood management is integrated within the design of other elements (e.g. Public Domain, Pooled Car Park, O'Riordan Street intersection and existing and proposed infrastructure).
- Prepare preliminary designs for any additional downstream and upstream flood mitigation works required to ensure no additional adverse impacts are created upstream or downstream of the GSTC site.

This study extended the SOBEK flood model developed for the Green Square and West Kensington Flood Study (2008) downstream to Alexandra Canal to allow the assessment of options for the GSTC development. The extended model incorporated field survey of open channels and culverts completed for the Sheas Creek Flood Study (1991) which have been included in the Alexandra Canal Catchment Flood Study model. Modelled flood results from the GSTC Flood Mitigation Options Report (2009) were used to verify results from the Alexandra Canal Catchment Flood Study model.

2.1.3 Green Square and West Kensington Flood Study (2008) by Webb McKeown

The Green Square and West Kensington study catchment covers 250 hectares 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. The study area extends west to Botany Road and O'Riordan Street below the proposed Green Square Town Centre precinct.

The study objectives included:

- define flood behaviour within the study catchment,
- prepare mapping showing the nature and extent of flooding,
- prepare suitable models of the catchment and floodplain suitable for use in subsequent Floodplain Risk Management Studies and Plans.

Modelled flood results from this study were used to verify results from the Alexandra Canal Catchment Flood Study model.

2.1.4 Ashmore Street Masterplan Flood Analysis (2008) by Cardno

The Ashmore Street Precinct is located in Erskineville in the Erskineville-Munni Street sub-catchment shown on **Figure 1.1**. Historical data indicates that the site is susceptible to flooding. The construction of buildings along pre-existing flowpaths and floodways has resulted in the alteration of overland flood paths and a change in design flood levels at some locations.

The study objectives included:

- Review of proposed masterplan
- Review of previous reports
- Design philosophy – to ensure that the design was incorporated appropriately into the flood model, discussions were held with Council and HBO+EMTB and the masterplan was reviewed in detail.
- Model Setup – the features of the masterplan were incorporated into the existing flood model.
- Results – various flood events were assessed using the flood model, and results included peak water levels, depths and velocities, together with impact analysis and hazard analysis.
- A discussion is provided on the implication of the results on the proposed masterplan.

The results of the flood model for this study were reviewed to verify the results of the Alexandra Canal Catchment Flood Study modelling. The current study results are verified and checked with this study.

2.1.5 South Sydney Stormwater Quality and Quantity Study (2003) by Hughes Trueman and Perrens Consulting

These studies were completed for the three sub-catchments, shown on **Figure 1.1**, which comprise the Alexandra Canal catchment.

2.1.5.1 Munni Street Catchment

The Munni Street Stormwater System (Sydney Water system number 74) conveys stormwater runoff from a catchment of approximately 214 hectares. It lies within the local government areas of City of Sydney and Marrickville. Nearly all of the catchment lies within the City of Sydney area. The catchment includes the suburbs of Newtown, Alexandria, Camperdown and Erskineville, roughly bounded by Sydney Park Rd to the south, King St to the west, Wilson St to the north and Mitchell Rd and Euston Rd to the east.

The study objectives included:

- An analysis of the origin and causes of the significant stormwater flows that contribute to stormwater flooding risks.
- Development of controls to manage existing stormwater flooding risk in the area.
- Development of options for reducing future stormwater flooding risks in the area.
- Integrate quantity and quality management.
- Water quality improvements.

2.1.5.2 Sheas Creek Subcatchment

Within the Sheas Creek sub-catchment, the trunk drainage network comprises four branches: Sheas Creek Branch, Main Branch, Victoria Branch, Alexandra and MacDonaldtown Branch.

The study objectives included:

- A refined assessment of the stormwater risk imposed on the proposed Green Square development, particularly within the Green Square Town Centre.

- A more comprehensive analysis of the origin and causes of the stormwater flows that contribute to stormwater flooding risks.
- Development of controls to manage existing risk in the area.
- Development of options for reducing stormwater risks associated with the area.

2.1.5.3 Botany Road – Doody Street and Gardeners Road Catchments

Doody Street and Gardeners Road catchments are gently sloping with nearly flat sections towards Alexandra Canal. They are located within the Rosebery sub-catchment shown on **Figure 1.1**. The Botany-Doody trunk drainage network comprises six main branches: Main Channel Branch, Harcourt Parade Branch, Morley Avenue Branch, Epsom Road Branch, Mentmore Avenue Branch, and Cressy Street Relief Branch. The Gardeners Road catchment covers 15 hectares of which approximately 4.7 hectares falls within the study boundary.

The study objectives included:

- An analysis of the origin and causes of the significant stormwater flows that contribute to stormwater flooding risks.
- Development of controls to manage existing stormwater flooding risk in the area.
- Development of options for reducing future stormwater flooding risks in the area.
- Integrated quantity and quality management.
- Water quality improvements.

A key outcome of these studies was an assessment of water quality improvements in the catchments which is not a component of the Alexandra Canal Catchment Flood Study. More detailed flood models are used for the assessments undertaken for the Alexandra Canal Catchment Flood Study. Details of previous flood inundation listed in these studies were used for calibration of the current flood model.

2.1.6 Sheas Creek Flood Study (1991) Webb McKeown

Sheas Creek is the main tributary of Alexandra Canal draining to the Cooks River and comprises portions of Surry Hills, Alexandria, Waterloo, Zetland, and Redfern. Sheas Creek has a catchment of approximately 6.6 km^2 and the majority of the catchment is occupied by residential, commercial and industrial land-uses.

The study objectives included:

- To determine the 1%, 2%, 5% and extreme flood profiles within the major tributaries.

Observed flood inundation from historical storm events detailed in this study was used for the calibration of the Alexandra Canal Catchment Flood Study model.

2.2 GIS Data

City of Sydney Council provided Geographic Information System (GIS) data for preparing the Alexandra Canal Catchment Flood Study model and reporting. The data included:

- Pit and pipe data

- Cadastre
- 1m and 2m Land Information Centre (LIC) contours
- Aerial photography (2006)

Field survey of more than 4500 pits and over 4000 pipes was undertaken by Cardno's surveyors (separate to this study) to provide a detailed database of the locations and dimensions of all Council's pits and pipes within the entire LGA. Invert and surface levels of pits was determined from airborne laser scanning (ALS) levels and details measured directly during survey.

2.3 Survey Information

Council provided aerial laser scanning (ALS) ground levels surveyed in 2007 and 2008 for the entire catchment. Generally, the accuracy of the ALS data is +/- 0.15m to one standard deviation on hard surfaces.

Additional field survey was undertaken by Cardno's surveyors to provide additional detail for the development of the flood model. This included cross-sections of some open-channels, bathymetry of Alexandra Canal, and historical flood level observations.

2.4 Site Inspections

Detailed site inspections of the study area were conducted. The site visits provided the opportunity to fine tune the modelling approach to capture various street drainage features which are common in the LGA, and to visually identify potential flooding hotspots in the catchment.

3 Community Consultation

Community consultation was undertaken through three key mechanisms throughout the project:

- Resident survey – a resident survey was sent to residents within the catchment. The key objective of this survey was to gain an understanding and information on historical flooding that has occurred within the catchment.
- Floodplain Management Committee – local residents were also involved in the development of the study and provided guidance through the floodplain management committee. Invitations for volunteers for the committee were sent with the resident survey.
- Public Exhibition – a draft version of this report was placed on exhibition to the community for review and comment.

3.1 Resident Survey

A brochure and questionnaire were created for the community in order to gain an understanding of their experience with historical flooding in the catchment. The brochure and questionnaire was sent to over 7000 properties identified from preliminary flood mapping as having potentially experienced flooding in the past or who would be in the vicinity of past flooding. It was also advertised in the local newspaper and provided on-line on Council's website.

A total of 219 responses were received, which represents a relative low response rate. This is likely to be due to a number of key factors:

- There are a high proportion of commercial and industrial properties, who may not have responded to the survey;
- The community has generally resided in the catchment for a relatively short period of time, which is discussed further below. It is likely that they may not have a significant knowledge of flooding in the area.

A summary of the responses is provided in **Appendix B**.

A summary of the years of residence working on the property is summarised in **Figure 3.1**. A key point to note on this graph is that nearly 70% of the community who responded to the survey have resided in the catchment for less than 10 years. By comparison, the most significant rainfall events in recent history occurred in the 1990s, with only smaller events occurring in the 2000s (Section 4). This means that that likely awareness or knowledge of significant flood events in the catchment is likely to be low. This is important to consider in reviewing the responses.

One of the questions inquired as to the experience with flooding in the catchment. The following responses were received.

- 88 respondents have been inconvenienced by flooding while 116 have not;
- 46 explained that there routine had been affected by flooding;
- 6 recorded that their safety had been threatened;

- 52 respondents had problems with property access;
- 21 incurred flood damage; and,
- 2 experienced business difficulties.

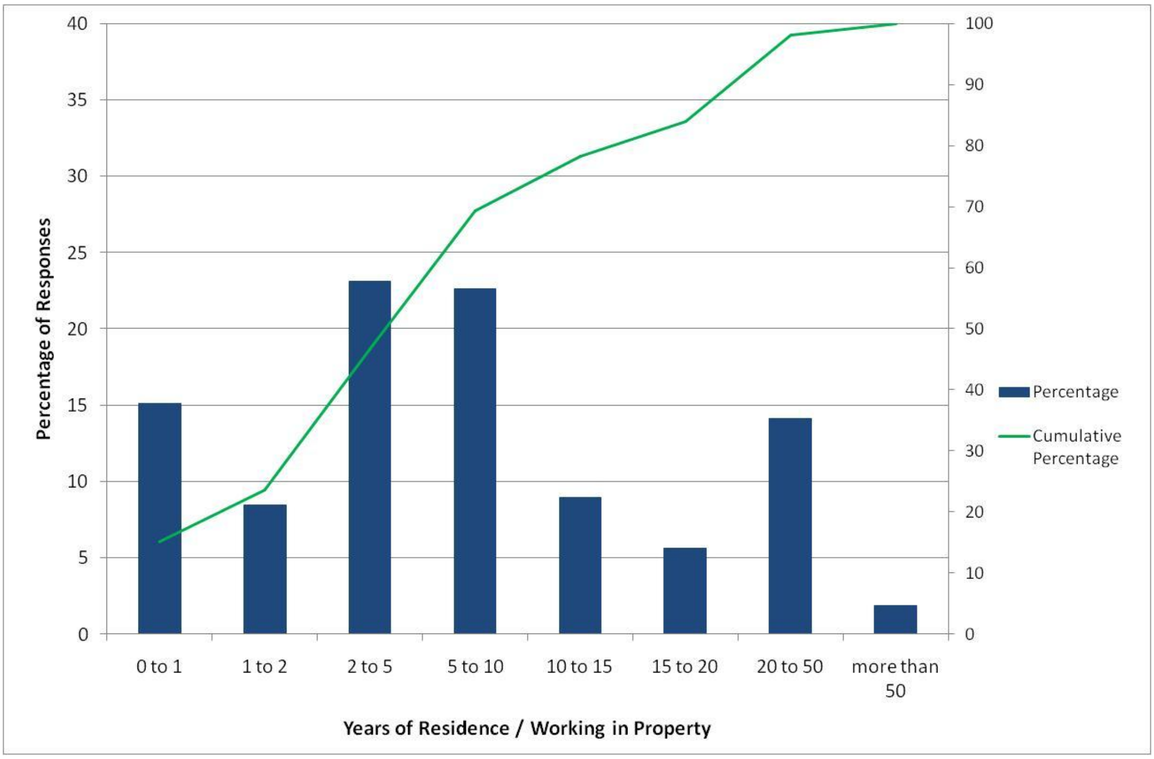

Figure 3.1 Time of Residency in Catchment

Questions were also asked in regards to the flood impacts on properties.

- Flood damage was recorded in the properties for 38 respondents. 17 of those in the front and back yard, 12 in the garage or shed and 12 indicating that flood waters inundated the floor level.
- 25 respondents advised that culverts and drains in their area were generally blocked with litter and debris causing local flooding. Some identified that railway bridges became 100% inundated during heavy rain reducing through traffic.

Respondents were asked to comment on historical flood events that they had witnessed. The storm most recalled in responses was the June 2007 event with a total of 17 residents recording some kind of flood effect. Storms with fewer responses recorded were April 1998 with 5 respondents and February 2001 and January 1989 with 3 respondents.

Responses to particular areas where flooding was noted include:

- Mitchell Road, Erskineville
- Botany Road, Alexandria - Rosebery
- Cope St, Waterloo
- Eve St, Erskineville
- Grandstand Pde Zetland
- Holdsworth St, Newtown
- Lawrence St, Alexandria

- Nobbs St. Surry Hills
- Park St, Erskineville
- Philip St, Waterloo
- Ralph St, Alexandria
- Victoria St, Beaconsfield

3.2 Floodplain Committee Meetings

Three floodplain committee meetings were held during the course of the project. The committee, in addition to representatives from various stakeholder organisations, also has community representatives.

The committee provided guidance and feedback throughout the project. The dates of committee meetings during the project were:

- 3 March 2010
- 1 September 2010
- 1 December 2010

3.3 Public Exhibition

The Draft Flood Study, Draft Floodplain Risk Management Study and Draft Floodplain Risk Management Plan were placed on public exhibition for a period of four weeks from 28 October 2013 to 25 November 2013. This allowed the community and interested parties to review the draft Study and submit comments on the Study and its outcomes.

The exhibition documents were publicly available at the One Stop Shop (Town Hall House), Redfern Neighbourhood Service Centre, Green Square Neighbourhood Service Centre, and Council's Website (www.cityofsydney.nsw.gov.au). Public notices were advertised on commencement of the exhibition in the Sydney Morning Herald, Central Sydney Magazine, Inner West Courier, and Southern Courier.

A community drop-in session was held on Wednesday 20 November 2013 at the Alexandria Town Hall, 73 Garden Street, Alexandria. Officers from Council, Office of Environment and Heritage and Cardno were present and available to answer community questions.

A notification of the public exhibition and an invitation to attend Community Information & Feedback Session was:

- Mailed to 130 stakeholders who had participated in flood surveys;
- Emailed to 560 stakeholders who had participated in flood surveys; and
- Emailed to local community and residents action groups: Cooks River Alliance, Alexandria Residents Action Group, Friends of Victoria Park, Surry Hills Neighbourhood Centre, Friends of Erskineville and Rosebery Residents Action Group.

A hard-copy display for the project was included at Neighbourhood Service Centres. The community drop-in session was promoted via Council's Twitter page with two tweets on the day of the community drop in session.

One resident telephone enquiry was received prior to the community drop-in session regarding proposals to upgrade the trunk drainage at the rear of properties facing Newtown Street, Alexandria. The resident was concerned about the potential for a future upgrade to impact the structural stability of his home. City staff advised that the exhibited studies and plan are a long term strategy, and that an upgrade to the trunk drainage in the location of concern would not occur for at least 10 years and could be up to 50 years away. The resident was concerned about short term works and was satisfied with this response.

There were three attendees at the community drop-in session and three issues were raised:

- A comment was made about historical flooding in Harcourt Parade, Rosebery and seeking information about planned measures in this area. The content of the studies and plans was then reviewed. No further action is necessary.
- A general question was asked regarding development in the Alexandria area and ensuring that there were no adverse impacts arising from future development. A response was provided to the satisfaction of the attendee. No further action.
- A general question was asked regarding opportunities for stormwater reuse as a flood mitigation measure. A response was provided to the satisfaction of the attendee. No further action.

The public exhibition page on Council's website received 170 page views. At closure of the exhibition period one written submission had been received. The submission was made using the resident comment sheet provided for the community drop-in session. The submission indicated general support for the Study and raised no further issues.

4 Flood Model Configuration

4.1 General Methodology

Two numerical modelling tools were utilised to assess flood behaviour in the catchment:

- Hydrologic Model
- Hydraulic Model

Both models are described in general below.

4.1.1 Hydrologic Model

The hydrologic model combines rainfall information with local catchment characteristics to estimate a runoff hydrograph. For this study, the Direct Rainfall method was used. This method was verified using the traditional hydrological model XP-RAFTS.

4.1.2 Hydraulic Model Method

A hydraulic model converts runoff into water levels and velocities throughout the major drainage or creek systems in the study area. The model simulates the hydraulic behaviour of the water within the study area by accounting for flow in the major stormwater pipes and channels as well as potential flow paths, which develop when the capacity of the stormwater pipes and channels is exceeded. It relies on boundary conditions, which include the runoff hydrographs produced by the hydrologic model and the downstream boundaries.

A 1D and 2D fully dynamic hydraulic model was established for the study area using SOBEK which is developed by WL|Delft Hydraulics of the Netherlands (2004) was used in this study. The system is used world-wide and has been shown to provide reliable, robust simulation of flood behaviour in urban and rural areas through a vast number of applications. The model allows addition of a 2 dimensional (2D) domain (representing the study area topography) to a one dimensional (1D) network (representing the channels, pits and pipes in the study area) with the two components dynamically coupled and solved simultaneously using the robust Delft Scheme.

An important feature of the model is the ability to model the hydraulic structures in the 1D component rather than in the 2D domain. The benefit of this approach is that structure hydraulics are modelled more precisely than the approximate representation possible in a 2D domain.

4.2 Hydrology

4.2.1 Direct Rainfall

In the application of rainfall directly on the 2D grid ('Direct Rainfall' method), the hydrology and the hydraulic calculations are undertaken in the same modelling package. In the model, rainfall is applied directly to the 2D terrain, and the hydraulic model automatically routes the flow using the same computation process that controls the routing of all other flows through the model. This means that catchment outlets do not have to be predefined, and flowpaths are identified by the model, rather than being assumed.

In this approach, the entire catchment is represented in the 2D terrain allowing for overland flow paths to be defined which would not otherwise be represented using traditional hydrologic and hydraulic approaches.

There are a number of advantages of the modelling approach, particularly given the nature of the Alexandra Canal Catchment. In flat areas, overland flow paths are not always obvious. Furthermore, additional and unexpected 'cross-catchment' flows may activate in larger events. The rainfall on the grid approach overcomes these issues, as the model will automatically divert flood waters along different flowpaths (based on the terrain and the roughness) during high flow events.

When there are a large number of stormwater pits and pipes, such as in the Alexandra Canal catchment, it can be difficult to determine the catchment that applies to a particular pit in using a traditional hydrological modelling approach. With the Direct Rainfall method, flows are automatically routed to the actual pit reducing potential errors in the application of input flows.

4.2.2 Design Rainfall Information

Design rainfall depths and temporal patterns for the 100 year ARI, 50 year, 20 year, 10 year, 5 year, 2 year and 1 year ARI events were developed using standard techniques provided in ARR (1999). IFD parameters obtained from the Bureau of Meteorology for the centre of the catchment are presented in **Table 4.1**.

Table 4.1: Design IFD Parameters for Alexandra Canal

Parameter	Value
2 Year ARI 1 hour Intensity	41.65 mm/h
2 Year ARI 12 hour Intensity	8.13 mm/h
2 Year ARI 72 hour Intensity	2.53 mm/h
50 Year ARI 1 hour Intensity	86.56 mm/h
50 Year ARI 12 hour Intensity	16.48 mm/h
50 Year ARI 72 hour Intensity	5.11 mm/h
Skew	0
F_2	4.29
F_{50}	15.86
Temporal Pattern Zone	1

Estimated design storm rainfall intensities for the full range of storm events and durations are presented in **Table 4.2**.

Table 4.2: Design Rainfall Intensities (mm/h)

Frequency - Duration	1 Year ARI	2 Year ARI	5 Year ARI	10 Year ARI	20 Year ARI	50 Year ARI	100 Year ARI
15 min	66	85	109	123	141	165	183
30 min	46.9	61	79	89	103	122	135
45 min	37.7	48.9	64	73	85	100	112
1h	32.1	41.7	55	63	73	87	97
1.5h	24.7	32.1	42.3	48.3	56	66	74
2h	20.5	26.6	35	40	46.4	55	61
3h	15.7	20.4	26.7	30.5	35.4	41.9	46.8

The Probable Maximum Precipitation (PMP) was determined using the publication "The Estimation of Probable Maximum Precipitation in Australia: Generalised Short - Duration Method" (Commonwealth Bureau of Meteorology, 2003). PMP parameters shown in **Table 4.3** were estimated based on the ellipse distribution shown in **Figure 4.1**. A weighted average intensity was calculated as shown in **Table 4.4** and applied to the model.

Table 4.3: PMP Calculation Values

Parameter					
PMP Ellipse	Area Enclosed	Area Between	Moisture Adjustment Factor	Elevation Adjustment Factor	Percentage Rough
A	2.6	2.6	0.70	1	0
B	11.09	8.49	0.70	1	0
C	12.23	1.14	0.70	1	0

Table 4.4: PMP Rainfall Intensities (mm/h)

Duration					
15 min	30 min	45 min	1h	1.5h	2h
680	500	413	360	273	225

4.2.3 Historical Rainfall Information

Rainfall gauges operated by Bureau of Meteorology (BOM) and Sydney Water (SW) near to the study area are shown in **Figure 4.2** and listed in **Table 4.5.** Pluviometer rainfall data recorded at frequent intervals, around five to six minute timesteps, is required for running the model for a particular storm event.

Table 4.5: Rain Gauges

Station No.	Station Name	Type	Source
66062	Sydney (Observatory Hill)	Pluvio	BOM
66037	Sydney Airport AMO	Pluvio	BOM
566065	Lilyfield (formerly Annandale)	Pluvio	SW
66160	Centennial Park	Daily	BOM
66073	Randwick Racecourse	Daily	BOM

SW = Sydney Water, BOM = Bureau of Meteorology

Rainfall data from the pluviometer gauges was analysed to rank the events with the highest rainfall and an equivalent average recurrence interval was estimated for the event. **Appendix A** includes the rating of peak storm events for the length of record for:

- Observatory Hill, Sydney Airport, and Lilyfield gauges;
- Durations of 30 minute, 60, 90, 120, and 180 minutes.

Observatory Hill has the longest period of record, extending from 1913 through to 2009. Based on the 90 minute storm, which is the critical duration for a large proportion of the catchment, the following provides the top 10 storm events in terms of rainfall intensities. It is noted that the estimated ARI of the rainfall does not always correspond with the ARI for the flood event.

Table 4.6: Highest Rainfall Intensities and Estimated ARIs (for 90 minute duration)

Year	ARI
November 1984	>100y
March 1975	>100y
January 1973	20-50y
August 1971	20-50y
September 1943	20y
January 1938	10-20y
November 1961	10-20y
February 1973	10y
April 1998	10y
January 1955	5 – 10y

Many of the storms listed above occurred more than 20 years ago. Based on the responses from the resident survey (Section 3), less than 20% of the respondents have lived or worked in the catchment for this period of time. Therefore, there is likely to be limited experience of some of these previous storm events.

Key events that were identified by the community in the survey include:

- 9th November 1984;
- 27th January 1991;
- 11th April 1998; and
- 1st March 2001.

In selecting calibration and verification flood events for the modelling, it is important to ensure that the historical floods cover the range of flood events to be assessed (where possible), and that sufficient data is available in order to undertake a calibration. In a number of the older events listed in **Table 4.6**, there is either no or limited observed flooding data available in order to undertake a meaningful calibration.

Based on the size of the flood event and the number of observed flood records from the resident survey and previous reports, the following storm events were selected for calibration and verification of the models:

- November 1984
- January 1991
- April 1998
- February 2001

Daily totals for each historical storm event are summarised in **Tables 4.7 to Table 4.10.** Estimated average recurrence intervals for these events are listed in **Table 4.11.** It is noted that the ARI of the rainfall does not always correspond with the ARI for the flood event.

Table 4.7: Rainfall Totals for November 1984 Flood Event

Station No.	Station Name	Total Daily Rainfall (mm to 9am 9th November 1984)
66062	Sydney (Observatory Hill)	234.6 (9th)
66037	Sydney Airport AMO	131.8 (9th)
566065	Lilyfield (formerly Annandale)	Not operational
66160	Centennial Park	136 (9th)
66073	Randwick Racecourse	240 (9th)

Peak intensity of the storm event occurred around 10pm to midnight on 8th November 1984.

Table 4.8: Rainfall Totals for January 1991 Flood Event

Station No.	Station Name	Total Daily Rainfall (mm to 9am 27th January 1991)
66062	Sydney (Observatory Hill)	65.4 (27th)
66037	Sydney Airport AMO	12.0 (27th)
566065	Lilyfield (formerly Annandale)	54 (27th)
66160	Centennial Park	49.0 (27th)
66073	Randwick Racecourse	58.0 (27th)

Peak intensity of the storm event occurred around 3pm to 5:30pm on 26th January 1991.

Table 4.9: Rainfall Totals for April 1998 Flood Event

Station No.	Station Name	Total Daily Rainfall (mm to 9am 11th April 1998)
66062	Sydney (Observatory Hill)	165.2
66037	Sydney Airport AMO	70.6
566065	Lilyfield (formerly Annandale)	185
66160	Centennial Park	68.0
66073	Randwick Racecourse	105

Peak Intensity of the storm event occurred around 10am to 11am on 10th April 1998.

Table 4.10: Rainfall Totals for February 2001 Flood Event

Station No.	Station Name	Total Daily Rainfall (mm to 9am 1st March 2001)
66062	Sydney (Observatory Hill)	27 (1st March)
66037	Sydney Airport AMO	6.8 (1st March)
566065	Lilyfield (formerly Annandale)	14(1st March)
66160	Centennial Park	25.8 (1st March)
66073	Randwick Racecourse	19 (1st March)

Peak intensity of the storm event occurred around 3:30pm to 6pm on 28th February 2001.

Table 4.11: Approximate ARI of Historical Rainfall Events for Observatory Hill

Storm Event	Details	Duration				
		30 mins	60 mins	90 mins	2 hour	3 hour
November 1984	Intensity (mm/h)	180	119	104	90	64
	Approx. ARI	*>100y*	*>100y*	*>100y*	*>100y*	*>100y*
January 1991	Intensity (mm/h)	120	65	43	32	20
	Approx. ARI	*~50y*	*10-20y*	*5-10y*	*2-5y*	*1-2y*
April 1998	Intensity (mm/h)	84	67	48	37	35
	Approx. ARI	*5-10y*	*10-20y*	*~10y*	*5-10y*	*~20y*
February 2001	Intensity (mm/h)	44	22	15	11	8
	Approx. ARI	*<1y*	*<1y*	*<1y*	*<1y*	*<1y*

4.2.4 Infiltration Losses

The study area is highly developed primarily comprising residential and industrial properties and thus is considered to be of relatively high imperviousness. Adopted rainfall losses due to infiltration in the model are:

- Initial loss 5mm;
- Continuing loss rate 1mm/h.

4.3 Hydraulic Modelling

Analysis of flooding and overland flow is a complex task in an urban environment. In many developed areas, the natural creek systems have been replaced with underground pipe drainage, which has a limited capacity. The overland flow resulting from a major flood event may affect areas that are different to those that would have otherwise been affected if the system were in its natural state. This is due to the complexity of overland flowpaths that are created as a result of the development of the area. A reasonably accurate assessment of flooding in such areas requires a two-dimensional approach in modelling the flood behaviour.

4.3.1 Model Schematisation

A fully dynamic one and two dimensional hydraulic model was developed for the study area using the SOBEK modelling system. The channel (up to the top of bank) has been modelled as a one-dimensional (1D) element with cross-sections defining the channel geometry. Once the channel capacity is exceeded, flow is able to spill into the two-dimensional (2D) overland flow grid, which overlies the 1D elements in the model. During the flood recession, flow is also able to drain from the overland areas back into the defined channel.

Pits and pipes have also been incorporated into the model as individual 1D elements. As the pipe capacity is exceeded, excess flow spills into the 2D domain via the pit. Similarly, overland flow is able to enter the pipe network through the pit when the pit or pipe capacity permits.

4.4 1D Network

The 1D component of the model includes a number of open channels, stormwater drainage culverts in the study area. **Figure 4.3** shows the layout of the pit, pipe and channel systems incorporated into the model.

Piped drainage systems are incorporated into the SOBEK model as distinct 1D elements connected to the terrain grid. The channel cross sections were located such that flow controls were captured, and so that the cross sections adequately represented variations in the channel definition. Details of structures within the study area (such as culverts) were also gathered, and included in the model.

The details of the majority of 1D cross sections and structures was based on survey data supplied by Cardno's surveyors and from the previous flood studies. Sufficient survey of the channels was obtained such that a reasonable representation of the flow behaviour is provided in the area.

The different size of the inlet pit openings was included in the model as orifice-links of the same size to represent the restriction of the flow in the piped system. An orifice-link was included between pipeline reaches to model the energy losses at pits. It is noted that no blockage was assumed for the pits. A sensitivity analysis of the effect of blockage is discussed in **Section 6.3**.

The larger channel of Alexandra Canal downstream of Huntley Street was represented in the 2D portion of the model.

4.5 2D Grid

Two-dimensional (2D) hydraulic modelling was carried out to determine the flood behaviour for the entire catchment. The input to the hydraulic modelling was not based on traditional methods of hydrological analysis. Rather, design rainfall time-series were applied directly on the model domain as input, which resulted in the generation of overland flow. Rainfall losses were subtracted from the design rainfall to derive excess hyetographs, as discussed in **Section 4.2.4.**

The 1D component of the model primarily covers the open channels, the pits and pipes in the study area. All other major flowpaths including the overland flow in the study area were modelled as part of the 2D model component.

The model grid was developed from the survey data, primarily the ALS levels. The civil and surveying package 12D was used to generate a detailed 3D surface (digital terrain model) of the study area. Important hydraulic controls such as bridges were represented at the correct levels in the topographical grid.

The 2D grid covers the entire Alexandra Canal catchment as shown in **Figure 4.4**. A grid cell size of 4m was adopted for the study comprising approximately 1.8 million cells. This provides a reasonable representation of flowpaths in the study area while also allowing for efficient computational run times. The SOBEK software allows for "nested" or "child" grids, which effectively allow a small grid cell size to be adopted within a portion of the larger grid. Further refinement of the model to evaluate potential mitigation options at particular locations could be adopted in the Floodplain Risk Management Study.

4.5.1 Buildings

All the industrial buildings in the study area were modelled as completely blocking overland flowpaths by raising the extent of their footprint in the elevation grid. **Figure 4.5** shows the extent of the raised buildings. Residential buildings were modelled with a higher roughness (0.50) rather than raising above the grid.

As a 4 metre grid cell resolution was adopted, it would not be possible to model the small and confined flowpaths between residential buildings within the catchment, particularly dense developments such as townhouses. Therefore, modelling the residential buildings as completely blocked was not feasible in this particular study. Instead, a high roughness effectively averages out the effect of the obstructions and overland flowpaths across the entire property.

It is important to note that this averaging effect will meant that velocities on individual properties may be underestimated in some cases, and should be kept in mind in reviewing the results. A more refined grid cell resolution would be required to estimate flood velocities on individual property lots.

Grid elevations in the model are shown in **Figure 4.6.**

4.5.2 Hydraulic Roughness

The hydraulic roughness for the 1D cross sections and 2D grid were determined based on the aerial photography supplied by Council, site inspections and previous studies.

There is no standard reference that provides guidelines on estimating the hydraulic roughness for overland flow in 2D models. Standard references such as Chow (1973) that provide roughness values for channels can provide an approximate estimate of 2D roughness. As such, roughness values used in the model have been based on past experience in model calibration in catchments of similar land use and topography. **Table 4.11** shows the adopted roughness values adopted in the 2D grid shown in **Figure 4.7**. The roughness values adopted for the piped drainage systems are listed in **Table 4.12.**

Table 4.12: Adopted 2D Grid Roughness Values

Classification	Roughness
Building	0.5
Channel	0.025
Open Space	0.03
Roads	0.02
Business	0.06
Industry	0.06
Concrete Hardstand	0.025
Residential	0.06
Railway	0.04
Raised Buildings	0.02

Table 4.13: 1D Element Roughness Values

Component	Roughness Value
Pipe	0.018
Culvert	0.015
Open Channel	0.02/0.025

4.5.3 Boundary Conditions

The downstream extent of the model is on Alexandra Canal at a short distance downstream of Ricketty Street. Water levels in Alexandra Canal were modelled for several recurrence intervals in the Cooks River Flood Study (2009). Peak levels were estimated from figures presented in the Cooks River Flood Study for the 2 year ARI, 20 year ARI, 100 year ARI and the PMF. Water levels for the other ARI events relevant to the Alexandra Canal study were estimated from these results. The peak water levels are listed in **Table 4.13.**

The Cooks River Flood Study (2009) reports a critical duration of 2 hours for flooding in the Cooks River. Peak water levels in Alexandra Canal from a storm event in the Cooks River catchment may as a result coincide with peak runoff from the Alexandra Canal catchment. Therefore, the peak levels in Alexandra Canal from the Cooks River Flood Study are adopted as the downstream tailwater levels for this Study.

Table 4.14: Alexandra Canal Tailwater Levels

Design Event	Tailwater Level (m AHD)
PMF	3.95
100y ARI	2.50
20y ARI	2.15
10y ARI *	2.10
5y ARI *	2.0
2y ARI	1.65
1y ARI *	1.65

** - Estimated based on reported levels.*

5 Model Verification and Calibration

5.1 Hydrology Verification

As the Direct Rainfall (rainfall on the grid) methodology is still relatively new to the industry, it was verified against a traditional hydrological model. The verification was undertaken by comparing the results from a 100 year ARI event for the Direct Rainfall Model with the results from a traditional hydrological model (XP- RAFTS). It is not always expected that the two models will exactly match (in fact, two separate traditional hydrological models with similar parameters can produce significantly different results). However, where there are differences some interpretation of the results can be made and the models can be checked as to why this is the case.

The comparison was undertaken on relatively small sub-catchments, as the larger the sub-catchment, the more likely significant hydraulic controls, such as culverts and localised depression storages, would not be accounted in the hydrological model. In addition, the primary aim of this comparison is to ensure that the timing and peak flows from the direct rainfall hydraulic model (SOBEK) are reasonable, with the focus on the runoff areas rather than the mainstream flooding areas.

Two sub-catchments are modelled for this comparison, near Erskineville Railway Station (Sub-catchment A) and near Gardeners Road (Sub-catchment B), as shown in **Figure 5.1.** Peak flow and volume estimated by the XP-RAFTS and SOBEK models for the 100 year ARI 90 minute event from the two sub-catchments are listed in **Table 5.1.**

Table 5.1: Sub-catchment Results for SOBEK and XP-RAFTS Models

Location	Catchment Area (ha)	XP-RAFTS Peak Flow (m^3/s)	XP-RAFTS Volume (m^3)	SOBEK Peak Flow (m^3/s)	SOBEK Volume (m^3)
Sub-catchment A	13.55	4.5	9,410	4.1	8,715
Sub-catchment B	10.70	6.4	13,135	5.9	12,603

These results indicate a reasonable agreement between the Direct Rainfall (SOBEK) and the XP-RAFTS models. The overall volume of runoff is higher in the XP-RAFTS model than in the SOBEK model due to storage effects. The SOBEK model has an elevation grid that details localised depression storages, such as at roads, properties, and buildings, that are not represented in the XP-RAFTS model.

Peak flows are also reduced in the SOBEK model compared to the XP-RAFTS model due to the storage effects and due to the elevation and roughness grids in SOBEK that result in more detailed assessment of the conveyance and concentration of flows. Time-series hydrographs in **Figure 5.2** show a similar rise and fall timing between the two models. The RAFTS hydrograph shows an earlier start to flow than the SOBEK model due to its detailed storage and conveyance calculations.

The SOBEK model utilising the Direct Rainfall methodology is therefore considered to suitably model flow behaviour compared with the traditional separate hydrology model methodology.

5.2 Historical Event Calibration

Four storm events were identified in **Section 4.2.3** as potentially suitable for calibration of the flood model due to available specific flood inundation responses. These are listed in **Table 5.2.**

Table 5.2: Storm Events for Calibration

Event	Approximate ARI
November 1984	100 year
January 1991	5 to 20 year
April 1998	5 to 20 year
February 2001	1 year

Isohyets of the daily rainfall for each storm event from the rainfall gauges are shown on **Figures 5.3 to 5.6** respectively. The pluviometer data from the Observatory Hill gauge was adopted for modelling as it provides a reasonable and conservative representation of potential rainfall onto the study area. Time-series graphs showing recorded rainfall depths per six minute period for the Observatory Hill gauge for these storm events are shown on **Figures 5.7 and 5.8.**

Three of the storm events were modelled in SOBEK - November 1984, January 1991, and February 2001. April 1998 was not modelled as there was only one flood inundation response and the January 1991 event was of similar recurrence interval and had more flood responses.

Figures showing the location of inundation responses and modelled extents are listed in **Table 5.3.**

Table 5.3: Calibration Event Figures

Event	Inundation Responses	Modelled Extent
November 1984	Figure 5.9	Figure 5.12
January 1991	Figure 5.10	Figure 5.13
February 2001	Figure 5.11	Figure 5.14

Modelled peak depth and peak water level results and observed water levels for the three storm events are listed in **Tables C1 to C3** in **Appendix C.** A statistical comparison of the modelled inundation compared to the observed levels is shown in **Table 5.4.**

Table 5.4: Calibration Event Levels Comparison

Historical Storm	Number of Observations	Average Difference (m)*	Standard Deviation*
1984	10	0.10	0.03
1991	12	0.07	0.07
2001	4	0.02	0.03

** - based on absolute differences, outlier results have been excluded from the analysis.*

Generally the model reproduces peak water levels and depths within ±0.1 metres of the reported inundation. Larger discrepancies are observed at a few locations, but these are potentially due to measurement and observation errors or due to specific localised conditions (such as pit blockages).

The results from the modelled calibration events show that the SOBEK model satisfactorily estimates the flood inundation for the historical storm events and is therefore representative for modelling of the design recurrence interval events.

5.3 Verification to Previous Studies

A comparison was undertaken between the results of the current study with two previous studies; Ashmore Street (Cardno, 2008) and Green Square (Cardno, 2009). This was undertaken as a secondary analysis, as the calibration to historical observations would generally be considered to be more robust.

It is also important to note that the Green Square modelling utilised a different rainfall method, as described in Cardno (2009) and followed from previous modelling that had been undertaken by Webb McKeown and Associates (2008). In order to provide a more realistic comparison, the models from the current study were re-run with the rainfall pattern adopted for the Green Square area.

A comparison has been undertaken by comparing both the flood extents and the peak water levels. This comparison is shown on **Figure 5.15**. There are a number of challenges in this comparison in general:

- The survey adopted for each study area is different. Ashmore Street and Green Square both utilised different sets of photogrammetry data which have different orders of accuracy to the ALS data adopted for the current study;
- The pit and pipe data was generally based on available records while the current study utilises survey pit and pipe data;
- The individual studies themselves were primarily focusing on their specific study area, and therefore may not incorporate aspects upstream and downstream in as much detail. This is particularly relevant for Ashmore Street.

Despite these limitations, the flood extents from the studies generally align, suggesting that the flood behaviour in the models generally agree. Furthermore, at the sample points shown, the peak flood levels are generally within +/- 0.2 metres. Given the different orders of accuracy of the survey data, this is considered a reasonable match.

6 Design Flood Modelling Results

6.1 Model Scenarios

Flood behaviour was modelled in SOBEK for the 1 year, 2 year, 5 year, 10 year, 20 year, 100 year ARI and PMF design flood events. Model runs were carried out for the rainfall event durations of 15 minutes, 30 minutes, 45 minutes, 60 minutes, 90 minutes, 2 hours and 3 hours for the 1 year to 100 year ARI. Durations of 15 minutes, 30 minutes and 45 minutes were run for the PMF design events.

Critical durations for peak flood levels in the study area vary depending on the location and flood characteristics for specific locations. These are listed in **Table 6.1.** Generally, shorter duration events result in higher peak water levels at the upstream and higher elevation areas whilst longer duration events are critical in main flowpaths and ponding areas.

Table 6.1: Event Critical Durations

Average Recurrence Interval	Critical Durations
1 year to 100 year	60 to 180 minutes
PMF	15 to 45 minutes

Peak water level, depth, and velocity in the study area are determined based on the peak value for each grid cell from all durations modelled in a particular ARI event. As the direct rainfall approach is used, every 2D cell is inundated with some flood depth. A filter is applied to clarify the results and highlight primary flowpaths excluding locations of minor localised runoff depths. The flood extents are shown for depths greater than 0.15 m or for a velocity-depth product >0.1 m^2/s, together with some manual manipulation to remove small isolated ponding areas. Results are presented only within these extents. Note that these figures are exclusive of the 1D results which include some of the drainage channels in the study area.

Flood extent, peak depth and peak velocity for each ARI modelled is included in the figures listed in **Table 6.2.**

Table 6.2: Model Results Figures

ARI	Flood Extent	Peak Depth	Peak Velocity
1 year	Figure 6.1	Figure 6.8	Figure 6.15
2 year	Figure 6.2	Figure 6.9	Figure 6.16
5 year	Figure 6.3	Figure 6.10	Figure 6.17
10 year	Figure 6.4	Figure 6.11	Figure 6.18
20 year	Figure 6.5	Figure 6.12	Figure 6.19
100 year	Figure 6.6	Figure 6.13	Figure 6.20
PMF	Figure 6.7	Figure 6.14	Figure 6.21

6.2 Sensitivity Analysis

The sensitivity of the model was analysed to determine the range of uncertainty in the model results for changes in key parameters. The following variables were tested for the 100 year ARI 90 minute storm event:

- Catchment roughness – increased and decreased by 20%
- Catchment rainfall - increased and decreased by 20%
- Tailwater level - increased and decreased by 20%

6.2.1 Catchment Roughness

Values of the hydraulic roughness parameter applied to the model in the 2D grid were increased and decreased by 20% for the sensitivity analysis. For this assessment the roughness was not adjusted in the 1D channels, pipes and culvert elements.

Differences of the peak water level compared to the base model with the roughness values increased by 20% and decreased by 20% are shown in **Figures 6.22 and 6.23** respectively. **Table 6.3** lists statistics of the differences for the two cases.

The summary statistics are based on the results within the 100 year ARI flood extent, using a 20 metre analysis grid. Averages are also presented for those locations where the difference is greater or less than 0.01 metres. This is undertaken to represent the average impact in those areas where changes occur.

Table 6.3 Model Sensitivity Statistics – Catchment Roughness

Statistics	Increased 20%	Decreased 20%
Average level difference (m)	0.00	0.00
Median level difference (m)	0.00	0.00
Standard Deviation (m)	0.00	0.01
Maximum level difference (m)	0.38	0.39
Minimum level difference (m)	-0.27	-0.82
Average where difference is > 0.01m	0.01	0.02
Average where difference is < 0.01m	0.00	0.00

The impact of 2D roughness values on the results of the modelling are generally relatively low with a negligible average and median level difference. Larger differences occur at isolated locations. Increases and decreases are observed in both scenarios, due to the either additional or less resistance of the roughness changes.

6.2.2 Catchment Rainfall

The average rainfall intensity for the 100 year ARI 90 minute duration storm was increased and decreased by 20% for the sensitivity analysis. The resultant average intensity for the 20% decrease case is between a 20 year and 50 year ARI intensity.

Differences of the peak water level compared to the base model for the rainfall increased by 20% and decreased by 20% are shown in **Figure 6.24 and 6.25** respectively. **Table 6.4** lists statistics of the differences for the two cases.

Table 6.4 Model Sensitivity Statistics – Rainfall

Statistics	Increased 20%	Decreased 20%
Average level difference (m)	0.02	-0.02
Median level difference (m)	0.00	0.00
Standard Deviation (m)	0.04	0.04
Maximum level difference (m)	1.76	0.01
Minimum level difference (m)	-0.02	-2.24
Average where difference is > 0.01m	0.06	0.01
Average where difference is < 0.01m	0.00	-0.02

Changes in rainfall intensities are generally widespread across the study area, although there are certain areas that are more significantly affected than others. The model is more sensitive to changes in rainfall intensities by comparison with 2D roughness values.

While the average change is generally +/- 0.02 metres within the flood extent, a reduction in rainfall intensities results in over 1 metre of water level difference in isolated locations.

A further discussion on rainfall is provided in the Climate Change assessment in **Section 8**.

6.2.3 Tailwater Level

The tailwater level for the model is applied in Alexandra Canal a short distance downstream of Ricketty Street. A peak flood level of 2.5m AHD is adopted for the 100 year ARI model from the Cooks River Flood Study (2009). Peak water level differences in the study area for the tailwater level increased by 20% and decreased by 20% are shown in **Figures 6.26 and 6.27** respectively. Statistics for the differences of the two cases are shown in **Table 6.5.**

Table 6.5 Model Sensitivity Statistics – Tailwater Level

Statistics	Increased 20%	Decreased 20%
Average level difference (m)	0.01	-0.01
Median level difference (m)	0.00	0.00
Standard Deviation (m)	0.06	0.05
Maximum level difference (m)	0.58	0.02
Minimum level difference (m)	-0.02	-0.49
Average where difference is > 0.01m	0.32	0.02
Average where difference is < 0.01m	0.00	-0.01

The impact of changes in downstream boundary primarily impact on the areas in the immediate vicinity of Alexandra Canal, and do not affect flood levels significantly upstream. This suggests that the model is not particularly sensitive to assumptions of the downstream boundary for the majority of the study area.

The largest changes in peak water levels occur in the areas near Alexandra Canal itself.

6.3 Blockages

Stormwater pits can potentially block through a number of factors, including the build-up of leaf litter, parked cars and garbage bins. Blockages to culverts and bridges within the study area can occur by the accumulation of debris washed down from upstream. This debris, from historical observations in other similar catchments, can include vegetation and trees, cars and garbage bins.

Blockage to inlet pits was modelled for two cases, 100% blockage and 50% blockage, by adjusting the size of the orifice control on inlets. Wollongong Council have developed a Conduit Blockage Policy (Wollongong City Council, 2002) based on historical observations during major flooding in the urbanised portions of Wollongong in 1998 and 1999.

In summary, the Wollongong City Council Conduit Blockage Policy (Wollongong City Council, 2002) adopts the following blockages:

- 100% blockage for structures with a major diagonal opening width of less than 6 metres,
- 25% bottom-up blockage for structures with a major diagonal opening width of greater than 6 metres.

For both pit blockage cases, culverts in the Alexandra Canal model have been adopted as 100% blocked, except for the culverts at Huntley Street and Maddox Street which have a 25% bottom-up blockage as they have a diagonal opening width of more than 6 metres.

Peak water differences for the 100% blockage and 50% pit blockage cases compared to the base 100 year ARI 90 minute event are shown in **Figures 6.28 and 6.29** respectively. Statistics for the differences of the two cases are shown in **Table 6.6.**

Table 6.6 Model Sensitivity Statistics – Blockage

Statistics	100% Blockage	50% Blockage
Average level difference (m)	0.02	0.00
Median level difference (m)	0.00	0.00
Standard Deviation (m)	0.08	0.01
Maximum level difference (m)	1.84	0.47
Minimum level difference (m)	-1.44	-0.23
Average where difference is > 0.01m	0.12	0.03
Average where difference is < 0.01m	0.00	0.00

The impact of pit and culvert blockages results in some significant localised increases in peak water levels. For a 50% blockage scenario, a reduction of up to 0.1m occurs in Bowden Street due to additional runoff being retained in the upper areas of the catchment.

The impact of the 100% blockage case results in more widespread impacts. Key areas impacted are the low lying trapped depression locations, such as Coulson Street, areas along Botany Road, the area to the north of Copeland Street and Erskineville Oval and the trapped low points in the vicinity of Danks Street. In these locations, the primary outflow points are via the pit and pipe system. Blockage of the underground drainage system means there are limited opportunities for water to be conveyed from these locations.

In a number of the locations which are particularly susceptible to pit blockages, the likelihood of blockage would be considered reasonably high. There is limited opportunity for self-cleaning of the pits in locations such as Coulson Street where runoff ponds. Furthermore, in a number of cases the pits themselves are quite old and have limited capacity.

This analysis suggests that the catchment is particularly sensitive to these factors, and this should be considered further in the Floodplain Risk Management Study for evaluation of mitigation options and flood planning levels.

6.4 Discussion of Results

6.4.1 Munni Street Catchment

The Munni Street catchment discharges into Alexandra Canal through a concrete channel near Burrows Road. The catchment incorporates a mix of residential and industrial.

The upper parts of the catchment are primarily residential and townhouses. The flowpaths in the upper portions are primarily overland flow, and proceed between the houses and across the roads in these areas. Some ponding occurs north of MacDonaldtown and the rail line, due to the obstruction that the rail line creates in this area on Holdsworth Street. Ponding in this area is in the order of 1.7 metres in the 100 year ARI event.

To the west of the Illawarra and Eastern suburbs rail line, an overland flow path forms a ponding and backwater area on Macdonald Street, due to the control of the rail underpass on Macdonald Street. Ponding in this area is in the order of 0.8 metres in the 100 year ARI event.

A significant isolated ponding area occurs north of Erskineville Oval and Copeland Street. This area is controlled by the high point and limited capacity of Fox Avenue, as well as from the obstruction of the oval itself. Ponding upstream of this area reaches depths in excess of 1 metre in the 100 year ARI, and affects a number of residential properties.

The industrial area in the centre of the Munni Street catchment is inundated by overland flowpaths which arrive from Macdonald Street (to the west of the rail line) and from the north of Ashmore Street. This overland flow accumulates at a trapped low point at the intersection of Coulson Street and Mitchell Avenue. At this location, the estimated 100 year ARI depths are in the order of 0.9 metres, and increase to around 1.3 metres further west of the intersection on Coulson Street. This ponding area is controlled by the high point which runs between Sydney Park Road and Huntley Street.

6.4.2 Sheas Creek Sub-catchment

The Sheas Creek catchment drains to a main open channel at Bowden Street conveying runoff to Alexandra Canal south of Huntley Street. Three subsections of the catchment drain toward Bowden Street – Alexandria and MacDonald town Branch, Main Branch, and Victoria Branch.

Lowpoints in the roads of the Alexandria and MacDonaldtown Branch result in ponding at Cope Street near Wellington Street, Buckland Street near Gerard Street and at Park Road.

In the Main Branch subsection, a series of lowpoints in the road show ponding of runoff in frequent storm events. These include Phelps Street, Arthur Street, Boronia Street near Marriott Street, along Baptist Street to Phillip Street, Phillip Street near Walker Street, Chalmers Street and Hunter Street. In a larger storm event, runoff flows out of these ponded areas primarily along roads from the north-east of the study area to the open channel at Wyndham Street.

The upstream areas of the Victoria Branch are located outside the study area in West Kensington to the east of South Dowling Street. Runoff is conveyed generally towards Joynton Avenue where box culverts are located to convey water through the area of the proposed Green Square Town Centre towards Mandible Street. Ponding occurs in lowpoints in roadways during frequent ARI events at Joynton Avenue, Botany Road near Bourke Street and O'Riordan Street near Johnson Street. In a larger storm event, a relatively contiguous flowpath along roads is evident from Lachlan Street and South Dowling Street along Joynton Avenue and O'Riordan Street to the open channels.

6.4.3 Rosebery Sub-catchment

Rosebery sub-catchment is comprised of several sections which drain either to Alexandra Canal or out of the study area south of Gardeners Road. A relatively small portion in the south-eastern corner of the study area, bounded by Dalmeny Avenue and Asquith Avenue, drains toward the south across Gardeners Road. The portion of the catchment bounded by Birmingham Street, Gillespie Avenue and Botany Road also drains across Gardeners Road into the City of Botany Bay Council.

The majority of the Rosebery sub-catchment is the Doody Street drainage area and drains towards the open channel located between properties from Doody Street to Bourke Road. Ponding of runoff is particularly evident at lowpoints in the road at Botany Road near Collins Street, Morley Avenue near Jones Lane, Harcourt Parade near Durdans Avenue, and Ralph Street near Shirley Street.

6.4.4 Alexandra Canal Sub-catchment

Rainfall on Sydney Park is conveyed to the ponds within the Park and excess runoff may flow towards Euston Road in large ARI events. This sub-catchment generally drains towards Burrows Road which has several lowpoints along its length that are drained by pit and pipe systems. Ponding of runoff occurs in the lowpoints of Euston Road and Burrows Road. In large ARI events, inundation to properties may result from overland flows from upstream areas and or elevated levels in Alexandra Canal itself.

7 Provisional Hazard

7.1 General

Flood hazard can be defined as the risk to life and limb caused by a flood. The hazard caused by a flood varies both in time and place across the floodplain. The Floodplain Development Manual (NSW Government, 2005) describes various factors to be considered in determining the degree of hazard. These factors are:

- Size of the flood
- Depth and velocity of floodwaters
- Effective warning time
- Flood awareness
- Rate of rise of floodwaters
- Duration of flooding
- Evacuation problems
- Access.

Hazard categorisation based on all the above factors is part of establishing a Floodplain Risk Management Plan. The scope of the present study calls for determination of provisional flood hazards only. The provisional flood hazard is generally considered in conjunction with the above listed factors as part of the Floodplain Risk Management Study to provide a comprehensive analysis of the flood hazard.

7.2 Provisional Flood Hazard

Provisional flood hazard is determined through a relationship developed between the depth and velocity of floodwaters (Figure L2, NSW Government, 2005). The Floodplain Development Manual (2005) defines two categories for provisional hazard - High and Low.

The model results were processed using an in-house developed program, which utilises the model results of flood level and velocity to determine hazard. Provisional flood hazard was prepared for three design events, namely PMF, 100 year and 5 year ARI shown in **Figures 7.1 to 7.3** respectively.

High provisional hazard is shown at several independent areas in the study area for the 5 year ARI storm event. Streets with occurrences of high provisional hazard in the 5 year ARI event include Burren Street, Joynton Avenue, and near South Dowling Street.

In a 100 year ARI event, high provisional hazard is shown to occur along the main flowpaths to the canal and in trapped lowpoints on roads. These locations include:

- At Macdonald Street through the Ashmore Precinct,
- Along Burren Street,
- At Mandible Street and Bowden Street and along the channel to Alexandra Canal,
- Along Harcourt Parade from Dunning Avenue, and
- Ponded areas on Arthur Street, Nobbs Street, Chalmers Street, Phillip Street, Cope Street, Botany Road, Joynton Avenue, Morley Avenue, and O'Riordan Street.

8 Climate Change

Changes to climate conditions are expected to have adverse impacts on sea levels and rainfall intensities. The NSW Office of Environment and Heritage (formerly Department of Environment, Climate Change and Water (DECCW)) guideline, Practical Consideration of Climate Change (2007), provides advice for consideration of climate change in flood investigations. The guideline recommends sensitivity analysis is conducted for:

- Sea level rise – for low, medium, and high level impacts up to 0.9m
- Rainfall intensities – for 10%, 20%, and 30% increase in peak rainfall and storm volume

Sea level rise planning benchmarks for assessing potential flood risk impacts due to sea level rise in coastal areas are listed in two documents:

- NSW Coastal Planning Guideline: Adapting to Sea Level Rise (August 2010, prepared by the NSW Department of Planning), and
- Flood Risk Management Guide - Incorporating sea level rise benchmarks in flood risk assessments (August 2010, prepared by the Department of Environment, Climate Change and Water NSW).

The benchmarks are a projected rise in sea level relative to the 1990 mean sea level of 0.4 metres by 2050 and 0.9 metres by 2100.

The climate change assessment in the Cooks River Flood Study (2009) modelled peak water levels for the case of 20% increase to rainfall intensity and a mid-range sea-level rise of 0.55m for the 100 year ARI. A peak tailwater level of 2.9m AHD was estimated from these climate change scenario results for application to the Alexandra Canal catchment model. Given that the model is generally only sensitive to downstream boundary levels in the immediate vicinity of Alexandra Canal (Section 6), a single downstream boundary scenario is considered reasonable.

Models were run for the 100 year ARI 90 minute storm for increased rainfall intensities of 10%, 20%, and 30% with an elevated tailwater level of 2.9m AHD. **Figures 8.1 to 8.3** show the difference in peak water level compared to the base 100 year ARI 90 minutes event for the rainfall increases of 10%, 20% and 30% respectively. **Table 8.1** provides a summary of the key statistics from the climate change modelling.

Table 8.1 Model Sensitivity Statistics – Climate Change

Statistics	Rainfall Intensity Increases		
	10%	20%	30%
Average level difference (m)	0.01	0.02	0.03
Median level difference (m)	0.00	0.00	0.00
Standard Deviation (m)	0.05	0.06	0.08
Maximum level difference (m)	0.77	1.76	2.66
Minimum level difference (m)	-0.02	-0.02	-0.02
Average where difference is > 0.01m	0.07	0.08	0.09
Average where difference is < 0.01m	0.00	0.00	0.00

The model indicates that areas most sensitive to climate change impacts, and in particular increases in rainfall intensities, are the trapped low points throughout the study area. The increase in rainfall intensities results in a greater volume of runoff arriving at these locations and an associated increase in peak water level as a result. Another sensitive location is Bowden Street which is the confluence point for a number of flowpaths. Large increases are also observed along Alexandra Canal which is directly affected by the backwater from the Cooks River.

9 Conclusion

This report has been prepared for the City of Sydney to define the nature and extent of flooding for the Alexandra Canal Catchment. Flood modelling was completed to define flood behaviour for a range of storm events from 1 year ARI to 100 year ARI and the PMF.

The modelling shows that flooding in the catchment upstream of Alexandra Canal is characterised by a series of trapped depressions and low points. A number of these are significantly affected by the capacity of the pit and pipe system, together with the surrounding terrain. Other locations are affected by obstructions and constrictions of overland and mainstream flowpaths throughout the study area.

The investigation and modelling procedures adopted for this study follow current best practice and considerable care has been applied to the preparation of the results. However, model set-up and calibration depends on the quality of data available and there will always be some uncertainties. Hence there will be an unknown level of uncertainty in the results and this should be borne in mind for their application.

The next stage of the floodplain risk management process following the adoption of the Flood Study is the Floodplain Risk Management Study and Plan. This next stage will investigate various floodplain risk management measures and prioritise these measures for implementation.

10 References

Cardno (2008). *Ashmore Street Masterplan Flood Analysis.*

Cardno and Connell Wagner (2009). *Green Square Town Centre Flood Mitigation Options Report.*

Commonwealth Bureau of Meteorology (2003). *The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method.*

Engineers Australia (1999). *Australian Rainfall and Runoff – A Guide to Flood Estimation (Volume 1)*

Engineers Australia (1999). *Australian Rainfall and Runoff (Volume 1)*

Hughes Trueman and Perrens Consulting (2003). *South Sydney Stormwater Quality and Quantity Study – Munni Street Catchment; Sheas Creek Subcatchment; Botany Road – Doody Street and Gardeners Road catchments.*

MWH+PB (2009). *Cooks River Flood Study* for Sydney Water Corporation.

NSW Government (2005). *Floodplain Development Manual*

Webb McKeown (2008). *Green Square and West Kensington Flood Study*

Webb McKeown (1991). *Sheas Creek Flood Study.*

Wollongong City Council (2002). *Wollongong City Council Conduit Blockage Policy*