ATTACHMENT B

ALEXANDRA CANAL FLOOD STUDY
(DRAFT REPORT)

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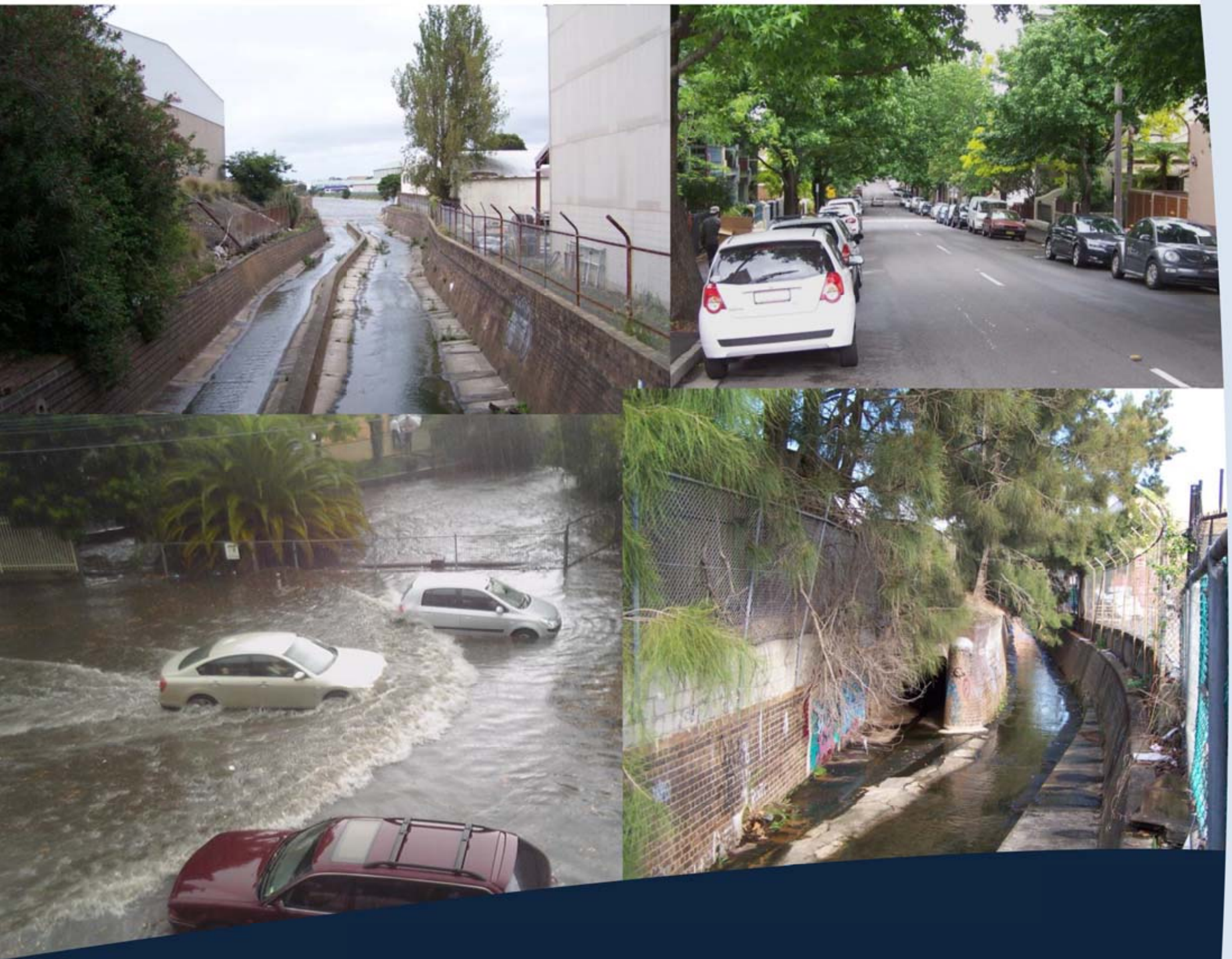

Alexandra Canal Catchment Flood Study

Report – Exhibition Draft

Project W4785
Prepared for City of Sydney
12 September 2013

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CITY OF SYDNEY

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Cover photo – Storm event courtesy Sydney Water

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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 management 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 experience of historical flooding in the catchment. The second stage is through the Floodplain Risk Management Committee, which contains community representatives and stakeholder organisations that provided guidance and review throughout the project. The final stage will be through the exhibition of a 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 Exhibition Draft Flood Study has been prepared to facilitate the Floodplain Risk Management Study (FRMS) for the Alexandra Canal Catchment. A public exhibition period for the Draft will be held concurrently with the FRMS to allow submissions from the community prior to finalisation of the studies.

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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.

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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).

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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.

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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.

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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, 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 were 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

The 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 will be placed on exhibition to the community. This section of the report will be updated following this exhibition period.

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.

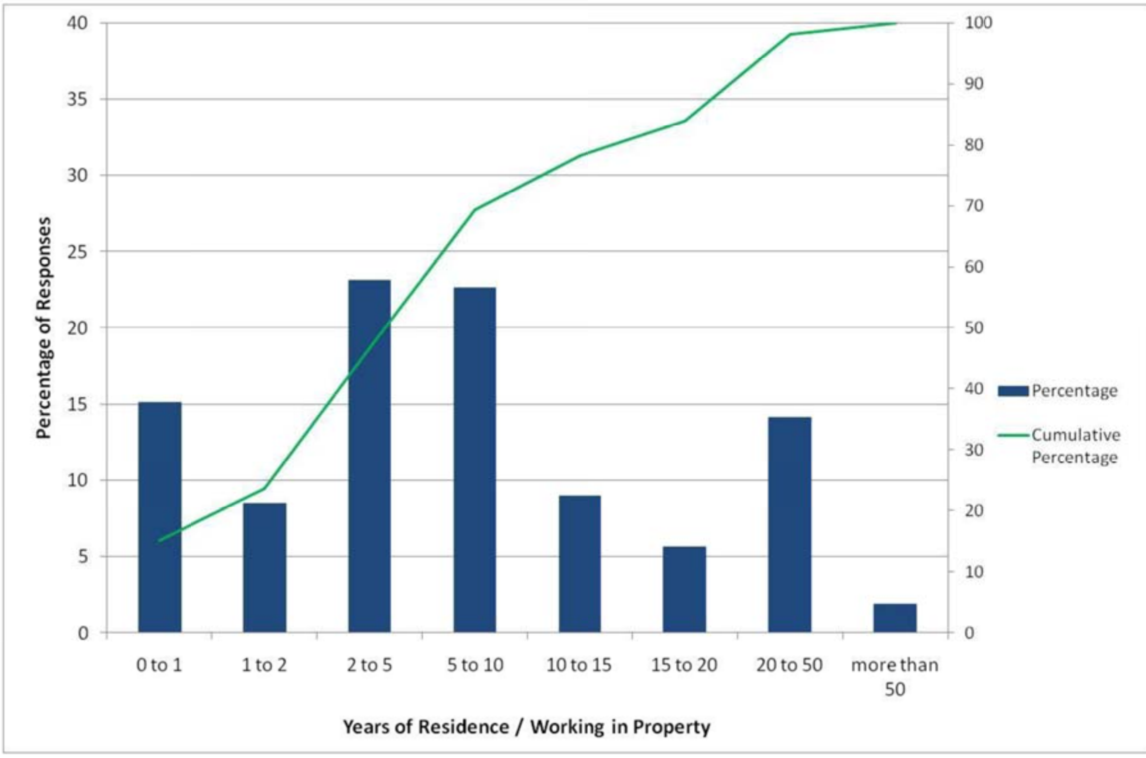

Figure 3.1 Time of Residency in Catchment

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 witnesses. 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 less record in the responses 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. Three committee meetings were held during the project:

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

3.3 Public Exhibition

[This section will be updated following the public exhibition of the draft report]

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**.

D
R
A
F
T

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 that 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 are 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 both 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.*