ATTACHMENT B

CITY AREA CATCHMENT FLOOD STUDY
(FINAL REPORT)

“Where will our knowledge take you?”

City Area Catchment Flood Study

Final Report **October 2014**

City Area Catchment Flood Study

Final Report

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FORWARD

The NSW State Government's Flood Prone Land Policy is directed towards providing solutions to existing flooding problems in developed areas and to potential future increases in flood risk, and ensuring that new development is compatible with the flood hazard and does not create additional flooding problems in other areas. Consideration is also given to the change in flood risk to existing and future development through potential climate change. Policy and practice are defined in the NSW State Government's Floodplain Development Manual (2005).

Under the Policy the management of flood liable land remains the responsibility of Local Government. The NSW State Government subsidises floodplain management studies and flood mitigation works to manage existing problems and provides specialist technical advice to assist Council in the discharge of Council's floodplain management responsibilities.

The Policy provides for technical and financial support by the NSW State Government through the six sequential stages:

1. **Formation of a Committee**
    - Established by Council and includes community group representatives and State agency specialists.
2. **Data Collection**
    - Past data such as 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 management options for the floodplain in respect of both existing and proposed developments.
5. **Floodplain Risk Management Plan**
    - Involves formal adoption by Council of a plan of management for the floodplain.
6. **Implementation of the Floodplain Risk Management Plan**
    - Construction of flood mitigation works to protect existing development. Use of local environmental plans to ensure new development is compatible with the flood hazard.

This study represents Stages 2 and 3 of this process and aims to provide an understanding of existing and future flood behaviour within the City Area catchment.

EXECUTIVE SUMMARY

Introduction

The Sydney City Area Catchment Flood Study has been prepared for the City of Sydney to define the existing flood behaviour in the City Area catchment and establish the basis for subsequent floodplain management activities.

The study is being prepared to meet the objectives of the NSW State Government's Flood Prone Land Policy.

The primary objective of the Flood Study is to define the flood behaviour within the City Area catchment through the establishment of appropriate numerical models. The study has produced information on flood flows, velocities, levels and extents for a range of flood event magnitudes under existing catchment conditions. Specifically, the study incorporates:

- Compilation and review of existing information pertinent to the study;
- Development and calibration of appropriate hydrologic and hydraulic models;
- Determination of design flood conditions for a range of design events including the 2 year ARI, 5 year ARI, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.2% AEP and PMF event; and
- Presentation of study methodology, results and findings in a comprehensive report incorporating appropriate flood mapping.

Catchment Description

The catchment is fully developed and comprises predominantly high-density housing and commercial development. There are some large open spaces within the catchment including Observatory Park and part of Hyde Park.

The catchment covers an area of about 199 ha and drains into the Sydney Harbour at various locations with the majority of the catchment discharging to Sydney Cove via Sydney Water's main trunk drainage system. This trunk drainage network is connected to Council's minor stormwater drainage system which comprises covered channels, pipes, culverts and pits. There are no open channel reaches within the City Area catchment.

The topography within the City Area catchment varies from steep surface slopes in excess of 15% on the western sides to the near flat lower catchment near Circular Quay and the other Sydney Harbour shoreline locations. The catchment therefore has regions where surface water runoff within the road network has high velocity with shallow depths, whilst in the lower catchment surface water is more likely to pond in sag points with typically lower flow velocities. The lower reaches of the catchment fringing Sydney Harbour are potentially affected by elevated water levels within the Harbour.

Within the catchment there are various excavation and cuttings, resulting in some vertical drops of over 10m.

The entire catchment is highly developed with little opportunity for water to infiltrate due to the high degree of impervious surfaces. It has been calculated that the combined area of roofs and roads is in excess of 50% of the catchment area. As a sign of the age of the region and high density nature, most residential properties are brick or sandstone construction with common walls to neighbours. In the central business district area numerous high rise buildings are built above the surrounding ground levels providing clear flow obstructions. There are very few opportunities for flow to pass through or between properties and as a result the roads form the primary overland flow paths.

Historical Flooding

Council has indicated that flooding within the catchment occurs at various locations in rainfall events exceeding 2 year ARI. June 1949, November 1961, March 1973, November 1984, January 1991 and February 2001 are noted historic major storm events which resulted in extensive flooding. Rainfall analysis was undertaken for these months using the Observatory Hill rain gauge. The November 1984 rainfall event was the largest analysed and was in excess of a 0.2 % AEP (500 year ARI) event.

It should be noted that the most recent of these key flood events (2001) occurred over 10 years ago and given the amount of time that has since passed it has been difficult obtaining records of flood behaviour for any of these events, specifically:

- Peak flood level survey data are not available for any of these events;
- Review of archived newspaper articles has found limited reports of the 1949 and other events. This data is useful, though due to its anecdotal nature it has limited value with respect to quantitative calibration data (e.g. observed flood levels and depths);
- Limited data has been recorded in the Sydney Water flooding database; and
- The median term of residency determined from the community consultation (refer to Section 3) is 8 years, indicating that many of the current residents did not experience any of these historic flooding events.

Community Consultation

Community consultation has been an important component of the current study. The consultation has aimed to inform the community about the development of the flood study and its likely outcome as a precursor to subsequent floodplain management activities. It has provided an opportunity to collect information on community members' flood experiences in the catchment and to collect feedback on concerns regarding flooding.

The key elements of the consultation process have been as follows:

- Distribution of a questionnaire to landowners, residents and businesses within the study area via mail delivery and online from the City of Sydney website;
- Regular presentations of progress to the Floodplain Management Committee, which includes community representatives and Council staff; and
- Review of the draft Flood Study by the Floodplain Management Committee.

Model Development

Development of hydrologic and hydraulic models have been undertaken to simulate flood conditions in the catchment. Traditionally the hydrological model provides for simulation of the rainfall-runoff processes. The hydraulic model, utilising established flows from the hydrologic model, simulates flood depths, extents and velocities.

The hydrologic and hydraulic modelling has been combined in TUFLOW two dimension (2D) software developed by BMT WBM, using the “direct-rainfall” approach (also referred to as “rainfall-on-grid”). A direct-rainfall approach models at the resolution of the grid all the minor flow features and also spatial variability in land uses categories which define rainfall infiltration potential and resistance to flow. Verification of the direct-rainfall approach has been undertaken by comparing results obtained using tradition hydrological modelling (WBNM) techniques.

The entire City Area catchment is modelled in the 2D domain while approximately 27 km of sub-surface pipe network is modelled as 1D elements dynamically linked to the 2D domain. The dynamically linked 1D pit and pipe network means that pit inlets and pipe surcharging is modelled to allow interaction with overland flows.

The 1D/2D modelling approach is suited to model the complex interactions between overland flows and sub-surface stormwater network and the converging and diverging flows through the urban environment.

The Digital Terrain Model (DTM) which underpins the 2D model was defined using aerial survey data provided by Council.

Model Calibration and Validation

The selection of suitable historical events for calibration of computer models is largely dependent on available historical flood information. Ideally the calibration and verification process should cover a range of flood magnitudes to demonstrate the suitability of a model for the range of design event magnitudes to be considered.

Review of the available data for the City Area catchment, including rainfall and tidal data, community consultation data, archived newspaper articles and Sydney Water flooding database, showed there are very few events with any recorded flood levels or observations of flood behaviour within the catchment.

Following assessment of available data and community consultation feedback, the 8 November 1984 and 26 January 1991 events were selected for the model calibration and verification process. To maximise the value of the community consultation, the 8 March 2012 event has also been used to verify general flooding behaviour reports within the City Area catchment.

The model was found to provide a good representation of the observed flood behaviour in the catchment.

Design Event Modelling and Output

The developed model has been applied to derive design flood conditions for the City Area catchment. Design rainfall depth is based on the generation of intensity-frequency-duration (IFD) design rainfall curves utilising the procedures outlined in AR&R (2001). A range of storm durations using standard

AR&R (2001) temporal patterns, were modelled. The design results represent the maximum envelope of all the durations assessed for the given design event frequency.

The design events considered in this study include the 2 year ARI, 5 year ARI, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.2% AEP and PMF events. The model results for the design events considered have been presented in a detailed flood mapping series for the catchment (Appendix A). The flood data presented includes design flood inundation, peak flood water levels and depths and peak flood velocities.

Provisional flood hazard categorisation in accordance with Figure L2 of the NSW Floodplain Development Manual (2005) has been mapped in addition to the hydraulic categories (floodway, flood fringe and flood storage) for flood affected areas.

Flood Emergency Response Planning Classifications (DECC, 2007) have been prepared for the range of design events considered.

Sensitivity Testing and Climate Change

A number of sensitivity tests have been undertaken to identify the impacts of the adopted model conditions on the design flood levels. Sensitivity tests included:

- The impact of potential future climate change, including sea level rise and increased rainfall intensities;
- Changes in the adopted design rainfall loss parameters;
- Changes in the adopted roughness parameters; and
- Stormwater drainage system blockages.

Results were shown to be generally insensitive to the values adopted for deriving the design flood levels and extents for the hydraulic roughness and rainfall losses tests. Higher sensitivity was exhibited for stormwater drainage system blockages for frequent events at trapped low points.

The most significant impacts of climate change within the study area are associated with increased rainfall intensities.

Conclusion

The primary objective of the Flood Study was to define the flood behaviour of the City Area catchment through the establishment of an appropriate numerical model. The principal outcome of the flood study is an understanding of flood behaviour in the catchment and in particular the design flood level information that will be used to set appropriate flood planning levels. The flood study forms the basis for the subsequent floodplain risk management activities, being the next stage of the floodplain management process. Accordingly, the adoption of the flood study and predicted design flood levels is recommended.

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GLOSSARY

annual exceedance probability (AEP)	The chance of a flood of a given size (or larger) occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (i.e. a 1 in 20 chance) of a peak discharge of 500 m^3/s (or larger) occurring in any one year. (see also average recurrence interval)
Australian Height Datum (AHD)	National survey datum corresponding approximately to mean sea level.
Astronomical Tide	Astronomical Tide is the cyclic rising and falling of the Earth's oceans water levels resulting from gravitational forces of the Moon and the Sun acting on the Earth.
attenuation	Weakening in force or intensity.
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 design flood will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event. (see also annual exceedance probability)
calibration	The adjustment of model configuration and key parameters to best fit an observed data set.
catchment	The catchment at a particular point is the area of land that drains to that point.
design flood event	A hypothetical flood representing a specific likelihood of occurrence (for example the 100 year ARI or 1% AEP flood).
development	Existing or proposed works that may or may not impact upon flooding. Typical works are filling of land, and the construction of roads, floodways and buildings.
discharge	The rate of flow of water measured in tems 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).
flood	Relatively high river or creek flows, which overtop the natural or artificial banks, and inundate floodplains and/or coastal inundation resulting from super elevated sea levels and/or waves overtopping coastline defences.
flood behaviour	The pattern / characteristics / nature of a flood.
flood fringe	Land that may be affected by flooding but is not designated as floodway or flood storage.
flood hazard	The potential risk to life and limb and potential damage to property resulting from flooding. The degree of flood hazard varies with circumstances across the full range of floods.

flood level	The height or elevation of floodwaters relative to a datum (typically the Australian Height Datum). Also referred to as "stage".
flood liable land	see flood prone land
floodplain	Land adjacent to a river or creek that is periodically inundated due to floods. The floodplain includes all land that is susceptible to inundation by the probable maximum flood (PMF) event.
floodplain management	The co-ordinated management of activities that occur on the floodplain.
floodplain risk management plan	A document outlining a range of actions aimed at improving floodplain management. The plan is the principal means of managing the risks associated with the use of the floodplain. A floodplain risk management plan needs to be developed in accordance with the principles and guidelines contained in the NSW Floodplain Management Manual. The plan usually contains both written and diagrammatic information describing how particular areas of the floodplain are to be used and managed to achieve defined objectives.
Flood planning levels (FPL)	Flood planning levels selected for planning purposes are derived from a combination of the adopted flood level plus freeboard, as determined in floodplain management studies and incorporated in floodplain risk management plans. Selection should be based on an understanding of the full range of flood behaviour and the associated flood risk. It should also take into account the social, economic and ecological consequences associated with floods of different severities. Different FPLs may be appropriate for different categories of landuse and for different flood plans. The concept of FPLs supersedes the "standard flood event". As FPLs do not necessarily extend to the limits of flood prone land, floodplain risk management plans may apply to flood prone land beyond that defined by the FPLs.
flood prone land	Land susceptible to inundation by the probable maximum flood (PMF) event. Under the merit policy, the flood prone definition should not be seen as necessarily precluding development. Floodplain Risk Management Plans should encompass all flood prone land (i.e. the entire floodplain).
flood source	The source of the floodwaters.
flood storage	Floodplain area that is important for the temporary storage of floodwaters during a flood.
floodway	A flow path (sometimes artificial) that carries significant volumes of floodwaters during a flood.
freeboard	A factor of safety usually expressed as a height above the adopted flood level thus determing the flood planning level. Freeboard tends to compensate for factors such as wave action, localised hydraulic effects and uncertainties in the design flood levels.
geomorphology	The study of the origin, characteristics and development of land forms.

gauging (tidal and flood)	Measurement of flows and water levels during tides or flood events.
historical flood	A flood that has actually occurred.
hydraulic	Relating to water flow in rivers, estuaries and coastal systems; in particular, the evaluation of flow parameters such as water level and velocity
hydrodynamic	Pertaining to the movement of water.
hydrograph	A graph showing how a river or creek's discharge changes with time.
hydrographic survey	Survey of the bed levels of a waterway.
hydrologic	Pertaining to rainfall-runoff processes in catchments
hydrology	The term given to the study of the rainfall-runoff process in catchments.
hyetograph	A graph showing the distribution of ranfall over time.
Intensity Frequency Duration (IFD) Curve	A statistical representation of rainfall showing the relationship between rainfall intensity, storm duration and frequency (probability) of occurrence.
isohyet	Equal rainfall contour.
morphological	Pertaining to geomorphology.
peak flood level, flow or velocity	The maximum flood level, flow or velocity that occurs during a flood event.
pluviometer	A rainfall gauge capable of continously measuring rainfall intensity
probable maximum flood (PMF)	An extreme flood deemed to be the maximum flood likely to occur.
probability	A statistical measure of the likely frequency or occurrence of flooding.
riparian	The interface between land and waterway. Literally means "along the river margins"
runoff	The amount of rainfall from a catchment that actually ends up as flowing water in the river or creek.
stage	See flood level.
stage hydrograph	A graph of water level over time.
sub-critical	Refers to flow in a channel that is relatively slow and deep
topography	The shape of the surface features of land

velocity	The speed at which the floodwaters are moving. A flood velocity predicted by a 2D computer flood model is quoted as the depth averaged velocity, i.e. the average velocity throughout the depth of the water column. A flood velocity predicted by a 1D or quasi-2D computer flood model is quoted as the depth and width averaged velocity, i.e. the average velocity across the whole river or creek section.
validation	A test of the appropriateness of the adopted model configuration and parameters (through the calibration process) for other observed events.
water level	See flood level.

1 INTRODUCTION

The Sydney City Area Catchment Flood Study has been prepared for the City of Sydney to define the existing flood behaviour in the City Area catchment and establish the basis for subsequent floodplain management activities.

The study is being prepared to meet the objectives of the NSW State Government's Flood Prone Land Policy.

The study was undertaken in a staged approach as outlined below:

- Stage 1 - Collection, Compilation and Review of Available Information;
- Stage 2 – Model development, Calibration and Validation;
- Stage 3 – Design Modelling and Mapping;
- Stage 4 – Draft Flood Study Report; and
- Stage 5 – Final Flood Study Report.

An interim report outlining the methodologies, analysis and key outcomes has been provided at the completion of each stage. This report is the Stage 5 Final Flood Study Report.

1.1 The Study Location

The City Area catchment, shown in Figure 1-1, is located in Sydney's inner-city suburbs of Millers Point, Dawes Point, The Rocks, Barangaroo and Sydney. The catchment lies wholly within the Local Government Area (LGA) under the control of the City of Sydney. The catchment drains an area of approximately 199 ha (1.99 km^2).

1.2 The Need for Floodplain Management within the City Area Catchment

Historical records indicate that flooding has occurred at various locations within the City Area catchment. Prior to this current study, a comprehensive flood study has not been undertaken for this catchment to accurately determine the flood liability within the catchment. In order to reduce the risk to existing flood prone properties and manage the future land use of flood prone land, effective floodplain management strategies are required.

The City Area Catchment Flood Study includes the entire catchment and includes all sources of flooding (e.g. rainfall, tides) in a single state-of-the-art model. Current practice in floodplain management also requires consideration of the impact of potential climate change scenarios on design flood conditions. For the City Area catchment this includes increases in design rainfall intensities and sea level rise scenarios impacting on ocean and estuarine boundary conditions.

Title:

City Area Catchment
Study Area Locality

Figure: 1-1

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Approx. Scale

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Accordingly, these potential changes will translate into increased design flood inundation in the catchment, such that future planning and floodplain management in the catchment will need to take due consideration of this increased flood risk.

1.3 The Floodplain Management Process

The NSW State Government's Flood Prone Land Policy is directed towards providing solutions to existing flooding problems in developed areas and to potential future increases in flood risk, and ensuring that new development is compatible with the flood hazard and does not create additional flooding problems in other areas. Consideration is also given to the change in flood risk to existing and future development through potential climate change. Policy and practice are defined in the NSW State Government's Floodplain Development Manual (2005).

Under the Policy the management of flood liable land remains the responsibility of Local Government. The NSW State Government subsidises floodplain management studies and flood mitigation works to manage existing problems and provides specialist technical advice to assist Council in the discharge of Council's floodplain management responsibilities.

The Policy provides for technical and financial support by the NSW State Government through the six sequential stages shown in Table 1-1.

Table 1-1 Stages of the Floodplain Management Process

Stage Number	Stage Name	Description
1	Formation of a Committee	Established by Council and includes community group representatives and State agency specialists.
2	Data Collection	Past data such as 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 management options for the floodplain in respect of both existing and proposed developments.
5	Floodplain Risk Management Plan	Involves formal adoption by Council of a plan of management for the floodplain.
6	Implementation of the Floodplain Risk Management Plan	Construction of flood mitigation works to protect existing development. Use of local environmental plans to ensure new development is compatible with the flood hazard.

This study represents Stages 2 and 3 of this process and aims to provide an understanding of existing and future flood behaviour within the City Area catchment.

1.3.1 Climate Change Policy

Climate change is expected to have adverse impacts upon sea levels and rainfall intensities, both of which may have significant influence on flood behaviour at specific locations. The primary impacts of climate change in coastal areas are likely to result from sea level rise, which, coupled with a potential increase in the frequency and severity of storm events, may lead to increased coastal erosion, tidal inundation and flooding.

In 2009 the NSW State Government announced the NSW Sea Level Rise Policy Statement (DECCW, 2009) that adopted sea level rise planning benchmarks to ensure consistent consideration of sea level rise in coastal areas of NSW. These planning benchmarks adopt increases (above 1990 mean sea level) of 40 cm by 2050 and 90 cm by 2100. However, on 8 September 2012 the NSW Government announced its Stage One Coastal Management Reforms which no longer recommends state-wide sea level rise benchmarks for use by local councils. Instead councils have the flexibility to consider local conditions when determining future hazards of potential sea level rise.

Accordingly, it is recommended by the NSW Government that councils should consider information on historical and projected future sea level rise that is widely accepted by scientific opinion. This may include information in the NSW Chief Scientist and Engineer's Report entitled 'Assessment of the Science behind the NSW Government's Sea Level Rise Planning Benchmarks' (2012).

The NSW Chief Scientist and Engineer's Report (2012) acknowledges the evolving nature of climate science, which is expected to provide a clearer picture of the changing sea levels into the future. The report identified that:

- The science behind sea level rise benchmarks from the 2009 NSW Sea level Rise Policy Statement was adequate;
- Historically, sea levels have been rising since the early 1880's;
- There is considerable variability in the projections for future sea level rise; and
- The science behind the future sea level rise projections is continually evolving and improving.

The potential impacts of sea level rise have been based on sea level rise projections from the 2009 NSW Sea Level Rise Policy Statement. Given that the Chief Scientist and Engineer's Report identifies the science behind these sea level rise projections is adequate, it was agreed between Council and BMT WBM that the potential impacts of sea level rise for the City Area catchment should be based on the best available information during preparation of this report.

For the City Area catchment, rising sea level is expected to increase the frequency, severity and duration of flooding in the lower reaches of the catchment.

In 2007 the NSW Government released a guideline for practical consideration of climate change in the floodplain management process that advocates consideration of increased design rainfall intensities of up to 30%. Accordingly, this increase in design rainfall intensity will translate into increased flood inundation in the City Area catchment. Future planning and floodplain management in the catchment will need to take due consideration of this increased flood risk.

In consultation with Council and the Office of Environment and Heritage (OEH), a range of climate change sensitivity tests incorporating combinations of sea level rise and increased design rainfall intensity have been formulated. The results of these sensitivity tests (refer Section 9) were then compared to the base case (i.e. models with existing sea level and climate) model results in order to assess the potential increase in flood risk due to climate change.

1.4 Study Objectives

The primary objective of the study is to define the flood behaviour under existing and future conditions (incorporating potential impacts of climate change) in the City Area catchment for a full range of design events. The study has produced information on flood levels and depths, velocities, flows, hydraulic categories and provisional hazard categories. This has been established for existing and future conditions for a full range of design flood events. The flood study has also identified the impact on flood behaviour as a result of future climate change and potential changes in the catchment. Specifically, the study incorporates:

- Compilation and review of existing information pertinent to the study;
- A community consultation and participation program to identify local flooding concerns, collect information on historical flood behaviour and engage the community in the on-going floodplain management process;
- Development and verification of appropriate hydrologic and hydraulic models;
- Determination of design flood conditions for a range of design events - including the 2 year ARI, 5 year ARI, 10% AEP (10 year ARI), 5% AEP (20 year ARI), 2% AEP (50 year ARI), 1% AEP (100 year ARI) and Probable Maximum Flood (PMF – an extreme flood event);
- Cost of flood damages for existing conditions using a full range of design flood events;
- Examination of potential impact of climate change using the latest guidelines for the 1% AEP design event; and
- Presentation of study methodology, results and findings in a comprehensive report incorporating detailed flood mapping.

The models and results produced in this study are intended to:

- Outline the flood behaviour within the catchment to aid Council's strategic land use management planning; and
- Form the basis for a subsequent floodplain risk management study where detailed assessment of flood mitigation options and floodplain risk management measures will be undertaken.

1.5 About this Report

This report documents the Study's objectives, results and recommendations.

Section 1 introduces the study.

Section 2 provides an overview of the study and summary of background information.

Section 3 outlines the community consultation program undertaken.

Section 4 details the development of the computer models.

Section 5 details the hydraulic model calibration and validation process.

Section 6 details the design flood conditions.

Section 7 presents the design flood results.

Section 8 presents the results of sensitivity analysis.

Section 9 presents results of climate change analysis.

Section 10 presents flood damage assessment.

2 STUDY APPROACH

2.1 The Study Area

2.1.1 Catchment Description

The catchment is fully developed and comprises predominantly high-density housing and commercial development. There are some large open spaces within the catchment including Observatory Park and part of Hyde Park.

The catchment covers an area of about 199 ha and drains into Sydney Harbour at various locations with the majority of the catchment discharging to Sydney Cove via Sydney Water's main trunk drainage system. This trunk drainage network is connected to Council's minor stormwater drainage system which comprises covered channels, pipes, culverts and pits. There are no open channel reaches within the City Area catchment.

The topography within the City Area catchment varies from steep surface slopes in excess of 15% on the western sides to the near- flat lower catchment near Circular Quay and the other Sydney Harbour shoreline locations. The catchment therefore has regions where surface water runoff within the road network has high velocity with shallow depths, whilst in the lower catchment surface water is more likely to pond in sag points and flow velocities will be lower. The lower reaches of the catchment fringing the Sydney Harbour are potentially affected by elevated water levels within the Harbour.

Within the catchment there are various excavation and cuttings, resulting in some vertical drops of over 10m.

The entire catchment is highly developed with very little opportunity for water to infiltrate due to the high degree of impervious surfaces. It has been calculated that the combined area of roofs and roads is in excess of 50% of the catchment area. As a sign of the age of the region and high density nature, most residential properties are brick or sandstone construction with common walls to neighbours. In the central business district area numerous high rise buildings are built above the surrounding ground levels providing clear flow obstructions. There are very few opportunities for flow to pass through or between properties and as a result the roads form the primary overland flow paths.

2.1.2 Stormwater Drainage System

The City Area catchment was first settled in the late 18th Century. The original natural drainage system comprised rock gullies draining to small pockets of mangroves along the shoreline. As development proceeded within the catchment, the land use changed to a higher proportion of impervious surfaces leading to increased runoff volumes and peak flows. It followed that the natural drainage lines were incorporated into the constructed drainage system of open channels. By the late 19th Century, much of the channel system was progressively covered over and piped, with much of the original system forming the backbone of the stormwater drainage system in place today.

The study area contains the Tank Stream, running between George Street and Pitt Street, which has been listed on the State Heritage Register. The Tank Stream was the first and main source of fresh water for NSW's colonial settlement from 1788, and now operates as a stormwater channel managed by Sydney Water.

Title:
City Area Catchment Study Area

Figure: 2-1

Rev: 1

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The Sydney Water Capacity Assessment Report for Drainage Area 29 (SWC, 1996) provides details of the trunk drainage components, indicating that the system is a combination of various eras of trunk drainage design and installation.

In rainfall events where flows exceed the piped system capacity, surface water runoff is generally conveyed within the road system as uncontrolled flow. When this occurs, there is potential for high hazard flooding conditions resulting from combined high flow velocities and depths.

There are no open channels within the study area to assist with drainage.

2.1.3 Known Flooding Problems

Council has indicated that flooding within the catchment occurs at various locations in rainfall events exceeding 2 year ARI. June 1949, November 1961, March 1973, November 1984, January 1991 and February 2001 are noted historic major storm events which resulted in extensive flooding. Rainfall analysis was undertaken for these months using the Observatory Hill gauge. Table 2-1 shows the results of this rainfall analysis. The November 1984 rainfall event was the largest analysed and was in excess of a 0.2 % AEP (500 year ARI) event. Review of rainfall data for the month of March 1973 and February 2001 indicated substantial gaps in data and no significant recorded rainfall event. It is therefore assumed that the gauge failed for the events.

Table 2-1 Rainfall analysis of key historic rainfall events

Event	Peak % AEP
15 June 1949	~ 20 % AEP (~5 year ARI)
18-19 November 1961	~ 5 % AEP (~20 year ARI)
March 1973	Gauge Failed
9 November 1984	< 0.2 % AEP (> 500 year ARI)
27 January 1991	~ 2 % AEP (~50 year ARI)
February 2001	Gauge Failed

It should be noted that the most recent of these key flood events (2001) occurred over 10 years ago and given the amount of time that has since passed it has been difficult obtaining records of flood behaviour for any of the events, specifically:

- Peak flood level survey data are not available for any of these events;
- Review of archived newspaper articles has found limited reports of the 1949 and other events. This data is useful, though due to its anecdotal nature it has limited value with respect to quantitative calibration data (e.g. observed flood levels and depths);
- Limited data has been recorded in the Sydney Water flooding database; and
- The median term of residency determined from the community consultation (refer to Section 3) is 8 years, indicating that many of the current residents did not experience any of these historic flooding events.

2.2 Compilation and Review of Available Data

2.2.1 Introduction

The data compilation and review was undertaken as the first stage in this flood study in order to consolidate and summarise all of the currently available data, and identify any significant data gaps that may affect the successful completion of the study. This allowed for the missing data to be collected during the initial phases of the study.

The review included:

- Previous studies undertaken within the City Area catchment;
- Available water level, tide and rainfall data; and
- Sydney Water flooding complaints register.

Council has provided digitally available information such as aerial photography, cadastral boundaries, watercourses, and drainage networks in the form of GIS datasets.

2.2.2 Previous Studies and Investigations

Comprehensive flood modelling has not previously been undertaken for the entire City Area catchment. A key Sydney Water document provides details of the trunk stormwater assets within in the study area including capacity assessment. Flood Studies in neighbouring catchments with similar topographic features and urban densities have recently been undertaken. Details of these relevant studies are summarised below.

1. **City Area SWC 29 Capacity Assessment (Sydney Water, 1996).**

This report prepared by Sydney Water assessed the quantitative performance of stormwater drainage elements within Sydney Water's City Area SWC29. The document categorises drainage elements into one of four "land use design ARI" as presented below. For each drainage element the actual performance (ARI flow required to exceed hydraulic capacity) is compared to desired performance for the land use design ARI categorisation. Further assessment and comment is made upon the likely impacts of future urban consolidation which would result in increased impervious areas and hence increased flows.

- Low density residential, minor roads and open spaces represented by a 5 year design ARI;
- Business, commercial and industrial areas, intensely developed residential areas, and local access road culverts reflected by a 10 year design ARI;
- Intense business, commercial and industrial, major secondary roads, major railway culverts, highways and freeways, 20 year design ARI: and
- Central business districts and the wider service corridors where the channel is obviously a trunk drain as designed by AR&R, a 100 year design ARI is compared to.

The drainage area SWC29 covers approximately the same extent of the City Area catchment study area.

Details of pipe capacity as well as dimensions and hydraulic parameterisation are extensively detailed within this report. These data have been digitised for the hydraulic model build of the current study.

2. Blackwattle Bay Catchment Flood Study (Final Report) (WMA, 2012a)

This flood study report prepared by WMAwater for the City of Sydney details the flooding behaviour in the Blackwattle Bay catchment. Blackwattle Bay catchment is approximately 2 km to the west of the City Area catchment.

The hydrodynamic modelling program TUFLOW was used to model both the hydrologic and hydraulic processes in the catchment (direct-rainfall). The study area covers approximately 315 ha and was modelled with a 2 m grid cell.

26th January 1991 and 17th February 1993 were adopted as the calibration and verification events, respectively, though very limited data were available for this process.

As part of the study a flood damage assessment was undertaken for all standard design events. Impacts of climate change and sea level rise were also considered.

A critical storm duration of 120 minutes was adopted for all non-PMF design event simulations, whilst the 1 hour event was adopted for the PMF event.

Design rainfall losses adopted were as follows:

- Pervious areas: Initial Loss 10 mm; Continuing Loss 2.5 mm/h
- Impervious areas: Initial Loss 1.5mm; Continuing Loss 0mm/h

3. Johnstons Creek Catchment Flood Study (Final Report) (WMA, 2012b)

This flood study report prepared by WMAwater for the City of Sydney details the flooding behaviour in the Johnstons Creek catchment. Johnstons Creek catchment is immediately adjacent (to the west) of the Blackwattle Bay Catchment and is approximately 3 km from the City Area catchment.

The hydrodynamic modelling program TUFLOW was used to model both the hydrologic and hydraulic processes in the catchment (direct-rainfall). The study area covers approximately 224 ha and was modelled with a 2 m grid cell.

Model calibration was not undertaken since surveyed records of flooding were unavailable and there is no flow monitoring within the catchment. Model verification therefore focused on simulating flood hot-spots and generating a similar specific yield to neighbouring calibrated catchments.

As part of the study a flood damage assessment was undertaken for all standard design events. Impacts of climate change and sea level rise were also considered.

A critical storm duration of 120 minutes was adopted for all non-PMF design event simulations whilst the 3 hour event was adopted for the PMF event.

Design rainfall losses adopted were as follows:

- Pervious areas: Initial Loss 10 mm; Continuing Loss 2.5 mm/h
- Impervious areas: Initial Loss 1.5mm; Continuing Loss 0mm/h

2.2.2.1 Summary of Previous Studies

Very little flood modelling has been undertaken in the City Area catchment, with no existing models which are suitable to adapt for this study.

Council commissioned Flood Studies have been completed for the neighbouring Blackwattle Bay and Johnstons Creek. In order to provide consistency for Council across the LGA, the current study has, were possible, ensure consistency between these studies with respect to modelling approach and parameterisation.

2.2.3 Rainfall Data

There is an extensive network of rainfall gauges across the Sydney area, many of which are operated by the Bureau of Meteorology (BoM) and Sydney Water Corporation (SWC). The closest BoM station, located at Observatory Hill, is within the City Area catchment. This rainfall station records continuous rainfall (pluviometer) and has a long period of record, commencing in 1858.

There are two more daily rainfall stations located in close proximity to the study area, resulting in a suitable density of daily rainfall stations to define historic rainfall. A list of these relevant rainfall stations with their respective period of record is shown in Table 2-2, with the spatial distribution of the rainfall stations shown in Figure 2-2. This combination of daily rainfall stations and the Observatory Hill pluviometer to define the temporal pattern of rainfall presents a high quality rainfall data set for use in this Flood Study.

Table 2-2 Rainfall stations in the City Area catchment locality area

Station #	Name	Record Period	Type
066006	Sydney Botanic Gardens	1885 – 2011	Daily
066062	Sydney (Observatory Hill)	1858 – 2013	Daily/Pluviometer
066160	Sydney Centennial Park	1990 - 2010	Daily

2.2.4 Stream Gauge Data

There are no stream gauging data within the study area. This is a common data deficiency in urban catchments.

2.2.5 Harbour Water Level Data

The City Area catchment primarily flows into Sydney Harbour via Sydney Cove. Consequently, the water level within Sydney Harbour can act as a significant downstream control for both overland and piped flows under flooding conditions resulting from rainfall events.

Consideration of the most appropriate tailwater condition is required for the historic event calibration and design event modelling. For all calibration events, a dynamic tailwater boundary for Sydney Harbour has been adopted based on water level records from Fort Denison (see Figure 2-2). This data has been obtained from the Bureau of Meteorology's National Tidal Centre. Design event water levels within Sydney Harbour comprise a constant water level based on a frequency analysis of Fort Denison's water level records. Table 2-3 presents the design peak water levels for Sydney Harbour (DECC, 2008). Discussion in later sections presents the assumed joint probability of rainfall events with elevated harbour tailwater level.

Table 2-3 Sydney Harbour design still water levels

Frequency	Maximum Water Level (m AHD)
0.02 year ARI	0.965
0.05 year ARI	1.045
0.1 year ARI	1.095
1 year ARI	1.235
2 year ARI	1.275
5 year ARI	1.315
10% AEP	1.345
5% AEP	1.375
2% AEP	1.415
1% AEP	1.435
0.5% AEP	1.455

2.2.6 Flood Level Data

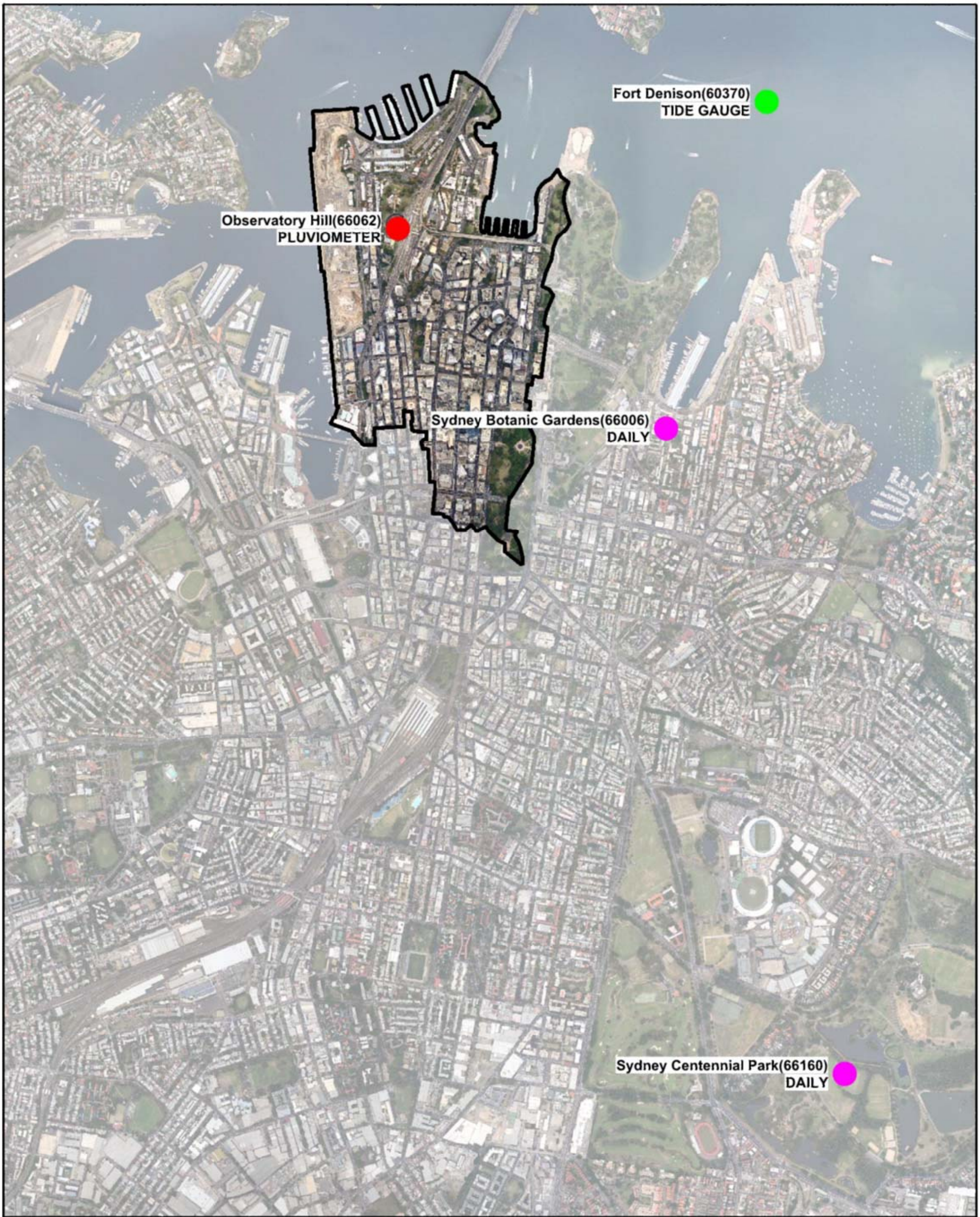
No peak flood level survey of historic flooding is available for this study. Model calibration has therefore relied on information received from community recollections of flooding via the community engagement process and from the Sydney Water Corporation (SWC) Historical Database of flooding incidents.

2.2.7 Topographic Data

Aerial topographic survey, also known as ALS (Airborne Laser Scanning) covering the study area has been provided by Council. ALS data typically has a vertical accuracy of +/- 0.15m with 68% confidence and horizontal accuracy of +/- 0.55m with 68% confidence.

The ALS data set has been provided as filtered data, where a filtering routine has been applied to remove non-ground features such as buildings and vegetation to provide a representation of the ground surface. The data set has been converted into a 1m resolution digital terrain model (DTM) using terrain modelling software. Non ground points have been provided as a separate dataset.

Section 4 discusses detailed interpretation of the ALS data and how the data has been enhanced for use in this study by applying post-processing methods since numerous large buildings and bridges within the study area influence the data provided.



Title:	Figure:	Rev:
City Area Catchment BOM Rainfall Stations	**2-2**	**1**

N

0 0.5 1km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : S:\WATER\PROJECTS\S20012 - Water - Darling Harbour Catchment Flood Study\Documents\Figures