Waverley LGA Flood Study

Final Report

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WAVERLEY COUNCIL

Document Control Sheet

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Synopsis: Report for the Waverley LGA Flood Study covering the data collection process, community consultation, development of computer models, determination of design flood behaviour and flood mapping.		

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Executive Summary

Study Background

The Waverley Local Government Area (LGA) Flood Study has been prepared for Waverley Council ("Council") to define the flood behaviour under historical, existing and future conditions (i.e. incorporating the potential impacts of climate change). Flooding has occurred at several locations within the Waverley LGA in the past. Prior to this study, Council had not undertaken an investigation with the ability to model the complex nature of floodplain flow patterns in the urban environment.

The study covers a total area of approximately 10km^2, including the entire Waverley LGA and a section of the Randwick LGA. The study is focused on local overland flood conditions within the urban environment that may occur when the capacity of local channels and stormwater drainage systems are exceeded by local catchment runoff resulting from intense rainfall. The oceanic interaction along the coastal boundary of the study area was also considered.

This flood study forms an initial stage towards the development of a comprehensive Floodplain Risk Management Plan that will ultimately guide the direction of future floodplain risk management activities across the Waverley LGA. Specifically, the study comprised the following components:

- Compilation and review of existing information relevant to the study;
- Community consultation and participation program;
- Development of appropriate computer flood models and calibration/verification for historical events to confirm that the simulated results match the observed conditions;
- Determination of flood conditions for a range of design events, ranging from relatively frequent events to more extreme/rare events;
- Assessment of the potential impact of climate change using the latest guidelines;
- Flood risk mapping, control lot tagging and hotspot identification.

Community Consultation

It is important to engage the community throughout the floodplain risk management process. A community consultation and participation program has been undertaken as part of this flood study to identify local flooding concerns, collect information on historical flood behaviour and community concerns regarding flooding, advise on the outcomes of the flood study and flood behaviour predictions, and engage the community in the on-going floodplain management process. The key elements of the community engagement process have included consultation with the Floodplain Management Committee, an information brochure and questionnaire mailout, resident interviews, community information sessions and public exhibition of the study findings.

Flood Modelling

The study has included the development of computer models to simulate the stormwater runoff resulting from intense rainfall across the study catchments. The models incorporate the sub-surface stormwater drainage pipe network. When the drainage capacity is exceeded, the additional water is modelled as overland flow and is typically contained within the road network. However, in some locations the overland flow escapes from roadway corridors and may present a risk to property.

The performance of the computer models has been assessed against historic rainfall events that occurred in 2015 and 2017 in order to confirm that the simulated results reflect observed conditions, where suitable data is available. The computer flood models have been used to derive expected flood conditions for a range of flood magnitudes for local overland flows resulting from intense rainfall and the oceanic interaction along the coastal boundary. These "design" modelling results are mapped and assessed to inform the overall flood risk throughout the study area and to guide future floodplain management activities, such as flood planning, flood mitigation and flood emergency response.

Flood Risk Mapping

The principal output from the flood modelling is a comprehensive set of design flood maps to visualise the potential flood inundation and associated flood risks across the study area. This includes peak flood level, depth, velocity, hazard and flood function mapping. The mapping outputs are presented in the separate Flood Mapping Compendium.

The study also includes the provision of information to assist Council in future floodplain management and land-use planning including:

- Identification of properties experiencing flooding in each design event;
- Derivation of a Flood Planning Area (FPA) for application of land use development controls;
- Flood Control Lot mapping identifying properties where flood-related development controls would apply;
- Emergency response considerations, such as mapping identifying roads that may not be trafficable during the peak of a flood event and individual properties that are considered unsafe for on-site refuge.

Lot Tagging

Flood control lots are properties that are known to have a flooding constraint and should be referred to Council's flood-related development controls because of their potential to be flood affected. There are significant uncertainties regarding flood modelling in complex urban environments. A ground-truthing exercise was undertaken to ensure that the model results are interpreted and correctly applied for flood planning purposes. The ground-truthing was conducted over a two-day period, verifying the modelled flow paths against site conditions. Further desktop analysis of the modelling results and topographic data was performed to establish a three-tiered classification system for the lot-tagging process. The lot-tagging classes can be summarised as:

- "Type A" – lots for which standard flood-related development controls can be applied;
- "Type B" – lots through which an overland flood flow path is conveyed;
- "Type C" – lots captured by the preliminary FPA.

The distribution of lots across the Waverley LGA as classified above is presented in Figure 7-5. Approximately 650 lots have been classified as Type A, 400 as Type B and over 2100 as Type C.

Flooding "Hotspot" Identification

The flood modelling results were reviewed to identify 12 hotspot locations within the study area where there is a concentration of flood-affected properties. The identified hotspot locations include:

- William Street – Owen Street, Rose Bay;
- Glenayr Avenue – Plowman Street, North Bondi;
- Elliott Street – Bonus Street, North Bondi;
- Brassie Street – Niblick Street, North Bondi;
- Beach Road – Warners Avenue, North Bondi;
- Wallis Parade – Ramsgate Avenue, North Bondi;
- Roscoe Street – Beach Road, Bondi Beach;
- Chambers Avenue – Jaques Avenue, Bondi Beach;
- Francis Street – Simpson Street, Bondi Beach;
- Tasman Street – Tamarama Street, Bondi;
- Palmerston Avenue – Murray Street, Bronte;
- Alt Street – York Road, Queens Park.

Future investigations and potential floodplain risk management activities should be aimed at reducing the flood risk at these hotspot locations.

Flood Insurance

It is worth noting the differences in terminology used by the floodplain risk management and insurance industries. This study refers to the accumulation of overland flows as flooding and to the hydraulic modelling used to represent this process as flood modelling. However, for the purposes of flood insurance, the current definition within NSW for "flooding" is effectively water that has escaped the confines of a natural or modified watercourse, or from a dam. There are only a few defined watercourses within the study area (such as Tamarama Gully and Bronte Gully) and thus, most of the inundation modelled and presented in this study would be regarded as "stormwater" for the purposes of the assessment of insurance claims.

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Glossary

afflux	The change in water level from existing conditions resulting from a change in the watercourse or floodplain – for example construction of a new bridge.
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 (that is 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 20yr 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).
Australian Rainfall and Runoff (AR&R)	Engineers Australia publication pertaining to rainfall and flooding investigations in Australia.
calibration	The adjustment of model confuguration 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.
critical duration	The critical duration is the design storm duration which provides the highest peak water levels for a given design flood (for example 1% AEP) at a given location. For example, if the following design durations were modelled - 2-hour, 6-hour, 9-hour and 12-hour – and the 9-hour duration resulted in the highest peak water level at a given location then the critical duration for that location would be 9-hours.
design flood event	A probabilistic or statistical estimate of flooding representing a specific likelihood of occurrence (for example the 100yr 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 vollume 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).
Extreme Flood	An extreme flood deemed to be the maximum flood likely to occur (for this study the Extreme Flood event was defined as three times the 1% AEP event).
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) or Extreme Flood 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 (FPLs)	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) or Extreme Flood 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 (that is 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	The term given to the study of water flow in rivers, estuaries and coastal systems.
hydrodynamic	Pertaining to the movement of water.
hydrograph	A graph showing how a river or creek’s discharge changes with time.
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 depth of rainfall 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.
LiDAR	Light Detection and Ranging –a remote sensing method used to generate ground surface elevation. Typically acquired through airborne surveys from which an aeroplane can cover large areas.
overland flow	Overland flow is surface run off before it enters a waterway. It is caused by rainfall which flows downhill along low points concentrating in gullies, channels, surface depressions and stormwater systems.
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 (also called a "pluvio").
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, that is 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, that is 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

1.1 Background

This flood study has been prepared for Waverley Council ("Council") to define the existing flood behaviour in the Waverley LGA. It defines the nature and extent of the flood risk within the LGA and with guidance from Council's Floodplain Management Committee, will establish the basis for subsequent floodplain risk management activities.

Council has undertaken past floodplain risk management in the study area through completion of the *'Waverley Council Stormwater System Mapping and Modelling – DRAINAGE SYSTEM MODELLING'* (Bankstown Civic Design, 2007), which resulted in some stormwater network improvements and upgrades. By undertaking the current study and developing up-to-date and best practice flood models, Council will be in a position to prioritise additional works and plan for future floodplain management actions to address the existing, future and residual overland flood risks in the LGA.

The study is designed to meet the objectives of the NSW State Government's Flood Prone Land Policy. It has been conducted under the State assisted Floodplain Management Program and received State financial support.

1.2 Study Area

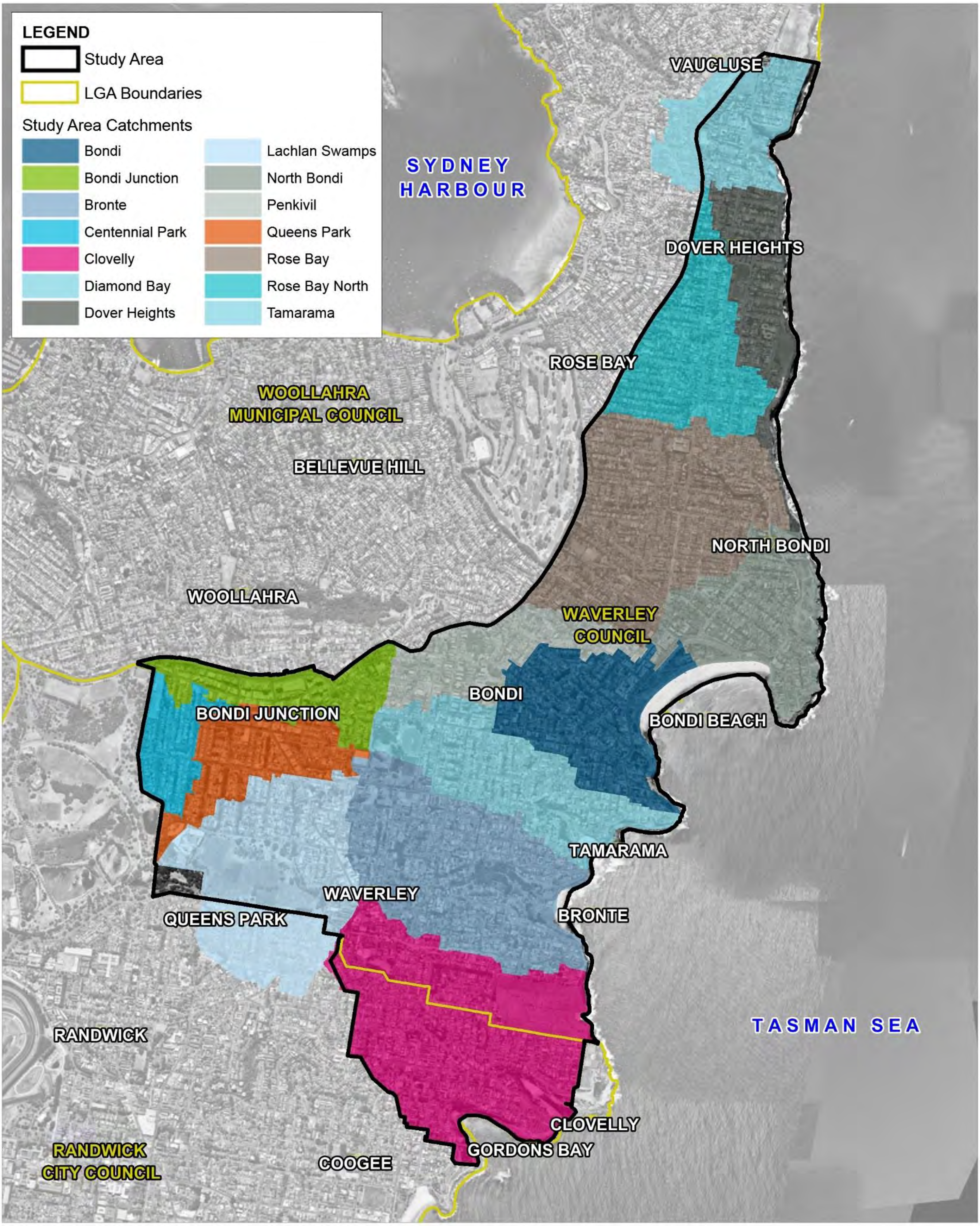
The study covers a total area of approximately 10km^2, encompassing the entire Waverley LGA and a section of the Randwick LGA. The study area is bounded by the South Tasman Sea to the East, Woollahra LGA to the West and Randwick LGA to the South.

There are fifteen sub-catchments within the study area: Bondi, Bondi Junction, Bronte, Centennial Park, Clovelly Beach, Diamond Bay, Dover Heights, Gordons Bay, Lachlan Swamps, North Bondi, Penkivil, Queens Park, Rose Bay, Rose Bay North and Tamarama. The Gordons Bay and Clovelly Beach catchments lie within both the Randwick and Waverley LGAs. The sub-catchments either flow overland into Sydney Harbour or directly into the South Tasman Sea. Figure 1-1 shows the location of the study area and the individual sub-catchments.

Land use within the study extent is predominantly low, medium and high residential housing with scattered mixed-use areas and private/public recreational space. Major public infrastructure includes the Bondi and Bondi Junction commercial centres, Bondi Junction train and bus terminals, and a number of private and public schools.

1.3 The Need for Floodplain Management within the Study Area

Historical records indicate that flooding has occurred at several locations within the Waverley LGA. Prior to this study, Council had not undertaken an investigation with the ability to model the complex nature of floodplain flow patterns in an urban environment.



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Study Locality

Figure: 1-1

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The Waverley LGA Flood Study includes all sources of flooding (e.g. rainfall and coastal inundation) 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. This includes increases in design rainfall intensities and sea level rise scenarios impacting on ocean boundary conditions.

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

1.3.1 The Need for a Review of the Existing Flood Studies

One of the key drivers of the Waverley LGA Flood Study is to update and build upon existing flood information for the Waverley LGA catchments. Key to this are the advances in modelling techniques since the completion of the 2007 Drainage System Modelling. Accordingly, the current study provides for a more robust tool with which to assess flood conditions in the Waverley LGA. Furthermore, the current study can be utilised as a foundation to manage and mitigate flood risk in the subsequent floodplain risk management study and plan.

Due to the complex nature of floodplain flow patterns in urban catchments, dynamically linked two-dimensional (2D) and one-dimensional (1D) hydrodynamic numerical models are currently the most accurate, cost-effective and efficient tools to predict the flood behaviour. For this study, a catchment-scale hydraulic model has been developed using TUFLOW that consists of a high resolution 2D domain of the floodplain that is dynamically linked to a series of 1D elements that simulate the drainage characteristics of the stormwater network (i.e. pit and pipe systems, open channels and culverts).

For the simulation of the catchment rainfall-runoff processes, a lumped hydrologic model can be used to determine flows that are then routed through the hydraulic model domain. In recent years, the advancement in computer technology has enabled the use of the direct-rainfall approach as a viable alternative over the use of lumped hydrologic models (e.g. XP-RAFTS, WBNM). This approach involves rainfall depths being applied directly to the individual cells of the 2D hydraulic model and can be useful for overland flow studies where model results are required in areas with small contributing catchments.

For this study, two hydrologic inflow methods have been utilised. The primary method using a lumped hydrologic model developed using XP-RAFTS software and the secondary method utilising direct-rainfall within the TUFLOW model for model validation.

1.4 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 ensuring that new development is compatible with the flood hazard and does not create additional flooding problems in other areas. The Policy and framework are defined in the NSW State Government's Floodplain Development Manual (2005).

The implementation of the Flood Prone Land Policy culminates in the preparation and implementation of a floodplain management plan in accordance with the floodplain management process outlined in the Floodplain Development Manual (NSW Government, 2005) (see Figure 1-2). Periodic reviews of floodplain management plans form part of the floodplain management process. Under the policy the management of flood liable land remains the responsibility of Local Government. The NSW State Government subsidises flood mitigation works to alleviate existing problems and provides specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities.

The policy provides for technical and financial support by the NSW State Government through the five sequential steps as shown in Figure 1-2. Steps 1 and 2 of this process form the basis of the current study and provide an understanding of the existing and future flood behaviour within the study area.

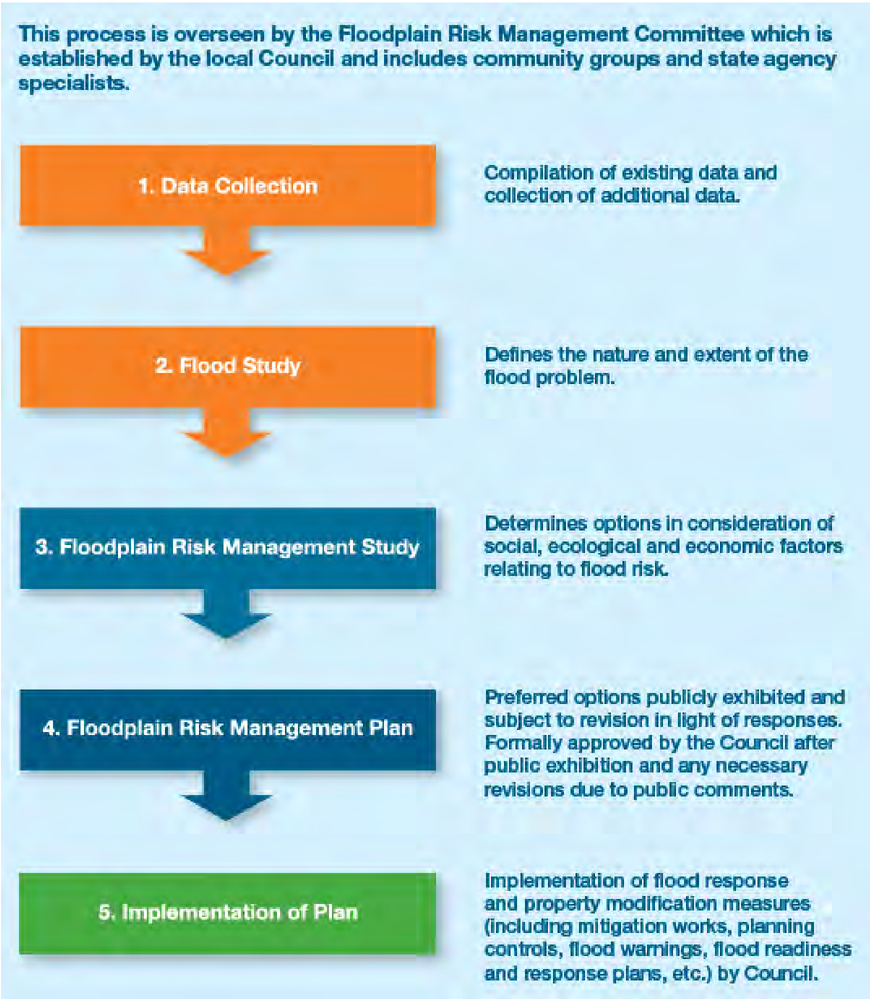


Figure 1-2 Steps of the Floodplain Management Process

1.4.1 The Floodplain Management Committee

This flood study has been overseen by the Floodplain Management Committee (Committee), who have assisted and advised Council in the preparation of the study. Members of the Floodplain Management Committee include representatives from:

- Waverley Municipal Council Mayor and Councillors;

- Staff from Waverley Municipal Council;
- Randwick City Council Councillors;
- Staff from Randwick City Council;
- Representatives from the NSW Office of Environment and Heritage (OEH);
- Representatives from the State Emergency Service (SES);
- Other NSW government agencies (Sydney Water);
- Community representatives.

The Committee is responsible for recommending the outcomes of the study for formal consideration by Council.

1.5 Study Objectives

The primary objective of this flood study is to define the flood behaviour under historic, existing and future conditions (incorporating potential impacts of climate change) in the study area for a range of design flood events. The study provides information on flood levels, depths, velocities, flows, hydraulic categories and provisional hazard categories. Specifically, the study incorporates:

- Compilation and review of existing information pertinent to the study and acquisition of additional data including survey as required;
- Community consultation and participation program to identify local flooding concerns, collect information on historic flood behaviour, advise on the outcomes of the flood study and predicted flood behaviour, and engage the community in the on-going floodplain management process;
- Development and calibration of appropriate hydrologic and hydraulic models;
- Determination of design flood conditions for a range of design events, including the 1EY (63.2% AEP), 50% AEP (1.44 year ARI), 20% AEP (5 year ARI), 10% AEP (10 year ARI), 5% AEP (20 year ARI), 2% AEP (50 year ARI), 1% AEP (100 year ARI), 0.2% AEP (500 year ARI) and the Probable Maximum Flood (PMF) (noting that EY refers to exceedances per year, AEP refers to Annual Exceedance Probability and ARI refers to Average Recurrence Interval);
- Examination of the potential impact of climate change using the latest guidelines.

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

- Outline the flood behaviour within the catchments to aid in Council's management of flood risk;
- 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.

1.6 About this Report

This report documents the study's objectives, results and recommendations, as follows:

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 model calibration and validation process.

Section 6 details the design flood conditions.

Section 7 details the design flood results and associated flood mapping.

Section 8 details the sensitivity testing conducted including climate change analysis.

2 Study Approach

2.1 The Study Area

2.1.1 Catchment Description

The extent and topography of the study area are shown in Figure 2-1. The study area contains fifteen fully developed catchments and comprises predominantly low, medium and high-density housing with pockets of commercial development, infrastructure and open recreational spaces. Some of the developed areas would have previously included creek alignments.

The study catchments cover an area of approximately 10km^2 and either flow overland into Sydney Harbour or drain directly into the South Tasman Sea. The natural creek systems have been heavily modified, and the study area is now drained entirely by stormwater network. When the capacity of this network is exceeded, overland flow will occur along the alignments of the developed creeks, which presents a significant flood risk to property in these areas.

The topography within the study area varies from steep surface slopes in excess of 20% in catchments such as Clovelly and Tamarama, to the relatively flat areas of Bondi and Bondi Beach. Therefore, the catchment has regions where surface water runoff within the road network has high velocity with shallow depths, whilst within the lower catchment the surface water is more likely to pond in sag points and flow velocities will be lower.

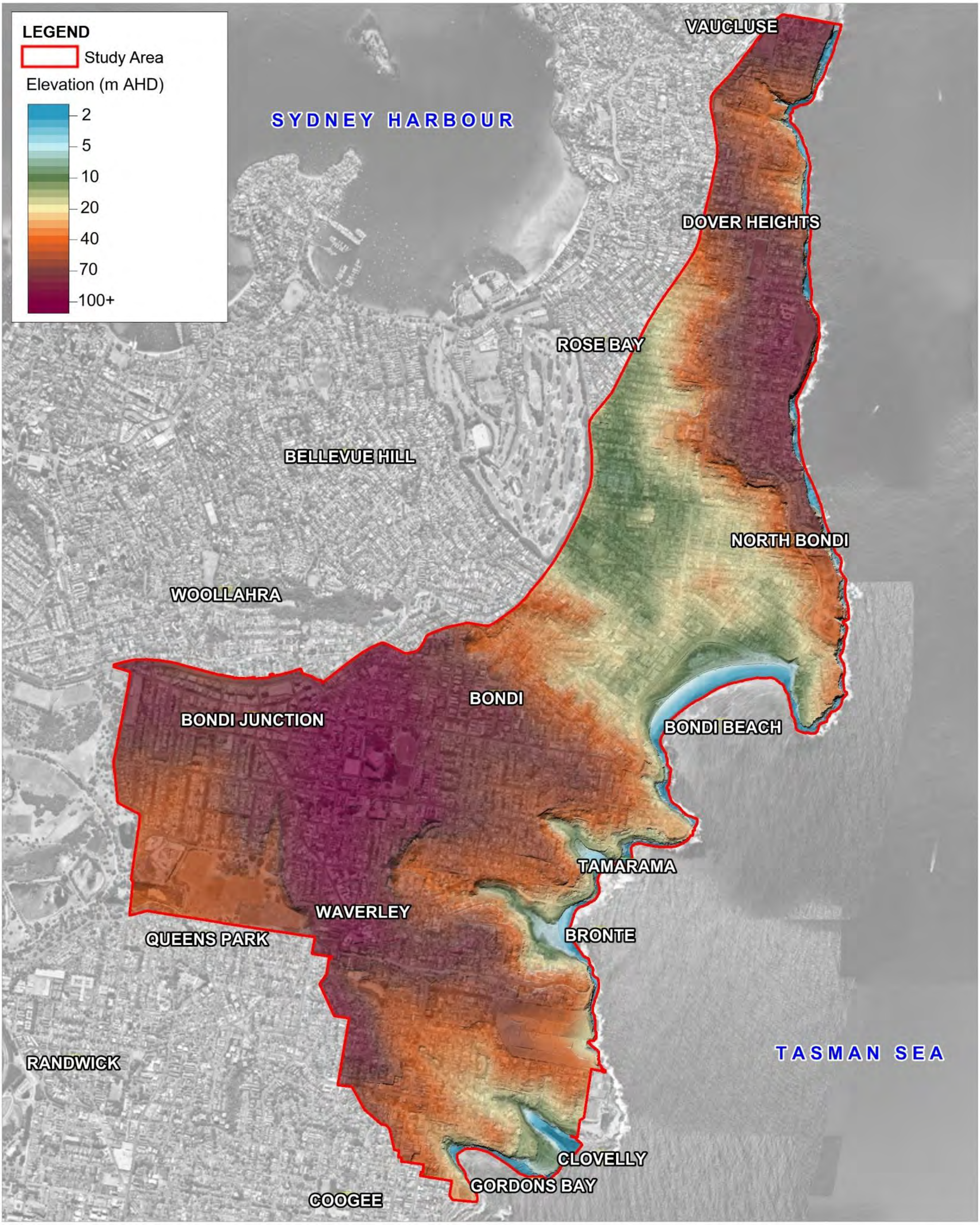
There are a number of localised depressions in the catchment topography, which will be liable to fill with water during flood events. Deep floodwaters in these locations will not be uncommon once the capacity of local drainage systems is exceeded. A number of such depressions are located in the low-lying region to the east of Old South Head Road. The topography of these depressions provides for no natural outlet, and hence the drainage is largely restricted to the capacity of the trunk drainage line and sub-surface infiltration.

2.1.2 Stormwater Drainage System

The Waverley LGA area was first settled with land grants in the early 19th Century (B. T. Dowd, 1959). The natural drainage system comprised earth gullies, watercourses, swampland and lagoons draining to the South Tasman Sea to the East, and Sydney Harbour to the North-West. From 1859, the municipality of Waverley was established, leading to a period of growth, and the land use changed to a higher proportion of impervious surfaces resulting in increased runoff volumes and peak flows.

An extensive network of stormwater infrastructure exists in the study area to provide drainage of surface water runoff. The infrastructure primarily consists of a pit and pipe stormwater network, comprising kerb inlet pits, grated pits, junction pits, pipes and box culverts.

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



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Topography of the Study Area

Figure: **2-1**

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2.1.3 Known Flooding Problems

The Waverley LGA Flood Study catchments have a history of experiencing frequent and hazardous flood events, primarily occurring in trapped localised depressions. Periods of sustained rainfalls causing saturated antecedent conditions, coupled with high intensity, short duration bursts of localised rainfall, have caused flooding and widespread damage in recent times.

The events in August 2015, December 2015 and February 2017 all resulted in flooding within the study catchments. Community consultation and information provided by Council staff indicates that there are a number of known problem areas typified by flooding due to:

- Trapped depressions with limited or no natural outlets;
- Blockage of drainage systems.

2.2 Compilation and Review of Available Data

2.2.1 Introduction

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

- Previous studies undertaken in surrounding catchments;
- Digitally available information provided by Council, such as aerial photography, topographical data, cadastral boundaries, watercourses and drainage networks in the form of GIS datasets;
- Available water level, tide and rainfall data;
- Register of data from historic flood events.

2.2.2 Previous Studies and Investigations

A comprehensive investigation into the Waverley LGA drainage system was undertaken in 2007. This study used the DRAINS hydraulic modelling software which is capable of modelling the performance of the drainage system, however complex interactions between overland flow paths cannot be reliably modelled, especially at such a large scale.

No previous investigations of flooding in the Gordons Bay and Clovelly Beach catchment have been completed by Randwick City Council, however several studies have been undertaken for neighbouring catchments.

Details of previous drainage and flood studies within and adjacent to the study area and their relevance to the current flood study are presented in the following sections.

2.2.2.1 Waverley Council Stormwater Drainage System Mapping & Modelling - DRAINAGE SYSTEM MODELLING (Bankstown Civic Design, 2007)

The report prepared by Bankstown Civic Design (Bankstown Council) for Waverley Municipal Council in 2007 provides a basic indication of flood behaviour within the entire Waverley LGA and identifies the location of flood problem areas.

The DRAINS hydrologic and hydraulic modelling software was used to determine catchment runoff and route flows through conduits and overland flow paths. The study applied the ILSAX method of calculating catchment runoff. Initial losses of 2mm and 20mm were adopted for impervious and pervious area depression storages. A Type 1 (sand and gravel) soil and an antecedent moisture condition (AMC) of 1 was adopted (indicating completely dry catchment conditions). Peak flood levels were determined at pits and natural basins, and floodways were identified at overland flow paths.

During the study, Bankstown Civic Design completed a comprehensive field investigation and survey. Approximately 4,400 pits and pipes and conduits were surveyed with pipe diameters ranging between 225mm and 1800mm and box culverts of varying size. The tasks involved in performing the drainage survey included:

- General inspection including photography of structures/conduits;
- GPS survey of structures to obtain accurate position and elevation data;
- Depth, lintel information, conduit inverts and sizes were determined for each structure.

The above data was entered into a GIS database, which has been continually managed and updated by Council following the conclusion of the 2007 study. This detailed drainage network database was utilised during the current study to inform the modelled stormwater network, as discussed further in Section 4.3.4.

Approximately 3,000 minor sub-catchments were determined for each modelled inlet pit. These sub-catchments have been used to develop the 805 XP-RAFTS sub-catchments defined as part of this study (refer further discussion in Section 4.2.1).

2.2.2.2 Coogee Bay Flood Study (BMT WBM, 2013)

In 2013, the Coogee Bay Flood Study was completed by BMT WBM for Randwick City Council. The study determined flood conditions in the Coogee Bay catchment, as well as incorporating future flood risk due to climate change.

The Coogee Bay study adopted the initial-continuing loss model used in this study. Based on recorded flood marks at Coogee Oval, initial and continuing loss rates were calibrated in the hydrologic model. Initial and continuing loss rates of 50mm and 5mm/hr (respectively) for pervious areas and 5mm and 0mm/hr (respectively) for impervious areas were found to best replicate those conditions that had been recorded during historic storm events in January 1999 and May 2009.

2.2.2.3 Rose Bay Catchment Flood Study (WMAwater, 2010)

In 2010, the Rose Bay Catchment Flood Study was completed by WMAwater for Woollahra Municipal Council. The study established flood conditions in the Rose Bay catchment, as well as incorporating future flood risk due to climate change.

The Rose Bay study utilised an existing DRAINS hydrologic model to simulate catchment runoff, adopting a soil type of 3 and an AMC of 3 for design event rainfall. A soil type of 3 refers to soils with a moderate infiltration rates and which are moderately well drained. An antecedent moisture condition of 3 is generally equitable to relatively wet catchment conditions. The two parameters determine the continuing loss (defined by Horton's infiltration equation) returning a diminishing infiltration over time. Whilst the ILSAX methodology employed by DRAINS modelling cannot be directly equated to the initial and continuing loss methodology used in this study, it can be generally stated that the Rose Bay catchment model used saturated catchment conditions and moderately draining soils to establish design event rainfall.

2.2.2.4 Double Bay Catchment Flood Study (Bewsher, 2008)

In 2008, the Double Bay Catchment Flood Study was completed by Bewsher Consulting in association with Brown Consulting for Woollahra Municipal Council. The study determined the nature and extent of flooding in the Double Bay catchment, as well as incorporating future flood risk due to climate change. As per the adjoining Rose Bay catchment, a soil type of 3 and an AMC of 3 was adopted for design event modelling.

2.2.2.5 Centennial Park Flood Study (WMAwater, 2016)

In 2016, the Centennial Park Flood Study was completed by WMAwater for the City of Sydney. The study determined the nature and extent of flooding in the Centennial Park catchment, as well as incorporating future flood risk due to climate change. As per the Rose Bay catchment and Double Bay catchment, a soil type of 3 and an AMC of 3 was adopted for design event modelling.

2.2.3 Council GIS Data

Digitally available GIS data such as aerial photography, cadastral boundaries and roads, Local Environmental Plan (LEP) zoning and drainage network information has been provided by Council. This data provides a means to distinguish between land use types across the study area to allow spatial variation of distinct hydrologic (e.g. rainfall losses) and hydraulic properties (e.g. Manning's roughness parameter 'n'). This data has also been used to identify any potential data gaps.

2.2.4 Historic Flood Level Data

Available flood level records in the catchment are limited. Simpson Street, Warners Avenue, Palmerstone Avenue, Surfside Avenue, Wallis Parade and Grafton Street are all areas where flood level information is available for recent flood events. Although no official (surveyed) flood marks were collected during these events, there are several flood photographs containing water marks and additional anecdotal evidence, enabling estimation of peak flood levels to be used in model calibration.

Flood photographs supplied by Council and collected during community consultation were identified for the following events:

- August 2015;
- December 2015;

- February 2017.

Observed flood levels and anecdotal recollections obtained during community consultation (refer Section 3.2) further supplement the flood photography. Data obtained from historic records and the community consultation process was subsequently used for the purposes of model calibration (discussed in Section 5).

2.2.5 Rainfall Data

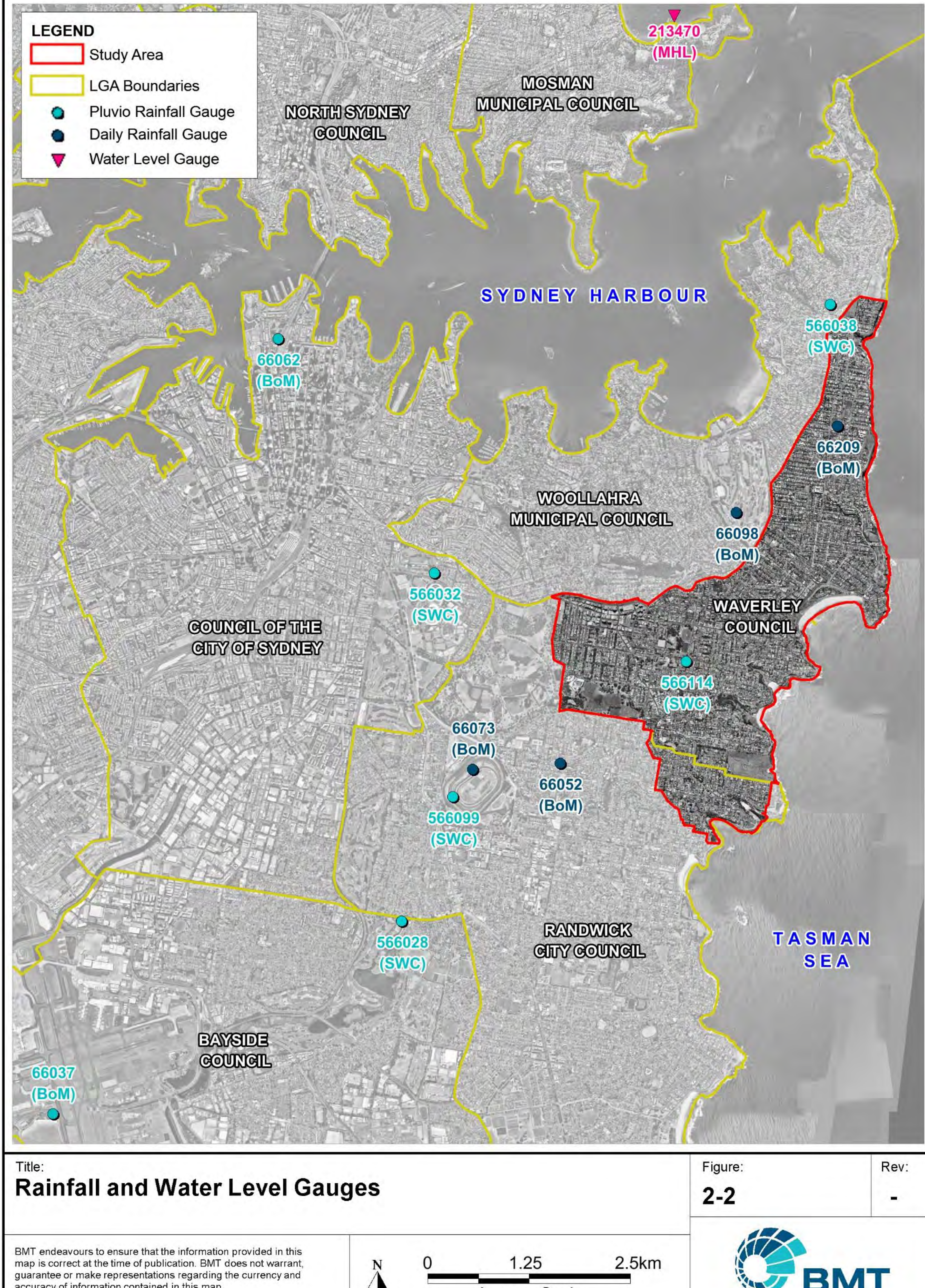
There is an extensive network of rainfall gauges across the Sydney area, the majority of which are operated by the Bureau of Meteorology (BoM) and the Sydney Water Corporation (SWC). Several gauges are located within the study area, as well as a number of gauges in close proximity to the study extent.

A list of rainfall stations relevant this study, the type of data available and their respective period of record are shown in Table 2-1. The spatial distribution of the rainfall stations is shown in Figure 2-2.

Table 2-1 Rainfall Gauges in the Vicinity of the Study Area

Gauge Station No.	Gauge Type	Station Name	Record Period	Data Type	Authority
566114	Pluvio	Waverley Bowling Club		Pluvio	SWC
566038	Pluvio	Vaucluse Bowling Club		Pluvio	SWC
566032	Pluvio	Paddington (Composite Site)		Pluvio	SWC
566099	Pluvio	Randwick Racecourse		Pluvio	SWC
566028	Pluvio	Eastlakes SW Depot		Pluvio	SWC
66062	Pluvio	Sydney (Observatory Hill)	1858 – current	Pluvio	BoM
66037	Pluvio	Sydney Airport AMO	1929 – current	Pluvio	BoM
66052	Daily	Randwick (Randwick St)	1917 – current	Daily	BoM
66098	Daily	Rose Bay (Royal Sydney Golf Club)	1928 – current	Daily	BoM
66073	Daily	Randwick Racecourse	1937 – current	Daily	BoM
66209	Daily	Dover Heights (Portland St)	2007 – current	Daily	BoM

The combination of daily rainfall stations and pluvio stations has been used to define the temporal pattern of historic rainfall events and provides a high-quality rainfall dataset for use in the model calibration and validation as part of this study.



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Rainfall and Water Level Gauges

Figure: 2-2

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2.2.6 Topographic Data

Aerial topographic survey, also known as Light Detection and Ranging (LiDAR) survey, covering the study area was provided by Council. The survey was captured by the NSW Government's Land and Property Information (LPI) in 2013. Horizontal and vertical accuracy quoted by the supplier are 0.8m and 0.3m, respectively.

In addition to the 2013 LiDAR data, Council provided Airborne Laser Scanning (ALS) flown in 2008 by specialist surveyor AAM HATCH. Digital Elevation Models (DEMs) were developed using the 2013 and 2008 datasets. The 2013 LiDAR and 2008 ALS have been cross-checked against control survey marks recorded in LPI's Survey Control Information Management System (SCIMS).

Analysis was undertaken on each point by extracting the elevation from the two topographic sources and subtracting the surveyed elevation at these locations. In total 430 control survey marks were analysed. Figure 2-3 shows the marks used in analysis and Table 2-2 summarises the findings in tabular format. A full list of survey marks and accompanying elevations are provided in Appendix A.

Table 2-2 Difference between Surveyed Elevations and Topographic Estimate

Statistic	2008 ALS	2013 LiDAR
Control Survey Marks (LPI)		
Count[1]	430	430
Maximum Difference (m)	6.08	6.26
Minimum Difference (m)	-1.56	-1.46
Average Difference (m)	0.20	0.16

[1] Number of control survey points eligible for comparison

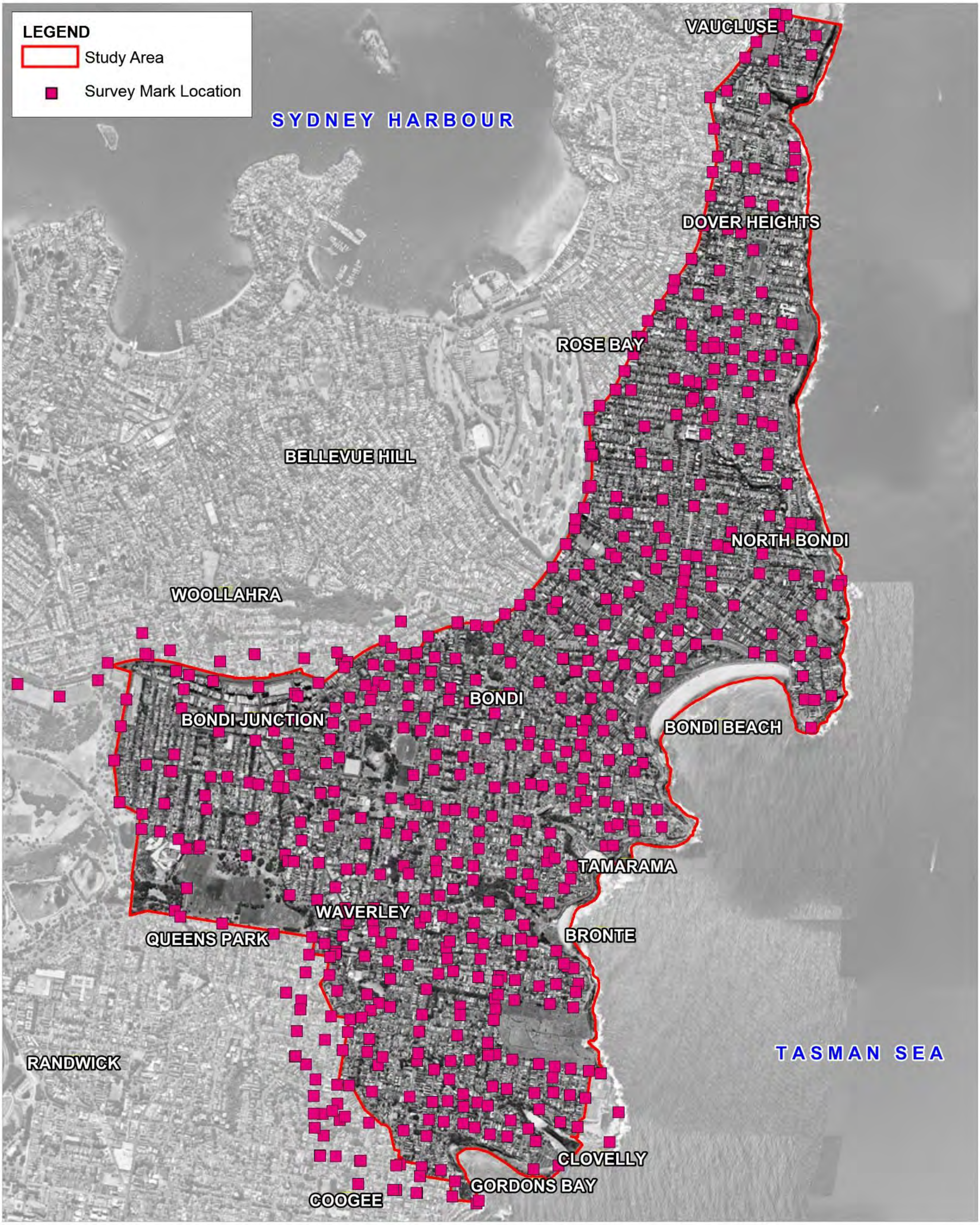
Analysis of the 430 points for the two topographic sources indicates a reasonable correlation between the surveyed ground levels and the ground levels estimated from the two aerial survey sources. The comparison indicates that all three topographic datasets fall within a general range of ±0.2m for vertical accuracy.

The results of the comparison indicate that the 2013 LiDAR is the most appropriate in representing ground elevations across the study area with an average vertical accuracy of ±0.16m.

2.2.7 Stormwater Drainage Network

An extensive network of stormwater drainage infrastructure exists in the study area to provide drainage of surface water runoff. The infrastructure primarily consists of a pit and pipe stormwater network and a small number of minor open channels.

No additional survey of the stormwater network was undertaken as part of this study due to the scale of survey conducted during the previous 2007 drainage investigation (Bankstown Civic Design, 2007), whereby over 4,000 individual Council assets were surveyed.



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Control Survey Marks

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2.3 Site Inspections

Site inspections have been undertaken during the course of the study to gain an appreciation of local hydraulic features and their potential influence on flood behaviour. Some of the key observations accounted for during site inspections included:

- Presence of local structural hydraulic controls;
- Location and characteristics of surface drainage pits and pipes;
- Location of existing development and infrastructure in the floodplain;
- Assessment of hotspot locations;
- General nature of the contributing catchment.

This visual assessment was useful for defining hydraulic properties within the flood model and ground-truthing of topographic features identified in the DEM.

2.4 Community Consultation

The success of a floodplain management plan hinges on its acceptance by the community and other stakeholders. This can be achieved by involving the local community at all stages of the decision-making process, including the collection of their views and knowledge on flood behaviour in the study area, as well as discussing the issues and outcomes of the study with them. The key elements of the consultation program undertaken for the study are discussed in Section 3.

2.5 Development of Computer Models

2.5.1 Hydrologic Model

A hydrologic model has been developed to simulate the rate of storm runoff from the catchment using the XP-RAFTS software (refer to Section 4). The study area has been delineated into 805 sub-catchments with a flow hydrograph output at the outlet of each sub-catchment. These flow hydrographs form the inflow boundaries to the hydraulic model.

2.5.2 Hydraulic Model

The TUFLOW hydraulic model (discussed in Section 4) developed for this study includes:

- 2D representation of the floodplain of the combined catchments (i.e. complete coverage of the total study area);
- 2D representation of the open/natural channel drainage network;
- 1D representation of the stormwater pit/pipe network.

The hydraulic model is applied to determine flood levels, velocities and depths across the study area for historic and design events.

2.6 Calibration/Validation and Sensitivity Testing of Models

The hydraulic model was calibrated and validated against available historic flood event data to establish the values of key model parameters and confirm that the models were capable of adequately simulating real flood events. The following criteria are generally used to determine the suitability of historical events to use for calibration or validation:

- The availability, completeness and quality of rainfall and flood level data;
- The amount of reliable data collected during the historic flood information survey;
- The variability of events – preferably events would cover a range of flood magnitudes.

The available historic information highlighted three flood events with sufficient data to potentially support a calibration and validation process. The calibration and validation of the hydraulic model is presented in Section 5.

A series of sensitivity tests were also carried out to evaluate the results of the modelling. These tests were conducted to examine the performance of the models and determine the relative impact of different hydrologic and hydraulic parameters. The sensitivity testing of the model is detailed in Section 8.

2.7 Establishing Design Flood Conditions

Design floods are statistical-based events which have a particular probability of occurrence. For the study area, design floods were based on design rainfall estimates according to the Australian Rainfall and Runoff (AR&R) 2016 guidelines (Ball et al., 2016).

The design flood conditions form the basis for floodplain management in the catchment and in particular design planning levels for future development controls. The predicted design flood conditions are presented in Section 6.

2.8 Mapping of Flood Behaviour

Design flood mapping is undertaken using outputs from the hydraulic model. Maps are produced showing peak values of water level, depth and velocity. Provisional flood hazard categories and hydraulic categories are derived from the hydrodynamic model results and are also mapped. The mapping outputs are described in Section 7 and presented in the separate Flood Mapping Compendium.

3 Community Consultation

3.1 The Community Consultation Process

Community consultation has been an important component of the study. The consultation has aimed to inform the community about the development of the flood study and its likely outcomes as a precursor to subsequent floodplain management activities. It has provided an opportunity to collect information on the flood experiences of community members in the catchment and to collect feedback on concerns regarding flooding. In addition, the consultation process raises awareness about the risk of flooding within the community and improves the community's receptiveness to flood related issues.

The key elements of the consultation process have included:

- Consultation with the Floodplain Management Committee;
- Distribution of a newsletter and questionnaire to landowners, residents and businesses within the study area;
- Follow up telephone conversations with a number of respondents to discuss information provided in more detail;
- Drop-in sessions with select residents in known flooding hotspots;
- An information session to present technical information and inform about the flood study outcome;
- Public exhibition of the draft Flood Study.

These elements are discussed in detail in the following sections. Copies of relevant consultation material are included in Appendix B, Appendix C and Appendix D.

3.2 Community Questionnaire

In late 2017, an information leaflet and questionnaire were distributed by Waverley Council (November 2017) and Randwick City Council (December 2017) to all residential properties and businesses within the study area. The questionnaire was also accessible through each Council's online community engagement portals:

- https://www.haveyoursaywaverley.com.au
- Yoursayrandwick.com.au/clovellyfloodstudy

The information leaflet provided an overview of the flood study while the questionnaire sought to collect information on the community's historic flood experiences and flooding issues of concern. Copies of the newsletter and questionnaire are provided in Appendix B.

A total of 446 completed questionnaires were received out of the 35,169 letters delivered, representing an overall response rate of 1%. This is considered to be a relatively low return rate; typically, BMT receives a return rate of between 5% and 10 % for initial consultation on a flood study. The response rate was 0.4% and 8% for Waverley and Randwick LGAs, respectively. Further details are provided in Table 3-1.

Table 3-1 Community Consultation - Response Rates

Council	Letters delivered	Returned Questionnaires	Response Rate
Waverley	35,169	144	0.4%
Randwick	3,810	302	8%
Total Study Area	38,979	446	1%

The responses have been compiled into a GIS database which was analysed to provide a graphical representation of the data. Figure 3-2 maps the geographical spread of each respondent's location. The map indicates a comprehensive coverage of responses across the study area.

The majority of the respondents have resided at their property for over 15 years. Where flooding was identified as an issue, the community were asked to separately report on flooding within their property and their street.

Property flooding experiences are summarised in Figure 3-1 and illustrated spatially in Figure 3-3. A total of 91 responses in the study area have experienced some degree of flooding within the grounds of their property, 23 of which experienced flooding above floor level. Of these 91 flood affected responses, 53 were from Waverley LGA and 38 were from Randwick LGA.

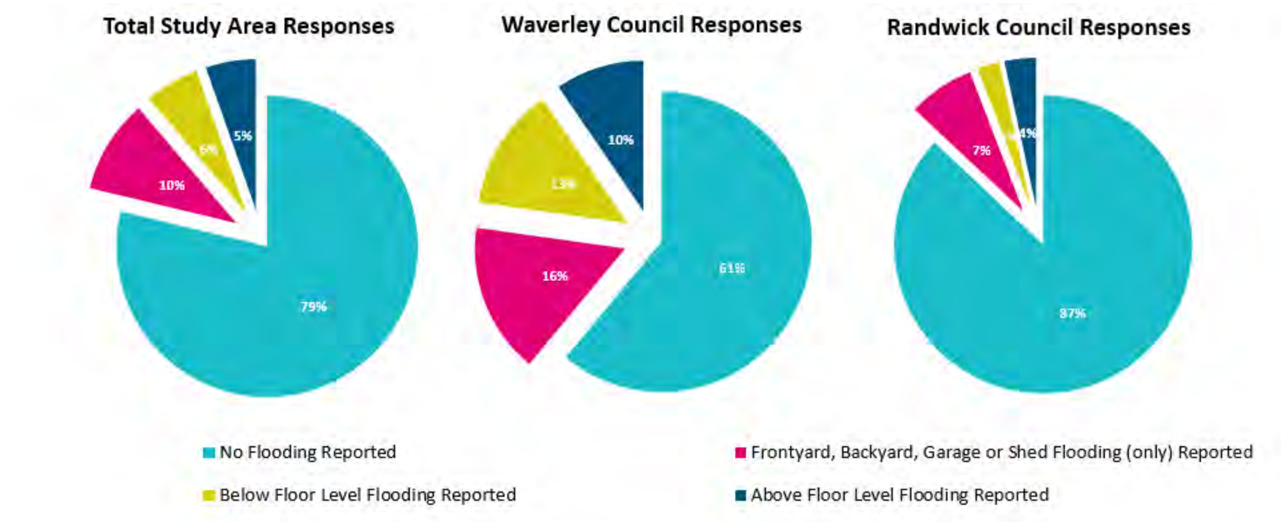
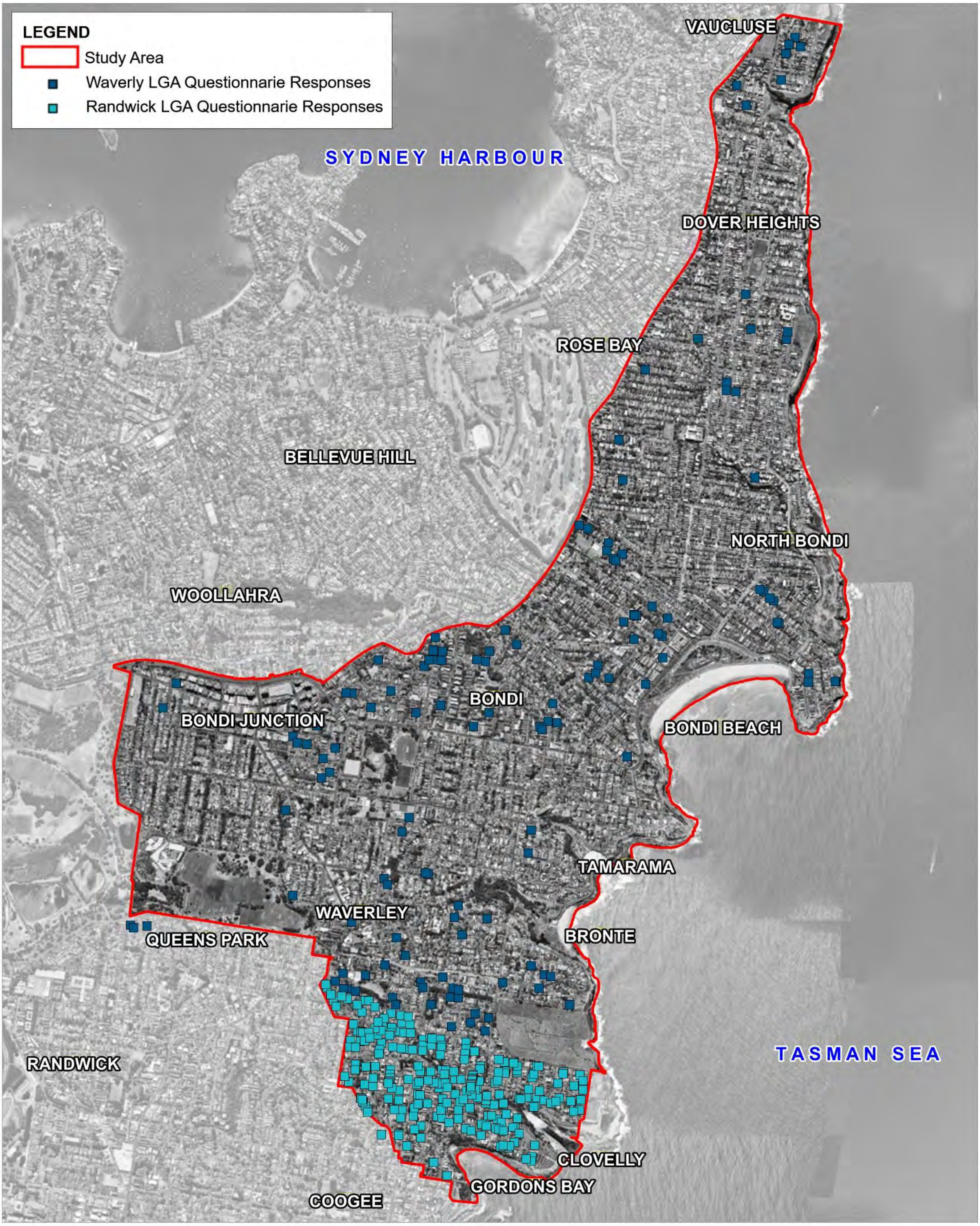


Figure 3-1 2017/18 Questionnaire Responses – Property Flooding Experienced



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Community Consultation Process

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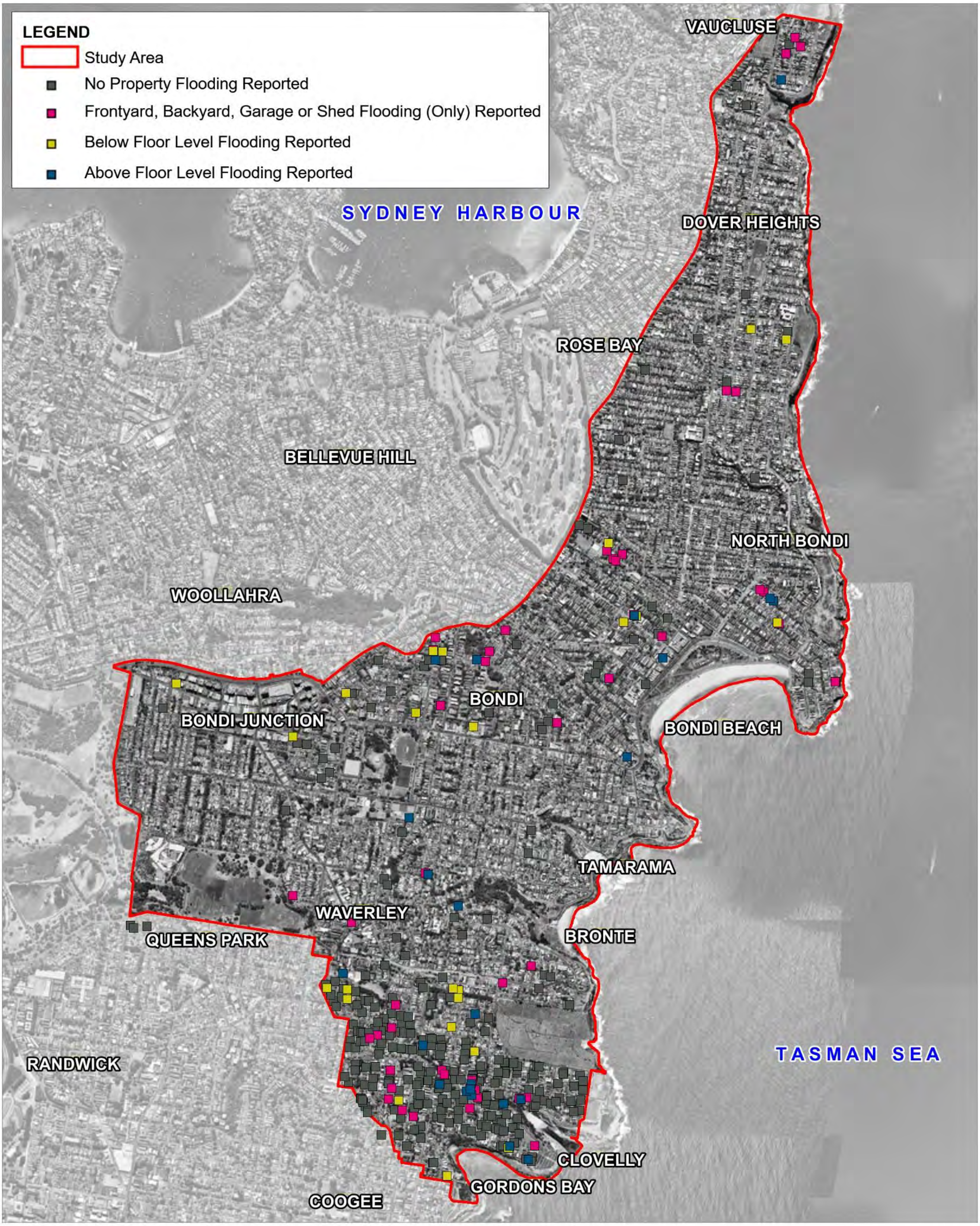

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Property Flooding Experienced

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Figure 3-4 provides a summary of responses that identified flooding on their street. A total of 214 residents indicated that they had experienced flooding within a roadway, 95 of which reported flooding across one or both traffic lanes. Of those 214 respondents, 92 were from the Waverley LGA and 134 were from Randwick LGA.

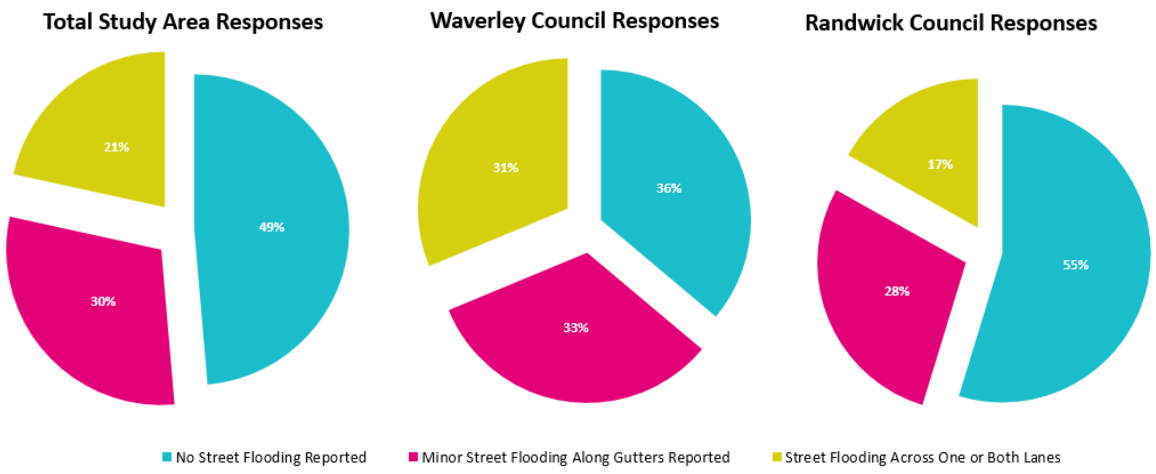


Figure 3-4 2017/18 Questionnaire Responses – Street Flooding Experienced

Figure 3-5 provides a summary of responses that identified culverts, drains and/or stormwater inlets were blocked during flooding on their street. A total of 153 residents noticed blockage, 53 of which reported the inlets were fully blocked during flooding. Of those 153 responses, 59 were from Waverley LGA, and 94 were from Randwick LGA.

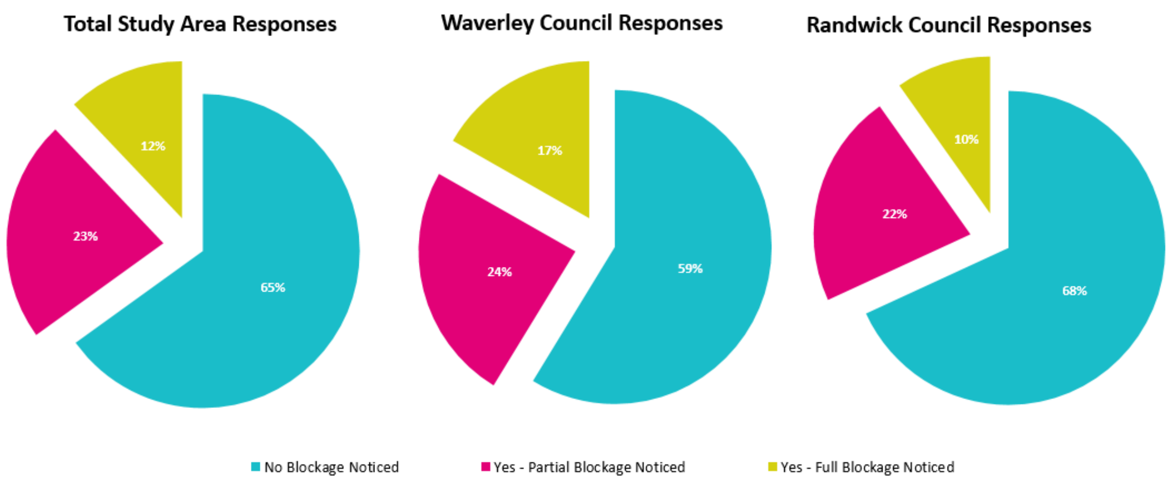


Figure 3-5 2017/18 Questionnaire Responses – Blockage During Flooding

Comments relating to flood behaviour have been compared with modelled flood behaviour as part of the flood model calibration and validation. A number of community responses identified flooding in the study area due to rainfall events in 2014, 2015, 2016 and 2017. Numerous comments included indicative flood depths; however, these are largely not attributed to specific flood events. Over ten responses provided photos and/or indicative flood depths resulting from the August 2015, December 2015 and February 2017 rainfall events.

A summary of the key issues raised by the community in the questionnaire responses include:

- Flooding due to under capacity of the drainage system;
- Blockage of drainage systems as a result of lack of maintenance exacerbates the flooding;
- Community suggestions for reducing flooding problems including:
  - Increased maintenance of the drainage system (e.g. ensuring pits, stormwater drains, and waterways are kept clear of debris);
  - Improvements and upgrades to stormwater and drainage infrastructure (e.g. increase number and capacity of stormwater pits).

3.3 Community Drop-in Sessions

Community members residing in flooding hotspots (compiled by Council) were contacted in the initial stages of the study to notify them of the study, and to collect information on their flood experiences in addition to any feedback on concerns regarding flooding. Drop-in sessions were conducted on Thursday 9 August and Thursday 23 August.

Where possible, the responses were used in model calibration and in confirming modelled flood behaviour. The compiled responses are provided in Appendix C.

3.4 Public Exhibition of Draft Flood Study Report

3.4.1 Public Exhibition and Information Session

The Draft Flood Study was placed on public exhibition from 29 July 2020 to 9 September 2020. This provided the community and key stakeholders with an opportunity to review the draft study and provide feedback that would be considered in finalising the report. The public exhibition and associated engagement activities were advertised to the community through a range of media, including social media and leaflet distribution to over 31,000 properties.

As this consultation period was during COVID-19 restrictions, face to face engagement opportunities were unavailable. Therefore, the exhibition primarily focused on the “Have Your Say Waverley” project webpage. A digital copy of the Draft Flood Study report was available on the webpage and this was supplemented with flood mapping, a project summary and responses to frequently asked questions (FAQ’s). An 8-question online survey was also provided to collect any feedback.

A precinct workshop/information session was held on 27 August 2020. This meeting was available for all community members to attend and included a presentation on the flood study and Q&A session.

3.4.2 Community Response

A total of 13 submissions were received from the community during the public exhibition period, including 5 online survey responses and 6 long form email submissions. The majority of responses related to concerns, suggestions or general feedback regarding specific properties.

A Public Exhibition Consultation Summary Report was prepared by Waverley Council after the public exhibition was completed. This report is enclosed in Appendix D and provides greater detail on the activities that formed part of the exhibition period, feedback received and the overall outcomes of the exhibition.

The submissions did not raise any concerns over the Flood Study report. Accordingly, no significant changes were required to the post-exhibited document as a result of the public exhibition.

3.5 Conclusion

Community consultation undertaken during the study has aimed to collect information on historic flooding and previous flood experience, and inform the community about the development of the flood study and its outcomes as a precursor to floodplain management activities to follow.

The key element of the consultation process involved the distribution of a questionnaire relating to historic flooding. The number of returned questionnaires was relatively low for Waverley LGA (0.4%) and high for Randwick LGA (8%) and useful additional historic flood information was obtained.

The draft Flood Study report was also placed on public exhibition to enable the community and key stakeholders to review and comment on the study prior to finalisation of the report.

4 Model Development

Computer models are the most reliable, cost-effective and efficient tools to assess a catchment's flood behaviour. Traditionally, for the purpose of a flood study, a hydrologic model and a hydraulic model are developed, where:

- The **hydrologic model** simulates the catchment rainfall-runoff processes, producing the stormwater flows which are used in the hydraulic model.
- The **hydraulic model** simulates the flow behaviour of the drainage network and overland flow paths, producing flood levels, flow discharges and flow velocities.

The following section outlies the methodology undertaken to establish the hydrologic and hydraulic flood models for the Waverley LGA Flood Study.

4.1 Modelling Methodology

The modelling approach adopted for this study has been developed through experience on a number of urban catchment overland flow studies across NSW. The key steps of the methodology include:

- Development of a detailed DEM for the catchment;
- Delineation of catchment flow paths and hydrologic sub-catchments;
- Development of hydraulic roughness surfaces for the catchment;
- Development of a 1D stormwater drainage network;
- Representation of hydraulic structures;
- Development of key hydraulic controls along main overland flow paths.

The modelling of overland flow paths in urban environments presents a number of challenges for flood modelling. The ability to represent intricate local hydraulic controls is limited by the resolution and accuracy of both the available data and the hydraulic model. Therefore, the available data and hydraulic model representation generate much uncertainty within the modelling results if significant controls on flood mechanisms are not accurately captured. These mechanisms include:

- Stormwater pit capture for on-grade locations;
- Available flow capacity of kerb and gutter profiles;
- Impact of parked vehicles on the road and stormwater network hydraulic performance;
- Crest level controls of driveway entrances;
- Complexity of urban lot vegetation;
- Flow under, over, around and through various fence types;
- Flood storage within underground basements;
- Flow under, around and between buildings and/or through gates;

- Collection and re-distribution of debris by catchment runoff and the potential impact on the inlet capacity of the stormwater drainage network and/or hydraulic structures such as culverts.

The above list demonstrates the many difficulties in representing the flood mechanics of small urban catchments within any modelling framework. This is particularly relevant higher up the catchment where flow paths are smaller, gradients steeper and flood depths lower. However, as the upstream contributing catchment size increases and the resultant overland flow path increases in significance, the effect of the many uncertainties reduces, and a reasonable level of confidence can be drawn from the outputs of the flood modelling.

The purpose of modelling overland flow paths in urban catchments is to identify and quantify flood risk along the major overland flow path alignments. Measures with which these risks can be managed can then be assessed through use of the hydraulic model as an assessment tool. There may be many other issues throughout the catchment that are perceived by the community as being “flooding”, which are in fact local drainage issues. These are typically located higher up the catchment in steeper areas, where either the gutter capacity is insufficient or the crest level of driveways too low to contain catchment runoff and inter-allotment drainage. This can initiate minor overland flow paths that direct floodwaters into private properties. These issues are not readily represented in flood modelling due to scale limitations and data accuracy. However, solutions to the problems also do not require the assistance of flood modelling tools and local drainage improvements are typically sufficient.

The adopted modelling methodology is most suited for the intended purpose of the hydraulic model outputs. It utilises the advantages of both traditional hydrologic models and the direct-rainfall approach of 2D hydraulic models, whilst avoiding the associated disadvantages. The scale at which hydrologic sub-catchments are defined results in the majority of catchment runoff routing occurring within the hydraulic model. This is advantageous compared to the simplified routing algorithms employed within hydrologic models. For areas upstream of the hydraulic model inflows, the rainfall-runoff is processed within the hydrologic model. There are a number of advantages gained by excluding these areas from the hydraulic model, which cannot be achieved through a direct-rainfall approach, including:

- Hydraulic roughness representation in hydraulic models (Manning’s ‘n’) is not directly translatable to the representation of roughness for sheet flow conditions;
- Local depressions within the DEM do not drain in the hydraulic model (but would typically drain in reality) and runoff volume is lost to these small distributed storages;
- Computational burden of a direct-rainfall approach produces significantly larger model simulation times;
- Attempting to hydraulically model areas with slopes in excess of a 10% grade typically introduces numerous instabilities into the model solution;
- Model results are not output for the entire catchment, prohibiting flood mapping within upper catchment areas, where the modelling uncertainty is significant and the adoption of model results for flood planning purposes is often inappropriate and/or erroneous.

Restricting hydraulic model computations to areas with a significant upstream contributing catchment area ensures that a reasonable level of confidence can be maintained across the full extent of the flood mapping output. It also prevents model outputs generating flood planning restrictions in areas that are dominated by shallow runoff, where flooding/drainage issues can be addressed through small-scale local measures and/or there is a low confidence level in the modelling to reproduce the actual flooding mechanisms and behaviour.

For this study, the XP-RAFTS software package has been used for the purposes of hydrologic modelling and TUFLOW HPC has been used for hydraulic modelling.

4.2 Hydrologic Model

The hydrologic model simulates the rate at which rainfall runs off the catchment. The amount of rainfall runoff from the catchment is dependent on:

- the catchment slope, area, vegetation, urbanisation and other characteristics;
- variations in the distribution, intensity and amount of rainfall;
- the antecedent moisture conditions (dryness/wetness) of the catchment.

Such factors are accounted for within the model by:

- sub-dividing (discretising) the catchments into a network of sub-catchments. The sub-catchments are delineated, where practical, so that they each have a general uniformity in their slope, land use, vegetation density, etc.;
- the amount and intensity of rainfall is varied across the catchment based on available information. For historical events, this can be very subjective if little or no rainfall recordings exist;
- the antecedent moisture conditions are modelled by varying the amount of rainfall which is “lost” into the ground and “absorbed” by storages. For very dry antecedent moisture conditions, there is typically a higher initial rainfall loss.

The XP-RAFTS software was used to develop a hydrologic model using the physical characteristics of the catchment including catchment areas, ground slopes and vegetation cover as detailed in the following sections. The output from the hydrologic model is a series of flow hydrographs which form the inflow boundaries of the hydraulic model.

The general modelling approach and adopted parameters are discussed in the following sections.

4.2.1 Catchment Delineation

There is a total of fifteen sub-catchments within the study area; Bondi, Bondi Junction, Bronte, Centennial Park, Clovelly Beach, Diamond Bay, Dover Heights, Gordons Bay, Lachlan Swamps, North Bondi, Penkivil, Queens Park, Rose Bay, Rose Bay North and Tamarama. The combined area of these catchments is approximately10km^2, draining to either Sydney Harbour or the Tasman Sea. A number of these catchments drain through the neighbouring Woollahra Municipal Council and Randwick City Council LGAs.

As discussed in Section 2.2.2.1, a database of pit catchments was developed as part of the 2007 drainage modelling study undertaken by Bankstown Civic. This database contained over 3,000 individual sub-catchments, one for each inlet pit in the Waverley LGA. For the purposes of this study, the pit sub-catchments were consolidated from 3000 to 805 so as to reduce the computational burden on both hydrologic and hydraulic modelling software. In defining sub-catchment outlets, consideration has been given to the underlying pipe drainage network. Sub-catchment boundaries coincide with the location of major trunk drainage system infrastructure inlets, junctions and outlets where appropriate. Figure 4-1 shows the delineated XP-RAFTS sub-catchments used in this study.

The hydrologic catchment boundary and the hydraulic model extent have been sufficiently extended to account for the potential interactions with neighbouring catchments.

4.2.2 Rainfall Data

Rainfall information is the primary input and driver of the hydrologic model that simulates the catchment's response in generating surface run-off. Rainfall characteristics for both historical and design events are described by:

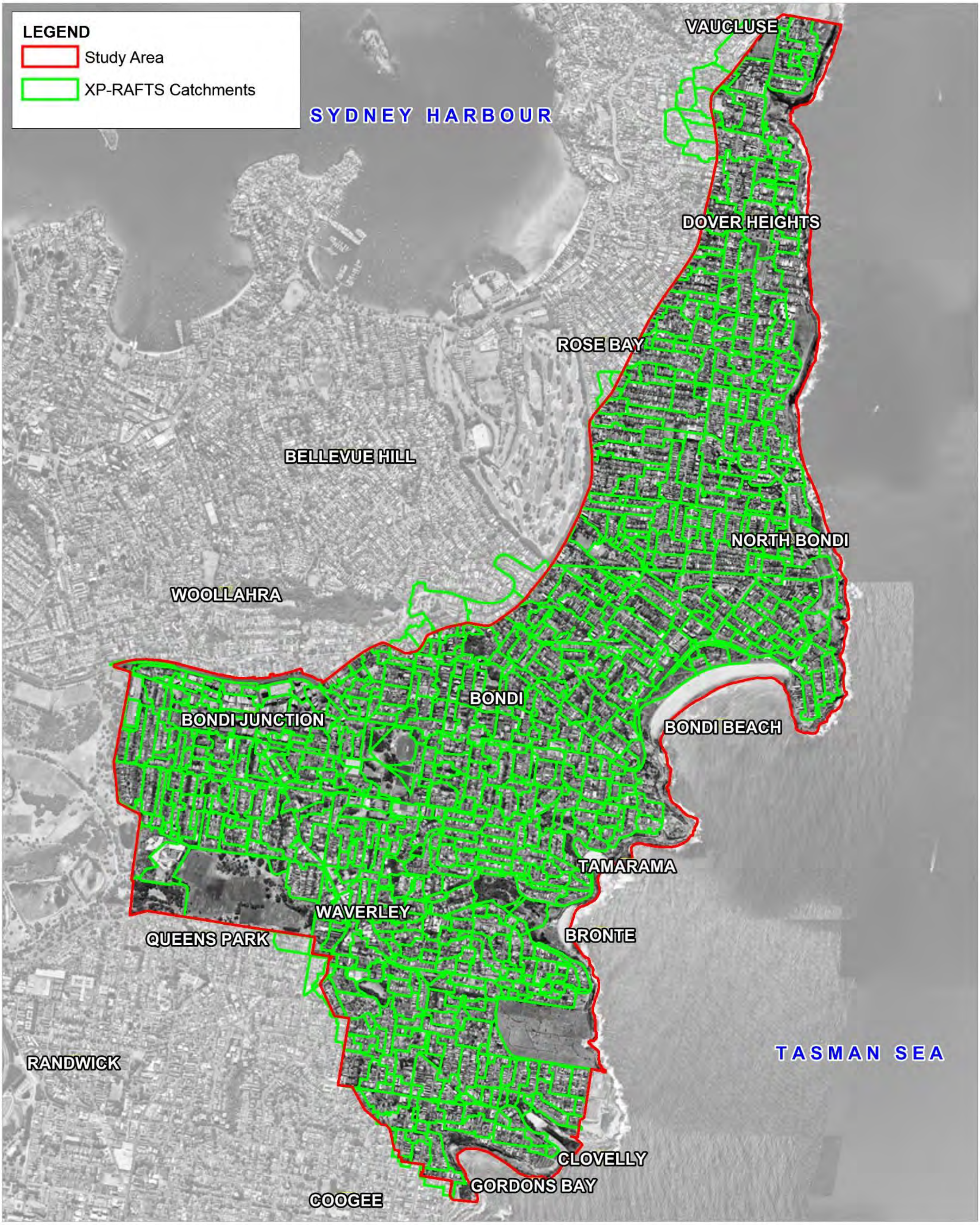
- Rainfall depth – the depth of rainfall occurring across a catchment surface over a defined period (e.g. 270mm in 36 hours or average intensity 7.5mm/hr);
- Temporal pattern –the distribution of rainfall depth at a certain time interval over the duration of the rainfall event.

Both of these properties may vary spatially across the catchment during any given event.

The procedure for defining these properties is different for historical and design events. For historical events, the recorded hyetographs at continuous rainfall gauges provide the observed rainfall depth and temporal pattern (refer to Figure 2-2 for rainfall gauge locations). Where only daily read gauges are available within a catchment, assumptions regarding the temporal pattern may need to be made.

For design events, rainfall depths are determined by the estimation of intensity-frequency-duration (IFD) design rainfall curves for the catchment. Standard procedures for derivation of these curves are defined in AR&R (Ball et al., 2016).

Australian Rainfall and Runoff: A Guide to Flood Estimation is a national guideline for the estimation of design flood characteristics in Australia. In August 2016, Engineers Australia completed a revision of AR&R. The revision process included 21 research projects, which were designed to fill knowledge gaps that have arisen since the 1987 edition was published.



Title: XP-RAFTS Catchments	Figure: 4-1	Rev: -

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4.2.2.1 AR&R 2016

The updated procedures provide some significant changes to previous procedures. Some of the key changes in AR&R 2016 are summarise below:

- Intensity-Frequency-Duration (IFD) 2016 design rainfalls – revised IFD rainfall estimates underpin the AR&R 2016 release. The updated IFD analysis includes a significant period of additional rainfall data since the 1987 IFDs were established. The variation between 1987 and 2016 IFD design rainfall is location dependent.
- Design rainfall losses – estimation of initial and continuing loss rates (as applied in the hydrologic model) are provided in AR&R 2016 as gridded spatial data. Representative losses for catchments are extracted from the database. This is a significant change from the previous approach (AR&R 1987) in which basic ranges were recommended for broad areas i.e. eastern or western NSW.
- Pre-burst rainfall – AR&R 2016 provides procedures for the consideration of pre-burst rainfalls for consideration along with design initial losses. The procedures provide for generation of tabular outputs of pre-burst rainfall for the catchment of interest based on a combination of storm duration and return period.
- Areal reduction factors – new equations have been developed as part of AR&R 2016 with regionalised parameters to define areal reduction factor for catchments based on catchment area and storm duration.
- Temporal patterns – the change in temporal patterns represents one of the most significant differences from the AR&R 2016 release. Each design duration now has a suite of 10 temporal patterns as opposed to single temporal pattern for each duration for AR&R 1987.

The rainfall inputs for the historical calibration/validation events are discussed in further detail in Section 5 and design rainfall inputs are discussed in Section 6.

4.2.3 Surface Type Hydrologic Properties

The response of the catchment to the input rainfall data is dependent on the spatial distribution and hydrologic properties of the land use surface types. The properties assigned to each surface type (or material) within TUFLOW that influence the hydrologic response of the model are:

- Initial and continuing losses- determine how much rainfall is lost to surface and soil storage etc. and therefore the effective rainfall contributing to surface runoff;
- Roughness parameters for sheet flow - govern the speed with which the runoff will travel, influencing the hydrologic response of the model.

The material layers input to the model were used to define initial loss, continuing loss and roughness parameters for each land use surface type within the catchment. Along with the model topography, it is these parameters which determine the runoff routing and hydrologic response of the model.

4.3 Hydraulic Model

The overland flow regime in urban environments is characterised by large and shallow inundation of urban development with interconnecting and varying flow paths. Road networks often convey a considerable proportion of floodwaters due to the hydraulic efficiency of the road surface compared to developed areas (e.g. blocked by fences and buildings), in addition to the underground pipe network draining mainly to natural channels. Given this complex flooding environment, a 2D modelling approach is warranted for overland flooding areas.

BMT has applied the fully 2D software modelling package TUFLOW HPC. TUFLOW was developed in-house at BMT and has been used extensively for over fifteen years on a commercial basis by BMT. TUFLOW has the capability to simulate the dynamic interaction of in-bank flows in open channels, major underground drainage systems and overland flows through complex overland flow paths using a linked 1D/2D flood modelling approach.

4.3.1 Model Configuration

Consideration needs to be given to the following elements in constructing the hydraulic model:

- Topographical data coverage and resolution;
- Location of recorded data (e.g. levels/flows for calibration);
- Location of controlling features (e.g. detention basins, levees, bridges and downstream boundaries);
- Desired accuracy to meet the study's objectives;
- Computational limitations.

With consideration of the available survey information and local topographical and hydraulic controls, a 2D model was developed incorporating all 15 catchments of the study area. A total length of about 101km of stormwater drainage is also included within the model.

A TUFLOW 2D domain model resolution of 2m was adopted for study area. It should be noted that TUFLOW samples elevation points at the cell centres, mid-sides and corners, so a 2m cell size results in DEM elevations being sampled every 1m. This resolution was selected to give necessary detail required for accurate representation of floodplain and channel topography and its influence on overland flows.

4.3.2 Topography

The ability of the hydraulic model to provide an accurate representation of the flow distribution on the floodplain ultimately depends upon the quality of the underlying topographic model. A 1m by 1m gridded DEM was derived using GIS modelling software Global Mapper^{TM}, incorporating data from NSW Land and Property Information (LPI) LiDAR survey in 2013.

The ground surface elevations for the TUFLOW model grid points are sampled directly from the DEM. It is a representation of the ground surface and does not include features such as buildings or vegetation.

In the context of the overland flood study, a high-resolution DEM is important to suitably represent available flow paths, such as roadways, that are expected to provide significant flood conveyance within the study area. Experience has proved this to be a successful approach and enables detailed simulation of flooding from overland flow paths.

Linear features that potentially influence the flow behaviour, such as gullies and embankments, were incorporated into the topography using 3D "breaklines" in TUFLOW to ensure that these were accurately represented in the model.

The resulting topography of the hydraulic model is illustrated in Figure 2-1.

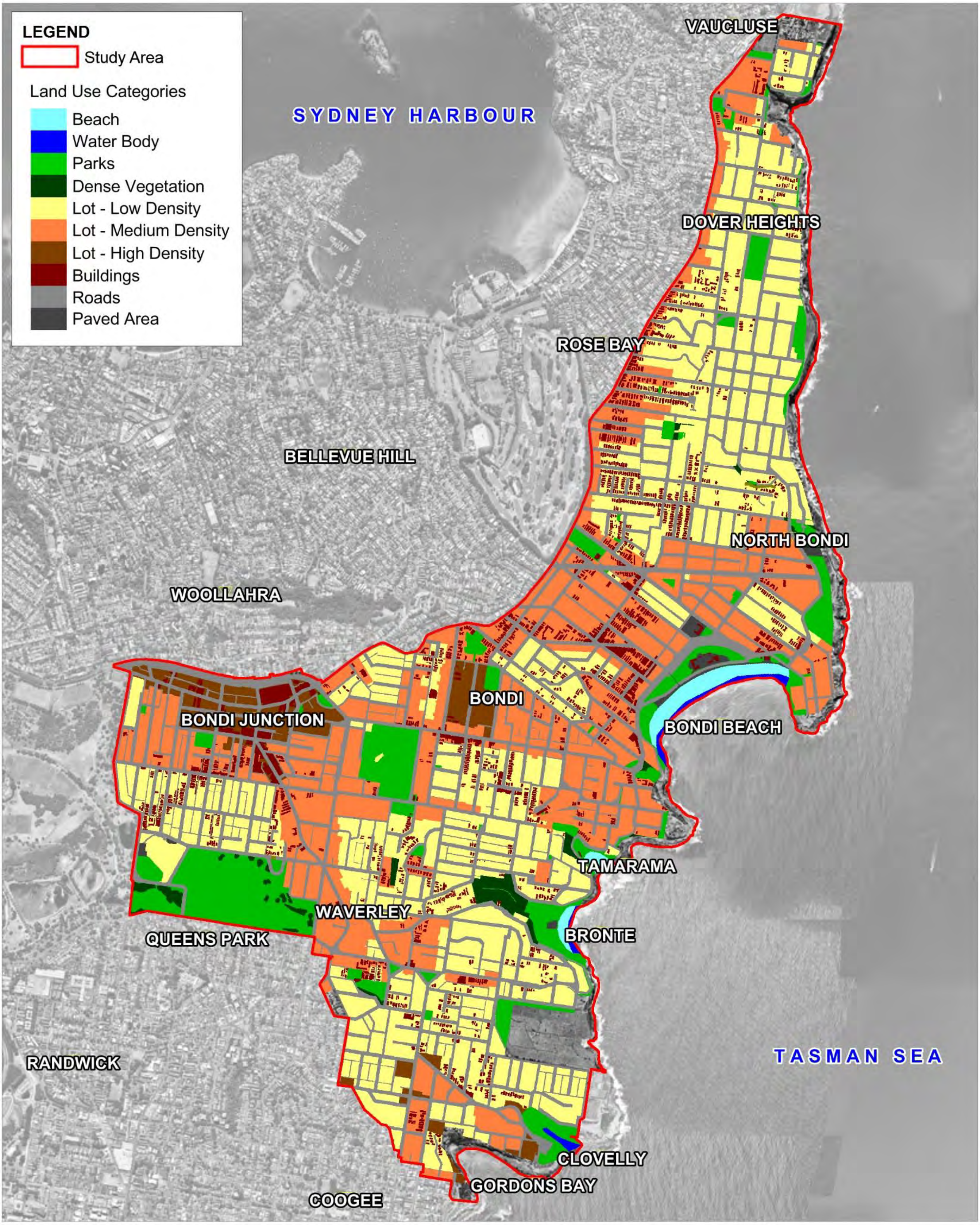
4.3.3 Hydraulic Roughness

The development of the TUFLOW model requires the assignment of different hydraulic roughness (Manning's 'n') zones. These zones are delineated from aerial photography and cadastral data, identifying different land uses (roads and urban areas, etc.) for modelling the variation in flow resistance.

Aerial photography and cadastral data supplied by both Waverley Council and Randwick City Council have been used to generate the land use surface types and roughness zones for the study area. The base land use map used to assign the different hydraulic roughness zones across the model is shown in Figure 4-2. The Manning's 'n' hydraulic roughness values adopted for each land use category are given in Table 4-1.

Table 4-1 Adopted Manning's 'n' Hydraulic Roughness Values

Land Use Category	Manning's 'n'
Low Density Residential lots (without buildings digitised)	0.040
Medium Density Residential lots (without buildings digitised)	0.060
High Density Residential lots (without buildings digitised)	0.060
Parklands	0.035
Dense Vegetation	0.080
Water Body	0.025
Beach/Coastal Areas	0.030
Roads	0.020
Paved Areas	0.020
Buildings (where digitised)	1.0



Title:

Land Use Categories

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4.3.4 Buildings

The presence of buildings and other structures (e.g. garages and sheds) may impede and divert flood flows in the catchment, and reduce the available overland flood storage. Therefore, representation of buildings is particularly important in areas conveying significant volumes of flow or experiencing significant ponding depth.

As shown in Figure 4-2, not all buildings have been digitised across the study area. Only buildings located within a predicted flow path, which are likely to reduce the conveyance of floodwater, have been included in the model. Buildings were represented within the TUFLOW model using an increased Manning's n roughness values of 1.0 (refer Table 4-1) to reflect the impediment to flow afforded by the buildings. Although the impediment to flow afforded by buildings can be represented by including the buildings as complete flow obstructions, this will fail to account for the potential flood storage provided within the buildings which, in an urbanised catchment, can be considerable. Overall, it is considered that modelling of buildings using a high Manning's n coefficient is appropriate.

4.3.5 Stormwater Drainage Network

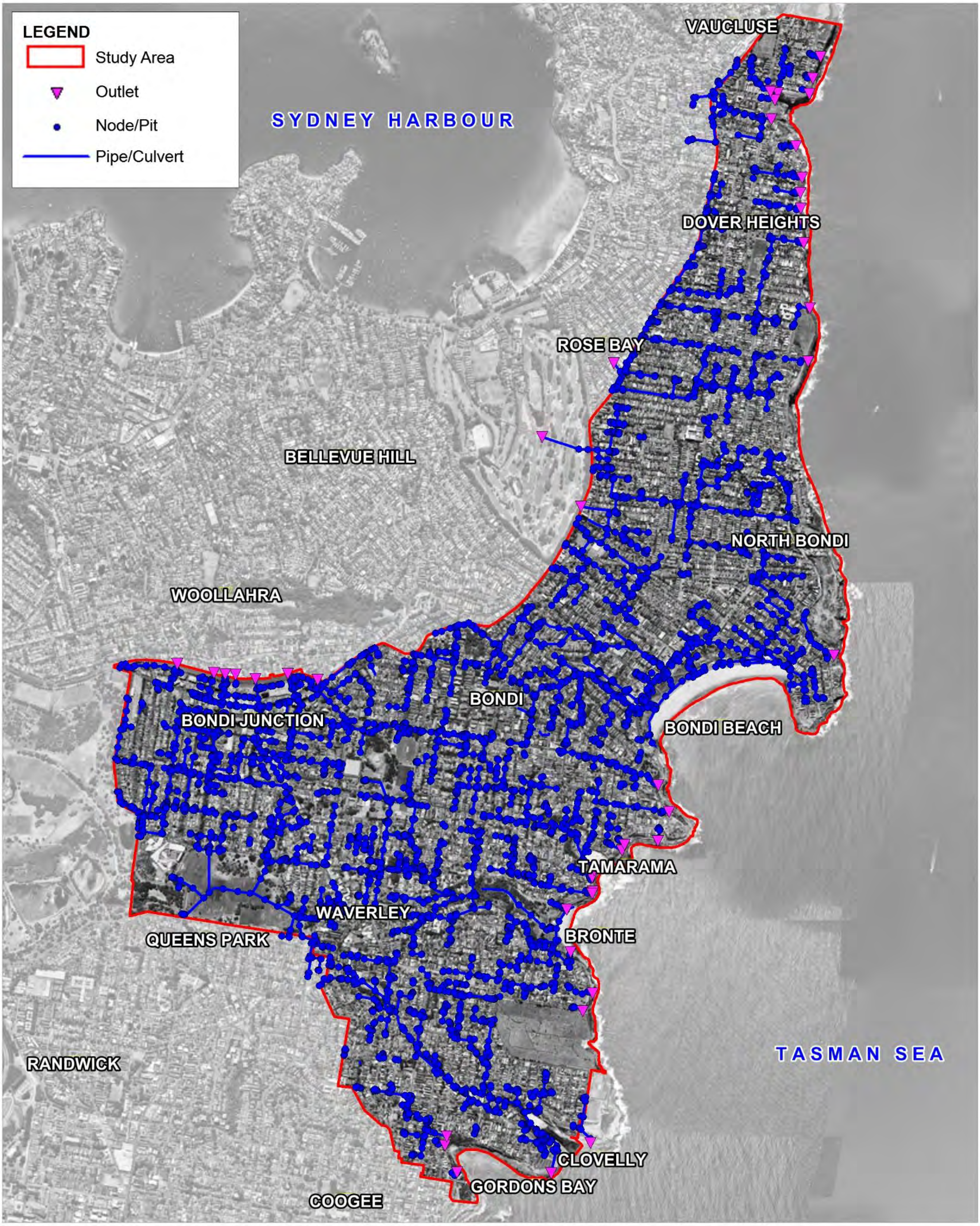
This study required the modelling of the stormwater drainage system across the catchment. Information on the pit and pipe drainage network has been compiled from a number of sources, as discussed previously in Section 2. Data comprising pit/pipe locations, pit inlet type/dimensions and pipe sizes was received in a number of formats including GIS layers and as survey data. These sources were used to build the necessary details of the stormwater pipe network into the TUFLOW model. Pipe size and invert levels were taken from the provided data where available. Where invert levels were not available, they were estimated from the DEM based on an assumed minimum cover of 600mm.

Table 4-2 provides a summary of the stormwater infrastructure. Figure 4-3 shows the modelled stormwater network.

Table 4-2 Summary of Modelled Stormwater Infrastructure Elements in Hydraulic Model

Stormwater Infrastructure Type	Number of Elements
Circular	4,940
Rectangular	278
TOTAL PIPES/CULVERTS	**5,218**
Pits	3,219
Nodes	1,992
Outlets/Headwalls	45
TOTAL NODES/PITS	**5,256**

The modelled pipe network, comprising approximately 5,200 pipes has a combined run length of over 101km, an example of which is shown in Figure 4-4. The figure shows the pipes invert and obvert levels relative to the ground surface level.



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Modelled Stormwater Network

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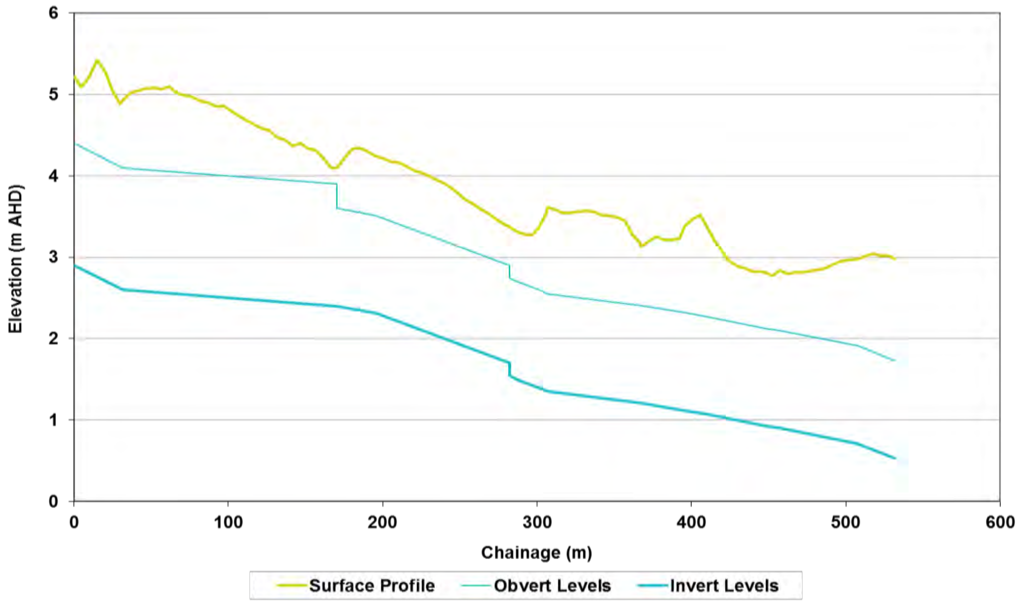


Figure 4-4 Example Drainage Line Long Section

The pipe network, represented as a 1D layer in the TUFLOW model, is dynamically linked to the 2D domain at specified pit locations, as illustrated in Figure 4-5.

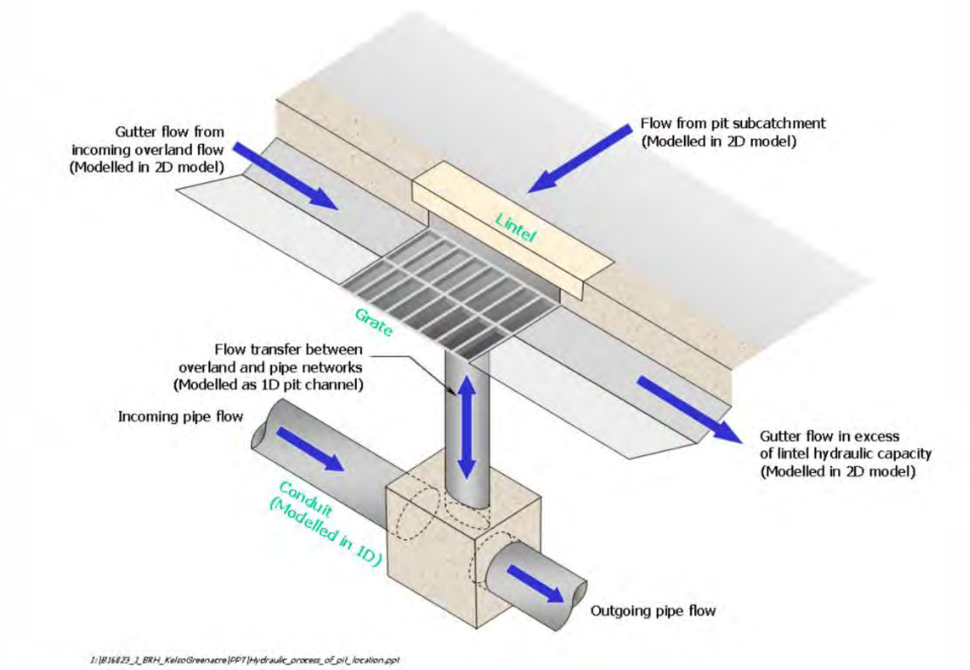


Figure 4-5 Linking Underground 1D Stormwater Drainage Network to the Overland 2D Domain

Pit inlet capacities have been modelled using lintel opening lengths and grate sizes based on the collected data. Pit inlet dimensions have been assumed where data were not available, based on site inspections and nearby pits. Pit inlet curves have been developed using an industry standard approach which rely on laboratory tests by the NSW Department of Main Roads and are considered sufficiently reliable for the purpose of this study.

For the magnitude of events under consideration in the study, the pipe drainage system capacity is anticipated to be exceeded with the major proportion of flow conveyed overland. Therefore, any limitations in the available pipe data or model representation of the drainage system is expected to have little effect on the reliability of the results.

4.3.6 Boundary Conditions

The catchment runoff is determined through the hydrologic model and is applied to the TUFLOW model as flow vs. time inputs (i.e. flow hydrograph). These are applied at the upstream modelled drainage limits and also as distributed inflows along the modelled drainage alignments. For most sub-catchments with modelled stormwater drainage, the hydrologic model inflows are applied directly to the 1D pipe network and will surcharge to the 2D surface representation when pipe full capacity is exceeded. This assumes that there is sufficient pit capture within the drainage design to reach pipe full capacity, which is typically the case. For sub-catchment areas containing no stormwater drainage, the catchment runoff is applied directly to the 2D domain, being distributed to the corresponding flow path or storage area.

The downstream model limit corresponds to the water level in either Sydney Harbour or the South Tasman Sea. Both of these water bodies are tidal boundaries. The adopted water levels for the calibration and design events are discussed in Section 5 and Section 6, respectively.

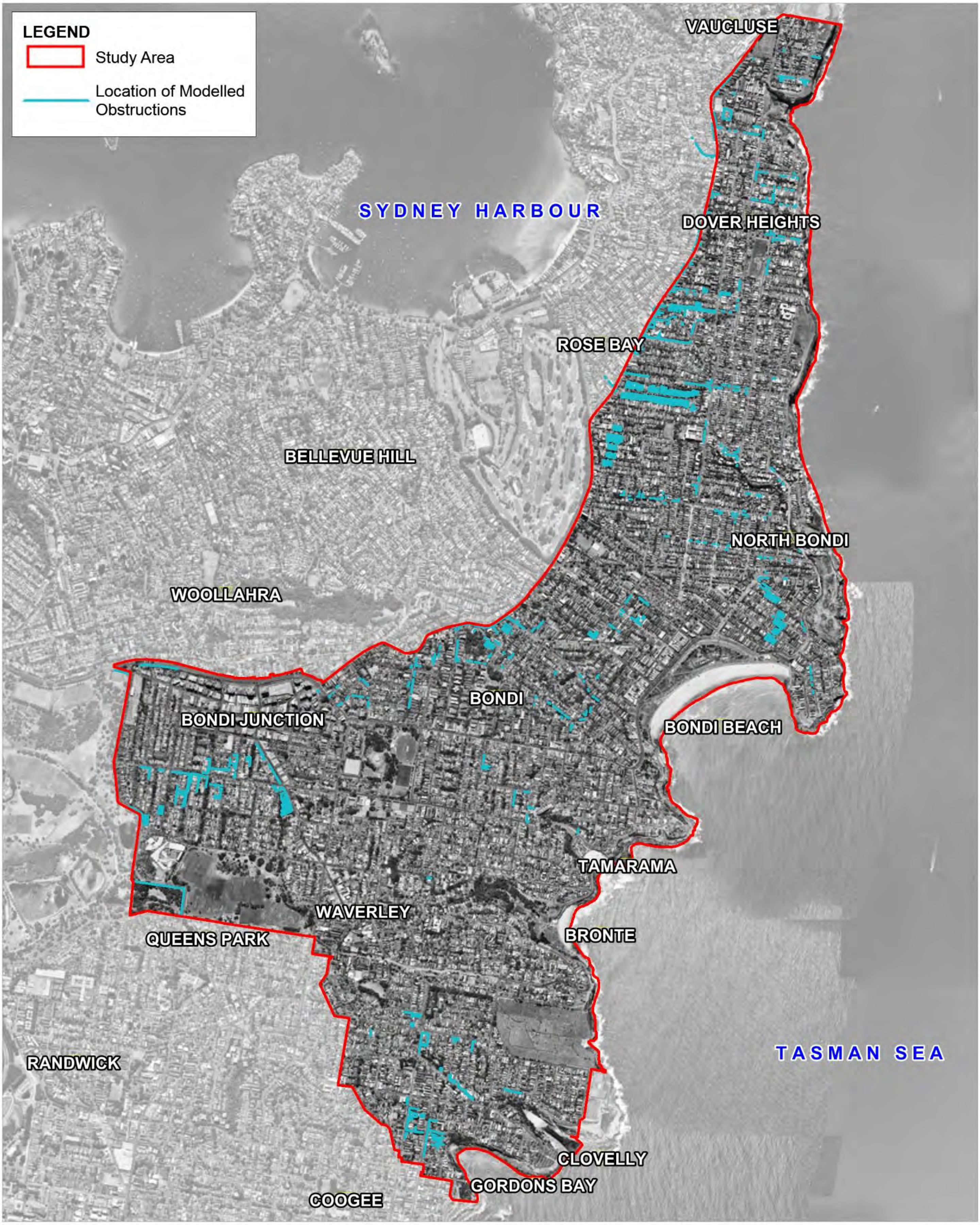
4.3.7 Major Flow Path Representation

The adopted modelling approach serves to model major overland flow paths within the Waverley LGA catchments and ensures reliable representation of the complex nature of hydraulic controls typical of the urban flood environment.

The process for model development along the overland flow paths was to assess preliminary model outputs in the context of urban features that may influence or control the progression of flooding as it moves downstream from the elevated areas of the upper catchment. The LiDAR elevation data typically provides a reasonable representation of the natural gully lines and their associated floodplains. However, local controls such as buildings, walls, gates and alleys can serve to alter the course of the natural catchment runoff. This can exacerbate flooding in some locations or even divert the preferred flood flow path to an alternative alignment.

Each modelled flow path has been verified based on LiDAR elevation data, site visit notes, aerial photography and Google Street View imagery to incorporate local hydraulic controls into the TUFLOW model, where appropriate. This involved the inclusion of brick and/or concrete walls as barriers to the progression of catchment runoff. Other obstructions less sturdy in nature (such as wooden or Colorbond fences) have not been incorporated, as they typically fail when floodwaters build on the upstream side.

The distribution of the hydraulic controls developed for the TUFLOW model along the major flow path alignments is presented in Figure 4-6.



Title:
Distribution of Modelled Hydraulic Controls

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5 Model Calibration and Validation

5.1 Selection of Calibration and Validation Events

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

Through consultation with Council, a set of flood events were identified as being suitable for use in the model calibration and validation process for this study. These are events of a reasonable flood magnitude, for which there are observed flood data available for comparison with the model performance. The principal event selected for model calibration is the December 2015 event, as this is the flood event with the most intense rainfall in recent years. There is also a reasonable amount of observed flood data collected by Council Staff following the event and provided during the community consultation for this study.

The August 2015 and February 2017 flood events have been selected for model validation. These events were identified as significant flood events from Council correspondence, photos, reports and the community consultation process, resulting in a reasonable amount of observed flood data available for use in model validation.

5.2 December 2015 Model Calibration

5.2.1 Calibration Data

5.2.1.1 Rainfall Data

Short duration, intense rainfall often has high spatial variability and it can be difficult to determine a reliable estimate of rainfall variability for a study area. However, two gauges are situated within the Waverley LGA and several other gauges are located within the wider study region. These rain gauges have been analysed to estimate the likely range of rainfall intensities experienced within the study catchment.

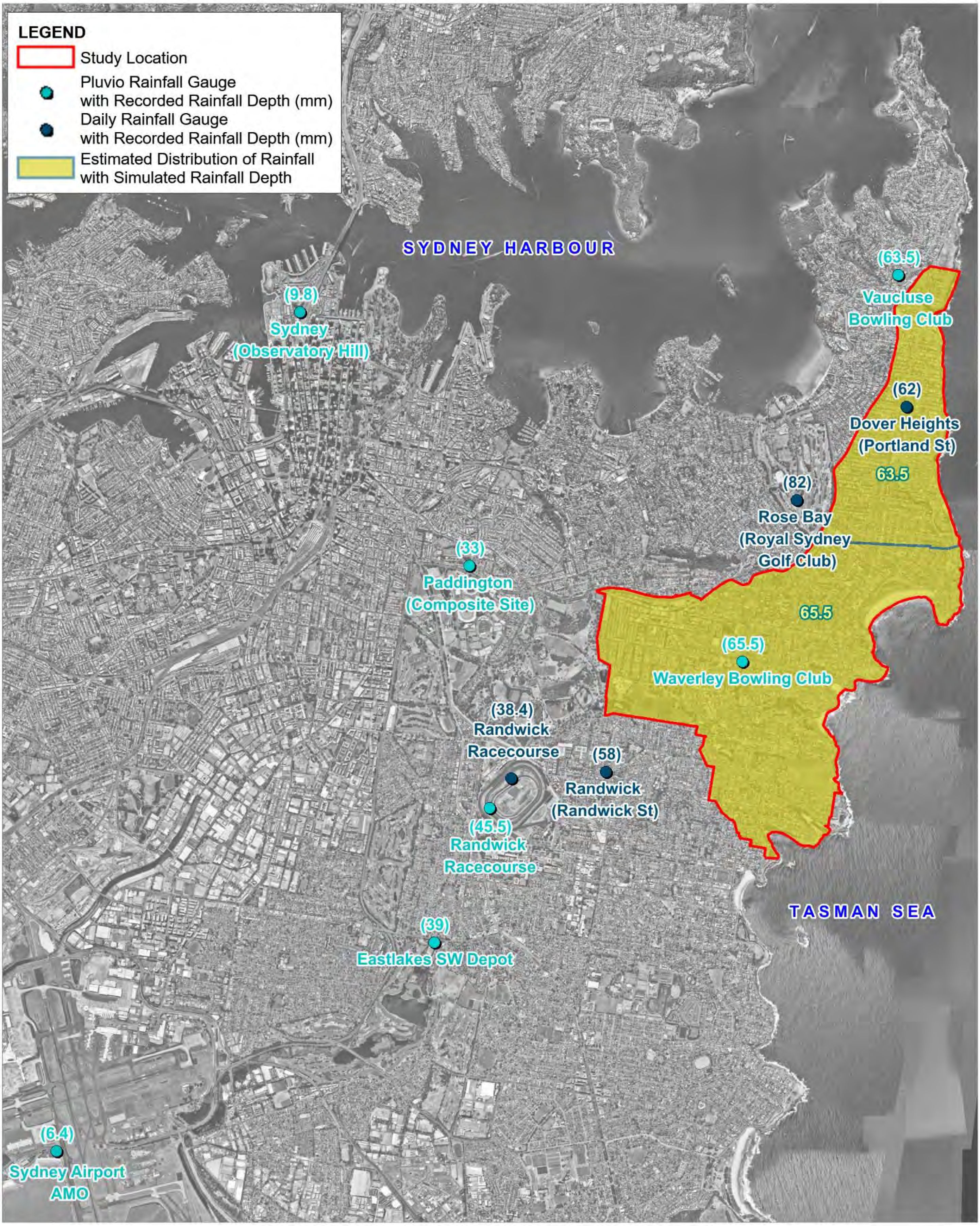
Seven pluvio gauges and four daily rainfall gauges have been considered in this analysis, as summarised in Table 5-1 and with gauge locations shown in Figure 5-1. Rainfall totals have been determined over the 24-hour period from 09:00 on 16 December 2015.

Analysis of the rainfall gauges (daily and pluvio) in the immediate vicinity of the study area show that rainfall totals range from 33mm to 82mm (refer Figure 5-1). The two nearest pluvio rainfall gauges are the Waverley Bowling Club (566114) and Vaucluse Bowling Club (566038) which recorded rainfall depths of 65.5mm and 63.5mm, respectively, showing little variability. Rose Bay (Royal Sydney Golf Club) (66098) and Sydney Airport AMO (66037) provided the highest (82mm) and lowest (6.4mm) recorded daily rainfall totals in the vicinity of the study area and show the potential range of rainfall conditions experienced across the eastern Sydney region.

Table 5-1 December 2015 Event Recorded Daily Rainfall Total

Gauge Station No.	Gauge Type	Location	Approximate Locality from the Centre of Study Area (km)	Daily Rainfall Total (mm)
566114	Pluvio	Waverley Bowling Club	1.7 SW	65.5
566038	Pluvio	Vaucluse Bowling Club	3.3 N	63.5
566032	Pluvio	Paddington (Composite Site)	4.4 W	33
566099	Pluvio	Randwick Racecourse	5 SW	45.5
566028	Pluvio	Eastlakes SW Depot	6.5 SW	39
66062	Pluvio	Sydney (Observatory Hill)	7 NW	9.8
66037	Pluvio	Sydney Airport AMO	11.3 SW	6.4
66052	Daily	Randwick (Randwick St)	3.7 SW	58
66098	Daily	Rose Bay (Royal Sydney Golf Club)	1 NW	82
66073	Daily	Randwick Racecourse	4.6 SW	38.4
66209	Daily	Dover Heights (Portland St)	1.8 N	62

Figure 5-2 shows the recorded rainfall hyetographs for four of the pluvio gauges listed in Table 5-1 that are closest to the study area. The hyetograph includes two short bursts of rainfall, the first less intense burst occurred between 10:30 and 11:00, followed by another short burst of heavy rainfall occurring over a 1.5 hour period from approximately 12:30 to 14:00. The most intense rainfall was recorded at the Waverley Bowling Club gauge (566114) between 12:30 and 13:30 on 16 December 2015.



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Daily Rainfall Totals December 2015 Event

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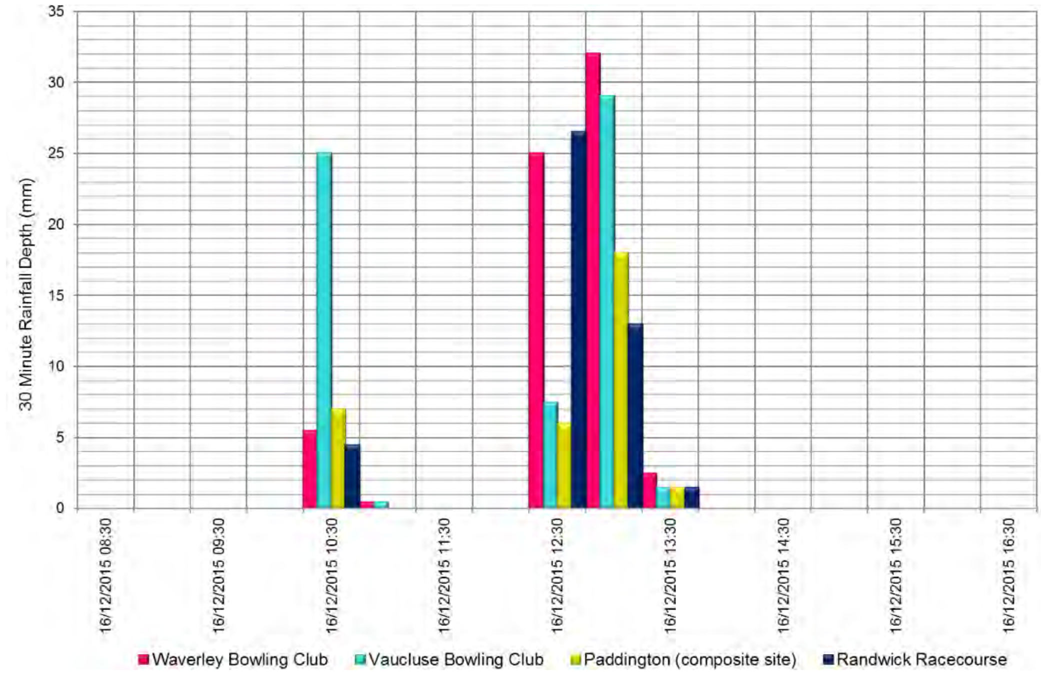


Figure 5-2 Rainfall Hyetograph – December 2015 Rainfall

In order to gain an appreciation of the relative intensity and magnitude of the December 2015 event, the recorded rainfall depth for various durations within the storm was compared with design IFD rainfall curves. Design IFD rainfall curves were obtained from BoM and are representative of the recent revisions following the release of AR&R 2016. Figure 5-3 presents a comparison of the recorded December 2015 rainfall intensities against the 2016 IFD.

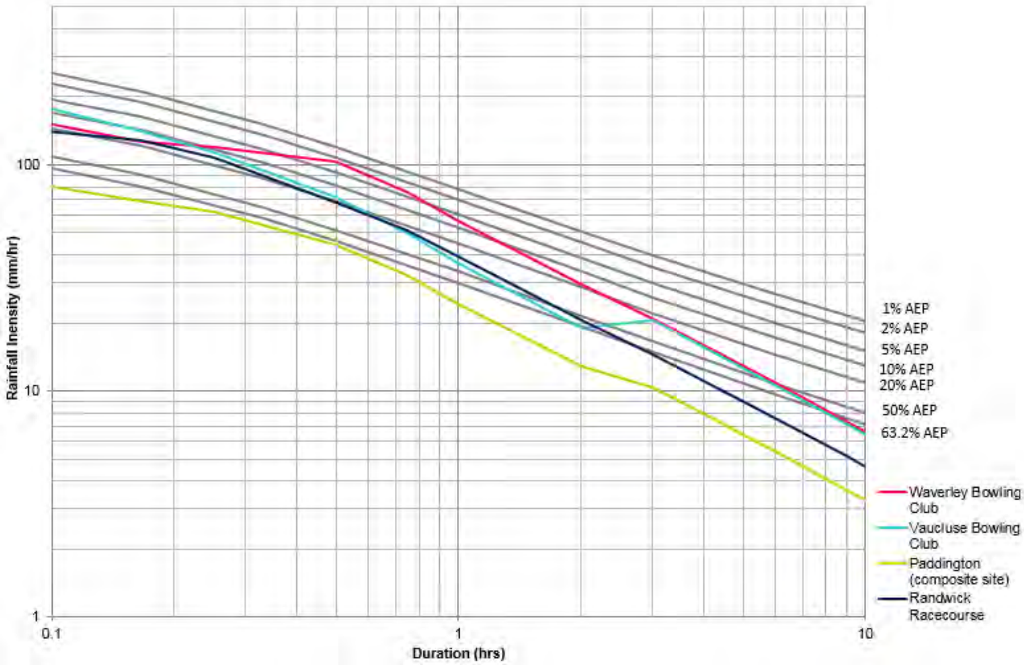


Figure 5-3 Comparison of Recorded December 2015 Rainfall with IFD Relationships

The recorded rainfall at the Waverley Bowling Club gauge is estimated to be in the order of between a 5% and 2% AEP design intensity for durations between 0.3 to 0.8 hours. The recorded rainfall at the Vaucluse Bowling Club is between a 20% and 10% AEP design intensity for durations less than 1 hour. Rainfall recorded at the Paddington gauge is less than the 63.2% AEP for all durations, and rainfall recorded at the Randwick Racecourse gauge is typically is at the 20% AEP design intensity for durations less than 1 hour.

The Waverley Bowling Club (566114) and Vaucluse Bowling Club (566038) gauges are considered to be the most suitable to define the catchment rainfall in the TUFLOW model, noting the relatively uniform spatial variability across the catchment for the December 2015 event.

5.2.1.2 Downstream Boundary Condition

In most instances, the tidal water level conditions will not be critical in determining overland flood levels in the local catchment. However, for completeness, the available recorded water level conditions at Sydney Live (213470) have been used to represent the tidal conditions within the model. Figure 5-4 shows the tidal levels applied to represent the oceanic conditions which peak at 1.7m (Zero Fort Denison Datum) at approximately 11:30 on 16 December 2015.

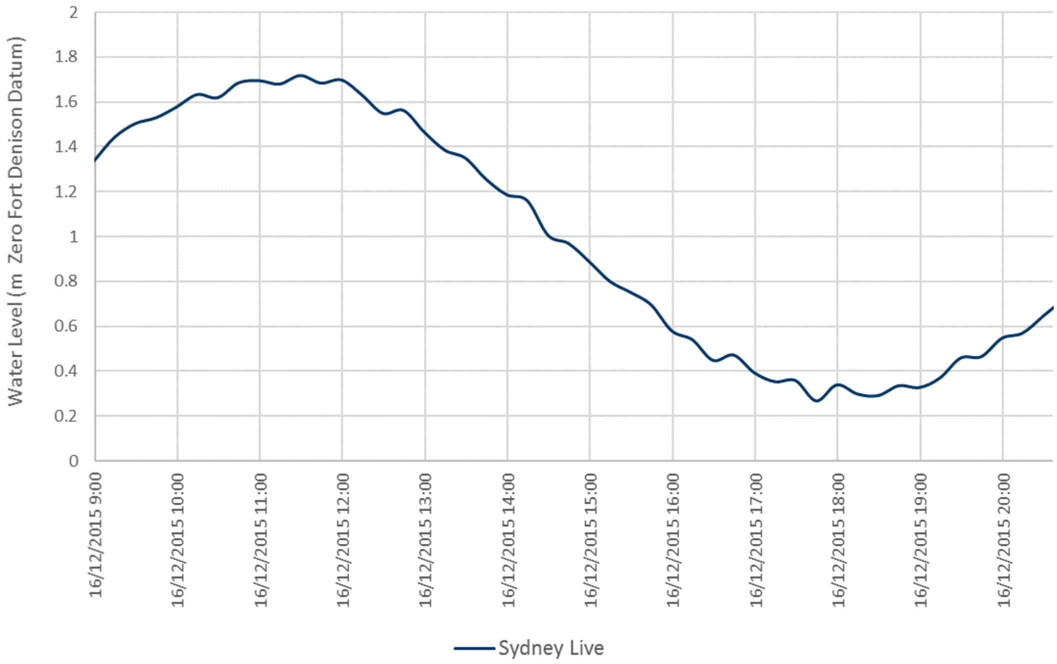


Figure 5-4 Recorded Water Level – December 2015

5.2.2 Adopted Model Parameters

The model parameters originally adopted (refer Section 4) were shown to provide a reasonable calibration to observed data and were not modified. Modifications to the model through the calibration process were restricted to the rainfall loss parameters, as discussed in the following section.

5.2.2.1 Rainfall Losses

The initial loss-continuing loss model has been adopted in the XP-RAFTS model developed for the Waverley LGA catchments. The initial loss component represents a depth of rainfall effectively lost from the system and not contributing to runoff and simulates the wetting of the catchment to a saturated condition. The continuing loss represents the rainfall lost through soil infiltration once the catchment is saturated and is applied as a constant rate (mm/hr) for the duration of the runoff event.

"Probability Neutral Burst Initial Loss" rates for the Waverley LGA catchments, accessed from the AR&R datahub (*data.arr-software.org*) estimate the initial loss and continuing loss rates for Waverley LGA ranging from 6.4 to 29.6mm (refer Appendix D) and 0.4mm/hr respectively. However, given the nature of the underlying sandy soils, these values could be much greater. The Coogee Bay Flood Study (BMT WBM, 2013) was completed for a neighbouring catchment and adopted much higher initial and continuing loss rates of 50mm and 5mm/hr, respectively, for pervious surfaces and 5mm and 0mm/hr for impervious surfaces. Furthermore, the previous drainage investigation within the Waverley LGA adopted high storage losses (refer Section 2.2.2.1), sandy soils (Type 1) and dry catchment conditions (AMC of 1). The wide variance in rainfall loss parameters across several adjoining catchments are summarised in Table 5-2 below.

Table 5-2 Adopted Rainfall Loss Parameters (Waverley LGA and Adjoining Catchments)

Catchment	Initial-Continuing Loss Parameters				ILSAX parameters			
	Pervious IL (mm)	Impervious IL (mm)	Pervious CL (mm/hr)	Impervious CL (mm/hr)	Soil Type	AMC	Pervious Storage Loss (mm)	Impervious Storage Loss (mm)
Coogee Bay	50	5	5	0	-	-	-	-
Rose Bay	-	-	-	-	3	3	n/a	n/a
Double Bay	-	-	-	-	3	3	n/a	n/a
Kensington – Centennial Park	-	-	-	-	3	3	5	1
Waverley					1	1	20	2

Given the availability of flood estimates taken at several flood storage areas including at Wallis Parade, Warners Avenue and Simpson Street, it was possible to assess the likely losses for the catchment. Being a flood storage area, the peak water level at these locations are predominantly driven by the volume of runoff generated during an event.

Modelled flood levels at Wallis Parade and Warner Street for the December 2015 event and the validation events were used to iteratively determine appropriate initial and continuing loss parameters. These were found to be 20mm and 2mm/hr for pervious areas and 2mm and 0mm/hr for impervious areas. These values are representative of the whole catchment but may vary locally.

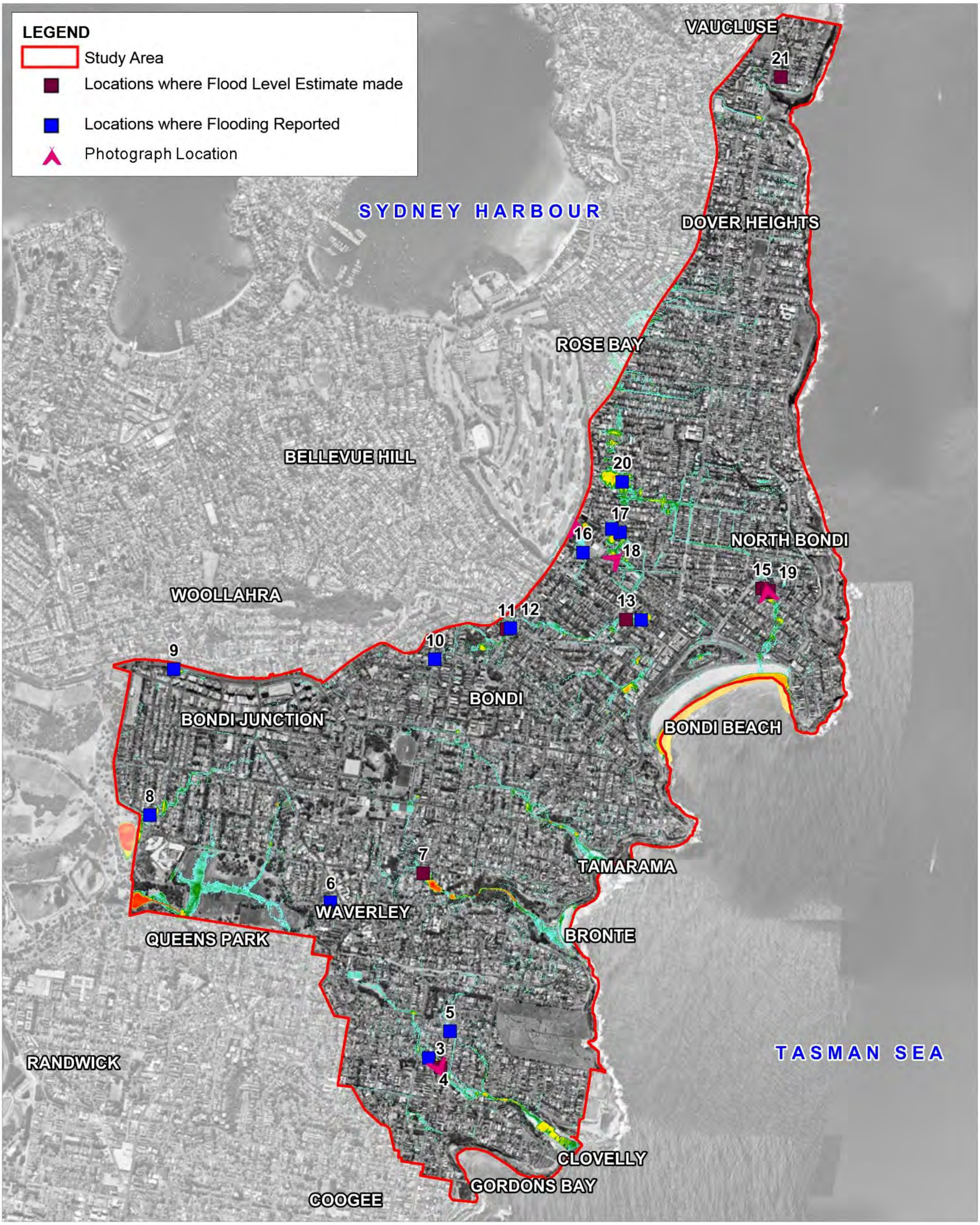
Noting the variance in catchment loss rates of the surrounding catchments, sensitivity testing was undertaken on the 1% AEP design storm to determine the sensitivity of the modelling results to increased and decreased initial and continuing loss rates. It was generally found that the initial and continuing loss rates had limited influence on catchment conditions, and therefore the comparative lower loss rates of 20mm and 2mm/hr, respectively, for pervious areas and 2mm and 0mm/hr, respectively, for impervious areas was deemed appropriate for the Waverley LGA catchments and adopted for the design flood modelling.

5.2.3 Flood Level Data

There are no stream gauges situated within the catchment to provide recorded water levels for the event. Therefore, flood level data is limited to anecdotal flood information, observations of the main flow path alignments and peak flood level estimates based on observed flood marks.

Anecdotal flood data for the December 2015 event was obtained through correspondence, reports and photos provided by Council, as well as the community questionnaire responses (refer Section 3). Most of this data does not provide definitive flood levels, but rather indicative depths of flooding and observations of flow paths and inundation. The observations are useful to confirm the locations of significant modelled flow paths and depth of flooding to provide some confidence in the model representation of the observed flow condition. For some locations, the available description of flooding combined with LiDAR elevations enabled the determination of approximate flood levels.

The distribution of observed flood data for the December 2015 event is discussed further in Section 5.2.5 and presented in Figure 5-5.



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Distribution of Observed Flood Data Available for the December 2015 Event

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5.2.4 Flood Photographs

Photographs depicting significant flooding as shown in Figure 5-6, and those that depict high water marks, such as those shown in Figure 5-7, Figure 5-8 and Figure 5-9, were used to confirm predicted flood behaviour, as discussed in Section 5.2.5.

Figure 5-6 Burnie Park, Clovelly - December 2015 Calibration Event

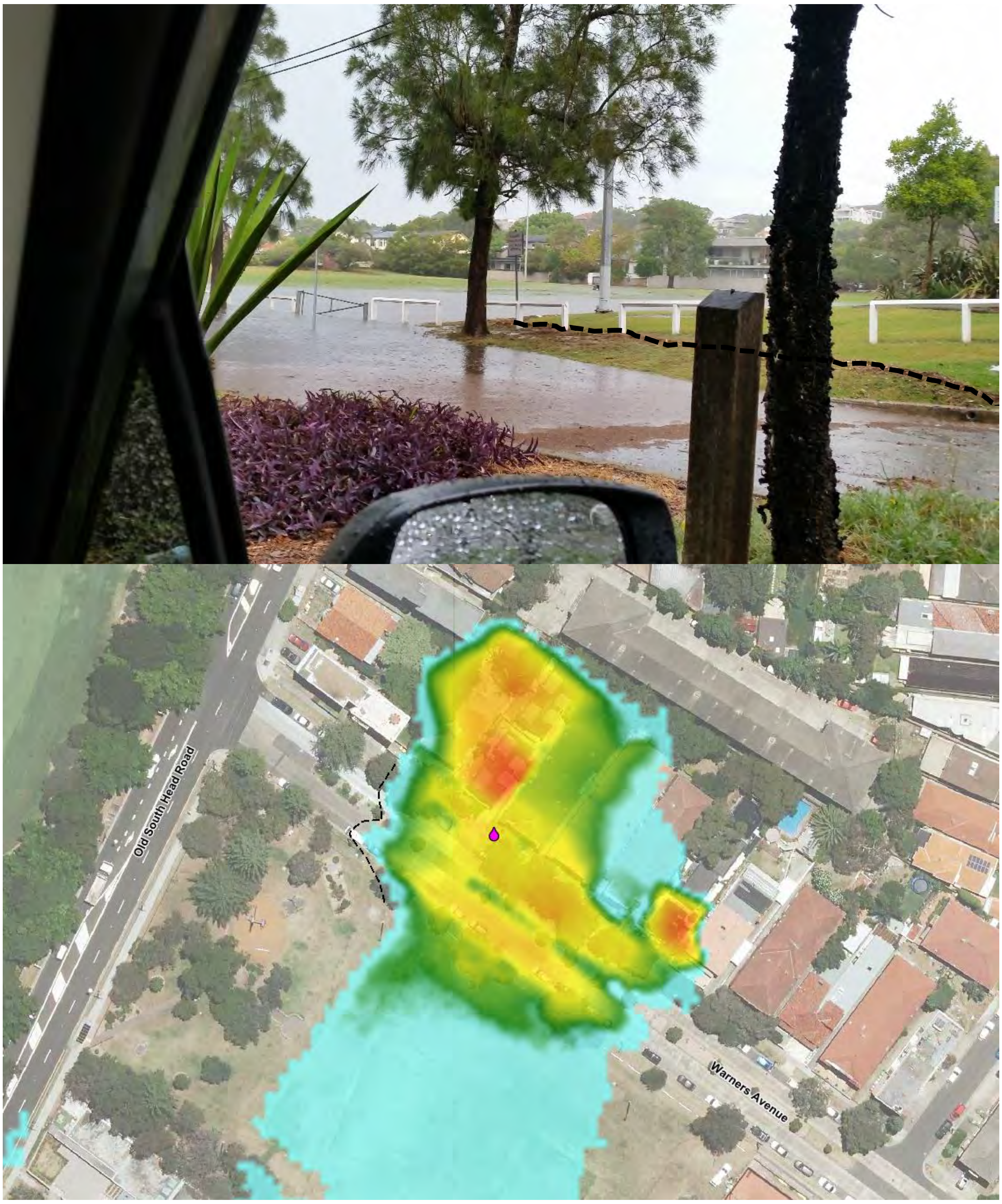


Figure 5-7 High Water Mark Vs. Modelled December 2015 Calibration Event - Warners Avenue, North Bondi

Figure 5-8 High Water Mark - Wallis Parade, North Bondi

Figure 5-9 High Water Mark - Warners Avenue, North Bondi

5.2.5 Observed and Simulated Flood Behaviour

Table 5-3 provides simulated flood inundation depths for the calibration event and comparison with the community's flooding observations. In general, it can be seen that there is a good correlation between the locations at which significant flooding was observed and the alignment of the major flow paths from the TUFLOW model results. The community flooding observations have been classified into three categories: locations where general flooding was reported; locations where flood depths were reported; and locations where flood photographs were taken.

For locations where some form of flood level estimation was possible, a comparison between observed and modelled flood levels are presented in Table 5-3. It can be seen from Table 5-3 that where reasonable estimates of the peak flood level can be made from the observed data, the modelled flood level is typically within 0.1m of this estimate. This indicates that the model generally provides a reasonable representation of the flood behaviour at these locations considering the relative bounds of uncertainty.

Table 5-3 Comparison of Observed and Modelled December 2015 Flood Levels

Reference Location (refer Figure 5-5)	Location and/or Observed Flood Depth	Estimated Flood Level from Observed Depth (m AHD)	Modelled December 2015 Level (m AHD)	Difference in Flood Levels (m)
3	Burnie Street, Clovelly 0.5-0.75m in front yard	32.95-33.2	33.2	0.0
7	Palmerstone Avenue, Bronte 1m ground floor and yard	42.0	42.0	0.0
13	Curlewis Street, Bondi Beach 1m in Car Basement	15.6	15.6	0.0
15	Wallis Parade, North Bondi 0.3m estimate	16.6	16.7	+0.1
19	Wallis Parade, North Bondi Flood level estimate based off Figure 5-8	16.6	16.7	+0.1
21	Macdonald Street, Vaucluse 0.1m in front yard	61.3	61.3	0.0

5.3 August 2015 Model Validation

5.3.1 Validation Data

5.3.1.1 Rainfall Data

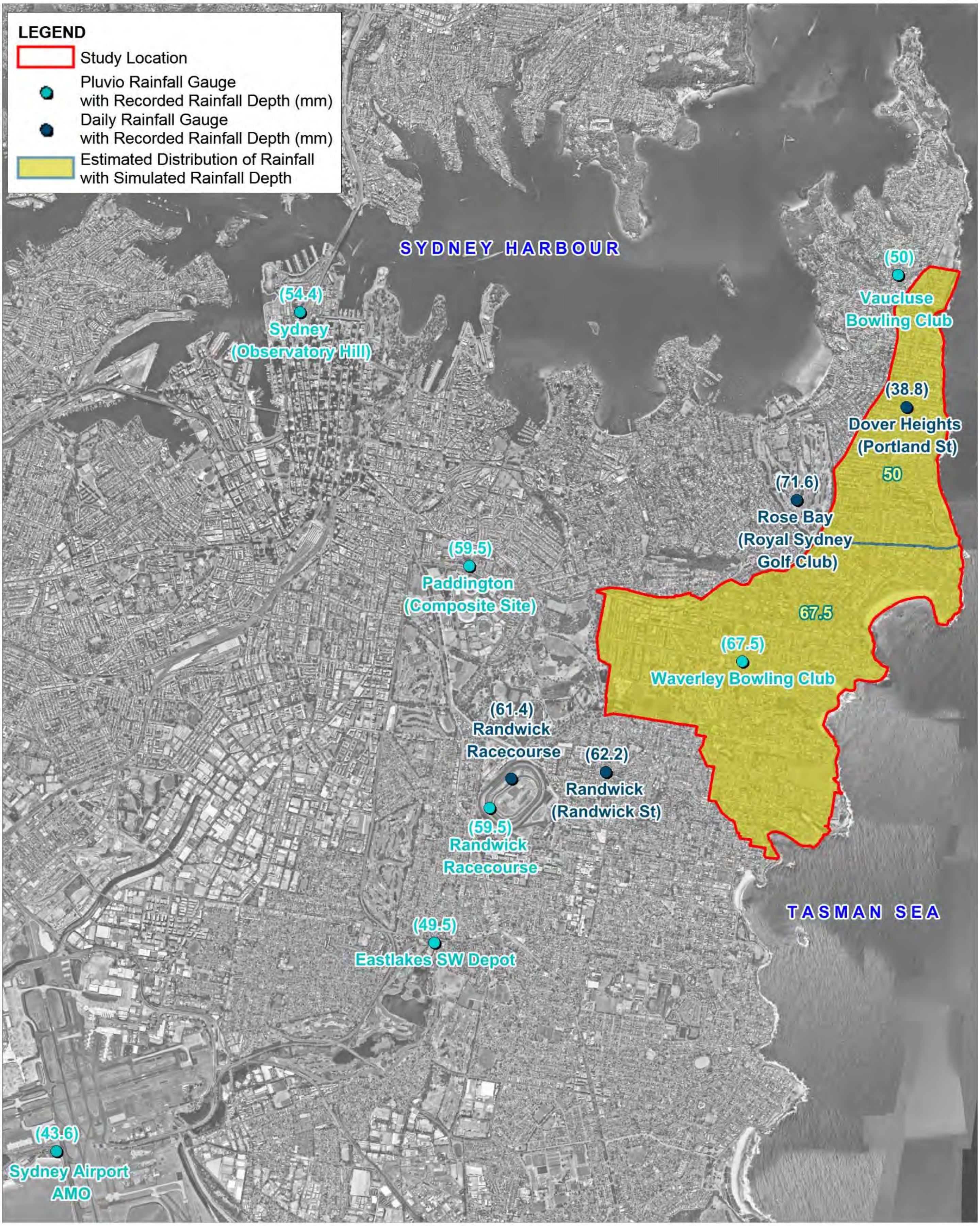
Two gauges situated within the study area and a number of gauges within the wider region have been analysed to estimate the likely range of rainfall intensities experienced within the study area catchment.

Seven pluvio gauges and four daily rainfall gauges have been considered in this analysis, as summarised in Table 5 1 and with gauge locations shown in Figure 5 1. Rainfall totals have been summed over the 24-hour period from 09:00 on 24 August 2015.

Table 5-4 August 2015 Event Recorded Daily Rainfall Total

Gauge Station No.	Gauge Type	Location	Approximate Locality from the Centre of Study Area (km)	Daily Rainfall Total (mm)
566114	Pluvio	Waverley Bowling Club	1.7 SW	67.5
566038	Pluvio	Vaucluse Bowling Club	3.3 N	50
566032	Pluvio	Paddington (Composite Site)	4.4 W	59.5
566099	Pluvio	Randwick Racecourse	5 SW	59.5
566028	Pluvio	Eastlakes SW Depot	6.5 SW	49.5
66062	Pluvio	Sydney (Observatory Hill)	7 NW	54.4
66037	Pluvio	Sydney Airport AMO	11.3 SW	43.6
66052	Daily	Randwick (Randwick St)	3.7 SW	62.2
66098	Daily	Rose Bay (Royal Sydney Golf Club)	1 NW	71.6
66073	Daily	Randwick Racecourse	4.6 SW	61.4
66209	Daily	Dover Heights (Portland St)	1.8 N	38.8

Analysis of the rainfall gauges (daily and pluvio) in the immediate vicinity of the study area show recorded rainfall totals range from 50mm to 71.6mm (refer Figure 5-10). The Rose Bay (Royal Sydney Golf Club) daily gauge (66098) recorded the highest daily total of 71.6mm. The lowest daily total was recorded at the Dover Heights (Portland St) daily gauge (68241) with a rainfall depth of 38.8mm.



Title:
Daily Rainfall Totals August 2015 Event

Figure: 5-10

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Figure 5-11 contains the recorded rainfall hyetographs for four of the pluvio gauges listed previously in Table 5-4 that are closest to the study area. The hyetograph includes three consecutive short bursts of rainfall increasing in magnitude. The period of heavy rainfall starts at 13:00 and concludes at 23:00, with a 1.5 hour break between the first and second burst, and about an hour break between the second and third burst. Each pluvio gauge indicated similar depths during each burst (5mm, 10mm, 25mm) however the most intense bursts from each gauge are spaced approximately half an hour apart. The most intense burst of rainfall recorded at the Waverley Bowling Club gauge (566114) occurred over a 1-hour period beginning at 21:00 on 26 August 2015.

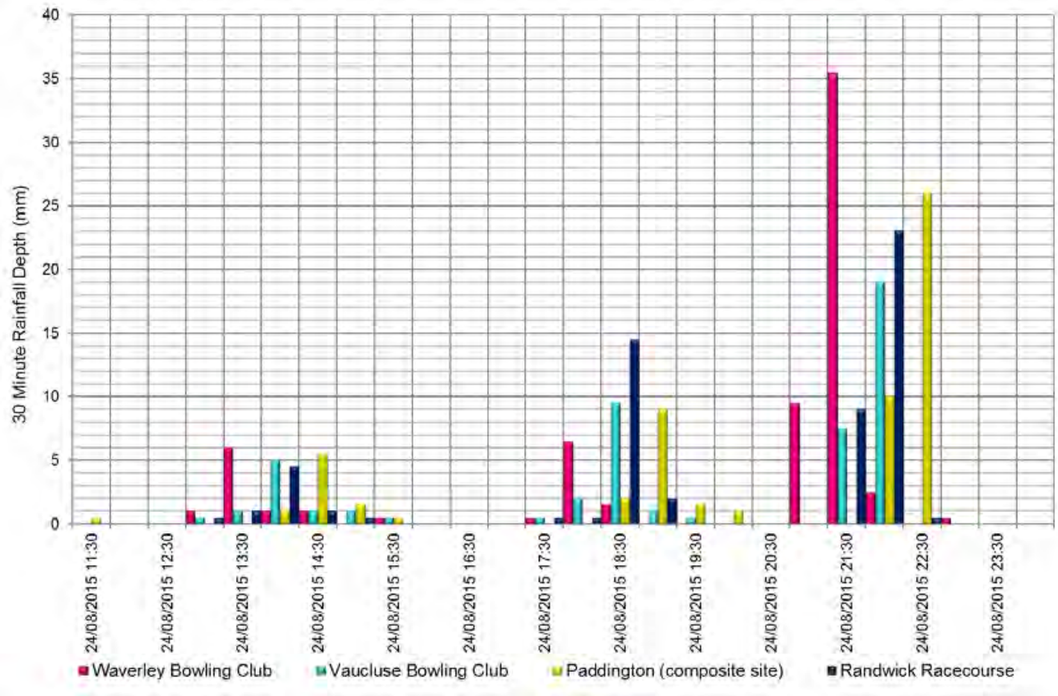


Figure 5-11 Rainfall Hyetograph – August 2015 Rainfall

In order to gain an appreciation of the relative intensity and magnitude of the August 2015 event, the recorded rainfall depth at the four pluvio gauges for various durations within the storm is compared with design IFD rainfall curves obtained from AR&R 2016. Figure 5-12 presents a comparison of the recorded August 2015 rainfall intensities against the 2016 IFD.

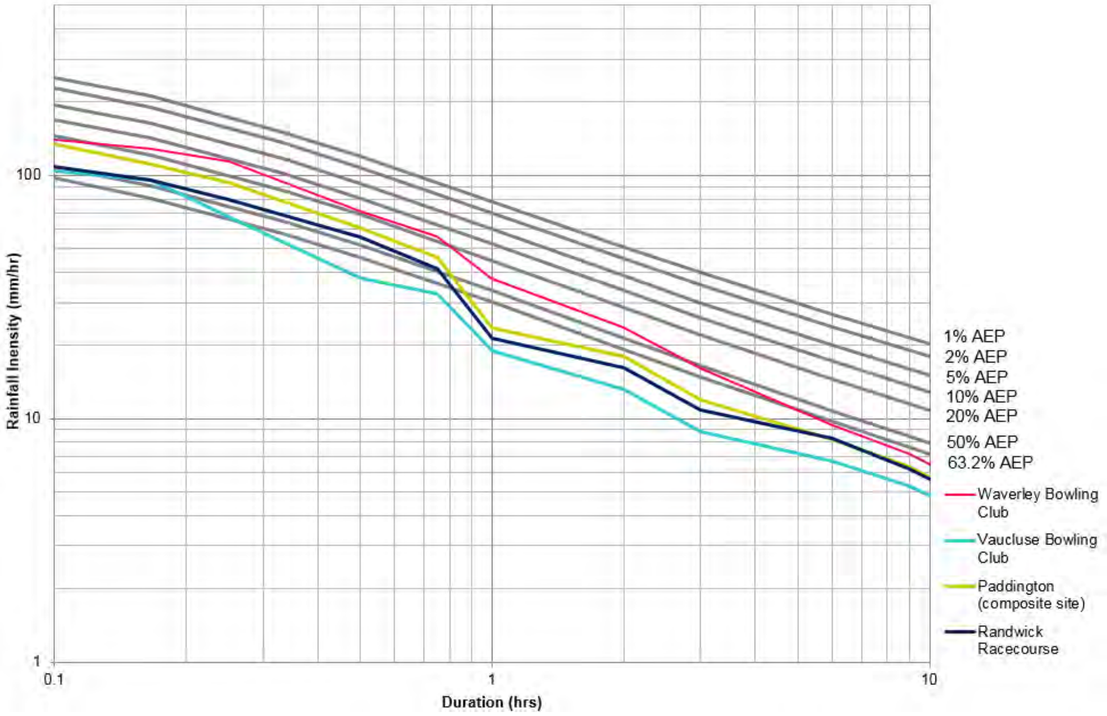


Figure 5-12 Comparison of Recorded August 2015 Rainfall with IFD Relationship

The recorded rainfall at the Waverley Bowling Club gauge (566114) is between the 20% AEP and 10% AEP for rainfall durations less 1 hour. All other pluvio gauges recorded rainfall intensities less than a 20% AEP event.

The Waverley Bowling Club gauge (566114) and Vaucluse Bowling Club gauge (566038) are considered to be the most suitable to define the catchment rainfall in the TUFLOW model given their relative proximity to the study area. The southern portion of the Waverley LGA was simulated using the recorded data from the Waverley Bowling Club gauge.

Noting the spatial variability of rainfall totals in the northern portion of the Waverley LGA, ranging from 38.8mm at the Dover Heights (Portland Street) gauge to 71.6mm at the Rose Bay (Royal Sydney Golf Club) gauge, the northern catchments were simulated using the recorded data from the Vaucluse Bowling Club gauge.

5.3.1.2 Downstream Boundary Condition

Recorded water level conditions at Sydney Live (213470) have been used to represent the tidal conditions within the model. Figure 5-13 shows the tidal levels applied to represent the oceanic conditions which peak at 1.4m (Zero Fort Denison Datum) at approximately 15:30 on 24 August 2015.

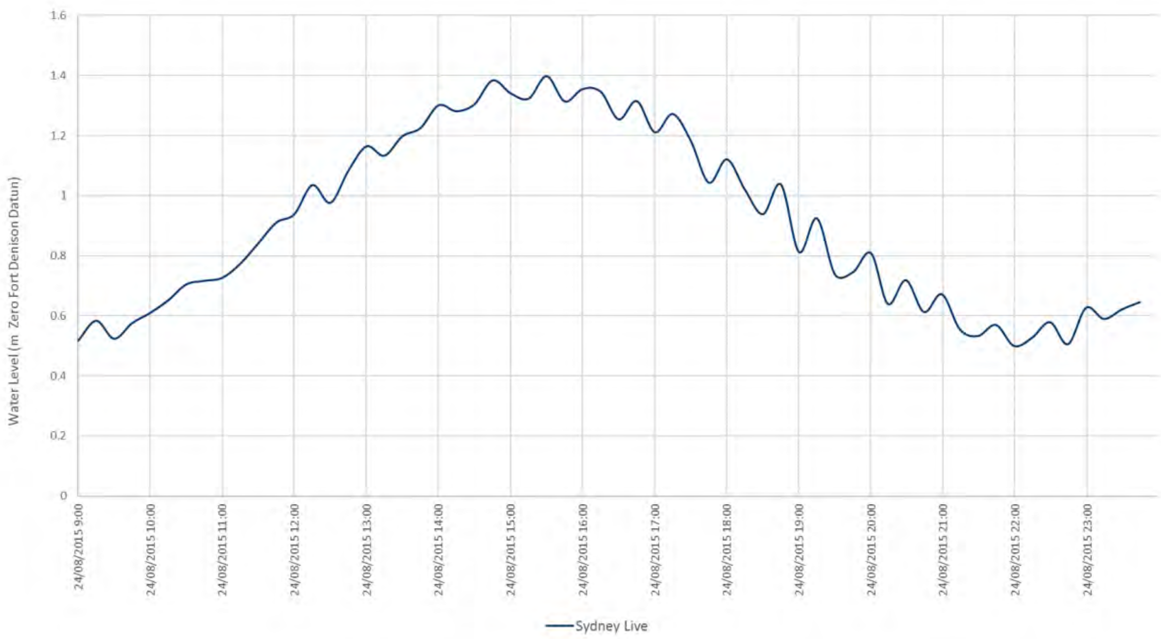


Figure 5-13 Recorded Water Level – August 2015

5.3.1.3 Flood Level Data

As noted for the December 2015 event, there are no stream gauges situated within the catchment to provide recorded water levels for the event. Data is limited to anecdotal flood data and observations of the main flow path alignments and peak flood level estimates based on flood marks.

Anecdotal flood data for the August 2015 event was obtained through correspondence, reports and photos provided by Council, as well as the community questionnaire responses (refer Section 3). Most of this data does not provide definitive flood levels, but rather indicative depths of flooding and observations of flow paths and inundation. The observations are useful to confirm the locations of significant overland flow paths and floodwater depths to provide some confidence in the model representation of observed conditions. For some locations, the available description of flooding combined with LiDAR elevations enabled the determination of approximate flood levels. The distribution of observed flood data for the August 2015 event compiled from Council data and community consultation feedback is discussed further in Section 5.3.2 and presented in Figure 5-16.

5.3.1.4 Flood Photographs

Historic flood photographs depicting flood levels during the August 2015 event are presented in Figure 5-14 and Figure 5-15. Figure 5-14 shows a water mark of approximately 550mm depth along a retaining wall at Simpson Street, Bondi. Figure 5-15 depicts flooding in a residence on Palmerston Avenue (Bronte) and indicates the height of the steps that were overtopped by the floodwaters. Flood level indicators from these figures were used to confirm modelled flood behaviour, as discussed in Section 5.3.2.

Figure 5-14 Simpson Street, Bondi

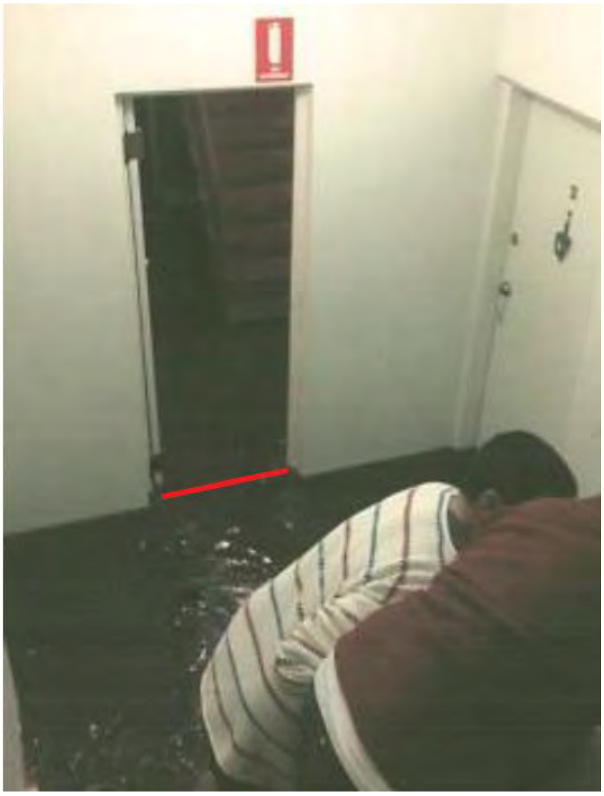


Figure 5-15 Palmerston Avenue, Bronte

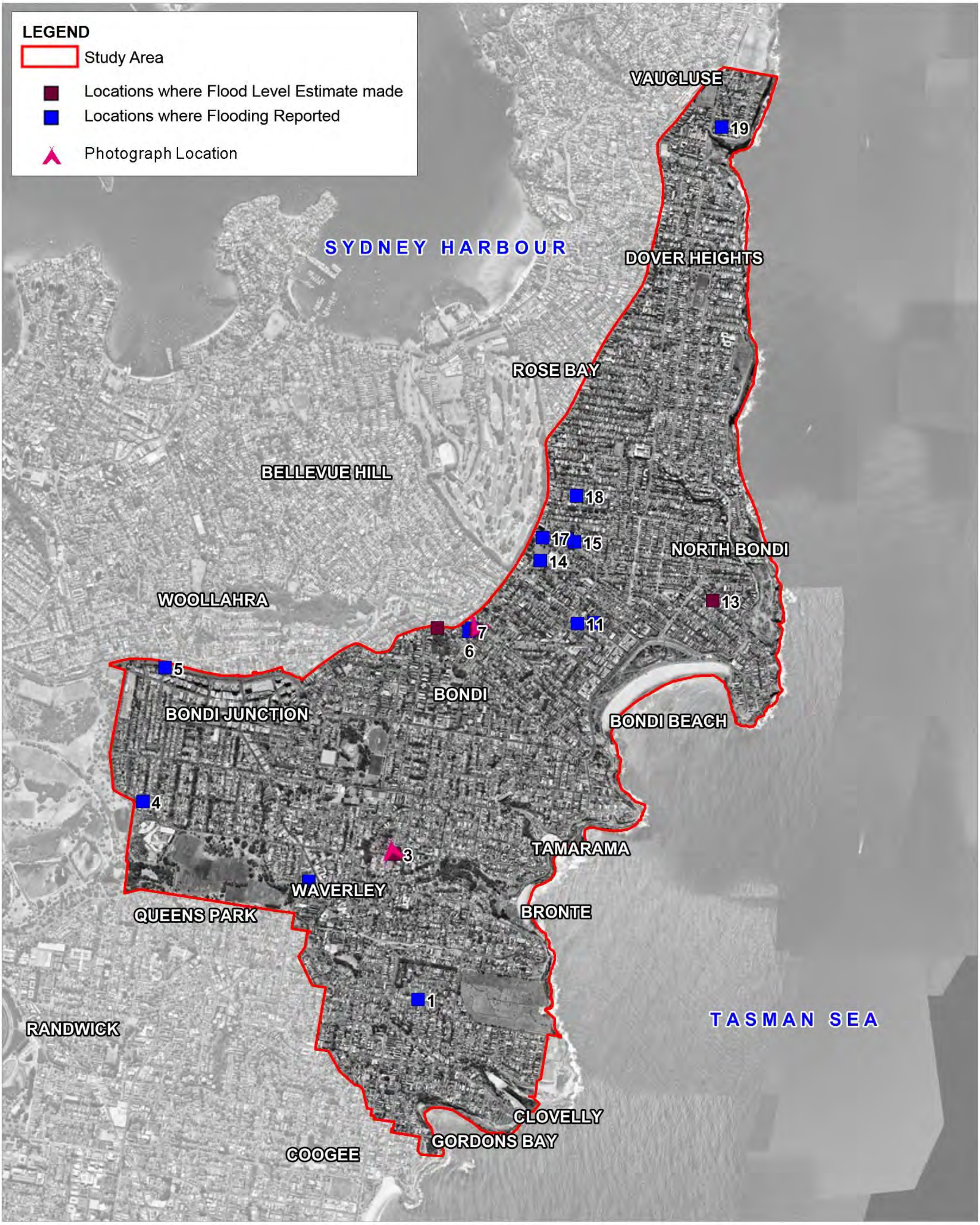
5.3.2 Observed and Simulated Flood Behaviour

Table 5-5 provides simulated flood inundation depths for the calibration event and comparison with the community's flooding observations. In general, it can be seen that there is a correlation between the locations at which significant flooding was observed and the alignment of the major overland flow paths in the TUFLOW model results. The community flooding observations have been classified into two categories: locations where general flooding was reported; and locations where flood depths were reported, as shown in Figure 5-16.

For locations where some form of flood level estimation was possible, a comparison between observed and modelled flood levels is presented in Table 5-5. It can be seen from Table 5-5 that where reasonable estimates of the peak flood level can be made from the observed data, the modelled flood level is typically within +0.2m of this estimate. This indicates that the model generally provides a reasonable representation of the flood behaviour at these locations considering the relative bounds of uncertainty.

Table 5-5 Comparison of Observed and Modelled August 2015 Flood Levels

Reference Location (refer Figure 5-16)	Location and/or Observed Flood Depth	Estimated Flood Level from Observed Depth (m AHD)	Modelled August 2015 Level (m AHD)	Difference in Flood Levels (m)
3	Palmerstone Avenue, Bronte 0.5-0.6m ground floor	41.7-41.8	42.0	+0.2
9	Simpson Street, Bondi 0.5-0.6m measurement during site visit (refer Figure 5-14)	36.1-36.2	36.6	+0.4
10	Old South Head Road Francis Street 0.3-0.4m	51.1-51.2	51.1	0.0
13	Wallis Parade, North Bondi 0.04m from entering ground floor apartment	16.4	16.5	+0.1



Title:
Distribution of Observed Flood Data Available for the August 2015 Event

Figure: 5-16

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5.4 February 2017 Model Validation

5.4.1 Validation Data

5.4.1.1 Rainfall Data

Two gauges situated within the study area and a number of gauges within the wider region have been analysed to estimate the likely range of rainfall intensities experienced within the study area catchment.

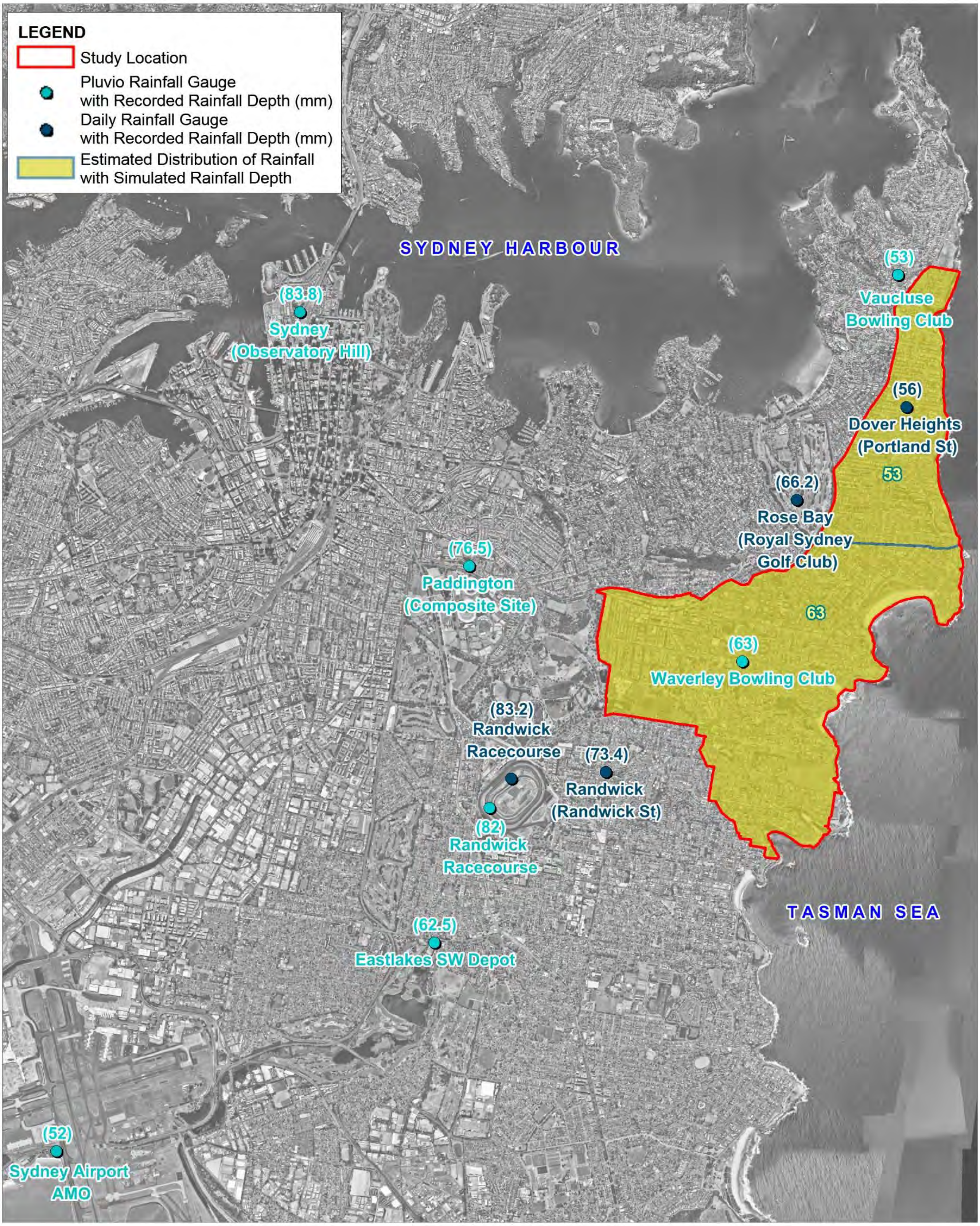
Seven pluvio gauges and four daily rainfall gauges have been considered in this analysis, as summarised in Table 5-6 and with gauge locations shown in Figure 5-17. Rainfall totals have been summed over the 24-hour period from 09:00 on 7 February 2017.

Table 5-6 February 2017 Event Recorded Daily Rainfall Total

Gauge Station No.	Gauge Type	Location	Approximate Locality from the Centre of Study Area (km)	Daily Rainfall Total (mm)
566114	Pluvio	Waverley Bowling Club	1.7 SW	63
566038	Pluvio	Vaucluse Bowling Club	3.3 N	53
566032	Pluvio	Paddington (Composite Site)	4.4 W	76.5
566099	Pluvio	Randwick Racecourse	5 SW	83.2
566028	Pluvio	Eastlakes SW Depot	6.5 SW	62.5
66062	Pluvio	Sydney (Observatory Hill)	7 NW	83.8
66037	Pluvio	Sydney Airport AMO	11.3 SW	52
66052	Daily	Randwick (Randwick St)	3.7 SW	73.4
66098	Daily	Rose Bay (Royal Sydney Golf Club)	1 NW	66.2
66073	Daily	Randwick Racecourse	4.6 SW	73.4
66209	Daily	Dover Heights (Portland St)	1.8 N	56

Analysis of the rainfall gauges in the vicinity of the study area and surrounding regions show the daily rainfall totals to be fairly uniform, with a minimum of 52mm to a maximum of 83.8mm at Sydney Airport AMO (66037) and Sydney (Observatory Hill) (66062), respectively. In general, the recorded daily rainfall within in the vicinity of the study area was in the order of 53 to 66.2mm.

Figure 5-18 shows the recorded rainfall hyetographs for the four most representative pluvio gauges listed in Table 5-6. The hyetograph shows continuous rainfall from 04:00 to 13:30, with the most intense burst of heavy rainfall over a one-hour period from 10:00 to 11:00.



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Daily Rainfall Totals February 2017 Event

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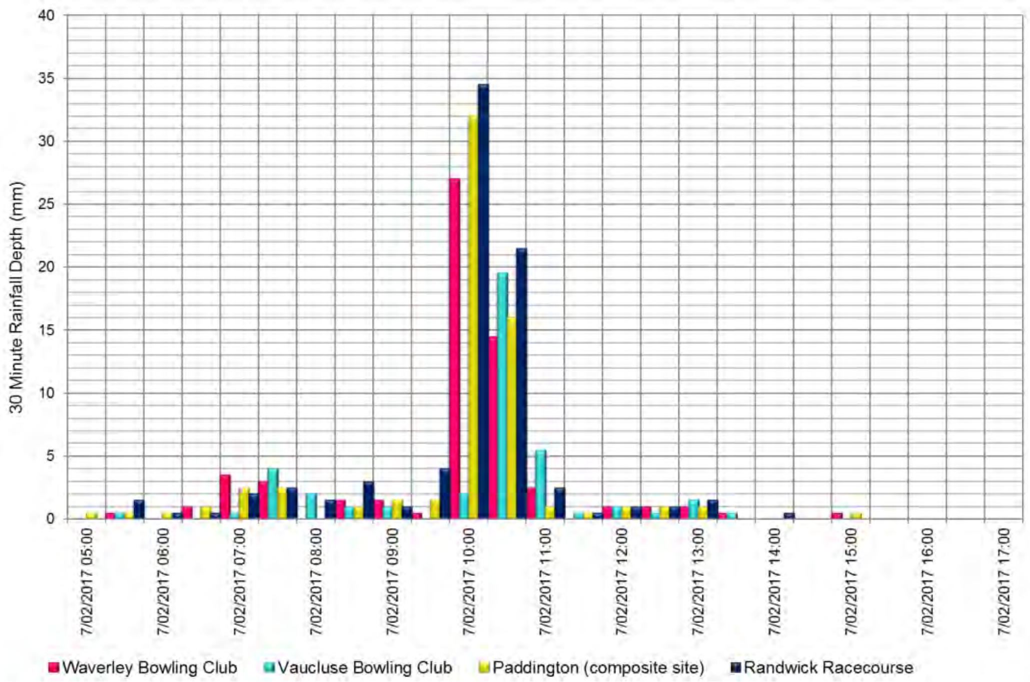


Figure 5-18 Rainfall Hyetograph – February 2017 Rainfall

In order to gain an appreciation of the relative intensity and magnitude of the February 2017 event, the recorded rainfall depth at the four pluvio gauges for various durations within the storm is compared with design IFD rainfall curves obtained from AR&R 2016. Figure 5-19 presents a comparison of the recorded February 2017 rainfall intensities against the 2016 IFD.

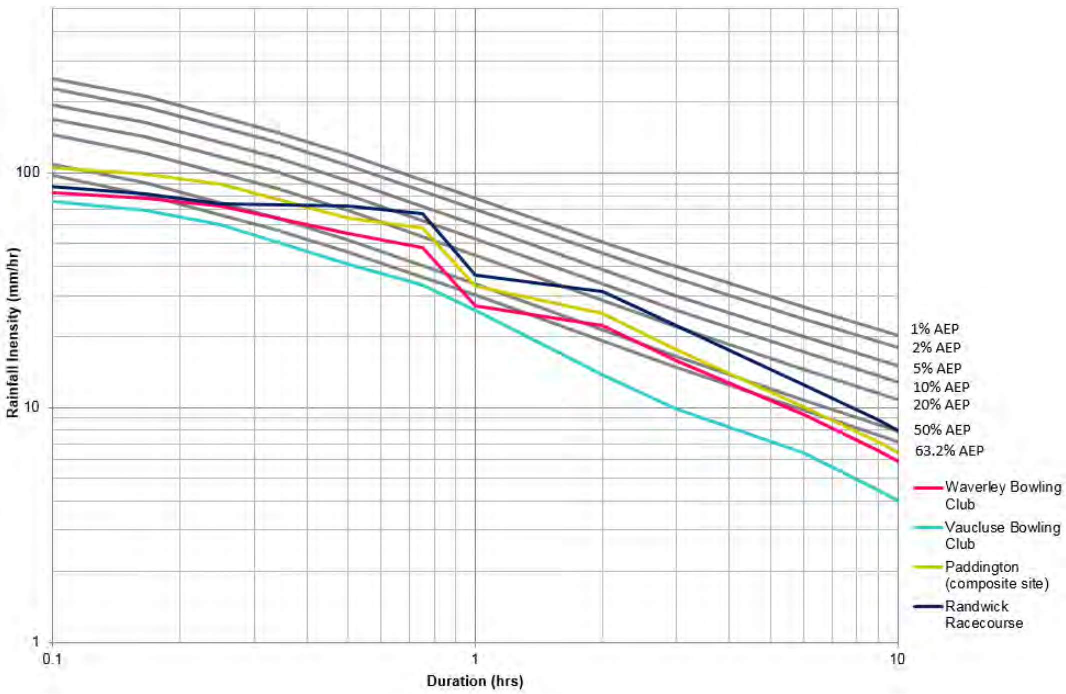


Figure 5-19 Comparison of Recorded February 2017 Rainfall with IFD Relationship

For durations under an hour, the majority of the rainfall for the Waverley Bowling Club (566114), Paddington (composite site) (566032) and Randwick Racecourse (566099) gauges were aligned between the 50% AEP and 20% AEP design intensity. For the durations of approximately 0.7 to 0.8 hours, the Randwick Racecourse and Paddington (composite site) gauges were between the 10% AEP and 5% AEP, and 20% AEP and 10% AEP design event respectively. Vaucluse Bowling Club (566038) remained below the 63.2 % AEP design event for all durations.

5.4.1.2 Downstream Boundary Condition

Recorded water level conditions at Sydney Live (213470) have been used to represent the tidal conditions within the model. Figure 5-20 shows the tidal levels applied to represent the oceanic conditions which peak at 1.37m (Zero Fort Denison Datum) at approximately 21:00 on 7 February 2017.

Figure 5-20 Recorded Water Level – February 2017

5.4.1.3 Flood Level Data

Anecdotal flood data for the February 2017 event was obtained through correspondence, reports and photos provided by Council, as well as the community questionnaire responses (refer Section 3). The observations are useful to confirm the locations of significant overland flow paths and floodwater depths to provide some confidence in the model representation of observed conditions. For some locations, the available description of flooding combined with LiDAR elevations enabled the determination of approximate flood levels. The distribution of observed flood data for the February 2017 event, compiled during community consultation, is discussed further in Section 5.4.2 and presented in Figure 5-23.

5.4.1.4 Flood Photographs

Historic flood photographs received from Waverley Council and collated during community consultation are presented below in Figure 5-21 and Figure 5-22. Photographs depicting significant flooding were used to confirm modelled flood behaviour, as discussed in Section 5.4.2.

Figure 5-21 Warners Avenue, North Bondi

Figure 5-22 Grafton Street, Bondi Junction

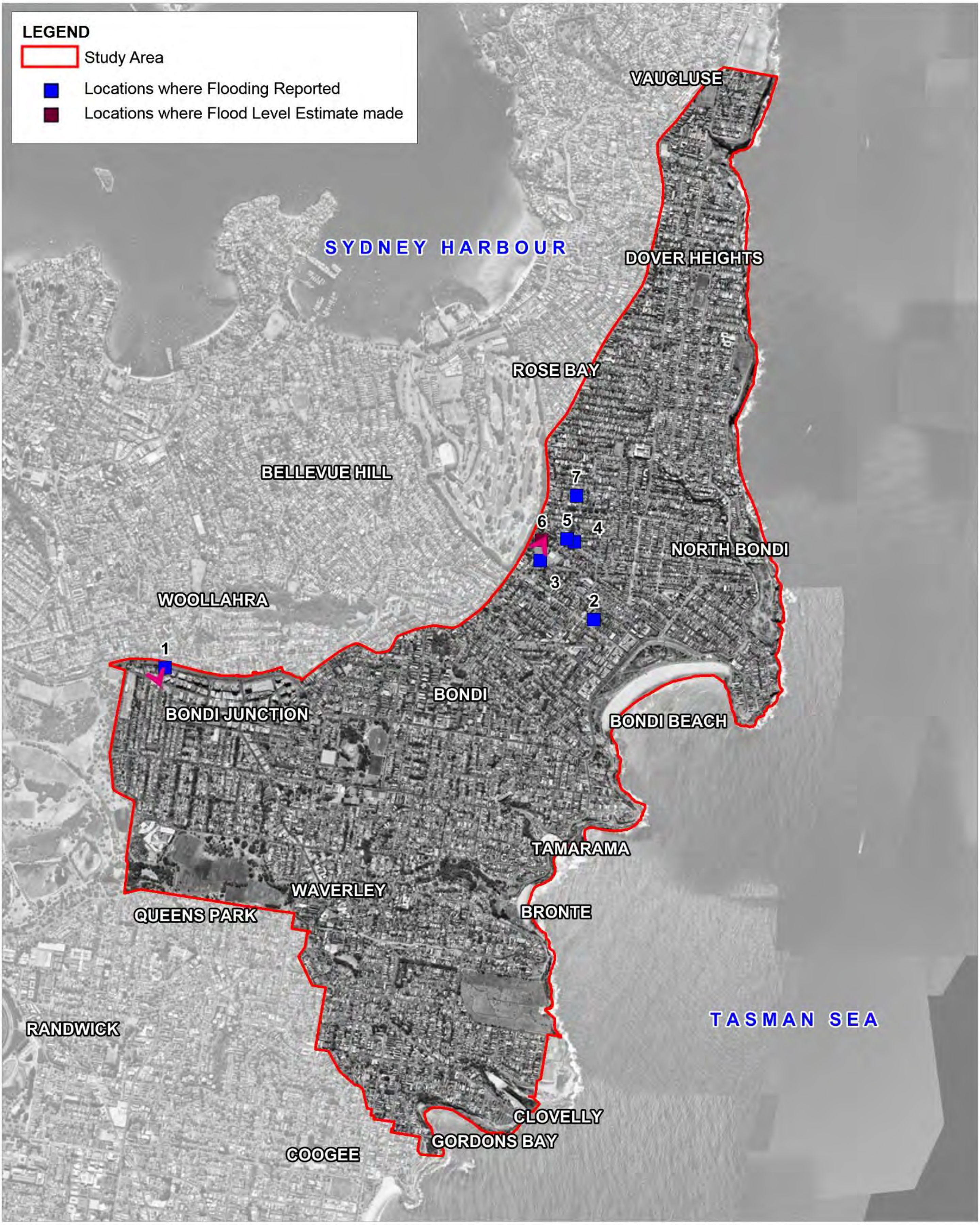
5.4.2 Observed and Simulated Flood Behaviour

Figure 5-23 provides simulated flood inundation depths for the calibration event and comparison with the community's flooding observations. In general, it can be seen that there is a good correlation between the locations at which significant flooding was observed and the alignment of the major overland flow paths in the TUFLOW model results. The community flooding observations have been classified into three categories: locations where general flooding was reported; locations where flood depths were reported; and locations where flood photographs were taken.

For locations where some form of flood level estimation was possible, a comparison between observed and modelled flood levels is presented in Table 5-7.

Table 5-7 Comparison of Observed and Modelled February 2017 Flood Levels

Reference Location (refer Figure 5-23)	Location and Observed Flood Depth	Estimated Flood Level from Observed Depth (m AHD)	Modelled February 2017 Level (m AHD)	Difference in Flood Levels (m)
6	Warners Avenue, North Bondi ~0.6m measurement during site visit (refer Figure 5-23)	10.6	10.4	-0.2



Title:

Distribution of Observed Flood Data Available for the February 2017 Event

Figure: 5-23

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5.5 XP-RAFTS Flow Validation

Hydrologic modelling for the study catchments was undertaken using the hydrologic modelling software XP-RAFTS (refer 2.5.1). The output from the hydrologic model is a series of flow hydrographs which form the inflow boundaries of the hydraulic model. To validate the XP-RAFTS hydrologic model, a separate method of hydrologic analysis was undertaken using the "direct-rainfall" approach. With the direct-rainfall method, design rainfall is applied directly to the individual cells within the 2D hydraulic model.

The direct-rainfall model was developed by utilising design rainfall hyetographs (applying a depth of rainfall directly to each individual cell) in addition to a catchment averaged initial loss (10mm) and continuing loss rate (0.7mm/hr). Validation has been undertaken for the following design rainfall events:

- 1% AEP, 45-minute duration storm;
- 1% AEP, 90-minute duration storm.

A flow path along Murriverie Road was chosen as an appropriate point for comparison, due to its size and the convergence of overland flows to a single flow path. Comparisons of the simulated catchment discharge and the cumulative volume are given in Figure 5-24 and Figure 5-25, respectively.

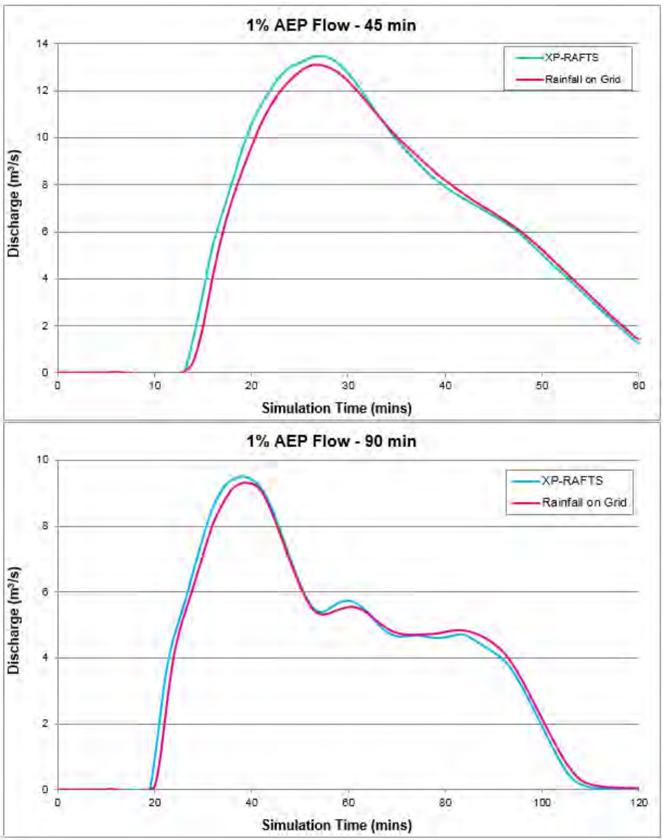


Figure 5-24 Catchment Flow Verification - Murriverie Road

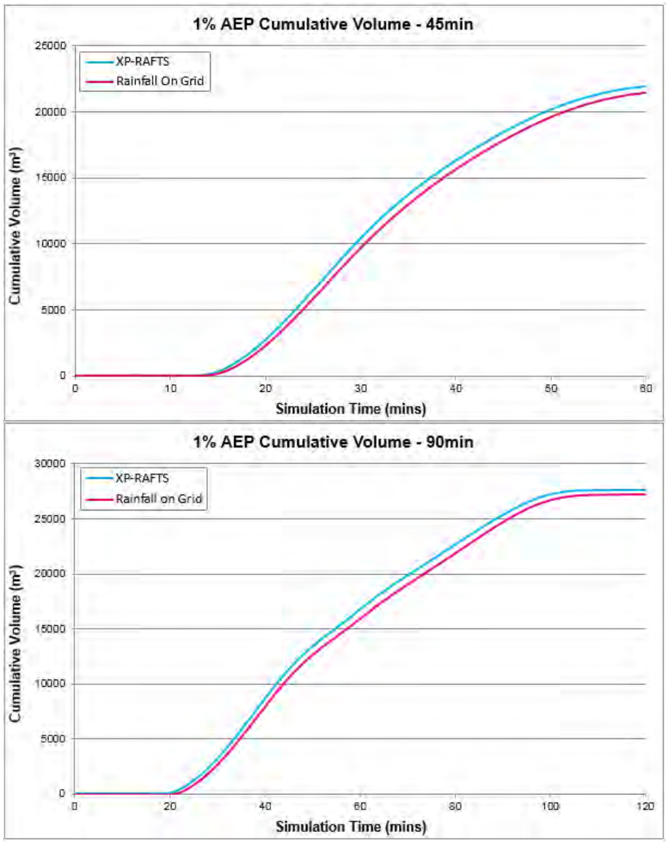


Figure 5-25 Catchment Volume Verification- Murriverie Road

Figure 5-24 and Figure 5-25 show that for the Murriverie Road catchment, the flow and cumulative volume generated by the XP-RAFTS hydrologic inputs correlates well with outputs from the direct-rainfall modelling. The following observations can be made:

- The XP-RAFTS produces marginally higher peak flows in the 1% AEP design storm;
- The cumulative volume in the XP-RAFTS model is marginally higher the direct-rainfall model, likely a result of minor depressions that cannot drain within the TUFLOW model terrain.

Overall, the catchment flow validation exercise demonstrated a good correlation between the two modelling methods and indicates that the XP-RAFTS modelling methodology adopted for the study provides a sound basis to assess design flood behaviour.

5.6 Conclusion

The model calibration process has involved the development of an appropriate hydraulic model in order to best represent flood conditions within the study area utilising available data. Model parameters have been adopted which are consistent with typical industry standard ranges and experiences learnt from other modelled catchments of a similar nature.

Rainfall inputs were developed for the models for three calibration/validation events utilising available rainfall gauge data: December 2015, August 2015 and February 2017. The results of the model simulations for these events have shown the adopted model configuration to perform well across a range of events, producing reasonable matches to observed flood level data where available.

Given the high variability of rainfall and the lack of empirical flood evidence with which to calibrate to, the developed TUFLOW model has been demonstrated to provide a sound representation of the catchment response to rainfall and accordingly is considered to be a suitable tool for design flood estimation.

Additional hydrologic modelling using direct-rainfall was undertaken as a validation exercise to compare flows generated within the TUFLOW model against flows generated by the XP-RAFTS modelling. Comparison of runoff hydrographs for the Murriverie Road catchment provided for a good match in terms of peak flows, timing and volume.

Thus, the developed TUFLOW and XP-RAFTS models have been demonstrated to provide a sound representation of the catchment response to rainfall and runoff, and are considered to be suitable tools for design flood estimation.

6 Design Flood Conditions

6.1 Introduction

Design floods are hypothetical floods used for planning and floodplain management investigations. They are not real rainfall events, rather values that are probabilistic in nature and are based on a probability of occurrence specified either as:

- Exceedances per Year (EY); or
- Annual Exceedance Probability (AEP) expressed as a percentage.

There are five broad classes of design rainfall estimates, each with their own set of methodologies and datasets. Each class is categorised by frequency of occurrence, as shown below in Table 6-1.

Table 6-1 Classes of Design Rainfall

Design Rainfall Class	Frequency of Occurrence	Probability Range
Very Frequent Design Rainfalls	Very Frequent	12EY to 1EY
Intensity Frequency Duration (IFD)	Frequent	1EY to 10% AEP
Intensity Frequency Duration (IFD)	Infrequent	10% AEP to 1% AEP
Rare Design Rainfalls	Rare	1% AEP to 0.05% AEP
Probable Maximum Precipitation (PMP)	Extreme	< 0.05% AEP

For this study, the simulated design events include the PMF, 0.2%, 1%, 2%, 5%, 10%, 20%, 50% AEP and 1EY (63.2% AEP) events for catchment derived flooding. The 1% AEP flood is generally used as a defined flood event for land use planning and control.

For design flood estimation, the adopted storm durations and temporal patterns are discussed in Section 6.2.4. The adopted ocean downstream boundary conditions are discussed in Section 6.3.

6.2 Design Rainfall

Design rainfall parameters are derived from standard procedures defined in AR&R, which are based on statistical analysis of recorded rainfall data across Australia. Established methods used since 1987 were revised in 2016. The 2016 guidelines (Ball et. al, 2016) were used for design flood estimation as part of this study. The derivation of location specific design rainfall parameters (e.g. rainfall depth and temporal pattern) for the Waverley LGA catchments is presented in the following sections.

6.2.1 Rainfall Depths

Design rainfall depth is based on the generation of intensity-frequency-duration (IFD) design rainfall curves, utilising the procedures outlined in AR&R 2016. The recently revised 2016 IFDs are based on a further 30 years of additional rainfall data, have a greater range in design magnitudes (from 12EY to 0.05% AEP) and are more accurate, combining contemporary statistical analysis in their determination.

The Probable Maximum Precipitation (PMP) is used in deriving the Probable Maximum Flood (PMF) event. The definition of the PMP is "the theoretical maximum precipitation for a given duration under modern meteorological conditions" (WMO, 2009). The ARI of a PMP/PMF event ranges between 10^4 and 10^7 years and is beyond the "credible limit of extrapolation". That is, it is not possible to use rainfall depths determined for the more frequent events (1% AEP and less) to extrapolate the PMP. The PMP has been estimated using the Generalised Short Duration Method (GSDM) derived by the Bureau of Meteorology. The method is appropriate for durations up to 6 hours and considered suitable for small catchments (< 1000km^2) in the Sydney region.

Design IFD data was derived across the entire Waverley LGA for a total of seven locations (constituting the seven individual IFD tiles across the entire study area) via the BoM website (Design Rainfall Data, 2018). Analysis indicated that the maximum variance in rainfall depth across the seven locations was between 2 and 5%, indicating minimal change in spatial variation across the study catchments. As such, two representative locations were selected using the centroid of the northern and southern portion of the study catchments. Table 6-2 shows the design rainfall depths adopted for the modelled events.

Table 6-2 Rainfall Depths for Design Events (mm)

Duration	63.2% AEP S/N[1] (mm)	50% AEP S/N[1] (mm)	20% AEP S/N[1] (mm)	10% AEP S/N[1] (mm)	5% AEP S/N[1] (mm)	2% AEP S/N[1] (mm)	1% AEP S/N[1] (mm)	0.2% AEP S/N[1] (mm)
20 min	19.2 / 19.2	21.5 / 21.6	28.6 / 28.9	33.4 / 34	38.1 / 38.9	44.4 / 45.4	49.1 / 50.4	60.2 / 61.8
25 min	21.2 / 21.3	23.7 / 23.8	31.6 / 31.9	36.9 / 37.5	42.1 / 42.9	49 / 50.1	54.2 / 55.7	66.6 / 68.3
30 min	22.9 / 23	25.6 / 25.7	34.1 / 34.4	39.8 / 40.4	45.4 / 46.3	52.9 / 54.1	58.6 / 60.1	72.1 / 73.2
45 min	27 / 27	30.1 / 30.2	39.9 / 40.3	46.6 / 47.2	53.2 / 54	62.1 / 63.2	68.9 / 70.4	85 / 86.8
1.0 h	30 / 30.1	33.5 / 33.6	44.4 / 44.7	51.8 / 52.4	59.2 / 60	69.2 / 70.3	76.9 / 78.3	95 / 96.7
1.5 h	34.8 / 34.8	38.7 / 38.8	51.3 / 51.6	60 / 60.5	68.7 / 69.4	80.5 / 81.5	89.8 / 91.1	111 / 112
2.0 h	38.6 / 38.6	43 / 43	56.9 / 57.2	66.7 / 67.1	76.5 / 77.1	89.9 / 90.7	101 / 102	124 / 125
3.0 h	44.7 / 44.8	49.8 / 49.9	66.2 / 66.4	77.9 / 78.1	89.6 / 89.9	106 / 106	119 / 119	145 / 146
4.5 h	52.1 / 52.2	58 / 58.1	77.6 / 77.6	91.6 / 91.7	106 / 106	126 / 126	141 / 142	172 / 173
6.0 h	58.1 / 58.3	64.9 / 65	87.2 / 87.2	103 / 103	120 / 120	143 / 143	161 / 161	195 / 195
9.0 h	68.1 / 68.3	76.2 / 76.4	103 / 103	123 / 123	143 / 143	171 / 171	194 / 194	235 / 234
12.0 h	76.2 / 76.6	85.5 / 85.8	117 / 117	140 / 140	163 / 163	195 / 195	221 / 221	268 / 268
18.0 h	89 / 89.7	100 / 101	139 / 139	166 / 166	195 / 195	235 / 234	266 / 266	324 / 323

[1]S/N: Southern catchment centroid rainfall depths / Northern catchment centroid rainfall depths

A range of storm durations ranging from 20 minutes to 18 hours was modelled in order to identify the critical storm duration. The critical durations for the PMF event were the 15 min, 30 min and 90 min storms, with rainfall depths of 180mm, 260mm and 540mm, respectively.

6.2.2 Areal Reduction Factors

The areal reduction factor takes into account the unlikelihood that larger catchments will experience rainfall of the same design intensity over the entire area. The Waverley LGA study catchments contain a series of smaller sub-catchments draining overland into Sydney Harbour or directly into the

South Tasman Sea. The sub-catchments range in size from 0.25km^2 to 1.3km^2, the largest sub-catchment being the Rose Bay catchment.

Due to the minor size of the sub-catchments, and as per guidance in AR&R (which does not recommend applying an ARF to catchments less than 1.0km^2 in size), an ARF was not applied for design flood estimation. In the case of those catchments larger than the 1.0km^2 (e.g. Rose Bay), the focal point for investigation is not at its outlet, but higher within the catchment, so the omittance of an ARF is still considered appropriate.

6.2.3 Design Rainfall Losses

In February 2019, OEH released a *Review of Australian Rainfall and Runoff Design Inputs for NSW* (WMA, 2019). The document was prepared to assess the suitability of default inputs developed as part of the Australian Rainfall and Runoff (ARR) 2016 project for use in New South Wales. The report findings and recommendations include:

(1) advice on a recommended hierarchy of approaches and information sources that practitioners should use when examining the best information sources and approaches for a study;

(2) improved information on initial and continuing losses and pre-burst information to use when a study would have otherwise used default initial and continuing loss or pre-burst information or approaches developed as part of ARR 2016.

The hierarchical approach for the selection of rainfall losses for NSW catchments is presented below in Table 6-3.

Table 6-3 Hierarchy of Approaches from Most (1) to Least Preferred (5)

Approach	Storm Initial Loss	Pre-burst (transformational)	IL Burst	Continuing Loss
1	Average Calibration	Not required or back calculated using $IL_{Storm} - IL_{Burst}$	Calculated from equation above	Average Calibration
2	Average Calibration	Not required or back calculated using $IL_{Storm} - IL_{Burst}$	Calculated from equation above	Average Calibration
3	Average Calibration	Not required or back calculated using $IL_{Storm} - IL_{Burst}$	Calculated from equation above	Average Calibration
4	NSW FFA reconciled initial loss	Not required or back calculated using $IL_{Storm} - IL_{Burst}$	Probability Neutral Burst Loss	NSW FFA reconciled continuing losses
5	ARR Data Hub initial loss	Not required or back calculated using $IL_{Storm} - IL_{Burst}$	Probability Neutral Burst Loss	NSW FFA reconciled continuing losses

In line with the recently released guidance from OEH, and as per the model calibration and validation (refer Section 5), the adopted loss rates for design event modelling are shown below in Table 6-4.

Table 6-4 Adopted Rainfall Loss Parameters

Rainfall Losses	Adopted Parameter
Pervious Initial Loss	20mm
Pervious Continuing Loss	2mm/hr
Impervious Initial Loss	2mm
Impervious Continuing Loss	0mm/hr

The fixed loss rates adopted in design event modelling (as per above table), represented the best fit during model calibration and are comparably higher than those provided for in the recently released ‘Probability Neutral Burst Initial Loss’ rates (refer to Appendix D). The higher catchment loss rates correspond with adjacent catchment studies (refer Table 5-2), which indicate that the underlying sand substrata can facilitate a high infiltration rate.

6.2.4 Temporal Patterns

The IFD data presented in Table 6-2 provides the average intensity that occurs over a given storm duration. Temporal patterns are required to define what percentage of the total rainfall depth occurs over a given time interval throughout the storm duration. Standard and non-standard temporal patterns are available from the AR&R online datahub for each frequency of occurrence (very-frequent, frequent, infrequent, rare and extreme). Each frequency class has a suite of 10 temporal patterns per design duration.

Figure 6-1 shows the 10 temporal patterns for the 1% AEP, 90 minute duration design storm for the study catchments. The 1% AEP belongs to the ‘Rare’ frequency of occurrence.

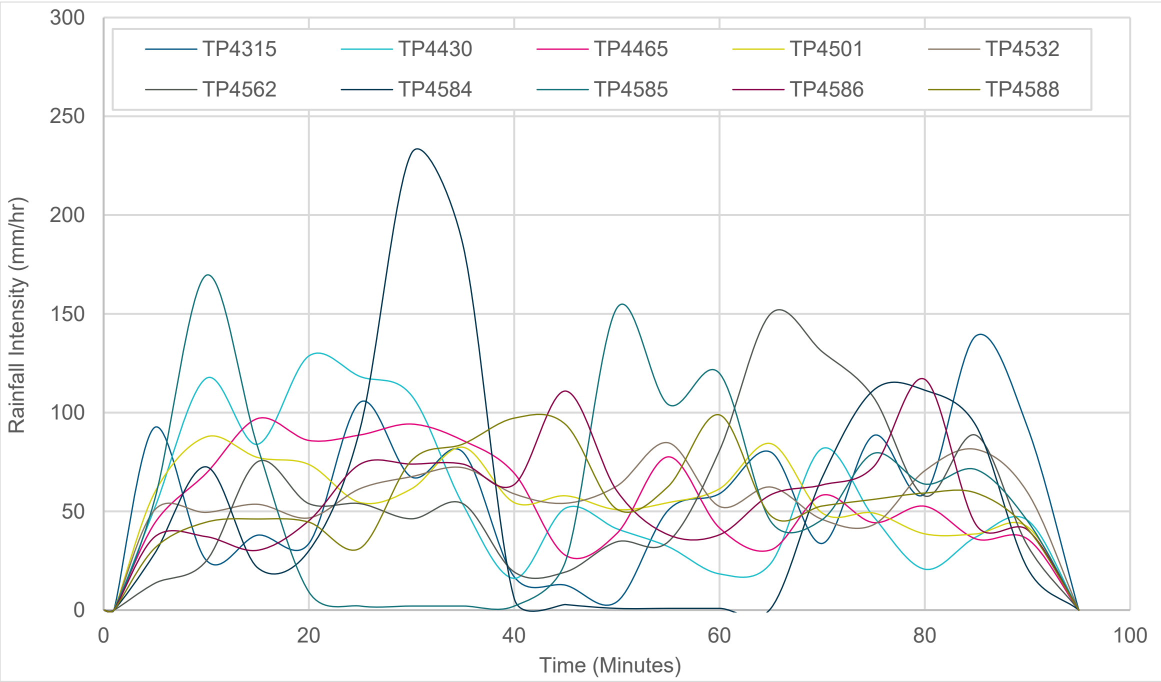


Figure 6-1 1% AEP 90-minute Duration Temporal Patterns

The procedures for AR&R provide for the selection of the temporal pattern that gives the peak flow closest to the mean of the peak flows from all ten temporal patterns across all design durations. This method was followed to find the critical temporal pattern for each event duration.

6.2.5 Critical Mean Assessment

Design flood levels in the catchment are a combination of flooding from rainfall over the local catchment (overland flooding), as well as elevated water levels in open channels and storage areas (storage flooding). As such, three locations of interest were selected when undertaking the critical mean assessment for the study area. The locations of interest were chosen as being representative of the remaining catchment areas – one for the upper catchment areas and lower catchment areas affected by overland flooding, and the third being representative of several storages located across the study catchments.

To determine the critical storm duration for the three locations of interest, modelling of the frequent, infrequent and rare temporal pattern bins was undertaken for a range of storm durations from 20 minutes to 9 hours. Each duration utilised ten temporal patterns extracted from the AR&R datahub relevant to the study area.

The following process was undertaken to determine the critical mean temporal pattern for the two locations of interest:

(1) 10 temporal patterns for each duration were simulated for the frequent, infrequent and rare temporal pattern bins (i.e. 20% AEP, 5% AEP and 1% AEP);

(2) The mean flood level was determined for each of the durations simulated;

(3) The critical mean was determined as the highest mean flood level amongst each of the durations simulated.

The design event analysis found that for all design event magnitudes, the 20-minute and 45-minute durations were critical for catchment areas affected by overland flooding, and the 90-minute duration was critical for areas affected by storage flooding. For the PMF, the critical durations were found to be the 15-minute, 30-minute and 90-minute durations.

A full summary of the critical durations and associated temporal patterns derived for design event modelling is provided in Section 6.5.

6.2.6 Comparison with 2016 Intensity-Frequency-Duration Graphs

As part of this study, a comparison of the standard AR&R IFD curves and a daily rainfall frequency analysis was undertaken on the continuous rainfall record at Waverley Bowling Club.

Daily rainfall depths have been recorded at Waverley Bowling Club since 1980, providing 40 years of data. This data was used to derive a rainfall frequency analysis for a range of storm durations. The data was converted into a series of annual maxima daily rainfall depths, ensuring that multiple day totals were excluded from the analysis. The FLIKE software package, an analysis package that calculates the probability of flood events based on historical records, was then used to derive a frequency analysis of the daily rainfall totals using the Generalised Extreme Value probability model. The results of this analysis are presented in Table 6-5.

Table 6-5 Daily Rainfall Frequency Analysis at Waverley Bowling Club

Duration	Daily Rainfall Depth (mm) per Design Rainfall Event Magnitude					
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
30-minute	22.5	31.72	38.63	45.93	56.48	65.27
60-minute	30.56	44.05	54.39	65.51	81.89	95.83
120-minute	38.63	54.25	65.99	78.43	96.44	111.5
180-minute	45.51	64.77	79.34	94.86	117.44	136.44

The rainfall depths generated from the frequency analysis were then compared to the standard IFD curves for the Waverly Bowling Club location from AR&R. The comparison of the rainfall frequency analysis and the standard IFD curves is shown graphically in Figure 6-2.

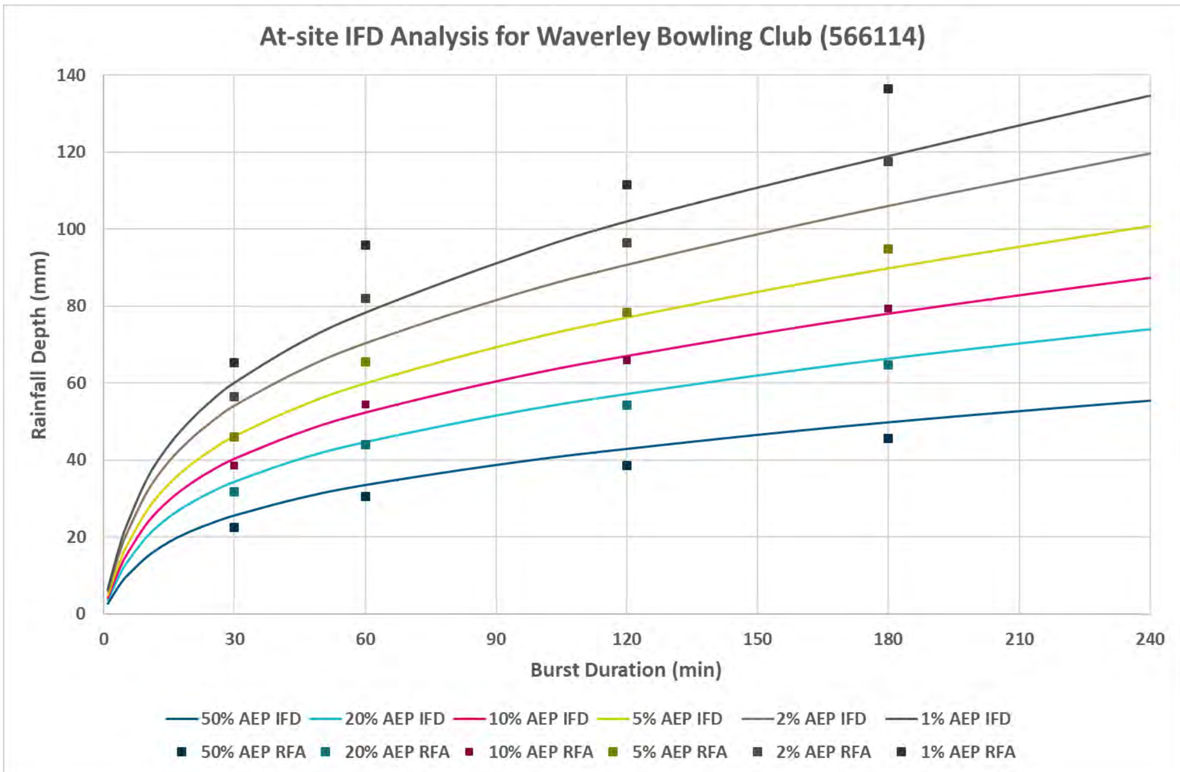


Figure 6-2 Waverley Bowling Club Site IFD Analysis

This analysis found that the consistency between the rainfall frequency analysis and the standard IFDs is reasonable up until the 5% AEP event across all durations. As the rainfall data used only had a 40-year record, events beyond the 5% AEP show noticeable deviation between the two approaches, as shown by both the 2% and 1% AEP events (i.e. 1 in 50 year and 1 in 100 year events, respectively). The rainfall analysis for these larger events produced significantly higher design rainfall estimates than the standard IFD curves. This is not unexpected due to the 40-year rainfall record available for assessment (i.e. less than the 50 and 100 year average recurrence intervals of the 2% and 1% AEP events).

6.3 Design Ocean Boundary

Design ocean boundaries for use in flood risk assessments are recommended by the Flood Risk Management Guide (OEH, 2015) where the recommended design ocean water levels have been determined based on long term records from Fort Denison in Sydney Harbour. The design levels include the following considerations:

- Barometric pressure set up of the ocean surface due to the low atmospheric pressure of the storm;
- Wind set up due to strong winds during the storm “piling” water upon the coastline;
- Astronomical tide, particularly the HHWS (SS);
- Wave set up.

OEH recommends different design ocean peak water levels are to be adopted based on the type of ocean entrance. Type A entrances are subject to little ocean tide attenuation and are not influenced by wind and wave set up. Type B estuaries are typically open but may be affected by shoaling and may have some potential for wave set up (e.g. Lake Illawarra). Type C estuaries are prone to heavy shoaling and often close completely (also known as Intermittently Closed and Open Lakes and Lagoons (ICOLLS)). Oceanic boundaries such as those adjacent to the Waverley LGA model outlets (i.e. the South Tasman Sea) are also classified as a Type C boundary.

Peak design ocean water levels for each of the different entrance types for locations south of Crowdy Head are presented in Table 6-6. The different peak levels reflect the degree of influence of wave set up applicable to the various types of entrances.

Table 6-6 Design Peak Ocean Water Levels (OEH, 2015) for Various Entrance Types, located South of Crowdy Head

Ocean Event	Peak Ocean Water Level (m AHD)		
	Entrance Type A	Entrance Type B	Entrance Type C
5% AEP	1.4	1.9	2.35
1% AEP	1.45	2.0	2.55

For determining design flood levels, OEH recommends that the local catchment 1% AEP flood should be run in conjunction with a 5% AEP tailwater. It further recommends that the inverse scenario be run to confirm that the dominant flooding mechanism is not from downstream water levels. If the flooding from the downstream water is demonstrated to produce peak flood conditions in parts of the catchment, an envelope of both scenarios must be used to define the extent of the 1% AEP flood. In addition, it is recommended to run the 1% AEP with Indian Spring Low Water (ISLW) tailwater to determine peak velocities.

The adopted design downstream boundary levels are shown in Table 5-5 and have been applied as a constant water level boundary condition over time.

Table 6-7 Design Peak Ocean Water Levels

Design Flood Event	Catchment Event	Ocean Event (Lake Illawarra)	Water Levels (m AHD)
63.2% AEP	63.2% AEP	HHWS[1] (SS)	0.95
50% AEP	50% AEP	HHWS (SS)	0.95
20% AEP	20% AEP	HHWS (SS)	0.95
10% AEP	10% AEP	HHWS (SS)	0.95
5% AEP	5% AEP	HHWS (SS)	0.95
2% AEP	2% AEP	5% AEP	2.35
1% AEP	1% AEP 1% AEP 5% AEP	ISLW[2] 5% AEP 1% AEP	-0.95 2.35 2.55
0.5% AEP	0.5% AEP	1% AEP	2.55
PMF	PMF	1% AEP	2.55

[1]HHWS (SS) = High High Water Springs (Solstice Spring)

[2]ISLW = Indian Springs Low Water

6.4 Blockage Scenarios

6.4.1 Blockage of Hydraulic Structures

During flood events, structure blockages can significantly increase local flood levels. The adopted methodology for determining appropriate consideration of blockages is documented in Chapter 6: Blockage of Hydraulic Structures, Book 8 in Australian Rainfall and Runoff - A Guide to Flood Estimation (2016). The types of structures or drainage elements affected by blockage can generally be grouped as follows:

- Bridges and culverts;
- Drainage system inlets and pipes;
- Open channels and waterways;
- Overland flow paths;
- Weirs and dams.

6.4.2 Pit Inlet Blockages

A pit blockage of 50% for sag pits and 20% for on-grade pits has been adopted in design event modelling in line with AR&R 2016 guidelines.

6.5 Modelled Design Events

6.5.1 Catchment Derived Flood Events

The catchment derived flood events that have been simulated for the design flood scenarios are summarised in Table 6-8.

Table 6-8 Modelled Design Flood Events

Event Magnitude	Upper Catchment Critical Duration	Lower Catchment Critical Duration	Storage Critical Duration
63.2% AEP	20min	45min	90min
50% AEP	20min	45min	90min
20% AEP	20min	45min	90min
10% AEP	20min	45min	90min
5% AEP	20min	45min	90min
2% AEP	20min	45min	90min
1% AEP	20min	45min	90min
0.2% AEP	20min	45min	90min
PMF	15min	30min	90min

The temporal pattern selected for each design event and duration is shown in Table 6-9.

Table 6-9 Temporal Pattern Selected

Event Magnitude	Upper Catchment Mean TP	Upper Catchment Mean TP	Storage Mean TP
63.2% AEP	4445	4545	4606
50% AEP	4445	4545	4606
20% AEP	4445	4545	4606
10% AEP	4383	4478	4597
5% AEP	4383	4478	4597
2% AEP	4359	4362	4465
1% AEP	4359	4362	4465
0.2% AEP	4359	4362	4465

7 Design Flood Results

A range of design flood conditions were modelled, the results of which are presented and discussed in the following sections. The simulated design events included the 0.2%, 1%, 2%, 5%, 10%, 20% and 50% AEP, and 1EY (63.2% AEP) events for catchment derived flooding. The PMF flood event has also been modelled.

The design flood results are presented in a separate Flood Mapping Compendium. For the simulated design events including the 0.2%, 1%, 2%, 5%, 10%, 20% and 50% AEP, 1EY (63.2% AEP) and PMF events, a map of peak flood level, depth and velocity is presented covering the modelled area.

7.1.1 Design Flood Extents Filtering

Due to the nature and complexity of the hydraulic modelling, it was deemed appropriate to filter the design flood extents. Foremost the results were filtered to remove sheet flow from the final design extents such that only regions of significant flood depth or of significant velocity-depth product were included. The methodology is as follows:

(1) Areas where depth does not exceed 0.15m were removed from the design flood extents;

(2) Areas where the velocity-depth product (i.e. V x D) exceeds 0.10m^2/s were re-instated;

(3) Flood islands with an area of less than 200m^2 were removed.

7.2 Flood Behaviour

The flood behaviour across the study area is characterised by relatively shallow overland flow within the upper catchment areas, which is initiated when the capacity of the available stormwater drainage network is exceeded. Within the lower catchment areas, major overland flow paths are formed as the size of the upstream contributing catchments increase. Areas of significant flooding are typically located where a major overland flow path is not aligned along a roadway or alternative easement, or within local topographic depressions. A more detailed description of local flood behaviour is provided within the discussion of flooding hotspots in Section 7.9.

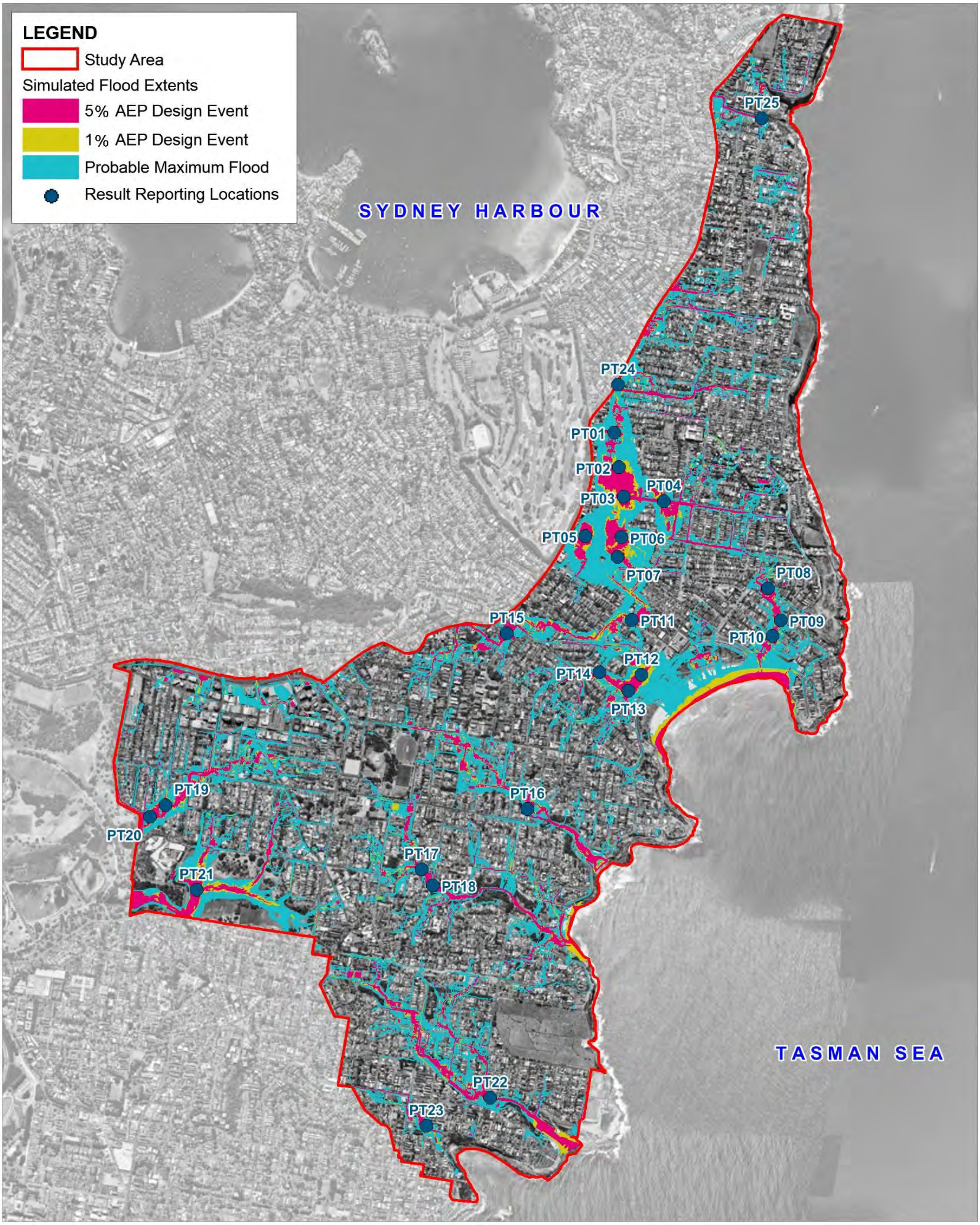
7.3 Peak Flood Conditions

Maps of peak flood level, depth and velocity covering the modelled area for all stimulated design events are included in the Flood Mapping Compendium. Modelled peak flood levels at selected locations (as presented Figure 7-1) are shown in Table 7-1 for the full range of modelled design flood events.

Table 7-1 Modelled Peak Flood Levels (m AHD) for Design Flood Events

ID	Design Event Frequency								
	63.2% AEP	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.2% AEP	PMF
1	10.67	10.70	10.79	10.88	10.91	11.06	10.98	11.06	13.67
2	NFI	NFI	9.57	9.72	9.89	10.91	10.40	10.91	13.67
3	9.42	9.45	9.63	9.76	9.90	10.91	10.40	10.91	13.67
4	11.50	11.54	11.65	11.83	11.89	12.13	12.00	12.13	13.69
5	10.38	10.46	10.80	10.91	11.03	11.48	11.28	11.48	13.63
6	10.67	10.72	10.87	10.92	10.97	11.34	11.22	11.34	13.66
7	10.77	10.79	10.88	10.94	10.98	11.35	11.23	11.35	13.66
8	16.48	16.52	16.62	16.75	16.81	17.02	16.92	17.02	17.71
9	14.37	14.44	14.56	14.73	14.79	15.01	14.89	15.01	15.74
10	11.69	11.84	11.99	12.11	12.17	12.40	12.26	12.40	13.17
11	15.50	15.55	15.61	15.64	15.66	15.82	15.76	15.82	16.06
12	14.80	14.84	14.99	15.08	15.29	15.97	15.72	15.97	16.93
13	NFI	NFI	14.41	15.07	15.29	15.97	15.72	15.97	17.01
14	NFI	16.87	17.27	17.52	17.62	17.84	17.75	17.84	18.51
15	36.47	36.52	37.37	37.79	37.93	38.22	38.06	38.22	39.05
16	56.82	56.82	57.32	57.46	57.50	57.68	57.59	57.68	58.35
17	41.74	41.80	42.02	42.22	42.32	42.74	42.53	42.74	44.18
18	39.38	39.84	40.45	40.86	40.99	41.47	41.17	41.47	43.44
19	47.05	47.07	47.34	47.53	47.60	47.91	47.76	47.91	49.20
20	NFI	46.56	46.75	46.94	47.03	47.35	47.20	47.35	48.42
21	46.81	46.82	46.89	47.00	47.04	47.20	47.12	47.20	47.75
22	19.32	19.35	19.41	19.55	19.65	19.96	19.80	19.96	20.92
23	32.60	32.61	32.70	32.78	32.85	33.25	33.08	33.25	34.16
24	12.53	12.57	12.66	12.74	12.77	12.89	12.84	12.89	13.33
25	40.75	40.90	41.01	41.14	41.18	41.28	41.22	41.28	41.67

NFI - No Flooding Indicated



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Design Flood Inundation Extents and Reporting Locations

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7.4 Flood Function / Hydraulic Categorisation

The flood function (or hydraulic categorisation) of a floodplain helps describe the nature of flooding in a spatial context and from a flood planning perspective can determine what can and can't be developed in areas of the floodplain.

There are no prescriptive methods for determining what parts of the floodplain constitute floodways, flood storages and flood fringes. Descriptions of these terms within the NSW Floodplain Development Manual (DIPNR, 2005) are essentially qualitative in nature. Of particular difficulty is the fact that a definition of flood behaviour and associated impacts is likely to vary from one floodplain to another depending on the circumstances and nature of flooding within the catchment. The hydraulic categories as defined in the Floodplain Development Manual are:

- **Floodway -** Areas that convey a significant portion of the flow. These are areas that, even if partially blocked, would cause a significant increase in flood levels or a significant redistribution of flood flows, which may adversely affect other areas.
- **Flood Storage -** Areas that are important in the temporary storage of the floodwater during the passage of the flood. If the area is substantially removed by levees or fill it will result in elevated water levels and/or elevated discharges. Flood Storage areas, if completely blocked would cause peak flood levels to increase by 0.1m and/or would cause the peak discharge to increase by more than 10%.
- **Flood Fringe -** Remaining area of flood prone land, after Floodway and Flood Storage areas have been defined. Blockage or filling of this area will not have any significant effect on the flood pattern or flood levels.

Several approaches were considered when attempting to define flood function categories across the study catchment. The approach that was adopted derived a preliminary floodway extent from the velocity-depth product (sometimes referred to as unit discharge). This extent was then locally adjusted, where appropriate, to produce a cleaner and more contiguous extent. The peak flood depth was used to define flood storage areas. The adopted hydraulic categorisation for design events is defined in Table 7-2. Due to extreme conditions during the PMF, a separate hydraulic categorisation was used, as shown in Table 7-3.

Table 7-2 Hydraulic Categories – 5% AEP and 1% AEP

Floodway	Velocity * Depth > 0.2	Areas and flow paths where a significant proportion of floodwaters are conveyed (including all bank-to-bank creek sections).
Flood Storage	Velocity * Depth < 0.2 and Depth > 0.5 metres	Areas where floodwaters accumulate before being conveyed downstream. These areas are important for detention and attenuation of flood peaks.
Flood Fringe	Velocity * Depth < 0.2 and Depth < 0.5 metres	Areas that are low-velocity backwaters within the floodplain. Filling of these areas generally has little consequence to overall flood behaviour.

Table 7-3 Hydraulic Categories – PMF

Floodway	Velocity * Depth > 0.4	Areas and flow paths where a significant proportion of floodwaters are conveyed (including all bank-to-bank creek sections).
Flood Storage	Velocity * Depth < 0.4 and Depth > 0.5 metres	Areas where floodwaters accumulate before being conveyed downstream. These areas are important for detention and attenuation of flood peaks.
Flood Fringe	Velocity * Depth < 0.4 and Depth < 0.5 metres	Areas that are low-velocity backwaters within the floodplain. Filling of these areas generally has little consequence to overall flood behaviour.

Preliminary hydraulic category mapping is included in the Mapping Compendium for the 1% and 5% AEP events and PMF.

7.5 Provisional Flood Hazard

The National Flood Risk Advisory Group (AIDR, 2017) considers a holistic approach to flood hazard to people, vehicles and structures. It recommends a composite six-tiered hazard classification, reproduced in Figure 7-2 and are summarised in Table 7-4.

The provisional flood hazard level is often determined based on the predicted flood depth and velocity. This is conveniently done through the analysis of flood model results. A high flood depth will cause a hazardous situation while a low depth may only cause inconvenience. High flow velocities are dangerous and may cause structural damage while low velocities generally do not.

Provisional hazard category mapping is included in the Mapping Compendium and is presented for the 1% and 5% AEP events and PMF.

Table 7-4 Combined Flood Hazard Curves – Vulnerability Thresholds

Hazard Classification		Description
H1	Depth < 0.3m and Velocity < 2.0m/s and Velocity*Depth <0.3	Relatively benign flow conditions. No vulnerability constraints.
H2	Depth < 0.5m and Velocity < 2.0m/s and Velocity*Depth <0.6	Unsafe for small vehicles.
H3	Depth < 1.2m and Velocity < 2.0m/s and Velocity*Depth <0.6	Unsafe for all vehicles, children and the elderly.
H4	Depth < 2.0m and Velocity < 2.0m/s and Velocity*Depth <1.0	Unsafe for all people and vehicles.
H5	Depth < 4.0m and Velocity < 4.0m/s and Velocity*Depth <4.0	Unsafe for all people and all vehicles. Buildings require special engineering design and construction.
H6	Depth > 4.0m OR Velocity > 4.0m/s OR Velocity*Depth >4.0	Unconditionally dangerous. Not suitable for any type of development or evacuation access. All building types considered vulnerable to failure.

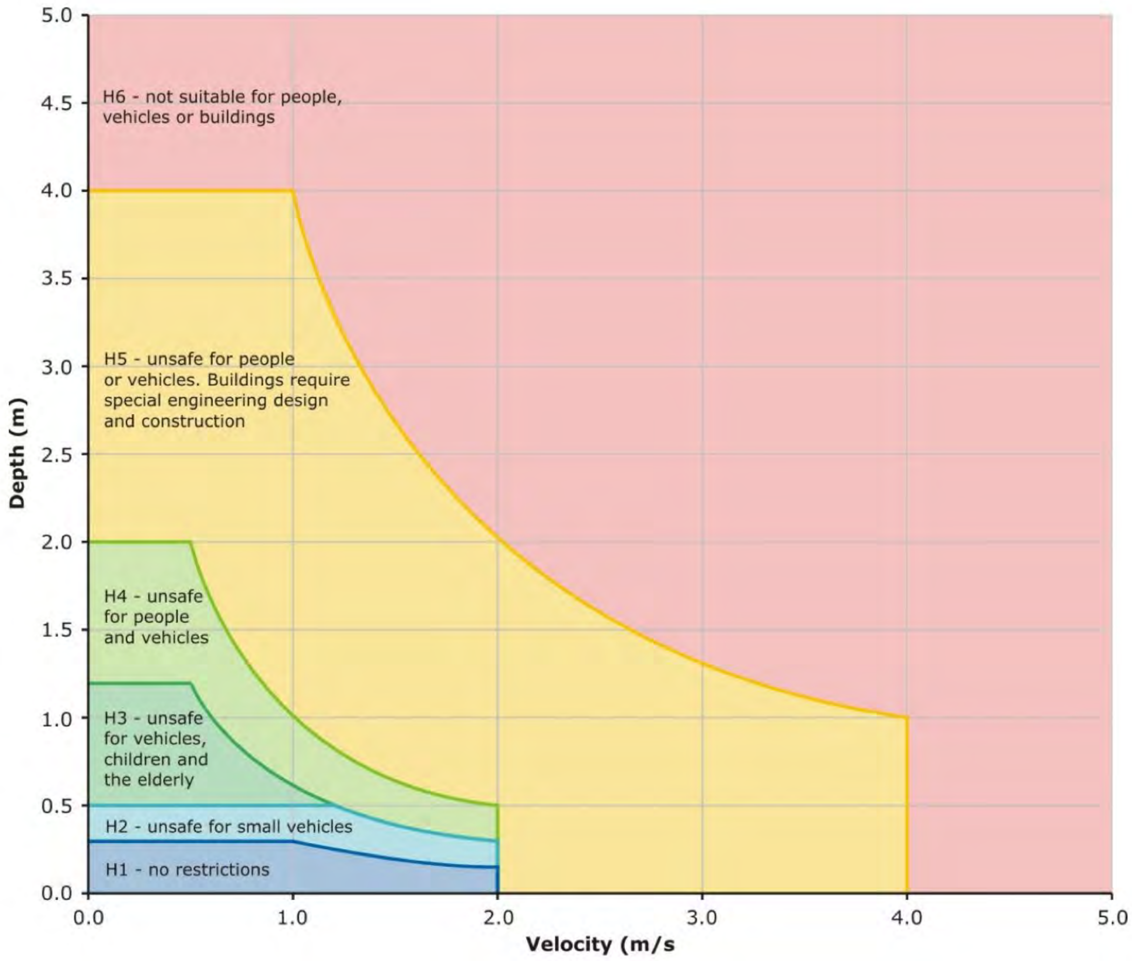


Figure 7-2 Combined Flood Hazard Curves

7.6 Flood Emergency Response Considerations

The State Emergency Service (SES) has formal responsibility for emergency management operations in response to flooding. Other organisations normally provide assistance, including the Bureau of Meteorology, Council, Police, fire brigade, ambulance and community groups.

The SES classifies communities according to the impact that flooding has on them. The primary purpose for doing this is to assist the SES in the planning and implementation of response strategies. Flood impacts relate to where the normal functioning of services is altered due to a flood, either directly or indirectly, and relates specifically to the operational issues of evacuation, resupply and rescue.

For the study area, the standard approach to classifying communities for flood emergency response is not considered appropriate or particularly useful due to the short duration nature of flooding within the catchment. However, it is still necessary to provide guidance and consideration on flood emergency response. As such, the approach undertaken was to assess and analyse properties and roads to determine those that have a high hazard or risk which can inform SES response. This approach considered the hydraulic hazard categorisation discussed in Section 7.4, however, it also considered other flood risks, particularly those relating to personal safety and evacuation.

The resulting flood emergency response considerations identify roads that may not be trafficable by heavy vehicles during the peak of a flood event and individual properties that are considered unsafe for onsite refuge. These properties are in particularly high-risk locations and are potentially at risk of structural damage due to flooding.

The 1% AEP event emergency response considerations mapping is provided in Figure 7-3.

7.7 Flood Planning Considerations

7.7.1 Flood Planning Levels

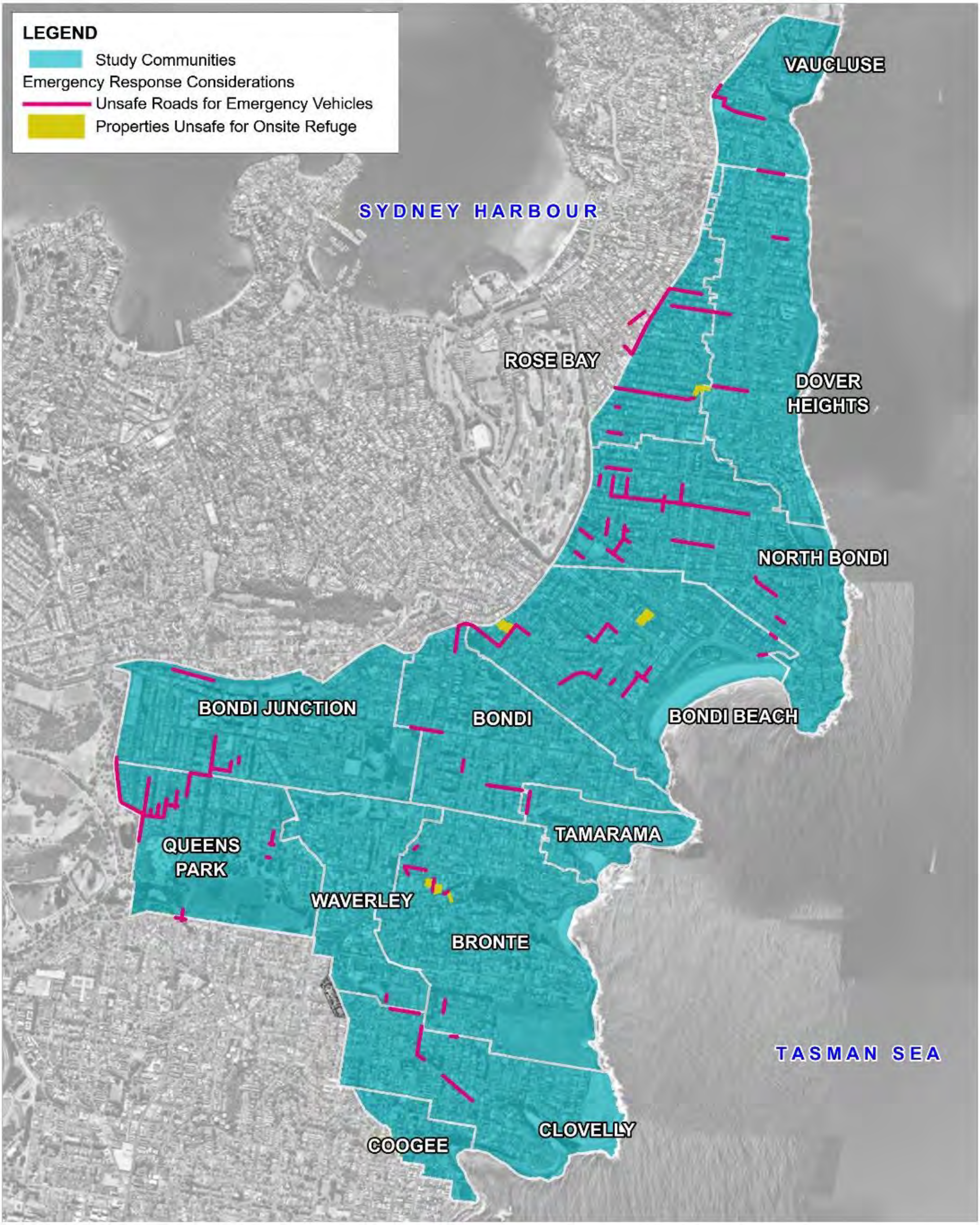
The flood levels and inundation extents determined through the design event modelling provides the basis for establishing the Flood Planning Level (FPL) and associated Flood Planning Area (FPA).

The Flood Planning Level (FPL) is the level below which a Council places restrictions on development due to the hazard of flooding. FPLs are used for planning purposes and can also be used to determine the extent of the Flood Planning Area (FPA), which is the area of land subject to flood-related development controls.

The various flood risk mapping outputs for the current study are recommended to be adopted by Council and used in the development assessment process. Flood risk mapping outputs for the 1% AEP design event (peak water level, depth and velocity), flood function (floodway, flood storage and flood fringe definition), flood hazard and Flood Planning Area mapping have been prepared for Council.

It is typical for the FPL to be derived from a designated design flood event plus a freeboard allowance, to account for underlying uncertainties, such as the variation between flood modelling results and actual flood events, the effect of localised factors on flood levels and potential wave action. The 1% AEP event is usually adopted as the designated flood, however the FPL and FPA can include allowances for future climate change conditions (i.e. rainfall intensity increases).

For this study, a freeboard of 0.3m above the 1% AEP peak flood surface was adopted, which is typical for overland flow environments. A 0.5m freeboard was applied to the areas of oceanic flooding. However, that flood mechanism is not a significant source of flood risk within the study area. A surface was extrapolated from the freeboard and intersected with the LiDAR DEM to identify a preliminary FPA extent, as presented in Figure 7-4.



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Emergency Response Considerations 1% AEP Event

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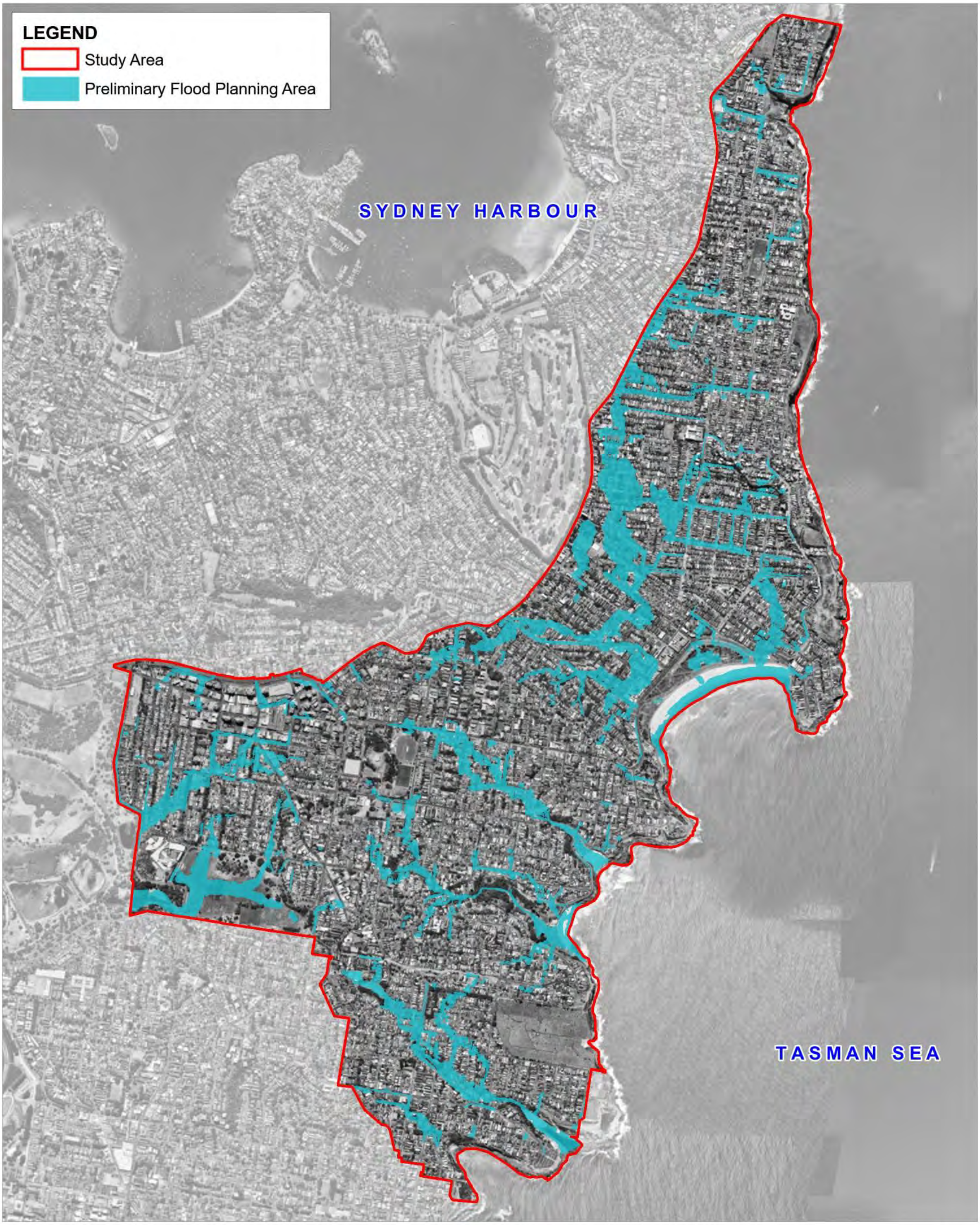

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Preliminary Flood Planning Area

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7.7.2 Ground-truthing and Lot-tagging

Flood control lots are properties that are known to have a flooding constraint and should be referred to Council's flood-related development controls because of their potential to be flood affected. The FPA can be used to determine properties to define as potential flood control lots. However, there are significant uncertainties regarding flood modelling in complex urban environments. Therefore, a ground-truthing exercise was undertaken to ensure that the model results are interpreted and correctly applied for flood planning purposes. The ground-truthing was conducted over a two-day period, verifying the modelled flow paths against site conditions. Further desktop analysis of the 1% AEP and 0.2% AEP model results and topographic data was performed to establish a three-tiered classification system for the lot-tagging process. The lot-tagging classes are discussed in further detail, but can be summarised as:

- "Type A" – lots for which standard flood-related development controls can be applied;
- "Type B" – lots through which an overland flood flow path is conveyed;
- "Type C" – lots captured by the preliminary FPA.

The distribution of lots across the Waverley LGA classified as the above is presented in Figure 7-5. Approximately 650 lots have been classified as Type A, 400 as Type B and over 2100 as Type C.

Type A lots are those for which standard flood-related development controls can be readily applied. Lots with this classification are typically located within areas along a major overland flood flow path. The surface grades are relatively gentle, and the modelling of flood extents and flood levels is relatively certain. Significant topographic controls often govern the modelled hydraulic gradients, such as within local topographic depressions, some of which are naturally occurring, and others formed behind elevated road crests. Local drainage measures would not adequately manage the risk of inundation at the locations. FPLs should be used to manage risk for future development.

Type B lots are those for which the presence of an overland flood flow path can be confirmed. These are typically located downstream of sag points in the road network. When the capacity of the sub-surface stormwater drainage network is exceeded, water will pond within the surface depression. Once filled, water will spill from the depression and flow through the lots on the downslope side of the road. Whilst the importance of these lots for the conveyance of overland flows can be confirmed, standard flood-related development controls cannot be readily applied – firstly because there is uncertainty in the modelled peak flood level and also because a single representative FPL for the lot is not appropriate.

Type B lots are typically in areas of relatively steep topography and the location, depth and velocity of overland flows cannot determined with certainty by the flood modelling as the model resolution and available data is not at a fine enough scale to resolve the local hydraulics. Much of the study area is characterised by urban (rather than sub-urban) residential development, where the spacing between buildings is often less than 2m. The LiDAR topographic data does not capture many ground elevations, with the modelled surface being a linear interpolation across the building footprint. This is often not representative of the local topography, which may comprise steps, terracing, solid fences and retaining walls. Local flow paths are often controlled by the presence of features at a finer scale than is represented in the model, rather than the predominant direction of surface slope.

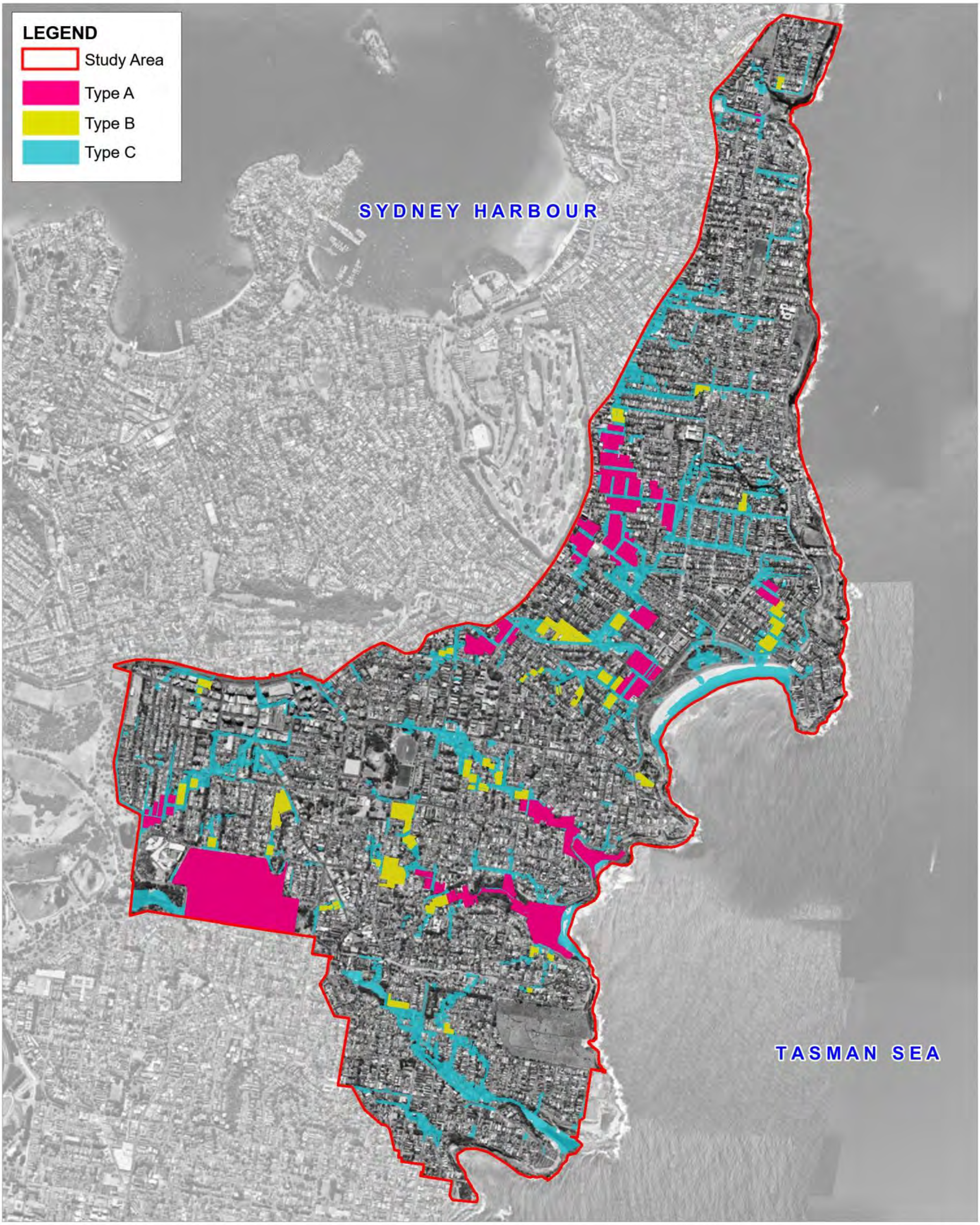
Within the modelling, most buildings have been represented through a high Manning's 'n' roughness parameter to limit flow through the building. In areas of steep topography, when modelled flow paths interface with the buildings, the flood depths increase significantly to overcome the modelled resistance. This often results in modelled peak flood depths exceeding 0.5m across the lot, which is representative of potential depths between buildings rather than unconstrained flow across the lot. Future development of Type B lots should consider principles of drainage design to enable the effective conveyance of overland flow across the lot and deter the diversion of surface water flows into the dwelling.

Type C lots are those for which the flood modelling should not be relied upon for determining the presence or absence of overland flow paths. These are typically located within steep upper catchment areas that have relatively small contributing catchments. Many lots were identified as being at risk through the modelled results and standard application of the FPA. Where flow paths through the lots could be confirmed the Type A or Type B classification has been used accordingly. However, the remaining lots did not warrant any special consideration compared to unmodelled locations, where standard planning and design considerations for development are appropriate.

A common error of commission in the initial lot-tagging by intersection of the preliminary FPA extent was the capturing of lots adjacent to a roadway that was effectively containing the overland flow. Adding a freeboard to the modelled water level surface extends the FPA into the front of lots adjacent to the road. However, the modelling suggests that the overland flows are being conveyed within the confines of the roadway and tagging of adjacent lots for flood-related development controls is not appropriate.

Another problem that is faced by the modelling in the steep upper catchment areas is where overland flow escapes the confines of the roadway and flows through properties to the new road below. Inspection of the available data and site verification suggests that overland flows would be expected to remain contained within the roadway. However, if the cross-fall through the properties is steeper than the gradient of the road then flow is encouraged to spill from the confines of the road in the model. The available LiDAR data and model resolution does not provide enough detail to fully capture the road geometry. With an elevation point every metre at best, key controls such as the kerb and gutter profile and crests of driveway entrances are not accurately represented. Whilst present in the model to some degree, localised discrepancies can result in artificial hydraulic controls. Lower down the catchment, when flow rates are higher and topographic grades are gentler, these deficiencies become negligible, but in the steep upper catchment areas they can produce modelling results that are misleading.

Unless a sag point in the road confirmed a likely flow path through downstream properties, instances of overland flow paths exiting the confines of the roadways have been treated as being too uncertain to rely upon the flood modelling results. Even if the capacity of the road to convey overland flow is exceeded during a rare enough event, the exact location of the affected properties remains uncertain. For example, local controls not captured within the available data could dictate that properties a few lots further up or down the road than those modelled are the actual spill location.



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Waverley LGA Lot Tagging

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7.7.3 Flood Insurance

It is worth noting the differences in terminology used by the floodplain risk management and insurance industries. This study refers to the accumulation of overland flows as flooding and to the hydraulic modelling used to represent this process as flood modelling. However, for the purposes of flood insurance, the current definition within NSW for "flooding" is effectively water that has escaped the confines of a natural or modified watercourse, or from a dam. There are only a few defined watercourses within the study area (such as Tamarama Gully and Bronte Gully) and so most of the inundation modelled and presented in this study would be regarded as "stormwater" for the purposes of the assessment of insurance claims.

7.8 Conduit Capacity Assessment

The simulated conduit capacity for the modelled design events are shown in Figure 7-6. The capacity assessment was undertaken using the 1D TUFLOW results for each design event, stating the percentage full capacity of each pipe within the simulation. The assessment was undertaken assuming a pipe blockage of 0% and standard pit blockage assumptions (refer Section 6.4.2).

A breakdown of the conduit capacity is shown below in Table 7-5. The table shows the percentage of pipes in the study catchments that are full (>99%) for each modelled design flood magnitude.

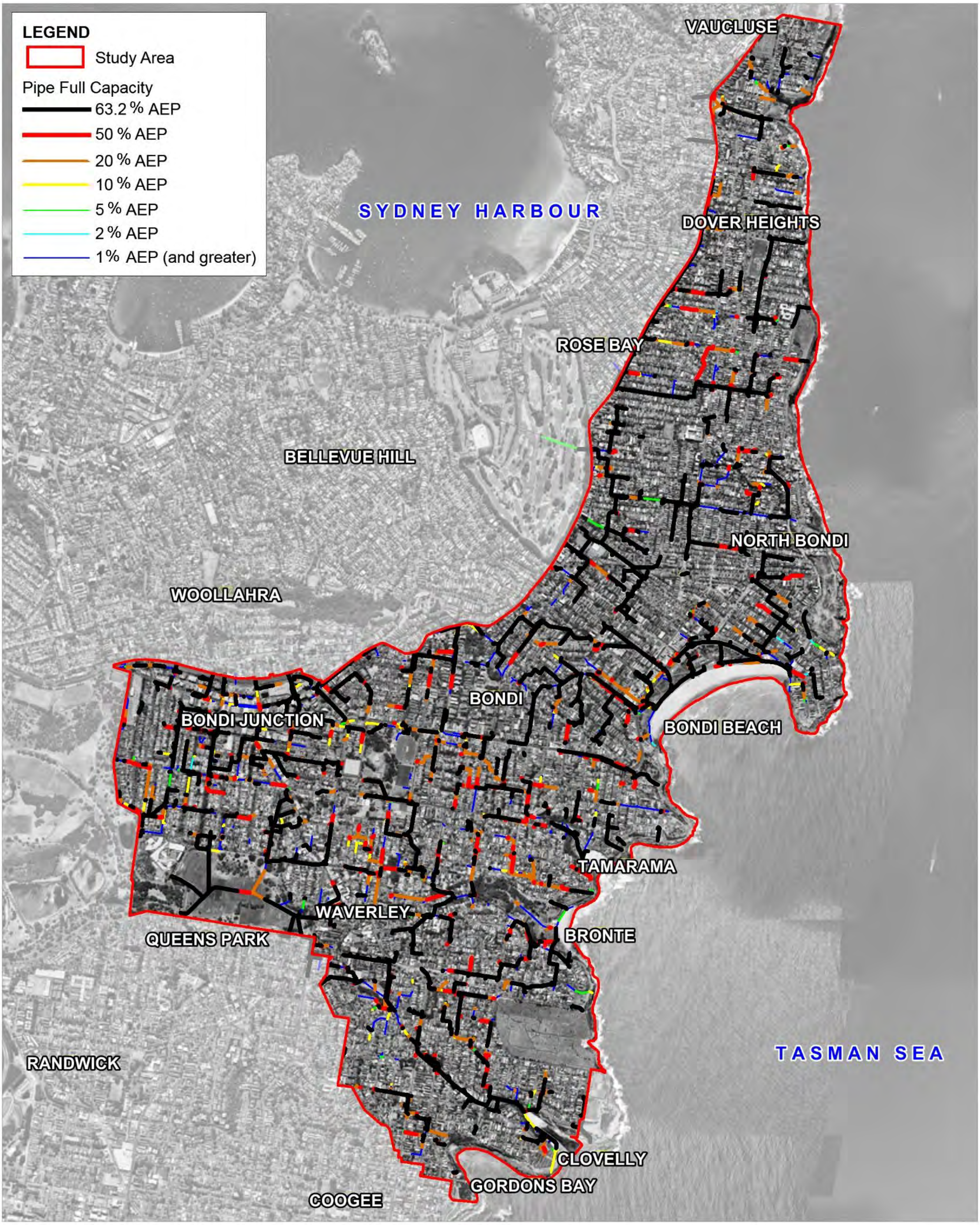
Table 7-5 Percentage of Pipes at Capacity in Varying Design Floods

Design Magnitude	Percentage of Pipes at Capacity
1EY (63.2% AEP)	55%
50% AEP	64%
20% AEP	78%
10% AEP	83%
5% AEP	85%
2% AEP	85%
1% AEP (and greater)	98%

The assessment shows that for the 1EY, 55% of pipes in the model are operating at capacity. For the 20% AEP, 78% of pipes are at capacity. For the 5% AEP and above, at least 85% of pipes are at capacity.

It must be noted that due to the hydraulic model configuration, several pipes may not indicate capacity, however, may in fact run at capacity. This is due to:

- Lengths of pipe which are retained in the model, however, are not utilised within the hydraulic calculations;
- Small catchment areas which do not generate enough flow to allow full capacity within the pipe network.



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Conduit Capacity Assessment

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7.9 Hotspot Identification

The flood modelling results were reviewed to identify 12 hotspots (i.e. locations within the study area at which there are a concentration of flood-affected properties). This section summarises the flood mechanism at each of the hotspots and identifies potential flood mitigation measures that may warrant further investigation. The identified hotspot locations include:

- William Street – Owen Street, Rose Bay;
- Glenayr Avenue – Plowman Street, North Bondi;
- Elliott Street – Bonus Street, North Bondi;
- Brassie Street – Niblick Street, North Bondi;
- Beach Road – Warners Avenue, North Bondi;
- Wallis Parade – Ramsgate Avenue, North Bondi;
- Roscoe Street – Beach Road, Bondi Beach;
- Chambers Avenue – Jaques Avenue, Bondi Beach;
- Francis Street – Simpson Street, Bondi Beach;
- Tasman Street – Tamarama Street, Bondi;
- Palmerston Avenue – Murray Street, Bronte;
- Alt Street – York Road, Queens Park.

7.9.1 William Street – Owen Street

The Williams Street – Owen Street hotspot is located in Rose Bay. Modelled peak flood depth mapping for the 1% AEP event is presented in Figure 7-7. A catchment area of about 14ha is drained along Chaleyer Street through to the Royal Sydney Golf Course via William Street and Owen Street. The trunk drainage servicing this catchment is a 750mm diameter pipe. When the capacity of the stormwater drainage is exceeded, overland flow is initiated through properties between William Street and Owen Street, as the natural flow path is not aligned along a roadway or alternative easement. The flat grade of the topography (~0.5%) produces relatively deep peak 1% AEP flood depths generally in the order of 0.4m to 0.6m, but deeper in some localised areas.

Model simulations testing increased stormwater drainage capacity resulted in only a limited reduction in modelled peak flood levels (~ 0.1m). Flood planning controls to guide future development of the affected properties likely represent the most effective flood management option.

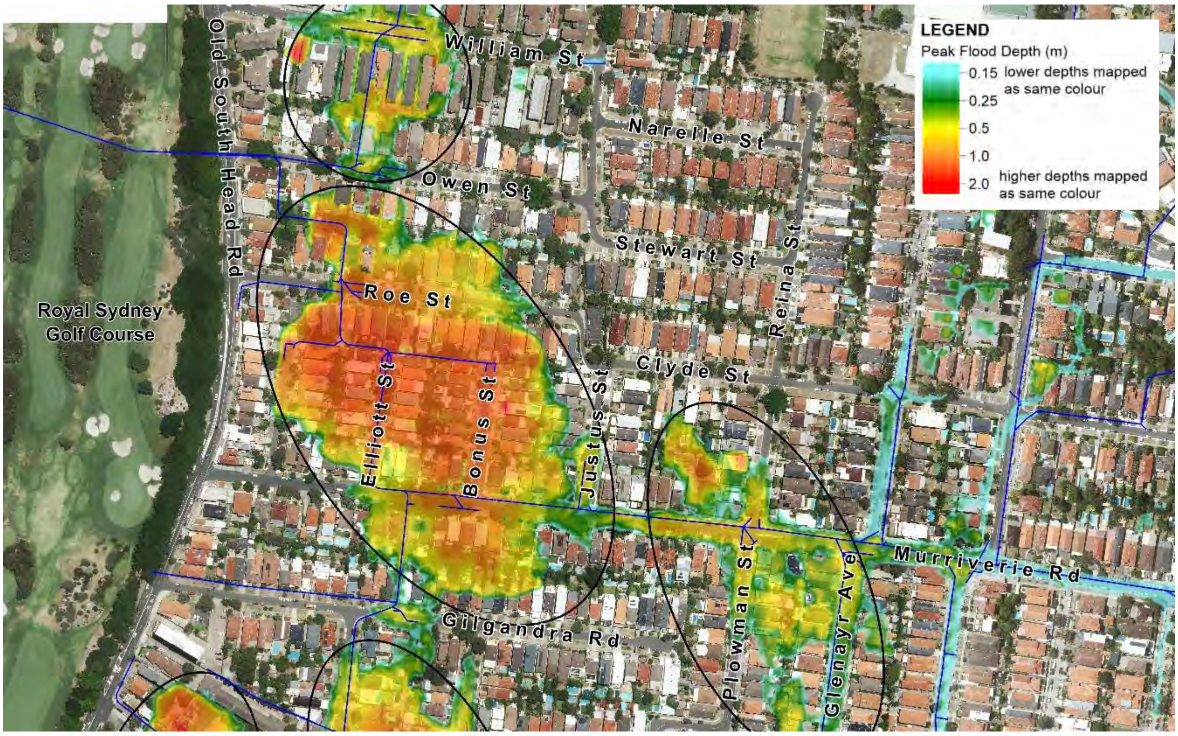

Figure 7-7 William St – Owen St, Glenayr Ave – Plowman St and Elliott St – Bonus St Hotspots

7.9.2 Glenayr Avenue – Plowman Street

The Glenayr Avenue – Plowman Street hotspot is located in North Bondi. Modelled peak flood depth mapping for the 1% AEP event is presented in Figure 7-7. A catchment area of approximately 57ha is drained along Murriverie Road through to the Royal Sydney Golf Course via Elliott Street and Owen Street. The trunk drainage servicing this catchment is a 1150mm (wide) x 900mm (high) box culvert. When the capacity of the stormwater drainage is exceeded, overland flow is initiated through properties between Glenayr Avenue and Plowman Street, as the natural topography flattens to a gentler grade (~0.5%). Peak 1% AEP floodwater depths in this area are typically 0.5m to 0.7m, but exceed 0.7m in some localised areas.

Model simulations testing increased stormwater drainage capacity resulted in only a limited reduction in modelled peak flood levels (~ 0.1m). Flood planning controls to guide future development of the affected properties likely represent the most effective flood management option.

7.9.3 Elliott Street – Bonus Street

The Elliott Street – Bonus Street hotspot is located in North Bondi. Modelled peak flood depth mapping for the 1% AEP event is presented in Figure 7-7. A catchment area of about 130ha is drained along Murriverie Road and Brassie Street through to the Royal Sydney Golf Course via Elliott Street and Owen Street. The trunk drainage servicing this catchment is a 2400mm (wide) x 1150mm (high) box culvert. When the capacity of the stormwater drainage is exceeded, surface water ponds in the natural topographic depression centred around Elliott Street and Bonus Street. Floodwaters cannot drain from the area as the ridge along Old South Head Road prevents overland flow. This produces deep flood depths of approximately 0.8m to 1.4m at the peak of the 1% AEP event.

Model simulations testing increased stormwater drainage capacity resulted in a significant reduction in modelled peak flood levels (~ 0.6m and 0.9m for a doubling and trebling of the existing drainage capacity, respectively). Therefore, stormwater drainage upgrades warrant further investigation. Otherwise, flood planning controls to guide future development of the affected properties would also provide an effective flood management option.

An alternative consideration is that the local topographic depression is naturally well-drained by sandy soils and that the modelled flood depths are overestimated. This was found to be the case for the Rainbow Street hotspot in the Coogee Bay Catchment of the Randwick LGA. A hotspot specific investigation including soil drainage testing was able to confirm this and the flood modelling and mapping was revised.

7.9.4 Brassie Street – Niblick Street

The Brassie Street - Niblick hotspot is located in North Bondi. Modelled peak flood depth mapping for the 1% AEP event is presented in Figure 7-8. A catchment area of about 46ha is drained along Warners Avenue and Brassie Street through to the Royal Sydney Golf Course via Elliott Street and Owen Street. The trunk drainage servicing this catchment is a 1450mm (wide) x 900mm (high) box culvert. When the capacity of the stormwater drainage is exceeded, surface water ponds in the natural topographic depression centred around Brassie Street and Niblick Street. The overland flow of floodwaters is prohibited by the ridge along Gilgandra Road. This produces deep peak flood depths of approximately 0.5m to 1.0m during the 1% AEP flood.

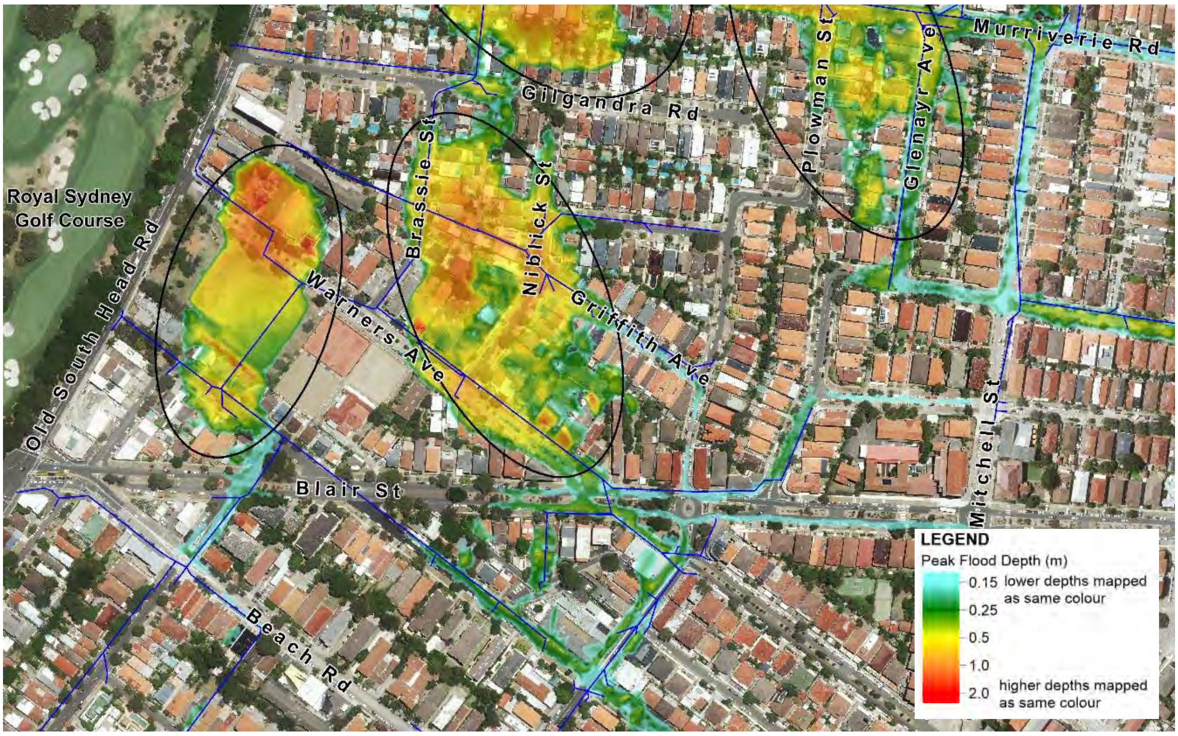

Figure 7-8 Brassie St – Niblick St and Beach Rd – Warners Ave Hotspots

Model simulations testing increased stormwater drainage capacity resulted in a significant reduction in modelled peak flood levels (~ 0.2m and 0.4m for a doubling and trebling of the existing drainage capacity, respectively). Thus, stormwater drainage upgrades warrant further investigation.

Otherwise, flood planning controls to guide future development of the affected properties would also provide an effective flood management option.

An alternative consideration is that the local topographic depression is naturally well-drained by sandy soils and that the modelled flood depths are overestimated. This was found to be the case for the Rainbow Street hotspot in the Coogee Bay Catchment of the Randwick LGA. A hotspot specific investigation including soil drainage testing was able to confirm this and the flood modelling and mapping was revised.

7.9.5 Beach Road – Warners Avenue

The Beach Road – Warners Avenue hotspot is located in North Bondi. Modelled peak flood depth mapping for the 1% AEP event is presented in Figure 7-8. A catchment area of about 17ha is drained along Wellington Street and Brassie Street through to the Royal Sydney Golf Course via Elliott Street and Owen Street. The trunk drainage servicing this catchment is an 800mm (wide) x 900mm (high) box culvert. When the capacity of the stormwater drainage is exceeded, surface water ponds in the natural topographic depression centred around Beach Road and Warners Avenue. The overland flow of floodwaters is prohibited by the ridge to the west of Brassie Street. This produces deep peak flood depths of approximately 0.5m to 1.2m during the 1% AEP event.

Model simulations testing increased stormwater drainage capacity resulted in a significant reduction in modelled peak flood levels (~ 0.3m and 0.5m for a doubling and trebling of the existing drainage capacity, respectively). Therefore, stormwater drainage upgrades warrant further investigation. However, the improved drainage may be linked to that of the adjacent Brassie Street – Niblick Street hotspot, from which the tailwater level controls the flood levels in Warners Avenue. Otherwise, flood planning controls to guide future development of the affected properties would also provide an effective flood management option.

An alternative consideration is that the local topographic depression is naturally well-drained by sandy soils and that the modelled flood depths are overestimated. This was found to be the case for the Rainbow Street hotspot in the Coogee Bay Catchment of the Randwick LGA. A hotspot specific investigation including soil drainage testing was able to confirm this and the flood modelling and mapping was revised.

7.9.6 Wallis Parade – Ramsgate Avenue

The Wallis Parade – Ramsgate Avenue hotspot is located in North Bondi. Modelled peak flood depth mapping for the 1% AEP event is presented in Figure 7-9. A catchment area of about 37ha is drained along Wallis Parade through to Bondi Beach via Hastings Parade, Brighton Boulevard and Ramsgate Avenue. The trunk drainage servicing this catchment are 750mm and 900mm diameter pipes upstream and downstream of Brighton Boulevard, respectively. When the capacity of the stormwater drainage is exceeded, overland flow is initiated through properties between Wallis Parade and Ramsgate Avenue, as the natural flow path is not aligned along a roadway or alternative easement. The flat grade of the topography (~0.5%) upstream of Hastings Parade results relatively deep peak 1% AEP flood depths of about 0.4m to 0.8m, in general, but depths may be deeper in localised areas.

Model simulations testing increased stormwater drainage capacity resulted in a moderate reduction in modelled peak flood levels (~ 0.1m and 0.2m for a doubling and trebling of the existing drainage capacity, respectively). Thus, stormwater drainage upgrades warrant further investigation. There is also the potential to investigate the utilisation of Williams Park for upstream flood detention storage. Otherwise, flood planning controls to guide future development of the affected properties would also provide an effective flood management option.

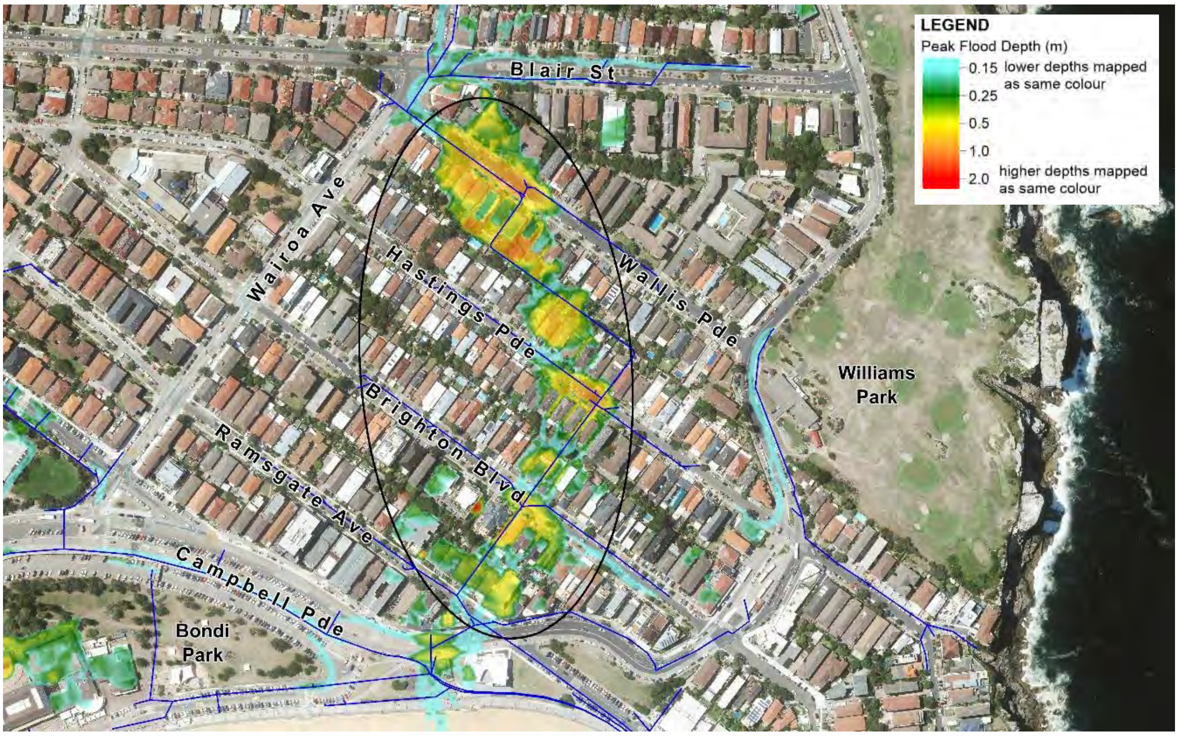

Figure 7-9 Wallis Parade – Ramsgate Ave Hotspot

7.9.7 Roscoe Street – Beach Road

The Roscoe Street – Beach Road hotspot is located in Bondi Beach. Modelled peak flood depth mapping for the 1% AEP event is presented in Figure 7-10. A catchment area of approximately 60ha is drained along O'Brien Street and Roscoe Street through to Bondi Beach via Gould Street and Campbell Parade. The trunk drainage servicing this catchment is a 1350mm diameter pipe at Glenayr Avenue. When the capacity of the stormwater drainage is exceeded, overland flow is initiated through properties between Roscoe Street and Beach Road, as the natural flow path is not aligned along a roadway or alternative easement, with a topographic depression also present between Curlewis Street and Beach Road. Flooding is typically between 0.3m and 0.8m deep at the peak of the 1% AEP flood, but exceeds 2m in localised topographic depressions.

Model simulations testing increased stormwater drainage capacity resulted in a moderate reduction in modelled peak flood levels (~ 0.2m for a doubling of the existing drainage capacity and up to 0.8m within the topographic depression when trebling the existing drainage capacity). Therefore, stormwater drainage upgrades therefore warrant further investigation. There is also the potential to investigate the utilisation of Thomas Hogan Reserve and Dickson Park for upstream flood detention storage. Otherwise, flood planning controls to guide future development of the affected properties would also provide an effective flood management option.

An alternative consideration is that the local topographic depression is naturally well-drained by sandy soils and that the modelled flood depths are overestimated. This was found to be the case for the Rainbow Street hotspot in the Coogee Bay Catchment of the Randwick LGA. A hotspot specific investigation including soil drainage testing was able to confirm this and the flood modelling and mapping was revised.

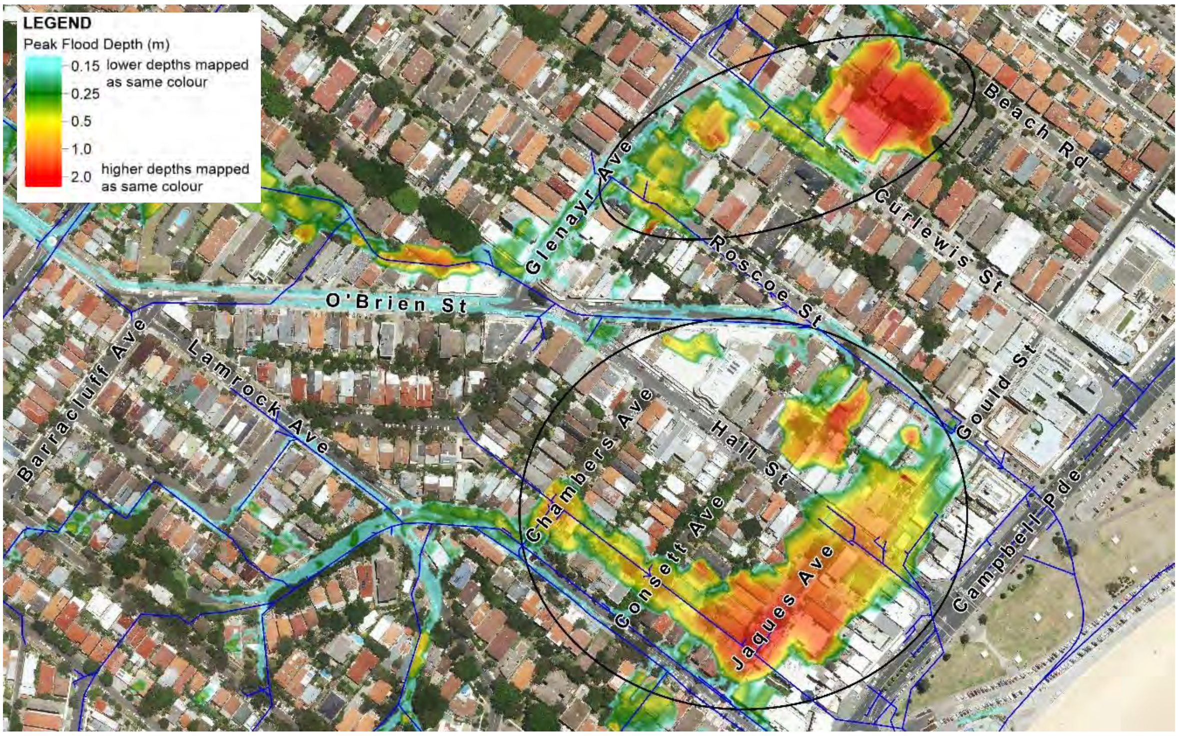

Figure 7-10 Roscoe St –Beach Rd and Chambers Ave – Jaques Ave Hotspots

7.9.8 Chambers Avenue – Jaques Avenue

The Chambers Avenue – Jaques Avenue hotspot is located in Bondi Beach. Modelled peak flood depth mapping for the 1% AEP event is presented in Figure 7-10. A catchment area of approximately 48ha is drained along Lamrock Avenue through to Bondi Beach, also via Chambers Avenue, Consett Avenue and Jaques Avenue. The trunk drainage servicing this catchment is twin 675mm diameter pipes and a 1650mm (wide) x 1050mm (high) box culvert along Lamrock Avenue. Additional drainage is provided from Jaques Avenue via a 750mm diameter pipe and from Hall Street via a 375mm diameter pipe. When the capacity of the stormwater drainage is exceeded, overland flow is initiated through properties between Chambers Avenue and Jaques Avenue as the natural flow path is not aligned along a roadway or alternative easement, with a topographic depression also present between Jaques Avenue, behind the ridge of Campbell Parade. Flooding is relatively deep in this area. Generally, peak 1% AEP flood depths are between 0.5m and 1.0m, but can reach about 2.0m in local topographic depressions.

Model simulations testing increased stormwater drainage capacity resulted in a significant reduction in modelled peak flood levels (~ 0.2m to 0.6m for a doubling of the existing drainage capacity and up to 1.2m within the topographic depression when trebling the existing drainage capacity). Thus, stormwater drainage upgrades warrant further investigation. Otherwise, flood planning controls to guide future development of the affected properties would also provide an effective flood management option.

An alternative consideration is that the local topographic depression is naturally well-drained by sandy soils and that the modelled flood depths are overestimated. This was found to be the case for the Rainbow Street hotspot in the Coogee Bay Catchment of the Randwick LGA. A hotspot specific investigation including soil drainage testing was able to confirm this and the flood modelling and mapping was revised.

7.9.9 Francis Street – Simpson Street

The Francis Street – Simpson Street hotspot is located in Bondi Beach. Modelled peak flood depth mapping for the 1% AEP event is presented in Figure 7-11. A catchment area of approximately 39ha is drained along Francis Street and Simpson Street through to Bondi Beach via O'Brien Street and Roscoe Street. The trunk drainage servicing this catchment is a 1050mm diameter pipe. When the capacity of the stormwater drainage is exceeded, surface water ponds along Simpson Street in the topographic depression formed behind O'Brien Street. Flooding is relatively deep at about 0.5m to 2.0m at the peak of the 1% AEP flood.

Model simulations testing increased stormwater drainage capacity resulted in a significant reduction in modelled peak flood levels (~ 0.2m and 0.5m for a doubling and trebling of the existing drainage capacity, respectively). Therefore, stormwater drainage upgrades warrant further investigation. There is also the potential to investigate the utilisation of Thomas Hogan Reserve and Dickson Park for upstream flood detention storage. Otherwise, flood planning controls to guide future development of the affected properties would also provide an effective flood management option.

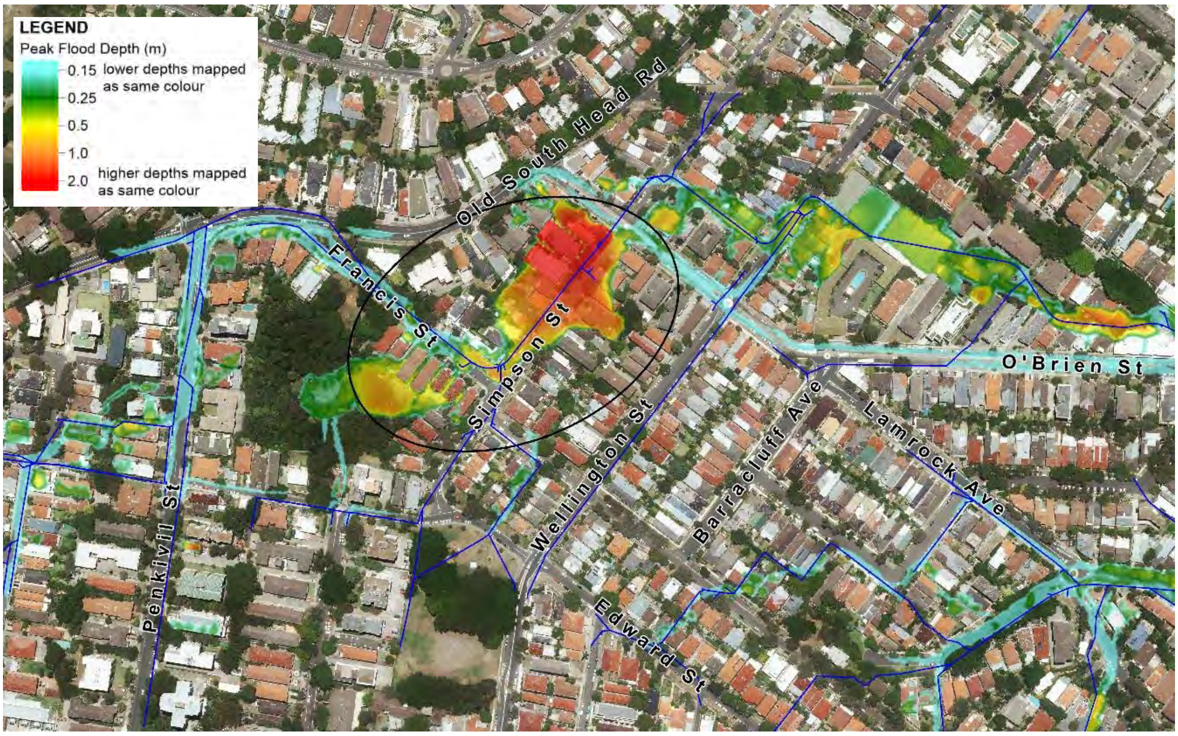

Figure 7-11 Francis St – Simpson St Hotspot

7.9.10 Tasman Street – Tamarama Street

The Tasman Street – Tamarama Street hotspot is located in Bondi. Modelled peak flood depth mapping for the 1% AEP event is presented in Figure 7-12. A catchment area of approximately 46ha is drained along Philip Street and Tamarama Street through to Tamarama Beach via Tamarama Park. The trunk drainage servicing this catchment is a 1500mm diameter pipe. When the capacity of the stormwater drainage is exceeded, surface water ponds along Tamarama Street in the topographic depression formed behind Illawong Avenue. Overland flow through properties between Tasman Street and Tamarama Street is also initiated through spilling from ponded surface water in a topographic depression on Tasman Street. Flooding is relatively deep at approximately 0.4m to 0.7m (typically) at the peak of the 1% AEP event.

Model simulations testing increased stormwater drainage capacity resulted in a moderate reduction in modelled peak flood levels (~ 0.1m and 0.3m for a doubling and trebling of the existing drainage capacity, respectively). Therefore, stormwater drainage upgrades warrant further investigation. There is also the potential to investigate the utilisation of Waverley Oval for upstream flood detention storage. Otherwise, flood planning controls to guide future development of the affected properties would also provide an effective flood management option.

Figure 7-12 Tasman St – Tamarama St Hotspot

7.9.11 Palmerston Avenue – Murray Street

The Palmerston Avenue – Murray Street hotspot is located in Bronte. Modelled peak flood depth mapping for the 1% AEP event is presented in Figure 7-13. A catchment area of about 60ha is drained along Palmerston Avenue through to Bronte Beach via Murray Street and Bronte Gully. The trunk drainage servicing this catchment is a 1350mm diameter pipe. When the capacity of the stormwater drainage is exceeded, overland flow is initiated through properties between Palmerston

Avenue and Murray Street, as the natural flow path is not aligned along a roadway or alternative easement. Water also ponds in Dickson Street within a topographic depression formed behind Murray Street. Flooding is relatively deep, typically between 0.7m and 1.2m at the peak of the 1% AEP flood, but may exceed 2.0m in localised topographic depressions.

Model simulations testing increased stormwater drainage capacity resulted in a moderate reduction in modelled peak flood levels (~ 0.2m for a doubling of the existing drainage capacity and up to 0.5m within the topographic depression when trebling the existing drainage capacity). Therefore, stormwater drainage upgrades warrant further investigation. Otherwise, flood planning controls to guide future development of the affected properties would also provide an effective flood management option.

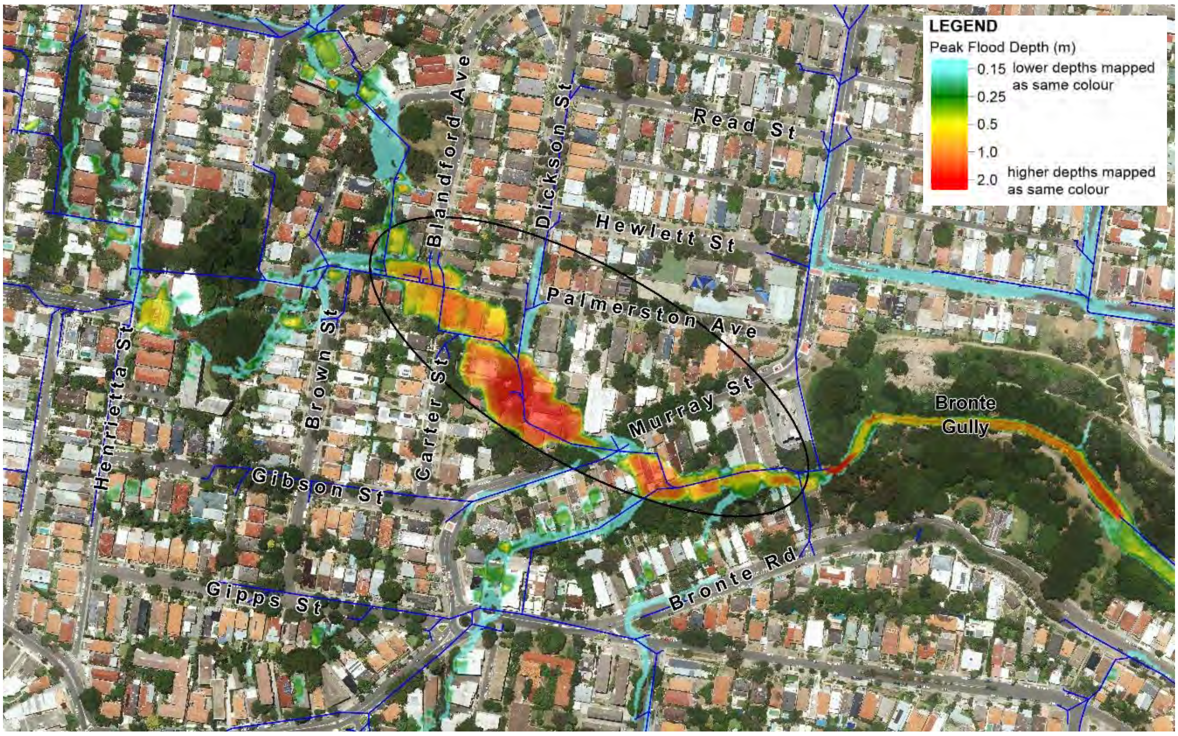

Figure 7-13 Palmerston Ave – Murray St Hotspot

7.9.12 Alt Street – York Road

The Alt Street – York Road hotspot is located in Queens Park. Modelled peak flood depth mapping for the 1% AEP event is presented in Figure 7-14. A catchment area of approximately 56ha is drained along Birrell Street and Alt Street through to Centennial Park via Denison Street and York Road. The trunk drainage servicing this catchment is a 1700mm (wide) x 1150mm (high) box culvert from Alt Street and an additional 1550mm (wide) by 1000mm (high) box culvert from Denison Street. When the capacity of the stormwater drainage is exceeded, overland flow is initiated through properties between Alt Street and York Road, as the natural flow path is not aligned along a roadway or alternative easement. Flooding is relatively deep, generally between 0.3m to 0.8m, but locally deeper in some areas during the 1% AEP event.

Model simulations testing increased stormwater drainage capacity resulted in a significant reduction in modelled peak flood levels (~ 0.2m and 0.4m for a doubling and trebling of the existing drainage capacity, respectively). Therefore, stormwater drainage upgrades warrant further investigation. Otherwise, flood planning controls to guide future development of the affected properties would also provide an effective flood management option.

Figure 7-14 Alt St – York Rd Hotspot

8 Sensitivity Testing

A number of sensitivity tests were undertaken to identify the sensitivity of the model to changes in parameters and the level of uncertainty associated with the model results. The sensitivity of the results to the following parameters was assessed:

- Modelled stormwater drainage blockages;
- Catchment surface roughness;
- Tailwater conditions;
- Climate change impacts (i.e. increased rainfall intensity).

Peak modelled flood levels for the above sensitivity tests are presented in Table 8-1. Mapping of changes in peak flood levels for all sensitivities are presented within the Flood Mapping Compendium.

Please note that sensitivity assessments were completed for the 1% AEP design event (and also the 5% AEP design event in some cases). The 1% AEP sensitivity runs all applied a 1% AEP design downstream water level unless stated otherwise. Additionally, all mapping of sensitivities shows unfiltered model results to sufficiently reflect response of the modelling results to varying conditions.

8.1 Stormwater Drainage Blockages

Structure blockage is an important consideration of the design flood modelling. A detailed sensitivity analysis of pipe blockage was undertaken to select the most appropriate value for use in design flood modelling. Blockages were assessed using a total of four separate model simulations that applied:

- 25% blockage to the stormwater drainage network (pipes and culverts);
- 50% blockage to the stormwater drainage network (pipes and culverts);
- 75% blockage to the stormwater drainage network (pipes and culverts);
- 100% blockage to the stormwater drainage network (pipes and culverts).

The Flood Mapping Compendium presents the spatial distribution of peak blockage impacts for each of the modelled blockage conditions against a base case (0% blockage) for the 1% AEP and 5% AEP events. The mapping indicates that the key areas affected by conduit blockage are predominantly located in the trapped basins, especially around the Bondi and North Bondi areas. Increases in peak flood level in the trapped low-points are particularly exacerbated as the stormwater network represents the only opportunity for these regions to drain. In overland flooding areas, there are limited increases to peak flood levels due to the relatively steep catchment slopes.

It must be noted that the likelihood of pipe blockage in the study area is low, due to the limited opportunity for blockage materials to enter the drainage network because there are no open channels or waterways. Furthermore, consideration of pit blockage already being applied (50% sag pits and 20% on-grade) may result in a ‘compounding’ of blockage assumptions.

8.2 Channel and Floodplain Roughness

The sensitivity of modelled peak flood levels to the adopted Manning's 'n' roughness values were tested for the 1% and 5% AEP design floods. Roughness values for all material types within the channel and floodplain were increased and decreased by 25%.

It is evident from mapped results within the Flood Mapping Compendium that peak flood levels around the study area have little sensitivity dependant on the adopted hydraulic roughness values. For both the 5% and 1% AEP events, changes in peak levels were largely ±0.02m with some storage areas having reduction of 0.05m and conveyance driven areas with increases of 0.05 AHD.

8.3 Ocean Boundary Water Levels

The adopted downstream boundary conditions were discussed in Section 6.3. To assess the sensitivity of the model to tailwater levels, increased and decreased ocean boundary water levels were modelled for the 5% and 1% AEP events.

For the 5% AEP event, downstream water level sensitivities were undertaken by implementing the ISLW water level (-0.95m AHD) and the 1% AEP downstream water level (2.35m AHD). For the 1% AEP event, downstream water level sensitivities were undertaken by implementing the ISLW water level (-0.95m AHD) and the PMF downstream water level (2.55m AHD).

As shown in the Flood Mapping Compendium, modifying the downstream water level does not have any effect on flood behaviour within those areas not immediately adjacent to the ocean. Changes in regions adjacent to the ocean boundaries are proportional to the change in the applied downstream water level.

8.4 Climate Change

The potential for climate change impacts is now a key consideration for floodplain management. Current guidelines predict that a likely outcome of future climatic change will be an increase in extreme rainfall intensities. The NSW Government released a guideline (DECC, 2007) for Practical Consideration of Climate Change in the floodplain management process that advocates consideration of increased design rainfall intensities of up to 30%. In line with this guidance, additional tests incorporating 10%, 20% and 30% increases to design rainfall have been undertaken. This assessment found the following:

- A 10% increase in rainfall intensities is predicted to result in a typical increase in peak 1% AEP flood levels of 0.07m;
- A 20% increase in rainfall intensity is predicted to result in a typical increase in peak 1% AEP flood level of 0.15m;
- A 30% increase in rainfall intensity is predicted to result in a typical increase in peak 1% AEP flood level of 0.21m;
- The modelled peak flood levels are most sensitive to increased rainfall intensity within the topographic depressions, where the total volume of floodwater is a significant component.

Peak modelled flood levels associated with these scenarios are presented in Table 8-1.

Table 8-1 Summary of Model Sensitivity Results – 1% AEP

ID	Modelled Peak Flood Level (m AHD) – Sensitivity to Adopted 1% AEP Design Condition											
	Adopted Design	25% blocked	50% blocked	75% blocked	100% blocked	-25% ‘n’	+25% ‘n’	ISLW Water Level	PMF Water Level	+10% Rainfall	+20% Rainfall	+30% Rainfall
1	10.98	10.99	11.00	11.22	11.40	10.97	10.98	10.98	10.98	11.02	11.05	11.08
2	10.39	10.70	11.00	11.23	11.40	10.44	10.35	10.40	10.39	10.63	10.85	11.05
3	10.40	10.70	11.00	11.23	11.40	10.44	10.36	10.40	10.40	10.63	10.85	11.05
4	12.00	12.02	12.04	12.06	12.08	11.99	12.00	12.00	12.00	12.06	12.11	12.17
5	11.28	11.35	11.41	11.45	11.47	11.29	11.28	11.28	11.28	11.37	11.45	11.53
6	11.22	11.28	11.33	11.36	11.41	11.22	11.23	11.22	11.22	11.29	11.33	11.37
7	11.23	11.29	11.33	11.37	11.41	11.22	11.23	11.23	11.23	11.29	11.34	11.38
8	16.92	16.93	16.94	16.95	16.96	16.91	16.92	16.92	16.92	16.97	17.01	17.06
9	14.89	14.91	14.93	14.95	14.96	14.91	14.89	14.89	14.89	14.95	15.00	15.04
10	12.26	12.29	12.32	12.35	12.37	12.24	12.28	12.26	12.26	12.32	12.38	12.43
11	15.76	15.78	15.80	15.81	15.82	15.75	15.77	15.76	15.76	15.79	15.82	15.83
12	15.72	15.87	16.00	16.01	16.09	15.74	15.71	15.72	15.72	15.85	15.95	16.01
13	15.72	15.87	16.00	16.01	16.09	15.74	15.70	15.72	15.72	15.85	15.95	16.01
14	17.75	17.78	17.81	17.84	17.85	17.68	17.79	17.75	17.75	17.79	17.83	17.86
15	38.06	38.11	38.15	38.18	38.21	38.06	38.06	38.06	38.06	38.13	38.21	38.27
16	57.59	57.60	57.63	57.67	57.69	57.56	57.61	57.59	57.59	57.62	57.66	57.70
17	42.53	42.57	42.61	42.66	42.69	42.49	42.54	42.53	42.53	42.60	42.69	42.77
18	41.17	41.22	41.29	41.35	41.40	41.19	41.16	41.17	41.17	41.27	41.40	41.52
19	47.76	47.81	47.87	47.91	47.97	47.76	47.75	47.76	47.76	47.81	47.88	47.94
20	47.20	47.25	47.31	47.36	47.40	47.23	47.17	47.20	47.20	47.25	47.32	47.38
21	47.12	47.14	47.16	47.17	47.19	47.11	47.13	47.12	47.12	47.15	47.18	47.21
22	19.80	19.84	19.88	19.95	19.93	19.78	19.82	19.80	19.80	19.86	19.92	19.98
23	33.08	33.16	33.24	33.32	33.40	33.10	33.06	33.08	33.08	33.14	33.21	33.28
24	12.84	12.85	12.86	12.83	12.87	12.82	12.85	12.84	12.84	12.86	12.88	12.90
25	41.22	41.24	41.25	41.26	41.26	41.22	41.22	41.22	41.22	41.25	41.27	41.30

9 Conclusions and Recommendations

The primary objective of this flood study was to define the flood behaviour within the study area under historical, existing and future conditions (incorporating potential impacts of climate change). Central to this has been the development of appropriate hydrologic and hydraulic models. In completing the study, the following tasks have been undertaken:

- Compilation and review of existing information pertinent to the study and acquisition of additional data (where necessary);
- Community consultation and participation program that included the identification of local flooding concerns, collection of information on historical flood behaviour, and engagement of the community in the on-going floodplain management process;
- Development and calibration/verification of appropriate hydrologic and hydraulic models;
- Determination of design flood conditions for a range of design events, including the 1EY (63.2% AEP), 50% AEP, 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.2% AEP and PMF events;
- Assessment of the potential impact of climate change using the latest guidelines;
- Design flood mapping to visualise the potential flood inundation and associated flood risks across the study area;
- Determination of flood emergency response considerations, including identifying roads that may not be trafficable by heavy vehicles during the peak of a flood event and individual properties that are considered unsafe for onsite refuge.
- Derivation of a Flood Planning Area (FPA) and identification of flood control lots;
- Identification and preliminary assessment of 12 flooding “hotspot” locations where there is a concentration of flood-affected properties, including:
  - William Street – Owen Street, Rose Bay;
  - Glenayr Avenue – Plowman Street, North Bondi;
  - Elliott Street – Bonus Street, North Bondi;
  - Brassie Street – Niblick Street, North Bondi;
  - Beach Road – Warners Avenue, North Bondi;
  - Wallis Parade – Ramsgate Avenue, North Bondi;
  - Roscoe Street – Beach Road, Bondi Beach;
  - Chambers Avenue – Jaques Avenue, Bondi Beach;
  - Francis Street – Simpson Street, Bondi Beach;
  - Tasman Street – Tamarama Street, Bondi;
  - Palmerston Avenue – Murray Street, Bronte;

- Alt Street – York Road, Queens Park.

The key study outputs include a full suite of flood risk mapping, incorporating peak flood depth, flow velocity, flood hazard and flood function, as well as mapping of the derived Flood Planning Area and lot-tagging. These are presented in the Flood Mapping Compendium.

This report and the key mapping outputs help to define the flood behaviour in the study area and establish the basis for subsequent floodplain management activities. Future investigations and potential floodplain risk management should be aimed at reducing the flood risk in the identified hotspot locations, where possible.

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Appendix A Community Consultation Materials

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Ultimo, Sydney 2007
Australia

Tel: +61 2 8960 7755
Fax: +61 2 8960 7745

ABN 54 010 830 421

www.bmtwbm.com.au

Our Ref: Waverley_LGA_Letter_to_Council

1 November 2017

55 Spring Street
Bondi Junction
NSW 2022

Dear Resident

RE: WAVERLY LGA FLOOD STUDY INITIAL COMMUNITY CONSULTATION

Waverley Council is calling on residents and business owners to share their ideas to improve flood management in the Waverley Local Government Area.

Council has recently commissioned engineering consultants BMT WBM to undertake a comprehensive Flood Study of the Waverley Local Government Area (LGA). The Flood Study forms an initial stage towards the development of a comprehensive Floodplain Risk Management Study and Plan, in accordance with the NSW Floodplain Development Manual (2005). Council has taken the initiative to carry out the Flood Study to assist with managing the risk the community faces from flooding. The Waverley LGA Flood Study is expected to be completed by late 2018 and will guide the direction of future floodplain management actions in Waverley.

The Flood Study is in its inception stage where the consultants are collecting and collating data on flooding and the catchment. These data will be essential for the development of detailed rainfall/runoff (hydrology) and flood (hydraulic) models. The models will provide the technical analysis required for the flood study and future development of the Floodplain Risk Management Plan.

Council and BMT WBM are eager to receive any comments and information for the project from the community within the Waverley LGA catchments. The participation of the community is essential to the success of the study, particularly when it comes to flood information.

If you have any information on flooding such as photographs, stories or flood marks on or near your property, or wish to make a comment on flooding, you can provide your comments by completing the flood questionnaire which will be posted to residents within the Waverley LGA in the coming weeks. The questionnaire and details of the study will also be made available at haveyoursaywaverley.com.au. Feedback will be accepted until 22 December 2017.

For enquiries phone Minas Kassiou, Manager Design and Project Coordinator at Waverley Council on (02) 9083 8679 or email minas.kassiou@waverley.nsw.gov.au.

This project was supported by the NSW Government's Floodplain Management Program.

Yours Faithfully
BMT WBM

Sebastian Froude

Waverley LGA Flood Study

Community Questionnaire 2017

Your feedback is valued

The Waverley Council is undertaking a detailed flood study to understand the risks within the Waverley Local Government Area (LGA). We are seeking the community's help by collecting information on any flooding or drainage problems that you may have experienced in the past.

Please take a minute or two to read through these questions and provide responses wherever you can. Please return this form to Council's consultant in the enclosed envelope (no stamp required) by **22 December 2017**. All information provided is confidential and used only for the purposes of the study. For more information or to complete the questionnaire online please visit:

HAVEYOURSAYWAVERLEY.COM.AU

Contact and Property Details (Optional)

Do you give permission for the study team to contact you? ☐ Yes ☐ No

Name: ………

Address:……

Phone or email:…………………………………………………………………………………………………

Please tick your type of property :

☐ House ☐ Unit/Flat/Apartment

☐ Business ☐ Other (please specify)

…………………………………………………………………………

How long have you been at this property?

Years: ………………………… Months: …………………………

Previous Flooding Experience

Are you aware of stormwater flooding from streets or channels in your catchment?

☐ Aware ☐ Some knowledge ☐ Not aware

Have you ever been inconvenienced by uncontrolled floodwater/stormwater from streets or channels?

☐ Yes ☐ No

If yes, please provide more detail in the space provided below.

Waverly LGA Flood Study

Community Questionnaire 2017

Please indicate how uncontrolled floodwater/stormwater has inconvenienced you:

☐ Daily routine was affected (e.g. it was difficult to get to work)

☐ Safety was threatened

☐ Access to property was affected (e.g. driveways or roads flooded)

☐ Property and/or its contents were damaged

☐ Business was unable to operate during the flooded period

☐ Other

Please provide more detail/dates or if other please specify:

....

....

Has your home or other property been flooded because of uncontrolled floodwater/stormwater from streets or channels?

☐ Yes ☐ No

If Yes, was your property flooded, and when did it happen?

☐ Front yard or backyard

☐ Garage or shed

☐ Residential (below floor level)

☐ Residential (above floor level)

☐ Commercial (e.g. shops, below floor level)

☐ Commercial (e.g. shops, above floor level)

☐ Industrial (e.g. factories)

☐ Other

Please provide more detail/dates or if other please specify:

....

Waverly LGA Flood Study

Community Questionnaire 2017

Have you ever experienced flooding on your street?

☐ Yes – across one or both lanes of traffic

☐ Yes – minor along gutters

☐ No

If yes, does this occur regularly? **Y / N**
(i.e. several times a year)

Are you able to indicate the depth that flood waters reached on your property or elsewhere such as roads?

………

Did you notice any culverts, drains and/or stormwater inlets that were blocked during the flooding?

☐ Yes ☐ No

If Yes, please provide more detail where possible:

☐ Partially blocked ☐ Fully blocked

Do you know what was causing the blockage?

………

Photographs and Video

Do you have any photographs or video of flooding that you are willing to share?

☐ Yes ☐ No

Photographs and video can be returned with this form or emailed to:

WaverleyFS@bmtwbm.com.au

Are there any flooding issues you would like the study to consider?

………

………

Please provide any additional comments or information that you think will help the study.

………

………

Are you interested in taking part in the Floodplain Risk Management Committee? This Committee will oversee the floodplain risk management process.

☐ Yes

☐ No

If yes, please provide your contact details on the first page for our staff to contact you.

THANK YOU for providing this information. Please remember to place all in an envelope and send to PO Box 9, Bondi Junction 1355 by 22 December 2017. A representative from BMT WBM may contact you in the near future to discuss your response.

If you are willing to share photographs and videos of flooding with the study team, these can be returned with this form or e-mailed to WaverleyFS@bmtwbm.com.au

Privacy notice: The information obtained form the Waverly LGA Flood Study questionnaire will be used by staff at Waverly Council and BMT WBM only. The information will be stored on Council's file for the duration of the project.

Appendix B Community Drop-in Sessions: Summary of Responses

Hot-Spot Location	Suburb	Community Responses/Comments
Craig Ave	Vaucluse	• Council made an improvement in street drainage • Craig Avenue is lowest point from 3 directions • Flooded 3 times in garage – neighbours had to claim insurance for their garage • April 2015: cars were inundated, water coming out from the drain outside neighbour's place into the garage • Flooding twice in one year • Jan 2016 – the water came all the way to the garage door • Flooding has never overtopped road • Flood extents reached edge of garage just near the opening at #8 • Resident did not receive the flood study survey last year • Suggested residents should be notified through the neighbourhood Precincts ♦ There is information on the website for contact details ♦ Conveners for different areas
Wallis Parade	North Bondi	38 Wallis • The street drains are not cleared regularly by council • During floods water levels on Wallis Parade have reached above the wheel of cars, as such cars have been written off Water has come into the lobby • Water levels reached an inch from the door step in the Dec 2015 flooding • Water flows down the side of the building and pools in the backyard, it also goes into the shed and the laundry • The property has flooded three times since the residents moved in (late 2015) • During the flooding, residents had to physically remove debris from drains • There has been a recent development next door, and the house behind. The lot behind is approximately 0.5 m higher than 36 Wallis Parade. • A pipe was built in the 80s between 28 and 40 Wallis Parade, but apparently it is not connected to the infrastructure • Have sand bags ready to be used to stop flood waters entering the property if there has been heavy rainfall • Have considered flood proofing doors but it is very expensive to do so • Big flood occurred 30 years ago. During this flood the laundry flooded to the extent that there were floating appliances • The peak water level during the flood reached just under the car window parked on the Wallis Parade. • Old maps show an easement between 38 and 40 Wallis Parade. • Have noticed that the impervious surfaces in the area have increased over time • When the gutter is clean the flood waters do flow into them • Flood water takes about 2-6 hours to reside after the storm event • Flash flooding occurs on Wallis Parade– the flooding happens very quickly 42b Wallis • Have photo evidence of flooding occurring on Wallis Parade • Have lived at the property for 5 years • Cars on Wallis Parade have been flooded • Needed to raise shelves in the garage due to flooding • The flooding does not get into the house, but it does reach up to the stairs leading to the house • The house behind the property was recently built and was raised 1.5m
Curlewis St	Bondi Beach	• The inlet at the front of property is the only inlet on the street (on the side of the road of the property) • The inlet at the front of the property is always blocked with leaves, plastic and paper • Water levels during flooding reached 1m • The property has pumps which pumps excess water into the retention tank under the balcony • The basement floods to levels up to 1m

		• The flooding starts from past Glenayr Avenue • Has been telling council about flooding for past 15 years • The property was completed in 2012 • In the plant room the circuit has been submerged under water during flood events • The basement in this property was the first basement in the area
Curlewis St	Bronte	• During the 2013 flood events, all units and the basement in the property flooded. As a result, the owners raised a hump before the entry into the property • In 2011/12 a gutter was built outside the property • The garage floods – 1m water level • Water flows through the side alley, next to the garage • All of the backyard was flooded from the neighbouring property– installed a mini fence, however this was not effective for stopping water • November 2015 – there was 1.5m of water in the backyard • The council cleans the drains monthly • Unit 12 is owned by council as per affordable housing policy • There is a pump in the garage but it pumps water back onto the road (which is usually already flooded when the pump is needed to be used) • Water marks are still on the wall outside the lower ground apartment that flooded • Water pushed the doors of the apartment open • Is going to sue council if the flooding happens again • The lower ground unit is currently not being rented due to flooding issues • The building is not getting insurance due to having a flooding incident three times • Aware of the flood study done by Bankstown council in 2007, there were recommendations suggested but not completed. • There is a pit in backyard • Water accumulates in basement, as it is the low point • Have reports about the flooding completed by hydraulic engineers • Owners would like to be cc-ed into correspondence with council • Previously Councillors have suggested to “put in a wall” however this would have other impacts on surrounding sites • It cost $75 000 to fix lift after a flooding event – 2m of lift shaft damaged from flood waters • The planning for DA was approved, questioning why it was approved with hydraulic plans • Have an email from council to say the area is not flood affected • Half of Curlewis Street has no drainage • When it rains heavily, water comes down Curlewis Street and it floods • Have not had flow since 2015, council has been cleaning the drains • Have a detention tank in the basement of the property
11 Warners Avenue	North Bondi	• Flood water comes from Blair street • The water level in photo evidence had been pushed up from people driving onto property • Footpath goes under flood water • Flood waters never reaches the property • The garages of the town houses opposite go under during flooding events • Dec 2015 was a key event • 2015 was a key period for flooding– 1 flood per month over a few months, there were numerous significant rain events • There is a kindergarten nearby which is a worry • Cars break down when they drive through the flood waters in the low points of Warner Avenue • Cars parked on Warners Avenue are inundated – just above the wheel • The flood level reaches 0.5 m on the road at the corner of Warner and Niblick street • The house is never underwater though • Has the building plan of the property at 11 Warners have – so can confirm RL

Niblick St	North Bondi	• Two major flooding incidents – August and December • Have had to replace floors in the property twice • Issues with insurance due to the flooding • Found cement in the pipes – which was subsequently blasted • There is not enough capacity to deal with stormwater in the drainage network • Have had lots of correspondence with Council regarding the flooding • In August – a car of number 19 Niblick was flooded • End of Warners and Niblick Streets turns into a big puddle that builds up during storm events • Flooding issues can arise after 10 minutes of high intensity rainfall • Leaves and debris block drains • Concerns about the price of the property decreasing • Griffith Avenue is not impacted by flooding • The flood waters gush through the front yard and down the side of the property to the back • Flash flooding occurs, doesn't recall rain in the lead up to the flooding event • Trees in the park with pine leaves block the gutters • Properties long Niblick Lane are flooded • The granny flat of property # 15 Niblick Street gets flooded
Simpson St	Bronte	• Flood waters come downhill from wellington and Francis street and collected at retaining wall to overland flow • The house at the end of Simpson Street near the retaining wall was flooded above floor level • Mega storm in Dec 2015 effected Simpson street • Turn up a class action Water overtopped the crest level of driveway, the driveway was rebuilt with a higher crest level . There should be an overland flow path relief • Number 27 and 25 had to be provided temporary housing by council due to flooding • There is a big pipe under the road but uncertainty as to where it goes • Number 39 Simpson street came very close to being inundated • Water on Simpson street flows like a river • Old South Head road overtops and floods down to Simpson street • During flood events the road gets covered in 100mm of sand • Simpson Street is an old water course • Thomas Scott reserve is an old billabong • How could Thomas Scott reserve be used for flood prevention as it is a natural basin • Potential engineering solution for this area? • Trench drains for Old South Head Road downhill? • Water in the garage reached to levels of 1.5m
Palmerston Ave	Bronte	Could not attend
Palmerston Ave	Bronte	• Easement on the right-hand side of the property • The property is in the low point in gully • The area is very leafy • 1994 – hail storm – drains were very blocked from the hail and debris • River of water through the building during flood events • The water sits for a long time after the storm event • The lobby of the property is inundated during flooding events • Roof drain is covered in debris • 2016 – there was a big sink hole on the road, approximately 2.3m wide. Couldn't leave the building • The flood levels do eventually dissipate after building up • River of water through the building

		• During flooding events there is enough water on Palmerston Avenue to move cars • Regrading of roads has occurred in the area – Blandford Road was re-graded in the last couple of years • The drains on Palmerston Avenue are cleaned when the council is called
Murray Street	Bronte	Could not attend
Warners Avenue	North Bondi	• Flooding occurs a couple times a year • Flood levels reach knee high • $30 000 to raise the house when building it – did this on own accord • Couldn't raise the garage • All flood water coming from Blair Street

Appendix C Public Exhibition Consultation Summary Report

WAVERLEY COUNCIL

Flood Study: Public Exhibition Consultation Summary Report

Waverley Council acknowledges the Bidjigal and Gadigal people, who traditionally occupied the Sydney Coast and we acknowledge all Aboriginal and Torres Strait Islander Elders both past and present.

Contents

Executive summary

The Waverley Flood Study aims to define the existing flood behaviour and better understand the flood risks with the LGA. It is informed by community feedback in 2017 and 2018.

Public exhibition of the draft Flood Study ran from 29 July to 9 September 2020 and primarily focused on the Have Your Say project page and precinct workshop. Five survey responses were received, as well as several long form email submissions.

Of the feedback received, the majority was in relation to specific properties. It is recommended that this specific feedback received is considered and amendments made where possible before finalising the final report. Where changes cannot be made, it is recommended that a rationale is provided.

Background

The Waverley Flood Study aims to define the existing flood behaviour and better understand the flood risks with the LGA. It is informed by community feedback in 2017 and 2018.

The study is focused on local overland flooding conditions within the urban environment that may occur when the capacity of local creeks, channels and stormwater drainage systems are exceeded in response to intense rainfall. The oceanic interaction along the coastal boundary of the study area was also considered.

The Waverley Flood Study is the initial stage towards the development of a comprehensive Floodplain Risk Management Plan that will ultimately guide the direction of future floodplain risk management activities across the Waverley LGA.

Approach

Noting that the project consultation was during COVID-19 restrictions, face to face engagement opportunities were unavailable.

Public exhibition of the draft Flood Study ran from 29 July to 9 September 2020 and primarily focused on the Have Your Say project page and precinct workshop.

Consultation objectives:

- Raise awareness of the draft Flood Study with affected residents and general community
- Provide opportunity to identify gaps and ask questions of the draft Flood Study

Engagement methodology

Engagement methods focused on an online survey on the Have Your Say Waverley project page here: haveyoursay.waverley.nsw.gov.au/waverley-flood-study.

A precinct workshop was also held on 27 August 2020.

The engagement process aligned with Waverley Council's adapted IAP2 model for community engagement.

Method	Overview	Date	Response
Have Your Say website	Council's 'Have Your Say Waverley' website had a dedicated page for the project: haveyoursay.waverley.nsw.gov.au/waverley-flood-study	Launched in November 2017 as part of the initial stage of community engagement.	Since inception: 1000 total visits 264 informed (opened a doc or the map) 406 document downloads
Online survey	An 8-question online survey on the Have Your Say Waverley dedicated project page, addressing the draft document.	29 July — 9 September 2020	5 survey responses
Long form submissions	Submissions received via email.	29 July — 9 September 2020	6 email submissions
Precinct meeting	A dedicated Flood Study precinct meeting was held. This meeting was also available for all community members to attend	27 August 2020	
Flyer drop	Flyers were dropped to approximately 31,000 residences	Completed by 20 August 2020	
Social media posts	**Facebook** Post 1: Raise awareness of the public exhibition period Post 2: Call out for people to attend the precinct webinar Post 3: Link to the precinct webinar on youtube and encouraging people to have their say.	29 July 2020 26 August 2020 8 September 2020	Reach: 932 Engagements: 67 Reach: 791 Engagements: 17 Reach: 612 Engagements: 8
	Twitter Post 1: Raise awareness of the public exhibition period Post 2: Call out for people to attend the precinct webinar Post 3: Link to the precinct webinar on YouTube and encourage people to have their say	29 July 2020 26 August 2020 8 September 2020	Impressions: 892 Engagements: 18 Impressions: 575 Engagements: 6 Impressions: 777 Engagements: 9

	Instagram Raise awareness of the public exhibition period	29 July 2020	Impressions: 1572 Engagements: 7
Advertising	Advert in the Wentworth Courier as part of the Council page	4 August 2020	—
Council Enewsletters	Waverley Weekly x 5	6, 13, 20, 27 August and 4 September 2020	Recipients: Approx. 1985 subscribers
	Engagement enews	11 August 2020	Recipients: 3583 subscribers
Stakeholder outreach	Direct emails and notifications to targeted stakeholders	29 July—9 September 2020	—

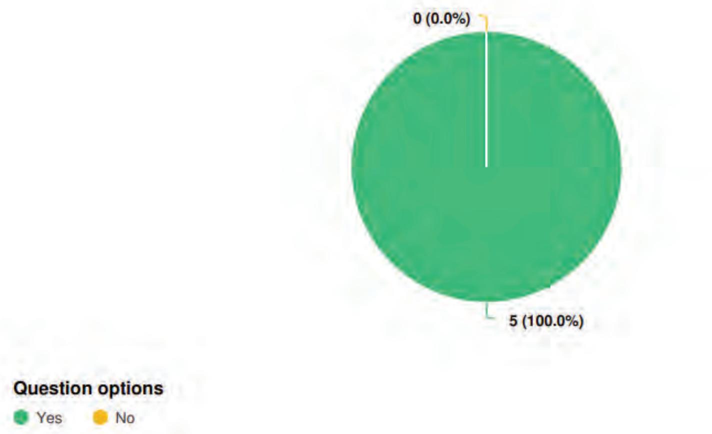
Data overview

Online survey on HYS

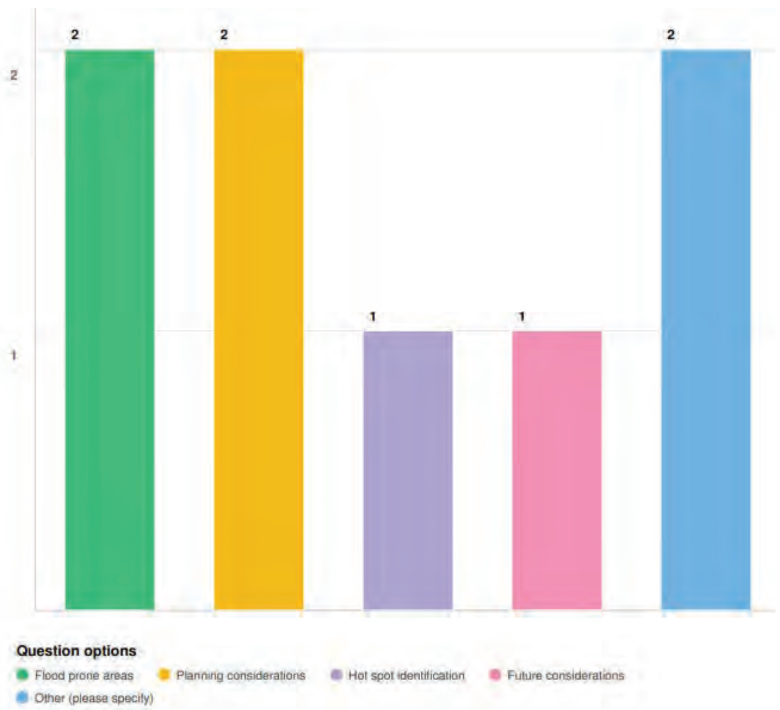
Five survey responses were received from Have Your Say Waverley.

Qualitative results are as follows:

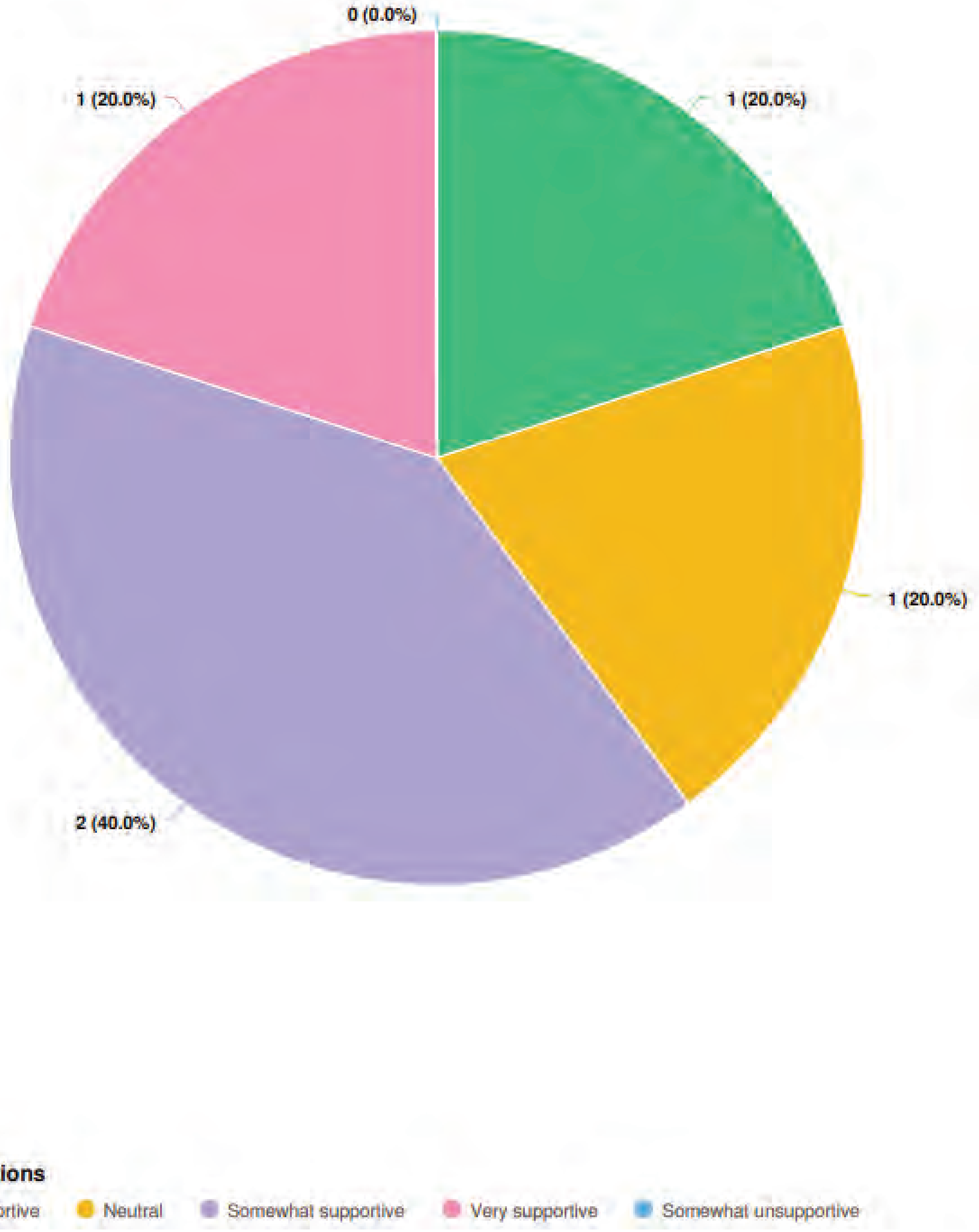
Q1 Have you read the draft Waverley Flood Study (or the part you are providing feedback on)?



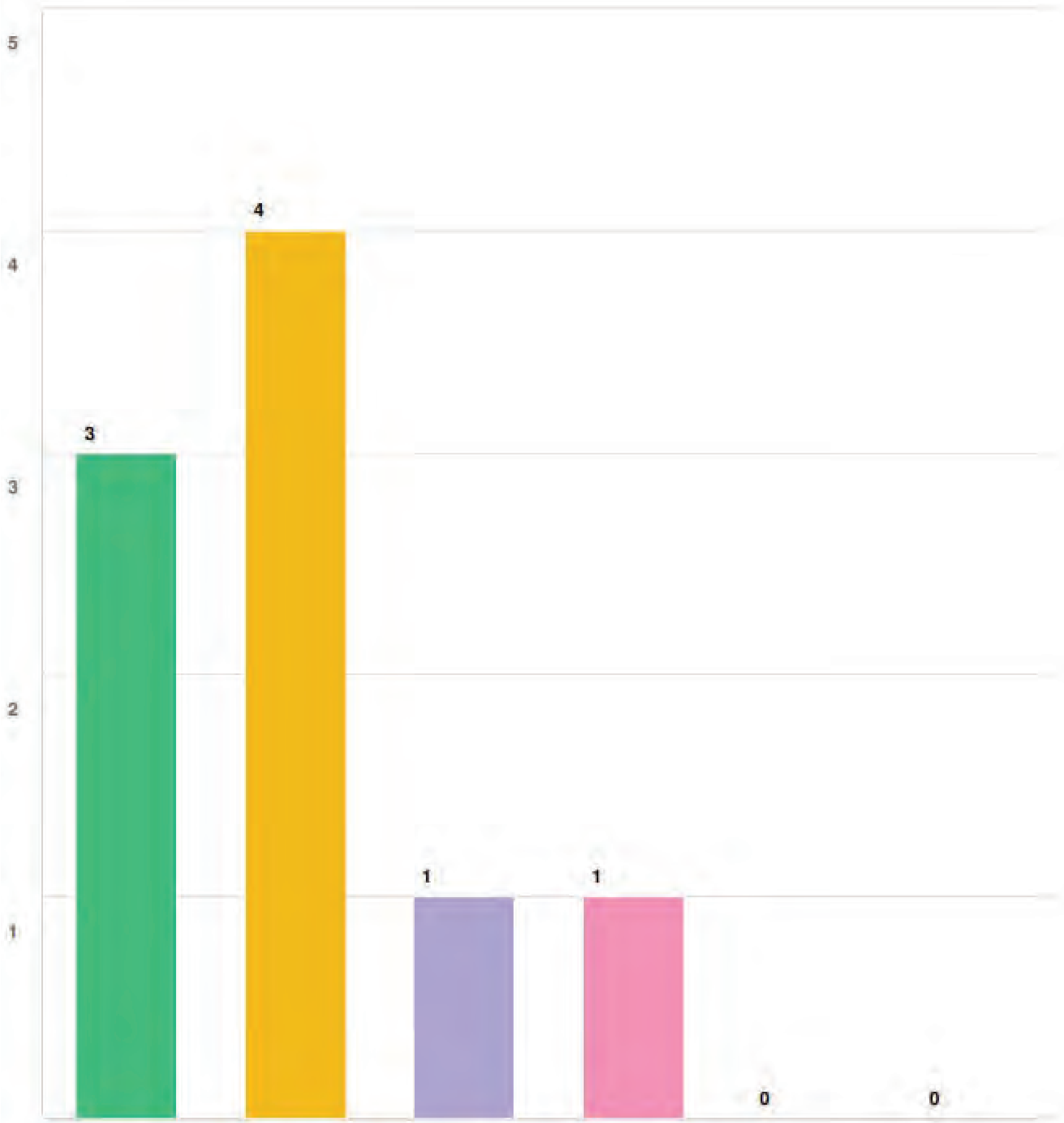
Q2 Which aspect of the draft Waverley Flood Study are you providing feedback to? (please select all that apply)



Q5 Are you supportive of what is outlined in the draft Waverley Flood Study?



Q7 What is your interest in the Waverley Flood Study? (please select all that apply)



Question options

- I live in an area identified in the draft Flood Study
- I live in the Waverley LGA
- I work in the Waverley LGA
- I visit an area identified in the draft Flood Study
- I work in an area identified in the draft Flood Study
- Other (please specify)

Quantitative feedback included items such as:

- “Maps included in the ‘Preliminary Flood Hazard Mapping’ do not cover all of Waverley”
- “Drain grates on roads such as Ebley St and Bronte Rd in Bondi Junction are unsafe for people cycling, for example the drain grate on the northwest corner of the intersection of Ebley St and Newland St. The gaps are parallel to the kerb, which means bicycle wheels can get stuck in them. People cycling have to ride close to these grates when cars overtake”
- “…planning controls need to limit paving, concrete, fake turf and other ‘built’ surfaces overland that is identified as green space or landscaping…the DA approval process increasingly allows hard options over areas that should be free-flow earth….The role of Council is to provide regulation for the benefit of the entire council area so it has a clear mandate to regulate land use to minimise flooding.”
- “In the model validation, there are very limited observed datapoints and those datapoints are not evenly spread across the catchment to validate the model sufficiently”

Other feedback received were related to specific properties. The full survey responses received are included as an appendix of this report.

Precinct workshop

A precinct workshop was held via Zoom on 27 August 2020.

This was primarily a question and answer session, the notes of which are included as an appendix of this report.

Long form submissions

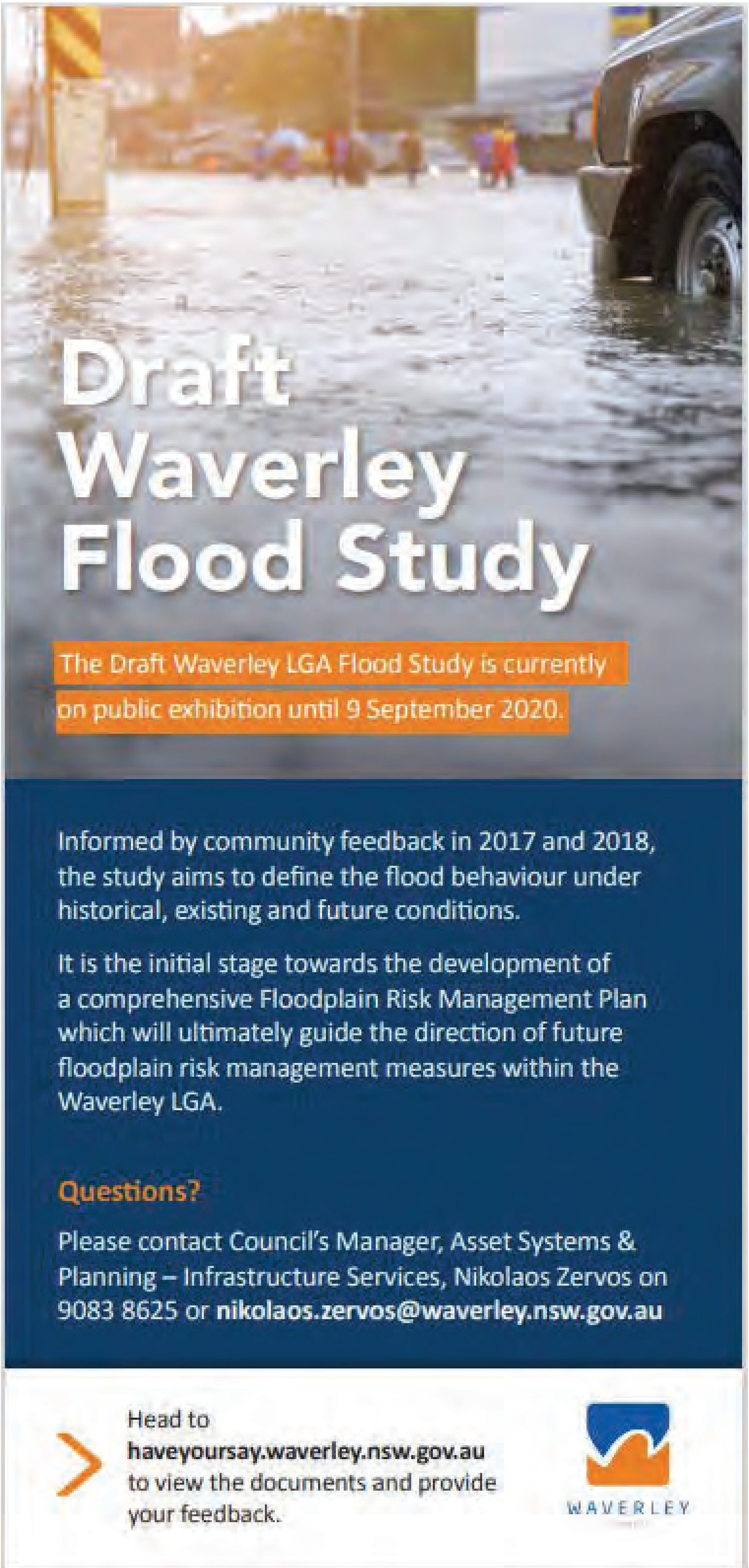
The long form submissions were primarily relating to concerns and feedback to specific properties, and are included in the appendix of this report.

Conclusion

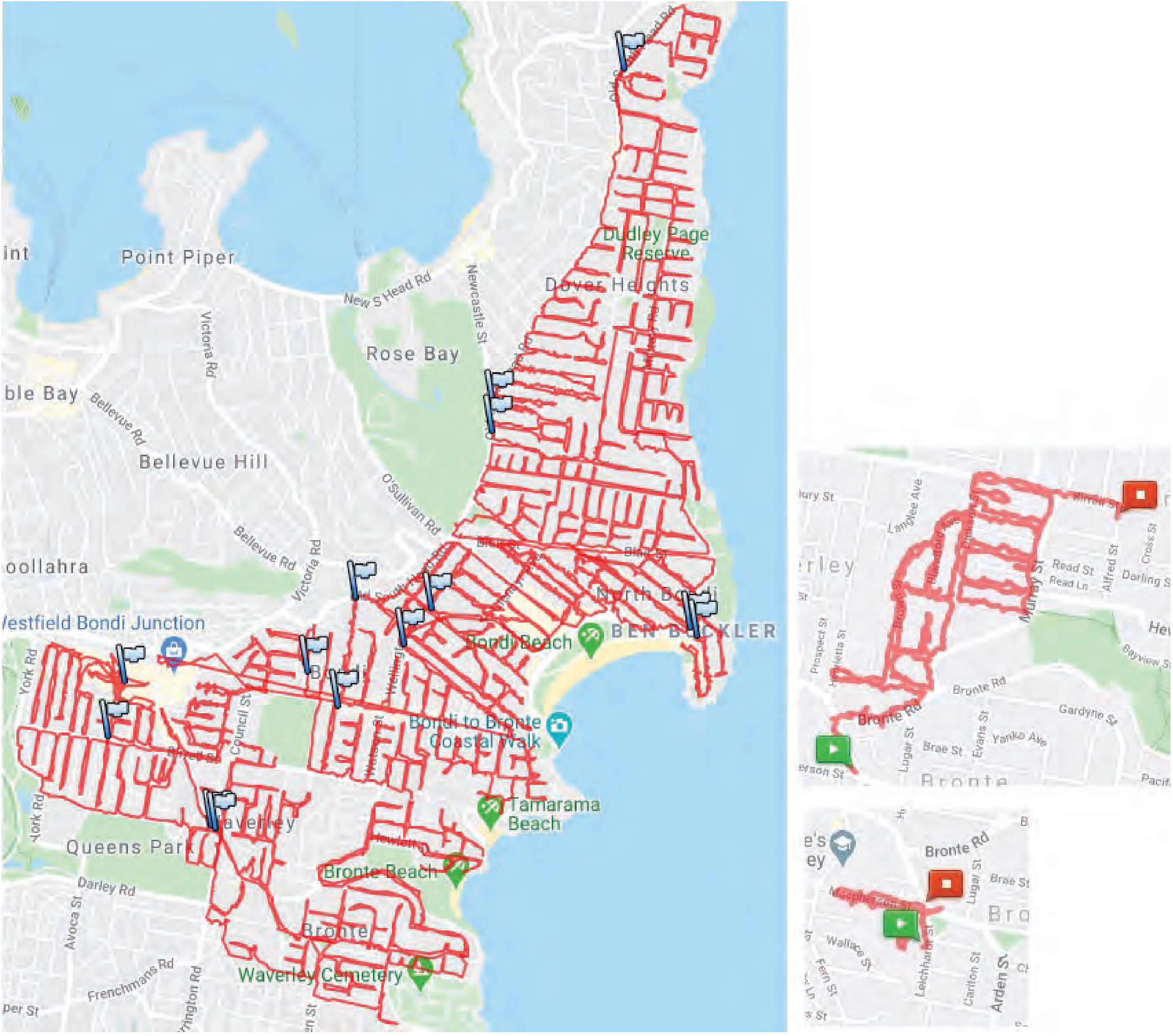
The community response demonstrated mixed support to the draft Flood Study, with majority of responses relating to concerns, suggestions or general feedback relating to their specific property.

It is recommended that this specific feedback received is considered and amendments made where possible before finalising the final report. Where changes cannot be made, it is recommended that a rationale is provided.

Appendix A – Flyer distributed to local residents



Appendix B – Flyer distribution map



Appendix C – Print advertising in the Wentworth Courier

Waverley Council Update

WAVERLEY COUNCIL

Mayor's Message

Mayoral Minutes

At the July Council meeting, I presented two Mayoral Minutes aimed at supporting our community. The first proposed that Council officers investigate the preparation of Social Impact Assessment Guidelines for inclusion in the new Waverley Development Control Plan (DCP) currently under review. Social

A Council Ranger with Rabbi Mendel Kastel OAM and the Mayor, Paula Masselos

In other COVID-19 news, Council's Coronavirus (COVID-19) Business Support Package will continue to be in place until 30 September. To find out what support is available, contact our business response team at **business@waverley.nsw.gov.au**

Mend app to help the

Have Your Say

Draft Heritage Assessment

Waverley's heritage buildings, streetscapes, landscapes and items are much loved by the community and contribute to the area's highly prized character.

These places have significant

Draft Flood Study

Our draft Flood Study is currently on public exhibition for your comment.

To see what properties and areas have been identified and to provide your feedback, head to **haveyoursay.waverley.nsw.gov.au/waverley-flood-study**

Submissions close 9 September 2020.

We also accept submissions in writing. Please address any correspondence to:
The General Manager
Waverley Council, PO Box 9
Bondi Junction NSW 1355

Please note that all submissions will form part of Council's public record and, as such, may be made publicly available.

Public Notice

Community safety reminder

As we work together to stop the spread of the COVID-19 outbreaks relevant public health orders, including limits on gatherings in and outside of the home.

We have been working with businesses in our area to help get them operate in a COVID-safe way, which means something different for each type of business. We ask the community to ensure you follow the requirements of a business you are visiting, and these requirements should clearly be visible to you upon entry of that space.

For community sporting activities that involve more than 20 participants, the organiser must have a COVID-19 Safety Plan.

For the latest COVID-19 information, including a summary of what is and isn't allowed in NSW, visit **nsw.gov.au/covid-19**

For more about Waverley Council's Business Support Package for local businesses, please contact our business response team at **business@waverley.nsw.gov.au**

Appendix D – Facebook posts

Waverley Council
Published by Sprout Social [?] · ★ Favourites · 29 July ·

🌧️ 🌧️ Our draft Flood Study is currently on public exhibition for your comment. To see what properties and areas have been identified and to provide your feedback, head to 👉 haveyoursay.waverley.nsw.gov.au/waverley-flood-study. Submissions close 9 September 2020.

Performance for your post

932 People Reached

7 Likes, Comments & Shares

5 Likes	5 On Post	0 On Shares
1 Comments	1 On Post	0 On Shares
1 Shares	1 On Post	0 On Shares

60 Post Clicks

5 Photo views	17 Link clicks	38 Other Clicks

Waverley Council
Published by Sprout Social [?] · ★ Favourites · 26 August ·

☔ Interested in hearing more about our draft Flood Study currently on public exhibition? We're holding a precinct workshop tomorrow night (27 August) 6–7pm, open for all to attend. Please register your attendance here: https://bit.ly/32tjCmf

Performance for your post

791 People Reached

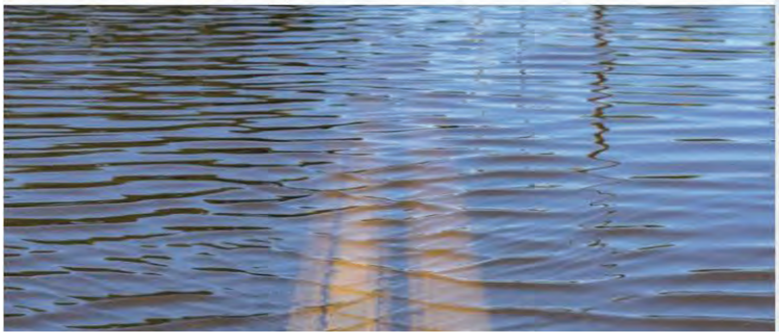
8 Reactions, comments & shares

2 Like	1 On post	1 On shares
1 Sad	0 On post	1 On shares
0 Comments	0 On Post	0 On Shares
5 Shares	5 On Post	0 On Shares

9 Post Clicks

Waverley Council
Published by Sprout Social [?] · ★ Favourites · 8 September ·

☔ Missed our information session on the Draft Flood Study? Watch it online instead! https://bit.ly/2GqvvSQ Then head to https://haveyoursay.waverley.nsw.gov.au/waverley-flood-study and let us know your feedback. Public exhibition closes Wednesday 9 September.



Performance for your post

612 People Reached

1 Likes, Comments & Shares

1 Likes	1 On Post	0 On Shares
0 Comments	0 On Post	0 On Shares
0 Shares	0 On Post	0 On Shares

7 Post Clicks

1 Photo views	4 Link clicks	2 Other Clicks

Appendix E – Twitter posts

Waverley Council
@WaverleyCouncil

🌧️ 🌧️ Our draft Flood Study is currently on public exhibition for your comment. To see what properties and areas have been identified and to provide your feedback, head to 👉 haveyoursay.waverley.nsw.gov.au/waverley-flood.... Submissions close 9 September 2020.

8:35 AM · Jul 29, 2020 · Sprout Social

Waverley Council
@WaverleyCouncil

☔ Interested in hearing more about our draft Flood Study currently on public exhibition? We're holding a precinct workshop tomorrow night (27 August) 6–7pm, open for all to attend. Please register your attendance here: bit.ly/32tjCmf

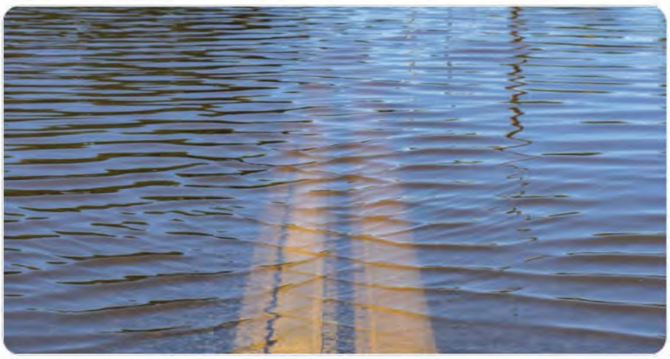
4:56 PM · Aug 26, 2020 · Sprout Social

View Tweet activity

1 Retweet

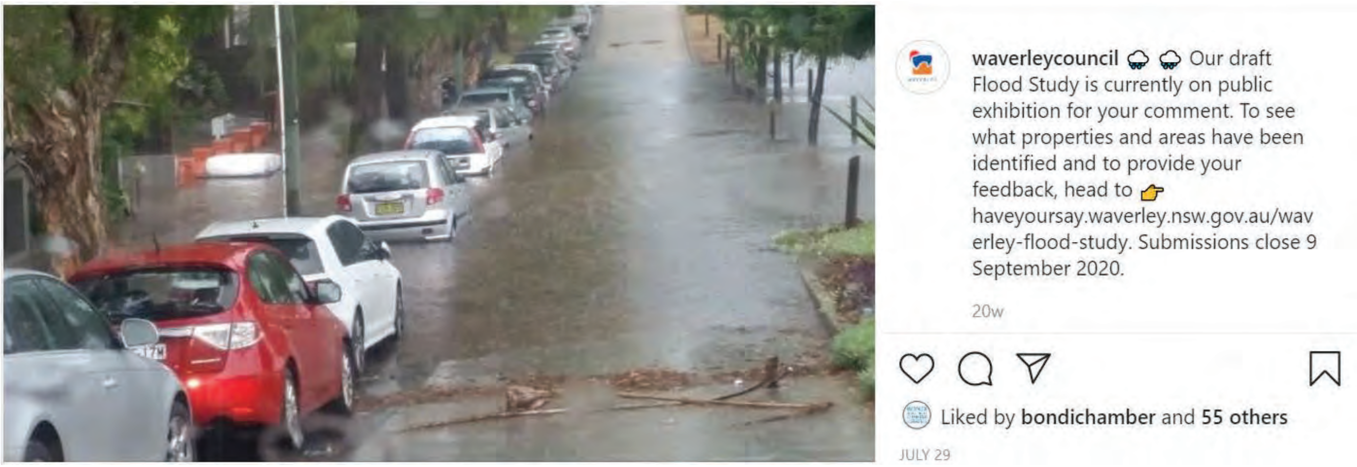
Waverley Council
@WaverleyCouncil

☔ Missed our information session on the Draft Flood Study? Watch it online instead! bit.ly/2GqvvSQ Then head to haveyoursay.waverley.nsw.gov.au/waverley-flood... and let us know your feedback. Public exhibition closes Wednesday 9 September.



5:55 PM · Sep 8, 2020 · Sprout Social

Appendix F – Instagram post



Appendix G — Council Enewsletters

Waverley Weekly example:

Let us know your thoughts on a Council project

Register online at haveyoursay.waverley.nsw.gov.au to be the first to hear of upcoming engagement projects and to let us know your ideas, feedback and views on Council's projects.

Current projects on consultation:

- Planning Proposals for 122 Bronte Road, Bondi Junction and Bondi Junction Strategic Centre –promoting and protecting non-residential floor space
- On public exhibition are drafts of our Flood Study and Heritage Assessment

HAVE YOUR SAY

Engagement enews

Thanks to everyone who provided a submission, filled in a survey or let us know their thoughts on a project over the past month — of particular mention the **Bondi Memorial Artwork** shortlist received 525 responses! We are currently reviewing and collating these into a summary report and will contact everyone with an update soon.

REGISTER FOR THE BONDI SURF CLUB UPGRADE AND CONSERVATION PROJECT

We're working with Bondi Surf Bathers Life Saving Club to conserve and upgrade the historically significant Bondi Surf Club building.

We are working towards starting our consultation on this project on 20 August. If you would like to register to take part in this consultation, please click here to fill out the dedicated registration form.

CURRENT PROJECTS

Let us know your thoughts on **dogs off-leash at Mackenzies Bay**. We want to know if you are supportive or unsupportive of a timed dogs off-leash trial, and if you have any ideas or concerns we should consider. Consultation runs until 20 September.

122 Bronte Road Bondi Junction Planning Proposal is currently on public exhibition. The proposal seeks to amend the Waverley LEP 2012. Submissions close 16 August.

The **draft Waverley Flood Study** aims to define flood behaviour under historical, existing and future conditions. It is an important piece in Council's work in looking at how we better understand and plan for any flood risks throughout Waverley. You can see what properties and areas have been identified, and provide feedback until 9 September.

The **draft Waverley Heritage Assessment** demonstrates the value we place on heritage in all forms – built environment, landscapes and streetscapes. These places have significant cultural value and help tell the story of Waverley's history as one of the earliest municipalities in NSW. You can see whether your property is identified, and provide feedback until 10 September.

Did you know that before each Council, you can **register to speak to the Councillors at a Public Forum**? These forums are an opportunity to talk about anything of importance to you.

Bondi Junction Strategic Centre Planning Proposal intends to create the provisions to protect and encourage non-residential floor space so it can be used for developing employment opportunities. Submissions close 6 September.

Appendix H — Online survey

2020 Survey: Draft Waverley Flood Study Public Exhibition

Have you read the draft Waverley Flood Study (or the part you are providing feedback on)?

(Choose any one option)

- ☐ Yes
- ☐ No

Which aspect of the draft Waverley Flood Study are you providing feedback to? (please select all that apply)

(Choose all that apply)

- ☐ Flood prone areas
- ☐ Planning considerations
- ☐ Hot spot identification
- ☐ Future considerations
- ☐ Other (please specify)

What is your feedback? (If responding to more than one section of the Flood Study, please use headings to differentiate, ie. XX STREET to identify which sections you're referring to throughout)

If you have any images or further information to upload as part of your feedback submission, please do so here.

Are you supportive of what is outlined in the draft Waverley Flood Study?

- ☐ Very unsupportive
- ☐ Somewhat unsupportive
- ☐ Neutral
- ☐ Somewhat supportive
- ☐ Very supportive

Why?

What is your interest in the Waverley Flood Study? (please select all that apply)

(Choose all that apply)

- ☐ I live in an area identified in the draft Flood Study
- ☐ I work in an area identified in the draft Flood Study
- ☐ I live in the Waverley LGA
- ☐ I work in the Waverley LGA
- ☐ I visit an area identified in the draft Flood Study
- ☐ Other (please specify)

Any further feedback on the draft Flood Study? Please let us know here.

Appendix I — Online survey results

Survey Responses

29 July 2020 - 09 September 2020

2020 Survey: Draft Waverley Flood Study Public Exhibition

Have Your Say Waverley

Project: Waverley Flood Study

BANG THE TABLE engagementHQ

VISITORS
30

CONTRIBUTORS			RESPONSES		
5			5		
4 Registered	0 Unverified	1 Anonymous	4 Registered	0 Unverified	1 Anonymous

Respondent No: 1
Login: Anonymous
Email: n/a

Responded At: Aug 03, 2020 21:20:12 pm
Last Seen: Aug 03, 2020 21:20:12 pm
IP Address: n/a

Q1. **Have you read the draft Waverley Flood Study (or the part you are providing feedback on)?**

Yes

Q2. **Which aspect of the draft Waverley Flood Study are you providing feedback to? (please select all that apply)**

Flood prone areas

Q3. **What is your feedback? (If responding to more than one section of the Flood Study, please use headings to differentiate, ie. XX STREET to identify which sections you're referring to throughout)**

Maps in " Preliminary Flood Hazard Mapping (7.99 MB) (pdf)" do not cover all of Waverley.

Q4. **If you have any images or further information to upload as part of your feedback submission, please do so here.**

not answered

Q5. **Are you supportive of what is outlined in the draft Waverley Flood Study?**

Somewhat supportive

Q6. **Why?**

not answered

Q7. **What is your interest in the Waverley Flood Study? (please select all that apply)**

I live in an area identified in the draft Flood Study

I live in the Waverley LGA

Q8. **Any further feedback on the draft Flood Study? Please let us know here.**

not answered

Respondent No: 2
Login: [redacted]
Email: [redacted]

Responded At: Aug 11, 2020 18:57:57 pm
Last Seen: Aug 11, 2020 08:10:44 am
IP Address: [redacted]

Q1. **Have you read the draft Waverley Flood Study (or the part you are providing feedback on)?**

Yes

Q2. **Which aspect of the draft Waverley Flood Study are you providing feedback to? (please select all that apply)**

Other (please specify)

Q3. **What is your feedback? (If responding to more than one section of the Flood Study, please use headings to differentiate, ie. XX STREET to identify which sections you're referring to throughout)**

The drain grates on roads such as Ebley St and Bronte Rd in Bondi Junction are unsafe for people cycling (one example is the drain grate on the northwest corner of the intersection of Ebley St and Newland St). The gaps are parallel to the kerb, which means bicycle wheels can get stuck in them. People cycling have to ride close to these grates when cars overtake. Waverley Council should act to avoid situations such as mentioned in this article: https://www.heraldsun.com.au/leader/south-east/council-under-fire-as-dangerous-grates-pose-cycling-threat/news-story/66bd542f70b53bbd60ac9e382d0291f7 Grid-style drain grates would be safer.

Q4. **If you have any images or further information to upload as part of your feedback submission, please do so here.**

not answered

Q5. **Are you supportive of what is outlined in the draft Waverley Flood Study?**

Very supportive

Q6. **Why?**

not answered

Q7. **What is your interest in the Waverley Flood Study? (please select all that apply)**

I visit an area identified in the draft Flood Study

Q8. **Any further feedback on the draft Flood Study? Please let us know here.**

not answered

Respondent No: 3
Login: [redacted]
Email: [redacted]

Responded At: Sep 01, 2020 17:18:01 pm
Last Seen: Sep 01, 2020 06:31:03 am
IP Address: [redacted]

Q1. **Have you read the draft Waverley Flood Study (or the part you are providing feedback on)?**

Yes

Q2. **Which aspect of the draft Waverley Flood Study are you providing feedback to? (please select all that apply)**

Other (please specify)

Q3. **What is your feedback? (If responding to more than one section of the Flood Study, please use headings to differentiate, ie. XX STREET to identify which sections you're referring to throughout)**

I note that [redacted] is identified as type c in the 2020 draft flood study, meaning you are uncertain about an overland flow path if council's nearby drainage system capacity is exceeded. I would like to confirm that any such overland flows from View St/Victoria Rd upstream of our property will occur in the [redacted] (see attached plan) This driveway is wholly contained within the unmade section of View St road reservation ; [redacted] and therefore will not be subjected to any overland flow surcharges. I would add that I have lived [redacted] the driveway (within councils public road) ever been subjected to flooding/damaging overland flows. This includes the significant storm event of November 1984 and other 1 in 100 plus subsequent ARI events I am therefore requesting that [redacted] be removed from the type C classification.

Q4. **If you have any images or further information to upload as part of your feedback submission, please do so here.**

[redacted]

Q5. **Are you supportive of what is outlined in the draft Waverley Flood Study?**

Somewhat supportive

Q6. **Why?**

Classifying properties needs to be carefully modelled and confirmed to avoid incorrect flood planning controls

Q7. **What is your interest in the Waverley Flood Study? (please select all that apply)**

I live in an area identified in the draft Flood Study

I live in the Waverley LGA

I work in the Waverley LGA

Q8. **Any further feedback on the draft Flood Study? Please let us know here.**

not answered

Respondent No: 4
Login: [redacted]
Email: [redacted]

Responded At: Sep 06, 2020 14:28:50 pm
Last Seen: Sep 06, 2020 04:12:45 am
IP Address: [redacted]

Q1. **Have you read the draft Waverley Flood Study (or the part you are providing feedback on)?**

Yes

Q2. **Which aspect of the draft Waverley Flood Study are you providing feedback to? (please select all that apply)**

Planning considerations

Future considerations

Q3. **What is your feedback? (If responding to more than one section of the Flood Study, please use headings to differentiate, ie. XX STREET to identify which sections you're referring to throughout)**

To address increased flooding, planning controls need to limit paving, concrete, fake turf and other 'built' surfaces over land that is identified as green space or landscaping. Flooding increases because over build surfaces, water does not seep into the ground and from there into underground streams. Unfortunately, the DA approval process increasingly allows hard options over areas that should be free-flow earth. Planning control for the common good is being co-opted for individual properties. The role of Council is to provide regulation for the benefit of the entire council area so it has a clear mandate to regulate land use to minimise flooding.

Q4. **If you have any images or further information to upload as part of your feedback submission, please do so here.**

not answered

Q5. **Are you supportive of what is outlined in the draft Waverley Flood Study?**

Neutral

Q6. **Why?**

not answered

Q7. **What is your interest in the Waverley Flood Study? (please select all that apply)**

I live in the Waverley LGA

Q8. **Any further feedback on the draft Flood Study? Please let us know here.**

not answered

Respondent No: 5
Login: [redacted]
Email: [redacted]

Responded At: Sep 09, 2020 09:36:10 am
Last Seen: Sep 08, 2020 22:54:47 pm
IP Address: [redacted]

Q1. **Have you read the draft Waverley Flood Study (or the part you are providing feedback on)?**

Yes

Q2. **Which aspect of the draft Waverley Flood Study are you providing feedback to? (please select all that apply)**

Flood prone areas
Planning considerations
Hot spot identification

Q3. **What is your feedback? (If responding to more than one section of the Flood Study, please use headings to differentiate, ie. XX STREET to identify which sections you're referring to throughout)**

Section 5.2.3 to 5.2.5 - Model Validation In the model validation, there are very limited observed datapoints and those datapoints are not evenly spread across the catchment to validate the model sufficiently. Those datapoints are limited to areas of existing Flood Prone Areas and does not align with validation of the model further upstream. In particular it only takes one or two observable validation datapoints from existing Flood Prone Areas (FPAs). For example there is a datapoint in Warners Avenue Tables 5-3 and 5-7 which is a known flood area at the end of a catchment. This then validates and extrapolates the model across the entire North Bondi area which is complex and requires broader validation. It should be also noted that the datapoint and its error within those tables compares it relative to the absolute mAHD rather than a delta to the flood level (ie relative to the ground level) which understates the level of error on a proportionate basis (ie 0.2m different on an mAHD of ~15m appears comparatively small but is significant when reflection on 0.2m relative to the flood depth) The model needs are far greater number of data points, particularly outside flood prone areas. The number Type A Properties (now 400) of the draft Waverley Flood Study (WFS) expands the Flood Prone Areas outlined in the 2012 LEP significantly and given the limited datapoints of validation to the model, particularly to those expanded areas suggests that the additional type A properties have been expanded prematurely and extensively without suitable validation. As such this determination is achieved with insufficient data and accuracy. Section 7.9.2 - Hotspots In terms of the hotspot recommendations, in particular for the Glenayr-Plowman hotspots, provide limited alternate options other than Flood Planning Controls (FPCs). As noted above the model is not sufficiently validated above and there is limited analysis as to alternate options of infrastructure improvement which would not require these FPCs and must be considered

Q4. **If you have any images or further information to upload as part of your feedback submission, please do so here.**

not answered

Q5. **Are you supportive of what is outlined in the draft Waverley Flood Study?**

Very unsupportive

Q6. **Why?**

The model requires further validation before there is an extensive expansion of the Flood Prone Areas definition to Type A properties with Flood Planning Controls.

Q7. **What is your interest in the Waverley Flood Study? (please select all that apply)**

I live in an area identified in the draft Flood Study
I live in the Waverley LGA

Q8. **Any further feedback on the draft Flood Study? Please let us know here.**

not answered

Appendix J — Long form submissions

Below are the long form submissions received during the draft Flood Study public exhibition period, 29 July—9 September 2020.

Contact details have been redacted and some submissions omitted from this public record due to their confidential nature.

1.

Dear Mr Zervos,

I've owned and lived at [redacted] for about 8 years. During this time, we've had 3 instances of 'flooding'. I think our property is most likely the lowest point of the street/gully.

The first year, 2012, not long after moving in in April, the tiled area outside the bottom glass doors facing backyard (natural gully)flooded up to level of doorway entry, despite having several large drains outside. However, water did not enter the home.

The 2nd time, we were overseas and the bottom floor was completely flooded, (clean water) - carpet and bookcases had to be replaced. We had the downstairs office internal floor and partway up the wall connecting to higher ground waterproofed, and the outside section of concrete between [redacted] gap sealed/filled.

The 3rd time, just recently after all the big rains, clear water has entered the home downstairs, but in a different place - where bottom wall connects with the earth/ground facing the street, but below road level. this had happened twice in the month. I think water is escaping the storm drain pipe or water pipe that runs under [redacted] (which Sydney water has dug up and patched all along the street several times this year) and flowing into the house. I do have a drain channel and water drain with pump under the house, but looks like the water has possibly made/found a new channel.

There also appears to be a few large sinkholes that have grown since the recent rains, along the boundary fenceline between [redacted].

I'm not sure if this forms part of the information for the flood study, or whether you can send someone to come and investigate.

Regards,

[redacted]

2.

Dear Manager

Regards: A/17/0168, Survey: Draft Waverley Flood.

As you are well aware our natural environment is in a very bad shape because governments are not doing anything to stop:

- Soil erosion
- Flooding
- Air pollution
- Heat in summer that kills people and is a major health hazard for people working outdoors.
- High energy bills in summer time

We should know that most of the problems can be rectified by having green cover and trees around our buildings,

So if Councils knows about it why it does not do anything about it?

Should not be its highest priorities? One small example on the areas that I am familiar with that are prone to flooding, the slopes coming down from Christison Park, Vaucluse to Chrisbang Cr and stopes coming down from Vaucluse Cemetery to Diamond Bay Road.

My question will the council take the long term residents that care about living in a sustainable environment into account when it makes a DA decision?

Yours sincerely

[redacted]

3.

Hi Nikolaos,

Good talking to you today. Things are sounding positive about water issues in our area.

[redacted] have lived at [redacted] for 33 years with no issues like we have had over the last couple of years.

My neighbour is [redacted] who built a pool [redacted]. Initially I put problems down to the pool being built but since then we all believe it is what is going on above us in [redacted].

Our first incident was 17 March 2019 where I lost a tree, pool fence and 6 tonnes of soil. [redacted] also had to do pool repairs. Insurance rejected the claim. I had it fixed at my own expense and changed the water flow with recommendations from engineers report who was involved with pool construction for [redacted] which I paid for.

Second incident was 10 February 2020, I was overseas but [redacted] relating to damage then. Once again I lost soil but have not repaired as I wanted council to view which has not been done as yet.

Below is [redacted] sent to council 26 February 2020, he had verbal communications as well with [redacted]

I also logged something with the council Waverley Council Customer Request: [redacted]

There is also lots of major construction behind [redacted].

Looking forward to hearing about changes.

Kind Regards,

[redacted]

3b.

[redacted]
Subject: massive storm water issues at [redacted]

Hi [redacted],

Nice talking to you.

Please [redacted] relating to the damage caused by the strong rainfall 2weeks ago.

Images and videos were taken at [redacted] pool, retaining wall, flooded garden

Videos and images were also taken at [redacted].

The other image showing "the waterfall" were taken at the end (north end) of MacLeay st.

My interpretation is, that there is literally too much water being injected from higher grounds (properties located above the waterfall - Kippara Rd) into MacLeay st which results in a sizeable waterfall (see images). The draining system located on MacLeay st is unable to cope with the large amount of water, therefore gets flooded and passes it onto [redacted]. This water then floods [redacted]t, comes out in large amounts (river stream - see video) between the concrete pillars of the pool located at [redacted], then bounces back from the retaining wall at [redacted], as a result washes out the soil between the pool and the retaining wall and ends up further down at the end of our retaining wall next to the [redacted] in our pool and garden. This is now the third time that this has happened as a result of strong rainfalls. [redacted], located between her pool and our retaining wall. Large amounts of the soil ended up in our pool, driveway and on the street. Our pool and garden had to be cleaned for +AUD1000/incident.

I would advise council to look into this issue as a matter of urgency. Due to the nature of our location (lower grounds) this issue is complete out of our hands; We are basically at the receiving end.

Can you please let us know if there is any way to apply for compensation for the damages caused by this oversight.

Please feel free to contact me at any time via email or phone as I’d be happy to show an engineer/project manger appointed by the council the issues described above.

I look forward to hearing from you,

Kind regards,

[redacted]

[redacted]

[redacted]

[redacted]

Appendix D Probability Neutral Burst Initial Loss

Website: http://data-dev.arr-software.org/

Time Accessed: 28 March 2019 04:12PM

Version: 2018_v1

Table D-1 Probability Neutral Burst Initial Loss

Duration	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
1.0	11.6	7.8	8.9	8.5	8.2	6.4
1.5	11.9	8.3	9.5	9.5	9.4	6.5
2.0	13.3	8.9	9.9	9.7	9.4	5.7
3.0	13.3	9.7	10.7	10.2	8.8	4.5
6.0	13	8.8	8.6	7.9	9	3
12.0	18.3	13	12.7	10.9	12.1	3.2
18.0	18.6	13.6	14.4	12	12.4	3.9
24.0	21.6	16.4	16.5	14.2	14.9	4.4
36.0	24.7	19	18.6	15.8	16.7	6.3
48.0	27.7	22.4	21.7	23.1	19.9	9.5
72.0	29.6	25.7	25.8	26.5	22.3	10.4

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