BIRDS GULLY & BUNNERONG ROAD FLOOD STUDY

DRAFT REPORT

FEBRUARY 2018

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Project **Birds Gully & Bunnerong Road Flood Study**	**Project Number** **116083**
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LIST OF ACRONYMS

AEP	Annual Exceedance Probability
ARI	Average Recurrence Interval
ALS	Airborne Laser Scanning
ARR	Australian Rainfall and Runoff
BOM	Bureau of Meteorology
DECC	Department of Environment and Climate Change (now OEH)
DNR	Department of Natural Resources (now OEH)
DRM	Direct Rainfall Method
DTM	Digital Terrain Model
GIS	Geographic Information System
GPS	Global Positioning System
IFD	Intensity, Frequency and Duration (Rainfall)
mAHD	meters above Australian Height Datum
OEH	Office of Environment and Heritage
PMF	Probable Maximum Flood
SRMT	Shuttle Radar Mission Topography
TUFLOW	one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software (hydraulic model)
WBNM	Watershed Bounded Network Model (hydrologic model)

ADOPTED TERMINOLOGY

Australian Rainfall and Runoff (ARR, Ball et al, 2016) recommends terminology that is not misleading to the public and stakeholders. Therefore the use of terms such as “recurrence interval” and “return period” are no longer recommended as they imply that a given event magnitude is only exceeded at regular intervals such as every 100 years. However, rare events may occur in clusters. For example there are several instances of an event with a 1% chance of occurring within a short period, for example the 1949 and 1950 events at Kempsey. Historically the term Average Recurrence Interval (ARI) has been used.

ARR 2016 recommends the use of Annual Exceedance Probability (AEP). Annual Exceedance Probability (AEP) is the probability of an event being equalled or exceeded within a year. AEP may be expressed as either a percentage (%) or 1 in X. Floodplain management typically uses the percentage form of terminology. Therefore a 1% AEP event or 1 in 100 AEP has a 1% chance of being equalled or exceeded in any year.

ARI and AEP are often mistaken as being interchangeable for events equal to or more frequent than 10% AEP. The table below describes how they are subtly different.

For events more frequent than 50% AEP, expressing frequency in terms of Annual Exceedance Probability is not meaningful and misleading particularly in areas with strong seasonality. Statistically a 0.5 EY event is not the same as a 50% AEP event, and likewise an event with a 20% AEP is not the same as a 0.2 EY event. For example an event of 0.5 EY is an event which would, on average, occur every two years. A 2 EY event is equivalent to a design event with a 6 month Average Recurrence Interval where there is no seasonality, or an event that is likely to occur twice in one year.

The Probable Maximum Flood is the largest flood that could possibly occur on a catchment. It is related to the Probable Maximum Precipitation (PMP). The PMP has an approximate probability. Due to the conservativeness applied to other factors influencing flooding a PMP does not translate to a PMF of the same AEP. Therefore an AEP is not assigned to the PMF>

This report has adopted the approach recommended by ARR and uses % AEP for all events rarer than the 50 % AEP and EY for all events more frequent than this.

Frequency Descriptor	EY	AEP (%)	AEP (1 in x)	ARI
Very Frequent	12			
	6	99.75	1.002	0.17
	4	98.17	1.02	0.25
	3	95.02	1.05	0.33
	2	86.47	1.16	0.5
	1	63.21	1.58	1
	0.69	50	2	1.44
Frequent	0.5	39.35	2.54	2
	0.22	20	5	4.48
	0.2	18.13	5.52	5
	0.11	10	10	9.49
Rare	0.05	5	20	20
	0.02	2	50	50
	0.01	1	100	100
	0.005	0.5	200	200
Very Rare	0.002	0.2	500	500
	0.001	0.1	1000	1000
	0.0005	0.05	2000	2000
	0.0002	0.02	5000	5000
Extreme			↓	
			PMP/ PMPDF	

FOREWORD

The NSW State Government's Flood Policy provides a framework to ensure the sustainable use of floodplain environments. The Policy is specifically structured to provide solutions to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

Under the Policy, the management of flood liable land remains the responsibility of local government. The State Government 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 Government through four sequential stages:

1. Flood Study
- Determine the nature and extent of the flood problem.

2. Floodplain Risk Management *Study*
- Evaluates management options for the floodplain in respect of both existing and proposed development.

3. Floodplain Risk Management Plan
- Involves formal adoption by Council of a plan of management for the floodplain.

4. Implementation of the Plan
- Construction of flood mitigation works to protect existing development, use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

EXECUTIVE SUMMARY

BACKGROUND

The Birds Gully and Bunnerong Road catchment covers a total area of 9.9 km^2 and is located in the eastern suburbs of Sydney, within Randwick City Council and City of Bayside Council local government areas (LGA). The study area encompasses the suburbs of Kingsford, South Coogee, Daceyville, Pagewood, Maroubra, Eastgardens, Hillsdale, Banksmeadow, Matraville and Port Botany. The study components are to:

- collate available historical flood related data;
- undertake a community consultation program;
- prepare suitable models for use in a subsequent Floodplain Risk Management Study;
- validate the models against historical events;
- undertake design flood estimation utilising the ARR2016 techniques
- provide design flood levels, depths, velocities, flows and flood extents;
- provide provisional hydraulic hazard and hydraulic categories mapping;
- assess sensitivity to potential climate change effects
- Undertake "hotspot" analysis

COMMUNITY CONSULTATION

Approximately 8798 questionnaires were distributed to residents within the catchment and 208 responses were received, 26 of which were completed using the online survey. This equates to a 2.36% return rate and therefore it should be recognised that the findings from this sample may not accurately represent the total population within the catchment. Of these responses, 44 have reported their property has previously been affected from flooding and of these 23 have experienced above floor flooding. The information above relates to the combined responses from both the Randwick and Bayside government areas, although relatively few responses were received from Bayside.

MODELLING SUMMARY

The study used hydrologic and hydraulic modelling techniques in order to define flood behaviour in the study area. The modelling programs used in the study are:

- DRAINS Hydrologic model converts rainfall to runoff for input into the TUFLOW model.
- TUFLOW 2D Hydraulic model was established to analyse the flooding behaviour.

MODEL VALIDATION

In order to provide robust design flood data the models should be calibrated to historical flood data but typically in an urban catchment there is insufficient high quality data available. The March 2014 and December 2015 events were chosen for model validation but the process was limited by the quality and quantity of the available rainfall and flood data.

DESIGN FLOOD MODELLING

The ARR 2016 methodology was adopted for design flood estimation which utilises an ensemble of 10 temporal patterns that are applicable across four AEP ranges for durations ranging from 15 mins to 7 days within each region. The four AEP categories are as follows:

- Frequent - more frequent than 14.4% AEP,
- Intermediate - between 3.2% AEP and 14.4% AEP,
- Rare - rarer than 3.2% AEP, and
- Very Rare – rarest 10 within the region.

The technique for the critical duration analysis of the temporal pattern ensembles is outlined in Section 7. It was determined that the upper reaches of the catchments where overland flow was the dominant flood mechanism had a shorter critical duration and the downstream region of the catchment where mainstream flooding was the dominant flood mechanism had a longer critical duration. For each AEP, design flood behaviour was based on a shorter duration event of either 30 minutes or 60 minutes, and a longer duration event of either 90 minutes, 180 minutes, or 120 minutes.

The study results have been provided to RCC and BCC in digital format and mapped in Appendix C as follows:

The results from this study are presented as:

- Peak flood depths in Figure C1 to Figure C9
- Peak flood velocities in Figure C10 to Figure C18
- Provisional hydraulic hazard in Figure C19 to Figure C22; and
- Provisional hydraulic categorisation in Figure C23 to Figure C24

HOTSPOT ANALYSIS

The following areas were identified for investigation in the Floodplain Risk Management Plan and are displayed in Figure C25 to Figure C40.

- Paton Street
- Holmes Street and Benevue Street
- Garden Street
- Glanfield Street
- Jersey Road
- Flack Avenue
- Denison Street and Nilson Avenue
- Boonah Avenue
- Parer Street
- Glanfield Street And Maroubra Road
- Edward Circuit
- Bunnerong Road
- Irvine Street
- Hinck Street
- Harbourne Road

1. INTRODUCTION

This flood study was prepared by WMAwater on behalf of the Randwick City Council and Bayside Council. The study was commissioned by the Randwick City Council and Bayside Council with funding from the NSW Office of Environment and Heritage (OEH) under the Floodplain Management Program. The main objective of the study is to define existing flood behaviour within the Birds Gully and Bunnerong Road catchment. The study examined past flood events that have occurred, in addition to undertaking a flood assessment for a range of design storms.

There have been a number of previous studies undertaken for Randwick City Council and Bayside Council adjacent to this study area. These studies and their locations are shown in Figure 1.

1.1. Study Area

The Birds Gully and Bunnerong Road catchment covers a total area of 9.9 km^2 and is located in the eastern suburbs of Sydney, within Randwick City Council and City of Bayside Council local government areas (LGA). The study area is shown in Figure 2 and encompasses the suburbs of Kingsford, South Coogee, Daceyville, Pagewood, Maroubra, Eastgardens, Hillsdale, Banksmeadow, Matraville and Port Botany.

The catchment can be divided into two separate catchments; the Birds Gully catchment and the Bunnerong Road catchment. The Birds Gully catchment is 1.7 km^2 and is located in the north western section of the catchment. The Bunnerong Road catchment comprises the remaining 8.2 km^2. The majority of the watercourses within the catchment have been replaced with trunk drainage with the Birds Gully catchment draining to the Botany Bay wetlands at the Eastlakes Golf Course, and the Bunnerong Road catchment discharges to both Botany Bay and Lurline Bay.

The study area is highly urbanised and consists of a combination of residential, commercial and industrial properties. There are some areas of open spaces within the catchment, including recreational parks, sporting fields and the Randwick Environmental Park in the north-east section of the catchment. The Randwick Army Barracks are located in the upper parts of the Bunnerong Road catchment. The Birds Gully and Bunnerong Road catchment consists of steeper topography in the upstream sections of the catchment, ranging from up to 80 mAHD along the north-eastern boundary of the study area before becoming flatter, reaching close to 0 mAHD in the downstream areas nearing closer to Port Botany.

Recently, the study area has undergone significant development and urbanisation, which may impact the flood behaviour of the catchment. There is a significant history of flooding within the catchment, with both councils receiving frequent complaints of flooding.

1.2. Objectives

The scope of this flood study is to develop a robust hydrologic and hydraulic modelling package with the capability to accurately simulate existing and historic flood behaviour. Given a history of flooding within the catchment, there is a strong need to define and map flood behaviour in the catchment in order to provide Council with the planning tools necessary to mitigate flood risk for current and future development. The information and results obtained from this study will provide the basis for the development of a subsequent Floodplain Risk Management Study and Plan (FRMS&P) which will explore flood modification works, various planning instruments and flood response measures.

Flood study elements undertaken as part of this study include:

- Undertake a community consultation program,
- Develop a hydrologic and hydraulic modelling package to appropriately represent the catchment and floodplain,
- Validate the hydrologic and hydraulic models against historical events,
- Determine the sensitivity of the model outcomes to modelling parameters and assumptions,
- Define flood characteristics including flood extent, levels, depths, velocities and flows,
- Determine floodplain planning categories including, hydraulic categories, hazard categories and the flood emergency response classification,
- Define the capacity of the existing drainage network and determine potential upgrades, and
- Undertake a climate change assessment including assessing the effects of an increase in different rainfall intensities.

A glossary of flood related terms is provided in Appendix A.

1.3. Description of the Catchment and Flood History Overview

Photo 1: Army truck in Garrett Street during the October 1959 Flood Event

a.

b.

Source: Randwick City Council Website, donated by Mrs Dorothy Stafford

The Birds Gully and Bunnerong Road catchment has largely been developed, with the majority of the waterways within the catchment having been replaced with urban drainage networks such as concrete lined channels and pipes. The drainage network within the study area was primarily constructed in the 1960s, however some of the oldest assets date back to the 1860s. Council receives frequent complaints of flooding from events exceeding the capacity of the drainage network, and flooding due to overland flow. Historic newspaper articles, SES reports, the Bureau of Meteorology (BoM) and council websites indicate that there has been previous flooding in 1959, 1984, 1989, 1998, 1999, 2009, 2014 and 2015, with the October 1959 event possibly being the largest event on record (see Photo 1 and Photo 2).

Photo 2: Corner of Garrett Street and Storey Street during the October 1959 Flood Event

Source: Randwick City Council Website, donated by Mrs Dorothy Stafford

The trunk drainage networks within both the Birds Gully catchment and the Bunnerong Road catchment are primarily owned by Sydney Water and comprise of three main trunk drainage lines. The Birds Gully trunk drainage line drains the Birds Gully catchment and discharges to the Botany Bay wetlands at Eastlakes Golf Course in Daceyville. The Bunnerong to Lurline Bay diversion line partially drains the northern Bunnerong catchment, which leaves the remaining section of the Bunnerong catchment draining via the Bunnerong to Botany Bay line (see Figure 12).

In addition to the catchment comprising a large proportion of residential properties, there are a number of notable institutional facilities, including educational and medical facilities. Figure 3 details the locations of these educational and medical facilities within the catchment. There are a number of major hospitals within the catchment that should be noted including:

- Sydney Children's Hospital,

- Prince of Wales Hospital,
- Royal Hospital for Women,
- Prince of Wales Private Hospital,
- Part of the university of New South Wales, and
- Randwick Army Barracks.

1.4. Community Consultation

Community consultation is an important element of the floodplain risk management process and is important in the development of a flood study as it facilitates community engagement and acceptance of the overall project. A newsletter and questionnaire was prepared and distributed to the residents within the Birds Gully and Bunnerong Road catchments to assess the flood experiences of the community and gather additional data. In addition, an online version of the questionnaire was also made available.

The newsletter described the purpose of the Flood Study and requested information residents may have of historical flooding in the catchment. 8798 questionnaires were distributed to residents within the catchment and 208 responses were received, 26 of which were completed using the online survey. This equates to a 2.36% return rate and therefore it should be recognised that the findings from this sample may not accurately represent the total population within the catchment. Of these responses, 44 have reported their property has previously been affected from flooding and of these 23 have experienced above floor flooding. Figure 4 and Figure 5 detail the location of all properties that have reported previous flooding and some statistics from the returned questionnaire. The information above relates to the combined responses from both the Randwick and Bayside government areas, although relatively few responses were received from Bayside.

The responses to the community questionnaire highlighted specific problems related to flooding that residents are particularly concerned about. These concerns include:

- Inadequate drainage, including undersized pits and pipes and ineffective gutter systems,
- Debris blocking drains and gutter systems,
- Flooding due to overland flow,
- Algae build up in water drains,
- Standing water in trapped low points unable to drain and remaining for time periods of up to a week,
- Flood damages to garages (in some locations properties are affected on roughly an annual basis); and,
- Some residents have employed their own flood mitigation measures; including building drains on the side of their properties and flood barrier gates along the front of their property.

The community consultation responses were used to identify potential flooding “hotspot” locations (see Figure 4). In addition to responding to the questionnaire, some residents have provided photographs of past rainfall events, as shown below in Photo 3 to Photo 5.

Photo 3: Flood photographs along Flack Street, Hillsdale

Photo 4: Flood photographs at the laneway connecting Apsley Avenue to Lancaster Crescent, Kingsford

Photo 5: Flood photographs outside 141 Bunnerong Road, Kingsford

2. AVAILABLE DATA

2.1. Overview

Data collection is the first stage in the floodplain risk management process and is essential to gain an understanding of the flooding characteristics within the catchment, including the nature, size and frequency of the problem. To determine an accurate understanding of the flooding problem within the catchment, it is preferable to have an extensive period of historical records including stream flow records and stream water level records. In some creek systems there are permanent water level gauges, maximum height records or stream flow gauges, which assist in the hydrologic and hydraulic model calibration and give insight into the size and frequency of the flooding problem. However, in urban catchments like Birds Gully and Bunnerong Road catchment, which are relatively small compared to major river or creek systems, there are generally no stream gauges or official historical records available.

2.2. Data Sources

The available data sets for this study are summarised in the following sections. Table 1 provides a summary of the type of data sources, the supplier, and its application in the study.

Table 1: Data Sources

Type of Data	Format Provided (Source)	Application
Ground Levels from ALS data (2013)	DEM (LPI)	Hydrologic and hydraulic models
Pits, Pipes and Hydraulic Structures	GIS (RCC and BCC)	Hydraulic model
Trunk Drainage and Hydraulic Structures	GIS and WAE plans (SWC)	Hydrologic and hydraulic model
GIS Information (Cadastre)	GIS (RCC and BCC)	Hydraulic model
ARR Design Rainfalls	Tabulated (BoM)	Hydrologic model
Rainfall Gauge (Daily)	Spreadsheet (BoM)	Hydrologic model
Pluviometer (Continuous)	Spreadsheet (SWC) Spreadsheet (BoM)	Hydrologic model

2.3. Topographic Data

The digital elevation model (DEM), which forms the basis of the two-dimensional hydraulic modelling for this study, was obtained from the Sydney North 1m dataset from the Department of Land and Property Information (LPI). The DEM was produced using Triangular Irregular Network (TIN) method to formulate a regular grid from the Airborne Laser Scanner (ALS). The Sydney North 1m DEM dataset was collected in June 2013. For areas of clear, hard ground is has an accuracy in the order of:

- ± 0.8m in the horizontal direction (95% CI); and
- ± 0.3m in the vertical direction (95% CI).

The accuracy of ALS data can be influenced by the presence of open water or vegetation (tree or shrub canopy) at the time of survey, which means in some areas data is missing or the points are of lesser quality than the stated accuracy. Figure 6 shows the DEM for the Birds Gully and Bunnerong Road catchment.

2.4. Pit and Pipe Data

Randwick City Council and Bayside Council provided a GIS database of pit and pipe data. In both cases, the pit and pipe data was missing some relevant information, and not appropriate for direct input into the hydraulic model. An initial desktop review was undertaken of both pit and pipe datasets to determine sections of missing data and sections of inaccurate data. It was determined the missing data was not extensive enough to require a comprehensive detailed survey of the drainage pits and pipes within the catchment area. However, WMAwater undertook a site visit to verify pit and pipe locations and obtain a more accurate understanding of the drainage network within the catchment. The site visit also included the inspection of other hydraulic controls within the catchment, such as detention basins and their outlet embankments, swales, bridges and open channels.

SWC provided both GIS data and Work-As-Executed (WAE) survey plans. The GIS trunk drainage database included major pipes and other hydraulic controls including open channel drainage structures. Although the GIS database was not complete for direct input into the hydraulic model, the missing data was verified by referring back to the WAE survey plans. The data from Sydney Water is relatively high quality and gives a high level of confidence about the geometry and levels of the trunk drainage systems through the catchment.

The GIS dataset provided from RCC was partly incomplete, containing sections where invert and geometry details were missing and other sections where the details appeared to be inaccurate. It was generally possible to infer the pit and pipe invert and geometry details in sections where there was adequate data upstream and downstream for comparison. There is a reasonably high level of confidence in the stormwater drainage network data within the RCC area.

The BCC GIS dataset was mostly incomplete with small sections of the pipe network missing and incomplete geometry details. A combination of the SWC trunk drainage data and the site inspection was useful in estimating pit and pipe locations. Where geometry and invert details were missing this data was assumed based on the ground level and upstream and downstream pipe details. The data was also supplemented by survey collected by Council across Rowland Park and Prince Edward Circuit. The confidence in the stormwater drainage network data in the BCC area is therefore relatively low. However for larger design storm events such as the 1% AEP, where a relatively small proportion of runoff is conveyed by the pipe network, it is not anticipated to significantly affect the study outcomes.

2.5. Historical Flood Level Data

Historical flood level data is important for hydrologic and hydraulic model calibration and validation. However, the Birds Gully and Bunnerong Road study area is lacking any stream flow or water level gauges. Therefore, an understanding of historical flooding within the study area must be sourced from a combination of previous flood assessment records, rainfall records, Council records and local knowledge of flooding obtained from the community consultation questionnaire. Table 2 details all estimated water levels and their corresponding locations that were obtained from the community consultation (see Figure B1 for locations).

Table 2: Historic water levels obtained from community consultation

ID	Location	Suburb	Date	Report
BG140	147 Bunnerong Road	Kingsford	25-04-15	25cm at front step of property.
BG009	1 Flack Avenue	Hillsdale	-	93cm at garages of Unit 6 and Unit 14.
BG016	1 Flack Avenue	Hillsdale	24-03-14	1m depth at garages.
BG010	143 Bunnerong Road	Kingsford	-	6-8inches at brick fence.
BG011	80 Perry Street	Matraville	-	Up to 1m. Drains back up into the property.
BG014	11 Snape Street	Maroubra		20cm deep in the street in front of property.
BG012	13 Snape Street	Maroubra	-	1m deep water at stormwater drain in front of property
BG019	Hastings Avenue between Macquarie Street and Hall Street	Chifley	-	4 – 6 inches in street.
BG025	Land adjacent 52 Eyre Street	Chifley	-	Up to 30cm deep at approximately 10m west of border with 52 Eyre Street.
BG027	Intersection of Haig Ave and Gwea Ave	Daceyville	-	About 22cm within intersection
BG031	21 Beulah Street	Kingsford	16-12-15 Midday 15-12-15	Up to 500mm deep in garage. 500mm at rear land access.
BG033	267 Botany Street	Kingsford	-	40-50cm in basement and backyard of property.
BG039	50 Irvine Street and Marville Lane	Kingsford	-	650mm above floor, 700mm in street and laneway.
BG041	105 Rainbow Street	Kingsford	-	60 cm above drain
BG043	8 Snape Street	Kingsford	16-12-15, 22-12-15	1-2 inches in driveway and garages.
BG044	82 Sturt Street	Kingsford	01-1999	55cm above floor.
BG048	Corner of Avoca Street and Holmes Street	Maroubra		1 foot at footpath
BG049	8 Benvenue Street	Maroubra	10:30am 29-01-99	Up to air vents in 1st row of bricks above ground.
BG051	102 Gale Road	Maroubra	-	Water up to step at the front door.
BG052	107 Garden Street	Maroubra	11-59	6 inches above floor.
BG054	55 Hannan Street	Maroubra		Millimetres from flooding inside.
BG055	8 Holden Street	Maroubra	25/04/14	2 feet at garage.
BG059	Corner of Royal St and	Maroubra	-	400-500mm above Royal Street.

ID	Location	Suburb	Date	Report
	Maroubra Rd			
BG062	Walsh Avenue and Wild Street	Maroubra	-	5-30cm
BG063	Australia Avenue	Matraville	-	Several inches at the footpath.
BG063	56 Australia Avenue	Matraville	-	Ankle deep water in backyard.
BG064	60 Australia Avenue	Matraville	02-16	2 foot water in garage.
BG065	20 Harold Street	Matraville		400mm in garage.
BG066	7 Harold Street	Matraville	21-12-16	20 inches above floor level.
BG135	42-56 Harbourne Road	Kingsford	1998 1999 02-10	18cm 67-78cm (Flooding above floor level) 54-63cm
BG136	307 Botany Street	Kingsford		1 foot deep front yard entry from Botany Street.
BG139	1-5 Apsley Avenue	Kingsford	22-04-15 and 22-12-15	Around 45cm from the footpath.
BG140	147 Bunnerong Road	Kingsford	4:40pm 25-04-15	25cm at front step of property.
BG143	Corner of Marville and Irvine Street	Kingsford	-	Half a car wheel.
BG144	South side of Waratah Avenue	Randwick	-	2-3 inches.
BG145	1 Apsley Avenue	Kingsford	-	20cm at front door.
BG145	Laneway at 1 Apsley Avenue	Kingsford	-	33cm
BG148	505/438-448 Anzac Parade	Kingsford	-	10cm
BG149	Corner of Walsh and Donovan Avenue	Maroubra	-	5-10cm
BG174	Belongings in garage and garden damaged		-	50cm

2.6. Historical Rainfall Data

2.6.1. Overview

Rainfall data is recorded either daily (24-hour rainfall totals to 9:00 am) or continuously (pluviometers measuring rainfall in small increments – less than 1 mm). Daily rainfall data has been recorded for over 100 years at many locations within the Sydney basin. However, pluviometers have only been installed for widespread use since the 1970s.

Care must be taken when interpreting historical rainfall measurements. Rainfall records may not provide an accurate representation of past flooding due to a combination of factors including local site conditions, human error or limitations inherent to the type of recording instrument used. Examples of limitations that may impact the quality of data used for the present study are highlighted in the following:

- Rainfall gauges frequently fail to accurately record the total amount of rainfall. This can occur for a range of reasons including operator error, instrument failure, overtopping and vandalism. In particular, many gauges fail during periods of heavy rainfall and records of very intense events are often lost or misrepresented.

- Daily read information is usually obtained at 9:00 am in the morning. Thus if a single storm is experienced both before and after 9:00 am, then the rainfall is "split" between two days of record and a large single day total cannot be identified.
- In the past, rainfall over weekends was often erroneously accumulated and recorded as a combined Monday 9:00 am reading.
- The duration of intense rainfall required to produce overland flooding in the study area is typically less than 4 hours (though this rainfall may be contained within a longer period of rainfall). This is termed the "critical storm duration". For the study area a short intense period of rainfall can produce more severe flooding than sustained rainfall with a higher total depth. If the rain occurs quickly (e.g. a thunder storm), the daily rainfall total may not necessarily reflect the severity of the storm and the subsequent flooding. Alternatively, the rainfall may be relatively consistent throughout the day, producing a large total but only minor flooding.
- Rainfall records can frequently have "gaps" ranging from a few days to several weeks or even years.
- Pluviometer (continuous) records provide a much greater insight into the intensity (depth vs. time) of rainfall events. This data has much fewer limitations than daily read data, but there are far fewer pluviometers available in the vicinity of the catchment.
- Pluviometers have moving parts and automated recording mechanisms, which can fail during intense storm events due to the extreme weather conditions.

Intense rainfall events which cause overland flooding in highly urbanised catchments are usually localised and as such are only accurately represented by a nearby gauge, preferably within the catchment. Gauges sited just a kilometre apart can show very different intensities and total rainfall depths.

2.6.2. Rainfall Stations

Table 3 and Table 4 present a summary of the official rainfall gauges operated by the BoM and pluviometer gauges operated by SWC and BoM located either within the catchment or nearby. The locations of these rainfall gauges are displayed on Figure 7 and show that no gauges are located within the catchment extent.

Table 3: Nearby daily rainfall sations

Station Number	Station Name	Operating Authority	Distance from catchment centroid (km)	Elevation (mAHD)	Date Opened	Date Closed
66073	Randwick Racecourse	BoM	3.48	25	1937	Open
66052	Randwick (Randwick St)	BoM	3.5	74	1917	Open
66160	Centennial Park	BoM	4.88	38	1990	Open
66051	Little Bay (The Coast Golf Club)	BoM	4.95	22	1925	Open
66037	Sydney Airport AMO	BoM	5.97	6	1929	Open
66098	Rose Bay (Royal Sydney Golf Club)	BoM	7.05	8	1928	Open
66006	Sydney Botanic Gardens	BoM	8.45	15	1885	Open
66209	Dover Heights (Portland St)	BoM	8.53	70.5	2007	Open
66036	Marrickville Golf Club	BoM	9.26	6	1904	Open
66062	Sydney (Observatory Hill)	BoM	9.28	39	1858	Open
66000	Ashfield Bowling Club	BoM	11.28	25	1894	Open
66058	Sans Souci (Public School)	BoM	11.66	9	1899	Open
66184	Mosmon Council	BoM	11.8	85	1984	Open
66194	Canterbury Racecourse AWS	BoM	12.04	3	1995	Open

Table 4: Nearby pluviometer gauges

Station Number	Station Name	Operating Authority	Distance from catchment centroid (km)	Date Opened	Date Closed
566028	Eastlakes SW Depot	SWC	2.22	1973	Open
566088	Malabar STP	SWC	2.61	1990	Open
566099	Randwick Racecourse	SWC	3.22	1991	Open
066037	Sydney Airport Amo	BoM	5.91	1998	Open
566032	Paddington (composite site)	SWC	5.96	1979	Open
566110	Erskineville Bowling Club	SWC	6.19	1993	Open
566091	Kyeemagh Bowling Club	SWC	7.09	1991	Open
566026	Marrickville Bowling Club	SWC	7.52	1979	Open
066062	Sydney (Observatory Hill)	BoM	9.22	1998	Open
566065	Lilyfield Bowling Club	SWC	9.95	1989	Open
566112	Ashfield (Ashfield Park Bowling Club)	SWC	11.24	1993	Open
566113	Canterbury Racecourse	SWC	11.63	1993	Open
566062	Bexley Bowling Club	SWC	11.73	1987	Open
566066	Five Dock SPS065	SWC	12.8	1989	Open
566020	Enfield (Composite Site)	SWC	14.45	1983	Open
566047	Mortdale Bowling Club	SWC	15.21	1977	Open
566064	Concord Greenlees BC (formerly Wests Rugby Club)	SWC	15.23	1988	Open
566078	South Cronulla BC (formerly South Cronulla PS)	SWC	16.5	1990	Open
566022	Homebush SPS041 (formerly Homebush BC)	SWC	17.09	1969	Open
566036	Potts Hill Reservoir	SWC	19.33	1981	Open
566031	Revesby Bowling Club (formerly Padstow)	SWC	20.13	2005	Open

2.6.3. Analysis of Daily Read Rainfall Data

An analysis of daily read data was undertaken to place past storm events in some context. The daily read rainfall data was analysed for past flooding events that had either been reported by the BoM, City Council websites, the SES or online news sources. The daily rainfall stations included in this analysis were chosen by proximity to the catchment centroid (see Figure 7 for locations). Typically, during major storm events, it is common for daily read gauges to remain unread for several days and the resulting record being an accumulated total over several preceding days.

Table 5 and Table 6 provide rainfall measurements for some past flooding events. From this data, it can be seen that the October 1959 event was by far the largest rainfall event recorded within the catchment. The April 1998 and January 1999 storm events were also significant rainfall events but of much lesser total rainfall in a single day. However, as described in Section 2.6.1 daily read rainfall data does not provide a clear indication of an events severity or rainfall intensity.

Table 5: Daily rainfall measurements (mm) for past significant flooding events

Station Name	**October 1959**		**April 1989**				**April 1998 Event**			
	29th	**30th**	**31st**	**1st**	**2nd**	**3rd**	**10th**	**11th**	**12th**	**13th**
Randwick Racecourse	11.9	266.7	14	57.5	96.02*		118	105	0	0
Randwick (Randwick St)	265.4	29.2	4.2	47	52.2	38	70.8	87.8	0	0
Centennial Park	-		0	47.4	54	29.4	109.4	68	0	0
Little Bay (The Coast Golf Club)	-		12.8	92.03*			30.4	52.03		
Sydney Airport AMO	8.1	112.3	11	42.2	42.2	35	75.2	70.6	0	0

* Rainfall was measured over a time period greater than 24 hours

Table 6: Daily rainfall measurements (mm) for past significant flooding events

Station Name	**January 1999**				**May 2009**			**March 2014**				**December 2015**
	22nd	**23rd**	**24th**	**25th**	**1st**	**2nd**	**3rd**	**25th**	**26th**	**27th**	**28th**	**17th**
Randwick Racecourse	57	34	0	69	85.03*			25.4	0.8	26	8.4	38.4
Randwick (Randwick St)	54.6	34	73.8	0	11	0	76.6	27.2	0.6	29	7.8	58
Centennial Park	113*			0	10	0	67	36.2	3	29.6	5.5	-
Little Bay (The Coast Golf Club)	34.2	167.43*			29	0	50	-				-
Sydney Airport AMO	84.6	32.8	61.6	1.4	43.4	4	0	40	0.2	22.8	6.4	5.6

* Rainfall was measured over a time period greater than 24 hours

2.6.4. Pluviometer Rainfall Data

Continuous pluviometer records provide a more detailed description of temporal variations in rainfall. While the October 1959 event has been noted as the worst flooding event in recorded history within the catchment, pluviometer data was not available for this event. The Eastlakes SW Depot and Malabar STP gauges were analysed to determine the peak burst intensities for the historical flooding events and are shown in Table 7 and Table 8. These stations were chosen based on their proximity to the catchment centroid (see Figure 7 for locations).

Table 7: Peak Burst Intensities of Significant Rainfall Events (mm/h)

Rainfall Event	Eastlakes SW Depot			Malabar STP		
	30 min	1 hour	2 hour	30 min	1 hour	2 hour
April 1998	46	39	28.75	27	17.5	14
Jan 1999	-			80	71	45.75
March 2014	89	59	30	107	58	29.75
Dec 2015	63	35	17.75	106	64	32.25

Table 8: Approximate AEP of Pluviometer Storm Bursts

Rainfall Event	Eastlakes SW Depot			Malabar STP		
	30 min	1 hour	2 hour	30 min	1 hour	2 hour
April 1998	> 1EY	20% AEP	20% AEP	> 1EY	> 1EY	> 1EY
Jan 1999	-			10% AEP	2% AEP	2% AEP
March 2014	5% AEP	5% AEP	20% AEP	2% AEP	5% AEP	20% AEP
Dec 2015	20% AEP	50% AEP	> 1EY	2% AEP	5% AEP	20% AEP

"> 1EY" indicates the intensity occurs roughly once a year or more frequently than this (i.e. not particularly intense)

Rainfall intensities at the gauges were assessed for the 30 minute, 1 hour and 2 hour storm burst durations and compared to intensities from the updated 2016 IFD. These durations were selected for analysis based upon experience that these types of storm durations would be critical (i.e. produce the highest flood levels) for the size of the Birds Gully and Bunnerong Road catchment. It can be seen that the March 2014 and January 1999 event produced more widespread high intensities for three storm bursts at the two gauges. A comparison of significant rainfall events and the design rainfall intensities from AR&R 2016 IFDs are shown in Figure 8 to Figure 11.

2.6.5. Design Rainfall Data

The BoM recently released new design rainfalls in 2016 (Reference 1) to be used in conjunction with the updated Australian Rainfall and Runoff (ARR) (Reference 2). These new design rainfalls are based on larger datasets, produce more accurate estimates and provide better estimates of the 2% and 1% AEP events. The rainfall intensities presented in Table 9 were extracted from BoM for the Birds Gully and Bunnerong Road catchment.

Table 9: ARR2016 IFD data

Duration	**Design Rainfall (mm) From Bureau of Meteorology**						
	EY	Annual Exceedance Probability (AEP)					
	1 EY	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**
5 min	8.5	9.4	12.4	14.4	16.4	19	21
10 min	13.3	14.8	19.5	22.7	25.8	29.8	32.9
15 min	16.5	18.4	24.3	28.3	32.2	37.2	41
30 min	22.7	25.3	33.3	38.8	44.1	51	56.3
1 hour	29.7	33.1	43.5	50.7	57.7	67.1	74.5
2 hour	38.2	42.5	56.1	65.6	75.1	88	98.2
3 hour	44.3	49.3	65.5	76.8	88.3	104	116.5
6 hour	57.6	64.4	86.7	102.6	119	141.4	159.2
12 hour	75.6	85.1	116.6	139.5	163.1	195.2	220.8
24 hour	98.6	112	156.2	188.3	221.4	266.1	301.3
48 hour	125.2	143.2	202	244	286.8	344.3	389
72 hour	141	161.7	228.5	275.4	322.5	385.6	434.1
96 hour	152	174.4	245.8	295.3	344.5	409.9	459.6

The guidelines to using the 2016 IFDs (Reference 2) recommend that the 2016 IFD data should not be used with the probabilistic rational method, any other regional flood techniques based on the 1987 IFDs and should not be used in conjunction with the 1987 temporal patters.

2.7. Temporal Patterns

Temporal patterns are a hydrologic tool that describe how rainfall falls over time and are often used in hydrograph estimation. Previously, a single burst temporal pattern has been adopted for each rainfall event duration. However ARR2016 (Reference 2) discusses the potential inaccuracies with adopting a single temporal pattern, and recommends an approach where an ensemble of different temporal patterns are investigated.

2.7.1. ARR1987 Temporal Patterns

The 1987 temporal patterns can be obtained from ARR87 (Reference 3) and were developed using the Average Variability Method (AVM). The 1987 method divides Australia into 8 zones and provides two temporal patterns for 20 storm durations for ARI ≤ 30 years and ARI > 30years.

The AVM provides a pattern that describes the rainfall pattern of the most intense burst within a storm event and should not be considered representative of a typical rainfall pattern. A limitation with the AVM, as discussed in ARR2016 (Reference 2), is that it assumes that the variability of the pattern is of less importance than the central tendency, that is the central value of the probability distribution of rainfall volume. In reality, the runoff response can be very catchment-specific and therefore it is recognised that a representative pattern will not necessarily produce the median response from an ensemble of patterns. In addition to these concerns, it is not recommended using design rainfall bursts on catchments with significant natural or man-made storages. The 1987 temporal patterns should only be used in conjunction with the 1987 IFD tables.

2.7.2. ARR2016 Temporal Patterns

Temporal patterns for this study were obtained from ARR2016 (Reference 2). The revised 2016 temporal patterns attempt to address the key concerns practitioners found with the 1987 temporal patterns. It is widely accepted that there are a wide variety of temporal patterns possible for rainfall events of similar magnitude. This variation in temporal pattern can result in significant effects on the estimated peak flow. As such, the revised temporal patterns have adopted a different method to the 1987 AVM and provide an ensemble of design rainfall events. Given the rainfall-runoff response can be quite catchment specific, using an ensemble of temporal patterns attempts to produce the median catchment response.

As hydrologic modelling has advanced, it is becoming increasingly important to use realistic temporal patterns. The 1987 temporal patterns only provided a pattern of the most intense burst within a storm, whereas the 2016 temporal patterns look at the entirety of the storm including pre-burst rainfall, the burst and post-burst rainfall. There can be significant variability in the burst loading distribution (i.e. depending on where 50% of the burst rainfall occurs an event can be defined as front, middle or back loaded). The 2016 method divides Australia into 12 temporal pattern regions, with the Birds Gully and Bunnerong Road catchment falling within the East Coast South region. Each region was analysed to determine the proportion of front, middle and back loaded events and was separated into events shorter and longer than 6 hours. Table 10 provides the burst loading distribution for the East Coast South region. Table 11 details the gauge and event information used to derive the temporal patterns for the East Coast South region.

Table 10: Burst Loading distribution for the East Coast South region

Region	Duration	Front Loaded (%)	Middle Loaded (%)	Back Loaded (%)
East Coast South	≤ 6hr	26.5	57.1	16.4
	> 6hr	17.1	58.6	24.3

Table 11: Number of gauges and events within the temporal pattern region

Region	Number of gauges	Number of station years	Number of events	Average number of events per station
East Coast South	331	8067	19856	2.46

An ensemble of 10 temporal patterns are applicable across four AEP ranges for durations ranging from 15 mins to 7 days within each region. The four AEP categories are as follows:

- Frequent - more frequent than 14.4% AEP,
- Intermediate - between 3.2% AEP and 14.4% AEP,
- Rare - rarer than 3.2% AEP, and
- Very Rare – rarest 10 within the region.

The ARR 2016 Temporal Patterns were used in this study for design storm modelling. Details of the methodology used to derive the critical duration are discussed in greater detail in Section 7.2.

2.8. Previous Studies

A number of previous studies have been undertaken in the vicinity of the Birds Gully and Bunnerong Road study area. These studies are detailed in Figure 1 and listed below:

- Daceyville Flood Study, 2011,
- Centennial Park Flood Study, 2013,
- Draft Mascot, Roseberry and Eastlakes Flood Study, 2014,
- Botany Wetlands – Draft MRE Flood Study, 2014,
- Draft Kensington – Centennial Park FRMS, 2014,
- Coogee Bay FRMS&P, 2016,
- Maroubra Bay FRMS&P, 2016,
- Springvale and Floodvale Drain FRMS&P Current; and
- Bay Street Catchment Flood Study (2016).

Additionally, Sydney Water has previously undertaken three capacity assessments of the pipe networks within the Birds Gully & Bunnerong Road catchment area. These capacity assessments were produced using a similar methodology for all three. The networks that the assessment reports relate to are the Birds Gully SWC 10 and Banks to Cook Avenue SWC 12, Bunnerong to Tasman Sea SWC 11AMP and Bunnerong to Botany Bay (SWC 11) and can be seen in Figure 12.

2.8.1. SWC 10 & SWC 12 Capacity Assessment (Reference 4)

The 1997 Birds Gully SWC 10, Banks to Cook Ave SWC 12 Capacity Assessment was undertaken by Sydney Water to assess the performance of the pipe network and determine impacts of future development on their performance. The systems discharge to the eastern corner of Astrolabe Park and eventually to Botany Bay. The catchment areas for the Birds Gully SWC 10 and Banks to Cook Avenue SWC 12 are 2.01 km^2 and 0.68 km^2 respectively.

The purpose of the capacity assessment was to determine the Storm Event Capacity (SEC) of each pipe section. The SEC represents the intensity of rainfall the pipe network can withstand before there is flooding outside of the drainage path or overland flow.

Hydrologic and hydraulic modelling was done using a spreadsheet approach. Peak flow rates were estimated using the Rational Method in conjunction with the 1987 IFD tables as per the methodology detailed in ARR 1987. The hydraulic capacity of each pipe section was determined using the Manning Formula and the ARR 1987 method for composite roughness and compound sections. From this, the SEC was determined by finding the corresponding storm event that resulted in a peak flow equal to the hydraulic capacity.

The report indicates that the pipe system in this area has relatively low capacity with:

- only a small component of the network with capacity for a 20% AEP rainfall event,
- one-fifth of the system with capacity for a 50% AEP rainfall event, and
- two-thirds of the network with capacity for a 1 EY rainfall event.

2.8.2. SWC 11AMP Capacity Assessment (Reference 5)

The 2002 Bunnerong to Tasman Sea SWC 11 Amp Capacity Assessment was prepared by Sydney Water to determine the capacity of this section of pipe network. The Bunnerong to Tasman Sea pipe network, shown in Figure 12, has a catchment area of 2.37 km^2 and drains to Lurline Bay.

This capacity assessment follows a similar methodology to the Reference 4 study. The peak flow estimates were calculated using a combination of the 1987 IFD tables and the Rational Method and the hydraulic capacity of each pipe section was estimated from the Manning's Formula.

Results from this capacity assessment show that the capacity of the pipe system ranges from 1 EY to 1% AEP, with the majority of pipe reaches rated with a 1 EY capacity.

2.8.3. SWC 11 Capacity Assessment (Reference 6)

Sydney Water completed the Bunnerong to Botany Bay (SWC 11) Capacity Assessment in

2002 and follows the same methodology adopted within the Reference 4 and Reference 5 capacity assessments. The Bunnerong to Botany Bay pipe network has a catchment area of 4.37 km^2 and discharges to Botany Bay. Figure 12 shows the location of the Bunnerong to Botany Bay pipe system. Results show that the pipe system ratings range from 1 EY to 1% AEP. Table 12 details a summary of the findings from Reference 6.

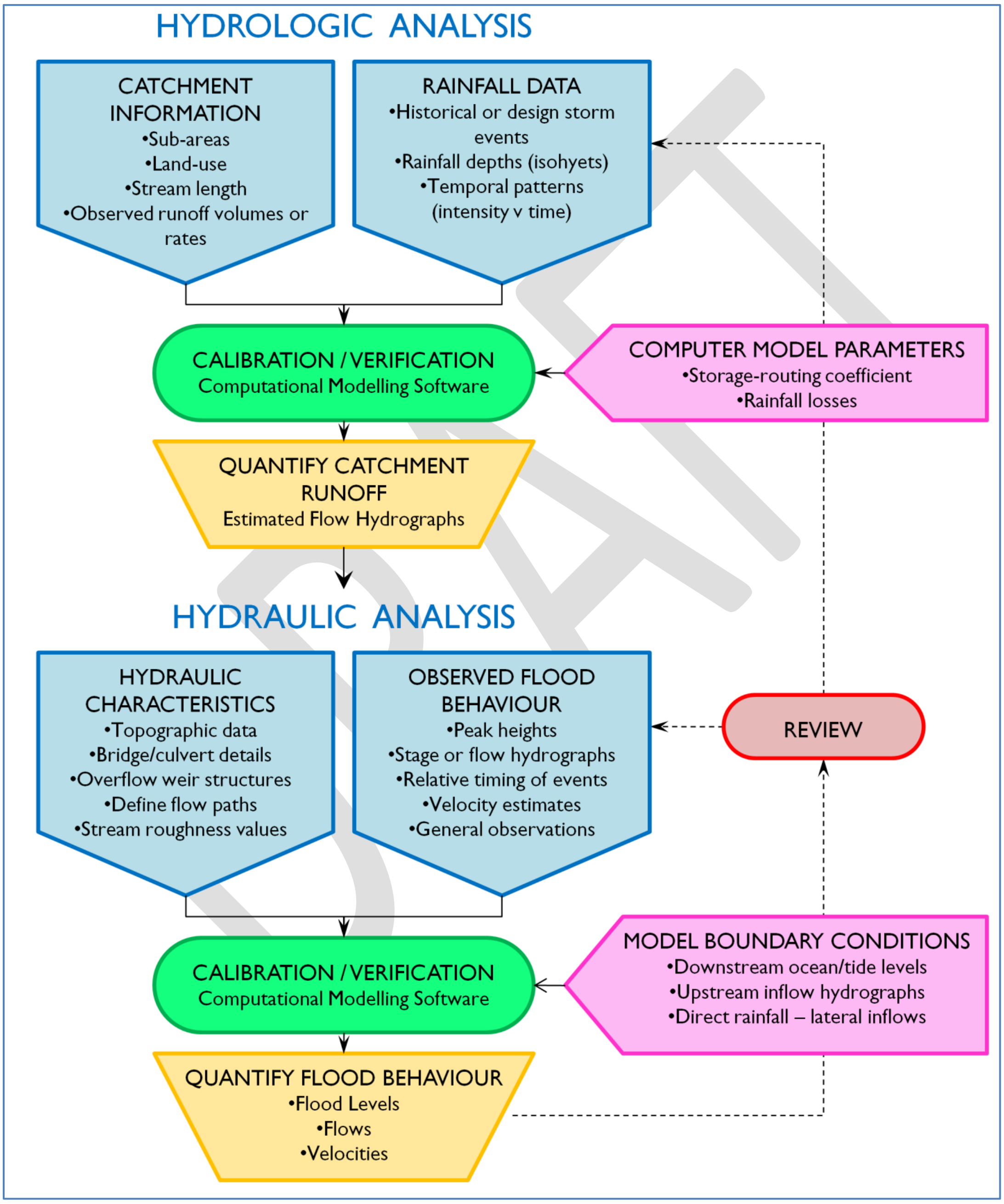
Table 12: Capacity ratings from Bunnerong to Botany Bay (SWC 11) Capacity Assessment

Pipe Network Branch	**Capacity**
Main Channel	Less than two-thirds 20% AEP or larger capacity Approximately 40% with 10% AEP capacity
Maroubra Bay Road Branch	50% less than 20% AEP capacity
Jersey Road Branch	50% less than 20% AEP capacity
Robey Street Branch	100% less than 20% AEP capacity
Fitzgerald Avenue Branch	Approximately 20% AEP to 10% AEP capacity
Holden Street Branch	Less than 20% AEP capacity
Taylor Street Branch	Less than 50% AEP capacity
North East Sub-branch	Approximately 20% AEP capacity
Snape Park Branch	Generally less than 20% AEP capacity

3. MODELLING METHODOLOGY OVERVIEW

The urbanised nature of the study area with its mix of pervious and impervious surfaces, and existing piped and overland flow drainage systems, creates a complex hydrologic and hydraulic flow regime. A diagrammatic representation of the Flood Study process to address the issues is shown in Diagram 1.

Diagram 1: Flood Study Process



For this study, the estimation of flood behaviour in a catchment was undertaken as a two-stage process, consisting of:

1. hydrologic modelling to convert rainfall estimates to overland flow runoff; and
2. hydraulic modelling to estimate overland flow distributions, flood levels and velocities.

The broad approach adopted for this study was to use DRAINS, a widely utilised and well-regarded hydrologic model for urban catchments, to conceptually model the rainfall concentration phase (including runoff from roof drainage systems, gutters, etc.). Design rainfall depths and patterns specified in AR&R (Reference 2) were input into the model and the runoff hydrographs were then used in a hydraulic model to estimate flood depths, velocities and hazard in the study area. Hydraulic modelling will be carried out using TUFLOW on a fixed 2 m grid.

The sub-catchments in the hydrologic model were kept small (on average approximately 2.5 ha) such that the overland flow behaviour for the study area was generally defined by the hydraulic model. This approach allows the concentration phase of the runoff to be modelled in a conceptual manner, since the scale of these concentration processes is too small to be modelled adequately by the hydraulic model (which has a grid cell size of 2 m). The concentration phase refers to runoff from roof/gutter/downpipe systems, intra-lot drainage, and other small scale flow paths in the most upstream parts of the catchment. WMAwater have previously used this method for similar overland flow catchment flood studies, and verified its suitability through comparisons with other commonly used hydrologic approaches.

The DRAINS hydrologic model software (Reference 7) was used to create the flow boundary conditions for input into a 2D unsteady flow (estimates the full storm hydrograph rather than just the peak flow as occurs with a steady state hydraulic model) hydraulic model using the TUFLOW software (Reference 8).

There are no stream-flow records in the catchment, so the use of a flood frequency approach for the estimation of design floods or calibration of the hydrologic model (independently from the hydraulic model) was not possible.

3.1. Hydrologic Model

DRAINS (Reference 7) is a widely used hydrologic and hydraulic modelling package built for the purpose of designing and analysing urban catchments and urban stormwater networks. It is capable of describing the flow behaviour of a catchment and pipe system for real storm events, as well as statistically based design storms. DRAINS models the conversion of rainfall to runoff and offers the option of routing these runoff hydrographs through a network of pipes, channels and streams.

For this study, DRAINS was used solely for the hydrological model and the hydraulic component of the modelling package was not utilised. The ILSAX hydrological model was adopted, as it has seen wide usage and acceptance throughout Australia. ILSAX adopts the time-area calculations and Horton infiltration procedures to determine flow hydrographs. The hydrologic outputs for each sub-catchment were used as inputs into the hydraulic model.

3.2. Hydraulic Model

The hydrodynamic modelling package TUFLOW (Reference 8), was used to assess the flooding behaviour of the Birds Gully and Bunnerong Creek catchments. TUFLOW is a widely used and accepted modelling package within Australia and internationally and was developed by BMT WBM in conjunction with the University of Queensland. An advantage of TUFLOW is its capability of dynamically simulating complex overland flow regimes. TUFLOW is particularly applicable to the hydraulic analysis of flooding in urban areas, which are typically characterised by short duration events, a combination of supercritical and subcritical flow behaviour and interactions between overland flow and a sub-surface drainage network.

This hydraulic modelling package utilises a grid based solution of the two-dimensional depth averaged, momentum and continuity equations for free surface flows. In addition to modelling of two-dimensional overland flow, TUFLOW incorporates one-dimensional elements within the model, including 1D open channels and sub-surface one-dimensional elements, such as pit and pipe networks. This component of the modelling packaged solves the full one-dimensional free-surface St Venant flow equation. The 1D and 2D components of the model can be dynamically linked during the simulation.

3.3. Calibration to Historical Events

When available, historical flood data can be used to calibrate the models and increases confidence in the estimates. The calibration process involves modifying the initial model parameter values to produce modelled results that concur with observed data. If records are available from multiple storms, validation can be undertaken to ensure that the calibration model parameter values are acceptable in other storm events with no additional alteration of values. Recorded rainfall and stream-flow data are required for calibration of the hydrologic model, while historic records of flood levels, velocities and inundation extents can be used for the calibration of hydraulic model parameters. In the absence of such data, model validation using limited historical data is the only option and a detailed sensitivity analysis of the different model input parameters constitutes current best practice.

Recent historical storms of significance are the April 1998, January 1999, March 2014 and December 2015. Sub-hourly rainfall data is available for these events to be modelled. Validation of the modelling package in comparison to the reported flood levels and flood behaviour is outlined in Section 6.

4. HYDROLOGIC MODEL SETUP

4.1. Sub-catchment Delineation

The total catchment represented by the DRAINS model is 9.9 km^2. This area was represented by a total of 395 sub-catchments shown in Figure 13, giving an average sub-catchment size of approximately 2.5 ha (approximately the size of two football fields). This relatively small sub-catchment delineation ensures that where significant overland flow paths exist that these are accounted for and able to be appropriately incorporated into hydraulic routing in the TUFLOW model. The sub-catchment layout is shown in Figure 13.

4.2. Impervious Surface Area

Runoff from connected impervious surfaces such as roads, gutters, roofs or concrete surfaces occurs significantly faster than from vegetated surfaces. This results in a faster concentration of flow within the downstream area of the catchment, and increased peak flow in some situations. It is therefore necessary to estimate the proportion of the catchment area that is covered by such surfaces.

DRAINS categorises these surface areas as either:

- paved areas (impervious areas directly connected to the drainage system);
- supplementary areas (impervious areas not directly connected to the drainage system, instead connected to the drainage system via the pervious areas); and
- grassed areas (pervious areas).

Within all sub-catchments, a uniform 5% was adopted as a supplementary area across the catchment. The remaining 95% was attributed to impervious (paved) and pervious surface areas, as estimated for each individual sub-catchment. The percentage of pervious surface was estimated by determining the proportion of the sub-catchment area covered by different land zoning classifications. The estimated impervious percentage of the chosen zoning classifications as summarised in Table 13. Sensitivity analysis was conducted on these assumptions.

Table 13: Impervious Percentage per Land-use

Land-use	Impervious Percentage
Urban Residential	70%
Open Space	5%
Roads	100%
Industrial	95%
Infrastructure	70%
Barracks	30%

The proportion of each zone within a sub-catchment was determined based GIS zoning files provided by RCC and BC.

4.3. Sub-catchment Slope

The slope of each sub-catchment was determined using an automated algorithm based on the following characteristics of each area:

- Minimum and maximum elevations based on LiDAR
- The ratio of the catchment area to its perimeter, used to estimate an indicative length

The typical slopes used for each sub-catchment were in the range of 1% to 6%, with an average of 3.5%. The minimum sub-catchment slope was 0.3% and the maximum was 17%.

4.4. Losses

Methods for modelling the proportion of rainfall that is “lost” to infiltration are outlined in AR&R (Reference 2). The methods are of varying degrees of complexity, with the more complex options only suitable if sufficient data are available. The method most typically used for design flood estimation is to apply an initial and continuing loss to the rainfall. The initial loss represents the wetting of the catchment prior to runoff starting to occur and the continuing loss represents the ongoing infiltration of water into the saturated soils while rainfall continues.

Rainfall losses from a paved or impervious area are considered to consist of only an initial loss (an amount sufficient to wet the pavement and fill minor surface depressions). Losses from grassed areas are comprised of an initial loss and a continuing loss. The continuing loss is calculated from an infiltration equation curve incorporated into the model and is based on the selected representative soil type and antecedent moisture condition.

The adopted loss parameters are summarised in Table 14. These are generally consistent with the parameters adopted flood studies in similar catchments within the Sydney metropolitan area.

Table 14: Adopted rainfall loss parameters

Rainfall Losses	
Paved Area Depression Storage (Initial Loss)	1.0 mm
Grassed Area Depression Storage (Initial Loss)	5.0 mm
SOIL TYPE	1
Slow infiltration rates (may have layers that impede downward movement of water). This parameter, in conjunction with the AMC, determines the continuing loss	
ANTECEDENT MOISTURE CONDITONS (AMC) (mm)	3
Description	Rather wet
Total Rainfall in 5 Days Preceding the Storm	12.5 to 25 mm

5. HYDRAULIC MODEL SETUP

5.1. Digital Elevation Model

A regularly spaced computational grid with a cell size 2 m by 2 m was utilised. This resolution was adopted as it was fine enough to accurately model roads and overland flow paths and did not result in excessive computational run-times. The model grid was established by sampling from a triangulation of filtered ground points from the 2011 LiDAR dataset.

The study area included in the 2D model encompassed an area of 9.9 km^2 as shown in Figure 14.

5.2. Boundary Locations

5.2.1. Inflows

For local sub-catchments within the TUFLOW model domain, local runoff hydrographs were extracted from the DRAINS model (see Section 4). These were applied to the receiving area of the sub-catchments within the 2D domain of the hydraulic model. These inflow locations typically correspond with gutter lines and inlet pits on the roadway, or specific drainage reserves. These features have typically been constructed to receive intra-lot drainage and sheet runoff flows in upstream catchment areas.

Utilising this method, the DRAINS model is essentially used to approximate the concentration phase of runoff, used a lumped conceptual approach to model features such as roofs, gutters, downpipes, gardens and other features of intra-lot drainage that are too complex or small to be accurately modelled by the TUFLOW hydraulic model. It is assumed that intra-lot drainage is effectively conveyed to the receiving street gutter, pipe system or overland flow path.

5.2.2. Downstream Boundary

There are multiple downstream boundaries built into the model. The boundaries fall into two separate categories:

- HQ Boundary – The outflow from this boundary is dependent on water level, using a rating curve in which the topographic gradient is assumed to equal the water level gradient (i.e. uniform flow); and
- HT Boundary – The water level at the boundary set, and can be a static or varying water level over time.

The boundary locations are shown in Figure 14 and are identified below:

HQ Boundary

- Belmore Road Randwick;
- Borrowdale Road Kingsford;
- Meares Avenue Randwick;
- Belmore Road Randwick;
- Anzac parade Maroubra;
- Bunnerong Road Matraville;
- Cornish Circuit Eastgardens; and
- Heffron Road Eastgardens.

These locations correspond to areas where cross-catchment flow occurs from the study area catchment into adjacent urban catchment areas.

HT Boundary

- Botany Bay
- Lurline Bay
- Astrolabe Park (Botany Wetlands)

The design tailwater levels for Botany Bay and Lurline Bay area shown in Table 15 and the design tailwater levels for Astrolabe Park are shown in Table 16.

Table 15: Assumed Lurline and Botany Bay Tailwater Levels

Design Event (AEP)	Design Tidal Level Botany Bay
100% AEP	1.2
50% AEP	1.2
20% AEP	1.2
10% AEP	1.2
5% AEP	1.4
2% AEP	1.42
1% AEP	1.43
PMF	1.45

Table 16: Assumed Astrolabe Park Tailwater Levels

Design Event (AEP)	Astrolabe North	Astrolabe South
100% AEP	16.84	14.95
50% AEP	16.84	14.95
20% AEP	16.98	15.11
10% AEP	17.01	15.27
5% AEP	17.12	15.45
2% AEP	17.29	15.67
1% AEP	17.39	15.81
PMF	17.97	16.73

5.2.3. Roughness Co-efficient

The hydraulic efficiency of the flow paths within the TUFLOW model is represented in part by the hydraulic roughness or friction factor formulated as Manning's "n" values. This factor describes the net influence of bed roughness and incorporates the effects of vegetation and other features which may affect the hydraulic performance of the particular flow path.

The Manning's "n" values adopted for the study area, including flow paths (overland, pipe and in-channel), are shown in Table 17). These values have been adopted based on site inspection and past experience in similar floodplain environments. The values are consistent with typical values given in Chow, 1959 (Reference 9) and Henderson, 1966 (Reference 10). The spatial variation in Manning's 'n' is shown in Figure 15

Table 17: Manning's 'n' roughness values adopted in TUFLOW

Surface	Manning's "n" Adopted
Urban Residential	0.05
Open Space	0.03
Roads	0.02
Industrial	0.07
Infrastructure	0.06
Barracks	0.06
Concrete Channel	0.015

5.3. Continuous Infiltration Rate

The study area catchment is located over the Botany Aquifer, and is renowned for relatively fast infiltration of runoff into the ground. Reports of flooding often indicate that ponded floodwaters dissipate relatively quickly, even in the absence of pipe drainage in some areas. It was found during the model calibration process that unless infiltration losses were applied to areas of ponded water in the hydraulic model, the modelling significantly overestimated observed flood levels for a given rainfall, particularly in localised depression storage areas.

An infiltration rate of 117.8 mm/h from Reference 11 was utilised to represent the sandy soils, and for different land-use zones, the loss was adjusted based on the percentage of impervious surface assumed for each zone. This rate was chosen as part of the validation process and is discussed further Section 6.

5.4. Hydraulic Structures

5.4.1. Buildings

Buildings and other significant features likely to act as flow obstructions were incorporated into the model network based on building footprints, defined using aerial photography. These types of features were modelled as impermeable obstructions to flow and are shown in Figure 16. Thus there is no assumed flood storage capacity within the buildings. Building delineation was based on aerial photographs, and validated for key overland flow areas by site inspection and use of Google "Streetview" photographs.

Buildings were "blocked out" from the 2D model grid, in line with research undertaken for the AR&R revision (Reference 2). The research project found that "Numerical model trials showed *that on the basis of the available data sets, the best performing method when representing buildings in a numerical model was to either remove the computational points under the building footprint completely from the solution or to increase the elevation of the building footprint to be above the maximum expected flood height.*" The project also found that "*Analysis of flood volumes on the floodplain has shown that in a floodplain with flows passing through the floodplain, achieving peak levels due to peak flow rate rather than peak stored volume, the influence of the flow volume stored inside buildings is not significant to the presented flood levels in the prototype floodplain.*"

5.4.2. Fencing and Obstructions

Smaller localised obstructions, such as fences, can be explicitly represented in TUFLOW in a number of ways including as an impermeable obstruction, a percentage blockage or as an energy loss. Often these obstructions are relatively transient, non-permanent structures, which do not require Council approval for modification. During site inspections for the study, WMAwater did not identify major fences or similar obstructions requiring specific modelling in TUFLOW. Instead, these obstructions were allowed for in a general sense by adopting a slightly increased Mannings "n" roughness value for residential and commercial land use areas, to represent the typical type of fencing used in such areas.

5.4.3. Sub-surface Drainage Network

The stormwater drainage network was modelled in TUFLOW as a 1D network dynamically linked to the 2D overland flow domain. This stormwater network includes conduits such as pipes and box culverts, and stormwater pits, including inlet pits and junction manholes and is shown in Figure 17. The schematisation of the stormwater network was undertaken using the detail "pit and pipe" database supplied by RCC and BC as well as Works-as-Executed plans from SWC (Reference 4, 5 and 6) to validate the information where appropriate. This validation was particularly necessary for some of the larger trunk drainage pipes, which in many instances pass for long distances through private property, and where junction pits are no longer accessible due to development over time.

Details of the 1D solution scheme for the pit and pipe network are provided in the TUFLOW user manual (Reference 8). For modelling of inlet pits the "R" pit channel type was utilised, which requires a width and height dimension for the inlet in the vertical plane. The width dimension represents the effective length inlet exposed to the flow, and the vertical dimension reflects the depth of flow where the inlet becomes submerged, and the flow regime transitions from the weir equation to the orifice equation. For lintel inlets, the width was based on the length of the opening. For inlet grates, the width was based on the perimeter of the grate. For combined lintel and grate inlets, the inlet width was the combination of the lintel and grate edge lengths, minus the portion of the grate adjacent to the lintel (to avoid double counting). This method applies to both sag and on-grade pits. Figure 17 shows the location and dimensions of drainage lines within the study catchment that have been included in the TUFLOW model.

5.4.4. Open Channels, Bridges and Culverts

Detailed schematisation of key hydraulic structures was included in the hydraulic model. Major open channel's culverts and bridges were generally modelled as 1D elements within the 2D domain, based on the scale of the structure and the key flow characteristics in comparison with the 2D cell size of 2 m. The decision on whether to model a structure in 1D or 2D was based primarily on the findings of Reference 12.

The modelling parameter values for the culverts and bridges were based on the geometrical properties of the structures, which were obtained from detailed SWC database and design plans, photographs taken during site inspections, and previous experience modelling similar structures.

The major hydraulic structures in the catchment are:

- The Bunnerong to Tasman Sea Trunk Drainage
- The Bunnerong to Botany Bay Trunk Drainage
- The Birds Gully Trunk Drainage

<u>Lurline Bay Trunk Drain Diversion</u>

The trunk drainage system consists of circular culverts upstream of Storey Street and a box culvert with dimension of 2.7 m x 2.4 m between Storey Street, Cooper Street and the ocean. The box culvert was modelled using the design cross section from Reference 5. The box culvert was modelled as an enclosed 1D open channel, since this gives a better solution for the super-critical flow regime caused by the steep gradient of the system.

The trunk drainage system includes a highly complex inflow structure at a location where the tunnel is located approximately 40 m below the ground surface. The structure includes an underground basin and weir to prevent the inflow disturbing flow in the culvert. This complex structure is not supported by the standard solution methods available in TUFLOW. Interpretation of the flow conditions was required to determine an appropriate method to schematise the structure in the model. It was determined that under the flood conditions being investigated, the key hydraulic control from this structure is the capacity of the incoming pipes, which is adequately resolved by the TUFLOW solution.

Bunnerong to Botany Bay Trunk Drainage

The system has been designed with circular culverts upstream of the major concrete channel between Pain Street and Port Botany. Sections of the channel have been enclosed by development since the channels were originally constructed in the 1970's. The channel was modelled using the SWC cross section from plans provided in Reference 6. The enclosed sections of the channel were modelled as a 1D rectangular culvert.

Several bridges traverse the open channel. The major bridges are located at Perry Street, Donovan Avenue and Wild Street. These major bridges were modelled in 2D. The pedestrian bridge at Rhodes St reserve and all the bridges within the downstream industrial area were modelled in 1D.

The 1D bridges were modelled in two sections:

- The section below the deck was modelled using the SWC cross-section. A loss versus depth relationship is applied, where as soon as the water reaches the bridge obvert, flow is affected by a reasonably high loss coefficient (K = 1.5).
- The section above the deck is modelled as a weir with a level taken from the LiDAR survey with the deck depth have been assumed to be 0.3m.

The Birds Gully Trunk Drainage

The trunk drainage system has been modelled using rectangular and circular culverts using conventional methods. A CCTV survey was undertaken by BC to investigate the network below Rowland Park. The results of that survey have been applied to the model

5.4.5. Road Kerbs and Gutters

LIDAR typically does not have sufficient resolution to adequately define the kerb/gutter system within roadways. The density of the aerial survey points is in the order of one per square metre, and the kerb/gutter feature is generally of a smaller scale than this, so the LIDAR does not pick up a continuous line of low points defining the drainage line along the edge of the kerb.

To deal with this issue, Reference 13 provides the following guidance:

> *Stamping a preferred flow path into a model grid/mesh (at the location of the physical kerb/gutter system) may produce more realistic model results, particularly with respect to smaller flood events that are of similar magnitude to the design capacity of the kerb and gutter. Stamping of the kerb/gutter alignment begins by digitising the kerb and gutter interval in a GIS environment. This interval is then used to select the model grid/mesh elements that it overlays in such a way that a connected flow path is selected (i.e. element linkage is orthogonal). These selected elements may then be lowered relative to the*

remaining grid/mesh.

The road gutter network plays a key role for overland flow in the Birds Gully and Bunnerong Road catchment. Preliminary modelling indicated that a significant portion of the catchment flows were within the roadways, which often traversed perpendicular to the land slope, and the flow depths were in the order of the depth of a typical kerb/gutter system (i.e. 0.1 m to 0.15 m), but using the raw LIDAR data resulted in multiple breakouts of flow over the kerb lines that did not appear to be realistic.

It was determined that in order to resolve these systems effectively, the gutters would be stamped into the mesh using the method described above, the locations of the gutters and are shown in Figure 16. The method used was to digitise breaklines along the gutter lines, and reduce the ground levels along those model cells by 0.15 m, creating a continuous flow path in the model.

5.5. Blockage Assumptions

5.5.1. Background

In order to determine design flood behaviour the likelihood and consequences of blockage needs to be considered. Guidance on the application of blockage can be found in AR&R Revision Project 11: Blockage of Hydraulic Structures, 2014 (Reference 14).

Blockage of hydraulic structures can occur with the transportation of a number of materials by flood waters. This includes vegetation, garbage bins, building materials and cars, the latter of which has been seen in the June 2007 Newcastle and August 1998 Wollongong Floods (Photo 6 and Photo 7).

Photo 6: Cars in a culvert inlet – Newcastle (Reference 14)

Photo 7: Urban debris in Wollongong (Reference 14)

The potential quantity and type of debris reaching a structure from a contributing source area depends on several factors. AR&R guidelines suggest adopted design blockage factors are based upon consideration of:

- the availability of debris;
- the ability for it to mobilise, and
- the ability for it to be transported to the structure.

The availability of debris is dependent on factors such as the potential for soil erosion, local geology, the source area, the amount and type of vegetative cover, the degree of urbanisation, land clearing and preceding wind and rainfall. However, the type of materials that can be mobilised can vary greatly between catchments and individual flood events.

Observations of debris conveyed in streams strongly suggest a correlation between event magnitude and debris potential at a site. Rarer events produce deeper and faster floodwater able to transport large quantities and larger sizes of debris, smaller events may not be able to transport larger blockage material at all. Debris potential is adjusted as required for greater or lesser probabilities to establish the *most likely* and *severe* blockage levels for that event.

The likelihood of blockage at a particular structure depends on whether or not debris is able to bridge across the structure inlet or become trapped within the structure. Research into culvert blockage in Wollongong showed a correlation with blockage and opening width. The *most likely* blockage to occur at a structure is determined by considering the potential quantity and type of debris and the structure opening size as in Table 18.

Table 18: Most Likely Blockage Levels – BDES (Table 6 in Reference 14)

Control Dimension	At-Site Debris Potential		
	High	**Medium**	**Low**
$W < L_{10}$	100%	50%	25%
$W \geq L_{10} \leq 3 \times L_{10}$	20%	10%	0%
$W > 3 \times L_{10}$	10%	0%	0%

Notes: W refers to the opening diameter / width
L_{10} refers to the 10% percentile length of debris that could arrive at the site

A severe blockage level is proposed where the consequences are very high and Reference 14 suggests a *severe* blockage of twice the *most likely* blockage criteria. At structures where the consequence of blockage is very low, a 0% blockage is suggested.

5.5.2. Blockage for Calibration Events

There was no indication of blockage identified for historical floods. Therefore no blockage factors were applied for the calibration events.

5.5.3. Blockage for Design Events

For design flood modelling, a blockage factor of 10% was applied to bridges and culverts along the open channel reaches of the Bunnerong line. This value was selected based on consideration of the ARR guidance summarised above. Sensitivity analysis was undertaken for this blockage assumption.

Blockage factors for stormwater inlets were based on whether the pit had a sag and or on-grade inlet, as shown in Table 19.

Table 19: Manning's 'n' roughness values adopted in TUFLOW

Pit Type	Blockage Adopted
On Grade Pit	20%
Sag Pit	50%

6. MODEL VALIDATION

6.1. Overview

Prior to defining design flood behaviour it is important that the performance of the overall modelling system be substantiated. Calibration involves modifying the initial model parameter values to produce modelled results that concur with observed data. Validation is undertaken to ensure that the calibration model parameter values are acceptable in other storm events with no additional alteration of values. Ideally the modelling system should be calibrated and validated to multiple events, but this requires adequate historical flood observations and sufficient pluviometer rainfall data.

Typically in urban areas such information is lacking. Issues which may prevent a thorough calibration of hydrologic and hydraulic models are:

- There is only a limited amount of historical flood information available for the study area. For example, in the Sydney metropolitan area there are only a few water level recorders in urban catchments, and none in this study area; and
- Rainfall records for past floods are limited and there is a lack of temporal information describing historical rainfall patterns (pluviometers) within the catchment.

In the event that a calibration and validation of the models is not possible or limited in scope, it is best practice to undertake a validation of the models based on what data is available, along with a detailed sensitivity analysis. This was the approach adopted for this study.

6.2. Summary of Historical Event Rainfall Data

The choice of calibration or validation events for flood modelling depends on a combination of the severity of the flood event and the quality of the available data. As is the case with most urban studies there was limited quantitative data available either in the form of flood marks or surveyed flood levels for the study area. There was qualitative information provided by residents through the community consultation process with regard to their properties being flood affected, and whether they had been flooded in their yard, garage or above floor level. In some cases this was used to estimate a depth of flooding or an extent of the flow path.

The majority of available flood observations were from the December 2015 storm. December 2015 was a relatively recent event that was identified through the community consultation as having caused significant flooding problems in the study area. Additional storms from March 2014 and January 1999 were also modelled for validation purposes, as there were some anecdotal reports of flooding issues, and these were known to be relatively intense rainfall events over the catchment. However most residents could not recall which event specifically had caused prior flood issues.

Figure 18 shows rainfall hyetographs adopted for the three above mentioned historical calibration events. Rainfall isohyets for the historical events were produced by gridding the recorded daily from the gauges in and adjacent to the catchment. The results were as follows:

- Figure 19 – 17th December 2015. Displays a rainfall gradient from south-east to north-east grading from approximately 100 mm to 50 mm
- Figure 20 – 25th March 2014. Displays a rainfall gradient from south to north grading from approximately 60 mm to 30 mm
- Figure 21 – 24th January 1999. Displays a rainfall gradient from east to west grading from approximately 90 mm to 30 mm

Comparisons of the rainfall data for the historical / calibration events with design rainfall intensities from AR&R 1987 (Reference 3) are shown in and summarised in Table 20.

Table 20: Data Available for Calibration Storm Events

Storm Event	Approximate AEP of recorded rainfall	Rainfall (mm)	Duration (minutes)	Pluviometer Stations
January 1999	2% to 1%	98.5	45	Malabar STP (566088)
	20% to 10%	58.5	30	Erskineville Bowling Club (566110)
March 2014	1%	64	30	Malabar STP (566088)
	2%	62	30	Eastlakes SW Depot (566028)
December 2015	2% to 1%	104	30	Malabar STP (566088)
	10%	45.5	15	Randwick Racecourse (566099)

The calibration and validation process was limited by incompleteness of the available rainfall data. The nearest pluviometers were outside the catchment, and it is likely they do not accurately reflect the actual rainfall that fell within the catchment during the historical events. In particular, the rainfalls at the Malabar STP site are likely to be more intense than those within the catchment, due to the proximity of the gauge to the coast. Given this level of uncertainty, and that results are typically more sensitive to the input rainfall than other model parameters, it was considered inappropriate to deviate significantly from typical modelling parameters used in similar urban catchments from the Sydney metropolitan area.

6.3. Recorded Flood Levels and Observed Behaviour

As part of the community consultation process data was received in regard to historical flooding in the catchment. This data ranged from residents qualitative descriptions of flood behaviour in and around their property to estimated flood depths for specific historical events. The locations for which data or observations were provided by the community are displayed on Figure B1.

Table 21: Estimated Flood Depths – Historical Events

ID	Resident Description	Depth (m)	Year
BG016	Garages in block.	1 m	March 2014, 2015
BG031	Rear Lane to Property	0.4 m approx.	2015
BG033	Basement and backyard only	0.4 – 0.5 m	2012
BG043	Driveway and garages	0.02 – 0.05 m	2015
BG044	Backyard	0.55 m	2015
BG037	Building 2 lifts, resident car damage	0.18 m	1998
		0.67 – 0.78 m	1999
		0.54 – 0.63 m	Feb 2010
		0.11 m	June 2010
		0.18 m	May 2011
		0.37 m	Dec 2015

Table 22: Historic Flood Observations – Unknown Events

ID	Resident Description	Depth (m)
BG009	Flooding of the garages	0.93 m
BG010	Flooding at rear granny flat	0.15 – 0.2 m
BG011	Drains back up	1 m
BG012	House front	1 m
BG019	Shallow, Garages and driveway	0.1 – 0.15m
BG039	Water into property and home	0.65 m
BG040	Above kerb level	-
BG045	Cannot walk onto footpath property flooded	high
BG049	Up to air vents in 1st row of bricks above ground	-
BG051	Water came up to the step at the front door	-
BG052	-	0.12 m
BG054	Millimetres inside the house	
BG063	None to house, some to contents of garage	0.1 – 0.15m
BG064	Backyard, garage	0.6m
BG065	Water runs down from street into backyard	0.4m
BG066	House cracked inside specially above windows and doors	0.5m
BG136	Front yard entry	0.3 - 0.6m
BG144	Water floods footpath on south side of road	0.02 – 0.05 m
BG145	Water on floorboards in entry to the house	0.2 m
BG148	Basement level 2 carpark	0.1 m
BG150	Floods garage near the water drain	0.01m
BG151	Driveway and garage	0.07 – 0.1m
BG173	Driveway to back of the house	0.25m
BG174	Belongings in garage and garden messed up	0.5m

The data points that provide an estimated flood depth that correspond to a specific historical event are shown in Table 21. The data points that provide a description of flood behaviour and typical flow behaviour but don't correspond to any specific historical flood depth are shown in Table 22. Example photographs of flood behaviour where flood depths have been recorded are shown in Photo 8.

Photo 8: Collection of sample model validation photographs

ID BG016

ID BG016

ID BG031

ID BG139

ID BG139

ID BG139

6.4. Hydraulic Model Validation

Validation of the hydraulic model was undertaken using two techniques:

- A comparison of the observed depths from the community consultation for the December 2015 event with the modelled depths for the same event.
- A qualitative assessment of all the locations that had reported flooding was undertaken for the January 1999, March 2014 and December 2015 events to determine if the TUFLOW model could replicate this reported flood behaviour at these locations.

6.4.1. Validation to Observed Depths – December 2015

The December 2015 event was modelled using the temporal pattern from Randwick Racecourse pluviometer. Multiple sets of parameters were used to obtain the best fit to the recorded flood levels based on catchment topography and historical conditions. The observed depths as well as the differences in modelled depths for all the validation scenarios is shown in Table 23. The results for the Randwick pluviometer and the final parameters chosen are shown in Figure B2 to Figure B10.

Table 23: Comparison of Modelled and Observed Peak Flood Depths – December 2015

ID	Observed Depth (m)	Modelled Depth minus Observed Depth (m)				
		Using Randwick Racecourse (566099) pluviometer pattern	**Using Randwick Racecourse (566099) pluviometer pattern with attenuated Malabar gauges**	**Using Randwick Racecourse (566099) pluviometer pattern with Dry initial Condition and porous soil**	**Using Randwick Racecourse (566099) pluviometer pattern with Infiltration modelled**	**Using Randwick Racecourse (566099) pluviometer pattern with Final parameters**
BG016	0.20	0.46	0.37	0.39	0.43	0.21
BG031	0.40	0.09	0.01	0.03	0.03	-0.10
BG043	0.05	-0.05	-0.05	-0.05	-0.05	-0.05
BG037	0.37	0.18	0.13	0.09	0.09	-0.03
BG139	0.20	0.00	0.00	0.00	0.07	0.07
BG145	0.30	0.22	0.20	0.20	0.18	0.12
BG010	0.20	0.32	0.17	0.24	0.17	0.01
BG010	0.10	0.24	0.09	0.16	0.09	-0.01
Average Error		0.19	0.13	0.14	0.14	0.07

Overall the model replicates the observed flooding behaviour quite well. The average is 0.07 m which is a reasonable match with the data available.

A sensitivity to the models parameters shows:

- The Malabar rainfall gauge recorded two peaks of same intensity during the 2015 events. The Randwick Racecourse gauge shows only the second rainfall peak. An attenuation of the Malabar first peak of rainfall depth gives a flood depth closer to the observed. The average error is 0.13 m by reducing the rainfall recorded at Malabar gauge.
- The lack of rainfall recorded prior the 2015 event indicates a relatively dry antecedent condition may have occurred. A dryer antecedent moister condition combined with a more porous soil type in the hydrologic model gives a flood depth closer to observed. The average error is 0.14 m by modelling the drier antecedent condition.
- The high infiltration rates of the Botany Aquifer sandy soils are also potentially influential on peak flood levels. The use of infiltration as discussed in Section 5.3 reduces the flood depth. The average error is 0.14 m by modelling infiltration.
- The combination of all the above changes gives a flood depth close to the observed depth. The average error is 0.07 m. This scenario was adopted for the final calibration results.

Sources of uncertainty to be considered include:

- The variation in rainfall depth that results from the two temporal patterns recorded at the Randwick and Malabar pluviometers suggests that the rainfall behaviour in the catchment was not uniform. Due to the pluviometers being located outside the catchment, the available rainfall data does not give an accurate record across the entire catchment.
- The recorded flood depths are estimations by the residents, rather than accurately surveyed depths or levels at a specific location. This can result in an observation errors by the resident as well as errors when sampling the modelled depth grid at the wrong location.
- The observed depth of inundation may not have been observed at the peak of the flood.

6.4.2. Validation to Observed Depths – March 2014

The March 2014 event was modelled using the temporal patterns from Malabar and East Lakes pluviometer's. The set of parameters use for the March 2014 event are the same than the final parameters of December 2015. It includes infiltration and dry antecedent condition. The Malabar pluviometer produced the best fit to observed flood depths with results shown in Figure B11 to Figure B16. The observed depths as well as the differences in modelled depths is shown in Table 24.

Table 24: Comparison of Modelled and Observed Peak Flood Depths – March 2014

ID	Observed Depth (m)	Modelled Depth minus Observed Depth (m)	
		Using East Lakes SW Depot (566028) pluviometer pattern with final parameters	**Using Malabar (566088) pluviometer pattern with final parameters**
BG016	0.20	0.34	0.11
BG033	0.40	0.23	-0.14
BG010	0.05	0.17	0.03
BG010	0.37	-0.18	-0.28
BG065	0.20	0.18	0.10
Average Error (m)		0.22	0.13

The model slightly overestimates the recorded depth at the observed locations, with a reasonable average error below 0.15 m using the Malabar pluviometer pattern. The same sources of uncertainty as for the 2015 storm also apply here.

6.4.3. Validation to Qualitative Flood Behaviour

While residents provided some descriptions of flooding that occurred in the late 1990s, there was generally little confidence regarding the year it occurred, or the exact depth. There were several residents who indicated that flooding above floor level occurred in this period, suggesting at least one storm caused relatively severe flooding.

A qualitative assessment was undertaken at each location that reported flood behaviour for the following the events listed below utilising both the Randwick Racecourse and the Malabar STP pluviometer data:

- December 2015
- March 2014

The assessment analysed whether the model replicated the observed flood behaviour, flood inundation or produced a flood extent similar to the the reported behaviour. The results are presented as a simple Yes or No and are displayed in Table 25. The flood depth grids for each event in conjunction with the observed flood behaviour locations are shown in

Figure B2 to Figure B16. The modelling showed a reasonable match to reported behaviour across the majority of events and temporal pattern combinations that were considered.

Table 25: Validation to Observed Flood Behaviour

ID	Resident Description	Approx. Depth (m)	Reproduce Reported Flood Behaviour	
			Dec-15 RRC 566099	Mar-14 M STP 566088
BG011	Drains back up into our property	1 m	Y	Y
BG012	2 motor of the front gate, flooded above motors	1 m	Y	N
BG039	Water comes into property and garage and home	0.65 m	Y	Y
BG040	the water just pours down to the flat point of the street and up to the front doors of a few of our	-	Y	Y
BG045	Cannot walk onto footpath. Totally flooded and comes into our property at the front.	high	N	N
BG049	Up to air vents in 1st row of bricks above ground	-	Y	Y
BG051	Water came up to the step at the front door	-	Y	Y
BG052	No comment	0.12 m	Y	N
BG054	Most of the water comes from Gale Rd and the great volume that comes to the gully that's in front	0	Y	Y
BG063	The front yard at number 52 floods. The backyard at number 56	0.1 m to 0.15 m	Y	Y
BG064	Plants and bags for garage	0.6 m	Y	Y
BG066	Front and the sided of the house	0.5 m	Y	Y
BG136	Front yard entry from Botany St, Kingsford	0.3 m - 0.6 m	Y	Y
BG144	Water floods footpath on south side of road	0.02 m to 0.05 m	Y	Y
BG148	Basement level 2 carpark	0.1 m	N	N
BG150	Floods garage near the water drain	0.01 m	N	N
BG151	Driveway and garage (sun-room)	0.07 to m 0.1 m	N	N
BG173	The water gushes down 29's driveway and enters my property via driveway	0.25 m	N	N
BG174	Belongings in garage wet garden messed up	0.5 m	Y	Y
BG016	2 motorbikes complete flooded	0.20 m	Y	Y
BG031	Garage completely flooded with major damage to property.	0.40 m	Y	Y
BG033	Basement and backyard only	0.40 m	Y	Y
BG043	flooded	0.05 m	N	N
BG044	flooding from Rainbow to Paton St, then through our backyards	0.55 m	Y	N
BG037	Building 2 lifts, resident car damage	0.37 m	Y	Y
BG139	in front of 3 Apsley Ave, Kingsford	0.20 m	Y	Y
BG145	Water on floorboards in entry to the house.	0.30 m	Y	Y
BG010	Flooding at rear granny flat	0.20 m	Y	Y
BG010	Pic of front gate	0.10 m	Y	Y
BG065	Water runs down from street into backyard and backyard	0.30 m	Y	Y

There are some points where the model does not replicate the reported flood behaviour.

These points are listed below with a brief explanation:

- BG148 – This point is located on the model boundary and it is not justified to delineate the subcatchments small enough to allocated flows in this area. The issues appear to be related to intra-lot drainage rather than flooding.
- BG173 – The reported issues here appear to relate to intra-lot drainage rather than catchment overland flow.

Note: For the calibration events the following details were not been included in the model:

- Sydney Water works at Astrolabe Park
- Stormwater upgrade Beauchamp Road
- Development of Heffron Park

The above works were included as part of the design event modelling.

6.4.4. Validation Conclusions

The adopted modelling parameters utilised in the validation process produce a good match to the observed flood behaviour. Where observed flood depths were available the model typically matched those depths to within 0.2 m which is considered to be within a reasonable range when considering the reliability of the available data. For locations where the community reported flood behaviour the model has replicated that behaviour in the majority of cases.

7. DESIGN EVENT MODELLING

7.1. Overview

Design flood levels in the catchment are a combination of flooding from rainfall over the local catchment (overland flooding), as well as elevated water level in open channels (mainstream flooding) and tail water levels in Botany Bay for the southern part of the catchment.

7.2. Critical Duration

To determine the critical storm duration for various parts of the catchment (i.e. produce the highest flood level), modelling of the 1% AEP, 5% AEP and 10% AEP events from separate temporal pattern bins was undertaken for a range of design storm durations from 20 minutes to 6 hours. Each duration utilised ten temporal patterns from AR&R 2016 (Reference 3). The result analysed to represent both the mainstream and overland flooding. The following process was undertaken in order to determine the critical duration for each temporal pattern bin:

1. Run 10 temporal patterns for each duration for the 1% AEP, 5% AEP and 10% AEP events.
2. Determine the mean enveloped level across the catchment from each duration modelled.
3. In order to determine which temporal pattern to use for each duration analyse each of the 10 flood level grids by producing difference mapping of each flood level grid against the mean enveloped level grid.
4. Statistically analyse the afflux grids utilising the mean, min, max and sum of difference.
5. The grid that produces statistics that is the closest to just above the mean level grid across the catchment was chosen, and then checked that it produced results that were a reasonable match to the mean across the catchment.
6. Two durations were chosen to reflect differences in behaviour between smaller subcatchments with faster response times, and the broader catchment behaviour.

It was found that for the 1 EY, 0.5 EY and 20% AEP events the 30 min duration event was critical for upper areas of the catchment affected by overland flow and the 2 hour event critical for lower areas of the catchment affected by mainstream flooding.

Modelling of the 10% and 5% AEP events determined that the 1 hour duration event was critical for upper areas of the catchment affected by overland flow and the 3 hour event critical for lower areas of the catchment affected by mainstream flooding.

Modelling of the 2%, 1% and 0.5% AEP events determined that the 1 hour duration event was critical for upper areas of the catchment affected by overland flow and the 3 hour event critical for lower areas of the catchment affected by mainstream flooding.

Modelling of the PMF determined that the 1 hour event was critical across the entire catchment.

The critical durations that were used for each duration are shown in Table 26.

Table 26: Design event critical duration

Design Event	Overland Critical Duration	Mainstream Critical Duration
1 EY	30 min	120 min
0.5 EY	30 min	120 min
20% AEP	30 min	120 min
10% AEP	60 min	180 min
5% AEP	60 min	180 min
2% AEP	60 min	90 min
1% AEP	60 min	90 min
0.5% EP	60 min	90 min
PMF	60 min	

The temporal pattern selected for each design event and duration is shown in Table 27.

Table 27: Temporal Pattern Selected

Design Event	**Overland Temporal Pattern**	**Mainstream Temporal Pattern**
1 EY	4523	4641
0.5 EY	4523	4641
20% AEP	4523	4641
10% AEP	4568	4639
5% AEP	4568	4639
2% AEP	4557	4588
1% AEP	4557	4588
0.5% EP	4557	4588
PMF	GDSM Method	

7.3. Design Results

The results from this study are presented as:

- Peak flood depths in Figure C1 to Figure C9
- Peak flood velocities in Figure C10 to Figure C18
- Provisional hydraulic hazard in Figure C19 to Figure C22; and
- Provisional hydraulic categorisation in Figure C23 to Figure C24

The results were provided in digital format compatible Council's Geographic Information Systems. The digital data should be used in preference to the figures in this report as they provide more detail.

7.3.1. Summary of Results

Peak flood levels, depths and flows at key locations within the catchment are summarised below. These key locations coincide with the key locations used for the sensitivity analysis discussed in Section 8. A tabulated summary of peak flood depth and level results at key locations as shown in Figure 21 are detailed in Table 28.

Table 28: Peak Flood Levels (m AHD) and Depths (m) at Key Locations

ID	Location	Type	1 EY	0.5 EY	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
H_01	Upstream Botany Road	Level	1.7	1.9	2.2	2.3	2.8	3.3	3.7	4.0	5.6
		Depth	0.2	0.3	0.6	0.7	1.1	1.6	1.9	2.2	3.8
H_02	Denison Street and Perry Street crossing	Level	-	-	7.3	7.3	7.3	7.4	7.4	7.4	8.7
		Depth	-	-	0.0	0.0	0.1	0.1	0.1	0.2	1.5
H_03	Australia Avenue	Level	7.6	7.7	7.8	7.8	7.8	7.9	7.9	7.9	8.3
		Depth	0.3	0.3	0.4	0.5	0.5	0.5	0.6	0.6	0.9
H_04	Baird Avenue and Perry Street crossing	Level	14.7	14.8	14.9	14.9	15.0	15.1	15.1	15.2	15.4
		Depth	0.0	0.1	0.2	0.3	0.3	0.4	0.4	0.5	0.8
H_05	Beauchamp Road	Level	11.1	11.1	11.2	11.2	11.2	11.3	11.3	11.3	11.7
		Depth	0.2	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.9
H_06	Grace Campbell Crescent and Nilsson Avenue crossing	Level	11.4	11.4	11.4	11.5	11.5	11.5	11.5	11.6	11.9
		Depth	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.8
H_07	Beauchamp Road	Level	12.3	12.5	12.5	12.7	12.7	12.7	12.7	12.8	13.2
		Depth	0.0	0.1	0.2	0.3	0.4	0.4	0.4	0.4	0.8
H_08	Bunnerong Open channel at Matraville Public School	Level	13.6	14.2	14.6	14.7	14.8	14.8	14.8	14.9	15.5
		Depth	1.3	1.8	2.1	2.3	2.3	2.4	2.4	2.4	3.1
H_09	Rhodes Street Reserve	Level	-	-	12.3	12.8	13.2	13.5	13.7	14.2	16.1
		Depth	-	-	0.1	0.6	0.9	1.2	1.4	1.9	3.8
H_10	Jersey Road - West	Level	21.7	21.8	22.0	22.0	22.1	22.1	22.1	22.2	22.3
		Depth	0.1	0.3	0.4	0.5	0.5	0.6	0.6	0.6	0.8
H_11	Jauncey Place	Level	-	16.3	16.4	16.4	16.5	16.5	16.6	16.7	17.3
		Depth	-	0.1	0.2	0.2	0.3	0.4	0.4	0.5	1.1
H_12	Boonah Avenue	Level	16.4	16.5	16.6	16.6	16.7	16.8	17.0	17.1	18.0
		Depth	0.2	0.3	0.4	0.4	0.4	0.6	0.8	0.9	1.8
H_13	Bunnerong Open Channel at Fitzgerald Avenue	Level	18.0	18.1	18.2	18.4	18.7	18.9	19.0	19.2	21.1
		Depth	1.1	1.1	1.2	1.4	1.7	1.9	2.0	2.2	4.1
H_14	Parer Street and Ulm Street crossing	Level	19.4	19.5	19.6	19.7	19.7	19.9	19.9	20.0	21.1
		Depth	0.3	0.4	0.5	0.5	0.6	0.7	0.8	0.9	2.0
H_15	Paine Street and Fitzgerald Avenue crossing	Level	20.8	20.9	21.0	21.2	21.4	21.5	21.6	21.6	21.8
		Depth	0.1	0.1	0.2	0.5	0.6	0.8	0.8	0.8	1.1
H_16	Jersey Road - East	Level	21.6	21.7	21.8	21.9	22.0	22.1	22.1	22.1	22.3
		Depth	0.0	0.1	0.1	0.2	0.4	0.4	0.4	0.5	0.7
H_17	Maroubra Road	Level	-	22.0	22.0	22.1	22.1	22.2	22.2	22.3	23.2
		Depth	-	0.0	0.1	0.1	0.2	0.2	0.3	0.3	1.2
H_18	Piccadilly Place and Bruce Bennetts Place crossing	Level	-	-	24.4	24.5	24.6	24.6	24.7	24.7	25.7
		Depth	-	-	0.0	0.1	0.1	0.2	0.2	0.3	1.3
H_19	Upstream Bunnerong Open Channel at Nagle Park	Level	19.7	19.7	19.7	19.7	19.8	19.8	19.8	19.8	21.6
		Depth	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	2.3

ID	Location	Type	1 EY	0.5 EY	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
H_20	Gale Road Low Point	Level	25.3	25.4	25.5	25.6	25.6	25.7	25.7	25.7	28.3
		Depth	0.1	0.2	0.3	0.4	0.4	0.5	0.5	0.5	3.1
H_21	Snape Park Basin	Level	23.4	23.4	23.5	23.6	23.7	23.7	23.8	23.9	25.2
		Depth	0.2	0.3	0.4	0.5	0.5	0.6	0.7	0.7	2.1
H_22	Percival Street	Level	-	24.1	24.2	24.3	24.4	24.5	24.6	24.7	25.4
		Depth	-	0.1	0.2	0.3	0.4	0.5	0.5	0.7	1.3
H_23	Prince Edward Circuit and Towner gardens crossing	Level	22.5	22.6	22.6	22.8	22.9	23.0	23.0	23.1	24.0
		Depth	0.2	0.2	0.3	0.5	0.5	0.6	0.7	0.8	1.6
H_24	Prince Edward Circuit	Level	23.2	23.2	23.3	23.3	23.3	23.3	23.3	23.3	23.4
		Depth	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.5
H_25	Gale Road	Level	25.7	25.8	26.0	26.2	26.3	26.4	26.5	26.7	28.5
		Depth	0.1	0.2	0.3	0.5	0.7	0.8	0.9	1.0	2.8
H_26	Holmes Street and Avoca Street Crossing	Level	27.4	27.5	27.6	27.7	27.8	27.9	27.9	28.1	28.8
		Depth	0.0	0.1	0.3	0.4	0.4	0.5	0.6	0.7	1.4
H_27	Tucabia Street	Level	60.3	60.4	60.5	60.5	60.6	60.6	60.6	60.6	60.8
		Depth	0.1	0.2	0.3	0.3	0.4	0.4	0.4	0.4	0.6
H_28	Irvine Street	Level	25.7	25.8	25.9	26.0	26.0	26.1	26.1	26.2	27.6
		Depth	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7	2.1
H_29	Botany Street and Marville Avenue crossing	Level	24.2	24.3	24.3	24.4	24.4	24.5	24.5	24.5	25.1
		Depth	0.0	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.9
H_30	Astrolabe Park	Level	-	19.2	19.3	19.6	19.8	20.1	20.2	20.2	21.6
		Depth	-	0.0	0.2	0.4	0.6	0.9	1.0	1.1	2.5
H_31	Anzac Parade near Rainbow Street	Level	23.3	23.3	23.4	23.4	23.4	23.5	23.5	23.5	23.9
		Depth	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.0	1.3
H_32	Byrd Avenue near Anzac Parade	Level	29.3	29.5	29.5	29.5	29.5	29.6	29.6	29.6	29.8
		Depth	0.5	0.7	0.7	0.7	0.7	0.7	0.7	0.8	1.0
H_33	Harbourne Road	Level	25.1	25.3	25.4	25.5	25.6	25.7	25.8	26.0	26.6
		Depth	0.2	0.4	0.5	0.5	0.7	0.8	0.9	1.1	1.7
H_34	Araluen Street - East	Level	-	-	31.4	31.5	31.6	31.6	31.7	31.8	32.3
		Depth	-	-	0.0	0.1	0.2	0.2	0.3	0.4	0.9
H_35	Rainbow Street at Randwick High School	Level	-	37.1	37.2	37.3	37.4	37.5	37.5	37.6	38.1
		Depth	-	0.0	0.1	0.2	0.3	0.4	0.4	0.5	1.0
H_36	Blenheim Street	Level	-	-	54.4	54.4	54.5	54.5	54.5	54.6	54.9
		Depth	-	-	0.0	0.1	0.1	0.1	0.2	0.2	0.5
H_37	Elphinstone Road	Level	-	49.4	49.6	49.6	49.6	49.6	49.7	49.7	49.9
		Depth	-	0.2	0.3	0.4	0.4	0.4	0.5	0.5	0.7
H_38	Byrd Avenue Low Point	Level	33.4	33.5	33.7	34.1	34.4	34.6	34.8	34.9	35.7
		Depth	0.0	0.1	0.4	0.8	1.1	1.3	1.4	1.5	2.4
H_39	Paton Street	Level	33.9	33.9	34.0	34.3	34.5	34.6	34.7	34.9	35.6
		Depth	0.1	0.1	0.2	0.5	0.6	0.8	0.9	1.0	1.7
H_40	Bunnerong Road near Rowland Park	Level	23.4	23.5	23.5	23.6	23.6	23.8	23.8	23.8	24.4
		Depth	0.2	0.3	0.3	0.3	0.4	0.6	0.6	0.6	1.2
H_41	Isis Lane	Level	26.4	26.5	26.6	27.0	27.1	27.2	27.2	27.2	27.6
		Depth	0.3	0.4	0.6	0.9	1.0	1.1	1.1	1.2	1.6
H_42	Glanfield Street near Bunnerong Road	Level	21.5	21.6	21.7	21.9	22.0	22.1	22.1	22.2	23.2
		Depth	0.1	0.2	0.3	0.5	0.6	0.7	0.8	0.9	1.8
H_44	Mason Street - West	Level	22.5	22.6	22.6	22.7	22.7	22.8	22.8	22.9	23.4
		Depth	0.3	0.3	0.4	0.4	0.5	0.6	0.6	0.7	1.1

ID	Location	Type	1 EY	0.5 EY	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
H_45	Glanfield Street - East	Level	23.9	24.0	24.1	24.3	24.4	24.6	24.6	24.7	25.3
		Depth	0.0	0.1	0.3	0.4	0.6	0.7	0.8	0.8	1.4
H_46	Alma Road	Level	25.6	25.7	25.9	26.1	26.3	26.4	26.5	26.7	28.5
		Depth	0.1	0.3	0.4	0.7	0.8	1.0	1.1	1.2	3.0
H_47	Jersey Road	Level	-	-	19.0	19.2	19.5	19.7	20.0	20.3	21.8
		Depth	-	-	0.0	0.2	0.5	0.7	1.0	1.3	2.8
H_48	Randwick Environmental Park	Level	30.1	30.2	30.2	30.3	30.4	30.5	30.6	30.7	32.1
		Depth	0.3	0.3	0.4	0.4	0.5	0.7	0.8	0.9	2.3

The tabulated summary of peak flows at the key locations sown in Figure 22 are detailed in Table 29.

Table 29: Peak Flows (m^3/s) at Key Locations

ID	Location	Type	1 EY	0.5 EY	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
Q_01	Flint Street	Overland	0.1	0.2	0.4	0.6	1.0	1.7	2.6	4.7	54.4
		Pipe/Channel	12.4	14.0	16.2	17.4	17.4	17.5	17.8	17.8	21.2
Q_02	Upstream Tierney Avenue	Overland	-	-	-	-	0.2	0.9	1.6	2.6	54.1
		Pipe/Channel	11.8	13.2	15.2	16.9	17.5	17.3	17.4	17.7	22.9
Q_03	Donovan Avenue	Overland	0.1	0.1	0.1	0.1	0.1	1.0	2.6	5.4	85.5
		Pipe/Channel	7.4	8.1	9.2	10.3	10.8	11.8	12.1	12.4	16.3
Q_04	Boyce Road	Overland	0.4	0.6	0.8	0.9	1.0	1.1	1.2	1.3	6.7
		Pipe/Channel	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
Q_05	Downstream Parer Street	Overland	-	-	-	-	-	-	-	0.3	7.6
		Pipe/Channel	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.5
Q_06	Maroubra Road - West	Overland	-	0.1	0.2	0.2	0.2	0.2	0.3	0.5	11.4
		Pipe/Channel	0.2	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.5
Q_07	Maroubra Road - West Downstream	Overland	-	-	-	-	0.0	0.1	0.1	0.3	10.7
		Pipe/Channel	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.5
Q_08	Glanfield Street - West	Overland	-	-	0.2	0.2	0.2	0.2	0.2	0.2	1.2
		Pipe/Channel	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.3	0.3
Q_09	Perry Street - West	Overland	0.0	0.3	0.9	1.2	1.6	2.3	2.6	3.2	88.2
		Pipe/Channel	14.3	17.7	18.8	20.6	21.9	24.5	26.1	27.2	29.1
Q_10	Australia Avenue	Overland	0.0	0.1	0.2	0.5	0.9	1.6	2.2	3.2	17.1
		Pipe/Channel	1.2	1.2	1.3	1.2	1.2	1.3	1.3	1.3	1.4
Q_11	Harold Street	Overland	0.1	0.2	0.2	0.5	1.0	1.7	2.4	3.5	16.7
		Pipe/Channel	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
Q_12	Nilson Ave and Grace Campbell Cres	Overland	1.1	1.6	2.1	2.9	3.4	4.2	4.6	5.4	15.1
		Pipe/Channel	2.4	2.3	2.4	2.3	2.2	2.4	2.4	2.4	3.7

ID	Location	Type	1 EY	0.5 EY	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
Q_13	Grace Campbell Cres - North	Overland	0.1	0.7	1.1	1.6	1.9	2.2	2.4	2.7	7.2
		Pipe/Channel	3.6	3.6	3.7	3.4	3.4	3.6	3.6	3.7	5.8
Q_14	Fitzgerald Avenue - East	Overland	-	-	0.0	0.4	0.6	0.7	1.3	2.7	18.3
		Pipe/Channel	1.6	1.8	1.9	2.0	1.9	2.0	1.9	1.8	1.9
Q_15	Alma Road	Overland	0.0	0.2	0.5	0.6	0.5	1.1	2.7	4.5	63.9
		Pipe/Channel	0.5	0.6	0.8	1.1	1.3	1.4	1.4	1.4	0.3
Q_16	Upsream Walengre Avenue	Overland	0.2	0.2	0.2	0.4	0.6	1.2	1.6	2.0	43.1
		Pipe/Channel	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.4
Q_17	Irvine Street at Fisher Street	Overland	0.1	0.1	0.2	0.2	0.2	0.3	0.4	0.7	34.6
		Pipe/Channel	0.4	0.4	0.5	0.4	0.4	0.5	0.5	0.5	0.6
Q_18	Upsream Ainslie Street	Overland	0.2	0.4	0.8	1.3	2.6	4.4	8.9	16.6	119.2
		Pipe/Channel	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.0
Q_19	Sturt Street	Overland	0.0	0.1	0.2	1.0	2.0	4.6	8.6	15.4	105.3
		Pipe/Channel	0.4	0.5	0.7	0.7	0.7	0.8	0.8	0.8	0.9
Q_20	Downstream Hayward Street	Overland	1.8	2.4	3.0	3.9	4.5	5.8	6.5	7.5	22.5
		Pipe/Channel	8.5	8.8	9.3	7.4	7.7	9.0	9.2	9.1	9.2
Q_21	Bunnerong Road - North	Overland	2.2	3.1	4.0	5.0	6.0	7.8	8.8	10.4	45.1
		Pipe/Channel	7.2	7.3	7.6	7.9	8.2	8.9	7.9	8.4	7.9
Q_22	High Street	Overland	-	-	0.1	0.3	0.6	0.7	0.9	1.4	9.0
		Pipe/Channel	1.6	1.9	2.2	2.3	2.5	2.5	2.6	2.7	3.3
Q_23	Barker Street	Overland	0.4	0.5	0.7	1.0	2.1	2.7	3.9	5.7	31.6
		Pipe/Channel	2.6	3.2	3.6	3.7	3.8	3.7	3.8	3.8	4.8
Q_24	Middle Street	Overland	0.7	1.6	2.7	3.6	4.8	6.1	7.8	10.4	49.6
		Pipe/Channel	2.3	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.5
Q_25	Rainbow Street	Overland	0.1	0.3	1.7	4.3	7.1	11.2	14.7	20.7	110.6
		Pipe/Channel	9.2	10.0	10.9	11.1	11.4	11.4	11.4	11.5	11.9
Q_26	Upstream Snape Street	Overland	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	5.2
		Pipe/Channel	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1
Q_27	Downstream Isaac Smith Street	Overland	-	-	-	-	-	-	-	-	-
		Pipe/Channel	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Q_28	Downstream Cook Avenue	Overland	-	-	-	-	-	0.0	0.0	0.0	0.6
		Pipe/Channel	9.7	10.8	11.9	12.5	12.9	12.9	12.7	12.9	13.0
Q_29	Boonah Avenue	Overland	0.1	0.3	1.1	1.6	2.4	2.8	3.2	3.6	10.4
		Pipe/Channel	3.5	3.7	3.8	3.5	3.6	3.6	3.8	4.0	5.8
Q_30	Brittain Crescent - South	Overland	0.0	0.0	0.1	0.4	0.6	0.8	1.1	1.4	23.9
		Pipe/Channel	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5

ID	Location	Type	1 EY	0.5 EY	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
Q_31	Brittain Crescent - South East	Overland	-	-	-	-	-	-	-	-	0.0
		Pipe/Channel	-	-	-	-	-	-	-	-	-
Q_32	Richardson Walk	Overland	-	-	-	0.1	0.6	1.2	2.0	3.2	26.3
		Pipe/Channel	12.4	14.3	16.3	16.9	17.2	17.5	17.7	17.9	20.2
Q_33	Downstream Flint Street	Overland	0.2	0.3	0.5	0.8	1.3	2.1	2.8	5.0	54.3
		Pipe/Channel	12.3	14.0	16.0	17.2	17.3	17.4	17.5	17.7	20.5
Q_34	Avoca Street and N Benvenue Street	Overland	0.6	1.0	1.5	2.0	2.5	4.4	7.9	15.0	135.3
		Pipe/Channel	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.3
Q_35	Parer Street at Hinkler street intersection	Overland	0.4	0.7	1.0	1.2	1.4	1.5	1.7	2.0	9.1
		Pipe/Channel	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Q_36	Grace Campbell Cescent - South	Overland	2.3	2.7	3.4	4.2	4.8	5.9	6.6	7.6	19.7
		Pipe/Channel	1.1	1.2	1.6	1.1	1.1	1.1	1.3	1.4	2.2
Q_37	Beauchamps Road - West	Overland	0.5	1.1	1.8	2.2	2.9	4.0	4.7	5.8	24.7
		Pipe/Channel	-	-	-	-	-	-	-	-	-
Q_38	Downstream Beauchamps Road	Overland	0.0	0.1	0.2	2.3	3.4	4.6	5.7	6.7	52.7
		Pipe/Channel	13.8	15.5	15.8	16.4	16.6	16.8	16.9	17.1	19.4
Q_39	Downstream Matraville Public School	Overland	-	-	0.2	3.0	3.8	5.0	5.6	7.2	58.7
		Pipe/Channel	13.3	15.2	15.8	16.0	15.9	15.9	15.8	15.9	15.4
Q_40	Bunnerong Road at Rowland Park	Overland	0.0	0.0	0.1	0.1	0.1	0.3	0.8	1.4	37.5
		Pipe/Channel	0.9	0.9	0.9	0.8	0.8	0.9	0.9	0.9	1.1
Q_41	Botany Street - West	Overland	-	-	0.0	0.1	0.3	0.8	1.1	1.5	36.1
		Pipe/Channel	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.9
Q_42	Anzac Parade at Byrd Avenue	Overland	0.3	1.2	2.1	2.8	3.2	3.7	4.0	4.6	17.7
		Pipe/Channel	8.6	8.8	8.7	8.4	8.5	8.7	8.7	8.8	9.5
Q_43	Raymond Avenue and McCauley Street	Overland	0.1	0.1	0.1	0.1	0.1	0.2	0.4	0.6	11.7
		Pipe/Channel	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.1
Q_44	Perry Street and Harold Street	Overland	0.2	0.4	0.6	0.8	1.0	1.6	2.2	3.3	15.0
		Pipe/Channel	0.4	0.4	0.4	0.4	0.5	0.4	0.4	0.4	0.5
Q_45	Perry Street and Bunnerong Road Intersection	Overland	0.4	0.8	1.2	1.3	1.5	1.8	2.0	2.8	13.7
		Pipe/Channel	1.1	1.1	1.1	1.1	1.1	1.0	1.0	1.0	1.1
Q_46	Wild Street	Overland	0.1	0.1	0.3	0.4	0.6	0.9	1.0	1.2	92.9
		Pipe/Channel	7.1	7.5	8.2	8.5	8.5	9.3	9.9	10.7	22.8
Q_47	Upstream Paine Street	Overland	0.4	0.6	0.9	1.1	1.4	1.6	1.7	2.2	90.1
		Pipe/Channel	2.6	2.7	2.7	2.7	2.7	2.7	2.7	2.7	3.1

ID	Location	Type	1 EY	0.5 EY	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
Q_48	Cook Avenue	Overland	0.4	0.9	1.6	2.9	3.6	4.8	5.5	6.6	27.9
		Pipe/Channel	8.7	9.2	9.6	9.8	9.9	10.0	10.1	10.3	10.4
Q_49	Storey Street - West	Overland	0.1	0.1	0.3	0.5	0.7	1.9	3.3	6.1	105.1
		Pipe/Channel	0.2	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.5
Q_50	Upstream Moverly Road - West	Overland	0.0	0.1	0.3	0.8	1.5	2.9	4.3	8.6	148.5
		Pipe/Channel	5.2	5.5	5.8	5.9	6.0	6.0	6.0	6.1	6.2
Q_51	Downstream Holmes Street - West	Overland	0.0	0.2	0.7	1.4	1.9	2.8	4.4	10.2	128.0
		Pipe/Channel	-	-	-	-	-	-	-	-	-
Q_52	Cook Avenue and Banks Avenue	Overland	0.3	0.5	1.2	2.9	4.1	6.0	7.2	9.2	50.9
		Pipe/Channel	8.8	9.7	10.4	11.1	11.1	11.3	11.3	11.4	11.2

7.3.2. Provisional Hydraulic Categorisation

The hydraulic categories, namely floodway, flood storage and flood fringe, are described in the Floodplain Development Manual (Reference 15). However, there is no technical definition of hydraulic categorisation that would be suitable for all catchments, and different approaches are used by different consultants and authorities, based on the specific features of the study catchment in question.

For this study, hydraulic categories were defined by the following criteria, which correspond in part with the criteria proposed by Howells et. al, 2003 (Reference 16):

- <u>Floodway</u> is defined as areas where:
    - the peak value of velocity multiplied by depth (V x D) > 0.25 m^2/s **AND** peak velocity > 0.25 m/s, **OR**
    - peak velocity > 1.0 m/s **AND** peak depth > 0.15 m

The remainder of the floodplain is either Flood Storage or Flood Fringe,

- <u>Flood Storage</u> comprises areas outside the floodway where peak depth > 0.5 m; and
- <u>Flood Fringe</u> comprises areas outside the Floodway where peak depth < 0.5 m.

7.3.3. Provisional Flood Hazard Categorisation

Hazard classification plays an important role in informing floodplain risk management in an area. Previously, hazard classifications were binary – either Low or High Hazard as described in the Manual. However, in recent years there has been a number of developments in the classification of hazard. *Managing the floodplain: a guide to best practice in flood risk management in Australia* (Reference 17) provides revised hazard classifications which add clarity to the hazard categories and what they mean in practice. The classification is divided into 6 categories (Diagram 2) which indicate the restrictions on people, buildings and vehicles:

- H1 - No constraints;
- H2 – Unsafe for small vehicles;
- H3 - Unsafe for all vehicles, children and the elderly;
- H4 - Unsafe for all people and all vehicles;
- H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction; and
- H6 – Unsafe for people or vehicles. All buildings types considered vulnerable to failure.

Diagram 2 Hazard Classifications

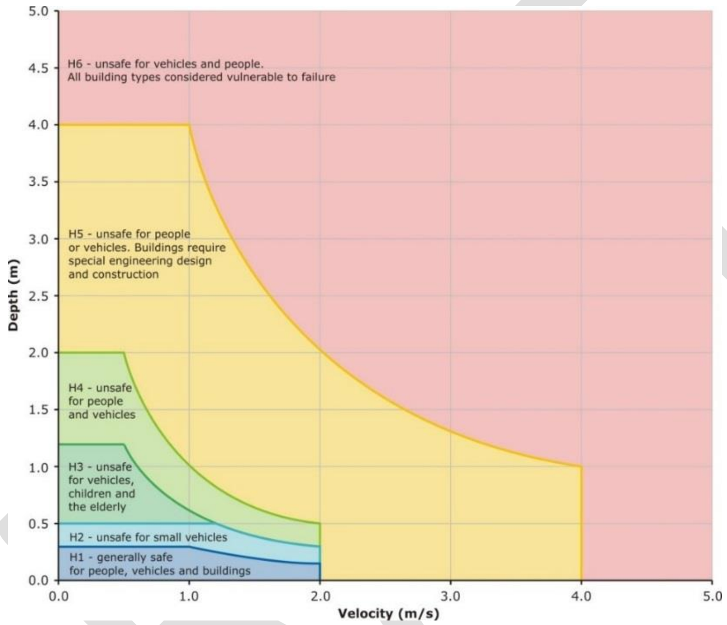


Figure C19 to Figure C22 provide the hazard classification for all the design events, according to the above classification. Under this classification, the most hazardous areas of the floodplain are generally constrained to the non-habitable areas, the parks, reserves, golf courses etc., lying adjacent to the waterways.

8. SENSITIVITY ANALYSIS

8.1. Overview

A number of sensitivity analyses were undertaken to establish the variation in design flood levels and flow that may occur if different parameter assumptions were made. These sensitivity scenarios are summarise in Table 30.

Table 30: Overview of Sensitivity Analyses

Scenario	Description
Manning's "n"	The hydraulic roughness values were increased and decreased by 20%
Infiltration	The Infiltration values were increased and decreased by 20%
Culvert and Bridge Blockage	Sensitivity to blockage of culverts and bridges on open channel sections was assessed for 25%, 50% and 75% blockage
Pit, inlet Blockage	Sensitivity to blockage of all culverts was assessed for a combination of: • 50% grade blockage, 100% sag blockage; • 100% blockage of all pits; and • 0% blockage of all pits.
Climate Change	Sensitivity to rainfall and runoff estimates were assessed by increasing the rainfall intensities by 10%, 20% and 30%. Sea level rise scenarios of 0.4 m and 0.9 m were assessed.

8.2. Climate Change Background

Intensive scientific investigation is ongoing to estimate the effects that increasing amounts of greenhouse gases (water vapour, carbon dioxide, methane, nitrous oxide, ozone) are having on the average earth surface temperature. Changes to surface and atmospheric temperatures are likely to change the future climate and sea levels. The extent of any permanent climatic or sea level change can only be established with certainty through scientific observations over several decades. Nevertheless, it is prudent to consider the possible range of impacts with regard to flooding and the level of flood protection provided by any mitigation works.

Based on the latest research by the United Nations Intergovernmental Panel on Climate Change, evidence is emerging on the likelihood of climate change and sea level rise as a result of increasing greenhouse gasses. In this regard, the following points can be made:

- greenhouse gas concentrations continue to increase;
- global sea levels have risen about 0.1 m to 0.25 m in the past century;
- many uncertainties limit the accuracy to which future rainfall intensity changes and sea level rises can be projected and predicted.

8.2.1. Rainfall Increase

The Bureau of Meteorology has indicated that there is no intention at present to revise design rainfalls to take account of the impact of climate change, as the implications of temperature changes on extreme rainfall intensities are presently unclear, and there is uncertainty about whether the changes would in fact increase design rainfalls for major flood producing storms.

Any increase in design flood rainfall intensities will increase the frequency, depth and extent of inundation across the catchment. It has also been suggested that the cyclone belt may move further southwards. The possible impacts of this on design rainfalls cannot be ascertained at this time as little is known about the mechanisms that determine the movement of cyclones under existing conditions.

Projected increases to evaporation are also an important consideration because increased evaporation would lead to generally dryer catchment conditions, resulting in lower runoff from rainfall. Mean annual rainfall is projected to decrease, which will also result in generally dryer catchment conditions.

The combination of uncertainty about projected changes in rainfall and evaporation makes it extremely difficult to predict with confidence the likely changes to peak flows for large flood events within the catchment under warmer climate scenarios.

In light of this uncertainty, the NSW State Government's (Reference 18) advice recommends sensitivity analysis on flood modelling should be undertaken to develop an understanding of the effect of various levels of change in the hydrologic regime on the project at hand. Specifically, it is suggested that increases of 10%, 20% and 30% to rainfall intensity be considered.

8.2.2. Sea Level Rise

The *NSW Sea Level Rise Policy Statement* (Reference 19) was released by the NSW Government in October 2009. This Policy Statement was accompanied by the *Derivation of the NSW Government's sea level rise planning benchmarks* (Reference 20) which provided technical details on how the sea level rise assessment was undertaken. Additional guidelines were issued by OEH, including the *Flood Risk Management Guide: Incorporating sea level rise benchmarks in flood risk assessments 2010* (Reference 21).

The Policy Statement says:

> *"Over the period 1870-2001, global sea levels rose by 20 cm, with a current global average rate of increase approximately twice the historical average. Sea levels are expected to continue rising throughout the twenty-first century and there is no scientific evidence to suggest that sea levels will stop rising beyond 2100 or that current trends will be reversed… However, the 4th Intergovernmental Panel on*

Climate Change in 2007 also acknowledged that higher rates of sea level rise are possible" (Reference 19).

In light of this uncertainty, the NSW State Government's advice is subject to periodical review. As of 2012 the NSW State Government withdrew endorsement of sea level rise predictions but still requires sea level rise to be considered. In the absence of any other advice the previous NSW State Government benchmarks of sea level rise of 0.4 m by the year 2050 and 0.9 m by the year 2100, relative to 1990 levels have been adopted in this study.

8.3. Sensitivity Analysis Results

The sensitivity scenario results were compared to the 1% AEP rainfall event with the 5% AEP ocean level. A summary of peak flood level and peak flow differences at various locations are provided in:

- Table 31 for variations in infiltration and roughness;
- Table 32 for variations in pit/inlet and structure blockage;
- Table 33 for variations in climate conditions.

8.3.1. Roughness and Infiltration Variations

Overall peak flood level results were shown to be relatively insensitive to 20% variations in the roughness and infiltration parameter. These results were found to be within ± 0.1 m. The results for the roughness sensitivity analysis are shown in Table 31.

Table 31: Results of Roughness and Infiltration Sensitivity Analysis – 1% AEP Levels (m)

ID	Location	Peak Flood Level 1% AEP	Difference with 1% AEP (m)			
			Roughness Decreased by 20%	Roughness Increased by 20%	Infiltration Decreased by 20%	Infiltration Increased by 20%
H01	Upstream Botany Road	3.71	0.03	-0.06	-0.08	0.07
H02	Denison Street and Perry Street crossing	7.41	0.00	0.00	0.00	-0.01
H03	Australia Avenue	7.90	0.00	0.00	0.00	-0.01
H04	Baird Avenue and Perry Street crossing	15.11	0.00	0.00	0.01	-0.01
H05	Beauchamp Road	11.30	0.00	0.00	0.01	-0.01
H06	Grace Campbell Crescent and Nilsson Avenue crossing	11.53	0.00	0.00	0.02	-0.02
H07	Beauchamp Road	12.73	0.00	0.00	0.01	-0.01
H08	Bunnerong Open channel at Matraville Public School	14.83	0.00	0.00	0.02	-0.01
H09	Rhodes Street Reserve	13.70	0.02	-0.02	-0.01	0.01
H10	Jersey Road - West	22.14	0.00	0.00	0.01	0.00
H11	Jauncey Place	16.61	0.01	0.00	0.00	0.00
H12	Boonah Avenue	16.98	0.01	-0.01	0.00	0.00

ID	Location	Peak Flood Level 1% AEP	Difference with 1% AEP (m)			
			Roughness Decreased by 20%	Roughness Increased by 20%	Infiltration Decreased by 20%	Infiltration Increased by 20%
H13	Bunnerong Open Channel at Fitzgerald Avenue	19.03	0.01	-0.01	-0.01	0.00
H14	Parer Street and Ulm Street crossing	19.93	0.01	-0.01	0.00	0.01
H15	Paine Street and Fitzgerald Avenue crossing	21.57	0.00	0.00	0.00	0.00
H16	Jersey Road - East	22.10	0.00	0.00	0.00	0.00
H17	Maroubra Road	22.22	0.00	0.00	0.01	-0.01
H18	Piccadilly Place and Bruce Bennetts Place crossing	24.67	0.00	0.00	0.00	0.00
H19	Upstream Bunnerong Open Channel at Nagle Park	19.79	0.00	0.00	0.01	-0.01
H20	Gale Road Low Point	25.70	0.00	0.00	0.00	0.00
H21	Snape Park Basin	23.82	0.02	-0.02	0.00	-0.01
H22	Percival Street	24.56	0.01	-0.01	0.00	0.00
H23	Prince Edward Circuit and Towner gardens crossing	23.01	0.01	-0.01	0.00	0.00
H24	Prince Edward Circuit	23.30	0.00	0.00	0.00	0.00
H25	Gale Road	26.54	0.01	-0.01	-0.01	0.01
H26	Holmes Street and Avoca Street Crossing	27.93	0.02	-0.02	-0.02	0.01
H27	Tucabia Street	60.61	0.00	0.00	0.01	-0.01
H28	Irvine Street	26.14	0.01	-0.01	0.00	0.00
H29	Botany Street and Marville Avenue crossing	24.48	0.00	0.00	0.00	0.00
H30	Astrolabe Park	20.17	0.01	-0.01	-0.01	0.02
H31	Anzac Parade near Rainbow Street	23.48	0.00	0.00	0.01	-0.01
H32	Byrd Avenue near Anzac Parade	29.56	0.00	0.00	0.01	0.00
H33	Harbourne Road	25.84	0.01	-0.01	0.01	-0.04
H34	Araluen Street - East	31.72	0.01	-0.01	-0.01	0.01
H35	Rainbow Street at Randwick High School	37.51	0.01	-0.01	0.00	0.00
H36	Blenheim Street	54.53	0.00	0.00	0.01	-0.01
H37	Elphinstone Road	49.67	0.00	0.00	0.01	-0.01
H_38	Byrd Avenue Low Point	34.75	0.01	-0.01	0.00	0.00
H_39	Paton Street	34.75	0.01	-0.01	0.00	0.00
H_40	Bunnerong Road near Rowland Park	23.82	0.01	-0.01	-0.01	0.01
H_41	Isis Lane	27.19	0.00	0.00	0.01	0.00
H_42	Glanfield Street near Bunnerong Road	22.14	0.01	-0.01	-0.01	0.01
H_44	Mason Street - West	22.84	0.01	-0.01	0.00	0.00
H_45	Glanfield Street - East	24.64	0.01	-0.01	0.00	0.00
H_46	Alma Road	26.52	0.01	-0.01	-0.01	0.01
H_47	Jersey Road	19.98	0.04	-0.03	-0.02	0.01

8.3.2. Blockage Variations

The culverts and bridges in the Bunnerong open channel alignment were tested for blockage sensitivity. The design scenarios assumed 10% blockage at these same culverts. Overall peak flood levels were only affected at areas adjacent to Bunnerong open channel, particularly upstream of Botany Road at the downstream end of the catchment, where there is a relatively large culvert crossing. Modelling showed variation at that location in peak flood levels of between 1.0 m and 1.3 m for the scenarios tested. The culvert blockage sensitivity results are shown in Table 32.

Table 32: Bunnerong Open Channel Blockage Sensitivity Analysis – 1% AEP Depths (m)

ID	Location	Peak Flood Level 1% AEP	Difference with 1% AEP (m)			
			Culverts unblocked	Culverts blocked 25%	Culverts blocked 50%	Culverts blocked 75%
H_01	Upstream Botany Road	3.71	-0.60	1.04	1.24	1.30
H_02	Denison Street and Perry Street crossing	7.41	0.00	0.27	0.23	0.31
H_03	Australia Avenue	7.90	0.00	0.00	0.00	0.00
H_04	Baird Avenue and Perry Street crossing	15.11	0.00	0.00	0.00	0.00
H_05	Beauchamp Road	11.30	0.00	0.00	0.00	0.01
H_06	Grace Campbell Crescent and Nilsson Avenue crossing	11.53	0.00	0.00	0.00	0.00
H_07	Beauchamp Road	12.73	-0.01	0.02	0.04	0.06
H_08	Bunnerong Open channel at Matraville Public School	14.83	-0.02	0.05	0.12	0.15
H_09	Rhodes Street Reserve	13.70	-0.01	0.02	0.05	0.08
H_10	Jersey Road - West	22.14	0.00	0.00	0.00	0.00
H_11	Jauncey Place	16.61	0.00	-0.01	-0.05	-0.09
H_12	Boonah Avenue	16.98	0.00	0.00	0.00	0.00
H_13	Bunnerong Open Channel at Fitzgerald Avenue	19.03	-0.02	0.09	0.30	0.80
H_14	Parer Street and Ulm Street crossing	19.93	0.00	0.01	0.02	0.06
H_15	Paine Street and Fitzgerald Avenue crossing	21.57	0.00	0.00	-0.01	-0.01
H_16	Jersey Road - East	22.10	0.00	0.00	-0.01	-0.01
H_17	Maroubra Road	22.22	0.00	0.00	0.00	0.01
H_18	Piccadilly Place and Bruce Bennetts Place crossing	24.67	0.00	0.00	0.00	0.00
H_19	Upstream Bunnerong Open Channel at Nagle Park	19.79	0.00	0.07	0.14	0.41
H_20	Gale Road Low Point	25.70	0.00	0.00	0.00	0.00
H_21	Snape Park Basin	23.82	0.00	0.00	0.00	0.00
H_22	Percival Street	24.56	0.00	0.00	0.00	0.00
H_23	Prince Edward Circuit and Towner gardens crossing	23.01	0.00	0.00	0.00	0.00

ID	Location	Peak Flood Level 1% AEP	Difference with 1% AEP (m)			
			Culverts unblocked	Culverts blocked 25%	Culverts blocked 50%	Culverts blocked 75%
H_24	Prince Edward Circuit	23.30	0.00	0.00	0.00	0.00
H_25	Gale Road	26.54	0.00	0.00	0.00	0.00
H_26	Holmes Street and Avoca Street Crossing	27.93	0.00	0.00	0.00	0.00
H_27	Tucabia Street	60.61	0.00	0.00	0.00	0.00
H_28	Irvine Street	26.14	0.00	0.00	0.00	0.00
H_29	Botany Street and Marville Avenue crossing	24.48	0.00	0.00	0.00	0.00
H_30	Astrolabe Park	20.17	0.00	0.00	0.00	0.00
H_31	Anzac Parade near Rainbow Street	23.48	0.00	0.00	0.00	0.00
H_32	Byrd Avenue near Anzac Parade	29.56	0.00	0.00	0.00	0.00
H_33	Harbourne Road	25.84	0.00	0.00	0.00	0.00
H_34	Araluen Street - East	31.72	0.00	0.00	0.00	0.00
H_35	Rainbow Street at Randwick High School	37.51	0.00	0.00	0.00	0.00
H_36	Blenheim Street	54.53	0.00	0.00	0.00	0.00
H_37	Elphinstone Road	49.67	0.00	0.00	0.00	0.00
H_38	Byrd Avenue Low Point	34.75	0.00	0.00	0.00	0.00
H_39	Paton Street	34.75	0.00	0.00	0.00	0.00
H_40	Bunnerong Road near Rowland Park	23.82	0.00	0.00	0.00	0.00
H_41	Isis Lane	27.19	0.00	0.00	0.00	0.00
H_42	Glanfield Street near Bunnerong Road	22.14	0.00	0.00	0.00	0.03
H_44	Mason Street - West	22.84	0.00	0.00	0.00	0.01
H_45	Glanfield Street - East	24.64	0.00	0.00	0.00	0.00
H_46	Alma Road	26.52	0.00	0.00	0.00	0.00
H_47	Jersey Road	19.98	0.00	0.00	0.00	0.00
H_48	Randwick Environmental Park	30.61	0.00	0.00	0.00	0.00

The following three pit blockage scenarios were tested:

1. Inlets totally unblocked
2. Graded inlets 50% blocked and sag inlets 100% blocked
3. All inlets totally blocked

The results for the pit inlet blockage analysis is shown in Table 33.

Table 33: Results of Pit Inlet Blockage Sensitivity Analysis – 1% AEP Depths (m)

ID	Location	Peak Flood Level 1% AEP	Difference with 1% AEP (m)		
			Inlets Unblocked	Graded Inlets Blocked 50% Sag Inlet Blocked 100%	Inlets Completely Blocked
H_01	Upstream Botany Road	3.71	0.02	-0.39	-1.86
H_02	Denison Street and Perry Street crossing	7.41	-0.01	0.03	-0.03
H_03	Australia Avenue	7.90	0.00	0.00	0.05
H_04	Baird Avenue and Perry Street crossing	15.11	0.00	0.00	0.10
H_05	Beauchamp Road	11.30	-0.01	0.02	-0.07
H_06	Grace Campbell Crescent and Nilsson Avenue crossing	11.53	0.00	-0.04	-0.14
H_07	Beauchamp Road	12.73	0.00	-0.01	-0.11
H_08	Bunnerong Open channel at Matraville Public School	14.83	0.01	0.00	-1.42
H_09	Rhodes Street Reserve	13.70	0.00	0.25	0.89
H_10	Jersey Road - West	22.14	0.00	0.02	0.05
H_11	Jauncey Place	16.61	0.00	0.03	0.07
H_12	Boonah Avenue	16.98	0.03	0.13	0.17
H_13	Bunnerong Open Channel at Fitzgerald Avenue	19.03	0.00	-0.18	-1.06
H_14	Parer Street and Ulm Street crossing	19.93	-0.01	0.01	0.20
H_15	Paine Street and Fitzgerald Avenue crossing	21.57	0.01	0.03	0.11
H_16	Jersey Road - East	22.10	0.00	0.03	0.08
H_17	Maroubra Road	22.22	0.00	0.03	0.14
H_18	Piccadilly Place and Bruce Bennetts Place crossing	24.67	0.00	-0.01	0.08
H_19	Upstream Bunnerong Open Channel at Nagle Park	19.79	0.00	-0.02	-0.30
H_20	Gale Road Low Point	25.70	-0.01	0.00	0.18
H_21	Snape Park Basin	23.82	0.00	-0.02	-0.35
H_22	Percival Street	24.56	-0.02	-0.08	0.27
H_23	Prince Edward Circuit and Towner gardens crossing	23.01	0.00	0.02	0.17
H_24	Prince Edward Circuit	23.30	0.00	0.03	0.03
H_25	Gale Road	26.54	0.00	0.05	0.87
H_26	Holmes Street and Avoca Street Crossing	27.93	0.00	0.02	0.23

ID	Location	Peak Flood Level 1% AEP	Difference with 1% AEP (m)		
			Inlets Unblocked	Graded Inlets Blocked 50% Sag Inlet Blocked 100%	Inlets Completely Blocked
H_27	Tucabia Street	60.61	0.00	0.03	0.05
H_28	Irvine Street	26.14	0.01	0.00	0.03
H_29	Botany Street and Marville Avenue crossing	24.48	0.01	0.01	0.04
H_30	Astrolabe Park	20.17	0.26	0.03	0.13
H_31	Anzac Parade near Rainbow Street	23.48	0.00	-0.02	-0.05
H_32	Byrd Avenue near Anzac Parade	29.56	0.00	0.02	-0.02
H_33	Harbourne Road	25.84	-0.01	0.06	0.42
H_34	Araluen Street - East	31.72	0.00	0.02	0.13
H_35	Rainbow Street at Randwick High School	37.51	0.00	-0.01	0.09
H_36	Blenheim Street	54.53	0.00	0.04	0.11
H_37	Elphinstone Road	49.67	0.00	0.00	0.04
H_38	Byrd Avenue Low Point	34.75	-0.01	0.06	0.25
H_39	Paton Street	34.75	-0.01	0.05	0.22
H_40	Bunnerong Road near Rowland Park	23.82	0.01	0.00	0.05
H_41	Isis Lane	27.19	0.01	0.01	-0.02
H_42	Glanfield Street near Bunnerong Road	22.14	0.00	0.05	0.22
H_44	Mason Street - West	22.84	0.00	0.04	0.10
H_45	Glanfield Street - East	24.64	0.00	-0.09	0.15
H_46	Alma Road	26.52	0.00	0.06	0.90
H_47	Jersey Road	19.98	-0.04	0.10	0.89
H_48	Randwick Environmental Park	30.61	0.01	0.03	-0.39

8.3.3. Climate Variations

The effect of increasing the design rainfalls by 10%, 20% and 30% was evaluated for the 1% AEP rainfall event with impacts on peak flood levels observed throughout the study area. Generally speaking, each incremental 10% increase in rainfall results in an increase in peak flood levels at most of the locations analysed. The largest variation in flood level occurred upstream of Botany Road within the open channel. Sea level rise scenarios have the greatest effect on the downstream reaches of the catchment, near Botany Bay. The climate change sensitivity results are shown in Table 34.

Table 34: Results of Climate Change Analysis – 1% AEP Depths (m)

ID	Location	Peak Flood Depth 1% AEP	Difference with 1% AEP (m)				
			Rain +10%	Rain +20%	Rain +30%	2050 Sea Level Rise + 0.4 m	2100 Sea Level Rise + 0.9 m
H01	Upstream Botany Road	3.71	0.02	0.27	0.50	0.33	0.76
H02	Denison Street and Perry Street crossing	7.41	0.00	0.02	0.04	0.00	0.00
H03	Australia Avenue	7.90	0.00	0.03	0.06	0.00	0.00
H04	Baird Avenue and Perry Street crossing	15.11	0.01	0.05	0.07	0.00	0.00
H05	Beauchamp Road	11.30	0.01	0.03	0.05	0.00	0.00
H06	Grace Campbell Crescent and Nilsson Avenue crossing	11.53	0.00	0.02	0.04	0.00	0.00
H07	Beauchamp Road	12.73	-0.01	0.01	0.02	0.00	0.00
H08	Bunnerong Open channel at Matraville Public School	14.83	-0.01	0.01	0.03	0.00	0.00
H09	Rhodes Street Reserve	13.70	-0.10	0.11	0.59	0.00	0.00
H10	Jersey Road - West	22.14	-0.01	0.01	0.03	0.00	0.00
H11	Jauncey Place	16.61	-0.03	0.01	0.05	0.00	0.00
H12	Boonah Avenue	16.98	0.06	0.16	0.24	0.00	0.00
H13	Bunnerong Open Channel at Fitzgerald Avenue	19.03	-0.10	0.05	0.20	0.00	0.00
H14	Parer Street and Ulm Street crossing	19.93	0.00	0.08	0.12	0.00	0.00
H15	Paine Street and Fitzgerald Avenue crossing	21.57	0.00	0.02	0.04	0.00	0.00
H16	Jersey Road - East	22.10	-0.01	0.01	0.03	0.00	0.00
H17	Maroubra Road	22.22	0.00	0.03	0.05	0.00	0.00
H18	Piccadilly Place and Bruce Bennetts Place crossing	24.67	0.02	0.05	0.06	0.00	0.00
H19	Upstream Bunnerong Open Channel at Nagle Park	19.79	0.00	0.02	0.04	0.00	0.00
H20	Gale Road Low Point	25.70	0.00	0.03	0.08	0.00	0.00
H21	Snape Park Basin	23.82	-0.05	0.02	0.08	0.00	0.00
H22	Percival Street	24.56	-0.06	0.03	0.11	0.00	0.00
H23	Prince Edward Circuit and Towner gardens crossing	23.01	0.00	0.05	0.10	0.00	0.00
H24	Prince Edward Circuit	23.30	0.00	0.00	0.01	0.00	0.00

ID	Location	Peak Flood Depth 1% AEP	Difference with 1% AEP (m)				
			Rain +10%	Rain +20%	Rain +30%	2050 Sea Level Rise + 0.4 m	2100 Sea Level Rise + 0.9 m
H25	Gale Road	26.54	-0.01	0.07	0.16	0.00	0.00
H26	Holmes Street and Avoca Street Crossing	27.93	-0.02	0.06	0.14	0.00	0.00
H27	Tucabia Street	60.61	0.00	0.02	0.03	0.00	0.00
H28	Irvine Street	26.14	0.00	0.04	0.08	0.00	0.00
H29	Botany Street and Marville Avenue crossing	24.48	0.00	0.02	0.03	0.00	0.00
H30	Astrolabe Park	20.17	-0.01	0.03	0.06	0.00	0.00
H31	Anzac Parade near Rainbow Street	23.48	0.00	0.02	0.03	0.00	0.00
H32	Byrd Avenue near Anzac Parade	29.56	0.00	0.01	0.01	0.00	0.00
H33	Harbourne Road	25.84	0.02	0.11	0.17	0.00	0.00
H34	Araluen Street - East	31.72	0.00	0.05	0.09	0.00	0.00
H35	Rainbow Street at Randwick High School	37.51	0.00	0.04	0.08	0.00	0.00
H36	Blenheim Street	54.53	0.00	0.03	0.06	0.00	0.00
H37	Elphinstone Road	49.67	0.00	0.01	0.03	0.00	0.00
H38	Byrd Avenue Low Point	34.75	0.00	0.08	0.15	0.00	0.00
H39	Paton Street	34.75	-0.01	0.07	0.14	0.00	0.00
H40	Bunnerong Road near Rowland Park	23.82	0.00	0.03	0.05	0.00	0.00
H41	Isis Lane	27.19	0.00	0.01	0.02	0.00	0.00
H42	Glanfield Street near Bunnerong Road	22.14	0.01	0.07	0.11	0.00	0.00
H44	Mason Street - West	22.84	0.00	0.04	0.06	0.00	0.00
H45	Glanfield Street - East	24.64	0.02	0.09	0.13	0.00	0.00
H46	Alma Road	26.52	-0.01	0.09	0.18	0.00	0.00
H47	Jersey Road	19.98	-0.10	0.13	0.33	0.00	0.00
H48	Randwick Environmental Park	30.61	-0.06	0.04	0.25	0.00	0.00

9. FLOODING HOT SPOTS

Some of the areas where flooding is problematic, sometimes referred to as "hotspots," are discussed below in further detail. Figure C25 provides an overview of the locations discussed.

9.1. Paton Street and Byrd Avenue Low Point

The Paton Street low point occurs in a natural depression of medium density residential land-use, and affects Paton Street, Byrd Avenue, and McNair Avenue. Overland flow originating in the upstream catchment is conveyed in a north to south direction through Randwick Girls High and Randwick Boys High, Inglis Newmarket Stables, Rainbow Street Public School and Paine Reserve, then enters the Paton Street Low point. Flooding within the low point is controlled by high ground levels along Sturt Street and once the drainage network reaches capacity, flood waters can reach depths of up to 2 m in the 1% AEP event.

The sag point is on the Birds Gully drainage line, but the relief flow path from the lowpoint is across Sturt Street, east of Paton Street, rather than at Byrd Avenue where the drainage line runs. The overtopping flows therefore result in a diversion of flow out of the Birds Gully catchment towards Avoca Street, via low points in Jellicoe Avenue and Ainslie Street.

Design flood levels within the low point are shown in Table 35 with Figure C26 showing the location of the low point, topography and flood depths.

Table 35: Design Flood Levels within the Paton Street Low Point

Event	Peak Flood Level H_90 (mAHD)
1 EY	33.8
0.5 EY	33.8
20% AEP	33.9
10% AEP	34.1
5% AEP	34.4
2% AEP	34.6
1% AEP	34.8
0.2% AEP	34.9
PMF	35.7

9.2. Holmes Street and Benvenue Street Low Point

The Holmes Street and Benvenue Street low point occurs in a natural depression of medium density residential land-use, which affects Holmes Street and Benvenue Street. Overland flow is conveyed down Avoca Street at a maximum rate of 6 m^3/s in the 1% AEP event, and is redirected into the Homes Street and Benvenue Street low point due to the raised elevation of Anzac Parade, which is approximately 1 m above the ground level in Holmes Street. Modelling indicates there may be minor surcharging of the drainage network into the Holmes Street low point.

Design flood levels within the low point are shown in Table 36 with Figure C27 showing the location of the low point, topography and flood depths.

Table 36: Design Flood Levels within the Holmes Street Low Point

Event	Peak Flood Level H_61 (mAHD)
1 EY	27.4
0.5 EY	27.5
20% AEP	27.6
10% AEP	27.7
5% AEP	27.8
2% AEP	27.9
1% AEP	27.9
0.2% AEP	28.1
PMF	28.8

9.3. Alma Road and Gale Road

Photo 9: Alma Road Residential Dwellings

The low points on Alma Road and Gale Road between Anzac Parade and Garden St occur in a depression in the topography exacerbated by the clustered nature of the residential development. Overland flow travelling down Garret Street and Garden St is conveyed into the low points on Alma Road and Gale Road, and the raised profile of Anzac Parade prevents outflow occurring along the natural drainage path to the south-west. The raised residential properties and their close proximity to each other also prevent draining of the low points as shown in Photo 9.

Design flood levels within the low point are shown in Table 37 with Figure C28 showing the location of the low point, topography and flood depths.

Table 37: Design Flood Levels within the Alma Road Low Point

Event	Peak Flood Level H_70 (mAHD)
1 EY	23.4
0.5 EY	23.5
20% AEP	23.5
10% AEP	23.6
5% AEP	23.6
2% AEP	23.8
1% AEP	23.8
0.2% AEP	23.8
PMF	24.4

9.4. Glanfield Street & Boyce Road Low Point

Photo 10: Glanfield Road Low Point

The low point on Glanfield Street and Boyce Road is a natural feature in the topography that is compounded by the elevated road crest of Maroubra Road. The low point in Glanfield Street is shown in Photo 10.

Design flood levels within the low point are shown in Table 38 with Figure C29 showing the location of the low point, topography and flood depths.

Table 38: Design Flood Levels within the Glanfield Road Low Point

Event	Peak Flood Level H_45 (mAHD)
1 EY	23.9
0.5 EY	24.0
20% AEP	24.1
10% AEP	24.3
5% AEP	24.4
2% AEP	24.6
1% AEP	24.6
0.2% AEP	24.7
PMF	25.3

9.5. Jersey Road Low Point

Flooding on Jersey Road is due to the topographic depression between Bunnerong Road and Dive Street. Overland flow enters the low point form four directions:

- From the east along Jersey Road
- From the north across Heffron Park
- From the north-west from Bunnerong Road
- From the south-west through residential properties on Bunnerong Road

The crest of Bunnerong Road is 1.5 m above the lowest section of Jersey Road creating a barrier that prevents stormwaters from flowing towards the Bunnerong drain. Although there is a reasonably large 1.05 m pipe conveying a peak flow of 2 m^3/s in the 1% AEP event, peak flood depths of 1.0 m are estimated to occur in the 1% AEP event.

Design flood levels within the low point are shown in Table 39 with Figure C30 showing the location of the low point, topography and flood depths.

Table 39: Design Flood Levels within the Jersey Road Low Point.

Event	Peak Flood Level H_21 (mAHD)
1 EY	19.1
0.5 EY	19.2
20% AEP	19.3
10% AEP	19.3
5% AEP	19.5
2% AEP	19.7
1% AEP	20.0
0.2% AEP	20.3
PMF	21.8

9.6. Flack Avenue Low Point

The low point on Flack Avenue north of the intersection with Beauchamp Road is inundated primarily by overtopping of the Bunnerong open channel near Matraville Public School, where the open channel enters a 3.5 m x 1.68 m box culvert. There is a peak flow of 16 m^3/s in the 1% AEP event through the culvert, but this is less than the total channel flow. The channel overtopping inundates the Flack street low point with a peak flow of 5.5 m^3/s through private property in the 1% AEP event.

Flooding in Flack Avenue is exacerbated by the crest of Beauchamp Road being 0.5 m above the low point in Flack Street which prevents overland flow being conveyed downstream. The two 0.375 m pipes in Flack Avenue are unable to disperse floodwaters once capacity is reached. An example of flooding in Flack Avenue is shown in Photo 11.

Design flood levels within the low point are shown in Table 40 with Figure C31 showing the location of the low point, topography and flood depths.

Photo 11: Flack Avenue Low Point

Table 40: Design Flood Levels within the Flack Avenue Low Point and Peak Flow Overtopping Channel Headwall.

Event	Peak Flood Level H_101 (mAHD)	Peak Flow Overtopping the channel headwall Q_284 (m^3/s)
1 EY	12.3	0.0
0.5 EY	12.4	0.0
20% AEP	12.5	0.2
10% AEP	12.7	2.9
5% AEP	12.8	3.8
2% AEP	12.8	5.0
1% AEP	12.8	5.6
0.2% AEP	12.9	7.2
PMF	13.5	58.7

9.7. Denison Street and Nilson Avenue Low Point

The Denison Street and Nilson Avenue low point encompasses the southern ends of Denison Street and Nilson Avenue as well as Beauchamp Street, with the residential properties bounded by the three streets heavily affected by ponded floodwaters. The flood affectation is caused by the following flood mechanisms:

- Local catchment runoff
- Overland flow conveyed down Nilson Avenue and Grace Campbell Crescent from the north
- Overland flow along Beauchamp Avenue, including flow that originates from the overtopped Bunnerong open channel near Flack Avenue.

Beauchamp Avenue is raised by between 0.4 m and 1.25 m above the low point which acts as a barrier to overland flow. Design flood levels within the low point are shown in Table 41 with Figure C32 showing the location of the low point, topography and flood depths.

Table 41: Design Flood Levels within the Denison Street and Nilson Avenue Low Point.

Event	Peak Flood Level in Denison Street H_104 (mAHD)	Peak Flood Level next to Nilson Street H_103 (mAHD)
1 EY	11.4	11.1
0.5 EY	11.4	11.1
20% AEP	11.4	11.2
10% AEP	11.4	11.2
5% AEP	11.4	11.2
2% AEP	11.4	11.3
1% AEP	11.5	11.3
0.2% AEP	11.5	11.3
PMF	11.7	11.7

9.8. Boonah Avenue Low Point

The Boonah Avenue low point is located between Fraser Avenue and Smith Street with Smith Street acting as a barrier preventing overland flow from escaping the low point. The most severely affected properties are just north of Smith Street. Ponding in this area is caused by two mechanisms:

- Localised runoff draining to the low point
- The drainage pits on Boonah Avenue surcharging

An image pf the low point in Boonah Avenue is shown in Photo 12. Design flood levels within the low point are shown in Table 42 with Figure C33 showing the location of the low point, topography and flood depths.

Table 42: Design Flood Levels within the Boonah Avenue Low Point.

Event	Peak Flood Level H_27 (mAHD)
1 EY	16.4
0.5 EY	16.5
20% AEP	16.6
10% AEP	16.6
5% AEP	16.7
2% AEP	16.8
1% AEP	17.0
0.2% AEP	17.1
PMF	18.0

Photo 12: Boonah Avenue Low Point

9.9. Parer Street Low Point

The Parer Street sag point is located in between Donavan Avenue and Hinkler Street. Water ponds at the location during a storm once the capacity of the trunk drainage system is exceeded. The source of the flood mechanism is primarily local subcatchment runoff. Design flood levels within the low point are shown in Table 43 with Figure C34 showing the location of the low point, topography and flood depths.

Table 43: Design Flood Levels within the Parer Street Low Point.

Event	Peak Flood Level H_32 (mAHD)
1 EY	19.4
0.5 EY	19.5
20% AEP	19.6
10% AEP	19.7
5% AEP	19.7
2% AEP	19.9
1% AEP	19.9
0.2% AEP	20.0
PMF	21.1

9.10. Glanfield Street /Maroubra Road Low Point

The low points in Glanfield Street and Maroubra Road are located between Bunnerong Road and Royal Street. Water ponds at the location during a storm once the capacity of the trunk drainage system is exceeded. Design flood levels within the low point are shown in Table 44 with Figure C35 showing the location of the low point, topography and flood depths.

Table 44: Design Flood Levels within the Glanfield Street Low Point.

Event	Peak Flood Level in Glanfield Street H_43B (mAHD)	Peak Flood Level in Glanfield Street H_42B (mAHD)
1 EY	21.5	22.0
0.5 EY	21.6	22.0
20% AEP	21.7	22.0
10% AEP	21.9	22.1
5% AEP	22.0	22.1
2% AEP	22.1	22.2
1% AEP	22.1	22.2
0.2% AEP	22.2	22.3
PMF	23.2	23.2

9.11. Edward Circuit Low Point

The Edward Circuit low point is located between Monash Gardens and Birdwood Avenue. Overland flow is conveyed down Wark Avenue and Towner Gardens towards the Edward Circuit low point. Once the capacity of the drainage system is reached the water begins to pond, to depths up to 0.7 m in the 1% AEP event.

Design flood levels within the low point are shown in Table 45 with Figure C36 showing the location of the low point, topography and flood depths

Table 45: Design Flood Levels within the Edward Circuit Low Point.

Event	Peak Flood Level H_54 (mAHD)
1 EY	22.5
0.5 EY	22.6
20% AEP	22.6
10% AEP	22.8
5% AEP	22.9
2% AEP	23.0
1% AEP	23.0
0.2% AEP	23.1
PMF	24.0

9.12. Bunnerong Road Low Point

The residential properties between located between Bunnerong Road and Botany Street directly across from Rowland Park are situated in a topographic depression. The low point is affected by overland flow from the following sources:

- Localised runoff between Bunnerong Road and Botany Street.
- Surcharging pits along Bunnerong Road.
- Backwater flow from the Marville Avenue drainage line, across Botany Road and into the low point. This overland flow path originates from as far north as Hincks Street and as far east as Anzac Parade

Once the capacity of the drainage network is met water begins to pond in the residential properties on Bunnerong Road Due to the flat topography floodwaters disperse slowly across Bunnerong Road and into Rowland Park.

An image of historical flooding in the 1% AEP event is shown in Photo 13. Design flood levels within the low point are shown in Table 46 with Figure C37 showing the location of the low point, topography and flood depths

Table 46: Design Flood Levels within the Bunnerong Road Low Point

Event	Peak Flood Level H_70 (mAHD)
1 EY	23.4
0.5 EY	23.5
20% AEP	23.5
10% AEP	23.6
5% AEP	23.6
2% AEP	23.8
1% AEP	23.8
0.2% AEP	23.8
PMF	24.4

Photo 13: Reported Flooding Bunnerong Road Low Point

9.13. Irvine Street Low Point

The low point on Irvine Street is located between Beulah Street and Walenore Avenue, directly above the trunk drainage line that continues towards Marville Avenue. Overland flow enters the low point down Irvine Street from a north to south direction and down Fischer Street from an east to west direction where it is trapped by the surrounding topography once the capacity of the drainage system is reached. The overland flow relief path is towards Marville Avenue, but the outflows are limited by an adverse grade of Marville Avenue near Walenore Avenue.

An image of the Irvine Street low point is shown in Photo 14. Design flood levels within the low point are shown in Table 47 with Figure C38 showing the location of the low point, topography and flood depths.

Table 47: Design Flood Levels within the Irvine Street Low Point

Event	Peak Flood Level H_67 (mAHD)
1 EY	25.7
0.5 EY	25.8
20% AEP	25.9
10% AEP	26.0
5% AEP	26.0
2% AEP	26.1
1% AEP	26.1
0.2% AEP	26.2
PMF	27.6

Photo 14: Irvine Street Low Point

9.14. Hincks Street Low Point

The Hinks Street low point is located on the residential block between Hincks Street, Irvine Street, Isis Street and Botany Street where residential properties are situated below the adjacent road levels. Overland flow enters the low point from two locations:

- Localised runoff from the residential block
- The overland flow path down Botany Road that originates north of Anzac Parade.

There is a relatively small drainage system inside the residential properties to drain the low point towards the Birds Gully trunk line to the north. Design flood levels within the low point are shown in Table 48 with Figure C39 showing the location of the low point, topography and flood depths

Table 48: Design Flood Levels within the Hincks Street Low Point

Event	Peak Flood Level H_81 (mAHD)
1 EY	26.4
0.5 EY	26.5
20% AEP	26.6
10% AEP	27.0
5% AEP	27.1
2% AEP	27.2
1% AEP	27.2
0.2% AEP	27.2
PMF	27.6

9.15. Harbourne Road Low Point

The Harbourne Road low point is located in Kingsford at the intersection of Anzac Parade and Rainbow Street, with the crest of Rainbow Street approximately 0.8 m above the lowest point of Harbourne Road. Overland flow enters the low point from three locations:

- Local catchment runoff
- Overland flow conveyed down Rainbow Street from the east inundates Harbourne Street
- Overland flow from as far east as Kennedy Street is conveyed to Forsyth Street and through the residential properties towards the Harbourne Street low point.

Once the capacity of the drainage system is exceeded, water begins to pond in the low point with depths up to 1.0m in the 1% AEP event. Design flood levels within the low point are shown in Table 49 Figure C40 with showing the location of the low point, topography and flood depths.

Table 49: Design Flood Levels within the Harbourne Road Low Point

Event	Peak Flood Level H_84 (mAHD)
1 EY	25.1
0.5 EY	25.3
20% AEP	25.4
10% AEP	25.5
5% AEP	25.6
2% AEP	25.7
1% AEP	25.8
0.2% AEP	26.0
PMF	26.6

10. PRELIMINARY FLOOD PLANNING AREA

10.1. Background

Land use planning is one of the most effective means of minimising flood risk and damages from flooding. The Flood Planning Area (FPA) identifies land that is subject to flood related development controls and the Flood Planning Level (FPL) is the minimum floor level applied to development proposals within the FPA.

The process of defining FPAs and FPLs is somewhat complicated by the variability of flow conditions between mainstream and local overland flow, particularly in urban areas. Traditional approaches that were developed for riverine environments and “mainstream” flow areas often cannot be applied in steeper urban overland flow areas.

Defining the area of flood affectation due to overland flow (which by its nature includes shallow flow) often involves determining at which point it becomes significant enough to classify as “flooding” rather than just drainage of local runoff. The difference in peak flood level between events of varying magnitude may be minor in areas of overland flow, such that applying the typical freeboard can result in a FPL much greater than the Probable Maximum Flood (PMF) level.

The FPA should include properties where future development would result in impacts on flood behaviour in the surrounding area and areas of high hazard that pose a risk to safety or life. Further to this, the FPL is determined with the purpose to decrease the likelihood of over-floor flooding of buildings and the associated damages.

The Floodplain Development Manual suggests that the FPL generally be based on the 1% AEP event plus an appropriate freeboard. The typical freeboard cited in the manual is that of 0.5 m; however it also recognises that different freeboards may be deemed more appropriate due to local conditions. In these circumstances, some justification is called for where a lower value is adopted.

Further consideration of flood planning areas and levels are typically undertaken as part of the Floodplain Management Study where council decides which approach to adopt for inclusion in their Floodplain Management Plan.

10.2. Identification of Flood Control Lots

Flood Tagging is the process where lots are identified as flood liable. The “tagged” lots will be subject to Section 149(2) notification (under NSW Local Government Act) indicating that their properties are subject to flood related development controls. This simply means that should development of the lots occur, flooding will need to be considered and Council’s LEP, DCP and any other relevant flood related policies will apply.

Flood tagging was undertaken using a three step process, shown below.

Diagram 3: Stages for Identification of Flood Control Lots

Step 1. GIS Analysis	Step 2. Desktop Analysis	Step 3. Ground Truthing
• Lots affected according to the "mainstream" or "overland flow" criteria identified from modelling results	• Initial tagged lots identified in Stage 1 are mapped with 1% flood depths, building footprint information and the DEM (ground elevation data) • Manual visual review undertaken to identify lots which may have been omitted or may have unessecarily been identified as tagged	• The lots ideintified for further review in Step 2 are assessed as part of a site visit • WMAwater engineers visit each lot, assess local ground conditions and determine their validity for tagging •A final tagging status is assigned, based on a range of assessment criteria

The methodology used in this report is consistent with that adopted in a number of similar studies throughout the Sydney metropolitan area. Identification of properties subject to flood-related development controls is undertaken by using the 1% AEP model results, with filtering to remove nuisance or non-damaging levels of flow, then applying subsequent ground truthing to determine whether individual properties are tagged or not. For this study, there were no areas where typical mainstream flood techniques (adding freeboard and stretching the results) produced reasonable outcomes. Each of the properties identified were based on overland flow criteria as identified below.

- Overland flooding: Lots were originally classified as "flood control lots" and therefore within the FPA, if they were affected by the modelled 1% AEP flood extent (after applying filtering). The flood depth map was filtered to remove areas less than 0.15 m deep. Properties were then identified as preliminary "flood control lots" where 10% or more of the property was affected by this filtered flood extent.

The Desktop Analysis (Step 2) and Ground Truthing (Step 3) processes were then undertaken. Some potentially flooded lots are not identified from the automated GIS Analysis process (Step 1), due to the approximations required to construct the computational model of the catchment, and due to the sensitivities of GIS processing. Furthermore, some lots may be initially identified as flood control lots, which in reality are unlikely to be subject to significant flooding. Ground truthing was undertaken first through desktop analysis, and then a site visit for properties requiring detailed investigation. The results of this process were provided in GIS format to Council. The considerations applied during this process, and categories assigned to various properties as part of this process, are summarised in Table 50.

Table 50: Ground truthing classifications for flood control lot identification process

Classification	Description
Tag Removed	
A1	Initially tagged due to localised ponding within property. Ground truthing indicated that the depression was an artifact of the LIDAR and not a genuine trapped drainage sag point. Tag removed.
A2	Initially tagged because of model grid cells in the gutter overlapping with the property boundary. Ground truthing confirmed that water would be confined to gutter and there is a significant gradient past the property. Tag removed.
Tag Added	
B1	Surrounding lots tagged. Ground truthing confirmed that the topography and flow behaviour for the lot was similar to adjacent tagged lots. Tag added.
B2	Lot identified to have a drainage easement. Ground truthing identified that the easement was associated with a potential overland flow path in the case of blockage of stormwater inlets or gutters. Tag added.
B3	Property downstream of or adjacent to a sag point. Ground truthing identified that there would be a potential overland flow path resulting from blockage of kerb inlets , pipes or gutters.
Tag Retained (confirmed by ground truthing)	
C1	Confirmed to be inundated or potentially inundated from nearby flow path or sag point.
C2	Overland flow area, intial tagging confirmed by ground truthing.
Not Tagged (confirmed by ground truthing)	
D1	Not tagged initially and still not tagged after investigation

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   (http://www.bom.gov.au/water/designRainfalls/ifd/)
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NSW State Government, August 2010

Figures

FIGURE 1
CATCHMENTS AND PREVIOUS STUDIES

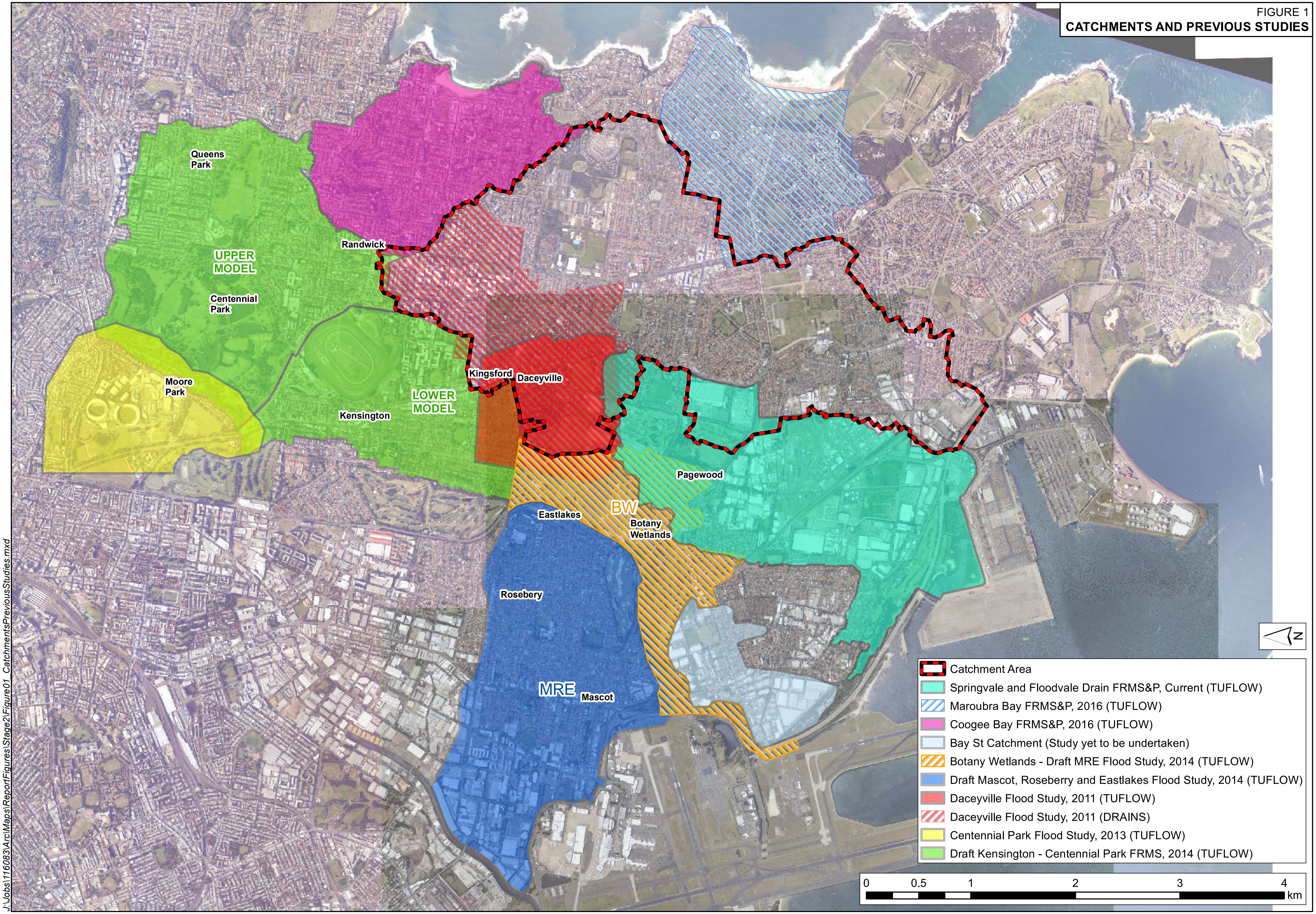

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FIGURE 2
BIRDS GULLY AND BUNNERONG ROAD STUDY AREA

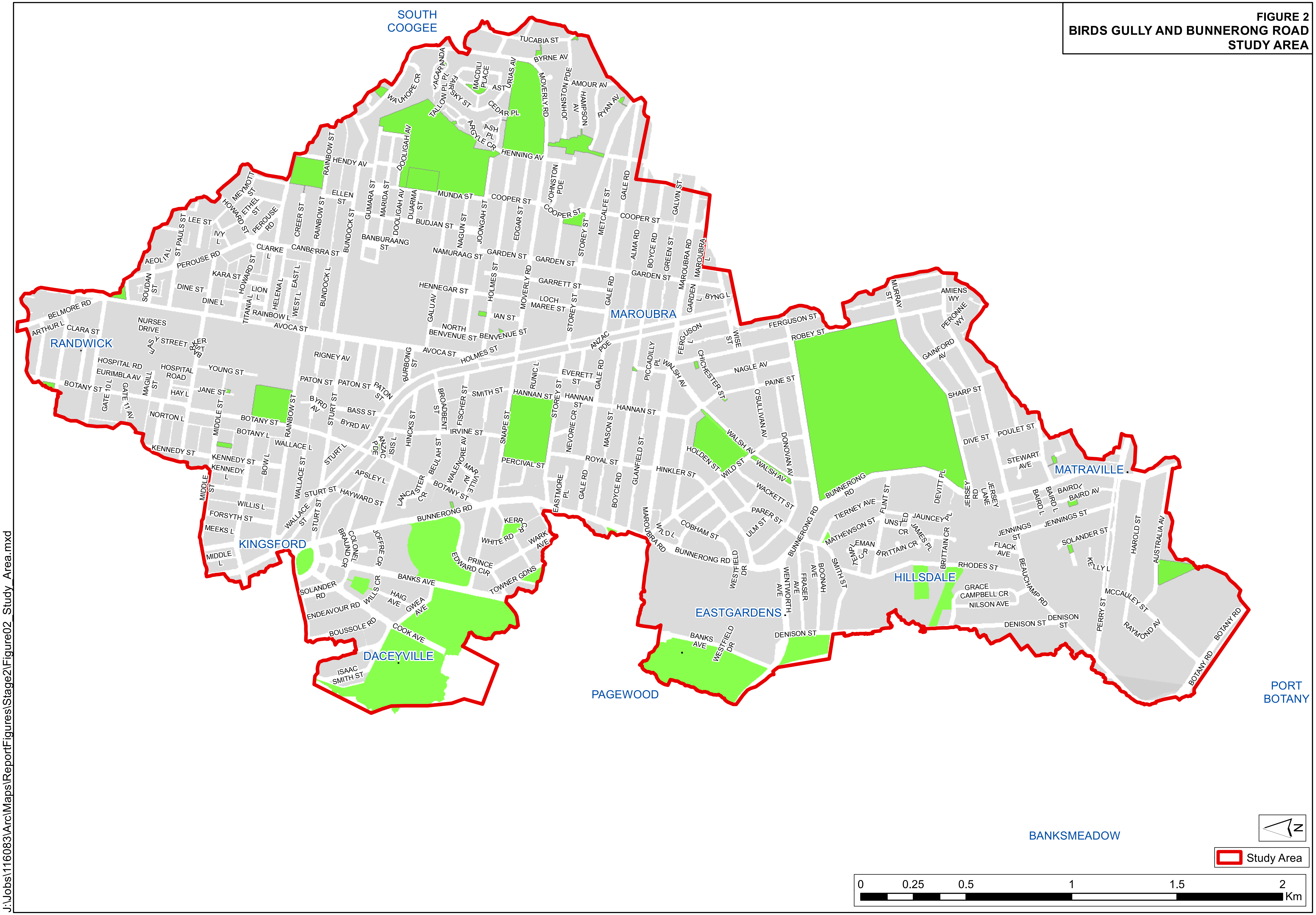

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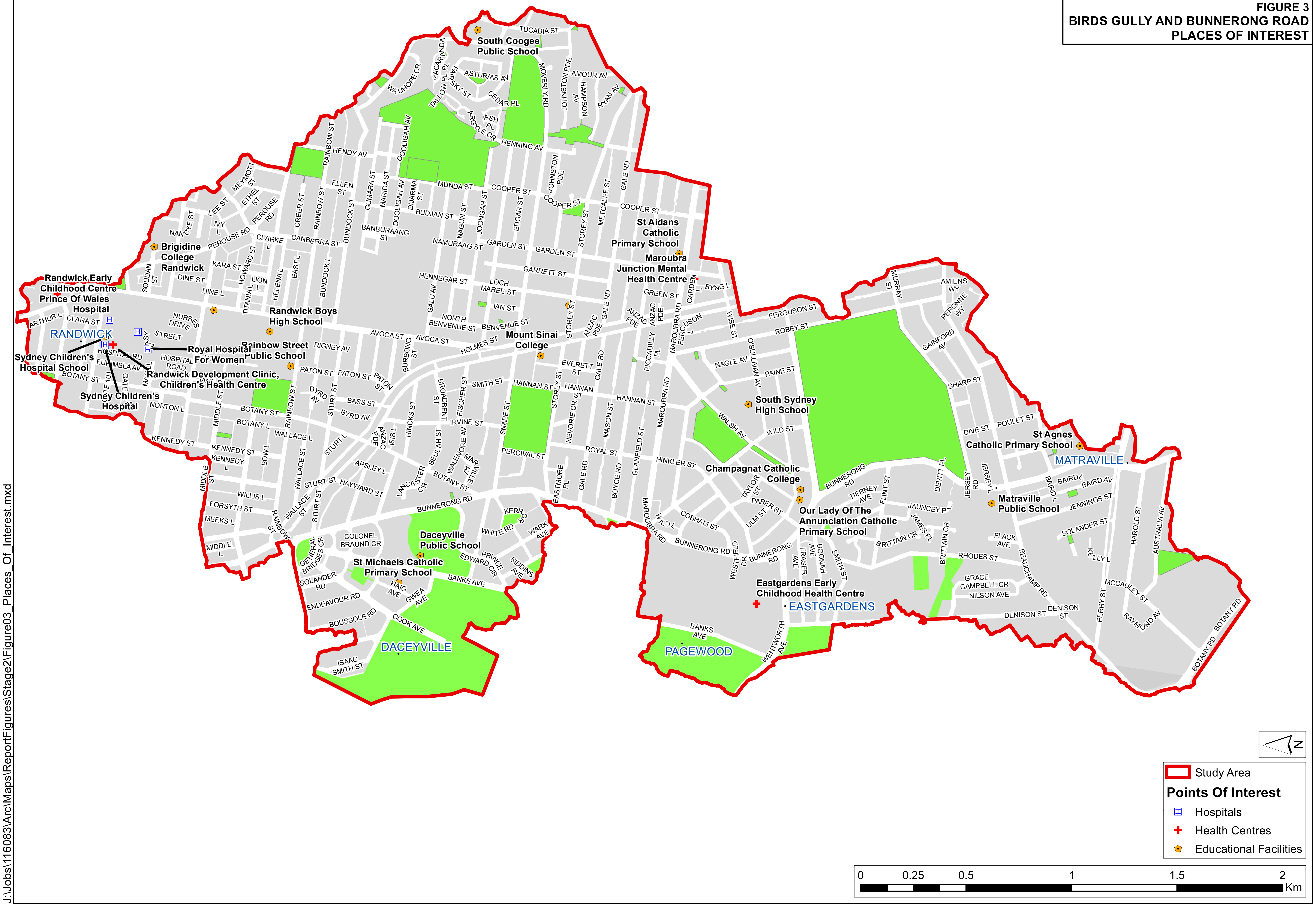
FIGURE 3
BIRDS GULLY AND BUNNERONG ROAD PLACES OF INTEREST



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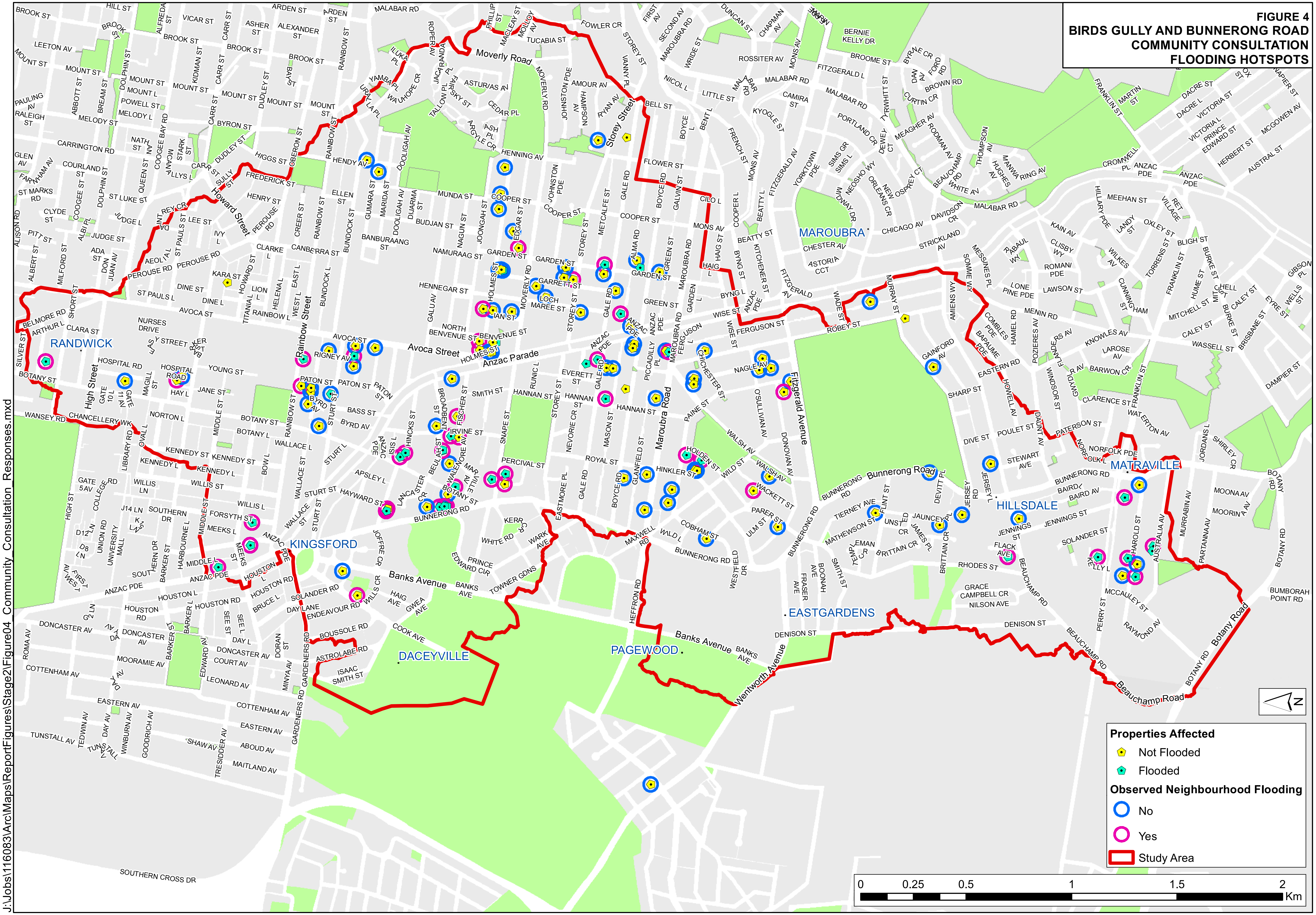

FIGURE 4
BIRDS GULLY AND BUNNERONG ROAD
COMMUNITY CONSULTATION
FLOODING HOTSPOTS

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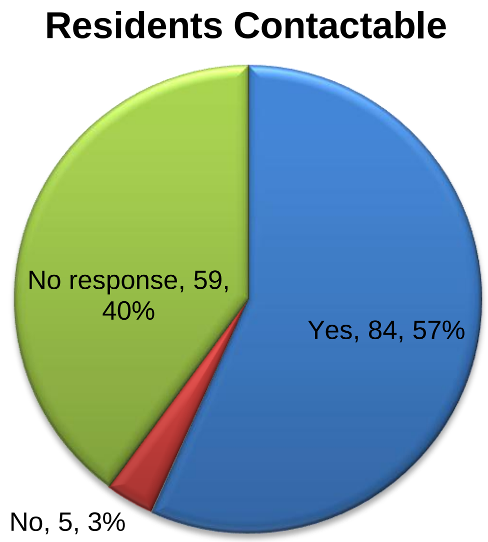
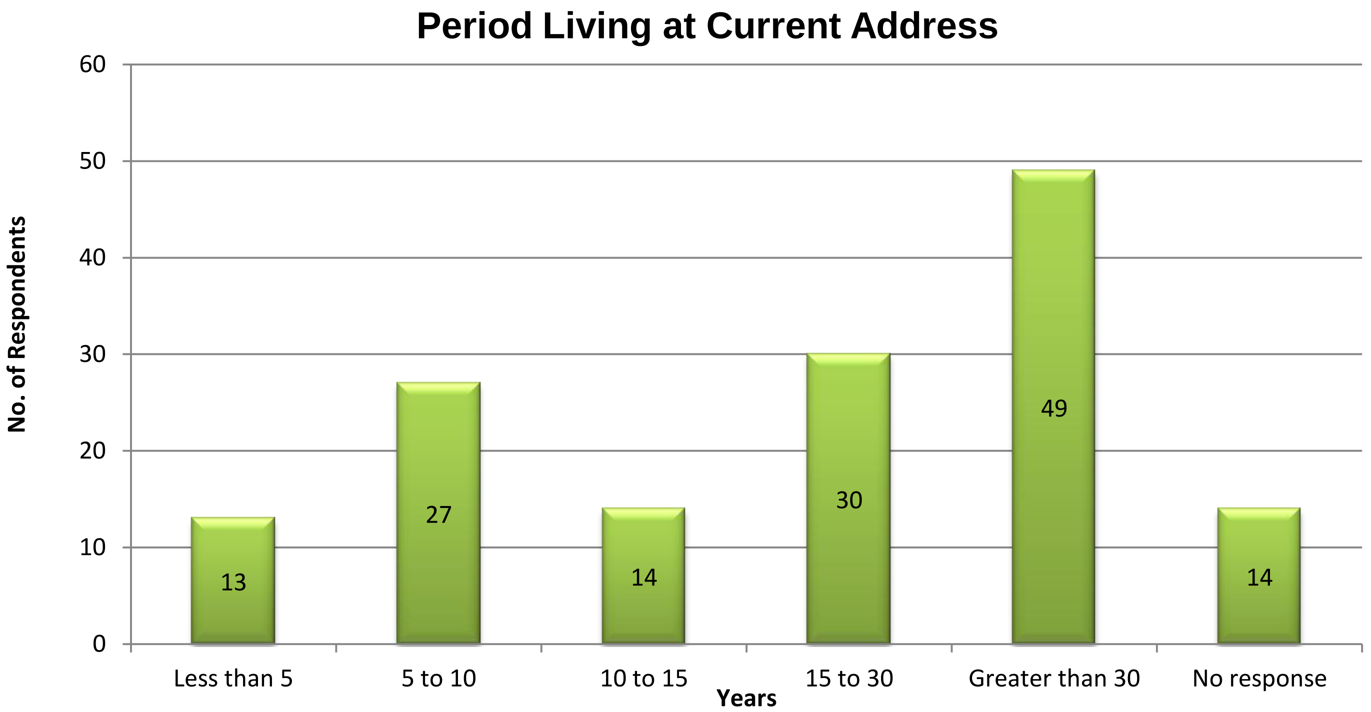
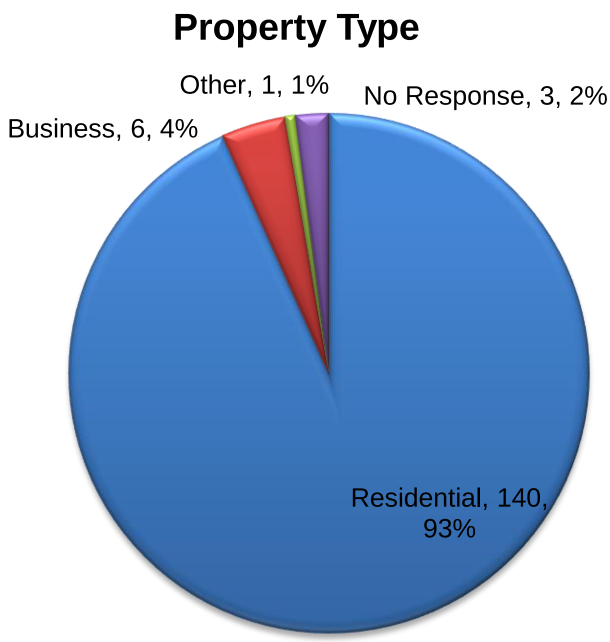
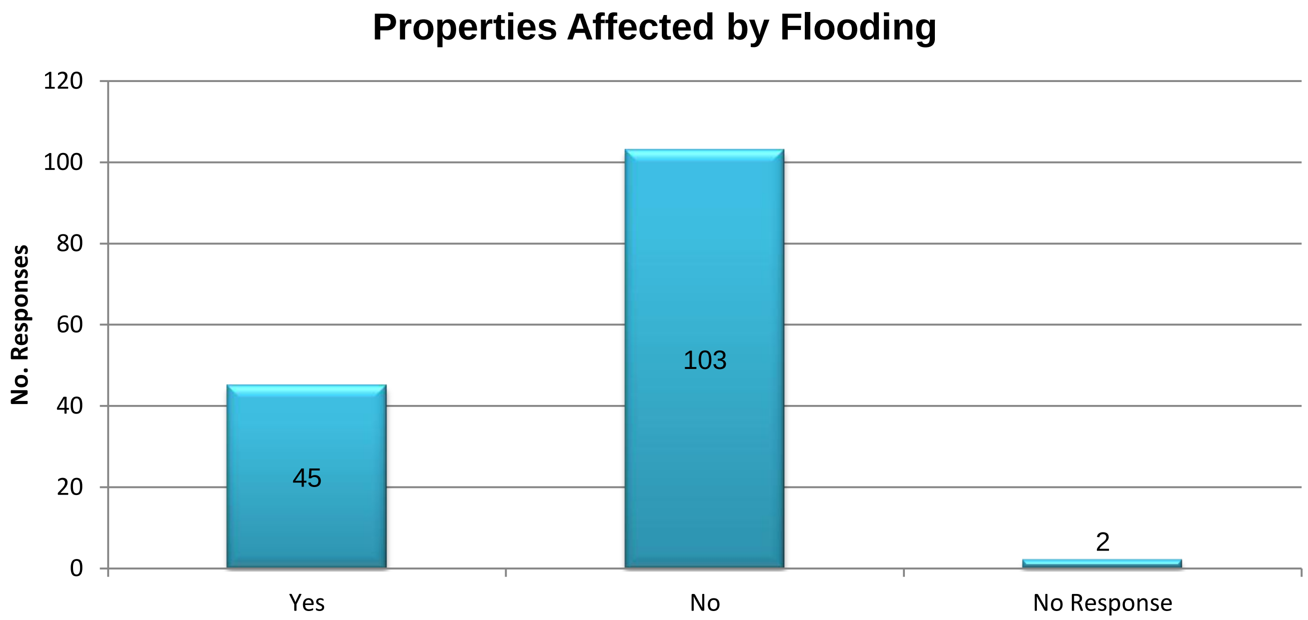
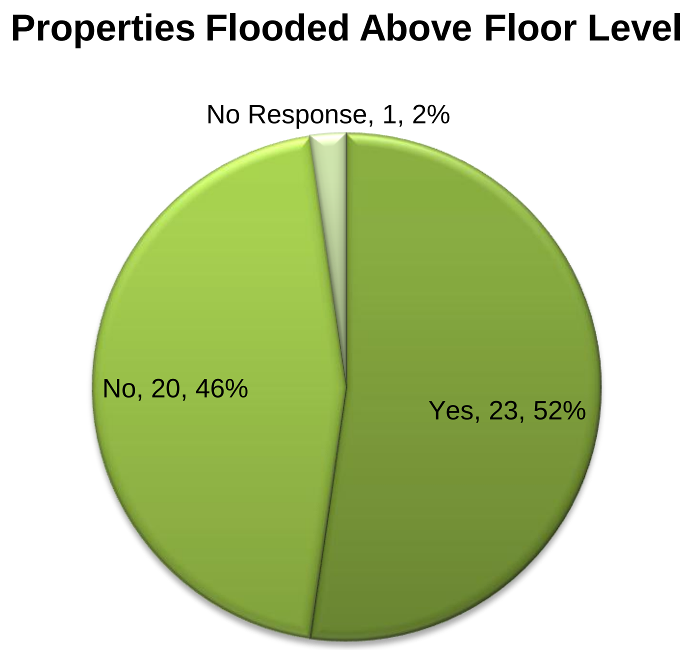
COMMUNITY CONSULTATION RESPONSES

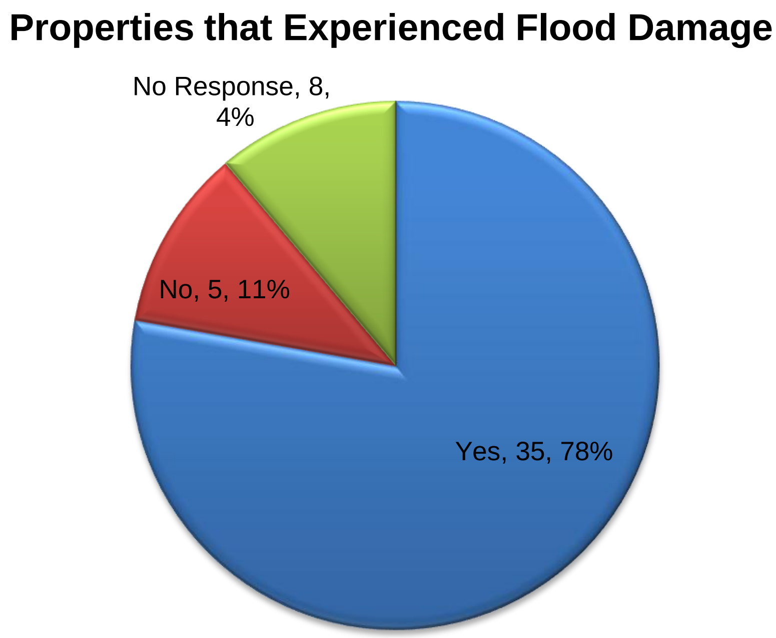




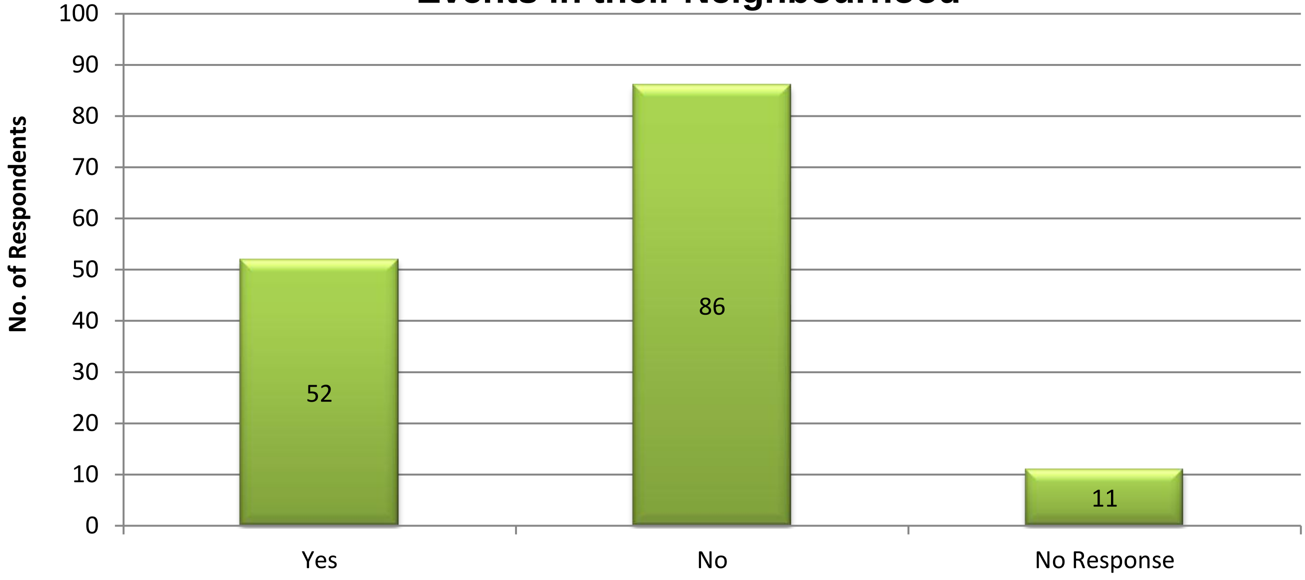



Properties Affected by Flooding
120
100
80
60
40
20
0
No. Responses
45
103
2
Yes
No
No Response

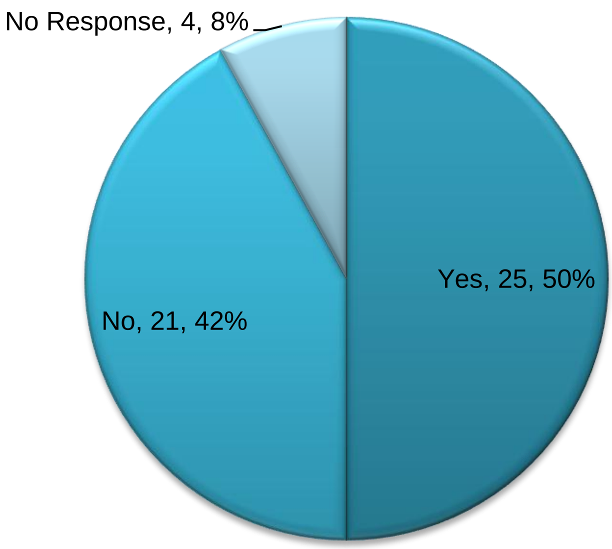

Properties Flooded Above Floor Level
No Response, 1, 2%
No, 20, 46%
Yes, 23, 52%


Properties that Experienced Flood Damage
No Response, 8, 4%
No, 5, 11%
Yes, 35, 78%

Residents who Observed Water Flowing Overland during Storm Events in their Neighbourhood



Where neighbourhood flooding observed, water was above floor Level



Where neighbourhood flooding observed, damaged was caused as a result

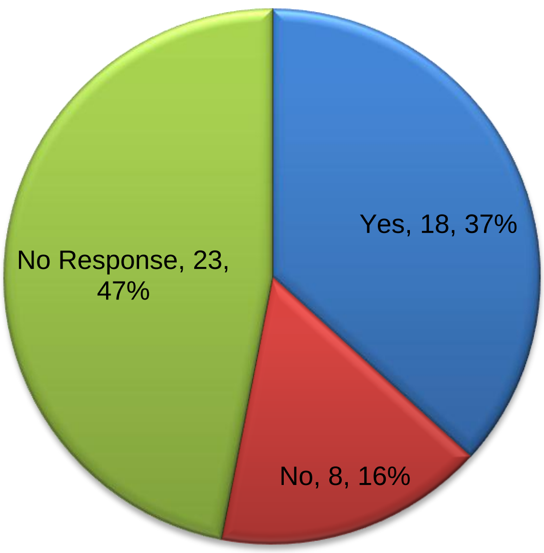
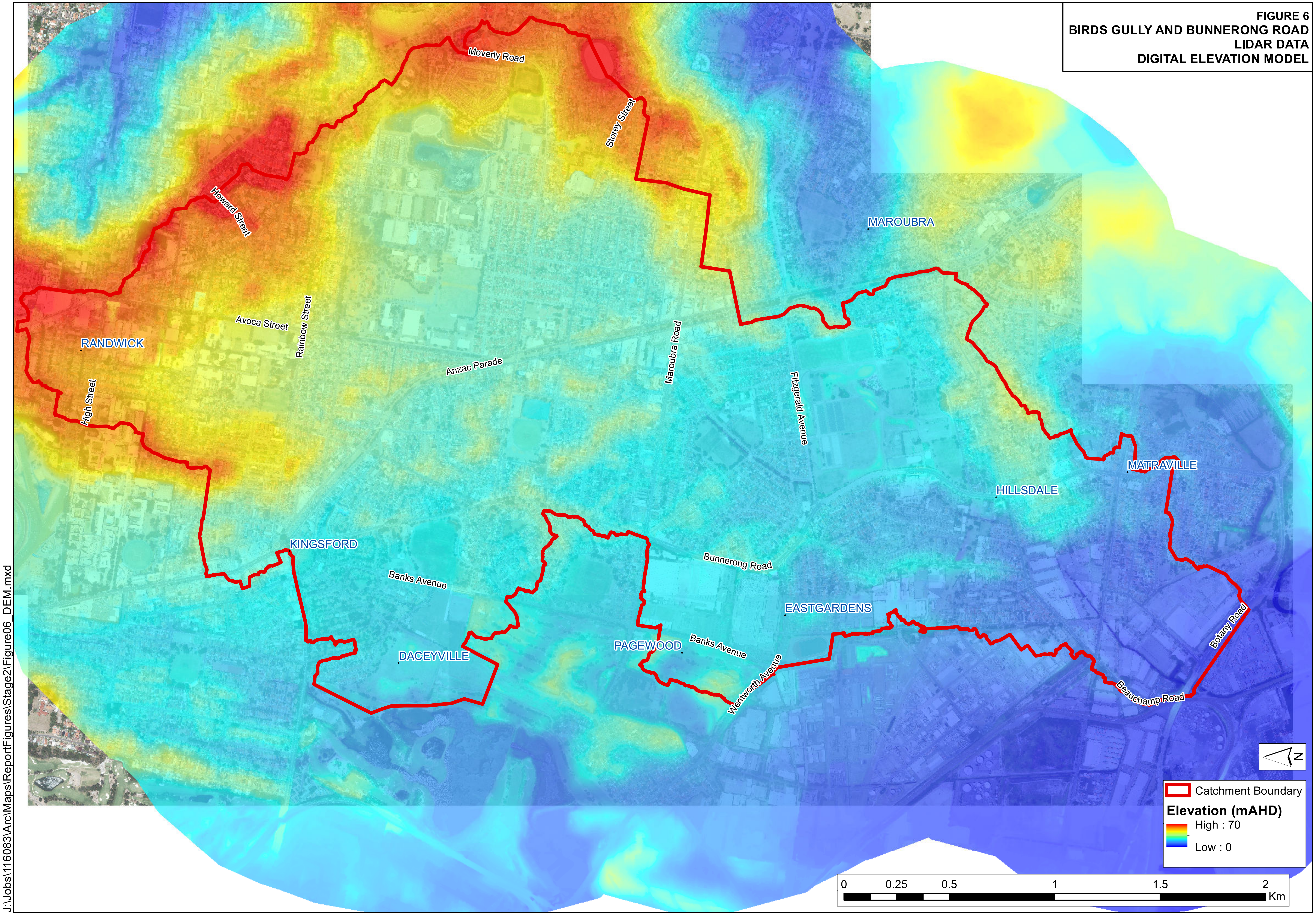


FIGURE 6
BIRDS GULLY AND BUNNERONG ROAD
LIDAR DATA
DIGITAL ELEVATION MODEL



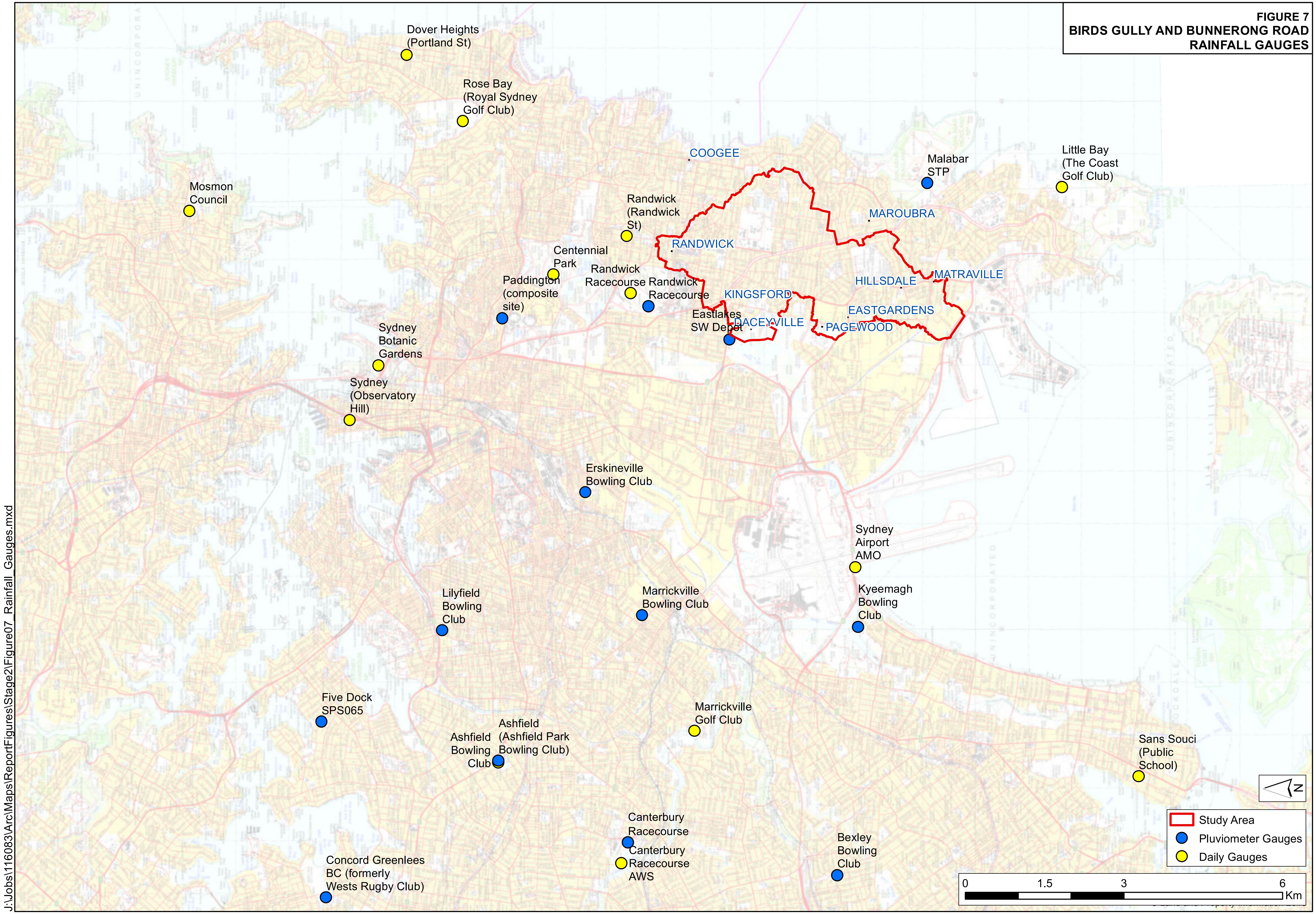


FIGURE 7
BIRDS GULLY AND BUNNERONG ROAD
RAINFALL GAUGES
Dover Heights (Portland St)
Rose Bay (Royal Sydney Golf Club)
COOGEE
Malabar STP
Little Bay (The Coast Golf Club)
Mosmon Council
Randwick (Randwick St)
MAROUBRA
RANDWICK
Centennial Park
Randwick Racecourse
Randwick Racecourse
Paddington (composite site)
KINGSFORD
HILLSDALE
MATRAVILLE
EASTGARDENS
Eastlakes SW Depot
DACEYVILLE
PAGEWOOD
Sydney Botanic Gardens
Sydney (Observatory Hill)
Erskineville Bowling Club
Sydney Airport AMO
Lilyfield Bowling Club
Marrickville Bowling Club
Kyeemagh Bowling Club
Five Dock SPS065
Ashfield Bowling Club
Ashfield (Ashfield Park Bowling Club)
Marrickville Golf Club
Sans Souci (Public School)
Canterbury Racecourse
Canterbury Racecourse AWS
Bexley Bowling Club
Concord Greenlees BC (formerly Wests Rugby Club)
Study Area
Pluviometer Gauges
Daily Gauges
0
1.5
3
6
Km
N
J:\Jobs\116083\Arc\Maps\ReportFigures\Stage2\Figure07_Rainfall_Gauges.mxd

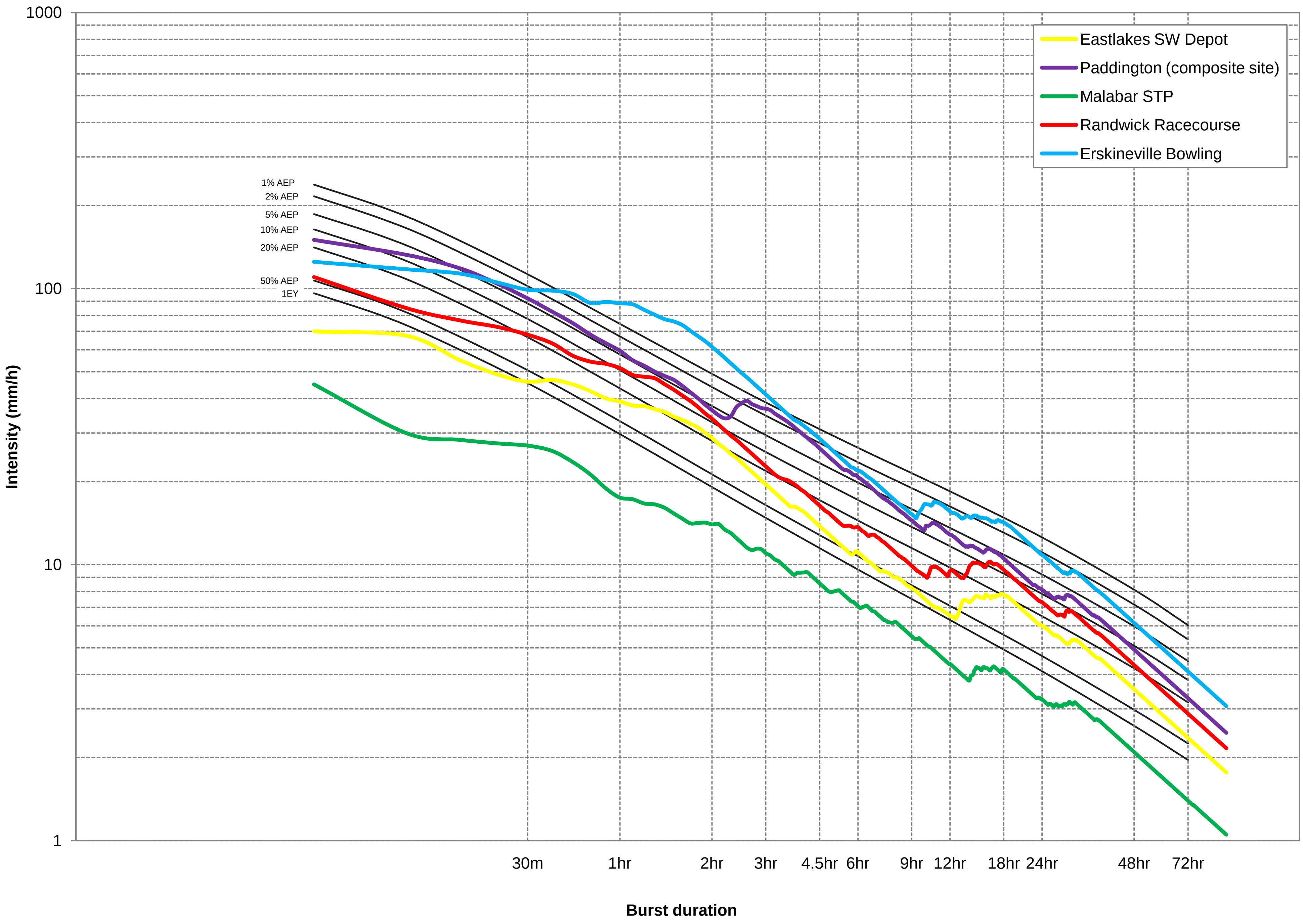


FIGURE 8
BURST INTENSITIES
AND FREQUENCIES
APRIL 1998 FLOOD EVENT

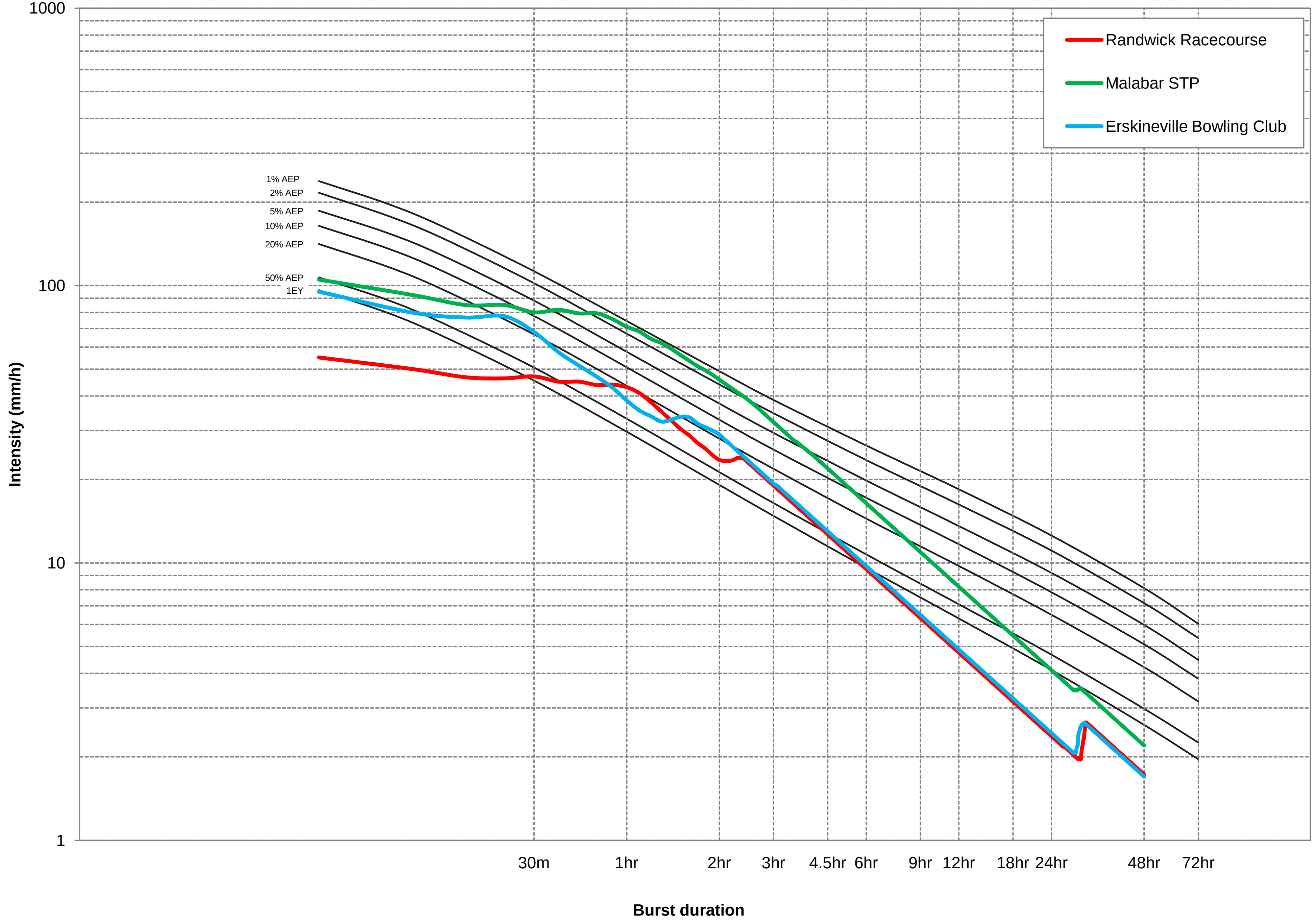


FIGURE 9
BURST INTENSITIES AND FREQUENCIES
JANUARY 1999 FLOOD EVENT

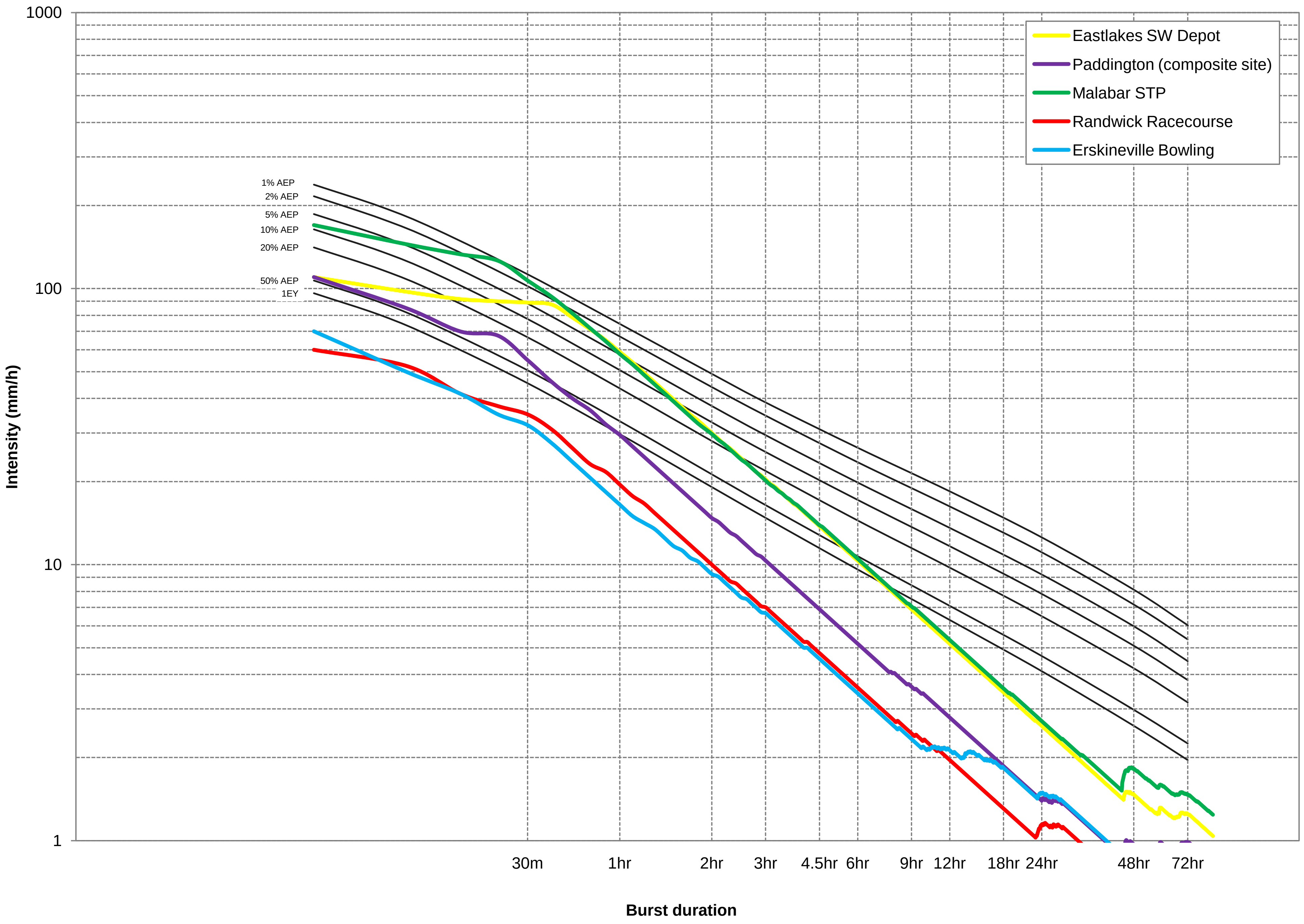


FIGURE 10
BURST INTENSITIES AND FREQUENCIES MARCH 2014 FLOOD EVENT

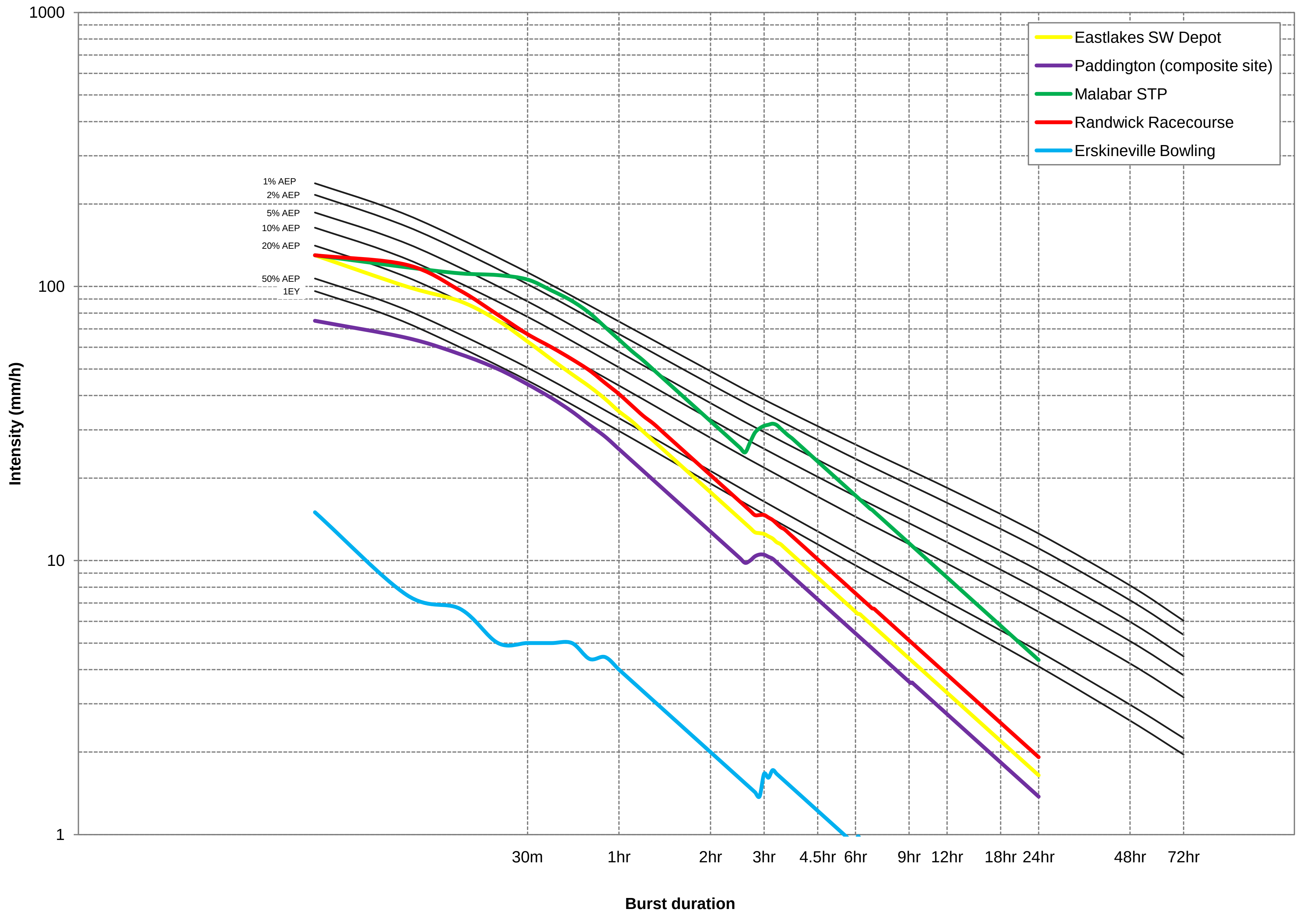


FIGURE 11
BURST INTENSITIES AND FREQUENCIES DECEMBER 2015 FLOOD EVENT

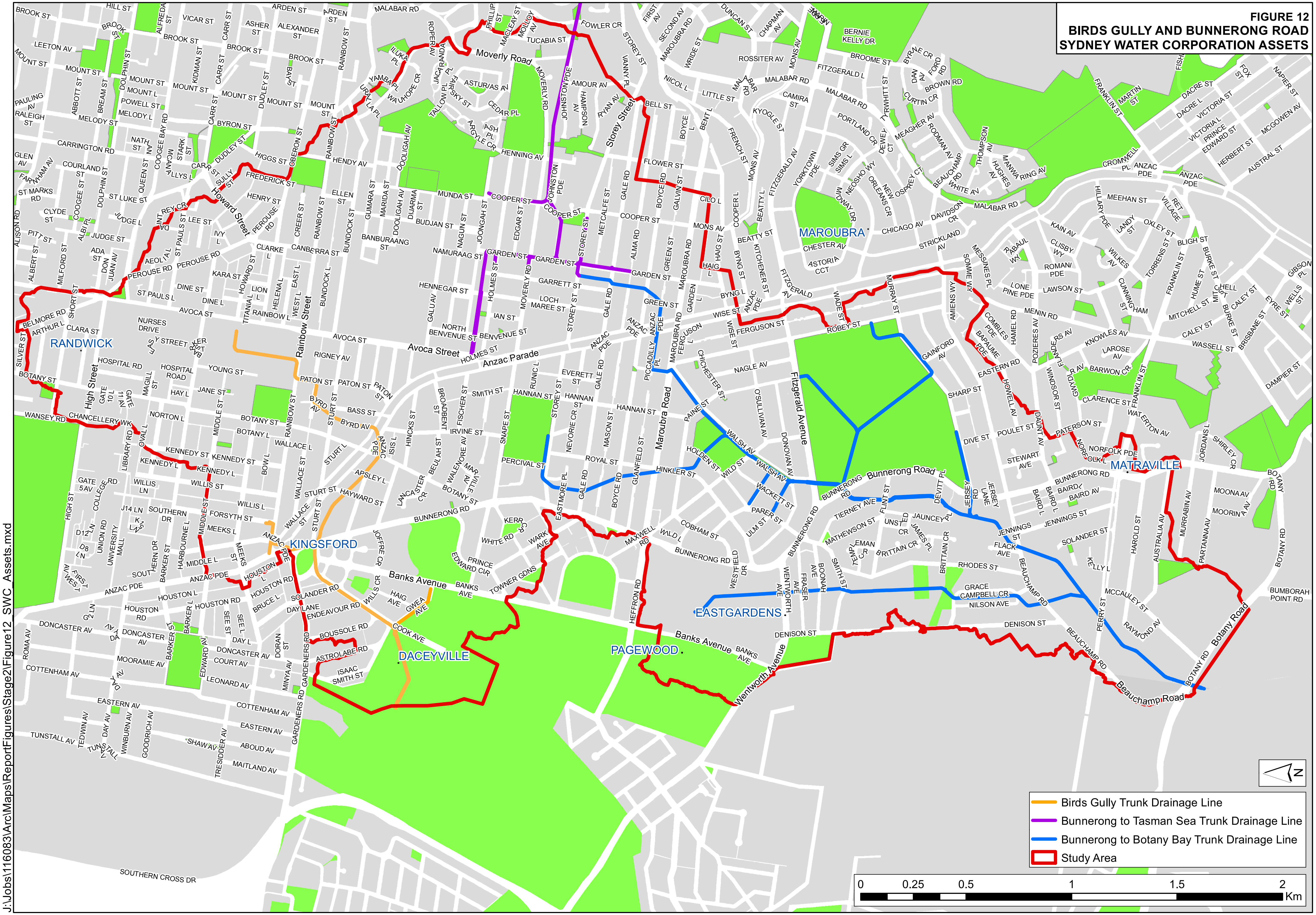


FIGURE 12
BIRDS GULLY AND BUNNERONG ROAD
SYDNEY WATER CORPORATION ASSETS

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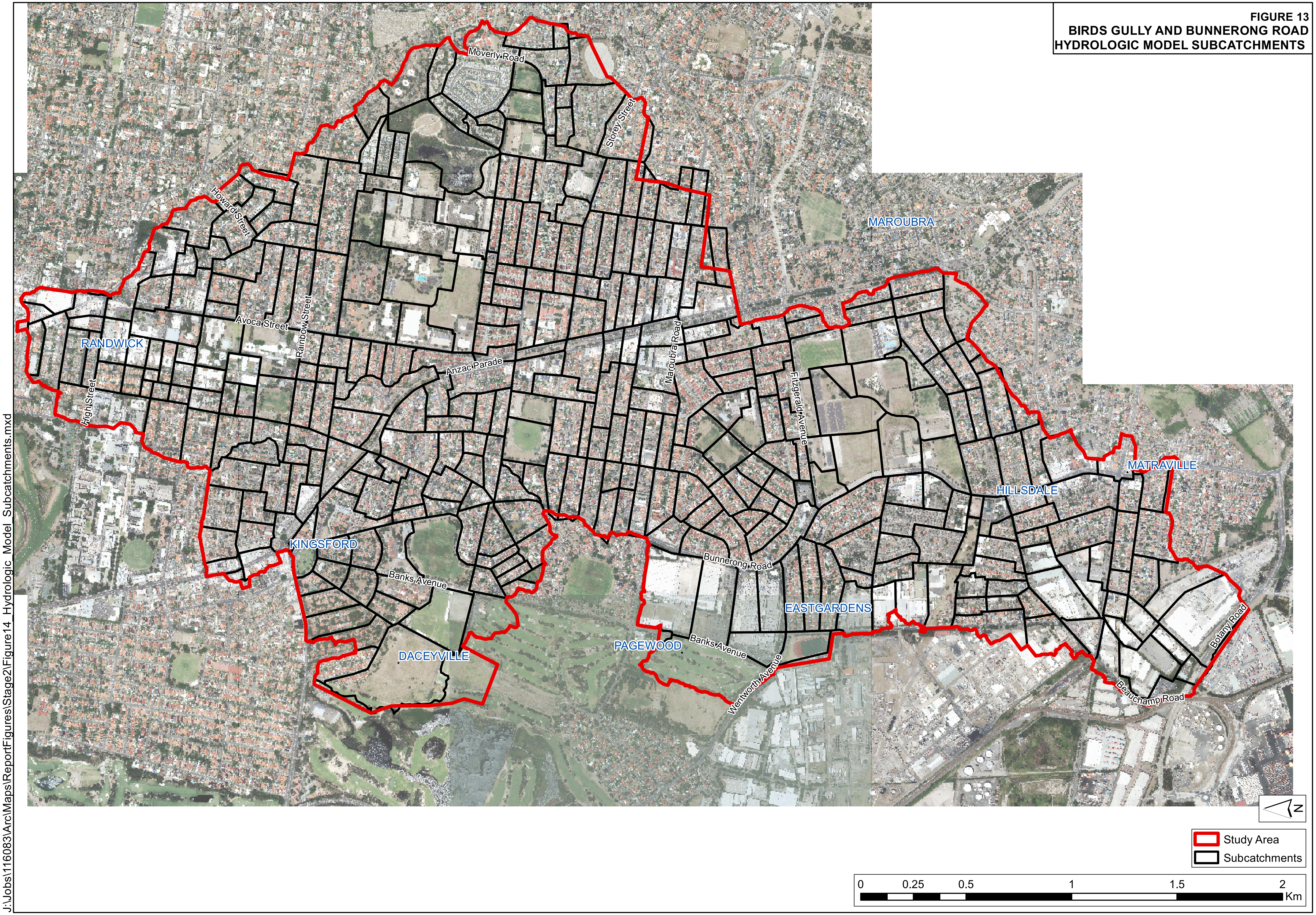
FIGURE 13
BIRDS GULLY AND BUNNERONG ROAD
HYDROLOGIC MODEL SUBCATCHMENTS
Moverly Road
Storey Street
Howard Street
Avoca Street
Rainbow Street
RANDWICK
High Street
Anzac Parade
Maroubra Road
MAROUBRA
Fitzgerald Avenue
MATRAVILLE
HILLSDALE
KINGSFORD
Bunnerong Road
Banks Avenue
EASTGARDENS
Botany Road
PAGEWOOD
DACEYVILLE
Wentworth Avenue
Beauchamp Road
N
Study Area
Subcatchments
0
0.25
0.5
1
1.5
2
Km
J:\Jobs\116083\ArcMaps\ReportFigures\Stage2\Figure14_Hydrologic_Model_Subcatchments.mxd

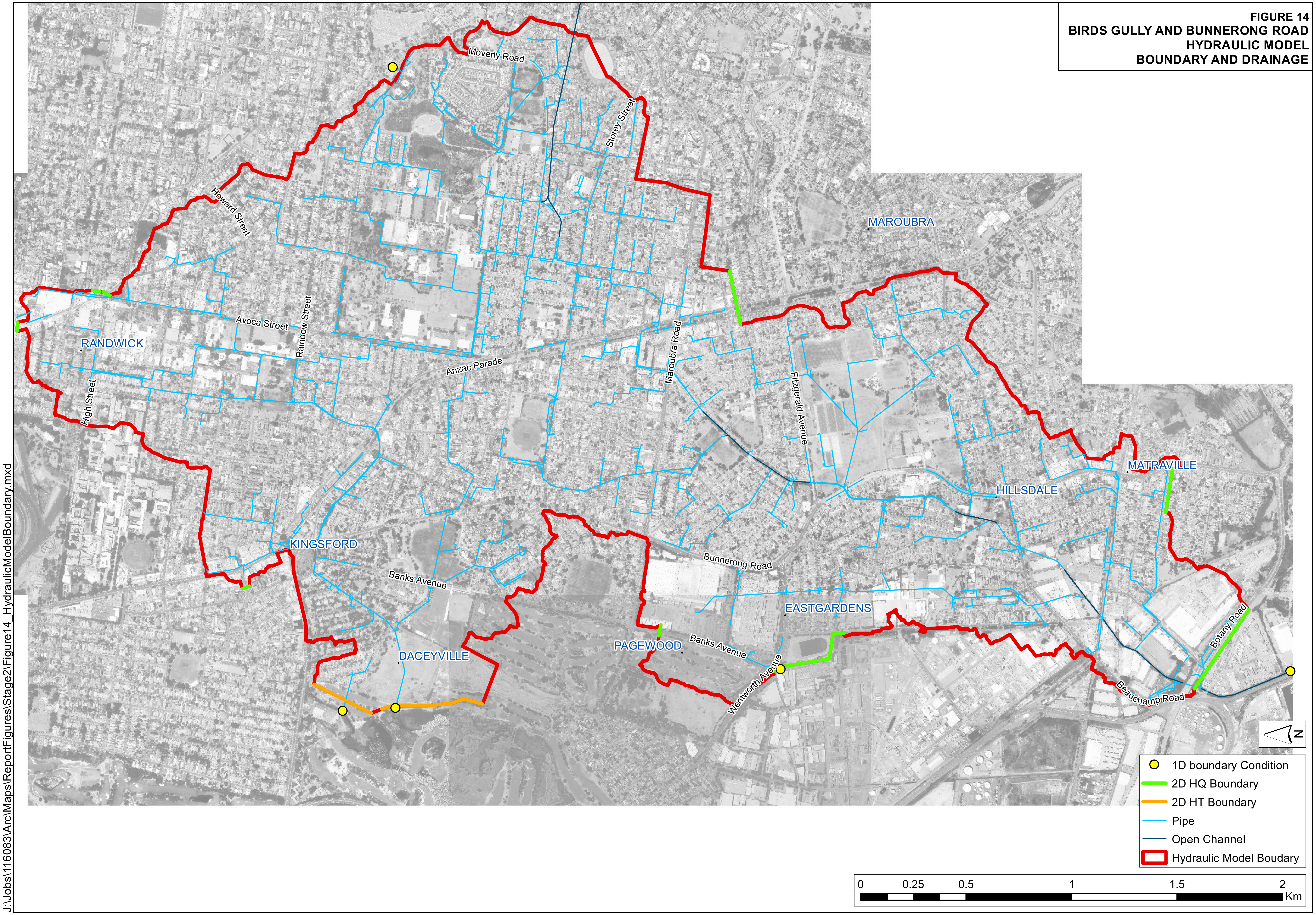
FIGURE 14
BIRDS GULLY AND BUNNERONG ROAD
HYDRAULIC MODEL
BOUNDARY AND DRAINAGE
Moverly Road
Storey Street
Howard Street
MAROUBRA
Avoca Street
Rainbow Street
RANDWICK
Anzac Parade
Maroubra Road
Fitzgerald Avenue
High Street
MATRAVILLE
HILLSDALE
KINGSFORD
Bunnerong Road
Banks Avenue
EASTGARDENS
Bolany Road
PAGEWOOD
Banks Avenue
DACEYVILLE
Wentworth Avenue
Beauchamp Road
N
1D boundary Condition
2D HQ Boundary
2D HT Boundary
Pipe
Open Channel
Hydraulic Model Boudary
0
0.25
0.5
1
1.5
2
Km
J:\Jobs\116083\Arc\Maps\ReportFigures\Stage2\Figure14_HydraulicModelBoundary.mxd

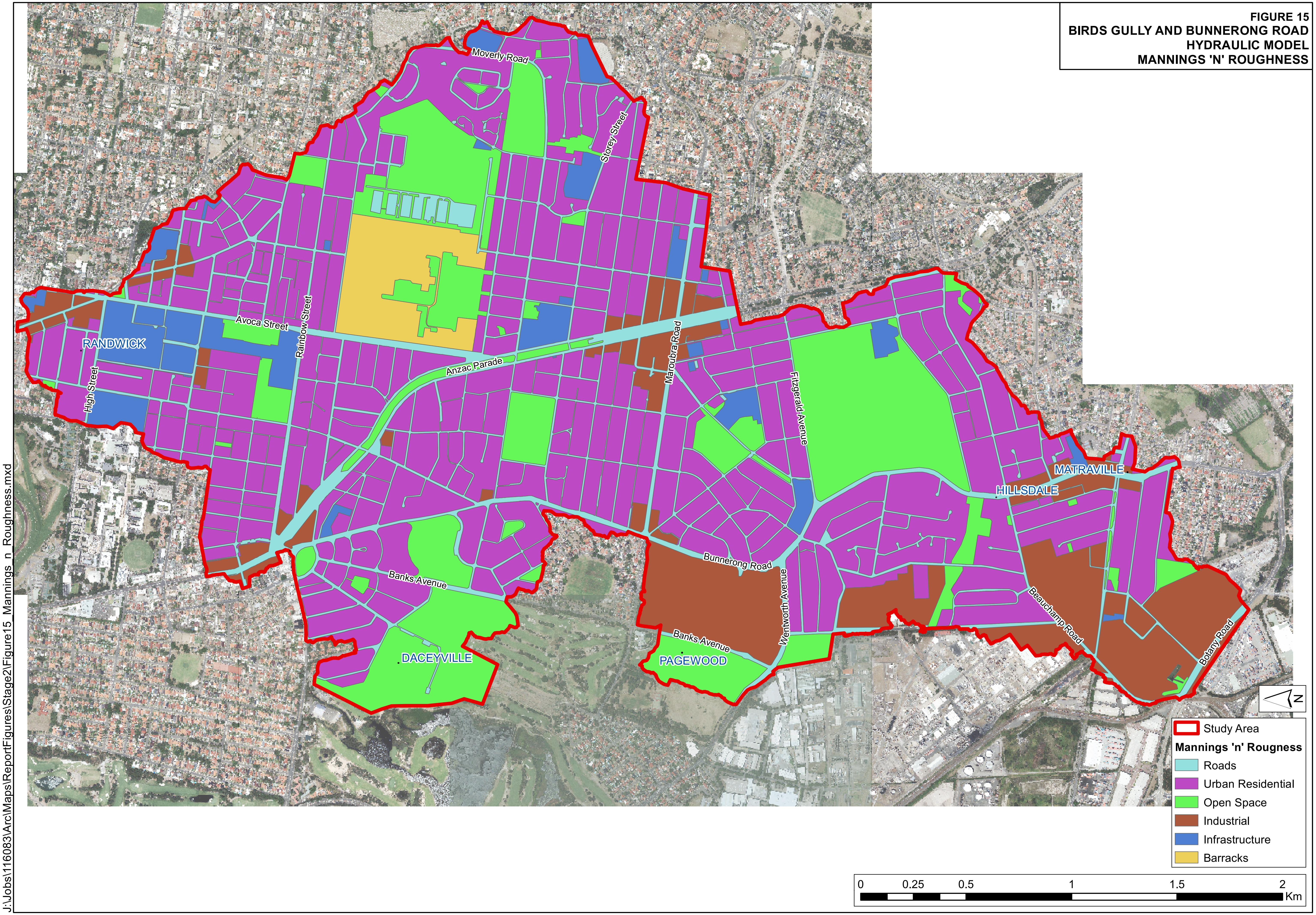

FIGURE 15
BIRDS GULLY AND BUNNERONG ROAD
HYDRAULIC MODEL
MANNINGS 'N' ROUGHNESS

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FIGURE 16
BIRDS GULLY AND BUNNERONG ROAD
HYDRAULIC MODEL
NULL BUILDINGS AND GUTTERS

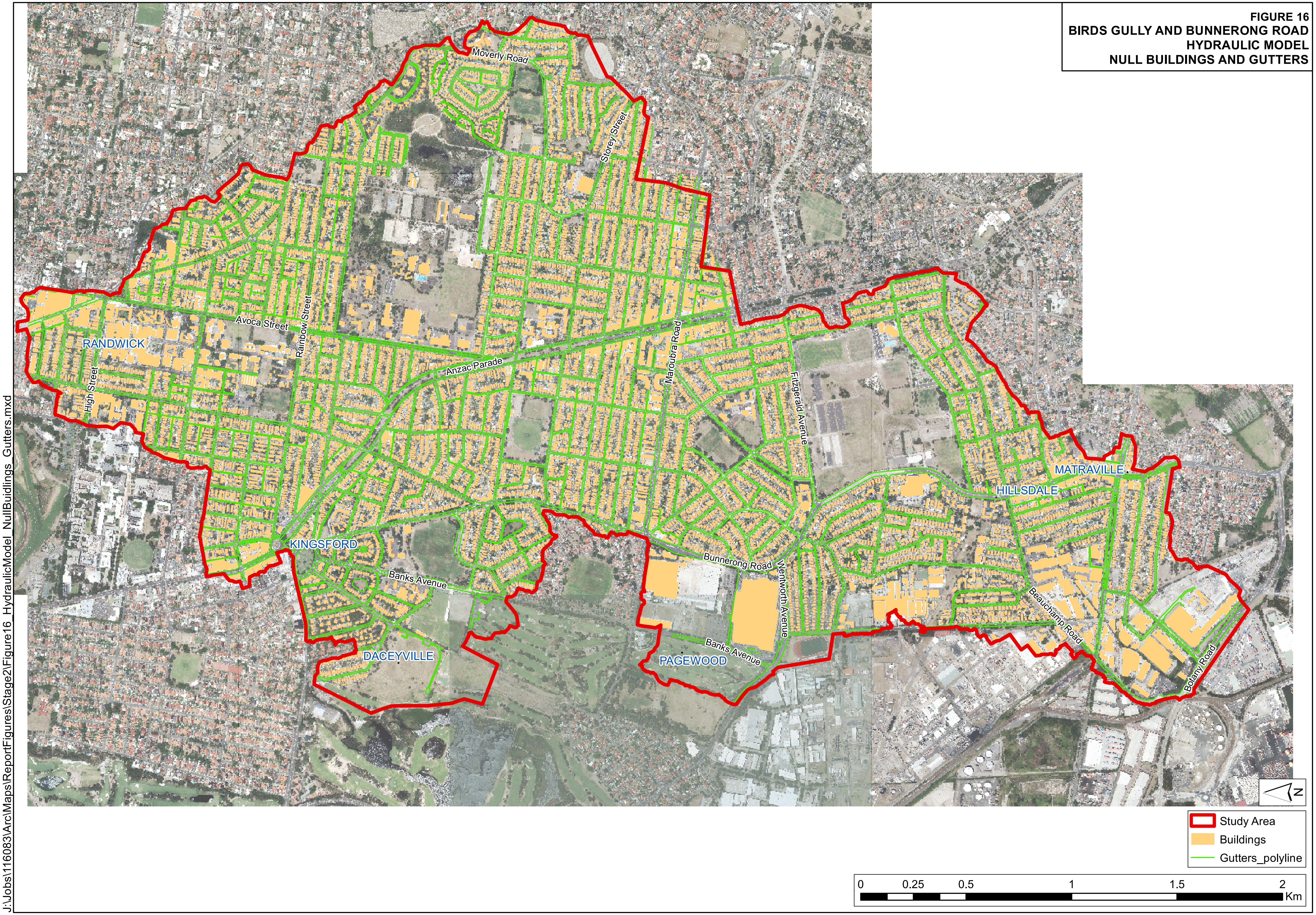

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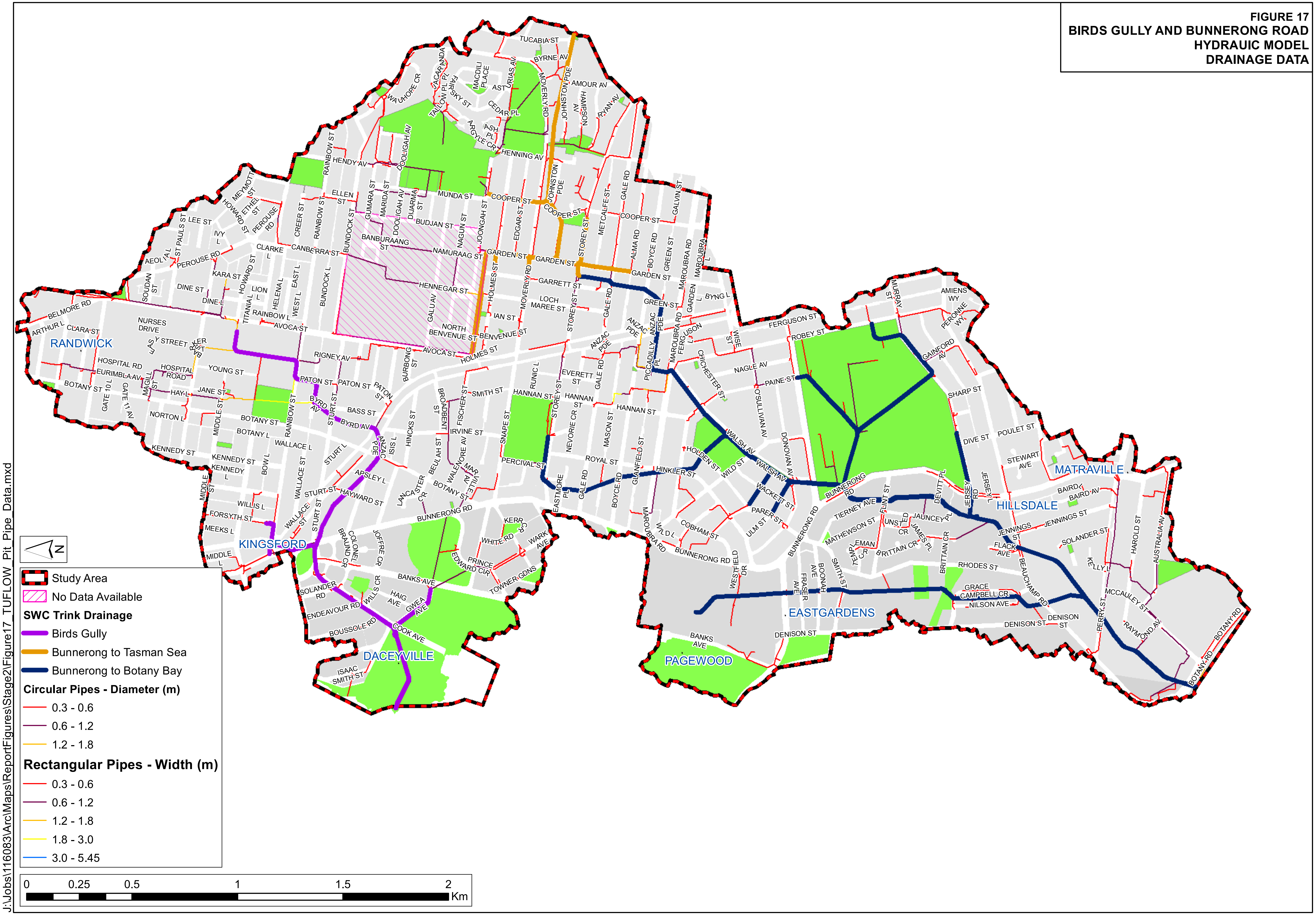
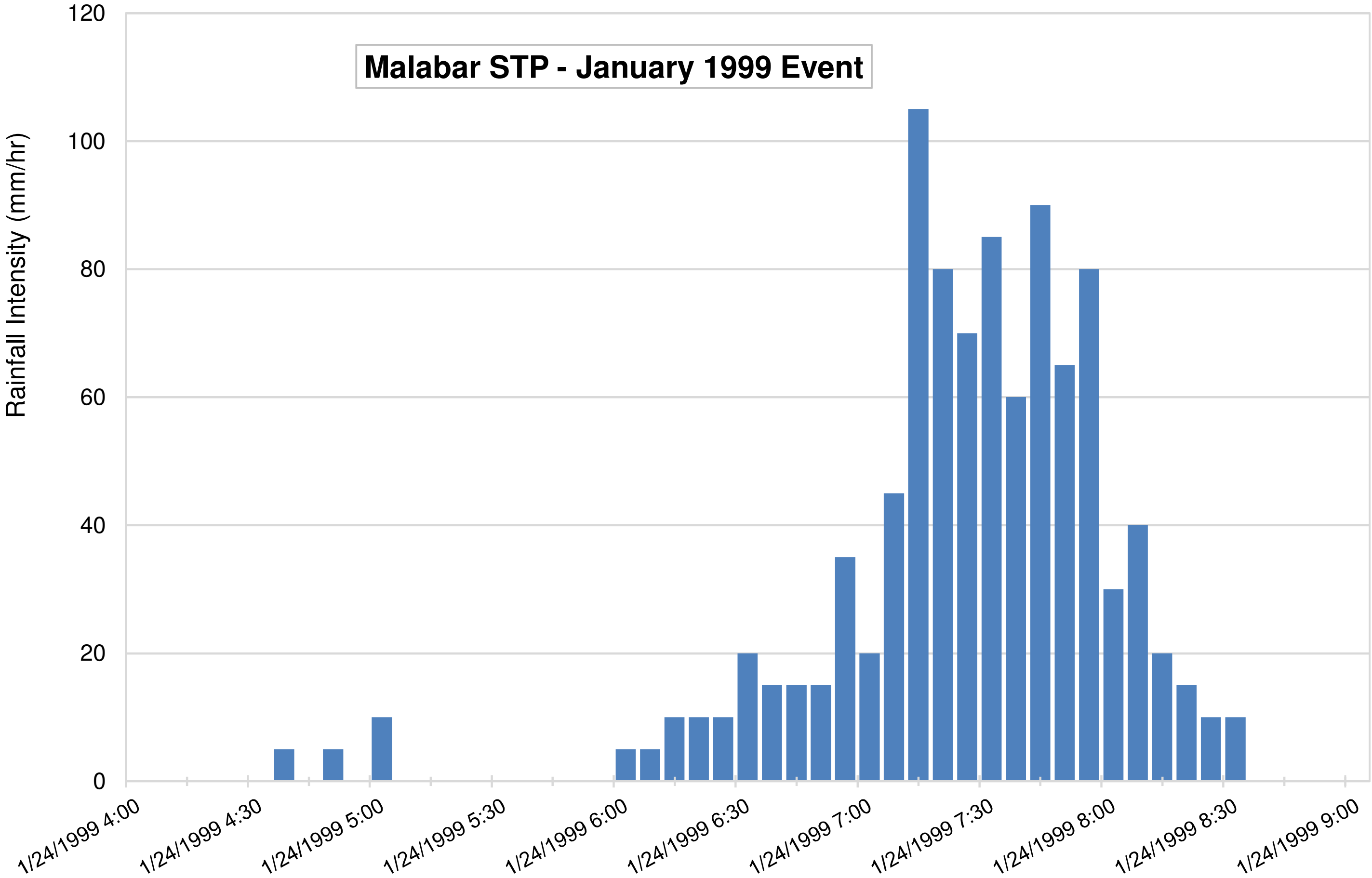
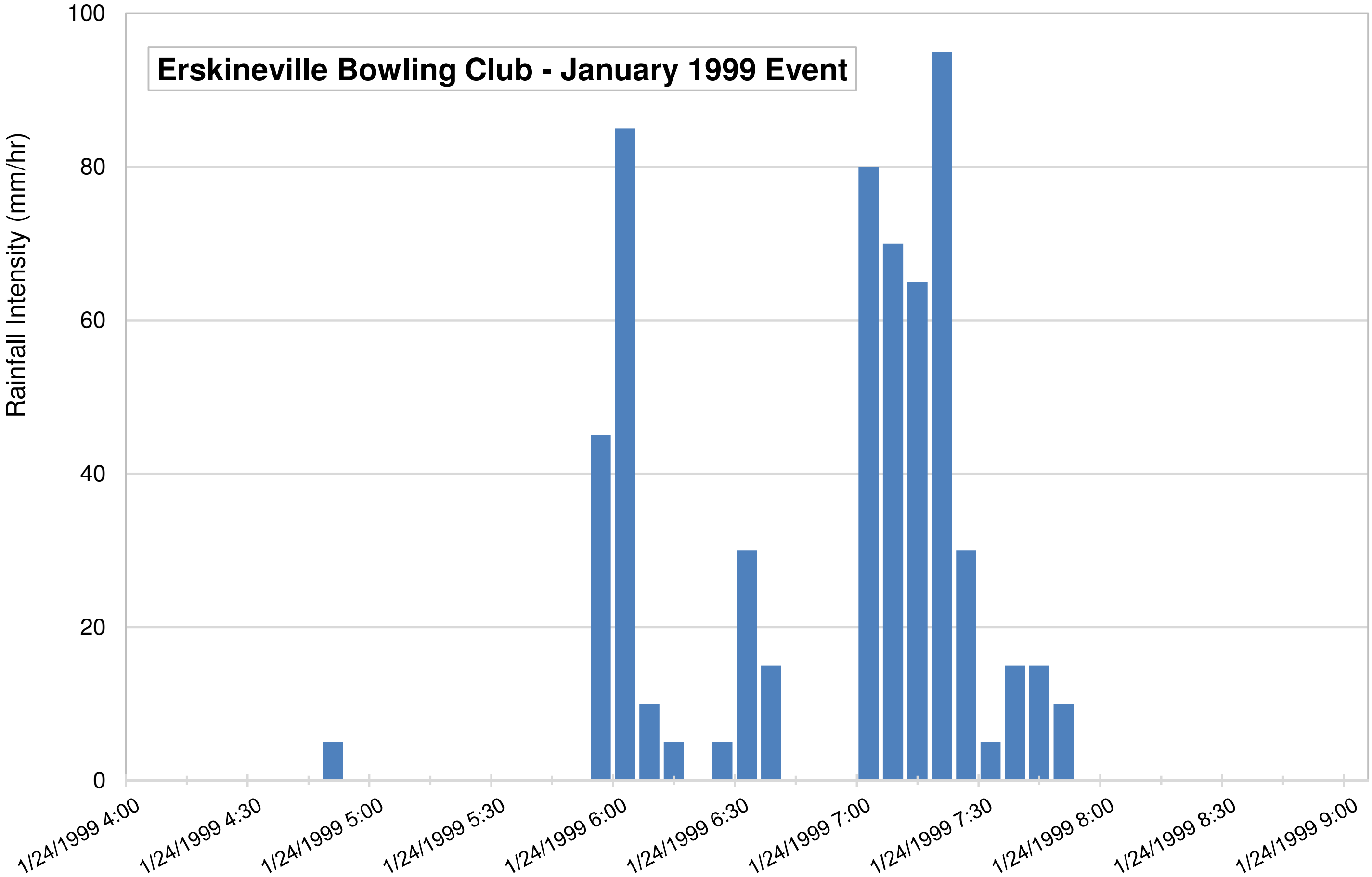
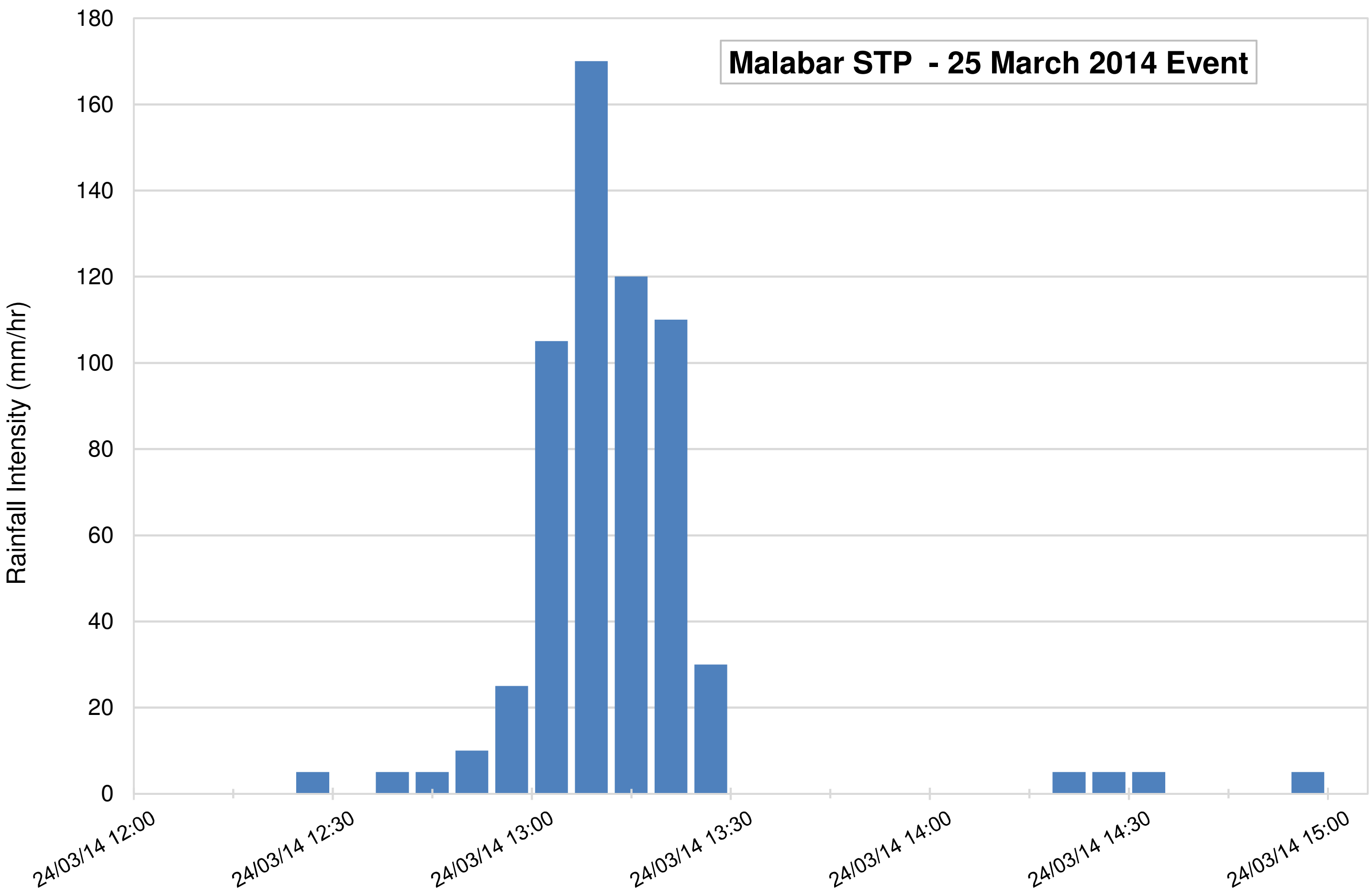
FIGURE 17
BIRDS GULLY AND BUNNERONG ROAD
HYDRAUIC MODEL
DRAINAGE DATA




Malabar STP - January 1999 Event
Rainfall Intensity (mm/hr)
0
20
40
60
80
100
120
1/24/1999 4:00
1/24/1999 4:30
1/24/1999 5:00
1/24/1999 5:30
1/24/1999 6:00
1/24/1999 6:30
1/24/1999 7:00
1/24/1999 7:30
1/24/1999 8:00
1/24/1999 8:30
1/24/1999 9:00


Erskineville Bowling Club - January 1999 Event
Rainfall Intensity (mm/hr)
0
20
40
60
80
100
1/24/1999 4:00
1/24/1999 4:30
1/24/1999 5:00
1/24/1999 5:30
1/24/1999 6:00
1/24/1999 6:30
1/24/1999 7:00
1/24/1999 7:30
1/24/1999 8:00
1/24/1999 8:30
1/24/1999 9:00


Malabar STP - 25 March 2014 Event
Rainfall Intensity (mm/hr)
0
20
40
60
80
100
120
140
160
180
24/03/14 12:00
24/03/14 12:30
24/03/14 13:00
24/03/14 13:30
24/03/14 14:00
24/03/14 14:30
24/03/14 15:00

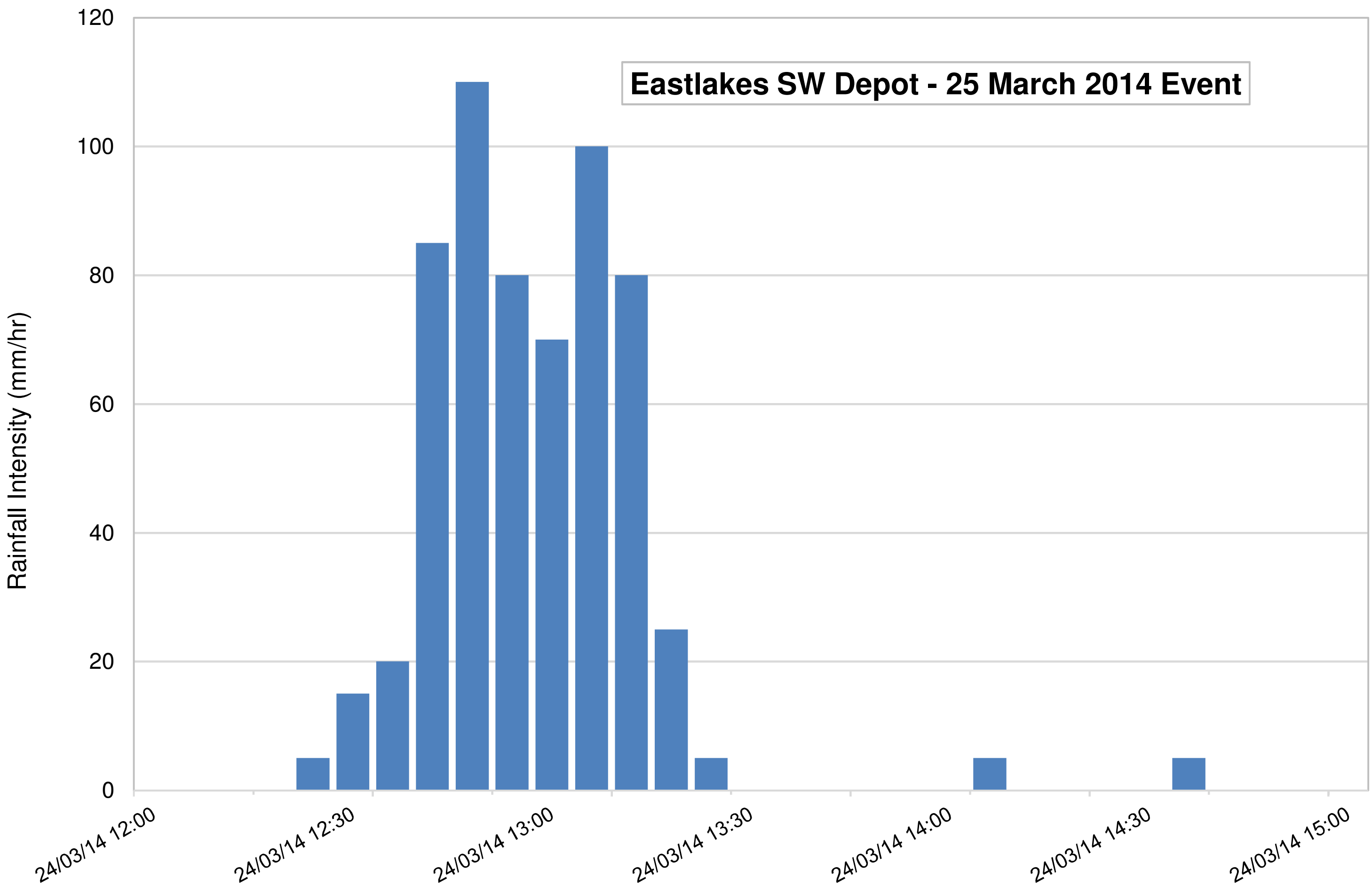
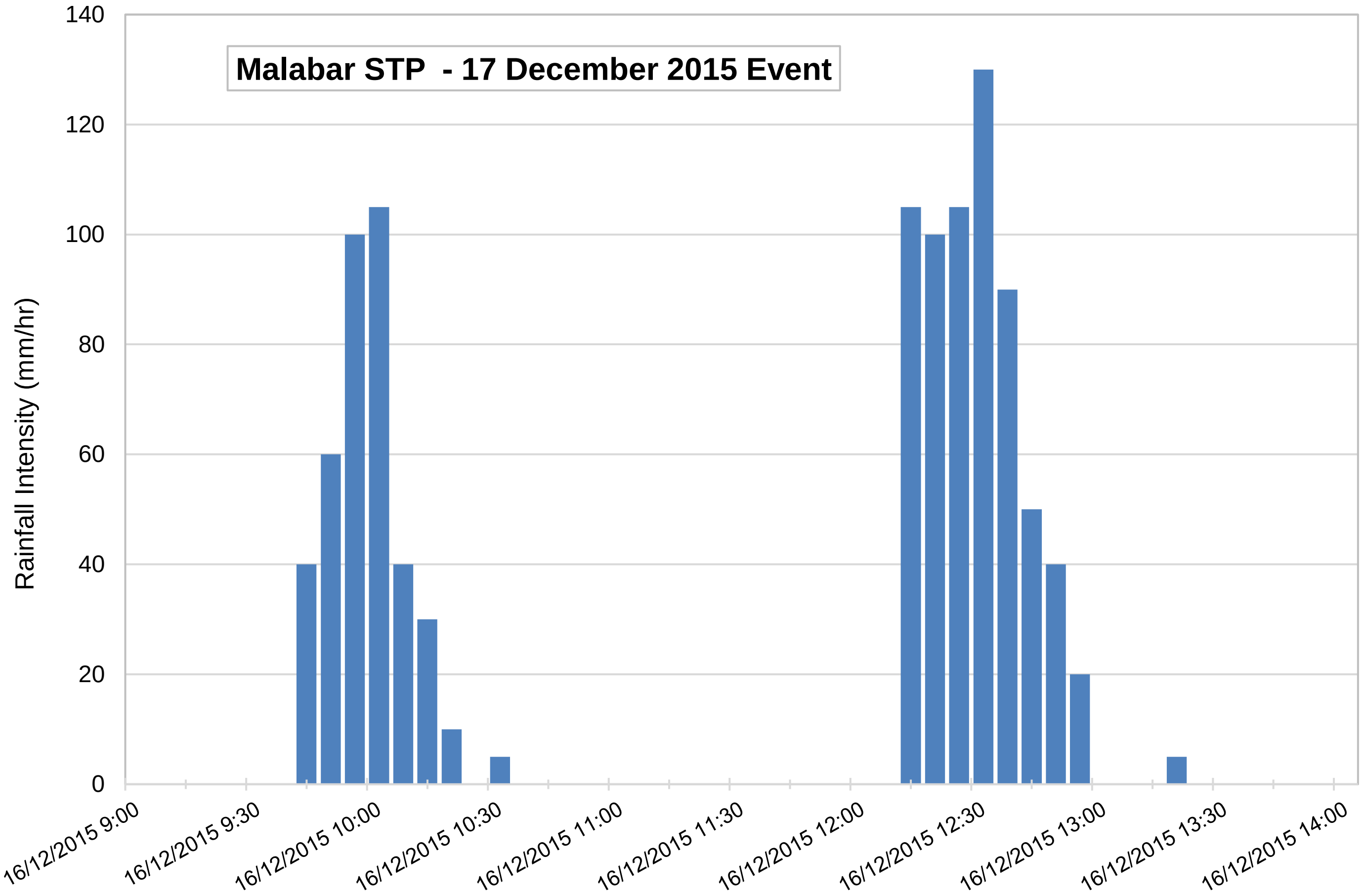
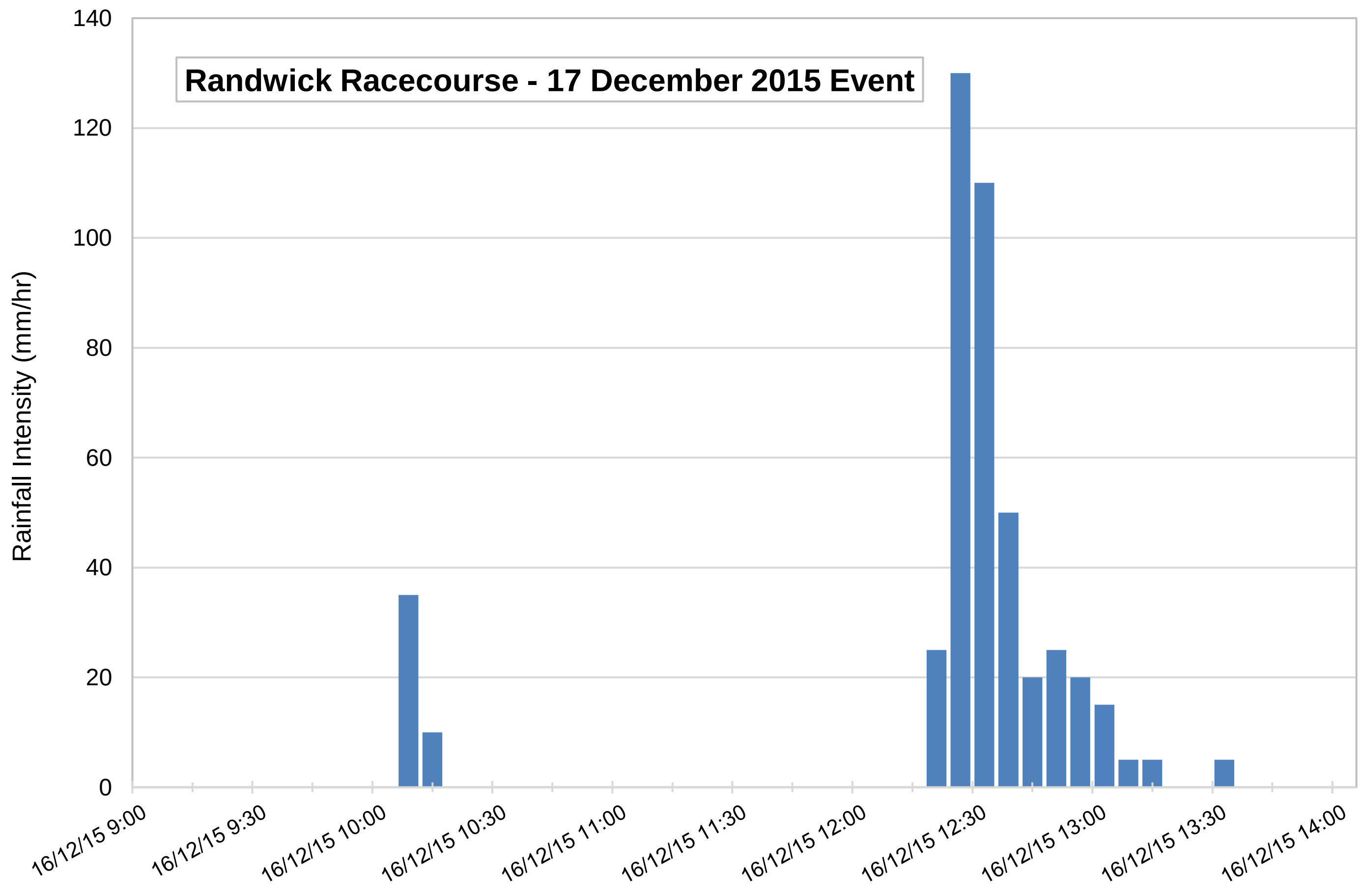

Eastlakes SW Depot - 25 March 2014 Event
Rainfall Intensity (mm/hr)
0
20
40
60
80
100
120
24/03/14 12:00
24/03/14 12:30
24/03/14 13:00
24/03/14 13:30
24/03/14 14:00
24/03/14 14:30
24/03/14 15:00

FIGURE 18C
HISTORICAL RAINFALL EVENTS
RAINFALL HYETOGRAPHS





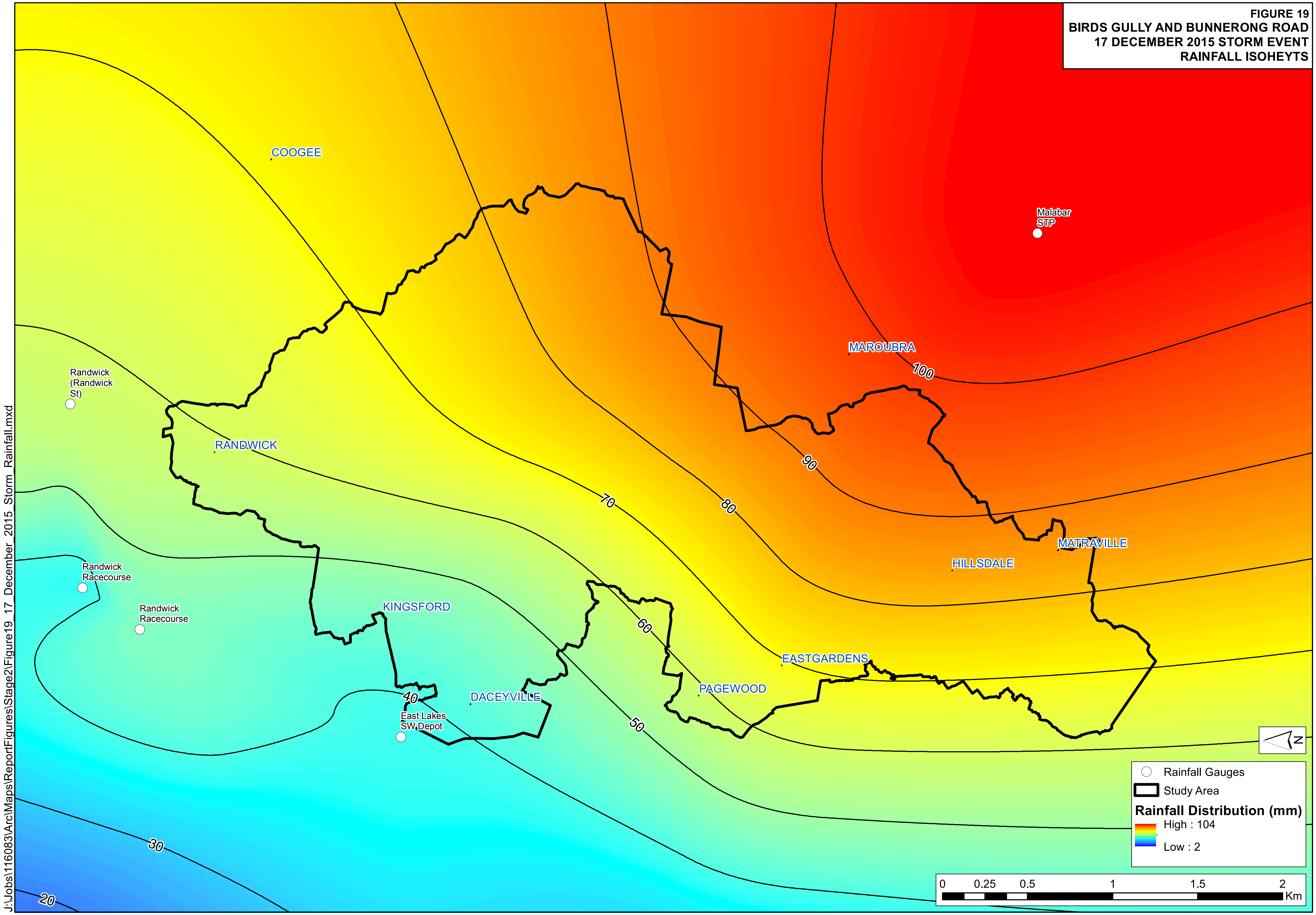


FIGURE 19
BIRDS GULLY AND BUNNERONG ROAD
17 DECEMBER 2015 STORM EVENT
RAINFALL ISOHEYTS
COOGEE
Malabar STP
MAROUBRA
100
90
80
70
60
50
40
30
20
Randwick (Randwick St)
RANDWICK
MATRAVILLE
HILLSDALE
Randwick Racecourse
Randwick Racecourse
KINGSFORD
EASTGARDENS
PAGEWOOD
DACEYVILLE
East Lakes SW Depot
N
Rainfall Gauges
Study Area
Rainfall Distribution (mm)
High : 104
Low : 2
0 0.25 0.5 1 1.5 2
Km
J:\Jobs\116083\ArcMaps\ReportFigures\Stage2\Figure19_17_December_2015_Storm_Rainfall.mxd

FIGURE 20
BIRDS GULLY AND BUNNERONG ROAD
25 MARCH 2014 STORM EVENT
RAINFALL ISOHEYTS

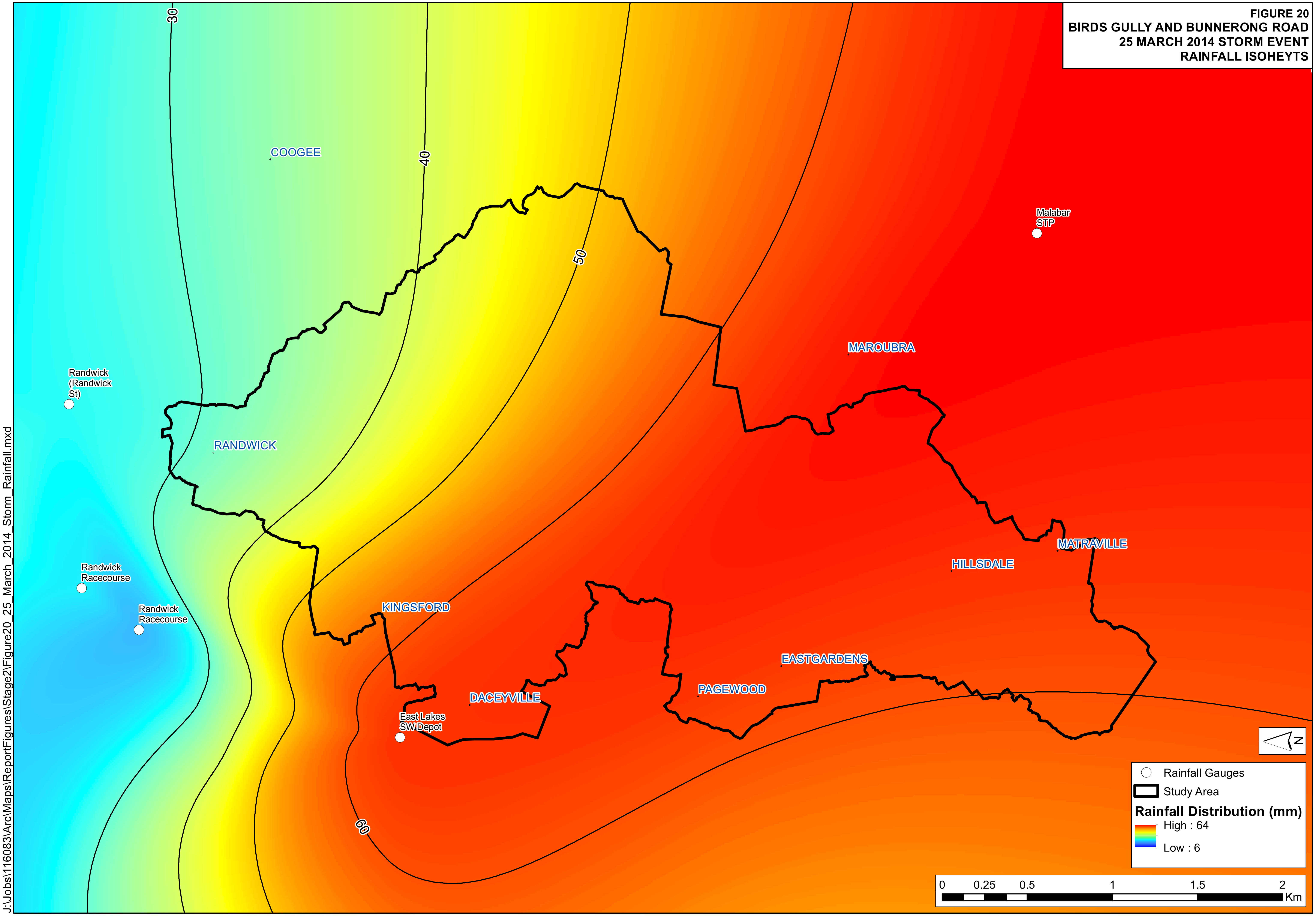


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FIGURE 21
BIRDS GULLY AND BUNNERONG ROAD
FLOOD LEVEL REPORT LOCATION

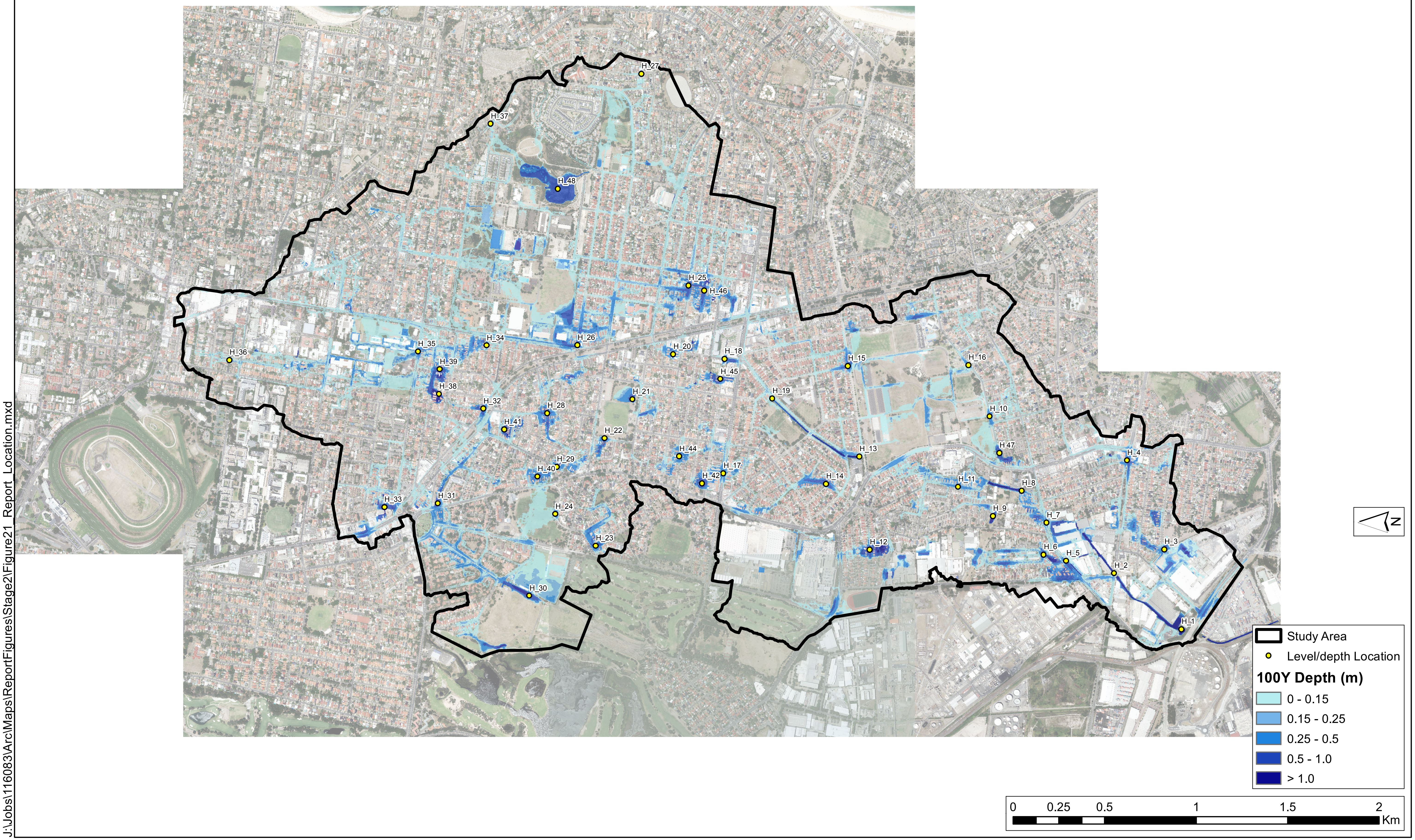

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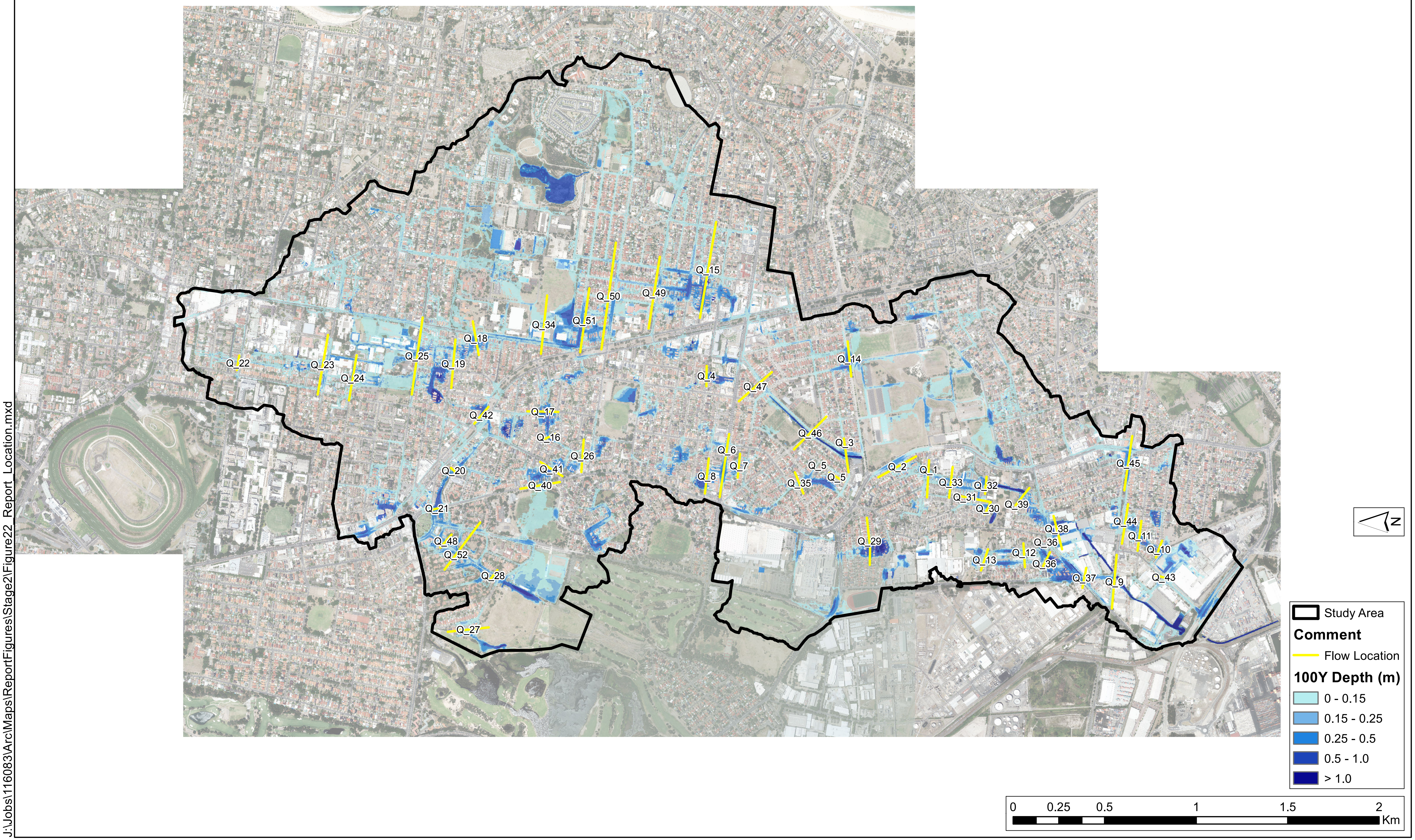
FIGURE 22
BIRDS GULLY AND BUNNERONG ROAD
PEAK FLOW REPORT LOCATION



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Appendix A

APPENDIX A. Glossary

Taken from the Floodplain Development Manual (April 2005 edition)

Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Annual Damage (AAD)	Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
Average Recurrence Interval (ARI)	The long term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
consent authority	The Council, Government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the Council, however legislation or an EPI may specify a Minister or public authority (other than a Council), or the Director General of DIPNR, as having the function to determine an application.
development	Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act). **infill development:** refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development. **new development:** refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power. **redevelopment:** refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services.
discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
effective warning time	The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.
emergency management	A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.

flash flooding	Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
flood awareness	Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.
flood education	Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves an their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.
flood fringe areas	The remaining area of flood prone land after floodway and flood storage areas have been defined.
flood liable land	Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).
flood mitigation standard	The average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.
floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
floodplain risk management options	The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
floodplain risk management plan	A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
flood plan (local)	A sub-plan of a disaster plan that deals specifically with flooding. They can exist at State, Division and local levels. Local flood plans are prepared under the leadership of the State Emergency Service.
flood planning area	The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the “flood liable land” concept in the 1986 Manual.
Flood Planning Levels (FPLs)	FPL’s are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the “standard flood event” in the 1986 manual.
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.
flood readiness	Flood readiness is an ability to react within the effective warning time.
flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and

	continuing risks. They are described below. **existing flood risk:** the risk a community is exposed to as a result of its location on the floodplain. **future flood risk:** the risk a community may be exposed to as a result of new development on the floodplain. **continuing flood risk:** the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.
flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.
freeboard	Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Manual.
hydraulics	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
hydrograph	A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
hydrology	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
local drainage	Are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.
mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
major drainage	Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purpose of this manual major drainage involves: • the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or • water depths generally in excess of 0.3 m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or • major overland flow paths through developed areas outside of defined drainage reserves; and/or

	• the potential to affect a number of buildings along the major flow path.
mathematical/computer models	The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
minor, moderate and major flooding	Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood: **minor flooding:** causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded. **moderate flooding:** low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered. **major flooding:** appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.
modification measures	Measures that modify either the flood, the property or the response to flooding. Examples are indicated in Table 2.1 with further discussion in the Manual.
peak discharge	The maximum discharge occurring during a flood event.
Probable Maximum Flood (PMF)	The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.
Probable Maximum Precipitation (PMP)	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
probability	A statistical measure of the expected chance of flooding (see AEP).
risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	Equivalent to “water level”. Both are measured with reference to a specified datum.
stage hydrograph	A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
survey plan	A plan prepared by a registered surveyor.
water surface profile	A graph showing the flood stage at any given location along a watercourse at a particular time.