northern beaches council

Newport Flood Study

Final Report

Volume 1 of 2: Report & Appendices

Revision 4
July 2019

Catchment Simulation Solutions

NORTHERN BEACHES
COUNCIL

Newport Flood Study

Final Report

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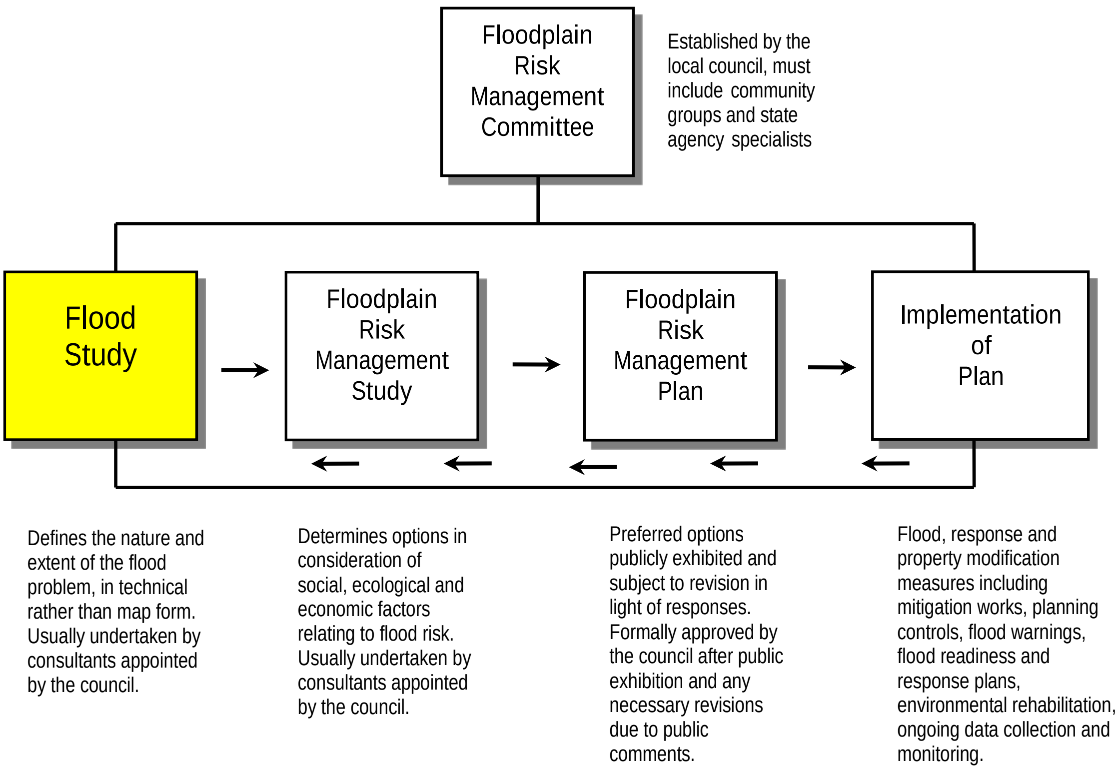
FOREWORD

The State Government's Flood Policy is directed towards providing solutions to existing flooding problems in developed areas and ensuring that new development is compatible with the flood hazard and does not create additional flooding problems in other areas. The Policy is defined in the NSW Government's *Floodplain Development Manual* (NSW Government, 2005).

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 Local Government in its floodplain management responsibilities.

The Policy provides for technical and financial support by the State Government through the following stages:



The Newport Flood Study represents the first of the four stages in the process outlined above. The aim of the Newport Flood Study is to produce information on flood discharges, levels, depths and velocities, for a range of flood events under existing topographic and development conditions. This information can then be used as a basis for identifying those areas where the greatest flood damage is likely to occur, thereby allowing a targeted assessment of where flood mitigation measures would be best implemented as part of the subsequent Floodplain Risk Management Study and Plan.

ACKNOWLEDGEMENTS

Catchments Simulation Solutions would like to extend thanks to Northern Beaches Council's Floodplain Management Branch for providing a considerable amount of information and insights into flooding across Newport. Thanks are also extended to the Floodplain Working Group and members of the community for their input at various stages of the project.

The project was funded by the NSW Government's *Floodplain Management Program* and *Northern Beaches Council*. Technical support for the project was provided by the *Office of Environment and Heritage*.

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1 INTRODUCTION

1.1 Catchment Description

Newport is located within the Northern Beaches Council Local Government Area (LGA) approximately 30 kilometres north of the Sydney central business district. As shown in **Figure 1,** Newport is bound by the Pacific Ocean to the east, the Pittwater Estuary to the west, the Bilgola Plateau to the north and Mona Vale to the south.

The catchment predominantly comprises residential properties with commercial properties adjoining Barrenjoey Road within the lower, eastern sections of the area. The steeper sections of the catchment are characterised by less intense residential development including extensive tree coverage.

McMahons Creek drains the north-east portion of Newport with the remainder of the catchments draining to the Pittwater Estuary or Pacific Ocean via several unnamed watercourses. The urbanised sections of the catchment are also drained by a stormwater system which carries runoff into the main drainage culverts and watercourses.

1.2 Purpose of Study

During periods of heavy rainfall across Newport, there is potential for the capacity of the stormwater system to be exceeded. In such circumstances, the excess water travels overland, potentially leading to inundation of roadways and properties. There is also potential for water to overtop the banks of the various watercourses and inundate the adjoining floodplain.

Flooding across Newport has been experienced on a number of occasions. This includes above floor inundation of a number of properties in March 1977, October 1987 and May 1988. More recently, significant floods occurred in February 2012, November 2015 and June 2016.

Pittwater Council (now Northern Beaches Council) commissioned an overland flow flood 'Overview Study' (Cardno, 2013) to help gain a better understanding of the overland flow flood risk across their LGA. The Pittwater Overland Flow Flood Study utilised modern 2-dimensional hydrodynamic modelling tools to assist Council in defining the location of major overland flow paths and identifying properties at risk of overland flooding. This information was used to define the variation in flood hazard and potential for flood damage and ultimately prioritise each subcatchment within the LGA for detailed overland flow flood studies.

Two subcatchments within the Newport study area were identified as high priority subcatchments and two subcatchment were identified as medium priority subcatchments. Therefore, Council resolved to undertake a detailed overland flow flood study for Newport to improve their understanding of the flood risk and provide a suitable foundation for the preparation of a floodplain risk management study for the catchment.

This report forms the Flood Study for Newport. It documents flood behaviour across the catchment for a range of historic and design floods. This includes information on flood discharges, levels, depths and flow velocities. It also provides estimates of the variation in flood hazard and hydraulic categories across the catchment and provides an assessment of the potential impacts of climate change on existing flood behaviour.

The flood study comprises two volumes:

- Volume 1 (this document): contains the report text and appendices
- Volume 2: contains all figures/maps

2 REVIEW OF AVAILABLE INFORMATION

2.1 Overview

A range of data were made available to assist with the preparation of the Newport Flood Study. This included previous reports, drainage information, hydrologic data, GIS data and topographic data.

A description of each dataset is summarised below.

2.2 Previous Reports and Investigations

A summary of flood-related reports that have previously been prepared are provided in the following sections. It summarises the extent of flood information across Newport and highlights data gaps that needed to be filled as part of the current study. The studies are listed in chronologic order.

2.2.1 Newport Beach Flood Study (Lawson and Treloar, 2002)

Pittwater Council, commissioned Lawson and Treloar to prepare the *'Newport Beach Flood Study'*. This flood study covered the 1.8 km^2 Newport Beach subcatchment which drains to the Pacific Ocean (the extent of the Newport Beach subcatchment is shown in **Figure 2**).

This study included the development of an XP-RAFTS hydrologic model to define rainfall-runoff processes. A total of six subcatchments were delineated and used to represent the hydrologic characteristics of the Newport Beach catchment within the XP-RAFTS model. The XP-RAFTS model was calibrated against available historic information for the March 1977, November 1984 and April 1998 flood events. The calibrated model was then used to generate design discharge hydrographs for the design 20%, 5%, 2% and 1% AEP events as well as the PMF. The XP-RAFTS modelling determined that the critical storm duration for the catchment was 2-hours.

A one-dimensional MIKE-11 hydraulic model of the Newport Beach catchment was also prepared as part of the study. The model was developed to include a representation of the main drainage lines including both the sub-surface stormwater drainage system as well as open channels and overland flow conveyance areas. The representation of the sub-surface stormwater drainage system was limited to the trunk drainage lines along the two main tributaries within the Newport Beach catchment, that being, the northern arm (from Howell Close) and the western arm (from King Street). The MIKE-11 model was calibrated against information obtained from a resident survey for the April 1998 flood. The MIKE-11 model was also validated against historic flood information for the November 1984 event.

The modelling results yielded the following findings:

- The most significantly impacted area of the catchment lies between The Boulevard, Myola Road and Barrenjoey Road. This includes properties in Ross Street and The Boulevard, shops on Barrenjoey Road as well as the Council carpark near Bramley Avenue.

- Other sections of the catchment subject to less significant flooding impacts include properties adjacent to the main drainage line between Foamcrest Avenue and Barrenjoey Road. The sub-surface stormwater system in this area conveys about 35% of the peak 1% AEP flow with the remaining flow distributed overland.
- Properties between Gladstone Street and Bardo Road are also vulnerable to inundation and the Newport Beach dune system acts as a significant detention area, forcing up to 80% of the 1% AEP flow to pass through the piped ocean outfall system.
- The study area was relativity insensitive to elevated ocean levels.

The Newport Beach Flood Study is considered to provide a reasonable description of mainstream flooding across a part section of the overall Newport study area. However, the study only incorporates that section of the catchment draining to the Pacific Ocean (refer **Figure 2**) and does not include a detailed assessment of overland flows. Moreover, the one-dimensional nature of the MIKE-11 software means that the complex two-dimensional flow patterns around urban flow obstructions (e.g., buildings) may not be reliably reproduced.

However, the details of major drainage features could be extracted from the MIKE-11 model and were used to assist in the hydraulic model developed for the current study (the location of cross-sections extracted from the model is shown in **Figure 2**). Peak floodwater depths, extents, velocities and levels were also extracted from the model results and were used to assist in the validation of the hydraulic model developed for the current study.

2.2.2 Newport Beach Floodplain Risk Management Study and Plan (SMEC, 2004)

The '*Newport Beach Floodplain Risk Management Study and Plan'* was prepared by SMEC Australia for Pittwater Council. This study built upon the work completed as part of the *'Newport Beach Flood Study'* (Lawson and Treloar, 2002), however, included additional community consultation, additional survey as well as MIKE-11 model updates to better describe flood behaviour along some additional flow paths.

The study assessed the existing and potential future flood risk to people and property across the Newport Beach floodplain. The study also evaluated the relative benefits of a range of floodplain risk management measures including flood, response and property modification measures. Based on the outcomes of the evaluation, the study recommended the following flood risk mitigation measures:

- Retarding Basin constructed above Howell Close
- Construction of overland bypass floodways between Foamcrest Avenue and Coles Parade, and between Ross Street to the ocean outfall
- Pipes flood bypass/tunnel from the proposed Howell Close retarding basin to the northern end of the Newport Beach
- Debris management by a maintenance program including debris traps
- A detailed analysis of overland flooding within the catchment and subsequent risk management investigations
- Increase community awareness and preparedness to floods by a regular educational/informational campaign
- Updating of the SES Flood Intelligence
- The generation of a Peninsula-wide Flood Plan

Council commissioned the *'Newport Beach Floodplain North – Flood Management Options Feasibility Study'* (Parsons Brinckerhoff, 2010) to investigate in greater detail the flood risk mitigation measures proposed as part of this study (refer Section 2.2.3). Pittwater Council also commissioned the 'Newport Flood Education and Communications Plan' (Molino Stewart, 2005) in order to address the community educational recommendation component of this study.

Flood information was extracted from this report and used to assist in verifying the results produced by the computer model developed for the current flood study. This data included details of historic flood levels, the number of flood affected properties (both residential and commercial), and the variation in flood hazard for the 20%, 5%, 2% and 1% AEP design floods, as well as the PMF.

2.2.3 Newport Beach Floodplain North – Flood Management Options Feasibility Report (Parsons Brinckerhoff, 2010)

The *'Newport Beach Floodplain North – Flood Management Options Feasibility Report'* was prepared by Parsons Brinckerhoff in 2010 and followed on from the '*Newport Beach Floodplain Risk Management Plan'* (SMEC, 2004). The main purpose of this study was to provide a more detailed assessment of the feasibility of the structural options that were recommended along the northern arm of the Newport Beach catchment. The structural options assessed as part of this study included;

- Option 1 - Howell Close Detention Basin and North Arm Flood Improvements
- Option 2a and 2b – Howell Close Detention Basin with Neptune Road Piped Flood Bypass (2a- to the back of Newport Beach and 2b - the Ocean Rock Shelf) and North Arm Flood Improvements
- Option 3 – Howell Close Storage Void, Flood bypass tunnel to the Ocean Rock Shelf and North Arm Flood Improvements

As noted above, all options include the North Arm Flood Improvements which broadly refer to works to reduce nuisance flooding, allow for better movement of overland flows and reduce the chance of blockages of the existing drainage system. These improvements include the reshaping of the existing channel in Seaview Avenue and Ocean Street, clearing and reshaping of the open channel through Ismona Avenue, lining the channel between Ocean Street and Foamcrest Avenue to improve hydraulic capacity, and installing additional stormwater pits in Foamcrest Avenue.

This study generated new 'baseline' flood results as well as flood damage estimates. This determined that the Average Annual Damages (AAD) was just over $2 million (2010$) across the Newport Beach catchment. Updated versions of the XP-RAFTS hydrologic and MIKE-11 hydraulic models including each of the proposed options were also prepared and allowed a detailed assessment of the hydraulic benefits of each option. The feasibility of each options was evaluated using a triple bottom line analysis which takes into consideration social, economic and environmental factors.

The recommendations of this study were to initially implement the North Arm Flood Improvements and follow this with the construction of the Howell Close detention basin (Option 1). Further to this, suggestions were made that Option 2a, the Neptune Road Pipes Flood Bypass, could also be constructed if funding became available.

2.2.4 Pittwater Stream Definition Project (Catchment Simulation Solutions, 2013)

The *'Pittwater Stream Definition Project'* was completed by Catchment Simulation Solutions in 2013 for Pittwater Council. The study follows on from the 'Pittwater Estuary Management Plan' (BMT WBM, 2010) which noted that Pittwater Council had no formal identification of the creek systems draining to the estuary. Therefore, the Plan recommended that mapping of streams draining to the estuary be completed.

The *'Pittwater Stream Definition Project'* represents the outcomes of Stage 1 of the stream mapping project. It involved the development of a GIS database of stream alignments across the Pittwater LGA based on available topographic information and field data logging using a differential GPS system.

A range of data were collected as part of the field data logging that was included in the GIS database. This included photographs of streams and man-made structures (e.g., pipes/culverts), invert elevations, water quality information and riparian/stream condition information.

The information contained in the stream mapping database was used as part of the current study to assist in defining watercourse alignments, the location and attributes of major hydraulic structures and watercourse inverts. The photographs also assisted is defining Manning's 'n' roughness values along the major creek alignments across the study area. However, it was noted that the differential GPS can have reduced horizontal and vertical accuracy in areas of significant vegetation and deep gullies, which are common across the Newport study area. Therefore, it was considered necessary to supplement the elevation information contained in this database with detailed ground survey at the location of major drainage features. Further details on the additional survey is provided in **Section 2.8**.

2.2.5 Pittwater Overland Flow Study (Cardno, 2013)

The *'Pittwater Overland Flow Study'* was commissioned by Pittwater Council and was completed by Cardno in 2013. The primary goal of the study was to define the nature and extent of overland flood behaviour across the LGA and generate sufficient information to define the variation in flood risk and prioritise subcatchments within the LGA for detailed overland flow studies.

Flood behaviour across the LGA was defined using seven different two-dimensional (2D) hydraulic models that were developed using the SOBEK software. The models utilised a 3-metre grid size to define the spatial variation in terrain and hydrologic/hydraulic properties.

The topography within the models was based on a Digital Terrain Model (DTM) developed from Airborne Laser Scanning (ALS) survey collected in 2009. The Direct Rainfall Method (DRM) was adopted to define hydrology as part of the study whereby rainfall is applied directly to the model and the physical characteristics of the catchment are used to route the rainfall excess across each catchment.

The sub-surface stormwater drainage system was not included in the models. Therefore, all flows within the models were assumed to travel overland and the overland flow estimates are considered to be conservative. To gain an understanding of the potential impacts of including the stormwater system in each model, an interim workaround was developed, whereby the 20-year ARI "fully blocked" flood results were assumed to represent the 100-year ARI flood with a completely unblocked stormwater system.

No culverts or bridges were included in each model and all channels were represented using the 3-metre grid. As a result, the conveyance characteristics of particularly narrow creek and drainage lines may not be well defined and flood levels upstream of hydraulic structures are likely to be overestimated and flood levels downstream of structures and likely to be underestimated. However, as the focus of the study was to define overland rather than main stream flood behaviour, this limitation was considered to be acceptable.

Buildings were not explicitly represented in the model; however, the roughness coefficient of urban areas was increased to account for the flow impediment afforded by buildings. This approach is considered appropriate for a broad scale study such as this, but it is unlikely to reliably represent local flood behaviour, particularly in areas where water is "squeezed" between building leading to localised velocity increases.

The study produced a range of maps showing flood extents, depths, velocities, provisional flood hazard and the location of floodways. The study also included an assessment of the potential impacts of climate change. The 1% AEP flood extent generated as part of this study is included on **Figure 2**.

The outputs from the study were used to calculate the flood risk for all properties within the Pittwater LGA based on the depth of inundation and flood hazard. The individual property risks were accumulated and used to rank each subcatchment. The ranking values were used to prioritise each subcatchment for undertaking detailed flood studies in the future (i.e., either a high, medium or low priority). The Newport West and Newport South subcatchments were assigned a high priority, and the Newport East and Bilgola West subcatchments were assigned a medium priority. These four subcatchments are contained in the current Newport Flood Study area.

Although the *'Pittwater Overland Flow Mapping and Flood Study'* has some limitations, it is currently the only study that identifies the potential overland flood risk across Newport. It also contains information that was used to assist in verification of the hydraulic model that was developed as part of the current study. This included information on peak overland flows, flood extents, depths, levels, velocities and hazard categorisation.

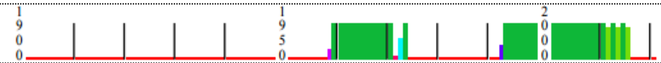
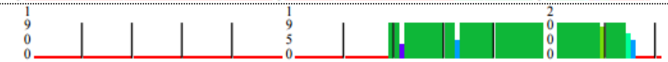
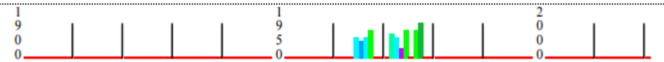
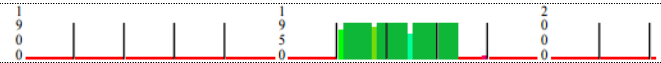
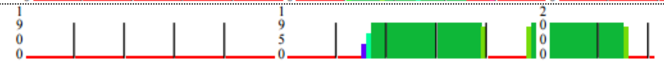
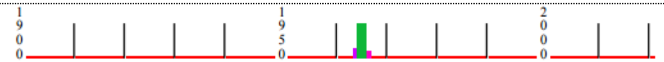
2.3 Hydrologic Data

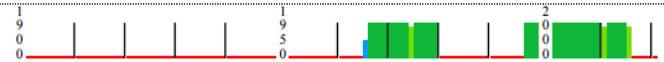
2.3.1 Historic Rainfall Data

A number of Bureau of Meteorology (BOM) daily read rainfall gauges are located within close proximity to the Newport study area. The BOM also operate a continuous gauge at Terrey Hills which is approximately 8 km from Newport. Sydney Water also operate a number of rainfall gauges near the study area, and these provide rainfall information at half hourly increments.

Manly Hydraulics Laboratory (MHL) also operate and collect rainfall data for a number of continuous gauges within close proximity to the Newport study area. The location of all available rainfall gauges is shown in **Figure 3** and key information for each gauge is summarised in **Table 1**.

Table 1 Available rain gauges in the vicinity of Newport

Gauge Number	Gauge Name	Gauge Type	Source*	Period of Record		Distance from Catchment Centroid (km)	Temporal Availability and Percentage of Annual Record Complete 
				From	To		
66045	Newport Bowling Club	Daily	BOM	Jul 1931	Dec 2010	1.9	
566188	Newport	Continuous	MHL	Nov 2015	Present	1.9	
566146	Mona Vale at Pittwater High School	Continuous	MHL	June 1994	Present	2.0	
566145	Avalon at Avalon Golf Course	Continuous	MHL	May 1994	Present	2.1	
566172	Avalon Bowling Club (Formerly Whale Beach)	Half-hourly	SW	Oct 2000	Present	2.4	
66079	Avalon (Palmgrove Rd)	Daily	BOM	Oct 1958	Jul 2016	2.6	
66183	Ingleside (Animal Welfare League NSW)	Daily	BOM	Jan 1984	Dec 2012	3.3	
66141	Mona Vale Golf Club	Daily	BOM	Feb 1969	Jun 2016	3.3	
66053	Avalon (Wollstonecraft Ave)	Daily	BOM	Jan 2002	Jul 2015	3.5	
566051	Warriewood STP	Half-hourly	SW	Nov 1981	Present	4.4	
566079	Whale Beach Road	Half-hourly	SW	July 1990	Nov 2006	4.7	
66123	Ingleside	Daily	BOM	May 1964	Dec 1977	4.8	
66083	Palm Beach Coaster Retreat	Daily	BOM	Apr 1960	Nov 1989	5.5	
66128	Palm Beach (Sunrise Road)	Daily	BOM	Sep 1965	Jun 2016	6.3	
66077	Terrey Hills	Daily	BOM	Oct 1963	Feb 1966	7.2	
566136	Narrabeen Lagoon	Half-hourly	SW	Apr 2001	Sept 2009	7.6	
66143	Kuring-Gai Chase (West Head)	Daily	BOM	Feb 1969	Dec 1991	7.7	

Gauge Number	Gauge Name	Gauge Type	Source*	Period of Record		Distance from Catchment Centroid (km)	Temporal Availability and Percentage of Annual Record Complete 
				From	To		
66059	Terrey Hills AWS	Daily	BOM	Sep 2004	Present	8.2	
		Continuous	BOM	Jan 2008	Present		
66044	Cromer Golf Club	Daily	BOM	Mar 1898	Jun 2011	8.7	
566120	Terrey Hills (Terrigal Road)	Half-hourly	SW	Nov 1995	Nov 1998	9.2	
66146	Broken Bay Natl Fitness Camp	Daily	BOM	Feb 1969	Nov 1975	9.7	
66140	Cottage Point (Nottings)	Daily	BOM	Feb 1969	Aug 1969	9.9	
566068	Dee Why Bowling Club	Half-hourly	SW	Feb 1990	Present	9.9	
66126	Collaroy (Long Reef Golf Club)	Daily	BOM	Aug 1965	Jul 2016	10.1	
566071	Belrose Bowling Club	Half-hourly	SW	Mar 1990	Present	12.4	

NOTE: * BOM = Bureau of Meteorology, MHL = Manly Hydraulics Laboratory, SW = Sydney Water

The information provided in **Table 1** indicates that the majority of rain gauges have a limited record length. Nevertheless, the Cromer Golf Club gauge has over 100 years of daily rainfall records (although the record is only 65% complete). **Table 1** also shows that no rainfall data with a resolution of less than half an hour is available prior to 1981. Nevertheless, there is a good spatial and temporal coverage of rainfall information from the early 1990s onwards.

2.3.2 Historic Stream Gauge Data

A single stream gauge is located within the Newport study area (gauge ID 2134100). The gauge was installed in April 2013 in the open channel that adjoins the Newport Bowling Club and is operated by Manly Hydraulics Laboratory. The location of the gauge is shown on **Figure 3**.

The gauge provides water level recordings at 5-minute increments. Flow estimates are also available at 5-minute increments. The flow estimates have been derived using the water level recordings and a rating curve.

2.4 Topographic Data

2.4.1 LiDAR Data

Light Detection and Ranging (LiDAR) data was collected across the northern beaches area in September 2011 by the NSW Government's Land and Property Information department. The LiDAR has a stated absolute horizontal accuracy of better than 0.8 metres and an absolute vertical accuracy of better than 0.3 metres. It is considered that the vertical and horizontal accuracy provided by the LiDAR data is suitable for the study.

The LIDAR was used to develop a Digital Elevation Model (DEM) of the study area, which is provided in **Figure 4**. **Figure 4** shows that ground surface elevations vary between 150 mAHD near the Bilgola Plateau Public School down to sea level at Newport Beach and the Pittwater Estuary. Although the northern, north-western and southern sections of the catchment are quite steep, the topography 'flattens' considerably from Newport Park, through the Newport commercial precinct down to Newport Beach. The topography is also subtle between Newport Beach and Foamcrest Avenue / Ocean Avenue.

As the LiDAR was collected in 2011 and only limited development/re-development has occurred within the catchment in the last 5 years, it is considered that the LiDAR provides a reliable representation of contemporary topographic conditions across most of the catchment.

However, it is also acknowledged that LiDAR can provide a less reliable representation of the terrain in areas of high vegetation density. Errors can also arise if non-ground elevation points (e.g., vegetation canopy) are not correctly removed from the raw LiDAR dataset. As the Newport study area is heavily vegetated (particularly in the upper catchment areas) additional checks were completed to confirm if the terrain representation provided by the LiDAR was reliable.

Plate 1 provides an example of the LiDAR ground point density in the vicinity of Porter Reserve/Newport Rugby Club playing fields which includes significant vegetation cover. **Plate 1** shows significant ground point density across areas of open space but a decrease in point density in the vicinity of the dense tree/vegetation coverage. Therefore, it appears that non-ground points have correctly been removed from the LiDAR data. However, this also means that the LiDAR provides more limited ground elevation points in the vicinity of dense vegetation. Accordingly, it was considered necessary to supplement the LiDAR data with additional ground survey to ensure a reliable representation of drainage features (e.g., creeks) is provided in the hydraulic model. In this regard, creek cross-sections were surveyed as part of the project. Further details on the cross-section survey is provided in **Section 2.8**.

Plate 1 LiDAR data points (yellow crosses) in the vicinity of the vegetated area of Porters Reserve/Newport Rugby Club playing fields

2.5 GIS Data

A number of GIS layers were also provided by Council to assist with the study. This included:

- Aerial Photography – provides 2014 ortho-rectified aerial imagery at a 0.5 metre pixel size;
- Cadastre – provides property boundary polygons;
- Stormwater Pipes – Provides alignments, lengths and diameters of stormwater pipes;
- Stormwater Pits – Provides locations and types of stormwater pits/inlets;
- Road Centrelines – Provides locations and names of roadways within the study area

The extent of the stormwater network GIS layers is shown in **Figure 2**. The stormwater pit and pipe layers were reviewed in detail to determine if there was sufficient information contained in these layers to describe the stormwater system in the hydraulic computer model. The review determined that these layers contained sufficient information to describe the capacity of the various pits and pipes across Newport study area including pipe sizes, pit grate/lintel size and pit invert depths. However, a review of the pits and pipe layers relative to contemporary aerial imagery revealed that there were 28 stormwater pits missing from the GIS layers. Therefore, it was considered necessary to survey these pits to ensure a full representation of the stormwater system could be provided in the computer model. Further details on the stormwater survey is provided in **Section 2.8**.

In addition, the spatial positioning of a number of pits was determined to be poor (refer **Plate 2**). Therefore, pits were relocated by hand to better align with the aerial imagery and LiDAR information.

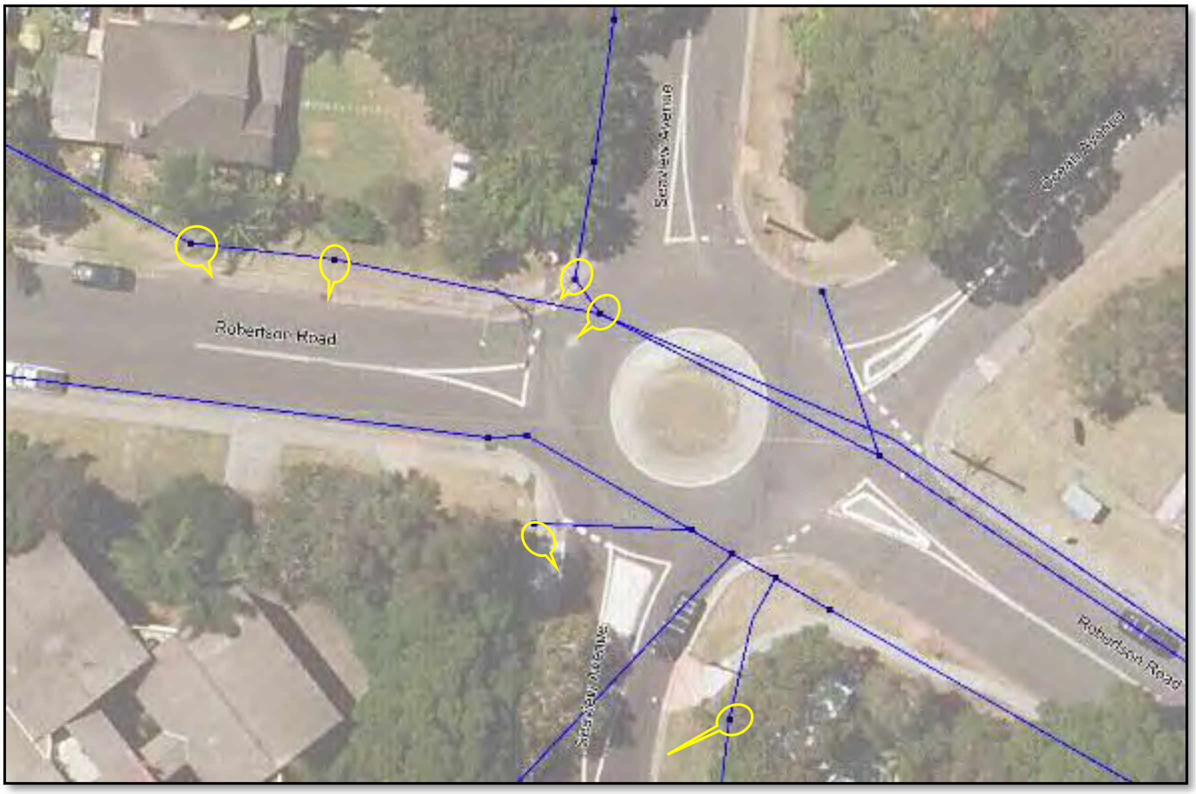


Plate 2 Incorrect spatial positioning of stormwater pits when compared to ortho-rectified aerial photography.

The stormwater pipe layer also incorporates major culverts across the study area. However, information describing major culvert sizes and inverts was not included. Therefore, it was also considered necessary to collect additional survey for major culverts (refer **Section 2.8**).

2.6 Remote Sensing

In addition to providing ground point elevations, the 2011 LiDAR also provides non-ground points (e.g., buildings, trees) as well as other information including point intensity and multiple return information. This information can be used with aerial imagery to assist with the identification of different land uses across the catchment. This, in turn, can be used to assist in defining the spatial variation in different land uses across the catchment which can inform Manning's "n" roughness coefficients and rainfall losses in the computer model.

This technique of land use classification was based on research documented in a paper prepared by Ryan titled *'Using LiDAR Survey for Land Use Classification'* (2013) and was applied based upon the 2011 LiDAR and 2014 aerial imagery. The classification algorithm divided the study area into the following land use classifications:

- Buildings
- Water
- Trees
- Grass
- Sand
- Impervious (concrete and roads)

It should be noted that perfect accuracy cannot be expected from any automated classification, particularly when the LiDAR and aerial imagery date from different periods (i.e., 2011 & 2014). Errors can also arise due to shadowing effects, and vegetation cover. As a result, manual updates to the remote sensing outputs were completed to ensure a reliable representation of the spatial variation in land use was provided across the catchment.

The final remote sensing output is shown in **Figure 5**.

2.7 Engineering Plans

Engineering plans were also provided by Council as part of the study. This included the "Howell Close Headwall Reconstruction Works, Howell Close, Newport" (Civil Certification, 2012). The plans provide design details of the upgraded channel works upstream of Howell Close as well as details of a new trash rack and headwall at the upstream end of the major culvert.

2.8 Survey

To enable development of a computer model capable of providing reliable estimates of flood behaviour across Newport, it was necessary to collect additional information describing major conveyance features including creeks, stormwater pits/pipes, culverts and bridges. Consulting surveyors, Paul Byrne and Associates, collected the additional survey information.

The additional data collection comprised the survey of:

- 28 stormwater pits
- 1 bridge
- 14 culverts
- 2 creek cross-sections

The location of each pit, cross-section, bridge and culvert that was surveyed is shown in **Figure 6**.

2.9 Historic Flood Data

Historic flood data is a valuable source of information when completing calibration of hydraulic computer models. This information can also assist in gaining an understanding of flooding "trouble spots" across the study area.

Pittwater Council has collated historic flood data for a number of events across the Newport study area, which are detailed below.

2.9.1 February 2012 Flood

A flood occurred within Newport on the 20th February 2012 and had a significant impact on properties within the catchment. This included some over-floor flooding of dwellings and damage to both public and private property, as well as traffic disruption. Pittwater Council conducted a survey of peak flood levels across Newport following this event. The survey resulted in 21 flood marks being captured, the location of which are shown on **Figure 2**. The peak flood levels that were surveyed were made available and formed the basis of the hydraulic model calibration of the February 2012 event.

2.9.2 April 2012 Flood

A second flood event in 2012 occurred on 18th April. Although this was not as severe as the February event and a flood mark survey was not conducted, a number of flood photos were provided. These photos are reproduced in **Plates 3** to **5** below.

Plate 3 Flood flows along the open channel between Seaview Avenue and Ocean Avenue during the April 2012 flood

Plate 4 Floodwater ponding at the front of an Ocean Avenue property during the April 2012 flood

Plate 5 Floodwater disrupting traffic along Barrenjoey Road at the intersection of Seaview Avenue and The Boulevard during the April 2012 flood

2.9.3 November 2015 Flood

Another major flood occurred across Newport on the 14 and 15th November 2015. Pittwater Council engaged Spatial Technologies to undertake a survey of all available flood marks within the area. However, a particular focus was placed on the area around Howell Close which was significantly impacted. This survey provided 15 flood marks, the location of which are shown on **Figure 2**. These flood marks were also used to calibrate the hydraulic computer model.

Several photos were also taken during the 2015 event which are shown in **Plates 6** and **7**. **Plate 6** shows the Howell Close culvert after the peak of the flood and shows a significant amount of accumulated debris. **Plate 7** shows the exterior of a property in Howell Close which was inundated above floor level.

Plate 6 Flood levels and debris build-up at the Howell Close culvert inlet during the November 2015 flood

Plate 7 Flood debris line on an external wall at a residence in Howell Close following the November 2015 flood

2.10 Community Consultation

2.10.1 General

A key component of the flood study involves development and calibration of a computer flood model. Calibration involves using the computer models to replicate floods that have occurred in the past. As noted in Section 2.9, Council holds some information on historic flooding across Newport and some flood information was also sourced from previous investigations.

However, it was considered that residents within the Newport area may be able to provide additional information on past flood events. Accordingly, several community consultation devices were developed to inform the community about the study and to obtain information from the community about their past flooding experiences. Further information on each of these consultation devices is provided below.

2.10.2 Flood Study Website

A flood study website was established for the duration of the study. The website address was: http://newport.floodstudy.com.au/

The website was developed to provide the community with detailed information about the study and also provide a chance for the community to ask questions and complete an online questionnaire (this online questionnaire was identical to the questionnaire distributed to residents and business owners, as discussed in **Section 2.10.3**).

During Stage 1 of the project (i.e., between June and September 2016), the website was visited 309 times by 254 unique visitors.

2.10.3 Community Information Questionnaire

A community questionnaire was prepared and distributed to 4,486 households and businesses within the Newport study area. A copy of the questionnaire is included in **Appendix A**.

The questionnaire sought information from the community regarding whether they had experienced flooding, the nature of flood behaviour, if roads and houses were inundated and whether residents could identify any historic flood marks. A total of 395 questionnaire responses were received. The spatial distribution of questionnaire respondents is shown in **Figure A1**, which is also enclosed in **Appendix A**.

The responses to the questionnaire indicate that:

- The majority of respondents have lived in or around Newport for about 20 years. Accordingly, most respondents would have been living in the area during the 2012, 2015 and 2016 flood events (discussed in more detail below) but not necessarily the 1977, 1987 or 1988 events, which are noted as large events in previous flooding investigations.
- 34% of respondents have experienced some form of inundation or disruption as a result of flooding in the study area. This includes (of the 395 responses received):
  -> 19 respondents have experienced traffic disruptions;
  -> 59 respondents have had their front or back yard inundated;
  -> 26 respondents have had their garage inundated; and,
  -> 18 respondents have had their house or business inundated above floor level.

  Plate 8 and **Plate 9** provide a summary of the types of flood impacts reported by the community and **Figure A1** in **Appendix A** shows the spatial distribution of respondents that have experienced past flooding problems (refer red dots).

- Flooding problems were reported in the following streets/areas in multiple questionnaire responses, which provide an indication of "trouble spots":
  -> Foamcrest Avenue
  -> Barrenjoey Road
  -> Myola Rd/Ross St/The Boulevard/Calvert Parade
  -> Neptune Road/Seaview Avenue
  -> Prince Alfred Parade/Elvina Av/Herbert Avenue
  -> Palm Road/Trevor Road
  -> Wollombi Road
  -> Grandview Drive/Sybil Street
  -> Ocean Avenue/Ismona Avenue
  -> Nullaburra Road
  -> Irrubel Road
- A number of respondents believe inundation across Newport is exacerbated by:
  -> Limited capacity of the existing stormwater system (41 respondents)
  -> Overland flow obstructions (e.g., fences, buildings) (38 respondents)
  -> Blockage of the creek, stormwater inlets and/or drains (30 respondents)
  -> Oceanic Influences (4 respondents)

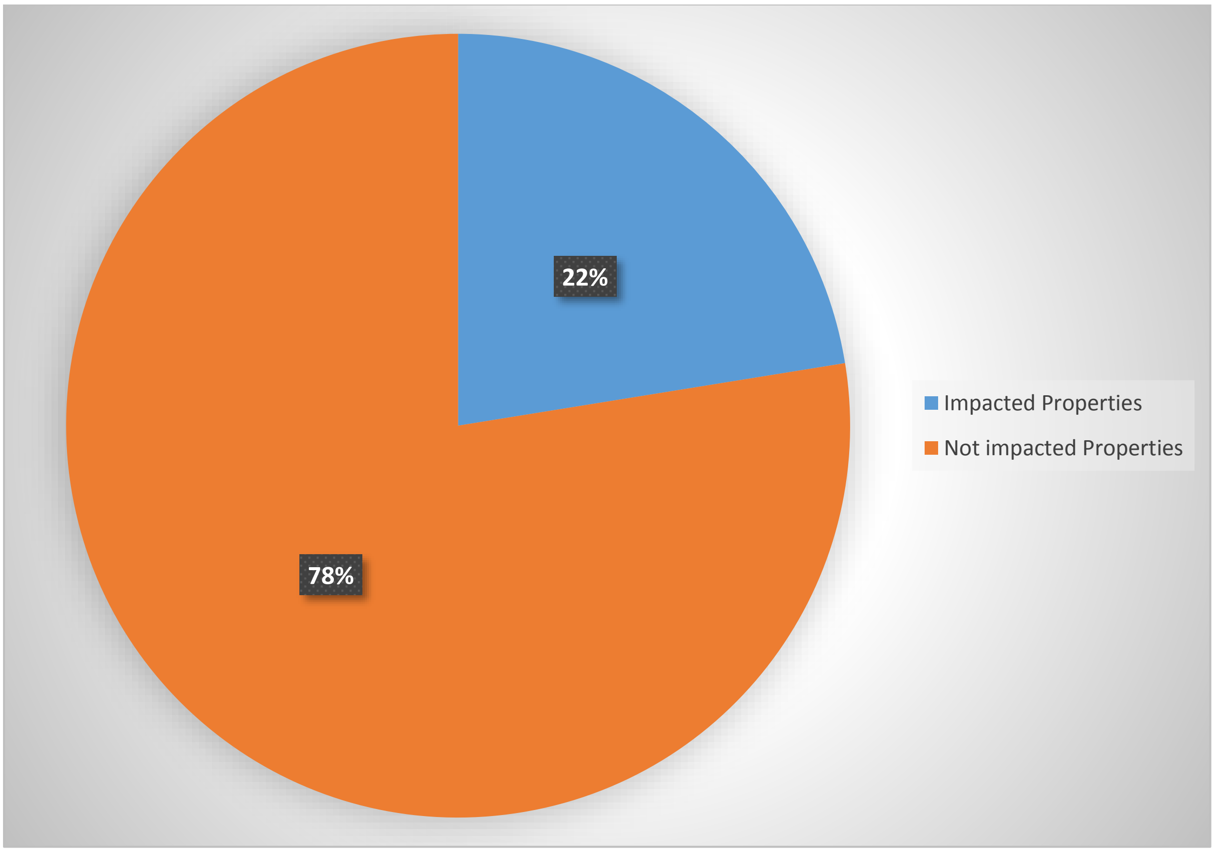


Plate 8 Proportion of questionnaire responses impacted by past flooding

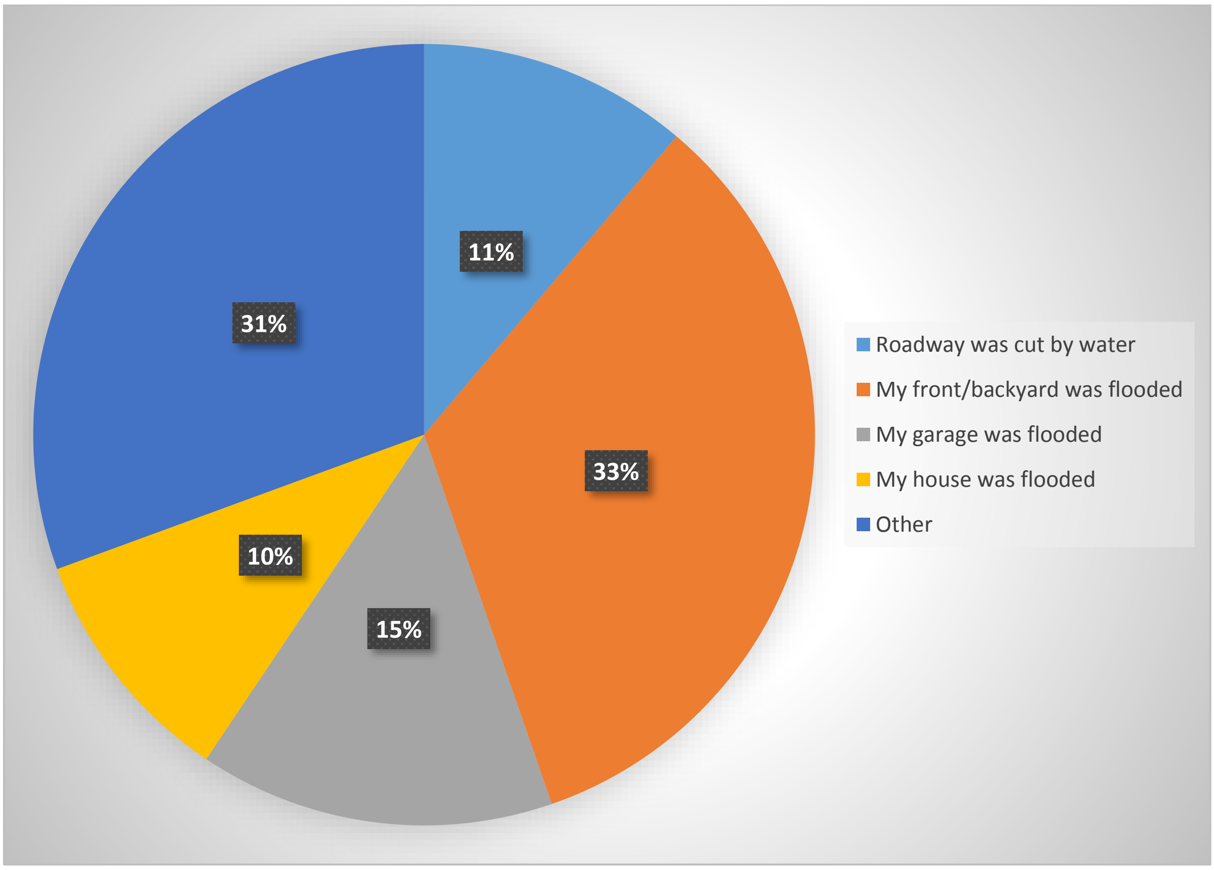


Plate 9 Types of flood impacts across the Newport catchment

A number of respondents also provided photos of the April 2012, November 2013, March 2016 and June 2016 flood events. A selection of these photographs is provided in **Appendix B**. Unfortunately, the photos were not necessarily taken at the peak of the flood making it difficult to identify specific peak water levels. Nevertheless, the photos can serve as a guide for establishing that water reached an elevation at least equal to that shown in the photos.

The photos show the April 2012 event caused significant inundation in the lower catchment, including:

- Barrenjoey Road
- The intersection of Bramley Avenue and Ross Street
- Yard inundation around Neptune Road.
- Damaged fences around Nullaburra Road

Photos of the June 2016 event also show notable depths of inundation around the intersection of Bramley and Ross Street.

A number of respondents also provided information on typical floodwater depths during past floods that could be used to assist in the verification of the computer models. This included:

- Depths of between 0.15 metres and 1 metre at locations around Ross Street and Trevor Road during the February 2010 event;
- Depths of 0.08 metres within a garage on Ocean Avenue and up to 0.2 metres in another garage on Ross Street during the April 2012 event;
- Depths of between 0.1 and 0.5 metres along Ross Street and depths of between 0.1 and 0.3 metres between Neptune Road and Foamcrest Avenue during the April 2015 flood event;
- Depths of 0.3 metres along Ocean Avenue and depths of 0.6 metres along Palm Road and down to the Ross Street locality during the March 2016 event; and,
- Depths of up to 0.9 metres in Palm Street to 0.1 metres at the corner of Ross Street and The Boulevard during the June 2016 event. Flooding was also identified around Foamcrest Avenue of 0.1 metres and depths of up to 0.3 metres were reported around Elvina Avenue and Prince Alfred Parade.

2.10.4 Public Exhibition

The draft "Newport Flood Study" (December 2018) was placed on Public Exhibition from the 4th March 2019 until 9th April 2019. A copy of the draft report was made available for review on Council's https://yoursay.northernbeaches.nsw.gov.au website during this period.

Four community information sessions were also held during the public exhibition period. The sessions were held at the following times and locations:

- Tuesday 12 March 2019, 11:30am – 3:00pm at the Newport Community Centre
- Monday 18 March 2019, 4:00pm – 7:00pm at the Mona Vale Memorial Hall Meeting Room
- Friday 22 March 2019, 2:00pm – 5:00pm at the Newport Community Centre
- Saturday 23 March 2019, 9:30am – 1:00pm at the Newport Community Centre

The community information sessions provided an opportunity for the community to sit down and ask questions one-on-one with Council and Catchment Simulation Solutions' staff. Forty-one people attended the information sessions.

A total of 19 submissions were received during the public exhibition period. A summary of each submission is included in **Appendix K**.

As shown in **Appendix K**, the submissions generally related to the issues summarised below:

- Insufficient stormwater pipe and inlet capacity. Also reports of stormwater inlets becoming blocked by debris and the lack of regular maintenance to clear blockages;
- Belief that that the flood mapping was not representative of local conditions and, therefore, their property was incorrectly identified as flood liable. This was often followed by a request for a site visit to verify and update the flood mapping. Some submissions also noted that recent construction work has likely changed local topographic conditions which was not reflected in the flood modelling results.
- A number of people noted that they were not identified as flood liable or were removed from the flood mapping prepared as part of the 'Pittwater Overland Flow Study' (2013) and did not understand what has changed since that time.
- Property owners have not experienced any historic flooding and, therefore, did not understand why their property was identified as flood liable.
- A number of submissions were also concerned of the potential impacts that the study may have on insurance premiums and property values.

Each submission was reviewed and, where necessary, updates to the flood mapping and/or reporting was completed. A summary of the modifications that were completed to address each public submission is provided in **Appendix K**. In general, the following responses were provided for each of the major issues identified above:

- Reports of insufficient stormwater infrastructure and blockage / lack of maintenance were forwarded to Council's stormwater section for actioning;
- Where reports of inaccurate flood mapping were provided, site visits were completed, and the draft flood inundation mapping was revised at some properties. In other cases, the mapping was unchanged as the flood model representation reliably reflected on-site conditions;
- The 'Pittwater Overland Flow Study' (2013) was a broad-scale study while the current study is more detailed and incorporates a better representation of the local drainage network as well as overland flow obstructions such as fences and buildings that were not included in the 2013 study. This can result in localised differences between the 2013 study and the current study. But overall, the current study affords an improved understanding of flood behaviour across the study area.
- A storm event of a 1% AEP magnitude has not occurred across Newport in recent history. A PMF event is the absolute worst flood that can occur and is only used for planning for vulnerable and critical services (e.g. hospitals, childcare, etc). As shown in **Figure F4** in **Appendix F**, the storm event of June 2016 (i.e., the largest recent flood) was estimated as a 5% to 10% AEP event. As such, residents are unlikely to have experienced larger events that are relevant to flood planning.

- Individual insurance companies typically identify flood prone land and assess risk through their own flood studies, analysis and flood mapping exercises, irrespective of whether Council has undertaken a flood study. The information is then used to set policies and premiums (i.e., this study should not alter existing premiums). Property prices are influenced by a range of market factors and there "…remains scant evidence for a sustained decrease in the value (or in growth rate) of houses with a flood risk" (Yeo et al, 2015). That is, other market factors tend to dictate property values.

Letters were prepared by Catchment Simulation Solutions and Council responding to each of the 19 public submissions. Each letter summarised how each submission was addressed (e.g., mapping modifications) as part of the final flood study.

3 Computer Flood Model

3.1 General

Computer models are the most common method of simulating flood behaviour through a particular area of interest. They can be used to predict flood characteristics such as peak flood level and flow velocity and the results of the modelling can also be used to define the variation in flood hazard.

The TUFLOW software (version 2016-04-AD) was used to develop a computer flood model of the Newport catchment. TUFLOW is a fully dynamic, 1D/2D finite difference model developed by BMT WBM (2016). It is used extensively across Australia to assist in defining flood behaviour.

The following sections describe the computer model development process.

3.2 Computer Model Development

3.2.1 Model Extent and Grid Size

A fully 2-dimensional computer model of the Newport catchment was developed using the TUFLOW software. The extent of the computer model is shown in **Figure 7**.

The TUFLOW software uses a grid to define the spatial variation in topography and hydrologic/hydraulic properties (e.g., Manning's "n" roughness, rainfall losses) across the model area. Accordingly, the choice of grid size can have a significant impact on the performance of the model. In general, a smaller grid size will provide a more detailed and reliable representation of flood behaviour relative to a larger grid size. However, a smaller grid size will take longer to perform all of the necessary calculations. Therefore, it is typically necessary to select a grid size that makes an appropriate compromise between the level of detail provided by the model and the associated computational time. A grid size of 2 metres was ultimately adopted and was considered to provide a reasonable compromise between reliability and simulation time.

A dynamically linked 1-dimensional (1D) channel was embedded within the 2D domain to represent areas that would not be well defined by the 2-metre grid (e.g., narrow creek channels). Hydraulic structures (e.g., culvert crossings) were also represented as a separate 1D domain. The extent of the 1D (i.e., channels and culverts) domains are shown in **Figure 7**.

3.2.2 Topography

Elevations were assigned to each grid cell based on the Digital Elevation Model derived from LiDAR data (refer Section 2.4.1). As the LiDAR data was collected in 2011, the terrain representation in TUFLOW is representative of topographic conditions at that time. That is, any topographic modifications completed since 2011 will not be reflected in the model. As noted in **Section 2.4.1**, only limited development/re-development has occurred since 2011.

Therefore, the LiDAR is considered to provide a reliable representation of contemporary topographic conditions across the study area.

However, a new development on the corner of Barrenjoey Rd and The Boulevarde was constructed since 2011. Due to its proximity to the main drainage channel, it was considered important to represent this development in the terrain model. Therefore, this development was manually incorporated into the terrain as a complete flow obstruction.

3.2.3 Material Types

The TUFLOW software uses land use information to define the hydrologic (i.e., rainfall losses) and hydraulic (i.e., Manning's 'n') properties for each grid cell in the model. As discussed in **Section 3.6**, a remote sensing approach was employed to provide a detailed spatial description of the variation in land use types across the catchment (refer **Figure 5**).

This land use information was used to inform the specification of rainfall losses and Manning's "n" roughness coefficients, which is described in more detail below.

Rainfall Losses

During a typical rainfall event, not all of the rain falling on a catchment is converted to runoff. Some of the rainfall may be intercepted and stored by vegetation, and some may infiltrate into the underlying soils.

To account for rainfall "losses" of this nature, the TUFLOW model incorporates a rainfall loss model. For this study, the "Initial-Continuing" loss model was adopted, which is recommended in *'Australian Rainfall and Runoff – A Guide to Flood Estimation'* (Engineers Australia, 1987) for eastern NSW.

This loss model assumes that a specified amount of rainfall is lost during the initial saturation/wetting of the catchment (referred to as the "Initial Loss"). Further losses are applied at a constant rate to simulate infiltration/interception once the catchment is saturated (referred to as the "Continuing Loss Rate"). The initial and continuing losses are effectively deducted from the total rainfall over the catchment, leaving the residual rainfall to be distributed across the catchment as runoff.

The catchment includes extensive urban areas that are relatively impervious as well as areas of "open" space that are pervious. The impervious and pervious sections of the catchment respond differently from a hydrologic perspective, i.e.:

- rapid rainfall response and low rainfall losses across impervious areas; and,
- slower rainfall response and higher rainfall losses across pervious areas.

In recognition of the differing characteristics of the two hydrologic systems, the rainfall losses were varied spatially based on the different material types / land uses shown in **Figure 5**. Initial and continuing losses were applied to each material type based on design values documented in *'Australian Rainfall and Runoff: A Guide to Flood Estimation' (Ball et al, 2016)* and are summarised in **Table 2**.

Table 2 Rainfall Loss Values

Material Description	Rainfall Losses	
	Initial Loss *(mm)*	Continuing Loss Rate *(mm/hr)*
Grass	10.0	1.8
Trees	10.0	1.8
Sand	10.0	5.0
Impervious Area/Roadway	1.0	0.0
Buildings	1.0	0.0
Water	0.0	0.0
Watercourse Bed	1.0	0.0

Manning's "n" Roughness Coefficients

Manning's "n" is an empirically derived coefficient that is used to define the resistance to flow (i.e., roughness) afforded by different material types / land uses. It is one of the key input parameters used in the development of the TUFLOW computer model. The material types / land uses shown in **Figure 5** were used to define Manning's "n" roughness values across the study area.

Manning's "n" values are dependent on a number of factors including vegetation type or density, topographic irregularities and flow obstructions. All of these factors are typically aggregated into a single Manning's "n" value for each material type and representative values can be obtained from literature (e.g., Chow, 1959). However, the Manning's "n" values found in literature are only valid when the flow depth is large relative to the material or vegetation height and the material is rigid (McCarten, 2011).

When using a "direct rainfall" computer model, the depth of flow across much of the catchment will be shallow (often referred to as "sheet flow"). In such instances, the depth of flow can be equal to or less than the height of the vegetation and the vegetation is not necessarily rigid (e.g., grass can bend under the force of flowing water). Therefore, Manning's 'n' values obtained from literature are generally no longer valid for shallow flow depths.

Research completed by McCarten (2011) and others (e.g., Engineers Australia, 2012) indicates that Manning's "n" values will not be "static" and will vary with flow regime or depth. Specifically, the research indicates that Manning's' "n" values will typically decrease with increasing flow depths. This is associated with the resistance to flow at higher depths being driven by bed resistance only, while at shallow depths, the resistance is driven by vegetation or stem drag as well as bed resistance (i.e., the "effective" roughness is higher at shallow depths).

To represent the depth dependence of Manning's "n" values in the TUFLOW model, flow depth versus Manning's "n" relationships were developed for each material type. The relationships were developed using the modified Cowan method, which is documented in the USGS water supply paper 2339 titled 'Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains' (Arcement & Schneider). The modified Cowan method was selected as it allows the Manning's "n" values to be calculated based on the depth of the flow relative to the vegetation or obstruction height. The Manning's "n" calculations are included in **Appendix C** and the final Manning's 'n' values for each material type at each depth are summarised in **Table 3**.

Table 3 Manning's 'n' Roughness Values

Material Description	Depth₁ *(metres)*	n₁	Depth₂ *(metres)*	n₂	Depth₃ *(metres)*	n₃	Depth₄ *(metres)*	n₄
Building*	<0.03	0.025	>0.03	10.00	-	-	-	-
Trees	<0.30	0.19	0.50	0.16	>2.00	0.12	-	-
Grass	<0.03	0.10	0.03	0.07	0.05	0.04	>0.07	0.03
Concrete / roadways	<0.005	0.034	>0.005	0.015	-	-	-	-
Watercourses	<0.1	0.11	0.2	0.1	0.3	0.09	>0.4	0.07
Sand	<0.02	0.03	0.05	0.025	>0.1	0.014	-	-

The Manning's "n" value assigned to buildings was treated differently to the other land uses across the catchment. The main goal of the Manning's "n" value assigned to buildings was to represent the significant impediment to flow afforded by buildings. However, a reduced "n" value was applied to shallow depths of inundation to reflect the relatively rapid runoff of water from the roof areas during the early stages of a rainfall event. Further information on the representation of buildings in the model is provided in **Section 3.2.5**.

3.2.4 Culverts/Bridges

Culverts and bridges can have a significant influence on flood behaviour. Therefore, all bridges and culverts were also represented within the 1D domain of the TUFLOW model. The location of culverts and bridges that were included within the TUFLOW model is shown in **Figure 7**.

For circular or rectangular culverts, the surveyed dimensions and invert elevations of the structures were included directly in the TUFLOW model. An entrance loss coefficient of 0.5 and an exit loss coefficient 1.0 was adopted for all culverts.

The catchment also includes a number of bridge crossings. The available waterway area beneath the bridge deck was specified using a surveyed cross-section of the underlying channel. All bridges within the catchment are single spans without piers. As such, energy losses due to contraction/expansion and piers are negligible and not included within the model.

Culvert/Bridge Blockage

During a typical flood, sediment, vegetation and urban debris (e.g., litter, shopping trolleys, fences) from the catchment can become mobilised leading to blockage of downstream culverts and bridges (**refer Plate 10**). Consequently, bridges and culverts will typically not operate at full efficiency during most floods. This can increase the severity of flooding across areas located adjacent to these structures.

In recognition of this, blockage factors varying between 0% and 100% were applied to all bridges and culverts. The blockage factors were applied based on blockage guidelines contained in the Australian Rainfall & Runoff document titled 'Blockage of Hydraulic Structures' (Engineers Australia, 2015). This guideline requires an assessment of potential debris type, debris availability, debris mobility and debris transportability at each structure location. This assessment was completed using the land use information shown in **Figure 5** as well the LiDAR information. The outcomes of the blockage assessment are summarised in **Appendix D** for each culvert/bridge located within the catchment.

Plate 10 View showing build-up of debris on the upstream side of the trash rack at the Howell Close culvert during the 2012 flood

3.2.5 Buildings

During significant rainfall events within an urban catchment, overland flow paths can traverse residential, commercial and industrial areas. When overland flow comes into contact with buildings, research has shown that the buildings significantly deflect the flows (Smith et al, 2012). Accordingly, buildings can have a significant impact on the distribution of overland flows in an urbanised catchment.

Typically, buildings are not "water tight". Therefore, as the depth of water surrounding each building increases, there is potential for water to enter the building through openings around doors and/or windows. Any water entering buildings is likely to move slowly through the building owing to the large number of internal obstructions (e.g., walls, doors, furniture). Accordingly, minimal conveyance capacity is typically provided through buildings. However, the cumulative amount of water stored by all buildings within a catchment can be significant, particularly in a highly urbanised catchment.

Therefore, the representation of buildings in the TUFLOW model needs to account for the following:

- the significant deflection of flow around the upstream walls of each building; and,
- the storage provided within each building.

To address this, a method of elevating TUFLOW model cells within building footprints by 0.3 metres above the existing ground surface was adopted. This is intended to represent the lower part of each building (i.e., the area between the ground surface and the floor level) as a complete flow obstruction (refer **Plate 11**). Once water depths exceed this level, water is permitted to "enter" the building but would still be subject to a significant flow impediment through application of a high Manning's "n" coefficient (as discussed in **Section 3.2.3**).

Plate 11 Example of a building on Howell Close with floor level roughly 0.3 metres above the surrounding ground surface

3.2.6 Stormwater System

The stormwater system has the potential to convey a significant proportion of runoff across each catchment during significant rainfall events. Therefore, it was considered important to incorporate the conveyance provided by the stormwater system in the TUFLOW model to ensure the interaction between piped stormwater and overland flows was represented.

The stormwater system was included within the TUFLOW model as a dynamically linked 1-dimensional (1D) network. This allowed representation of the conveyance of flows by the stormwater system below ground as well as simulation of overland flows in 2D once the capacity of the stormwater system is exceeded.

The properties of the stormwater system were defined based upon information contained in Council's stormwater GIS layer as well as details for 24 pits and pipes that were surveyed as part of the project. The extent of the stormwater system is shown in **Figure 2**.

It was recognised that the capacity of the stormwater system is dependent not only on the characteristics of the individual stormwater pipes, but also the various stormwater pits/inlets that capture surface runoff and distribute this runoff to the pipe system. Council's stormwater GIS layer provided stormwater pit type information including lintel lengths, invert depths and pit types (e.g., grated inlet, kerb inlet). It is also important to identify if a pit is located in a "sag" location, or "on grade", which was assessed based on interrogation of the surrounding ground surface elevations at each pit location.

Once all stormwater pit types were defined across the catchment, inlet capacity curves were prepared to define the variation in pit inflow capacity with respect to water depth at each pit location. The 'Drains Generic Pit Spreadsheet' (Watercom Pty Ltd, July 2005), was used to develop the inlet capacity curves. The inlet capacity curves were developed to take account of:

- The different pit inlet types (e.g., grated, side entry, combination);
- The different topographic locations (e.g., sag or on-grade); and,
- The different pit dimensions and lintel sizes.

A total of 424 unique relationships were ultimately developed to define pit inflow capacities for all pit types located within the catchment. A selection of inlet capacity curves for the most common pit types are presented in **Appendix E.**

Hydraulic 'losses' throughout the stormwater system were estimated using the Engelhund loss approach (BMT WBM, 2015). This loss approach automatically accounts for the following loss components at each stormwater pit for each model time step:

- Pit entrance loss
- Loss associated with a drop in elevation between inlet and outlet pipes
- Loss associated with a change in flow direction between the inlet and output pipes
- Pit exit loss

Stormwater Blockage

There is also potential for blockage of stormwater inlets/pits to occur during storms (refer **Plate 12**). Accordingly, blockage factors were assigned to all stormwater pits to reflect the reduced inflow capacity that would occur with partial pit blockage.

The adopted stormwater pit blockage factors were:

- 50% for all pits located in sag locations, and
- 20% for pits located on-grade.

The pit blockage factors were applied for all calibration and design flood simulations.

Plate 12 Typical blockage of a stormwater pit

3.2.7 Fences

Fences can have a significant impact on flow in urbanised catchments (refer **Plate 13**). Therefore, it was also considered important to include a representation of fences within the TUFLOW model. An automated approach was employed to extract approximate fence alignments based on information contained in cadastre, roadway and LEP GIS layers. The extent of fence lines that were generated based on this approach is shown in **Plate 14**.

Plate 13 Example of fence causing a notable impediment and redistributable of overland flows

Plate 14 Extent of fences (yellow lines) extracted using cadastre, zoning and roadway GIS layers

The fence alignments were then reviewed relative to 2014 aerial imagery and adjustments to the alignments were completed by hand, where necessary, to ensure a reliable representation of fence locations was provided across the catchment.

It was recognised that even relatively permeable fence types can become partially blocked during a flood. During the early stages of a flood, debris (e.g., litter, leaves, branches) will be mobilised and conveyed down major flow paths until it reaches an obstruction whose aperture is too small to transmit the debris. Therefore, by the peak of the flood there is a significant probability that most fences will be at least partially blocked with debris.

It was recognised that there is likely to be considerable variability in the degree of blockage provided by different fence types as well as the additional blockage that may be contributed by debris. Therefore, a comprehensive review of the blockage provided by all fence types across the catchments was considered to be prohibitively time consuming and subject to considerable uncertainty. Therefore, all fences were implemented with a global blockage factor of 50%. That is, a 50% reduction in conveyance capacity is provided through the fences. It was considered that a 50% blockage factor provided a conservatively realistic estimate of the average degree of blockage provided by all fence types across the study area (even for relatively permeable fence types when debris blockage is considered).

It was also assumed that all fences were 0.5 metres high. Therefore, all flow that approaches a fence will be subject to 50% blockage up to a depth of 0.5 metres. Although most fences will be higher than 0.5 metres, once the water upstream of the fence exceeds this depth, failure of the fence is likely. Therefore, only the bottom 0.5 metres of each fence was subject to 50% blockage with all flow in excess of 0.5 metres being able to travel across the top of the fence “unabated”.

4 COMPUTER MODEL CALIBRATION

4.1 Overview

Computer flood models are approximations of a very complex process and are generally developed using parameters that are not known with a high degree of certainty and/or are subject to natural variability. This includes catchment roughness/vegetation density as well as blockage of hydraulic structures. Accordingly, the model should be calibrated using rainfall, flow and flood mark information from historic floods to ensure the adopted model parameters are producing reliable estimates of flood behaviour.

Calibration is typically completed by routing recorded rainfall from historic floods through the computer model. Simulated flows and flood levels are extracted from the model results at locations where recorded data are available. Calibration is completed by iteratively adjusting the model parameters within reasonable bounds to achieve the best possible match between simulated and recorded flood flows and flood marks.

A number of daily and continuous rainfall gauges are located in close proximity to Newport that provide a good description of the spatial and temporal variation in rainfall for a range of historic events. Surveyed flood marks are also available for floods in 2012, 2015 and 2016 which are supplemented by anecdotal reports of flooding extents and depths that were provided as part of the community consultation. Stream gauging data are also available for post-2013 events.

Overall, it was considered that there is sufficient information available to calibrate the TUFLOW model. Further details on the model calibration are provided in the following sections.

4.2 February 2012 Flood

4.2.1 Rainfall

The February 2012 flood was produced by an intense downpour that was part of a very wet period which saw flooding across the majority of NSW. The main downpour occurred between 9pm on the 19th February and 2am on the 20th February and generated over 70mm of rain leading to flash flooding within the Newport catchment.

Accumulated daily rainfall totals for each rainfall gauge that was operational during the 2012 event were used to develop a rainfall isohyet map for the event, which is shown in **Figure 8**. The isohyet map shows that between 75 and 80 mm of rain fall across the catchment within a 24-hour period. The isohyet map was used as the basis for describing the spatial variation in rainfall in the TUFLOW model for the 2012 event.

The temporal (i.e., time-varying) distribution of rainfall was applied based on the closest, active, continuous rainfall gauge. The closest continuous gauge was determined to be the

Avalon Golf Course Gauge (Gauge #566145), which is located approximately 2 kilometres north-east of the centroid of the Newport catchment. The location of the gauge is shown in **Figure 8** and the pluviograph for the gauge is presented in **Appendix F** as **Figure F1**.

The continuous rainfall information for Gauge #566145 was also analysed relative to design rainfall-intensity-duration information (ARR 1987) for the catchment. This information is presented in **Appendix F** as **Figure F4** and indicates that the 2012 rainfall was roughly equivalent to a 20%AEP flood event.

4.2.2 Downstream Boundary Conditions

Hydraulic computer models also require the adoption of a suitable downstream boundary condition in order to reliably define flood behaviour throughout the area of interest. The downstream boundary condition is typically defined as a known water surface elevation (i.e., stage). The downstream boundary of the computer model is the Pacific Ocean to the east, and the Pittwater Estuary to the west. Accordingly, the ocean/estuary water level will influence the water levels across the lower reaches of the catchment.

A gauge at Dee Why (Gauge #213424) was used to define the time varying water level for the Pacific Ocean boundary. A water level gauge within the Pittwater Estuary at Great Mackerel Beach (Gauge #212485) was used to define time varying water levels along the Pittwater Estuary.

4.2.3 Modifications to Represent Historic Conditions

Although the February 2012 flood occurred relatively recently, there have been some minor changes across the catchment since this flood occurred. Therefore, the TUFLOW model that was developed to represent "contemporary" catchment conditions was modified in an attempt to reflect catchment conditions at the time of the 2012 flood.

Council provided some guidance on newly installed drainage infrastructure and developments within the catchment that have occurred since the 2012 flood event. This information was used to assist in making updates to the following TUFLOW input layers to represent 2012 catchment conditions:

- The earthworks and installation of the culvert headwall and debris barriers upstream of Howell Close were removed
- Newly installed stormwater pits on Foamcrest Avenue and Irrubel Rd were removed from the model
- The development on the corner of Barrenjoey Road and The Boulevard was removed and the open channel (now enclosed) was re-instated
- The elevated median strip along Barrenjoey Road was removed

4.2.4 Antecedent Catchment Conditions

The rainfall hyetograph presented in **Figure F1** in **Appendix F** indicates that the main down pour during the 2012 event was preceded by some significant rainfall (i.e., over 50 mm). Although this preceding rainfall occurred about 20 hours beforehand, it would likely indicate that the catchment was relatively "wet" prior to the main rainfall event. Therefore, no initial losses were applied for the 2012 flood simulation.
Structure Blockage

As noted in **Section 4.2.1**, the rainfall during the 2012 flood is considered to be approximately equal to a 20% AEP flood event. Therefore, blockage factors for the '>5% AEP' design range were adopted for the 2012 flood simulation based on the blockage calculations included in **Appendix D**. This equates to blockage factors of between 0% and 50%.

The only exception to these calculated blockage factors were the Howell Close and Ocean Avenue culverts. Blockage factors of 90% and 95% were adopted for these structures respectively, based upon advice provided by Council as well as evidence of structure blockage provided in historic flood photographs.

4.2.5 Results

Calibration of the TUFLOW computer model was attempted based upon twenty-two (22) surveyed flood marks as well as five (5) anecdotal reports of floodwater depths supplied by the community. The calibration was undertaken by routing the historic rainfall described in **Section 4.2.1** through the TUFLOW model and comparing reported and simulated flood levels and depths at each location.

Peak floodwater depths were extracted from the results of the 2012 flood simulation and are included on **Figure 9**. A comparison between the peak flood levels generated by the TUFLOW model and the surveyed flood mark elevations are tabulated in **Table 4** and are also presented in **Figure 9**. Depths of inundation reported by the community are tabulated in **Table 5** along with the corresponding simulated floodwater depth (the simulated floodwater depths and reported depths of inundation are also included on **Figure 9**). The 'confidence level' that was reported by the community for each reported floodwater depth is also provided in **Table 5** and provides an indication of the flood depth reliability provided by the respondent, i.e.:

- High = exact
- Medium = better than 0.1m
- Low = better than 0.5m.

The flood level comparison provided in **Table 4** shows that the TUFLOW model generally provides a reasonable reproduction of recorded floodwater depths. In all cases the TUFLOW model predicts levels that are within 0.11 metres of surveyed flood levels. The average difference between the simulated and surveyed flood levels is 0.01 metres.

The simulated flood depth comparison also shows a good correlation, with depths within 0.03 metres from those reported, indicating that the TUFLOW model is representing the flood conditions observed by members of the community.

Therefore, it is considered that the TUFLOW model is providing a reasonable reproduction of the 2012 event.

Table 4 Comparison between simulated and surveyed floodwater levels for the 2012 flood event

Location ID	Street	Surveyed Flood Mark Elevation (mAHD)	Simulated Flood Elevation (mAHD)	Difference Between Surveyed Flood Mark Elevation and Simulated Flood Level (m)
1	Barrenjoey Road	4.96	4.96	0.00
2	Barrenjoey Road	4.92	4.92	-0.01
3	Barrenjoey Road	4.99	4.94	-0.05
4	Barrenjoey Road	4.93	4.92	-0.01
5	Foamcrest Avenue	5.27	5.26	-0.01
6	Barrenjoey Road	5.24	5.24	0.01
7	Foamcrest Avenue	5.23	5.21	-0.01
8	Foamcrest Avenue	5.22	5.20	-0.02
9	Foamcrest Avenue	5.22	5.22	0.00
10	Foamcrest Avenue	5.59	5.65	0.05
11	Ocean Avenue	5.66	5.69	0.03
12	Ocean Avenue	5.66	5.71	0.05
13	Ocean Avenue	6.69	6.76	0.07
14	Ocean Avenue	6.71	6.78	0.07
15	Ocean Avenue	6.64	6.64	0.01
16	Ocean Avenue	6.85	6.74	-0.10
17	Neptune Road	8.81	8.90	0.09
18	Howell Close	12.53	12.50	-0.02
19	Howell Close	12.94	12.92	-0.02
20	Howell Close	13.51	13.50	0.00
21	Howell Close	13.35	13.46	0.11
22	Howell Close	13.33	13.28	-0.05

Table 5 Comparison between simulated and observed floodwater depths for the 2012 flood event

Location ID	Street	Observed Flood Depth (m)	Flood Depth Confidence Level	Simulated Flood Depth (m)	Difference Between Observed Flood Depth and Simulated Flood Depth (m)
1	Ocean Ave	0.08	High	0.06	-0.02
2	Nullaburra Rd	0.15	Medium	0.15	0.00
3	Foamcrest Ave	0.3	Medium	0.29	-0.01
4	Ross St	0.2	High	0.23	0.03

* Flood depths are based upon interpretation of photographs and flood descriptions provided by the community. Therefore, they should be considered approximate only.

4.3 November 2015 Flood

4.3.1 Rainfall

The November 2015 flood was produced by an intense downpour that occurred between 1am and 3:30am on the 15th November. During this period, around 25mm of rain fell.

Accumulated daily rainfall totals for each rainfall gauge that was operational during the 2015 event were used to develop a rainfall isohyet map for the event, which is shown in **Figure 10**. The isohyet map shows that between 35 and 50 mm of rain fall across the catchment within a 24-hour period. The isohyet map was used as the basis for describing the spatial variation in rainfall in the TUFLOW model for the 2015 event

The temporal (i.e., time-varying) distribution of rainfall was applied based on the closest, active, continuous rainfall gauge. The closest continuous gauge was again determined to be the Avalon Golf Course Gauge (Gauge #566145). The pluviograph for the gauge is presented in **Appendix F** as **Figure F2**.

The continuous rainfall information for Gauge #566145 was also analysed relative to design rainfall-intensity-duration information (ARR 1987) for the catchment. This information is presented in **Appendix F** as **Figure F4** and indicates that the 2015 rainfall was less severe than a 1 in 2-year ARI food event.

4.3.2 Downstream Boundary Conditions

The water level record from the Dee Why gauge (Gauge #213424) was used to define the time varying water level of the Pacific Ocean. The water level gauge at Great Mackerel Beach (Gauge #212485) was used to define time varying water levels along the Pittwater Estuary.

4.3.3 Modifications to Represent Historic Conditions

Based on discussion with Council engineers, it was determined that no significant alterations to catchment conditions have occurred since the 2015 event. Therefore, no changes were made to the TUFLOW model to reflect 2015 conditions.

4.3.4 Antecedent Catchment Conditions

The rainfall hyetograph presented in **Figure F2** in **Appendix F** indicates that the main down pour during the 2015 event was preceded by some notable rainfall bursts in the preceding 24 hours (i.e., over 15 mm). This lead up rainfall suggests that the catchment was at least party "wet" prior to the main rainfall event. Therefore, no initial rainfall losses were applied for the 2015 flood simulation.

4.3.5 Structure Blockage

As noted in **Section 4.3.1**, the rainfall during the 2015 event is considered to be less severe than a 1 in 2-year ARI. Therefore, blockage factors for the '>5% AEP' design range were adopted for the 2015 flood simulation based on the blockage calculations included in **Appendix D**. This equates to blockage factors of between 0% and 50%. The only exception to these calculated blockage factors were the Howell Close and Ocean Avenue culverts where 90% blockage was applied.

4.3.6 Results

Calibration of the TUFLOW computer model was attempted based upon fifteen (15) surveyed flood marks. The surveyed floodmarks were supplemented with three (3) anecdotal reports of flooding supplied by the community. The calibration was undertaken by routing the historic rainfall described in **Section 4.3.1** through the TUFLOW model and comparing reported and simulated flood levels at each location.

Peak floodwater depths were extracted from the results of the 2015 flood simulation and are included on **Figure 11**. A comparison between the peak flood levels generated by the TUFLOW model and the surveyed flood marks are included in **Table 6** and are shown on **Figure 11**. A comparison between simulated flood depths and anecdotal flood depths provided by the community is provided in **Table 7**, and also included on **Figure 11**.

Table 6 Comparison between simulated and surveyed floodwater levels for the 2015 flood event

Location ID	Street	Surveyed Flood Mark Elevation (mAHD)	Simulated Flood Elevation (mAHD)	Difference Between Surveyed Flood Mark Elevation and Simulated Flood Level (m)
1	Howell Close	12.32	12.32	0.00
2	Howell Close	12.35	12.31	-0.04
3	Howell Close	12.67	12.68	0.01
4	Howell Close	13.06	13.04	-0.02
5	Howell Close	13.06	13.05	0.00
6	Howell Close	13.05	13.11	0.07
7	Howell Close	13.49	13.41	-0.08
8	Howell Close	13.50	13.43	-0.07
9	Howell Close	13.51	13.43	-0.07
10	Howell Close	13.48	13.43	-0.05
11	Howell Close	13.28	13.34	0.06
12	Howell Close	13.84	13.82	-0.02
13	Howell Close	13.92	13.93	0.01
14	Howell Close	10.93	11.11	0.18
15	Howell Close	10.83	10.95	0.12

The flood level comparison provided in **Table 6** shows that the TUFLOW model generates flood levels that are generally within 0.1 metres of surveyed flood levels. An exception to this occurs along Howell Close where the simulated flood levels are over 0.1 metres higher than the surveyed flood marks. A review of the flood marks along Howell Close indicates that they were surveyed beneath some significant tree canopies / vegetation where the LiDAR information provides a less reliable description of road geometry. Therefore, this discrepancy appears to be an anomaly associated with the under-representation of the flow carrying capacity of the roadway (most notably the gutter). However, this only appears to be a localised anomaly and does not impact on the reliability of the results elsewhere across the model. Overall, the average difference between the simulated and recorded flood levels is 0.01 metres.

Table 7 Comparison between simulated and observed floodwater depths for the 2015 flood event

Location ID	Street	Observed Flood Depth (m)	Flood Depth Confidence Level	Simulated Flood Depth (m)	Difference Between Observed Flood Depth and Simulated Flood Depth (m)
1	Neptune Rd	0.3	Not provided	0.39	0.09
2	Livingstone Pl	0.15	Not provided	0.16	0.01
3	Prince Alfred Ave	0.2	Not provided	0.17	-0.03

* Flood depths are based upon interpretation of photographs and flood descriptions provided by the community. Therefore, they should be considered approximate only.

The simulated flood depth comparison for the November 2015 event also shows a good correlation with reported depths of inundation provided by the community. In all instances, simulated and reported depths agree to within 0.1 metres.

The TUFLOW model was also verified against recorded water level information for a stream gauge located within the open channel that adjoins the Newport Bowling Club (gauge #2134100). A comparison between the time variation in water level produced by the TUFLOW model and the recorded stage hydrograph at the gauge location is provided in **Plate 15**.

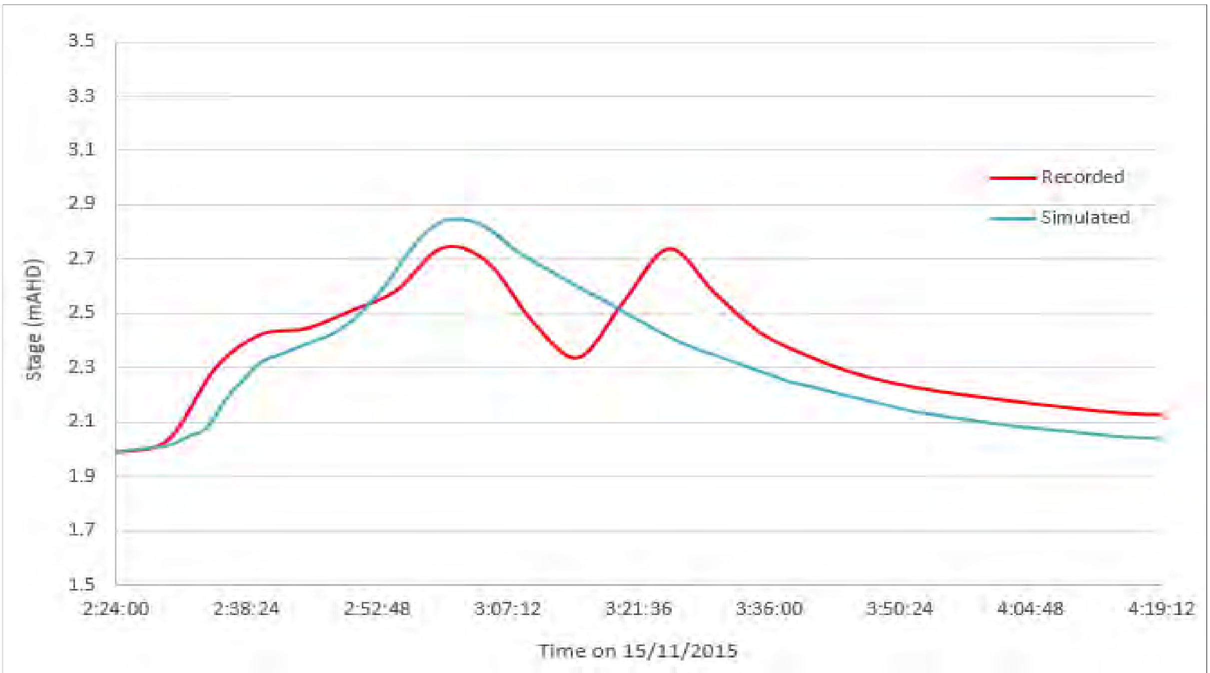


Plate 15 Comparison between simulated flood levels and recorded stage hydrograph at the Newport Bowling Club for the November 2015 flood

Plate 15 shows that there is generally a good correlation between the recorded and simulated flood levels on the rising limb as well as the timing of the peak water level. The peak water level is also reproduced closely by the TUFLOW model (i.e., within 0.1 metres).

However, the recorded hydrograph shows a second "peak" which is not reproduced by the TUFLOW model. A review of rainfall information was completed and the reason for the second peak could not be identified (i.e., the input rainfall information only contained a single peak). There is the potential that blockage of the culverts located upstream and downstream of the stream gauges may have had an impact on the recorded hydrograph results. However, as a post-flood survey was not completed along this section of channel, this could not be verified.

Overall, it is considered that the TUFLOW model is providing a reasonable reproduction of the 2015 event based upon surveyed flood marks, reports of inundation extents/depths and recorded stream gauge data.

4.4 June 2016 Flood

4.4.1 Rainfall

The June 2016 flood was produced by an east coast low combined with a king tide that caused widespread flooding and damage along the east coast of NSW. This event is best remembered by the damage that occurred along Collaroy Beach (located ~9km south of Newport) which saw severe erosion and damage to many beach-side properties. This same system caused flooding and damage within the Newport catchment, the worst of which occurred between 11am and 3pm on the 5th June where over 60mm of rain fell.

Accumulated daily rainfall totals for each rainfall gauge that was operational during the 2016 event were used to develop a rainfall isohyet map for the event, which is shown in **Figure 12**. The isohyet map shows that between 95 and 110 mm of rain fall across the catchment within a 24-hour period. The isohyet map was used as the basis for describing the spatial variation in rainfall in the TUFLOW model for the 2012 event

The temporal (i.e., time-varying) distribution of rainfall was applied based on the Newport Bowling Club continuous rainfall gauge (Gauge #566188). The pluviograph for the gauge is presented in **Appendix F** as **Figure F3**.

The continuous rainfall information for Gauge #566188 was also analysed relative to design rainfall-intensity-duration information (ARR 1987) for the catchment. This information is presented in **Appendix F** as **Figure F4** and indicates that the 2016 rainfall was between a 10% AEP and 5% AEP flood event.

4.4.2 Downstream Boundary Conditions

As discussed, the June 2016 flood event coincided with a king tide. As a result, elevated ocean levels were experienced along the ocean and Pittwater Estuary foreshore areas.

The water level gauge record from Dee Why (Gauge #213424) was used to define the time varying water level of the Pacific Ocean. The water level gauge at Great Mackerel Beach (Gauge #212485) was used to define time varying water levels along the Pittwater Estuary.

4.4.3 Modifications to Represent Historic Conditions

No significant alterations to catchment conditions have occurred since June 2016. Therefore, no modifications were completed to the TUFLOW model to reflect June 2016 conditions.

4.4.4 Antecedent Catchment Conditions

The rainfall hyetograph presented in **Figure F3** in **Appendix F** indicates that the 2016 event was preceded by many days of intermittent rainfall. The main rainfall burst occurred within a period of extended rainfall. This lead up rainfall suggests that the catchment was "wet" prior to the main rainfall event. Therefore, no initial rainfall losses were applied for the 2016 flood simulation.

4.4.5 Structure Blockage

As noted in **Section 4.4.1**, the rainfall during the 2016 is considered to be between a 50%AEP and 10% AEP flood event. Therefore, blockage factors for the '>5% AEP' design range were adopted for the 2016 flood simulation based on the blockage calculations included in **Appendix D**. This equates to blockage factors of between 0% and 50%. 90% blockage was assigned to the Howell Close and Ocean Avenue culverts based on advice provided by Council.

4.4.6 Results

Validation of the TUFLOW computer model was completed based upon thirteen (13) anecdotal reports of floodwater depths provided by the community. The validation was undertaken by routing the historic rainfall described in **Section 4.4.1** through the TUFLOW model and comparing simulated flood depths with those reported by the community at each location.

Peak floodwater depths were extracted from the results of the 2016 flood simulation and are included on **Figure 13**. A comparison between the peak flood depths generated by the TUFLOW model and that provided by the community responses is also provided on **Figure 13**. The flood depth comparison is also summarised in **Table 8**

The simulated flood depths compare favourably with the majority of anecdotal floodwater depths. More specifically, the majority of the comparisons show an agreement of within 0.1 metres.

The only major exception occurs at Location 3, where there is a difference of 0.68 metres. Based upon inspection of **Figure 13.2**, it is difficult to understand how a floodwater depth of 0.9 metres would occur at this location (floodwaters would likely "spill" around the building once a depth of 0.2 metres is reached). Therefore, the reliability of this flood mark is questionable. An attempt was made to contact the resident to confirm the flood depth, but this proved unsuccessful.

The simulated flood levels for the 2016 recorded flood were also compared against recorded stages for the Newport Bowling Club stream gauge. This comparison is provided in **Plate 16**.

Plate 16 shows that there is generally a good correlation between simulated and recorded flood levels. Although there are some variations, simulated and recorded levels generally agree to within 0.1 metres.

Overall, it is considered that the TUFLOW model is providing a reasonable reproduction of recorded flood information for the 2016 event.

Table 8 Comparison between simulated and observed floodwater depths for the 2016 flood event

Location ID	Street	Observed Flood Depth (m)	Flood Depth Confidence Level	Simulated Flood Depth (m)	Difference Between Observed Flood Depth and Simulated Flood Depth (m)
1	Foamcrest Ave	0.1	High	0.1	0
2	Ross St	0.15	High	0.15	0
3	Palm Rd	0.9	Medium	0.22	-0.68
4	Prince Alfred Pde	0	-	0.1	0.1
5	Loombah St	0	Medium	0.04	0.04
6	Gladstone St	0.01	High	0.04	0.03
7	Elvina Avenue	0.3	Medium	0.02	-0.28
8	Grandview Drive	0.02	High	0.03	0.01
9	Walworth Court	0.04	Medium	0.04	0
10	Trevor Rd	0.20	High	0.19	-0.01
11	Neptune Road	0.15	High	0.16	0.01
12	Ocean Ave	0.30	Medium	0.33	0.03
13	Livingstone Pl	0.08	Medium	0.1	0.02

NOTE: # Flood depth confidence level is the confidence level reported by the community as part of the questionnaire responses.
* Flood depths are based upon interpretation of photographs and flood descriptions provided by the community. Therefore, they should be considered approximate only.

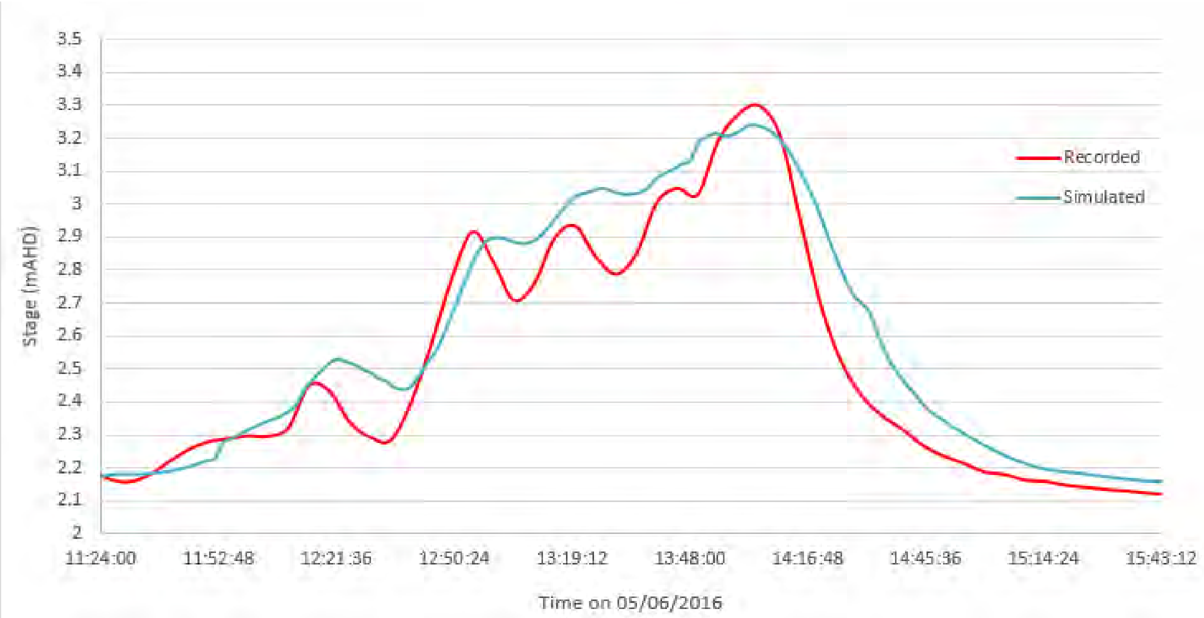


Plate 16 Comparison between the recorded stage hydrograph at the Newport Bowling Club and that predicted by the TUFLOW hydraulic model for the June 2016 flood event

5 Design Flood Simulations

5.1 General

Design floods are hypothetical floods that are commonly used for planning and floodplain management investigations. Design floods are based on statistical analysis of rainfall and flood records and are typically defined by their probability of exceedance. This is typically expressed as an Annual Exceedance Probability (AEP).

The AEP of a particular flood level or discharge at a specific location is the probability that the flood level/discharge will be equalled or exceeded in any one year. For example, a 1% AEP flood has a 1% chance of being equalled or exceeded in any one year.

Design floods are typically estimated by applying design rainfall to the computer model and using the model to route the rainfall excess across the catchment to determine design flood level, depth and velocity (speed) estimates. The procedures employed in deriving design flood estimates are outlined in the following sections.

5.2 Computer Model Setup

5.2.1 Boundary Conditions

Design Rainfall

Design rainfall for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP events were extracted using standard procedures outlined in *'Australian Rainfall and Runoff – A Guide to Flood Estimation'* (Engineers Australia, 1987). This involved extracting base design intensity-frequency-duration values at the centroid of the Newport catchment from Volume 2 of *'Australian Rainfall and Runoff – A Guide to Flood Estimation'* (Engineers Australia, 1987) (refer **Table 9**).

This base design rainfall information was used to interpolate design rainfall for other design rainfall frequencies and durations. Adopted rainfall intensities for each design storm and duration are summarised in **Table 10**. The resulting intensity-frequency-duration (IFD) curves for the Newport catchment are also provided in **Appendix F** as **Figure F4**. The resulting design rainfall information was also verified against design rainfall extracted using the Bureau of Meteorology's Computerised Design IFD Rainfall System and was found to be consistent.

Table 9 Design IFD Input Parameters

Parameter	Value	Parameter	Value
${}^{2}I_{1}$	39.2	${}^{50}I_{1}$	78.93
${}^{2}I_{12}$	8.58	${}^{50}I_{12}$	17.02
${}^{2}I_{72}$	2.49	${}^{50}I_{72}$	5.27
F2	4.297		
F50	15.89		

Table 10 Design Rainfall Intensities

DURATION	Rainfall Intensity (mm/hr)								
	20% AEP	**10% AEP**	**5% AEP**	**2% AEP**	**1% AEP**	**0.5% AEP**	**0.2% AEP**	**0.1% AEP**	**PMP**
10 mins	121.99	136.79	156.54	182.26	201.62	N/A	N/A	N/A	N/A
15 mins	103.14	116.05	133.17	155.47	172.35	179.91	192.77	218	640
30 mins	74.33	84.12	96.98	113.81	126.62	132.02	141.18	160	460
1 hour	51.03	57.95	67.02	78.93	88.02	92.10	99.03	113	340
90 mins	40.25	45.74	52.92	62.37	69.58	73.20	79.35	92	293
2 hours	33.83	38.44	44.47	52.40	58.45	61.71	67.25	78	260
3 hours	26.35	29.92	34.58	40.71	45.39	48.00	52.43	61	207
6 hours	17.11	19.38	22.36	26.26	29.23	31.00	34.00	40	138
12 hours	11.10	12.57	14.49	17.02	18.94	N/A	N/A	N/A	N/A
24 hours	7.16	8.13	9.41	11.09	12.38	N/A	N/A	N/A	N/A
48 hours	4.48	5.13	5.97	7.09	7.95	N/A	N/A	N/A	N/A
72 hours	3.31	3.80	4.44	5.27	5.93	N/A	N/A	N/A	N/A

NOTE: N/A indicates a design rainfall is not available/calculated for the nominated storm duration

Design rainfall intensities for the 0.1% AEP event were established by interpolating between the 1% AEP and PMP rainfall. Further details on the 0.1% AEP rainfall interpolation is provided in **Appendix G**.

For all design storms up to and including the 0.1% AEP event, the design rainfall was uniformly distributed across the entire study area. That is, there was no spatial variation in design rainfall across the study area. Due to the small size of the catchment, no areal reduction factors were applied to the point rainfall intensities.

The design rainfall estimates were used in conjunction with design temporal patterns documented in *Australian Rainfall and Runoff* to describe how the design rainfall varies with respect to time throughout each design storm. The temporal pattern for the 0.1% AEP event was based on the standard PMP temporal pattern, which is discussed in more detail below.

Probable Maximum Precipitation (PMP)

As part of the flood study it was also necessary to define flood characteristics for the Probable Maximum Flood (PMF). The PMF is estimated by routing the Probable Maximum Precipitation (PMP) through the computer model. The PMP is defined as the greatest depth of precipitation that is meteorologically possible at a specific location. Accordingly, it is considered the largest quantity of rainfall that could conceivably fall within a particular catchment.

PMP depths were derived for the Newport catchment for a range of storm durations up to and including the 6-hour event based on procedures set out in the Bureau of Meteorology's

'Generalised Short Duration Method' (GSDM) (Bureau of Meteorology, 2003). The PMP estimates were varied spatially and temporally based on the GSDM approach before application to the TUFLOW model.

The GSDM PMP calculations are included in **Appendix G**. The PMP rainfall intensities are also included in **Table 10** as well as the intensity-frequency-duration curves provided in **Appendix F** as **Figure F4**.

Downstream Boundary Conditions

As discussed in **Section 4.2.2**, the downstream boundary of the computer model is the Pacific Ocean to the east, and the Pittwater Estuary to the west. Accordingly, the ocean/estuary water level will influence the water levels across the lower reaches of the catchment.

It was considered appropriate to model a coincident static peak 1%AEP ocean/estuary level of 1.45m AHD for local design flood events for the PMF, 0.1% AEP, 0.2% AEP, 0.5% AEP and 1% AEP. The mean Highest High Water Solstice Springs (HHWSS) level for Sydney of 0.95m AHD was used for the ocean/estuary level for more frequent events (2%AEP, 5% AEP, 10% AEP, 20%AEP). These water levels were extracted from the '*Development of Practical Guidance for Coincidence of Catchment Flooding and Oceanic Inundation*' (Toniato et. Al, 2014).

5.3 Results

The TUFLOW model was used to simulate design flood behaviour across the Newport catchment for the 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% and 0.1% AEP events as well as the PMF.

5.3.1 Critical Duration

It was recognised that a single storm duration will not necessarily produce the "critical" flood behaviour across all sections of the catchment. That is, some parts of the catchment may be more susceptible to flooding associated with short, high intensity rainfall bursts while other areas may experience more significant flooding from longer, more voluminous rainfall events.

Therefore, the TUFLOW model was used to simulate flood behaviour across the Newport catchment for a range of durations for each design storm (i.e., 30 minutes up to 6 hours). The results from the 1% AEP design flood simulations were subsequently interrogated to determine the "critical" storm duration or durations across the catchment (i.e., the storm duration that produced the highest flood water level). The outcomes from this assessment are shown graphically in **Plate 17** and are also tabulated in **Table 11**.

The information contained in **Plate 17** and **Table 11** show that the 90-minute storm duration produces the highest 1% AEP flood levels across the majority of the catchment. However, this is generally represented by very shallow inundation depths in the upper areas of the catchment. The 120-minute storm duration becomes more dominant once the inundation depths become more significant (i.e., greater than 0.15 metres). Peak 1% AEP flood levels in some areas are also produced by the 60-minute storm duration. These results agree with those documented within the "Newport Beach Flood Study" (Lawson and Treloar, 2002) which identified the 120-minute storm duration as critical for the lower section of the Newport Beach Catchment, and the 60 and 90-minute durations critical in the upper reaches of the catchment.

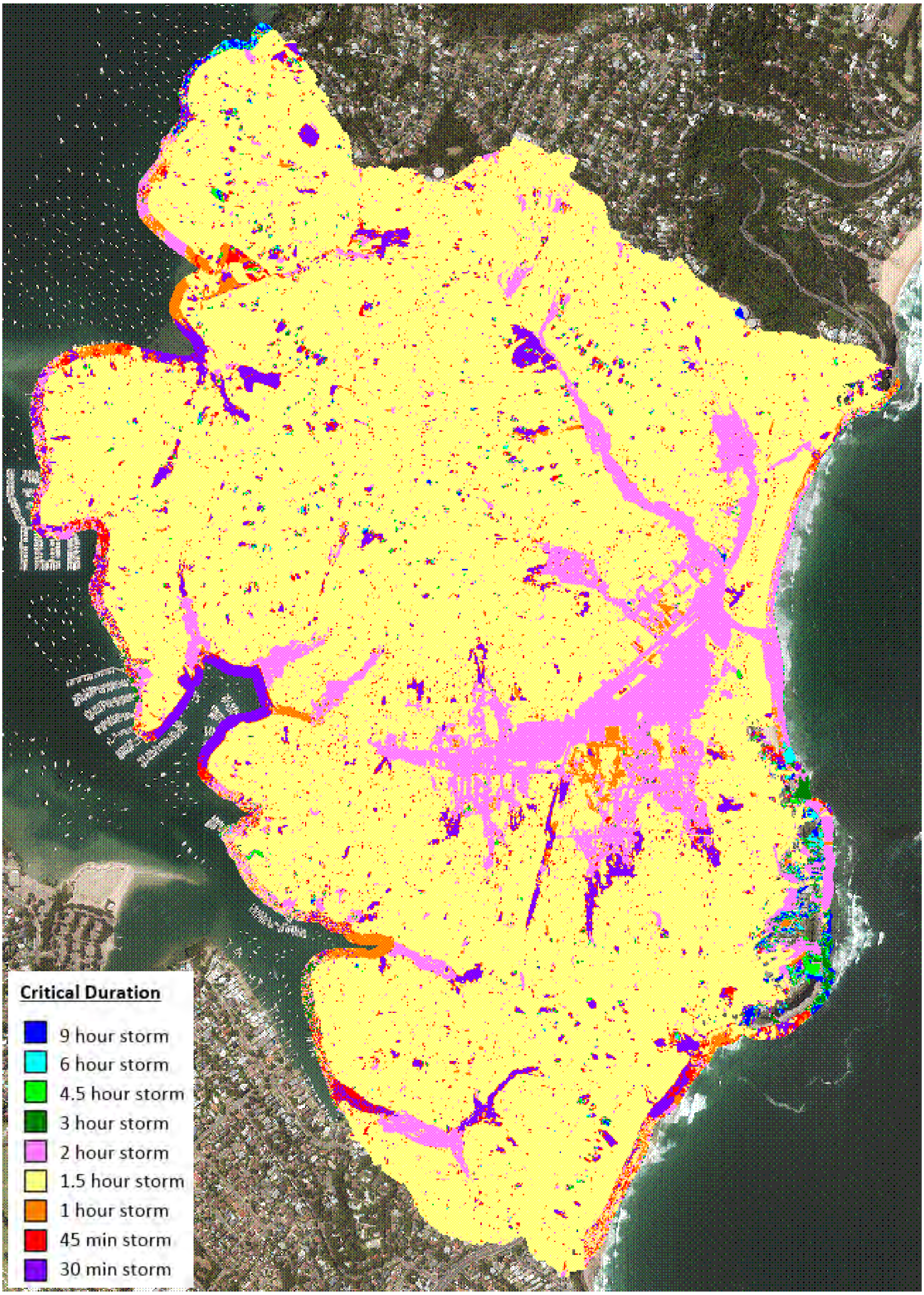


Plate 17 Spatial Variation in Critical Duration for the 1% AEP Storm

Table 11 Summary of Critical Storm Durations for 1% AEP flood level

Storm Duration (minutes)	Percentage of Flooded Area Where Storm Duration is Critical	Rank
540	0.3%	8
360	0.3%	9
270	0.4%	7
180	0.5%	6
120	12.5%	2
90	80.1%	1
60	2.4%	3
45	1.5%	5
30	2.0%	4

The 30 and 45-minute storms are critical across small sections of the catchment, and the 180, 270, 360 and 540-minute storm durations were not critical across any significant area of the catchment. Therefore, only the 60, 90 and 120-minute durations were simulated as part of the final design flood simulations.

5.3.2 Design Flood Envelope

As discussed, a range of different storm durations were simulated for each design flood (ranging from the 60-minute storm up to the 120-minute storm) to ensure the highest peak flood level was defined across all sections of the catchment. As a result, a range of results were generated as part of the design flood modelling.

Therefore, the results from each of the individual simulations (i.e., different storm durations) were subsequently merged to form a "flood envelope" for each design flood. This involved extracting and comparing peak flood levels, depths and velocities at each TUFLOW grid cell and adopting the highest depth, level and velocity at each grid cell. It is this design flood envelope, comprising the critical depths, velocities and levels at each grid cell that forms the basis for the results documented in the following sections.

5.3.3 Presentation of Model Results

The adopted modelling approach for the study involves applying rainfall directly to each cell in the computer model and routing the rainfall excess based on the physical characteristics of the catchment (e.g., variation in terrain, stormwater system). Once the rain falling on each grid cell exceeds the rainfall losses, each cell will be "wet". However, water depths across the majority of the catchment will be very shallow and would not present a significant flooding problem. Therefore, it was necessary for the results of the computer simulations to be "filtered" to distinguish between areas of significant inundation depth / flood hazard and those areas subject to negligible inundation.

In this regard, the following filter criteria was adopted to define areas that would be retained in the flood mapping:

- Depth > 0.15 metres; or,

- Velocity x Depth > 0.3 m^2/s

Therefore, only areas subject to the minimum depth and velocity depth product criteria outlined above were retained in the mapping.

It was noted that application of the depth and VxD filter resulted in a number of isolated "puddles". Therefore, an additional filter was applied whereby all "puddles" less than 100 m^2 in size were also removed from the presentation of results as they were not considered to represent a significant flood risk.

In addition to identifying areas with a significant flood risk, Council requires the identification of areas subject to minor "stormwater" inundation. These are described by Council as areas outside of the filter criteria described above but where the velocity-depth product (VxD) is predicted to exceed 0.025 m^2/s.

The filter criteria discussed above have been applied to all mapping figures. Areas that satisfy the stormwater inundation criteria are shown by a yellow polygon in the mapping.

5.3.4 Ground Truthing of Preliminary Results

Preliminary floodwater depth maps were prepared for the 1% AEP flood based upon the depth and area filter criteria outlined above. The preliminary maps were subject to an initial desktop review to determine if the mapped inundation depths and extents appeared realistic.

The preliminary maps were also subject to "ground truthing" to confirm the veracity of the modelling results. The ground truthing involved undertaking a field review of modelling results where it passed through any residential or commercial property. This aimed to confirm whether the modelling results were realistic in the first instance and whether modifications to the flood model were required to better represent topographic features or hydraulic controls that were not included as part of the model setup.

In a number of cases the modelling results were considered to overestimate floodwater depths, particularly in areas where there were relatively narrow flow paths between buildings that could not be well represented in the model. Consequently, the ground truthing resulted in the model being modified at a number of locations to better reflect conditions "on the ground". The revised model results were subsequently reviewed, and further refinement was completed until the results provided a realistic description of the movement of floodwaters across the catchment.

Not all locations within the study area could be verified in the field (e.g., some backyards and steep areas that were not readily accessible). In such cases, a desktop review of the available topographic and flood information was completed. In instances where the available information indicated that the flood results were not a true reflection of reality, they were removed from the mapping. This most commonly occurred in the vicinity of buildings where the relatively narrow flow paths between some buildings could not be reliably represented by the 2 metre grid size adopted in the TUFLOW model, resulting in an unrealistic localised "build-up" of water behind the buildings.

5.3.5 Design Floodwater Depths, Levels and Velocities

Peak flood levels, depths and velocities for the 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% and 0.1% AEP events as well as the Probable Maximum Flood (PMF) were extracted from the results of the TUFLOW model and were used as the basis for preparing flood result mapping. The peak floodwater depth maps are presented in **Figures 14.1** to **22.5** inclusive and peak velocities are presented in **Figures 23.1** to **31.5** inclusive.

Peak flood levels at a selection of locations are also presented in **Table 12**. The location of the identification (ID) numbers are shown by the green points in **Figure H1** in **Appendix H**.

Peak floodwater surface profiles for the main watercourses within the Newport study area for each design flood were also extracted and are provided in **Figure 32.**

Table 12 Peak Design Floodwater Stages at Key Locations within the Newport Catchment

ID	Location Description	**Peak Stage** (mAHD)								
		20% AEP	**10% AEP**	**5% AEP**	**2% AEP**	**1% AEP**	**0.5% AEP**	**0.2% AEP**	**0.1% AEP**	**PMF**
1	Howell Close Culvert	14.71	14.77	14.84	14.89	14.93	14.96	15.00	14.98	15.72
2	Upstream Ocean Ave	6.80	6.85	6.98	7.05	7.11	7.14	7.27	7.28	9.06
3	Foamcrest Avenue	5.57	5.81	5.93	6.05	6.13	6.15	6.18	6.19	6.99
4	Barrenjoey Rd/Coles Pde	4.27	4.36	4.49	4.57	4.63	4.66	4.73	4.60	5.51
5	Coles Pde Carpark	3.40	3.58	3.75	3.96	4.11	4.19	4.33	3.71	5.45
6	Barrenjoey Rd	6.76	6.81	6.86	6.91	6.97	7.00	7.04	7.04	7.47
7	Upstream of The Boulevarde	3.52	3.65	3.82	4.01	4.15	4.22	4.37	3.89	5.48
8	Barrenjoey Rd/The Boulevarde	3.52	3.66	3.82	4.01	4.15	4.22	4.37	3.90	5.48
9	Upstream of Bramley Ave	3.43	3.59	3.76	3.97	4.12	4.19	4.38	3.73	5.38
10	Prince Alfred Pde at Florence Park	4.16	4.17	4.20	4.21	4.22	4.24	4.25	4.24	4.45
11	Irrubel Rd/Crystal St	6.82	6.86	6.94	6.98	7.01	7.02	7.05	7.03	7.40

5.3.6 Design Discharges

Plot Output (PO) lines were incorporated within the TUFLOW model to allow overland discharges to be extracted for each design flood. This overland discharge information was combined with sub-surface pipe discharges (also extracted from TUFLOW) to allow the total peak discharge to be determined at discreet locations throughout the Newport study area. The peak discharges that were extracted from the TUFLOW model results are summarised in **Table 13**.

The location of each flow hydrograph identification (ID) number is shown in **Figure H1** in **Appendix H**.

5.3.7 Stage Hydrographs

Stage hydrographs, describing the time variation in water level during each design flood, were extracted upstream of key roadway crossings and are presented in **Appendix H**. Key details of the hydraulic structure at each crossing such as culvert obvert and roadway elevations are also superimposed to help identify if a roadway may become submerged during a particular design flood and, if so, how much warning time may be available.

5.3.8 Stormwater System Capacity

The TUFLOW model also produces information describing the amount of water flowing into each stormwater pit and through each stormwater pipe. This includes information describing which pipes are flowing completely full during each design flood. This information can be used to provide an assessment of the capacity of each pit and pipe in the stormwater system. In doing so, it allows identification of where stormwater capacity constraints may exist across the catchment.

Table 13 Design Discharges at Key Locations within the Newport Catchment

ID	Location Description	Peak Discharge (m^3/s)								
		20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	0.1% AEP	PMF
1	De Lauret Avenue	4.0	4.7	5.4	6.2	6.9	7.4	8.0	7.8	28.5
2	Irrubel Road near King Street	1.9	2.2	2.6	2.9	3.2	3.4	3.8	3.8	12.8
3	Palm Road	6.2	7.4	8.9	10.4	11.9	12.7	13.9	14.8	36.8
4	Newport Park	2.4	2.9	3.5	4.1	4.6	5.0	5.6	5.9	16.6
5	Howell Close Reserve	9.3	11.0	13.4	14.9	16.8	17.9	19.4	18.6	63.8
6	Upstream of Newport Rugby Fields	3.3	3.9	4.7	5.1	5.8	6.2	6.9	6.9	22.1
7	Prince Alfred Parade cul-de-sac	1.2	1.4	1.7	1.7	2.1	2.3	2.5	2.2	6.6

The pipe flow results of all design flood simulations were interrogated to determine the capacity of each stormwater pipe in terms of a nominal return period (i.e., AEP). The capacity of the pipe was defined as the largest design event whereby the pipe was not flowing completely full. For example, if a particular stormwater pipe was flowing 95% full during the 10% AEP event and 100% full during the 5% AEP event, the pipe capacity would be defined as "10% AEP".

A nominal return period was also calculated for each pit based on one of the following "failure" criterion:

- AEP at which the pit begins to surcharge;
- AEP at which the water depth at the pit exceeds 0.2 metres;

The resulting stormwater capacity maps are presented in **Figure 33**. As shown in **Figure 33**, the pit and pipe capacities are colour coded based on the nominal capacity that was calculated. Furthermore, different symbols have been applied to each pit to define whether the pit first "fails" via ponding depth or surcharge.

The information presented in **Figure 33** shows that the capacity of the system varies considerably across the catchment. However, in general, the major trunk drainage lines, where flows are concentrated, appear to have a lower capacity less than or equal to the 20% AEP event. **Figure 33** also indicates that the pipe capacity rather than pit capacity appears to be the limiting factor in the performance of the stormwater system.

5.3.9 Source of Inundation

Flooding across the study area can occur as a result of a number of different flooding mechanisms, including:

- Mainstream flooding (i.e., flooding associated with water overtopping the banks of a waterway/creek and inundating the adjoining floodplain)
- Overland flooding (flooding associated with water making its way towards the waterway/creek)
- Coastal inundation (inundation associated with elevated ocean/estuary water levels)

Therefore, an additional map was prepared showing the dominant flooding mechanism across different parts of the study area. In this regard, the following methodology was employed to define the different flooding mechanisms:

- All areas were initially defined as "overland" flooding areas
- All areas subject to permanent inundation along the Pittwater foreshore or Pacific Ocean were modified to "coastal" inundation
- All areas adjoining an open channel where the flood level was equal to the water level within the channel were defined as "mainstream" flooding areas

The outcomes of this assessment are provided in **Figure 34**.

5.4 Results Verification

As described in **Section 4**, the TUFLOW model developed as part of this study was calibrated against recorded and observed flood information for three historic floods. In general, the model was found to provide a good reproduction of historic flood information. However, the outcomes of the calibration only provide evidence that the model is providing a reliable representation of flood behaviour at isolated locations (i.e., at recorded/anecdotal flood mark locations).

Therefore, additional verification of the TUFLOW model was completed by comparing the results generated by the TUFLOW model against past studies as well as alternate computer modelling approaches.

Further details on the outcome of the TUFLOW model verification is presented below.

5.4.1 Comparison with Past Studies

A number of flooding and drainage investigations have previously been prepared to define flood behaviour across various parts of the Newport catchment. This includes:

- Newport Beach Flood Study (Lawson and Treloar, 2002).
- Pittwater Overland Flow Study (Cardno, 2013).

The results documented in these previous studies were used as basis for verifying the results produced by the TUFLOW model. **Table 14** provides a comparison between peak 20% and 1% AEP design flood levels from the current study against those reported in the 'Newport Beach Flood Study' (Lawson and Treloar, 2002).

The comparison in **Table 14** shows a close correlation in model results at most locations. In general, the 2002 model predicts higher peak 20% AEP and 1% AEP flood levels across the catchment relative to the TUFLOW model developed for the current study. However, in areas where significant "ponding" occur, the 2002 model predicts flood levels that are up to 0.15 metres lower. This is particularly notable upstream of Foamcrest Avenue, as well as upstream of the sand dunes fronting Newport Beach.

Table 14 Comparison between current study TUFLOW model and the Newport Beach Flood Study (2002) for 20% AEP and 1% AEP Water Levels

Location	Peak Water Level (mAHD)					
	20% AEP			1% AEP		
	2002 Study	Current Study	Difference	2002 Study	Current Study	Difference
Bishop St	5.08	4.9	-0.18	5.18	5.05	-0.13
Barrenjoey Rd (West)	4.09	3.98	-0.11	4.18	4.16	-0.02
The Boulevard	3.51	3.45	-0.06	4.07	4.13	0.06
Bramley Ave	3.49	3.42	-0.07	4.08	4.13	0.05
Council Car Park nr Bramley Ave	3.47	3.41	-0.06	4.07	4.12	0.05
Beach Dune	3.39	3.32	-0.07	3.93	4.08	0.15
Crown of Newport Reserve	13.78	13.79	0.01	13.99	13.9	-0.09
Top of Howell Cl	11.44	11.38	-0.06	11.67	11.65	-0.02
Seaview Ave/Neptune Rd	11.18	11.17	-0.01	11.44	11.35	-0.09
Ocean Ave	6.71	6.60	-0.11	6.95	6.89	-0.06
Foamcrest Ave	5.62	5.60	-0.02	6.04	6.14	0.10
Barrenjoey Rd (North)	4.59	4.27	-0.32	4.73	4.65	-0.08
Average			-0.09			-0.01

These differences are associated with differences in adopted sand dune elevation, the extent of the stormwater/drainage system included in the model representation as well as the blockage assigned to major drainage structures. More specifically:

- the current study utilised recent LiDAR information to define the height of the dunes (the maximum dune elevation in the LiDAR is 3.7m AHD). The 2002 study used a 3.2m AHD maximum longitudinal dune elevation;

- The current study includes a full representation of the stormwater system while the previous study only included the trunk drainage system. Consequently, the current study allows for more water to be conveyed underground through the stormwater system and produce lower overland flood levels.
- The current study applied blockage to all stormwater pits as well as culverts and bridges. The 2002 study did not include a representation of blockage resulting in lower overall design flood levels.

The peak flood level results from the TUFLOW model were also compared against those presented in the 'Pittwater Overland Flood Study' (Cardno, 2013). This comparison is provided in **Table 15** for the 20% and 1% AEP design floods.

Table 15 Comparison between TUFLOW and Pittwater Overland Flow Study for 20% AEP and 1% AEP Water Levels

Location	Peak Water Level (mAHD)					
	20% AEP			1% AEP		
	Pittwater Overland Flow Study	Current Study	Difference	Pittwater Overland Flow Study	Current Study	Difference
Bishop St	5.15	4.9	-0.25	5.22	5.05	-0.17
Barrenjoey Rd (West)	4.45	3.98	-0.47	4.98	4.16	-0.82
The Boulevard	4.45	3.45	-1.00	4.98	4.13	-0.85
Bramley Ave	4.45	3.42	-1.03	4.98	4.13	-0.85
Council Car Park nr Bramley Ave	4.45	3.41	-1.04	4.98	4.12	-0.86
Beach Dune	4.42	3.32	-1.10	4.92	4.08	-0.84
Crown of Newport Reserve	13.81	13.79	-0.02	13.9	13.9	0.00
Top of Howell Cl	11.52	11.38	-0.14	11.8	11.65	-0.15
Seaview Ave/Neptune Rd	11.34	11.17	-0.17	11.5	11.35	-0.15
Ocean Ave	6.92	6.6	-0.32	7.12	6.89	-0.23
Foamcrest Ave	5.69	5.6	-0.09	5.93	6.14	0.21
Barrenjoey Rd (North)	4.7	4.27	-0.43	4.98	4.65	-0.33
Prince Alfred Pde/Loombah St	34.00	34.49	0.49	34.05	34.59	0.54
Prince Alfred Pde at Florence Park	4.01	4.16	0.15	4.07	4.23	0.16
Irrubel Rd/Crystal St	7.00	6.83	-0.17	7.10	7.01	-0.09
Average			-0.37			-0.30

As discussed in **Section 2.2.5**, the hydraulic model used as part of the Pittwater Overland Flood Study utilised a coarser 5m grid size and did not include a representation of the stormwater network or major hydraulic structures (i.e., bridges/culverts). As a result, the LGA wide model does not provide a detailed representation of the conveyance characteristics of the stormwater system or the various waterways or narrow flow paths (e.g., between buildings) relative to the TUFLOW model developed for this study. As a result, the LGA model tends to predict high 20% and 1% AEP floods across the majority of the catchment.

Like the 'Newport Beach Flood Study', the flood level differences are most prominent in areas of significant "ponding". Flood level differences of up to 1.1m in the 20% AEP and 0.86m in the 1% AEP flood are predicted in some areas. These differences are primarily driven by the lack of any stormwater system in these areas. Consequently, water will continually "build up" in these areas leading to higher flood level estimate.

Overall, the verification of the TUFLOW model against other studies shows comparable results across most locations. However, there are some notable differences in design flood levels in some areas. In general, the TUFLOW model developed for the current study produced lower peak flood level estimates and is associated with the TUFLOW model including a full representation of the stormwater system and providing a more detailed description of major conveyance areas.

5.4.2 Alternate Calculation Approaches

XP-RAFTS Hydrologic Model

The ability of the TUFLOW model to represent rainfall-runoff processes was validated relative to a hydrologic model of the Newport catchment that was established using the XP-RAFTS software. Detailed information on the XP-RAFTS model setup is provided in **Appendix I**.

The XP-RAFTS model was used to simulate the 1% AEP flood using the same hydrologic inputs as the TUFLOW model (i.e., design rainfall, rainfall losses, impervious proportion etc). Peak 1% AEP discharges were extracted from the XP-RAFTS model at key locations throughout the catchment for the 2-hour storm duration and are presented in **Table 16**. The corresponding TUFLOW 1% AEP discharges at each location are also provided in **Table 16** for comparison.

Table 16 Verification of TUFLOW 1%AEP Peak Discharges against alternate calculation approaches

Location	XP-RAFTS Subcatchment	Peak 1% AEP Flow (m^3/s)			Difference (%)
		TUFLOW	XP-RAFTS	Difference	
De Lauret Avenue	_junc_46	6.61	6.46	0.16	2.3
Irrubel Road near King Street	_junc_123	3.22	2.80	0.42	13.0
Palm Road	167	11.25	9.84	1.41	12.5
Newport Park	_junc_142	3.88	3.93	-0.06	-1.3
Howell Close Reserve	79	16.38	14.41	1.96	12.0
Upstream of Newport Rugby Fields	_junc_58	5.77	4.83	0.94	16.3
Prince Alfred Parade cul-de-sac	16	2.11	1.85	0.27	12.3

The peak discharge comparison provided in **Table 16** shows that the TUFLOW model produces peak 1% AEP discharges that are generally within 15% of the XP-RAFTS model. In general, the TUFLOW model produces higher peak 1% AEP discharge estimates.

Full discharge hydrographs showing the time variation in flows at discrete locations throughout the catchment were also extracted from the XP-RAFTS and TUFLOW model results and are included in **Appendix I**. The hydrograph comparison shows that the overall hydrograph shapes and time of peak flow generally compare well. It was noted that the TUFLOW hydrographs shows a greater delay before the hydrograph begins to rise and a slightly smaller volume of runoff (represented by the area under the hydrograph) relative to the XP-RAFTS model. This is likely to be associated with the TUFLOW model providing a more comprehensive representation of “micro” storage across the catchment (e.g., small depressions) that are difficult to represent in a lumped hydrologic model such as XP-RAFTS.

Overall, the results of the verification indicate that the TUFLOW model is providing a reasonable reproduction of rainfall-runoff processes across the Newport catchment.

6 EMERGENCY RESPONSE CLASSIFICATION, FLOOD HAZARD AND HYDRAULIC CATEGORIES

6.1 Flood Emergency Response Classifications

In an effort to understand the potential emergency response requirements across different sections of the study area, flood emergency response precinct (ERP) classifications were prepared. The ERP classifications can be used to provide an indication of areas which may be inundated or may be isolated during floods. This information, in turn, can be used to quantify the type of emergency response that may be required across different sections of the floodplain during future floods. This information can be useful in emergency response planning.

The ERP classifications were prepared based upon information contained in the Australian Institute of Disaster Resilience's Guideline 7-2: 'Flood Emergency Response Classification of the Floodplain' (2017). This involved delineating the catchment into emergency response classifications based upon the flow chart presented in **Plate 18**.

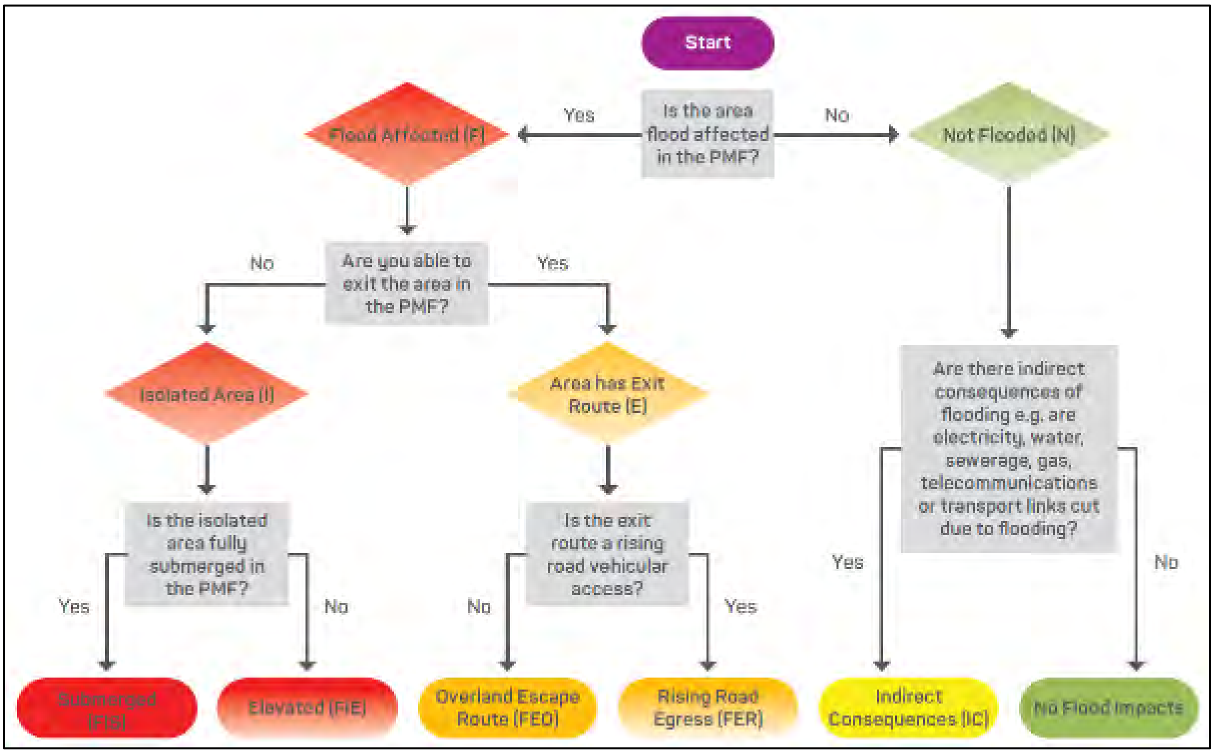


Plate 18 Flow Chart for Determining Flood Emergency Response Classifications (AIDR, 2017).

Each allotment within the catchment was assigned an ERP classification based upon the flow chart shown in **Plate 18** for the 20% AEP, 5% AEP, 1% AEP and PMF. This was completed using the TUFLOW model results, digital elevation model and a road network GIS layer in conjunction with proprietary software that considered the following factors:

- whether evacuation routes/roadways get “cut off” (a 0.2m depth threshold was used to define a “cut” road);
- whether evacuation routes continuously rise out of the floodplain;
- whether an allotment gets inundated during the nominated design flood and whether evacuation routes are cut, or the lot becomes completely surrounded (i.e., isolated) by water before inundation;
- if evacuation by car was not possible, whether evacuation by walking was possible (a 0.5 metre depth threshold was used to define when a route could not be traversed by walking).

The resulting ERP classifications for each design flood are provided in **Figures 35**, **36, 37** and **38**. A range of other datasets were also generated as part of the classification process to assist emergency services. This includes the locations were roadways first become cut by floodwaters, the time at which the roadways first become cut and the length of time the roadways are cut. This roadway inundation information is also presented in **Figures 35**, **36, 37** and **38**.

6.2 Flood Hazard

Flood hazard defines the potential impact that flooding will have on development and people across different sections of the floodplain. The provisional flood hazard at a particular area of a floodplain can be established from Figure L2 of the *‘Floodplain Development Manual’* (NSW Government, 2005), which is reproduced on the right.

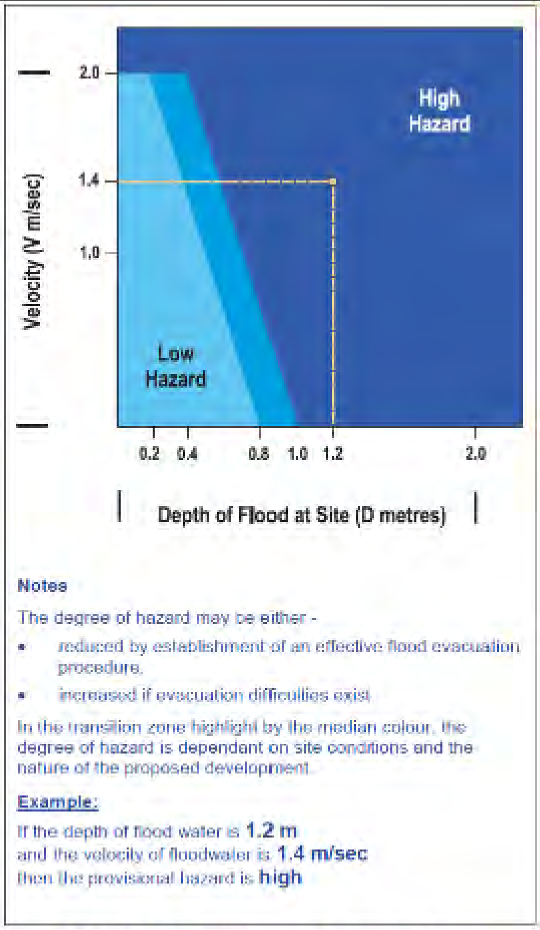


FIGURE L2 - Provisional Hydraulic Hazard Categories

Figure L2 in the *‘Floodplain Development Manual’* (NSW Government, 2005) divides hazard into two categories, namely high and low. It also includes a “transition zone” between the low and high hazard categories. Sections of the floodplain located in the “transition zone” may be classified as either high or low depending on site conditions or the nature of any proposed development.

In general, those areas subject to a low flood hazard can, if necessary, be evacuated by trucks and able-bodied adults would have little difficulty wading to safety (NOTE: evacuation by car may not be possible). Those areas of the floodplain exposed to a high flood hazard would have difficulty evacuating by trucks, there is potential for structural damage to buildings and there is possible danger to personal safety (i.e., evacuation by wading may not be possible).

The TUFLOW hydraulic software was used to automatically calculate the variation in provisional flood hazard across the Newport catchment based on the depth and velocity criteria shown in Figure L2.

It should be noted that the provisional hazard categories only assess the potential hazard associated with the depth and velocity of floodwaters. The determination of true hazard categories requires the consideration of a number of additional factors to determine the potential vulnerability of the community during specific floods. These factors include (NSW Government, 2005):

- size of the flood;
- effective warning time;
- flood awareness;
- rate of rise of floodwaters;
- duration of flooding; and
- potential for evacuation.

To provide a preliminary understanding of the true flood hazard categories, the ERP classifications discussed in **Section 6.1** were combined with the provisional hazard categories. It was considered that the ERP classifications provided a reasonable assessment of the "other" emergency response factors that influence flood hazard, including the potential for isolation and evacuation difficulties.

In general, the provisional hazard categories were retained in the preliminary true hazard mapping. However, the provisional "transition" flood hazard was changed to "high" based on the limited flood warning time and rapid rate of rise of water across the area. In addition, the low provisional hazard was changed to a high hazard if it was identified as being "isolated" as part of the ERP classification (due to the flood liability of the land in conjunction with potential evacuation difficulties):

The preliminary true hazard mapping for the 20%, 5% and 1% AEP floods as well as the PMF is presented in **Figures 39**, **40, 41** and **42**.

It should be noted that the true hazard categories provided in **Figures 39**, **40, 41** and **42** are preliminary and will be reviewed and finalised as part of the subsequent Floodplain Risk Management Study for Newport.

6.3 Flood Risk to Life

6.3.1 Overview

Northern Beaches Council requests that "flood risk to life" mapping be prepared as part of all flood studies. The risk to life mapping provides Council with information describing where acceptable, tolerable and unacceptable risks to life exist across its LGA.

The risk to life categories are documented in Pittwater Council's 'Pittwater 21 Development Control Plan – Appendix 15: Flood Emergency Response Planning for Development in Pittwater Policy'. The risk to life categories documented in the DCP draw strongly from research presented in the Australian Institute of Disaster Resilience's Guideline 7-3: 'Flood Hazard' (2017), which breaks down the potential risk to life into six categories (H1 to H6) The categories are reproduced in **Plate 19**.

Council's risk to life policy subsequently groups the H1 to H6 categories into three risk to life categories which are summarised in **Table 17** and are described below

- H1-H2: Acceptable flood risk to life;
- H3-H5 and H6 where evacuation is possible: Tolerable flood risk to life
- H6 where evacuation is not possible: Unacceptable flood risk to life

Peak depth, velocity and velocity-depth product outputs generated by the TUFLOW model were combined with the criteria outlined in **Plate 19** to prepare the risk to life mapping for the PMF. As shown **Table 17**, the H6 category is subdivided into two subcategories based upon whether evacuation is possible. In this regard, the two "isolated" emergency response categories (i.e., "flooded isolated submerged" and "flooded isolated elevated" where used to define where evacuation would not be possible.

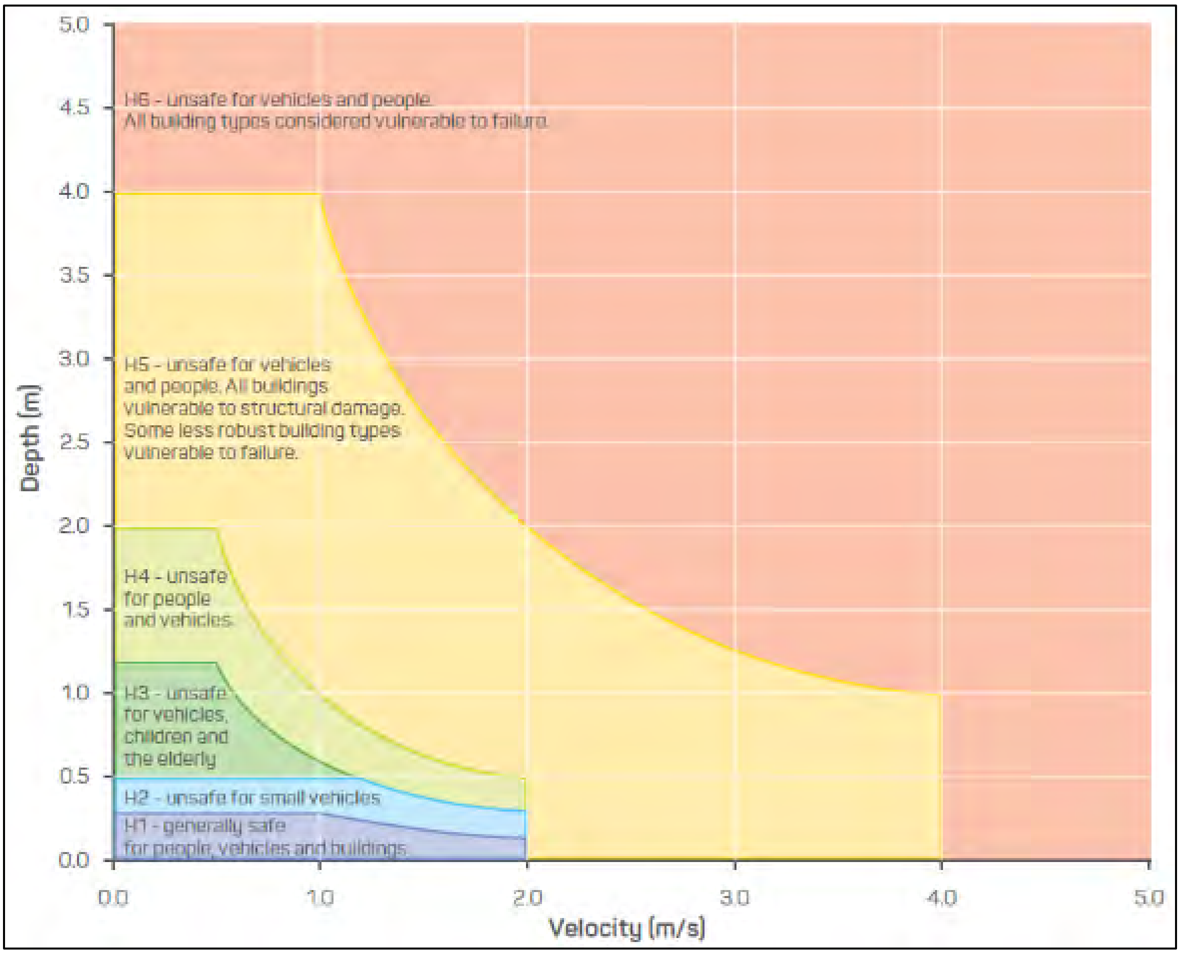


Plate 19 Flood Risk to Life categorisation based on depth and velocity criteria (AEDR, 2017)

Table 17 Flood Risk to Life Category Descriptions

Life Hazard Category	Hazard Description	Likelihood of Loss of Life Rating	Discussion
H1 – H2	Relatively benign flow conditions. Unsafe for small vehicles.	Unlikely	Risk to life within the floodplain is not expected to be significantly impacted by the potential de-stabilisation of small vehicles as pedestrian stability for all demographics is not compromised at this hazard level. Therefore, loss of life in these regions is unlikely
H3 – H4	Unsafe for all pedestrians and all vehicles.	Possible	All pedestrians and vehicles are unstable, posing a risk to a significant portion of the population, meaning loss of life is possible.
H5	Unsafe for all pedestrians and all vehicles. Buildings require special engineering design and construction.	Likely	All pedestrians and vehicles are unstable, buildings that are not specially designed are at risk, posing a risk to a significant portion of the population, meaning loss of life is likely.
H6 – Evacuation Possible		Likely	All pedestrians, vehicles, and buildings are unstable, however as there is still an opportunity to evacuate, loss of life is likely (but not almost certain).
H6 – Evacuation Not Possible	Unconditionally dangerous. Not suitable for any type of development or evacuation access. All building types considered vulnerable to failure.	Almost Certain	All pedestrians, vehicles, and buildings are unstable, as people cannot evacuate, shelter-in-place is the only response option. As the stability of refuge buildings is compromised, loss of life is almost certain.

This resulting risk to life mapping is presented in **Figure 43.**

6.4 Hydraulic Categories

6.4.1 Overview

The NSW Government's *'Floodplain Development Manual'* (NSW Government, 2005) also characterises flood prone areas according to the hydraulic categories presented in **Table 18** The hydraulic categories provide an indication of the potential for development across different sections of the floodplain to impact on existing flood behaviour and highlights areas that should be retained for the conveyance and storage of floodwaters.

6.4.2 Adopted Hydraulic Categories

Unlike provisional hazard categories, the *'Floodplain Development Manual'* (NSW Government, 2005) does not provide explicit quantitative criteria for defining hydraulic categories. This is because the extent of floodway, flood storage and flood fringe areas are specific to a particular catchment.

In an effort to provide quantitative criteria, Howell et al (2004) suggested that floodways can be defined using a combination of velocity depth product and velocity outputs. The criteria proposed by Howell et al is summarised in **Table 18** and was adopted for the current study. However, an additional criterion was added so that all areas contained within open channels (i.e., from top of bank to top of bank) were also defined as floodways in accordance with definition of floodways provided in the *'Floodplain Development Manual'*.

Table 18 Qualitative and Quantitative Criteria for Hydraulic Categories

Hydraulic Category	Floodplain Development Manual Definition	Adopted Criteria
Floodway	• those areas where a significant volume of water flows during floods • often aligned with obvious natural channels and drainage depressions • they are areas that, even if only partially blocked, would have a significant impact on upstream water levels and/or would divert water from existing flow paths resulting in the development of new flow paths. • they are often, but not necessarily, areas with deeper flow or areas where higher velocities occur.	• Minimum top of bank to top of bank (for open channels) **AND** • VxD >= 0.25 m^2/s AND V >= 0.25 m/s **OR** • V >= 1.0 m/s AND D >= 0.15 m
Flood Storage	• those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood • if the capacity of a flood storage area is substantially reduced by, for example, the construction of levees or by landfill, flood levels in nearby areas may rise and the peak discharge downstream may be increased. • substantial reduction of the capacity of a flood storage area can also cause a significant redistribution of flood flows.	• If not FLOODWAY and D >=0.15 m
Flood Fringe	• the remaining area of land affected by flooding, after floodway and flood storage areas have been defined. • development (e.g., filling) in flood fringe areas would not have any significant effect on the pattern of flood flows and/or flood levels.	• Remaining areas after FLOODWAY and FLOOD STORAGE are defined

NOTES: V = Velocity, D = Depth
*Hydraulic categories were only applied to areas subject to inundation (i.e., as per the filter criteria discussed in **Section 5.3.3**)*

Flood storage areas were then defined as those areas located outside of floodways but where the depth of inundation was greater than 0.15 metres. This aimed to identify areas where a significant amount of flow was not necessarily conveyed, however, the depths of water indicate a significant amount of storage capacity was being provided.

As discussed in **Section 5.3.3**, “filtering” of the raw modelling results was completed to remove areas of insignificant inundation from the flood mapping (i.e., areas where the depth of inundation was less than 0.15 metres and VxD was less than 0.3 m^2/s). It was considered that the areas that were removed from the flood mapping would fall under the “flood fringe” hydraulic category. Accordingly, it is suggested that those areas where no depth or hydraulic category mapping is presented would be considered flood fringe.

The resulting hydraulic category maps for the 1% AEP floods as well as the PMF are shown in **Figures 44** and **45**.

7 Sensitivity Analysis

7.1 General

Computer flood models require the adoption of some parameters that are not necessarily known with a high degree of certainty or are subject to variability. Each of these parameters can impact on the results generated by the model.

As outlined in **Section 4**, computer models are typically calibrated using recorded rainfall, stream flow and/or flood mark information. Calibration is achieved by adjusting the parameters that are not known with a high degree of certainty until the computer model is able to reproduce the recorded flood information. Calibration is completed in an attempt to ensure the adopted model parameters are generating realistic estimates of flood behaviour.

As discussed in **Section 4**, the TUFLOW model was calibrated against recorded and observed flood information for three historic events and was further verified against alternate calculation approaches and results documented in past studies. In general, this information confirmed that the model was providing realistic descriptions of flood behaviour across the catchment where historic flood information and past flood study results were available.

Nevertheless, it is important to understand how any uncertainties and variability in model input parameters may impact on the results produced by the model. Therefore, a sensitivity analysis was undertaken to establish the sensitivity of the results generated by the computer model to changes in model input parameter values. The outcomes of the sensitivity analysis are presented below.

7.2 Model Parameter Sensitivity

7.2.1 Initial Loss / Antecedent Conditions

An analysis was undertaken for the 1% AEP storm to assess the sensitivity of the results generated by the TUFLOW model to variations in antecedent wetness conditions (i.e., the dryness or wetness of the catchment prior to the design storm event). A catchment that has been saturated prior to a major storm will have less capacity to absorb rainfall. Therefore, under wet antecedent conditions, there will be less "initial loss" of rainfall and consequently more runoff.

The variation in antecedent wetness conditions was represented by increasing and decreasing the initial rainfall losses in the TUFLOW model. Specifically, initial losses were changed from the "design" values of 10mm/1mm (for pervious/impervious areas respectively) to:

- "Wet" catchment: 5mm for pervious and 0mm for impervious areas; and,
- "Dry" catchment: 15mm for pervious areas and 2mm for impervious areas

The TUFLOW model was used to re-simulate the 1% AEP event with the modified initial losses. Peak water levels were extracted from the results of the modelling and were compared against peak water flood levels for "base" design conditions. This allowed water level difference mapping to be prepared showing the magnitude of any change in water levels associated with the change in initial loss values. The difference mapping is presented in **Plate 20** and **Plate 21** for the "wet" and "dry" catchment scenarios respectively. Decreases in 1% AEP "design" flood levels are shown in shades of blue and increases in 1% AEP flood levels are shown in shades of yellow and red.

Peak 1% AEP flood levels were also extracted from the results of the sensitivity simulations at various locations across the catchment and are presented **Table 19**. The location of each flood level comparison point is shown in the difference mapping.

Table 19 Peak 1% AEP Flood Levels from Sensitivity Simulation at Various Location across the Catchment

Location (refer to Plates 20 to 27 for locations)		Peak 1% AEP Flood Levels (mAHD)								
		"Base" Case	Lower Initial Loses	Higher Initial Loses	Lower Continuing Loses	Higher Continuing Loses	Lower Manning's "n"	Higher Manning's "n"	No Blockage	Complete Blockage
1	Howell Close Culvert	14.94	14.94	14.94	14.95	14.94	14.91	14.97	14.83	14.96
2	Upstream Ocean Ave	7.11	7.11	7.11	7.11	7.11	7.04	7.15	7.07	7.24
3	Foamcrest Avenue	6.13	6.14	6.12	6.13	6.13	6.11	6.15	6.13	6.28
4	Barrenjoey Rd/Coles Pde	4.64	4.66	4.63	4.65	4.64	4.61	4.67	4.63	4.83
5	Coles Pde Carpark	4.13	4.16	4.09	4.15	4.10	4.09	4.18	4.11	4.71
6	Barrenjoey Rd	7.00	7.02	6.99	7.01	7.00	7.00	7.01	6.98	7.14
7	Upstream of The Boulevarde	4.16	4.19	4.12	4.17	4.14	4.12	4.20	4.14	4.71
8	Barrenjoey Rd/The Boulevarde	4.16	4.19	4.13	4.18	4.15	4.12	4.21	4.15	4.71
9	Upstream of Bramley Ave	4.13	4.16	4.10	4.15	4.12	4.09	4.18	4.12	4.82
10	Prince Alfred Pde at Florence Park	4.23	4.23	4.22	4.24	4.23	4.24	4.25	4.21	4.25
11	Irrubel Rd/Crystal St	7.01	7.01	7.01	7.01	7.01	6.99	7.03	7.01	7.11

The difference mapping shows that a lower initial loss value (i.e., representing a wetter catchment) will produce increases in 1% AEP flood levels that are primarily concentrated in areas of major "ponding". Conversely, higher initial loss values (i.e., representing a drier catchment) will generate decreases in 1% AEP water levels that are again concentrated in areas of major ponding. The magnitude of the differences is typically less than 0.04 metres with the median difference being ±0.00 metres for both the increased and decreased initial loss scenarios.

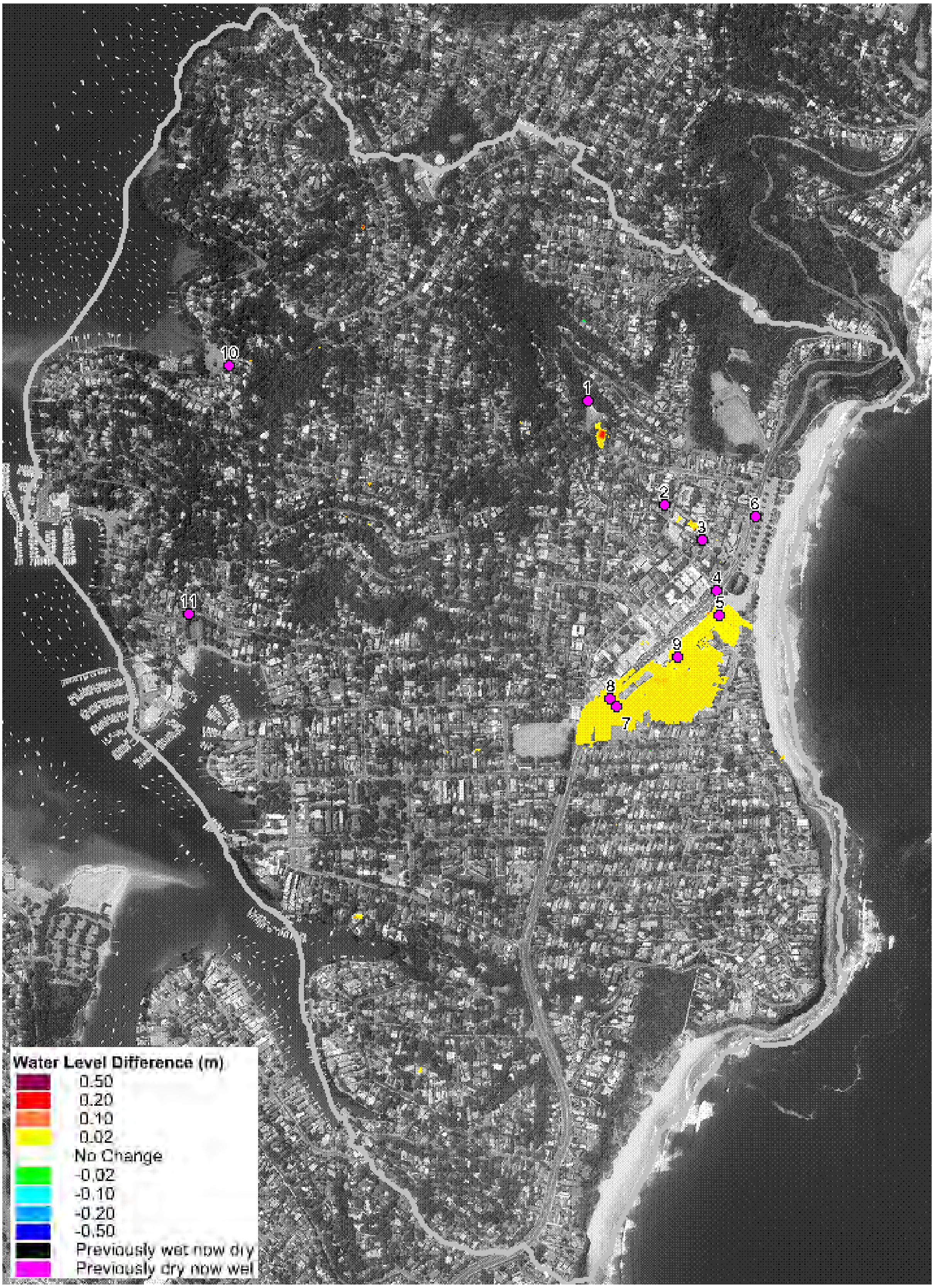


Plate 20 Flood level difference map with lower initial rainfall losses (i.e., wet catchment)

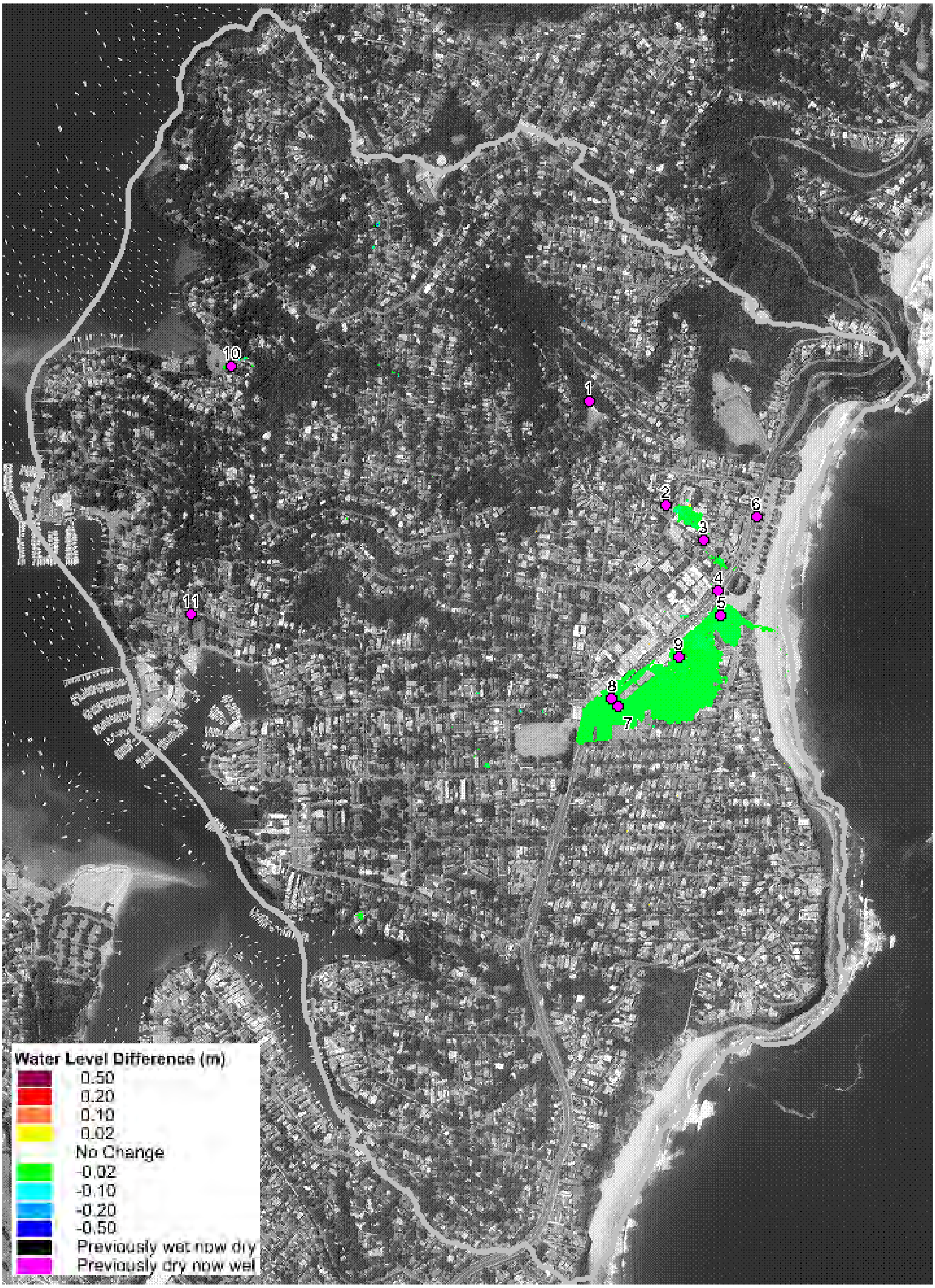


Plate 21 Flood level difference map with higher initial rainfall losses (i.e., dry catchment)

The most significant differences tend to be concentrated in the immediate vicinity of Bramley Ave/Ross St/The Boulevarde area where changes in 1%AEP flood levels of about 0.05 metres are predicted.

Overall, it can be concluded that the model is relatively insensitive to changes in the adopted initial losses across the majority of the catchment. *'Australian Rainfall & Runoff'* (Engineers Australia, 1987) suggests adopting an initial loss of between 10 mm and 30 mm for design flood estimation. The adopted initial loss of 10 mm is at the lower end of the suggested range and would, therefore, provide reasonably conservative design flood level estimates across the catchment.

7.2.2 Continuing Loss Rate

An analysis was also undertaken to assess the sensitivity of the results generated by the TUFLOW model to variations in the adopted continuing loss rates. Accordingly, the continuing loss rates within the TUFLOW model were changed from the "design" values of 1.8 mm/hr (pervious areas) and 0 mm/hr (impervious areas) to:

- Decreased Continuing Loss Rates: 0mm/hr for pervious and impervious areas.
- Increased Continuing Loss Rates: 3.6mm/hr for pervious areas and 1mm/hr for impervious areas.

The TUFLOW model was used to re-simulate the 1% AEP flood with the modified continuing loss rates. Peak flood levels were extracted from the results of the modelling and were used to prepare flood level difference mapping, which is presented in **Plate 22** and **Plate 23**.

Peak 1% AEP flood levels were also extracted from the results of the sensitivity simulations at various locations across the catchment and are presented in **Table 19**.

The results of the sensitivity analysis show that the TUFLOW model is relatively insensitive to changes in continuing loss rates. More specifically, **Plate 22** and **Plate 23** shows that only relatively small, localised changes in 1% AEP flood levels are predicted with the modified continuing loss rates.

Therefore, it can be concluded that any uncertainties associated with the adopted continuing loss rates are not predicted to have a significant impact on the results generated by the TUFLOW model.

7.2.3 Manning's "n"

Manning's' "n" roughness coefficients are used to describe the resistance to flow afforded by different land uses and surfaces across the catchment. However, they can be subject to variability (e.g., vegetation density in the summer would typically be higher than the winter leading to a higher flow resistance). Therefore, additional analyses were completed to quantify the impact that any uncertainties associated with Manning's "n" roughness values may have on design flood behaviour.

The TUFLOW model was updated to reflect a 20% increase and a 20% decrease in the adopted design Manning's "n" values and additional 1% AEP simulations were completed with the modified "n" values. Flood level difference mapping was prepared based on the results of the revised simulations and are presented in **Plate 24** and **Plate 25**.

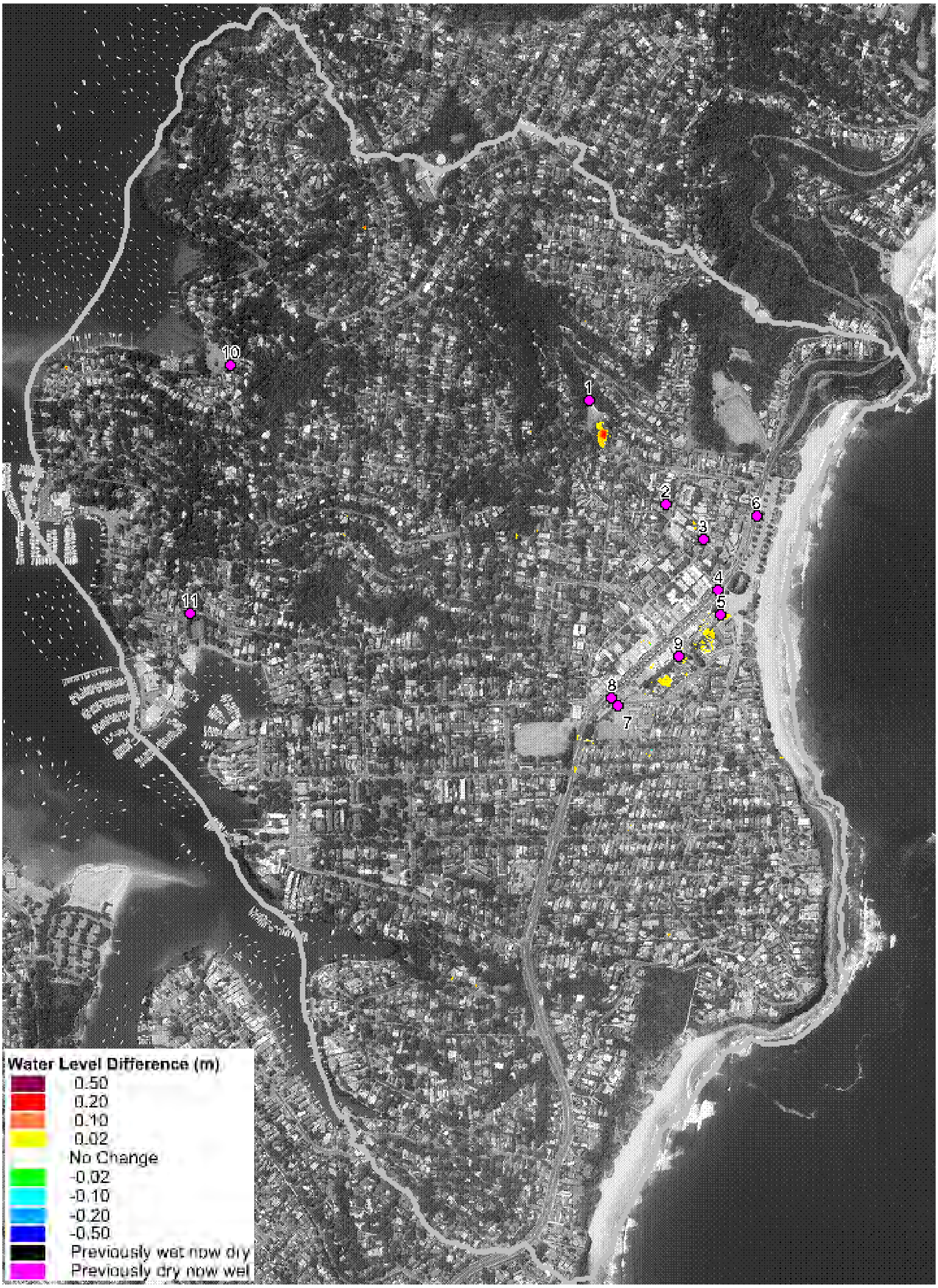


Plate 22 Flood level difference map with reduced continuing loss rates

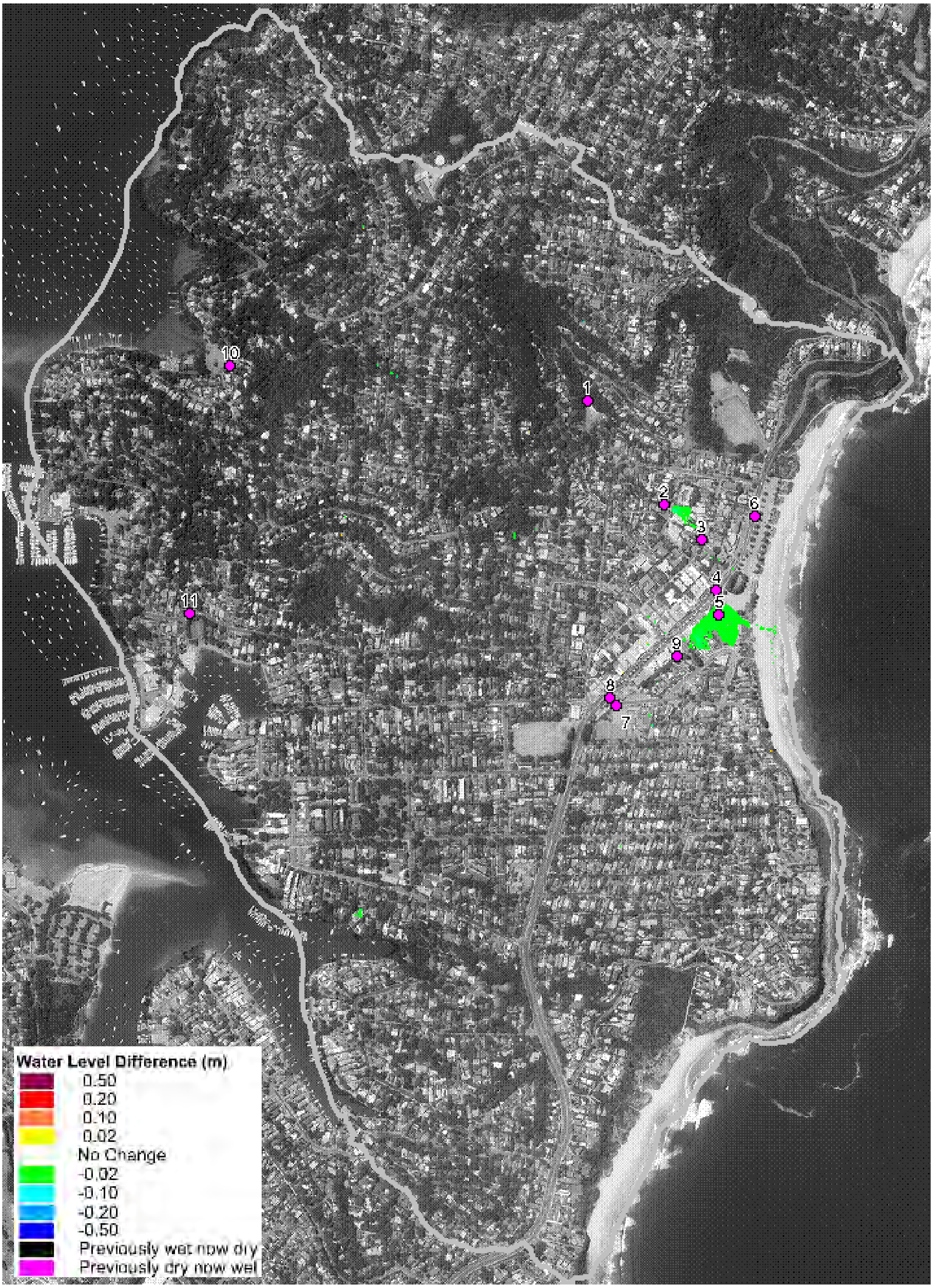


Plate 23 Flood level difference map with increased continuing loss rates

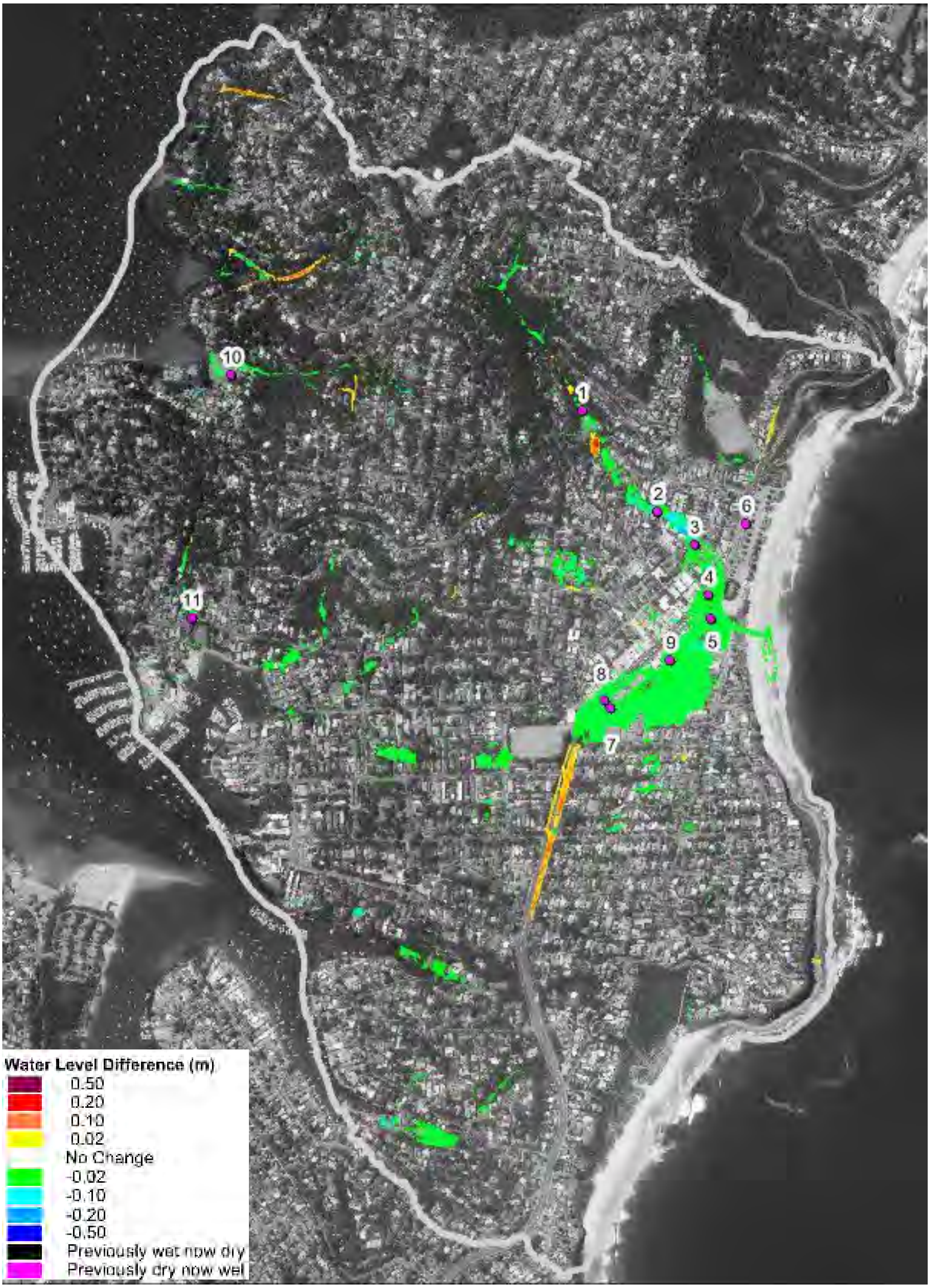


Plate 24 Flood level difference map with decreased Manning's "n" roughness values

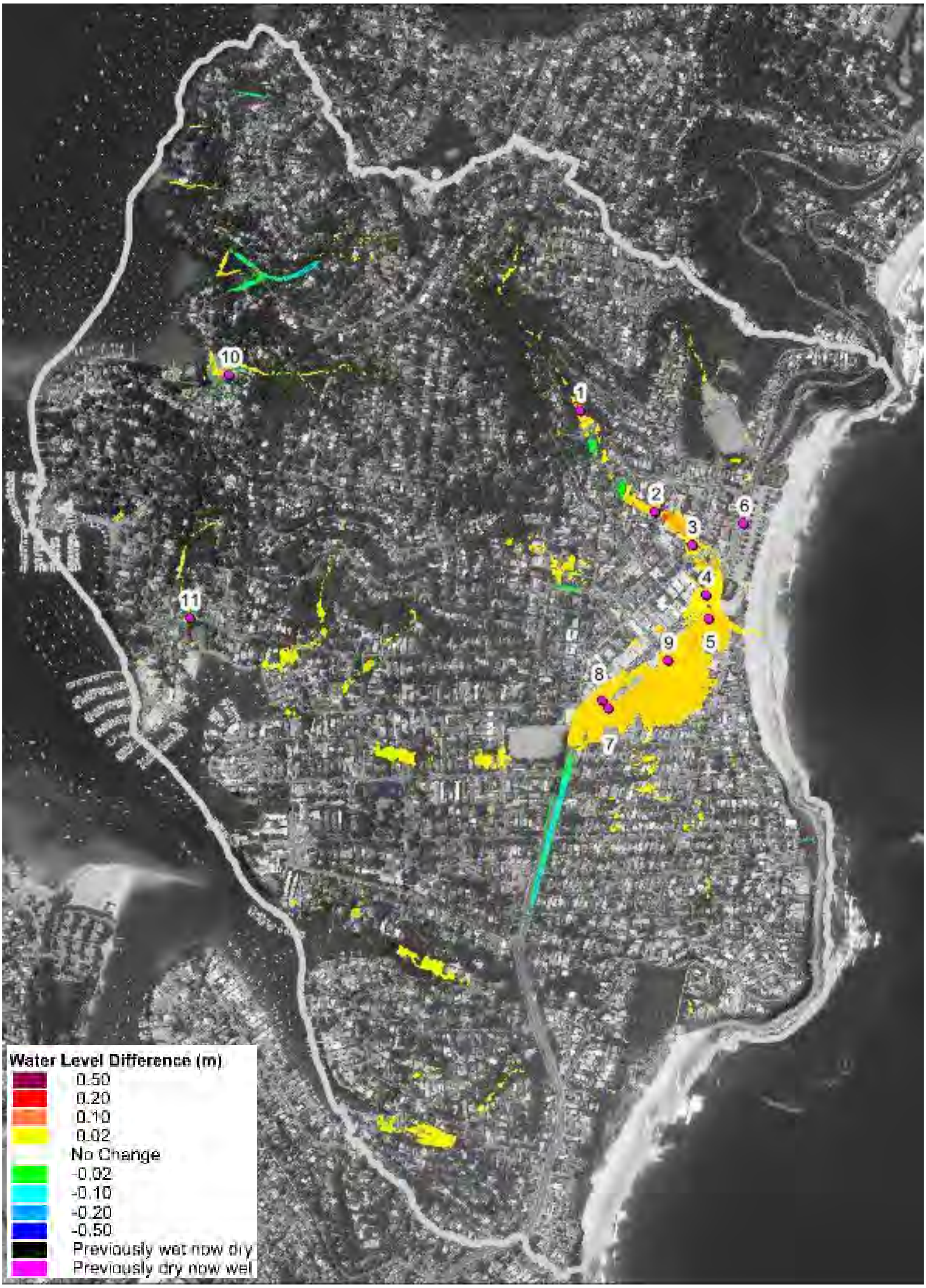


Plate 25 Flood level difference map with increased Manning's "n" roughness values

Peak 1% AEP flood levels were also extracted from the results of the sensitivity simulations at various locations across the catchment and are presented in **Table 19**.

Plate 24 shows that decreasing the "n" values will typically decrease flood levels as the flows are subject to less resistance. However, flood levels are predicted to increase in some location. This is associated with the lower "n" values allowing water to drain and "fill" these areas more rapidly.

Plate 25 shows that increasing the "n" values will generally increase 1% AEP water levels. The increase in water levels are associated with the higher "n" values "holding" back the floodwaters. This reduces the speed of the water but results in the water level increasing.

However, overall, altering the "n" values by 20% is predicted to change 1% AEP flood levels by less than 0.06 metres. As a result, it is considered that the model is relatively insensitive to changes in Manning's 'n' values.

7.2.4 Hydraulic Structure Blockage

As discussed in **Section 3.2.4**, blockage factors ranging between 0% and 100% were applied to all bridges, culverts and stormwater inlets as part of the design flood simulations. However, as it is not known which structures will be subject to what percentage of blockage during any particular flood, additional TUFLOW simulations were completed to determine the impact that alternate blockage scenarios would have on flood behaviour. Specifically, additional simulations were undertaken with no blockage as well as complete blockage of all stormwater inlets, bridges and culverts.

Flood level difference mapping was prepared based on the results of the blockage sensitivity simulations and is presented in **Plate 26** and **Plate 27**. Peak 1% AEP flood levels were also extracted from the results of the sensitivity simulations at various locations across the catchment and are presented in **Table 19.**

Plate 26 shows that removing blockage from all structures will produce decreases in 1% AEP water levels upstream of major hydraulic structures and along major flow paths. Localised decreases in flood levels of over 0.1 metres are predicted at some locations. However, the majority of the reductions are predicted to be less than 0.07 metres.

Plate 27 shows that complete blockage of all hydraulic structures will cause some significant changes to 1% AEP flood levels. This is particularly evident across the Newport CBD where completing blocking the drainage system combined with the elevated dune adjacent to Newport Beach results in water ponding within a large "basin". Water levels are predicted to increase by over 0.5 metres across this area.

There are predicted to be some minor decreases in water level downstream of some structures and is associated with the blockage effectively creating a "dam", which reduces flows immediately downstream of these structures. However, complete blockage is predicted to increase water levels across the vast majority of the catchment.

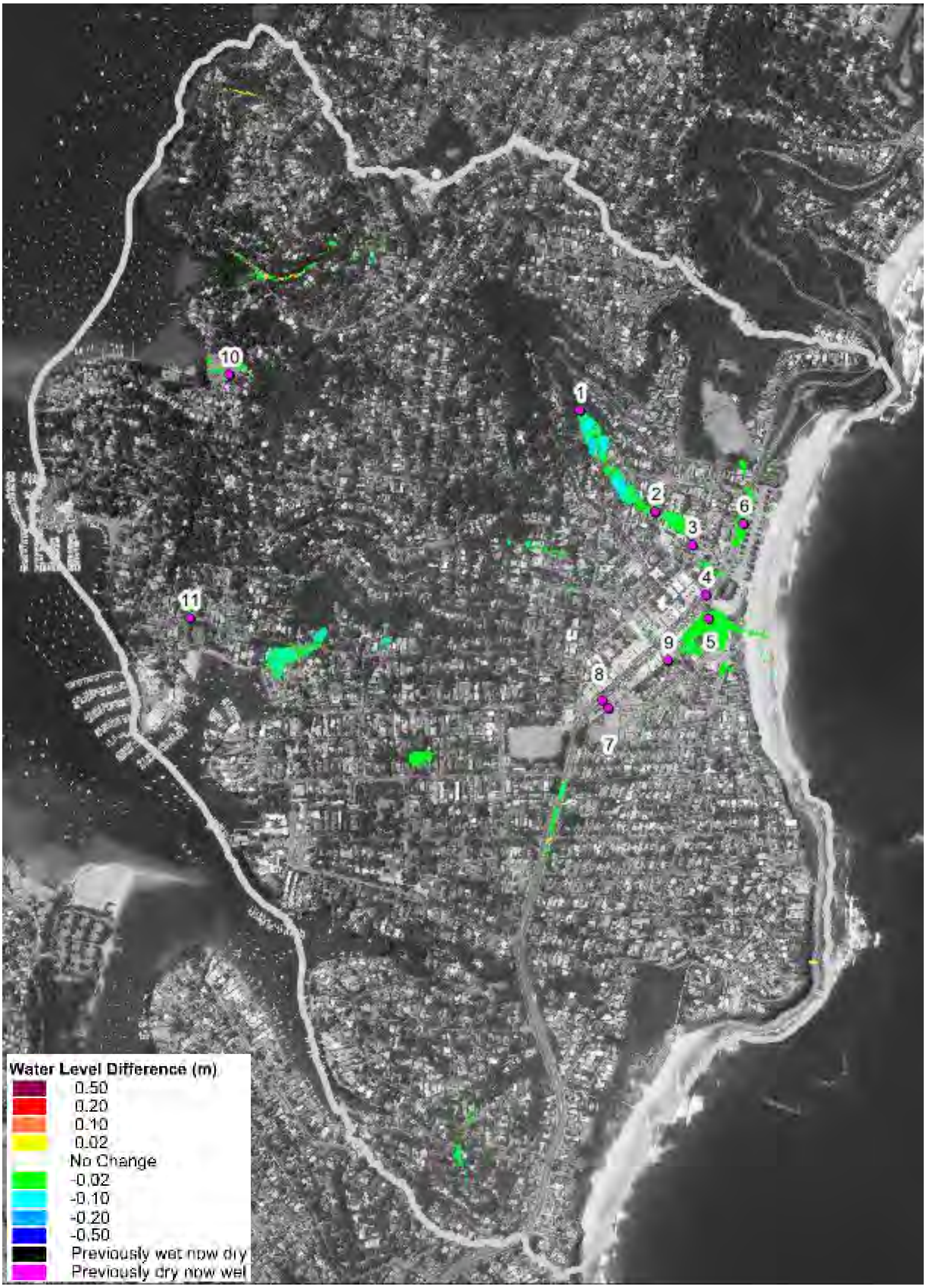


Plate 26 Flood level difference map with no blockage of hydraulic structures

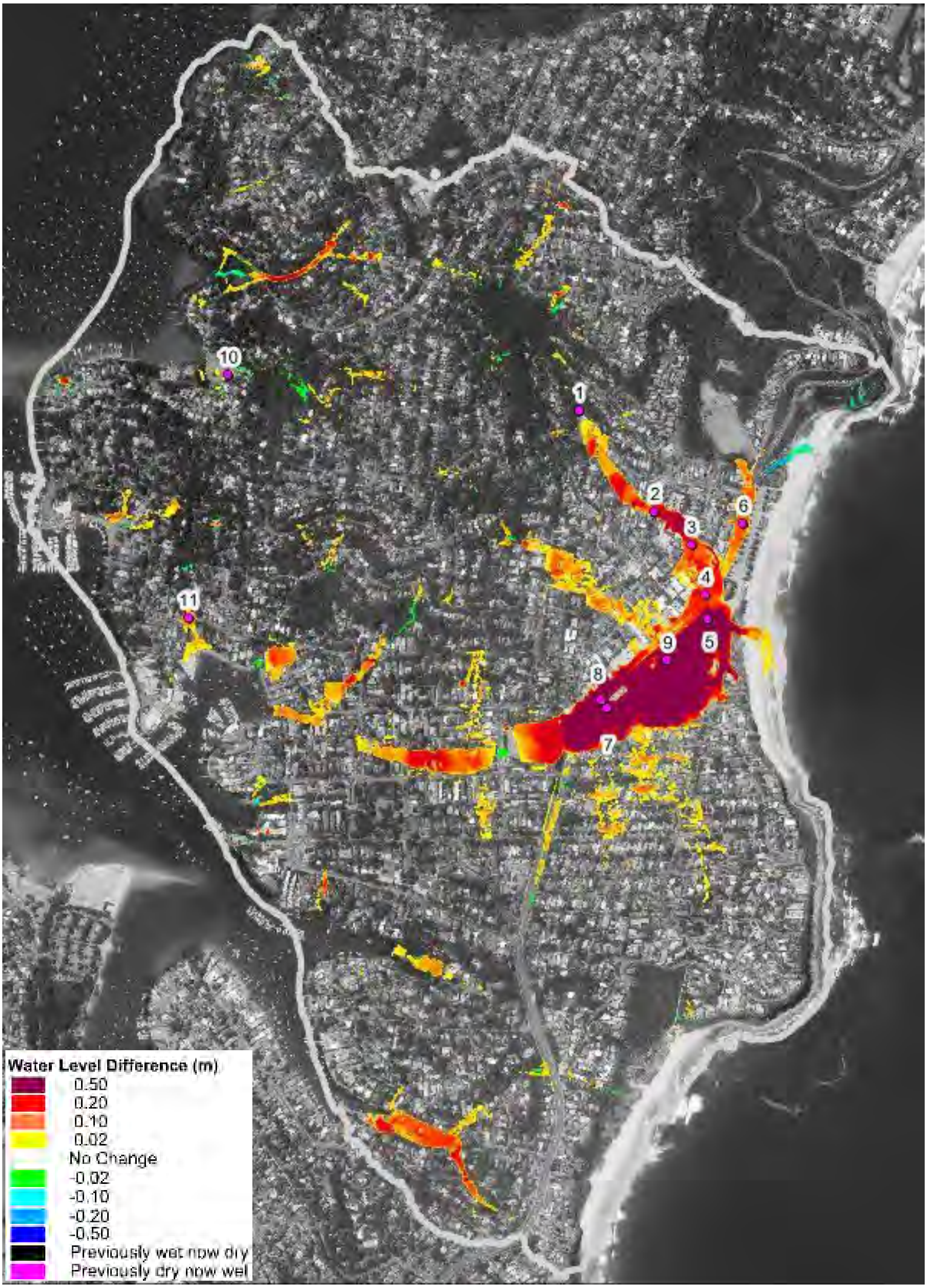


Plate 27 Flood level difference map with complete blockage of hydraulic structures

The results of the blockage sensitivity analysis do show that the model results are sensitive to variations in blockage in the immediate vicinity of major hydraulic structures, particularly if complete blockage occurs. This outcome emphasises the need to ensure key drainage infrastructure and bridges and culverts are well maintained (i.e., debris is removed on a regular basis).

7.3 Australian Rainfall & Runoff 2016

The design flood estimates documented in this study are based upon hydrologic procedures outlined in 'Australian Rainfall and Runoff – A Guide to Flood Estimation' (Engineers Australia, 1987) (referred to herein as ARR1987). A revised version of Australian Rainfall and Runoff was released in late 2016 (Geoscience Australia, 2016) (referred to herein as ARR2016). Therefore, additional investigations were completed to confirm the impact that the revised hydrologic procedures may have on design flood behaviour across Newport.

Although the TUFLOW model developed as part of this study was used to simulate both hydrologic and hydraulic processes, the large number of simulations required by ARR2016 required the bulk of the hydrologic analysis in this assessment to be completed in an XP-RAFTS hydrologic model. Once the XP-RAFTS model was used to narrow down the number of storms that required assessment, the remainder of the analysis was completed in TUFLOW.

A review of the ARR1987 versus ARR2016 1% AEP rainfall depths (refer **Table 20**) indicates that the ARR2016 rainfall depths are higher than ARR1987 depths for storm durations less than 30 minutes. However, the differences are less than 10%. For storm durations greater than 30 minutes, ARR2016 rainfall depths are lower than the equivalent ARR1987 rainfall depth. Most notably, for the 2-hour storm (i.e., the storm duration that is most commonly critical across the Newport study area), the ARR2016 rainfall depths are approximately 20% lower than the ARR1987 rainfall depths.

One of the most significant differences between ARR2016 and ARR1987 is in the use of temporal patterns. ARR1987 used a single temporal pattern for each AEP/storm duration while ARR2016 uses 10 temporal patterns for each AEP/storm. The ARR2016 temporal patterns were downloaded from the ARR data hub. In accordance with ARR2016, the "rare" group of temporal patterns were applied to the ARR2016 1% AEP rainfall depths.

The range of temporal patterns was used in conjunction with the ARR2016 rainfall information. The XP-RAFTS model was used to simulate each 1% AEP storm duration for the full suite of temporal patterns. The peak discharges from the full suite of temporal patterns were reviewed to determine the "critical" temporal pattern. The temporal pattern that generated the closest, but next highest peak discharge to the average discharge, was selected as the "critical" temporal pattern for each subcatchment. This determined the following critical durations and temporal patterns:

- 20-minute storm with temporal pattern ID 4404 (this was the most commonly critical duration and temporal pattern across the study area);
- 25-minute storm with temporal pattern ID 4460;
- 30-minute storm with temporal pattern ID 4498; and,
- 60-minute storm with temporal pattern ID 4559.

Table 20 Comparison between ARR1987 and ARR2016 1% AEP Rainfall Depths

DURATION	Rainfall Depth (mm)		Difference between ARR2016 and ARR1987 Rainfall Depths (%)
	ARR1987	ARR2016	
10 min	33.6	37.1	9%
15 min	43.1	46.7	8%
20 min	50.9	53.6	5%
25 min	57.5	58.9	2%
30 min	63.3	63.2	0%
45 min	77.3	72.7	-6%
1 hour	88.0	79.6	-11%
1.5 hour	104	89.9	-16%
2 hours	117	98.3	-19%
3 hours	136	112	-22%
4.5 hours	158	130	-21%
6 hours	175	145	-21%
9 hours	204	173	-18%
12 hours	227	196	-16%

As noted in Section 5.3.1, the ARR1987 analysis indicated that the critical storm duration across Newport typically varied between 60 and 120 minutes. Accordingly, the ARR2016 critical durations are typically much shorter.

The critical storms and temporal patterns were subsequently applied to the TUFLOW model and the TUFLOW model was used to re-simulate the 1% AEP flood. Flood level difference mapping was prepared to show the location and magnitude of changes in 1% AEP levels and extents. The difference mapping is provided in **Plate 28**.

Plate 28 shows that ARR2016 is predicted to produce lower flood levels and depths relative to the 1987 version of ARR across the study area. In general, the flood level reductions are predicted to be less than 0.1 metres. However, reductions of about 0.25 metres are predicted across the Newport CBD. Therefore, the adoption of the hydrologic approach documented in the 1987 version of ARR is considered to be providing conservative flood level estimates.

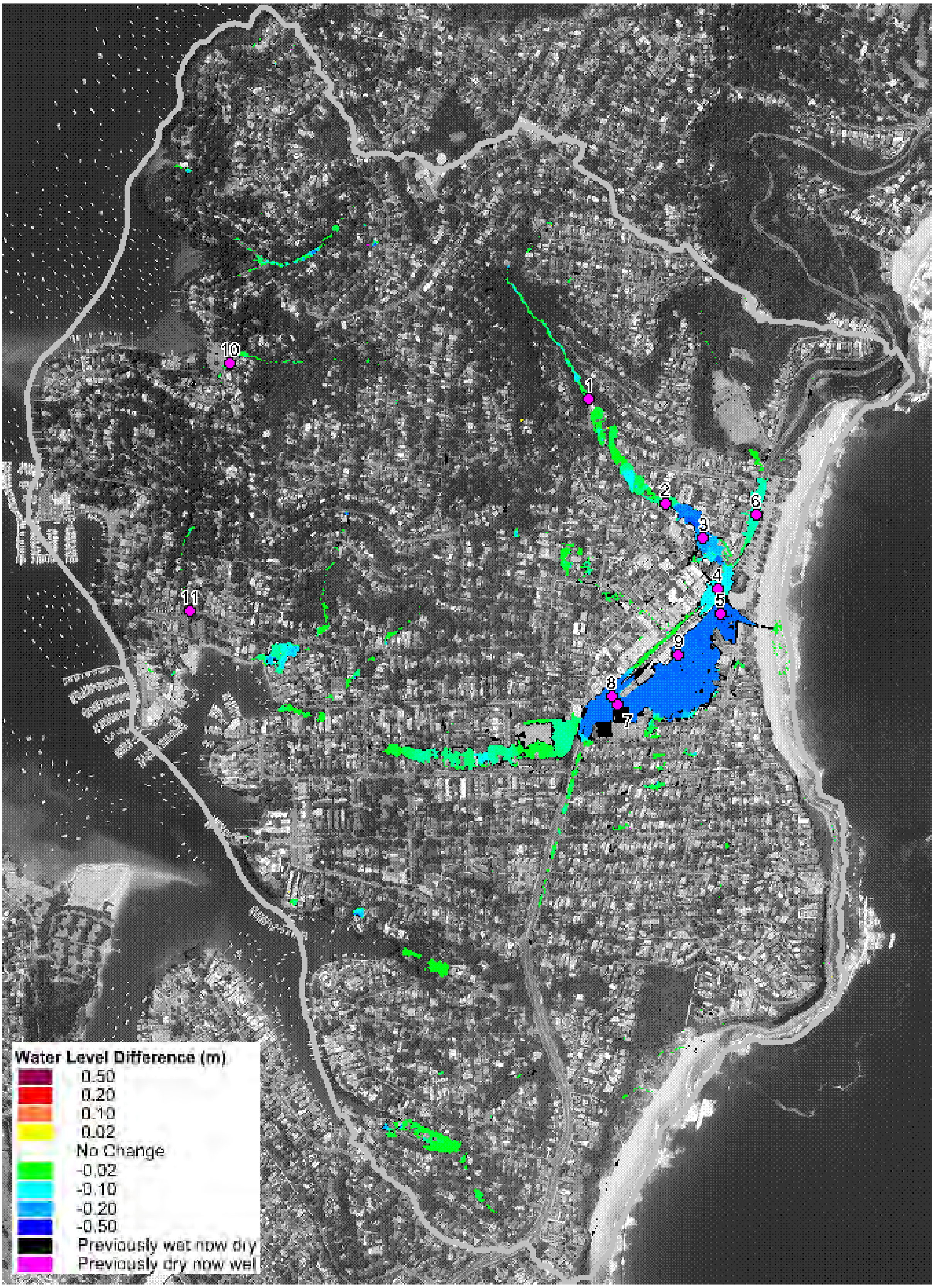


Plate 28 Flood level difference map with ARR2016

8 CLIMATE CHANGE ASSESSMENT

8.1 General

Climate change refers to a significant and lasting change in weather patterns arising from both natural and/or human induced processes. The Office of Environment and Heritage's (formerly Department of Environment, Climate Change and Water) *'Practical Consideration of Climate Change'* states that climate change is expected to have adverse impacts on sea levels and rainfall intensities into the future.

Increases in rainfall intensities would result in increases in runoff volumes and discharges across the catchment. This, in turn, would likely produce an increase in the depth, extent and/or velocity of floodwaters.

The lower reaches of the catchment adjoining the Pittwater Estuary and Pacific Ocean are influenced by the tide. Therefore, elevated sea levels have the potential to increase the depth and extent of inundation across the lower reaches of the catchment during flood and non-flood times. Elevated estuary/ocean levels would also make it more difficult for water from the local catchment to drain away during floods.

This flood study will form the basis for defining flood behaviour for a number of years into the future. It will also form the basis for the future Floodplain Risk Management Study, where a range of flood risk mitigation measures will be evaluated. Therefore, it is important that potential climate change impacts are quantified so that development decisions and the robustness of flood risk mitigation measures can be assessed in an informed manner.

The following sections describe the process that was employed to quantify potential climate change impacts on flooding across the Newport study area.

8.2 Rainfall Intensity Increases

8.2.1 Overview

The *'Practical Consideration of Climate Change'* (Department of Environment and Climate Change, 2007) guideline states that rainfall intensities are likely to increase in the future. The NSW Government's *'Climate Change in the Sydney Metropolitan Catchments'* (CSIRO, 2007) elaborates on this further and suggests that annual rainfall is likely to decrease, however, extreme rainfall events are likely to be more intense. It is anticipated that extreme rainfall intensities could increase by between 2% and 24% by 2070 (Department of Environment and Climate Change, 2007). This has the potential to increase the severity of flooding across Newport in the future.

To gain an understanding of the potential impact that climate change-induced rainfall intensity increases may have on flood behaviour across the catchment, additional climate simulations were completed. Due to the wide potential variability of future rainfall intensities, the *'Practical Consideration of Climate Change'* (Department of Environment and Climate Change, 2007) recommends that additional simulations should be completed with 10%, 20% and 30% increases in rainfall intensities to quantify the potential impacts associated with climate change across a range of different rainfall intensity increases. The outcomes of the additional simulations are presented below.

8.2.2 Increase in Rainfall Intensity Simulations

The TUFLOW model was used to perform additional simulations including a 10%, 20% and 30% increases in 1% AEP rainfall intensities. The ocean level adopted as part of the "base" design flood simulations was not altered as part of these simulations.

Peak floodwater levels were extracted from the results of the modelling and were compared against peak water flood levels for 'base' 1% AEP conditions. This allowed water level difference mapping to be prepared showing the magnitude of any change in water levels associated with the increases in rainfall intensity. The difference mapping is presented in **Plate 29**, **Plate 30** and **Plate 31**.

Peak 1% AEP flood levels were also extracted from the results of the climate change simulations at various locations across the catchment and are presented in **Table 21**.

The results show that a 10% increase in rainfall intensity has the potential to increase peak 1% AEP water levels by over 0.1 metres at some locations. A 30% increase in rainfall is predicted to increase peak 1% AEP flood levels by over 0.3 metres across some locations.

The most significant increases in flood level are concentrated near the Newport commercial area (specifically in the Bramley Ave/Ross St/The Boulevard). As discussed, this area serves as a large "basin". Therefore, the inclusion of additional runoff combined with the already limited drainage capacity in this area results in this basin filling more rapidly.

In addition to the Newport commercial area, notable increases in flood level are expected along all major overland flow paths and "ponding" areas significantly impacted. Steeper areas where currently inundation depths are shallow are not predicted to be significantly impacted as a result of rainfall intensity increases

Accordingly, the outcomes of the climate change simulations show that increases in rainfall intensity have the potential to increase the severity of flooding across the catchment in the future.

8.3 Increases in Ocean Level

8.3.1 Overview

The 'NSW Coastal Planning Guideline: Adapting to Sea Level Rise' (Department of Planning, 2010) provides guidance on the expected impacts that climate change may have on ocean levels. The '*NSW Sea Level Rise Policy Statement*' (Department of Environment and Climate Change, 2009) states that ocean level increases of 0.4 metres could be expected by 2050 and a 0.9 metre increases could occur by 2100. This has the potential to increase the frequency and severity of flooding across the lower reaches of the Newport catchment in the future.

Table 21 Peak 1% AEP Flood Levels from Climate Change Simulation at Various Location across the Catchment

Location (refer to Plates 28 to 30 for locations)		Peak 1% AEP Flood level (mAHD)							
		Base Case	Rainfall Intensity Increases			Ocean Level Increase		Rainfall Intensity & ocean Level Increase	
			10% Increase	20% Increase	30% Increase	0.4m Increase	0.9m increase	10% Increase in Rainfall & 0.9m Increase in Ocean Level	30% Increase in Rainfall & 0.9m Increase in Ocean Level
1	Howell Close Culvert	14.94	14.98	15.02	15.07	14.94	14.94	14.98	15.07
2	Upstream Ocean Ave	7.11	7.16	7.23	7.30	7.11	7.11	7.16	7.30
3	Foamcrest Avenue	6.13	6.18	6.21	6.24	6.13	6.13	6.18	6.25
4	Barrenjoey Rd/Coles Pde	4.64	4.70	4.74	4.79	4.65	4.65	4.71	4.79
5	Coles Pde Carpark	4.13	4.25	4.36	4.47	4.16	4.24	4.35	4.55
6	Barrenjoey Rd	7.00	7.05	7.09	7.13	7.00	7.00	7.05	7.13
7	Upstream of The Boulevarde	4.16	4.28	4.39	4.49	4.19	4.26	4.37	4.56
8	Barrenjoey Rd/The Boulevarde	4.16	4.28	4.39	4.49	4.19	4.26	4.37	4.56
9	Upstream of Bramley Ave	4.13	4.27	4.38	4.50	4.17	4.25	4.37	4.58
10	Prince Alfred Pde at Florence Park	4.23	4.25	4.27	4.29	4.23	4.24	4.26	4.29
11	Irrubel Rd/Crystal St	7.01	7.03	7.06	7.08	7.01	7.01	7.03	7.08

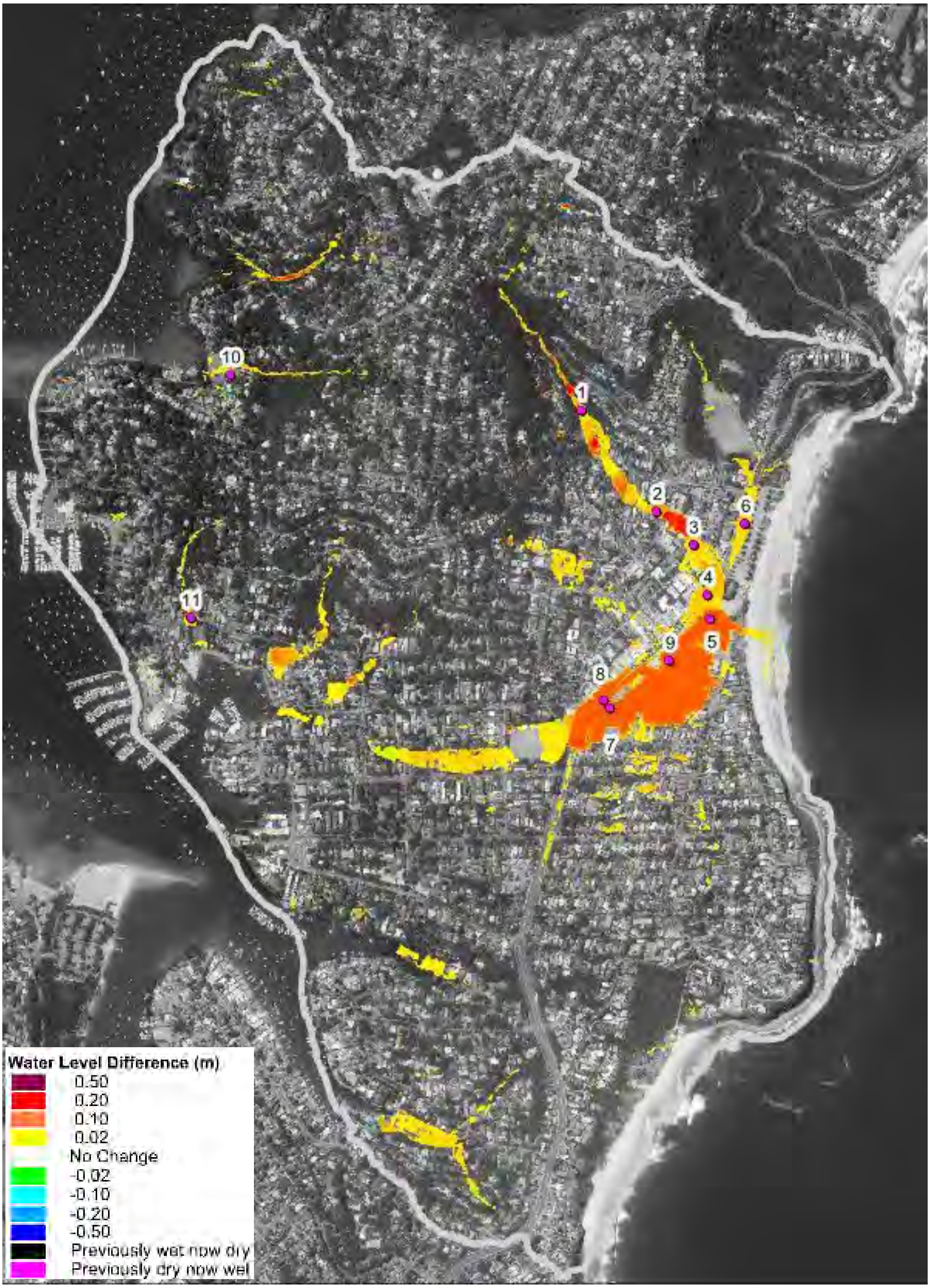


Plate 29 Flood level difference map with 10% increase in Rainfall

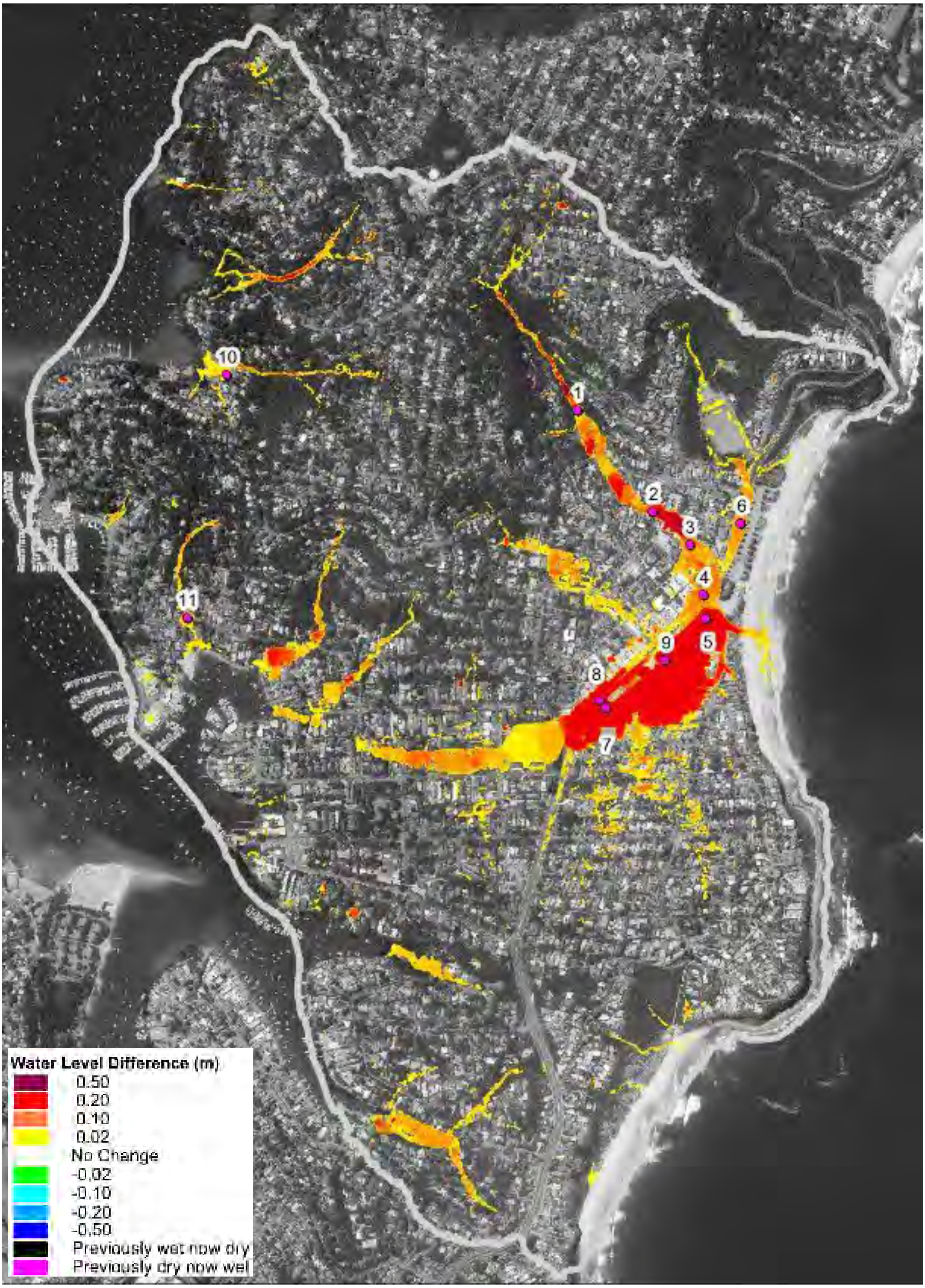


Plate 30 Flood level difference map with 20% increase in Rainfall

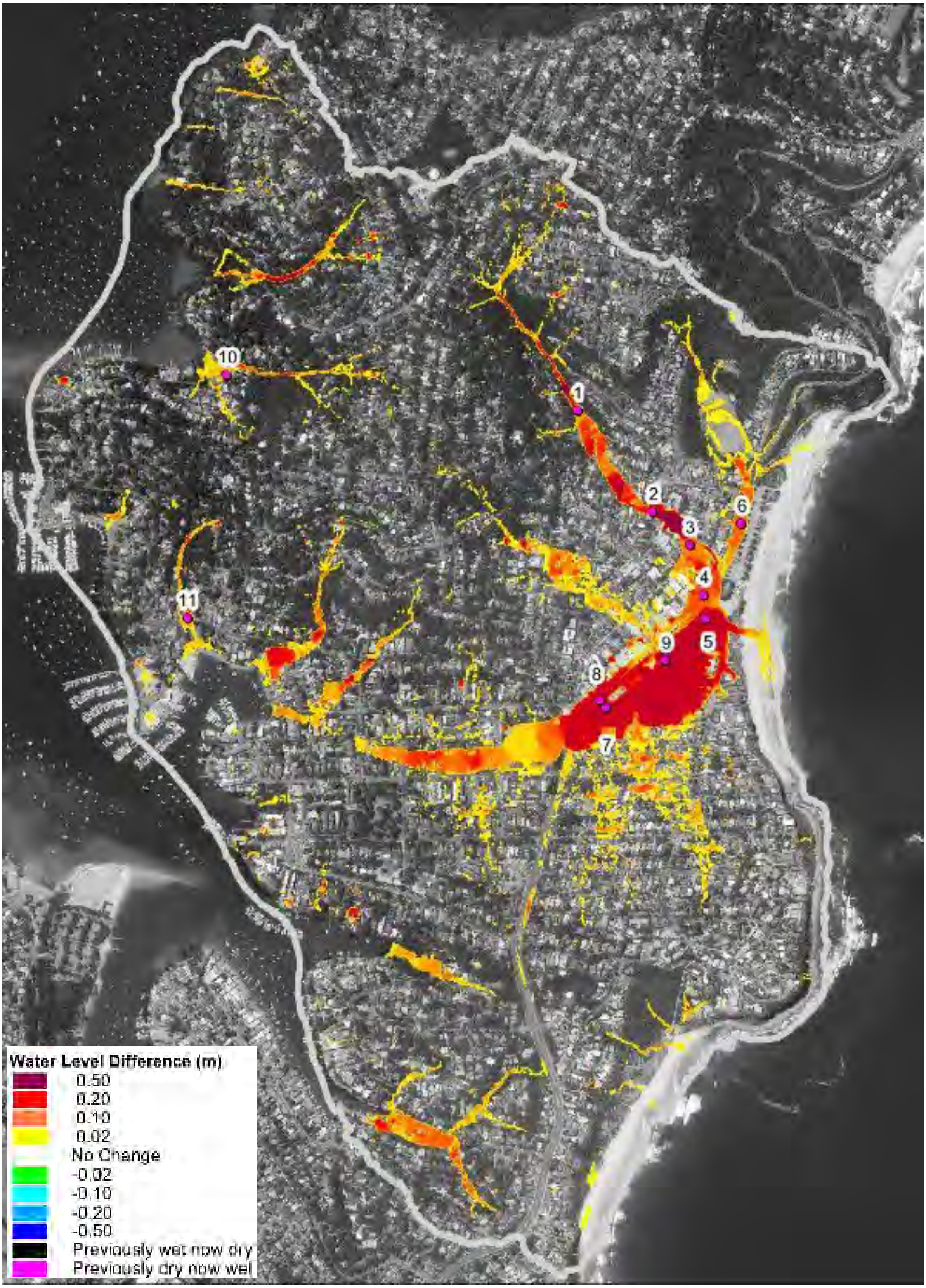


Plate 31 Flood level difference map with 30% increase in Rainfall

8.3.2 Ocean Level Rise Simulations

To gain an understanding of the potential impact that sea level rise may have on flood behaviour across the catchment, additional 1% AEP and PMF simulations were completed with increases in ocean and estuary levels. To represent these conditions, the TUFLOW model was updated to reflect the two elevated ocean level scenarios:

- 0.4 metre increase (2050 scenario): Peak ocean/estuary water level increased from 1.45 mAHD to 1.85 mAHD
- 0.9 metre increase (2100 scenario): Peak ocean/estuary water level increased from 1.45 mAHD to 2.35 mAHD

The updated model was used to re-simulate the 1% AEP and PMF events for both ocean level increase scenarios. Peak floodwater levels for the 1% AEP and PMF were extracted from the results of the modelling and were compared against peak water flood levels for 'base' conditions. This allowed water level difference mapping to be prepared showing the magnitude and location of any change in flood level associated with the increases in ocean and estuary water levels. The difference mapping for the 0.4 metres increase in ocean level is presented in **Figure 46** for the 1% AEP and **Figure 47** for the PMF. Difference mapping for the 0.9 metre increase in ocean level scenario is presented in **Figure 48** for the 1% AEP and **Figure 49** for the PMF.

Peak 1% AEP flood levels were also extracted from the results of the sea level rise simulations at various locations across the catchment and are presented in **Table 21**.

Figure 45 shows that a 0.4 metre increase in ocean level has minimal impact during the 1% AEP for areas adjoining the Pittwater Estuary. This is primarily due to the steeper terrain across this section of the catchment and the significant buildings setbacks. Areas along the Pacific Ocean frontage, particularly around the Newport CBD, are predicted to experience flood level increases of up to 0.08 metres. The flood level increases that are predicted in this area are primarily associated with the elevated ocean level reducing the ability of the stormwater system to drain runoff from this area into the ocean.

Figure 47 indicates that during the PMF, the 2050 sea level will increase flood levels on properties adjoining Crystal Bay by less than 0.1 metres. Low lying areas near the Newport CBD are predicted to experience flood level increases of up to 0.2 metres in isolated locations, however, increases are more typically less than 0.1 metres. Flood level increases are also predicted along the north-west flow path extending through Coles Parade, Foamcrest Avenue and Ocean Street. The increases are, again, associated with the elevated ocean levels reducing the efficiency of the drainage system. The magnitude of the increases through most of these areas is predicted to be less than 0.1 metres.

Figure 48 shows that a 0.9 metre increase in ocean level is predicted to result in a more significant impact on properties adjoining Crystal Bay on the Pittwater Estuary during the 1% AEP flood. Flood level increases of up to 0.5 metres are predicted across this area. The Newport CBD is also predicted to experience increases in 1% AEP flood levels of over 0.15 metres.

The flood level difference mapping for the PMF shown in **Figure 49** show that the year 2100 sea level predictions will increase the flood affectation of multiple properties adjoining Crystal Bay. Flood level increases of over 0.2 metres are predicted across much of this area. Along the Pacific Ocean frontage, flood level increases of up to 0.4 metres are predicted within the Newport CBD. The flow path running between Coles Parade, Foamcrest Avenue and Ocean St is predicted to experience increases In PMF flood levels of up to 0.15 metres.

Accordingly, the outcomes of the climate change simulations show that increases in sea level have the potential to increase the severity of flooding across the lower sections of the catchment adjoining the Pittwater Estuary and Pacific Ocean. The most vulnerable areas include properties adjoining Crystal Bay, and the low-lying areas of the Newport CBD, Barrenjoey Road, Coles Parade/Foamcrest Avenue and Gladstone St.

8.4 Increases in Rainfall Intensity and Ocean Level

8.4.1 Overview

In order to gain an understanding of the combined impacts that rainfall intensity and ocean level increases may have on existing flood behaviour, additional climate change simulations were completed. Two separate scenarios were represented;

- 0.9 metre increase in ocean level with 10% increase in rainfall intensity; and,
- 0.9 metre increase in ocean level with 30% increase in rainfall intensity.

The 0.9 metre increase in ocean level was represented for each design flood by making the following modifications to the Pittwater Estuary / Pacific Ocean level in the TUFLOW model:

- 2%AEP, 5% AEP, 10% AEP, 20%AEP floods: ocean/estuary level was raised from 0.95 mAHD to 1.85 mAHD; and,
- PMF, 0.1% AEP, 0.2% AEP, 0.5% AEP and 1% AEP floods: ocean/estuary level was raised from 1.45 mAHD to 2.35 mAHD; and,

8.4.2 Year 2100 Sea Level Rise with 10% Increase in Rainfall Intensity

The TUFLOW model was used to simulate the 0.9 metre increase in ocean level with 10% increase in rainfall intensity for the 1% AEP and PMF floods. Peak floodwater levels were extracted from the results of the modelling and were compared against peak water flood levels for 'base' conditions. Water level difference mapping was prepared showing the magnitude and location of any change in flood levels. The difference mapping is presented in **Figure 50** for the 1%AEP and **Figure 51** for the PMF.

Peak 1% AEP flood levels were also extracted from the results of the sea level rise simulations at various locations across the catchment and are presented in **Table 21**.

The flood level difference mapping shown in **Figure 50** and **51** indicate that a 10% increase in rainfall, when combined with the 0.9 metre increase in ocean level, will increase water levels along all overland flow paths, waterways and "ponding" areas. Most area are predicted to be subject to relatively small flood level increases (i.e., 0.1 metres). Some areas, particularly those adjacent to major flow paths will experience flood level increases of up to 0.2 metres in the 1% AEP and 0.4 metres in the PMF.

In general, the impact of ocean level and rainfall intensity increases is magnified in the lower lying areas (e.g., Newport CBD). Across the more elevated sections of the catchment, the elevated ocean levels are not predicted to increase flood levels further (relative to the scenario which considered rainfall intensity increases in isolation).

8.4.3 Year 2100 Sea Level Rise with 30% Increase in Rainfall Intensity

The TUFLOW model was then used to simulate the 0.9 metre increase in ocean level scenario with a 30% increase in rainfall intensity for the 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% and 0.1% AEP events as well as the PMF. Peak floodwater depth mapping was prepared for all simulated flood events and is shown in **Figures 52** to **60**.

Velocity mapping was also prepared for the 1% AEP and rarer flood events and is presented in **Figures 61** to **65**.

Floodwater surface profiles were also extracted and are presented in **Figure 66**. Peak flood levels at a selection of roadway intersections across the catchment are also presented in **Table J1** within **Appendix J**. The location of the identification (ID) numbers are shown by the yellow points in **Figure J1** in **Appendix J**.

Water level difference mapping was prepared showing the magnitude of any change in flood levels associated with the increases in ocean water levels and rainfall intensities. The difference mapping is presented in **Figures 67** to **75**.

Provisional flood hazard and hydraulic category mapping was also prepared for the 1%AEP and PMF events and are presented in **Figures 76** to **79**.

Peak discharges at discreet locations throughout the Newport study area were extracted and are provided in **Table J2** in **Appendix J.** Peak discharges for existing climate conditions are also provided for comparison. The location of each flow hydrograph identification (ID) number is shown in **Figure H1** in **Appendix H**.

Discussion

Figures 67.1 to 75.5 indicate that a 30% increase in rainfall intensity together with a 0.9 metre increase in ocean level will have a significant impact on existing flood level across Newport. Increases in 1% AEP flood level of up to 0.2 metres are common within and adjacent to major flow paths and increases of up to 0.7 metres are anticipated in major “ponding” areas (the Newport CBD being the most notable “ponding” areas). Properties backing onto the Pittwater Estuary could expect increases in flood levels of up to 0.9 metres during most events.

Figure 76 and **77** shows that although the rainfall intensity and ocean level increases are predicted to generate flood level increases through the Newport CBD, there is not predicted to be a substantial increase in the “high hazard” area (although there is predicted to be a notable increase in the low hazard extent).

9 FLOOD PLANNING AREA

9.1 Background

Flood Planning Levels (FPLs) are an important tool in the management of flood risk. FPLs are derived by adding a freeboard to the "planning" flood. The FPLs can then be combined with topographic information to establish the Flood Planning Area (FPA). The FPL and FPA can then be used to assist in managing the existing and future flood risk by:

- Setting design levels for mitigation works (e.g., levees); and
- Identifying land where flood-related development controls apply to ensure that new development is undertaken in such a way as to minimise the potential for flood impacts on people and property (e.g., minimum floor level requirements).

As part of the flood study Council requested that a flood planning area be defined to assist in identifying land subject to flood related development controls. The following sections describe the approach that the former Pittwater Council used to define flood planning levels and areas (referred in herein as the "Cardno 2013" approach). It also provides an assessment of the suitability of applying these approaches to the Newport study area and makes suggestions on an alternate approach.

9.2 Cardno 2013 Criteria/Approach

As discussed, flood planning levels are derived by combining a "planning flood" with a "freeboard". Northern Beaches Council has defined the 100-year ARI (1% AEP) flood as the planning flood through its Local Environmental Plan. This is consistent with the "Guideline on Development Controls on Low Flood Risk Areas – Floodplain Development Manual" (Department of Planning, 2007) which states that "*…unless there are exceptional circumstances, councils should adopt the 100-year flood as the FPL for residential development*". Accordingly, the 1% AEP flood is considered to be appropriate for application as the planning flood to the Newport catchment.

In areas of mainstream flooding (i.e., areas with defined channels/waterways), Council applies a 0.5 metre vertical freeboard directly to the 1% AEP flood level to define the flood planning level. This flood planning level is then extended laterally until it strikes higher ground to define the floodplain area. This approach is commonly employed to define mainstream flood planning levels/areas across NSW.

However, in areas of particularly steep terrain, it was frequently found that the flood planning areas derived using this traditional approach were not significantly different to the base 1% AEP flood extent. Therefore, an alternative means of defining the flood planning area in overland flooding areas as part of the 'Overland Flow Mapping and Flood Study' (Cardno, 2013). This aimed to provides a more conservative description of the flood planning area in areas of overland flow where steep terrain was typical. The study ultimately defined two different overland flow regimes with different flood planning criteria applied to each;

- Major Overland Flow (areas where the overland flow depths exceeded 0.3 metres): A 5 metre horizontal extension is applied to the 1% AEP extent to define the flood planning area. The flood planning level in this area is defined as the peak 1% AEP flood level plus a 0.5 metre vertical freeboard.
- Minor Overland Flow (areas where overland flow depths were greater than 0.15 metres but less than 0.3 metres): No horizontal extension of the planning flood (i.e., the 1% AEP flood extent is used to define the flood planning area). A 0.3 metre vertical freeboard is applied to the 1% AEP flood level to define the flood planning level.

Therefore, the Cardno 2013 approach defines the flood planning area according to whether main stream or overland flooding is predicted. The overland flooding is further subdivided based on the overland flow depth to determine the flood planning level and area.

9.3 Suitability of Freeboard

As discussed, freeboard is a factor of safety that is used to account for uncertainties in deriving the planning flood levels. Freeboard is used to account for the following uncertainties:

- Modelling uncertainty (i.e., uncertainty associated with modelling inputs such as Manning's "n" roughness and blockage of stormwater pits);
- Factors that can't be explicitly represented in the modelling (e.g., parked cars, flow obstructions from debris mobilised during a flood, wave action from vehicles or coastal/oceanic forces).

9.3.1 Modelling Uncertainty

As discussed previously, the development of computer models requires the specification of parameters that are not always known with a high degree of certainty. The computer model that was created as part of this study was developed based upon best estimates of model parameters. The model was subsequently shown to produce realistic results relative to available historic flood information as well as past studies and alternate calculation techniques. Accordingly, the computer model is considered to provide a reasonable estimate of design flood behaviour across the catchment.

However, the outcomes of the sensitivity analysis indicate that the design flood level estimates may be subject to variations if one or more of the input variables change (e.g., stormwater and culvert blockage, hydraulic roughness, initial and continuing losses). Accordingly, the model input parameters and design flood level estimates presented in this report are subject to some uncertainty.

To gain an understanding of how this parameter uncertainty may impact on the 1% AEP flood level estimates, additional statistical analyses were completed based upon the outcomes of the various sensitivity simulations. This analysis aimed to assign "confidence limits" to the peak 1% AEP flood level estimates.

In order to reliably define confidence limits to the 1% AEP results, it would be necessary to undertake thousands (potentially tens of thousands) of simulations to reflect the numerous combinations of potential parameter estimates and provide a sufficiently large population to enable meaningful statistical analysis. Unfortunately, the long simulation times only permit a limited number of parameter scenarios to be investigated.

In instances where a sufficiently large "population" of results is not available, it is still possible to derive confidence limits using the Student's t-test (Zhang, 2013). This approach involves interrogating peak flood level estimates from all "base", sensitivity simulations at each TUFLOW grid cell. This information is used to calculate a mean water level and standard deviation at each grid cell. This information can then be combined with the number of degrees of freedom (i.e., number of different 1% AEP simulations minus 1) and a "t-table" to develop 95% confidence limit estimates at each TUFLOW grid cell.

The resulting "95% Confidence Limit" grid is shown in **Plate 32**. Yellow colours indicate small confidence limits (i.e., more confidence in results) and red colours indicate higher confidence limits (i.e., less confidence in results). It is noted that the Student's t-test assumes that the population of results is "normally" distributed with the majority of the parameters and results located in close proximity to the mean. However, the sensitivity analysis typically adopts parameter values that are at the extremes of realistic ranges. As a result, the population of water level results is unlikely to be normally distributed. As a result, the calculated confidence limits are likely to be conservative.

The confidence interval grid provided in **Plate 32** shows that across the majority of the catchment, the confidence limit is better than 0.10 metres. That is, we are 95% confident that the "true" 1% AEP flood level is contained within ±0.10 metres of the "base" design simulation results documented in **Section 5** across the majority of the catchment.

However, some localised areas are subject to greater uncertainty (i.e., larger confidence limits). This includes the area just upstream of the Howell Close culvert inlet, a small section of overland flow path between Ocean and Foamcrest Ave, and across the rear of properties that back onto the Pittwater Estuary, where the confidence limits approach 0.2 metres.

Therefore, there appears to be greater uncertainty in main stream flooding areas. This is not unexpected as open channels will typically include bridges/culverts where blockage can have a significant impact on flood level estimates.

Overall it is considered that the following allowances are sufficient to account for modelling uncertainty:

- Mainstream (i.e., open channels) and foreshore areas: 0.2 metres
- Overland flooding areas: 0.1 metres

9.3.2 Other Uncertainty

It is more difficult to quantify the potential uncertainty associated with "other" factors that cannot be explicitly represented by the model (refer **Plate 33**). However, it is argued that the potential impact of these "other" factors is proportional to the flow velocity. That is, there is a greater potential for a flow obstruction to alter flood behaviour in areas of faster moving water relative to areas of "ponded" water. Therefore, a greater allowance should be made for "other" factors in areas of fast moving water.

Plate 32 Water level uncertainty grid for modelling uncertainty

Plate 33 Examples of urban flow obstructions that cannot be explicitly represented in computer model

The impacts of flow obstructions that are commonly encountered in flood modelling (e.g., bridge deck/piers) is quantified by multiplying an empirical loss coefficient (K) by the velocity head ($v^2/2g$) at a particular location. The velocity head can be calculated at any location using the computer model outputs for the 1% AEP flood. The appropriate loss coefficient will vary depending on the location and the type of obstruction. Unfortunately, loss coefficients are not readily documented for the types of flow obstructions typically encountered in an urban environment. Furthermore, Franz and Melching (1997) note that flow through an abrupt transition is a complex phenomenon and evaluation of hydraulic losses is difficult. It also noted that the adoption of a loss coefficient / velocity head to calculate hydraulic losses is an approximation, but no suitable replacement/alternative is readily available. Therefore, this approach was pursued.

The *'HEC-RAS River Analysis System - Hydraulic Reference Manual'* (US Army Corp of Engineers, 2016) notes that loss coefficients will not exceed 1.0 and will generally be higher for subcritical flows than supercritical flows. It goes on to note that:

- A contraction/expansion coefficient of 0.8 is generally appropriate for "abrupt" transitions in cross-sectional area where subcritical flow is evident.
- A contraction/expansion coefficient of 0.2 is generally appropriate for "abrupt" transitions in cross-sectional area where supercritical flow is evident.

It was considered that the types of flow obstructions shown in **Plate 33** would represent an "abrupt" change in flow conveyance so the coefficients listed above were considered appropriate to use to assist in quantifying the potential uncertainty in flood level estimates associated with these "other" factors. The following steps were subsequently employed for developing a layer describing the potential variation in 1% AEP water levels associated with other factors.

- Calculate the 1% AEP Froude number and velocity head at each model grid cell;
- If the Froude number is greater than 1 (i.e., supercritical flow), multiply the velocity head by a loss coefficient of 0.2
- If the Froude number is less than 1 (i.e., subcritical flow), multiply the velocity head by a loss coefficient of 0.8

The resulting water level uncertainty grid for "other" factors is shown in **Plate 34**.

As expected, areas of significant uncertainty associated with other factors is restricted to areas of significant flow velocity. The maximum uncertainty typically occurs along defined waterways/channel and varies between 0.2 and 0.25 metres. Some localised uncertainty of up to 0.2 metres is also predicted along roadways in the steeper sections of the catchment.

Another factor that can impact on flood level estimates is wave action (e.g., waves generated by cars driving through floodwaters). These uncertainties cannot be explicitly quantified using flood modelling results. However, as water depths within the study area are generally shallow and any cars would typically be operating at low speeds, the potential wave heights are unlikely to exceed 0.15 metres and would dissipate significantly in height by the time the wave reaches the edges of the road. Therefore, the uncertainty factor of 0.2 metres discussed above is also considerd to be sufficient to cater for wave action.

9.3.3 Total Uncertainty

The modelling confidence limit grid was added to the uncertainty grid for 'other' factors to represent the total water level uncertainty at a particular location. The resulting total uncertainty grid is presented in **Plate 35**.

It shows that the total uncertainty across overland flooding areas is typically less than 0.3 metres. However, localised increases approaching 0.5 metres are predicted across some areas.

Plate 34 Water level uncertainty grid for other factors that cannot be represented in flood model

Plate 35 Total uncertainty grid that considers model uncertainty, as well as other uncertainty that cannot be explicitly represented in the modelling

A closer review of some of the higher uncertainty areas was completed (refer **Plate 36**). This review indicated that the areas of higher uncertainty were generally localised (e.g., in the immediate vicinity of culverts and fences where blockage can have a significant impact on flood levels in the immediate vicinity of these structures). Although these areas of higher uncertainty are localised, they do have the ability to extend across areas that have the potential to be developed/redeveloped in the future. Therefore, with regard to specifying a suitable freeboard for building controls (e.g., minimum floor levels) it is considered that application of a 0.5 metres freeboard for defining the flood planning level is appropriate.

Plate 36 Example of localised areas of higher uncertainty near The Boulevard

However, when it comes to establishing a suitable freeboard for defining the flood planning area, it is the uncertainty around the perimeter of the 1% AEP extent that will govern the flood planning area (FPA) extent. In this regard, the uncertainty around the perimeter of the 1% AEP extent does not exceed 0.3 metres. Accordingly, a 0.3 metre freeboard is considered suitable for establishing the flood planning area in both overland and mainstream flooding areas.

This suggested approach is slightly different to the Cardno 2013 approach which applies a 0.5 metre freeboard for all areas subject to inundation depths of more than 0.3 metres and a 0.3 metre freeboard in areas subject to depths of between 0.15 and 0.3 metres. Council could continue to use this approach and it will provide a conservative flood planning level and flood planning area. However, Council could consider adopting:

- Overland flow areas: 0.3 metre freeboard for defining the FPA and FPL.
- Mainstream areas: 0.3 metre freeboard for defining the FPA and a 0.5 metre freeboard for defining the FPL.

9.4 Flood Planning Area

As discussed, a freeboard of 0.3 metres is considered appropriate to define the flood planning area in both mainstream and overland flows areas (although a 0.5 m freeboard is considered necessary for defining the flood planning level in mainstream areas).

The 0.3 metre freeboard was applied to the 1% AEP flood level results to form a preliminary flood planning level grid. The flood planning level was subsequently extended into higher ground to form the flood planning area. However, the flood planning area was "clipped" to the PMF extent as it was considered unreasonable for a property located beyond the floodplain (as defined by the extent of inundation during the PMF) to be included in the flood planning area. The resulting flood planning area is shown in **Figure 80**. Also included on **Figure 80** is the PMF extent as well as the 1% AEP "local stormwater" inundation extent.

The number of lots falling within the flood planning area is summarised in **Table 22**. The number of lots is broken down according to the Local Environmental Plan zone to provide an indication of the property types that are impacted. As shown in **Table 22**, 875 lots are predicted to fall at least partly within the flood planning area (out of a total of 4034 lots located within the study area). The majority of the lots are zoned low density residential.

Table 22 Number of Lots Falling within the Flood Planning Area for Existing Conditions

LEP Zone	Description	Number of Lots Impacted
B2	Local Centre (Business)	68
E2	Environmental Conservation	16
E4	Environmental Living	250
R2	Low Density Residential	419
R3	Medium Density Residential	66
RE1	Public Recreation	47
RE2	Private Recreation	1
SP2	Special Activities	6
W2	Recreational Waterways	2
	TOTAL	875

10 HOT SPOTS INVESTIGATION

10.1 General

As part of the study a detailed analysis of flood behaviour was completed across a number of high flood hazard "hot spots". The areas that were identified as "hot spots" are summarised below:

- Howell Close Reserve to Barrenjoey Road, Newport;
- Bramley Ave, Ross St, The Boulevarde, Newport;
- Yachtsmans Paradise, Newport (due to evacuation difficulties); and
- King Street to Bishop Street, Newport

A detailed explanation of the local flood mechanisms for each hot spot is included below.

10.2 Flooding "Hot Spots"

10.2.1 Howell Close Reserve to Barrenjoey Road

As shown in **Figure 18.2** and **Figure 18.4**, a major overland path extends through a number of residential properties extending from the Howell Close Reserve down to Barrenjoey Road. The degree of flooding in the vicinity of Howell Close is significantly impacted by blockage of the culvert located upstream of the reserve. Anecdotal and photographic evidence suggests this culvert is subject to relatively high blockage during most rainfall events (owning to the significant vegetation across the upstream catchment). The severity of flooding across this area could likely be reduced if blockage of the main culvert was minimised.

Floodwaters that are not captured by the main culvert are predicted to travel across the reserve and through a number of Howell Close properties before running through properties on Neptune Road, and Ismona Avenue. Water is then discharged onto Ocean Parade before moving along an open reserve towards Foamcrest Avenue. A large brick wall along the rear of 65-67 Foamcrest Avenue then causes significant ponding and a diversion of flow through 397 Barrenjoey Road before spilling over the wall crest and moving down to Barrenjoey Road.

At the peak of the 1% AEP event, flood depths within properties on Howell Close can reach over 1 metre. Properties on Neptune Road and Ismona Avenue are predicted to reach depths of almost 2 metres, and depths on 65-67 Foamcrest Avenue can reach over 2 metres. Velocities within properties on Howell Close, Neptune Road and Ismona Avenue can exceed 2m/s, however velocities within 65-67 Foamcrest Avenue are generally maintained at below 2m/s as a result of the water primarily ponding in this area.

The flooding described above leads to many properties located adjacent to this overland flow path to be classified with an emergency response classification of 'Flooded Isolated Elevated' or 'Flooded Isolated Submerged', indicating evacuation difficulties and a notable risk to residents.

10.2.2 Bramley Avenue, Ross Street and The Boulevarde

The area contained by Bramley Avenue, Ross Street and The Boulevarde is vulnerable to inundation during both frequent and more severe rainfall events. This area serves as a large topographic “bowl” owing to the elevated terrain to the west as well as the elevated sand dunes fronting Newport Beach to the east. As a result of this topography, water can only escape from this area to the Pacific Ocean via the culvert system. However, the stormwater capacity assessment presented in **Section 5.3.8** and **Figure 33** indicates that this culvert has insufficient capacity to convey the 50% AEP event. Consequently, in events that exceed the 50% AEP event, the capacity of the culvert system is exceeded and the excess flow “builds up” resulting in significant inundation of the area.

Peak depths of over 1 metre are predicted during the 5% and 1% AEP events. Velocities generally do not exceed 1 m/s during the 1% AEP event.

Plate 37 shows that, after 35 minutes of rainfall during the 1% AEP event, many of the roadways in the area would be cut by floodwaters despite many of the properties not being flooded at this time. However, at the peak of the 1% AEP event many of the properties in the area are predicted to be completed inundated. Consequently, the area does present a concern from an emergency response perspective (i.e., evacuation is cut early with potential for above floor inundation, which may result in people attempting to evacuate by walking or driving through >1 metres of water).

Plate 37 1% AEP Depths in vicinity of Ross Street and Bramley Avenue after 35mins of rainfall showing multiple roadway cut locations.

10.2.3 Yachtsmans Paradise

Yachtsmans Paradise is a roadway located on the western side of the study area and is located in a subcatchment that drains to the Pittwater Estuary. The area is located on flat terrain at the confluence of two overland flow paths, the first originating in steep terrain north-east of The Crescent, and the second originating near Philip Rd, south-east of The Crescent. During the 1% AEP event, floodwaters of depths between 0.5 and 1 metres are predicted within the road reserve before spilling through properties on the northern side of Yachtsmans Paradise and draining to the Estuary (refer **Figure 18.5**).

The significant flooding in this area again appears to be associated with the lack of stormwater capacity. However, elevated water levels within the Pittwater estuary may also be contributing to the reduced capacity of the stormwater system in this area (i.e., when water levels in the estuary are elevated, they can "fill" the downstream pipes, which reduces their capacity to covey flows from the local catchment). As shown in **Plate 38**, the stormwater system fails after approximately 30 minutes during the 1% AEP flood near the sag point in Yachtsmans Paradise. As a result, evacuation would be cut relatively early for properties located at the western end of Yachtsmans Paradise. Evacuation is predicted to remain cut for about an hour.

Plate 38 1% AEP Depths in vicinity of Yachtsmans Paradise after 30mins of rainfall showing significant depths forming on the roadway and isolating properties requiring roadway access.

It is noted that the most significant depths of inundation are predicted across the backyards of the properties and the residential buildings themselves tend to be located on more elevated ground. Nevertheless, inundation of multiple residential buildings could occur during the 1% AEP flood and significant depths across the rear of the properties could expose occupants to a significant hazard.

10.2.4 King Street to Bishop Street

Figure 18.3 and **Figure 18.4** show that during the 1% AEP event, a significant overland flow path extends between King Street and Bishop Street, Newport. The topographic relief in this area is subtle, but the available terrain information indicates a topographic depression to the north of Gladstone Street. When this is combined with a stormwater system with limited capacity (i.e., the drainage in this area has less than a 50% AEP capacity), inundation depths of greater than 0.5 metres are predicted across most of the area. Once water moves through this area, it spills onto Bishop Street, across Newport Oval and then on to Barrenjoey Road.

Plate 39 shows that Woolcott Street (located midway along the flow path) is predicted to be cut 40 minutes after the start of rainfall during a 1% AEP event. Accordingly, properties on the northern side of Woolcott Street would become isolated.

Plate 39 1% AEP Depths between King and Bishop Street after 40mins of rainfall showing significant depths forming within properties and isolating properties requiring access from Woolcott Street.

Fortunately, Gladstone Street and Bardo Road, which provide access to/from the majority of the properties in the area, are not predicted to be cut during the 1% AEP flood. As a result, with the exception of properties at the northern end of Woolcott Street, residents should be able to evacuate along Gladstone Street and Bardo Road by walking or vehicle to elevated ground (floodwaters typically recede within 90 minutes).

11 CONCLUSION

This report summarises the outcomes of investigations completed to quantify overland and mainstream flood behaviour across the suburb of Newport. It provides information on design flood levels, depths and velocities as well as hydraulic and flood hazard categories for a range of design floods.

Flood behaviour across the study area was defined using a direct rainfall computer model that was developed using the TUFLOW software. The computer model included a full representation of the stormwater drainage system and all bridges and culverts. Major overland flow impediments including buildings, fences and road embankments were also included in the model.

The computer model was validated using historic flood information for events that occurred in 2012, 2015 and 2016. The model was also verified against alternate modelling techniques as well as results presented in other flood-related reports for the area.

The calibrated and verified model was used to simulate the 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% and 0.1% AEP floods. The Probable Maximum Flood (PMF) was also simulated. The following conclusions can be drawn from the results of the investigation:

- Flooding across the catchment can occur as a result of major watercourses overtopping their banks, overland flooding when the capacity of the stormwater system is exceeded as well as inundation from elevated water levels in the Pacific Ocean and Pittwater Estuary.
- Flooding can occur from a variety of different rainfall durations. The worst-case flooding across Newport typically occurs as a result of rainfall bursts that are less than 3 hours in duration. Accordingly, flooding across the catchment would typically be produced by relatively short, high intensity thunderstorms.
- Some notable overland flow paths are predicted across multiple areas. In general, most of the overland flooding is a result of relatively limited stormwater capacity. More specifically, significant portions of the trunk drainage system do not have sufficient capacity to carry a 20% AEP flood. As a result, during large events, a significant proportion of the flow is conveyed overland.
- Hazard and velocity mapping prepared as part of the study indicates that flow velocities may exceed 2 m/s along some of these overland flow paths, which may pose a danger to adults, young children and the elderly.
- A number of roadways are predicted to be overtopped during the 1% AEP flood. Most roadways would first be cut 30-45 minutes after the initial onset of rainfall and would remain cut for at least 1 hour. As a result, several locations within the study area are predicted to experience evacuation difficulties.
- The following flooding "hot spots" were identified as part of the study:
  - Howell Close to Barrenjoey Road

- Bramley Avenue, Ross Street & The Boulevarde
- Yachtsmans Paradise
- King Street to Bishop Street

12 REFERENCES

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13 Glossary

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. Eg, 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 events 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.
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 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	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 and 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 PMF event. Note that the term flood liable land covers the whole floodplain, not just that part below the FPL (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 SES.
flood planning area	the area of land below the FPL and thus subject to flood related development controls.
flood planning levels (FPLs)	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.

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 — land susceptible to flooding by the PMF event. Flood prone land is synonymous with flood liable land.

flood readiness — 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 flow, or a significant increase in flood levels.

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 study the hazard is flooding which has the potential to cause damage to the community.

Definitions of high and low hazard categories are provided in Appendix L of the *Floodplain Development Manual* (*2005*).

historic flood a flood which has actually occurred.

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 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. Major drainage involves:

- the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or
- water depths generally in excess of 0.3m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or
- major overland 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.

overland flow
is the movement of water (typically from homes, driveways and other surfaces in a built up environment) making its way downslope towards a defined waterway.

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 annual exceedance probability*).

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 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.

TUFLOW	is a 1-dimensional and 2-dimensional flood simulation software. It simulates the complex movement of floodwaters across a particular area of interest using mathematical approximations to derive information on floodwater depths, velocities and levels.
velocity	the speed or rate of motion (*distance per unit of time, e.g., metres per second*) in a specific direction at which the flood waters are moving.
water surface profile	a graph showing the flood stage at any given location along a watercourse at a particular time.
wind fetch	the horizontal distance in the direction of wind over which wind waves are generated.

APPENDIX A

COMMUNITY CONSULTATION

NORTHERN BEACHES
COUNCIL

Newport Flood Study

Community Questionnaire

Northern Beaches Council is preparing a flood study for Newport. The study is the first step in assisting Council to better understand, plan and manage the risk of flooding across the catchment. The extent of the study area is shown in the image below.

Council has engaged consulting engineers Catchment Simulation Solutions to prepare the flood study that will include the development of a computer flood model.

The information that you provide in the accompanying questionnaire will be invaluable in the calibration of the computer model. It will also provide Council with an understanding of existing flooding problems and help identify areas where flood damage reduction measures should be investigated in the future.

The following questionnaire should take no more than 10 minutes to complete. Please try to answer as many questions as possible and give detailed responses (attach additional pages if necessary). Once complete, please return the questionnaire via email or mail (no postage stamp required) by **5 September 2016**. Alternatively, you may complete an online version of the questionnaire at: www.newport.floodstudy.com.au

NORTHERN BEACHES
COUNCIL

If you have any questions or require any further information, please contact:

Melanie Schwecke
Northern Beaches Council
(02) 9970 1111
floodplain@northernbeaches.nsw.gov.au

OR

David Tetley
Catchment Simulation Solutions
(02) 9355 5501
dtetley@csse.com.au

CONTACT DETAILS

Please provide your contact details in case we need to contact you for additional information. This information will remain confidential at all times and will not be published.

Name: ____

Address: ____

____

Phone No. ____

Email: ____

1. WHAT TYPE OF PROPERTY DO YOU LIVE IN / OWN?

☐ Residential
☐ Commercial
☐ Industrial
☐ Vacant Land
☐ Other (Please specify:____)

2. WHAT IS THE OCCUPIER STATUS OF THIS PROPERTY?

☐ Owner occupied
☐ Rental property
☐ Business
☐ Other (Please specify:____)

3. HOW LONG HAVE YOU LIVED / WORKED IN THE AREA?

(a) At this address? ____

(b) In the Newport area? ____

4. HAS YOUR PROPERTY EVER BEEN AFFECTED BY FLOODING?

☐ Yes
☐ No (If you answered No, please go to Question 10)

5. HOW WAS YOUR PROPERTY AFFECTED BY FLOODING?

☐ Roadway was cut by water
☐ My front/backyard was flooded
☐ My garage was flooded
☐ My house was flooded
☐ Other (Please specify:____)

6. CAN YOU PROVIDE ADDITIONAL INFORMATION ON THESE PAST FLOODS?

Date of flood(s)			
Flood depth / height & location			
How confident are you with the height / depth of the flood?	☐ High (exact) ☐ Medium (within 10cm) ☐ Low (within 50cm)	☐ High (exact) ☐ Medium (within 10cm) ☐ Low (within 50cm)	☐ High (exact) ☐ Medium (within 10cm) ☐ Low (within 50cm)

7. DO YOU HAVE ANY PHOTOGRAPHS OR VIDEOS OF THESE FLOODS?

☐ Yes ☐ No

If you answered Yes, can you provide a copy of these photos/videos to assist with the computer flood model calibration?

☐ Yes ☐ No

8. WAS YOUR PROPERTY DAMAGED BY FLOODWATERS?

☐ Yes ☐ No

If 'Yes', please provide details:

____
____
____
____
____
____

NORTHERN BEACHES
COUNCIL

9. IN YOUR OPINION, WHAT WAS THE MAIN CAUSE OF FLOODING?

10. DO YOU HAVE ANY SUGGESTIONS ON WAYS OF REDUCING THE FLOODING PROBLEMS?

11. DO YOU HAVE ANY OTHER COMMENTS, SUGGESTIONS OR INFORMATION THAT YOU THINK MAY ASSIST THE STUDY?

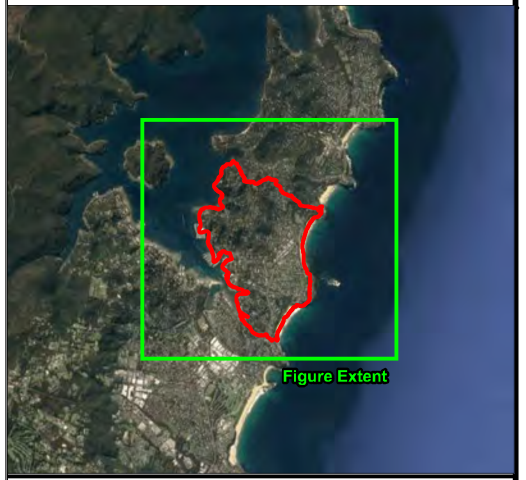
Thank you for taking the time to complete this questionnaire.

The completed questionnaire can be scanned and emailed to: dtetley@csse.com.au or sent to the address below by **5 September 2016**. Flood photos and videos can also be sent to this email or postal address:

Newport Flood Study
Northern Beaches Council
Reply Paid 882
Mona Vale NSW 1660

Catchment Simulation Solutions will analyse the community responses and report back to Council. If you would like to have items returned, please note this and the items will be returned at the conclusion of the study.

NORTHERN BEACHES COUNCIL



LEGEND

Newport Study Area

Questionaire Response Locations
Has flooding been experienced?
- No
- Yes

Notes:

Aerial photograph date: 2014

N
W E
S

Scale 1:13,000 (at A3)

0 0.4 0.8
Km

Figure A1: Spatial Distribution of Questionaire Responses

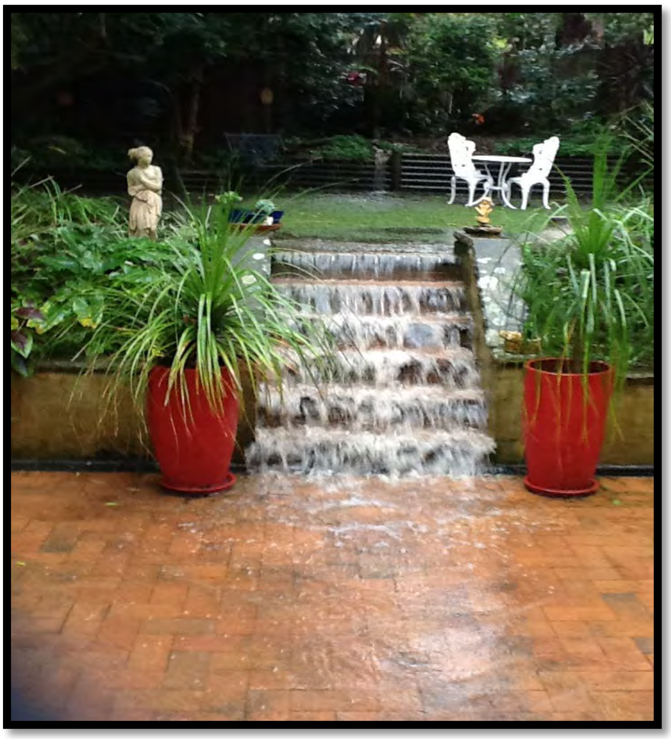
Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: Fig1 - Newport Study Area.wor

Appendix B

Historic Flood Photos

APRIL 2012 FLOOD PHOTOS



Flood water cascading down steps of a private residence on Neptune Road, Newport during the April 2012 flood event (Source L. Barnard)

Flood water across along Barrenjoey Road, Newport during the April 2012 flood event (Source R. Taylor)

Flood waters across Bramley Avenue (view looking north-west) during the April 2012 flood event (Source C. Hastie)

November 2013 Flood Photos

Flood waters along main channel adjoining Newport Bowling Club during the November 2013 flood event (Source C. Hastie)

March 2016 Flood Photos

Flood waters across Bramley Avenue (view looking north-west) during the March 2016 flood event (Source C. Hastie)

June 2016 Flood Photos

Flood water along Ross Street, Newport during the June 2016 flood event

Flood water at the corner of Bramley Avenue and Ross Street, Newport during the June 2016 flood event

Flood water pooling adjacent to the carpark behind Ross Street, Newport during the June 2016 flood event (Source C. Hastie)

Flood waters across Ross Street, Newport during the June 2016 flood event (Source M. Gurman)

Flood waters across Ross Street, Newport during the June 2016 flood event (Source M. Gurman)

Flood Photos with Unknown Dates

Flood waters across Ross Street and Bramley Avenue (view looking south-west down Ross Street from Bramley Avenue).

APPENDIX C

MANNING'S "N" CALCULATIONS

Manning's 'n' Calculations

Prepared by: D. Fedczyna **Date:** 8/11/2016
Checked by: **Date:**

The following provides Manning's' n roughness coefficient calculations based on the modified Cowan method documented in the USGS Paper 2339: "Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains' (Arcement & Schneider). The approach was adopted for direct rainfall modelling as it can account for the higher effective roughness likely to be encountered at shallow flow depths

Overview

Manning's 'n' is calculated using the modified Cowan method based on the following formula:

$n = m\,(n_b + n_1 + n_2 + n_3 + n_4)$

Where: n_b = a base value of n for the floodplain's natural bare soil surface

n_1 = a correction factor for the effect of surface irregularities

n_2 = a value for variations in shape and size of the floodplain cross-section (assumed to be 0.0)

n_3 = a value for obstructions

n_4 = a value for vegetation on the floodplain

m = a correction factor for sinuosity (assumed to be 1.0)

Description of Surface / Material Type

Material Type - Main watercourses
Dense undergrowth with significant boulders/rocks.

n_b Calculation

n_b is extracted from the following table:

Table 1. Base Values of Manning's *n*

Bed Material	Median Size of bed material (in millimeters)	Base *n* Value: Straight Uniform Channel[1]	Base *n* Value: Smooth Channel[2]
Sand Channels			
Sand[3]	0.2	0.012	--
	.3	.017	--
	.4	.020	--
	.5	.022	--

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	.6 .8 1.0	.023 .025 .026	-- -- --
Stable Channels and Flood Plains			
Concrete	--	0.012-0.018	0.011
Rock Cut	--	--	.025
Firm Soil	--	0.025-0.032	.020
Coarse Sand	1-2	0.026-0.035	--
Fine Gravel	--	--	.024
Gravel	2-64	0.028-0.035	--
Coarse Gravel	--	--	.026
Cobble	64-256	0.030-0.050	--
Boulder	>256	0.040-0.070	--

[Modified from Aldridge & Garret, 1973, Table 1 --No data
1Benson & Dalrymple --No data
[2] For indicated material; Chow(1959)
[3] Only For Upper regime flow where grain roughness is predominant

Assume "coarse sand" for watercourse beds

n_b = 0.028

n_1 Calculation (Degree of Irregularity)

n_1 is extracted from the following table:

Smooth	0.000	Compares to the smoothest, flattest flood-plain attainable in a given bed material.
Minor	0.001-0.005	Is a Flood Plain Slightly irregular in shape. A few rises and dips or sloughs may be more visible on the flood plain.
Moderate	0.006-0.010	Has more rises and dips. Sloughs and hummocks may occur.
Severe	0.011-0.020	Flood Plain very irregular in shape. Many rises and dips or sloughs are visible. Irregular ground surfaces in pasture land and furrows perpendicular to the flow are also included.

Assume "severe" to cater for significant undulationsalong most of the watercourse beds

n_1 = 0.011

n_3 Calculation (Effect of Obstructions)

n_3 is extracted from the following table:

Negligible	0.000-0.004	Few scattered obstructions, which include debris deposits, stumps, exposed roots, logs, piers, or isolated boulders, that occupy less than 5 percent of the cross-sectional area.
Minor	0.040-0.050	Obstructions occupy less than 15 percent of the cross-sectional area.
Appreciable	0.020-0.030	Obstructions occupy from 15 percent to 50 percent of the cross-sectional area.

Appreciable obstructions from boulders/rocks present:

n_3 = 0.02

n_4 Calculation (Effect of Vegetation)

n_4 is largely driven by the height of flow relative to the height of vegetation as defined in the following table:

Small	0.001-0.010	Dense growths of flexible turf grass, such as Bermuda, or weeds growing where the average depth of flow is at least two times the height of the vegetation; supple tree seedlings such as willow, cottonwood, arrow-weed, or saltcedar growing where the average depth of flow is at least three times the height of the vegetation.

		three times the height of the vegetation.
Medium	0.010-0.025	Turf grass growing where the average depth of flow is from one to two times the height of the vegetation; moderately dense stemy grass, weeds, or tree seedlings growing where the average depth of flow is from two to three times the height of the vegetation; brushy, moderately dense vegetation, similar to 1-to-2-year-old willow trees in the dormant season..
Large	0.025-0.050	Turf grass growing where the average depth of flow is about equal to the height of the vegetation; 8-to-10-years-old willow or cottonwood trees intergrow with some weeds and brush (none of the vegetation in foliage) where the hydraulic radius exceeds 0.607 m.;or mature row crops such as small vegetables, or mature field crops where depth flow is at least twice the height of the vegetation.
Very Large	0.050-0.100	Turf grass growing where the average depth of flow is less than half the height of the vegetation; or moderate to dense brush, or heavy stand of timber with few down trees and little undergrowth where depth of flow is below branches, or mature field crops where depth of flow is less than the height of the vegetation.
Extreme	0.100-0.200	Dense bushy willow, mesquite, and saltcedar(all vegetation in full foliage), or heavy stand of timber, few down trees, depth of reaching branches.

n_4 = 0.045	When water depth is < 0.1m	(water depth less than height of vegetation)
n_4 = 0.03	When water depth is ~ 0.2m	(water depth equal in height to any vegetation)
n_4 = 0.028	When water depth is ~ 0.3m	(water depth less than twice height of grass)
n_4 = 0.02	When water depth is > 0.4m	(water depth more than twice height of grass)

Final 'n' Value

$n = m (n_b + n_1 + n_2 + n_3 + n_4)$

n = 0.114	When water depth is < 0.1m
n = 0.099	When water depth is ~ 0.2m
n = 0.092	When water depth is ~ 0.3m
n = 0.073	When water depth is > 0.4m

Manning's 'n' Calculations

Prepared by: D. Fedczyna **Date:** 8/11/2016
Checked by: **Date:**

The following provides Manning's' n roughness coefficient calculations based on the modified Cowan method documented in the USGS Paper 2339: "Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains' (Arcement & Schneider). The approach was adopted for direct rainfall modelling as it can account for the higher effective roughness likely to be encountered at shallow flow depths

Overview

Manning's 'n' is calculated using the modified Cowan method based on the following formula:

$n = m\,(n_b + n_1 + n_2 + n_3 + n_4)$

Where: n_b = a base value of n for the floodplain's natural bare soil surface

n_1 = a correction factor for the effect of surface irregularities

n_2 = a value for variations in shape and size of the floodplain cross-section (assumed to be 0.0)

n_3 = a value for obstructions

n_4 = a value for vegetation on the floodplain

m = a correction factor for sinuosity (assumed to be 1.0)

Description of Surface / Material Type

Material Type 3 - Trees
Trees (> 2metres in height) with significant undergrowth

n_b Calculation

n_b is extracted from the following table:

Table 1. Base Values of Manning's *n*

Bed Material	Median Size of bed material (in millimeters)	Base *n* Value: Straight Uniform Channel[1]	Base *n* Value: Smooth Channel[2]
Sand Channels			
Sand[3]	0.2	0.012	--
	.3	.017	--
	.4	.020	--
	.5	.022	--

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	.6	.023	--
	.8	.025	--
	1.0	.026	--
Stable Channels and Flood Plains			
Concrete	**--**	**0.012-0.018**	**0.011**
Rock Cut	**--**	**--**	**.025**
Firm Soil	**--**	**0.025-0.032**	**.020**
Coarse Sand	**1-2**	**0.026-0.035**	**--**
Fine Gravel	**--**	**--**	**.024**
Gravel	**2-64**	**0.028-0.035**	**--**
Coarse Gravel	**--**	**--**	**.026**
Cobble	**64-256**	**0.030-0.050**	**--**
Boulder	**>256**	**0.040-0.070**	**--**

[Modified from Aldridge & Garret, 1973, Table 1 --No data
1Benson & Dalrymple --No data
2 For indicated material; Chow(1959)
3 Only For Upper regime flow where grain roughness is predominant

Assume "Coarse Sand" for tree covered areas

n_b = 0.026

n_1 Calculation (Degree of Irregularity)

n_1 is extracted from the following table:

Smooth	0.000	Compares to the smoothest, flattest flood-plain attainable in a given bed material.
Minor	0.001-0.005	Is a Flood Plain Slightly irregular in shape. A few rises and dips or sloughs may be more visible on the flood plain.
Moderate	0.006-0.010	Has more rises and dips. Sloughs and hummocks may occur.
Severe	0.011-0.020	Flood Plain very irregular in shape. Many rises and dips or sloughs are visible. Irregular ground surfaces in pasture land and furrows perpendicular to the flow are also included.

Assume "severe" to cater for steep slopes/cliffs across most of the tree covered portion of the study area

n_1 = 0.015

n_3 Calculation (Effect of Obstructions)

n_3 is extracted from the following table:

Negligible	0.000-0.004	Few scattered obstructions, which include debris deposits, stumps, exposed roots, logs, piers, or isolated boulders, that occupy less than 5 percent of the cross-sectional area.
Minor	0.040-0.050	Obstructions occupy less than 15 percent of the cross-sectional area.
Appreciable	0.020-0.030	Obstructions occupy from 15 percent to 50 percent of the cross-sectional area.

Many obstructions present across tree covered portion of study area

n_3 = 0.03

n_4 Calculation (Effect of Vegetation)

n_4 is largely driven by the height of flow relative to the height of vegetation as defined in the following table:

Small	0.001-0.010	Dense growths of flexible turf grass, such as Bermuda, or weeds growing where the average depth of flow is at least two times the height of the vegetation; supple tree seedlings such as willow, cottonwood, arrow-weed, or saltcedar growing where the average depth of flow is at least three times the height of the vegetation.

		three times the height of the vegetation.
Medium	0.010-0.025	Turf grass growing where the average depth of flow is from one to two times the height of the vegetation; moderately dense stemy grass, weeds, or tree seedlings growing where the average depth of flow is from two to three times the height of the vegetation; brushy, moderately dense vegetation, similar to 1-to-2-year-old willow trees in the dormant season..
Large	0.025-0.050	Turf grass growing where the average depth of flow is about equal to the height of the vegetation; 8-to-10-years-old willow or cottonwood trees intergrow with some weeds and brush (none of the vegetation in foliage) where the hydraulic radius exceeds 0.607 m.;or mature row crops such as small vegetables, or mature field crops where depth flow is at least twice the height of the vegetation.
Very Large	0.050-0.100	Turf grass growing where the average depth of flow is less than half the height of the vegetation; or moderate to dense brush, or heavy stand of timber with few down trees and little undergrowth where depth of flow is below branches, or mature field crops where depth of flow is less than the height of the vegetation.
Extreme	0.100-0.200	Dense bushy willow, mesquite, and saltcedar(all vegetation in full foliage), or heavy stand of timber, few down trees, depth of reaching branches.

Thick Undergrowth up to 0.4 m in height, tree tunks up to 2m & tree branches + trunk above 2m

n_4 = 0.12	When water depth is < 0.3m	(Thick undergrowth in contact with flow)
n_4 = 0.09	When water depth is ~ 0.5m	(Tree trunks and some undergrowth in contact with flow)
n_4 = 0.05	When water depth is >2m	(Tree trunks+ some branches in contact with flow)

Final 'n' Value

$n = m (n_b + n_1 + n_2 + n_3 + n_4)$

n = 0.191	When water depth is < 0.3m
n = 0.161	When water depth is ~ 0.5m
n = 0.121	When water depth is >2.0m

Manning's 'n' Calculations

Prepared by: D. Fedczyna **Date:** 8/11/2016
Checked by: **Date:**

The following provides Manning's' n roughness coefficient calculations based on the modified Cowan method documented in the USGS Paper 2339: "Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains' (Arcement & Schneider). The approach was adopted for direct rainfall modelling as it can account for the higher effective roughness likely to be encountered at shallow flow depths

Overview

Manning's 'n' is calculated using the modified Cowan method based on the following formula:

$n = m\ (n_b + n_1 + n_2 + n_3 + n_4)$

Where: n_b = a base value of n for the floodplain's natural bare soil surface

n_1 = a correction factor for the effect of surface irregularities

n_2 = a value for variations in shape and size of the floodplain cross-section (assumed to be 0.0)

n_3 = a value for obstructions

n_4 = a value for vegetation on the floodplain

m = a correction factor for sinuosity (assumed to be 1.0)

Description of Surface / Material Type

Material Type - Grass
Relatively short grass. Occasional obstruction (e.g., fence post)

n_b Calculation

n_b is extracted from the following table:

Table 1. Base Values of Manning's *n*

Bed Material	Median Size of bed material (in millimeters)	Base *n* Value: Straight Uniform Channel[1]	Base *n* Value: Smooth Channel[2]
Sand Channels			
Sand[3]	0.2	0.012	--
	.3	.017	--
	.4	.020	--
	.5	.022	--

	.6	.023	--
	.8	.025	--
	1.0	.026	--
Stable Channels and Flood Plains			
Concrete	--	0.012-0.018	0.011
Rock Cut	--	--	.025
Firm Soil	--	0.025-0.032	.020
Coarse Sand	1-2	0.026-0.035	--
Fine Gravel	--	--	.024
Gravel	2-64	0.028-0.035	--
Coarse Gravel	--	--	.026
Cobble	64-256	0.030-0.050	--
Boulder	>256	0.040-0.070	--

[Modified from Aldridge & Garret, 1973, Table 1 --No data
1Benson & Dalrymple --No data
[2] For indicated material; Chow(1959)
[3] Only For Upper regime flow where grain roughness is predominant

Assume "Firm Soil" for grass areas

n_b = 0.025

n_1 Calculation (Degree of Irregularity)

n_1 is extracted from the following table:

Smooth	0.000	Compares to the smoothest, flattest flood-plain attainable in a given bed material.
Minor	0.001-0.005	Is a Flood Plain Slightly irregular in shape. A few rises and dips or sloughs may be more visible on the flood plain.
Moderate	0.006-0.010	Has more rises and dips. Sloughs and hummocks may occur.
Severe	0.011-0.020	Flood Plain very irregular in shape. Many rises and dips or sloughs are visible. Irregular ground surfaces in pasture land and furrows perpendicular to the flow are also included.

Assume "minor" to cater for gradual terrain undulations across grassed areas of the study area

n_1 = 0.003

n_3 Calculation (Effect of Obstructions)

n_3 is extracted from the following table:

Negligible	0.000-0.004	Few scattered obstructions, which include debris deposits, stumps, exposed roots, logs, piers, or isolated boulders, that occupy less than 5 percent of the cross-sectional area.
Minor	0.040-0.050	Obstructions occupy less than 15 percent of the cross-sectional area.
Appreciable	0.020-0.030	Obstructions occupy from 15 percent to 50 percent of the cross-sectional area.

Occasional tree stump or obstruction may be present:

n_3 = 0.003

n_4 Calculation (Effect of Vegetation)

n_4 is largely driven by the height of flow relative to the height of vegetation as defined in the following table:

Small	0.001-0.010	Dense growths of flexible turf grass, such as Bermuda, or weeds growing where the average depth of flow is at least two times the height of the vegetation; supple tree seedlings such as willow, cottonwood, arrow-weed, or saltcedar growing where the average depth of flow is at least three times the height of the vegetation.

		three times the height of the vegetation.
Medium	0.010-0.025	Turf grass growing where the average depth of flow is from one to two times the height of the vegetation; moderately dense stemy grass, weeds, or tree seedlings growing where the average depth of flow is from two to three times the height of the vegetation; brushy, moderately dense vegetation, similar to 1-to-2-year-old willow trees in the dormant season..
Large	0.025-0.050	Turf grass growing where the average depth of flow is about equal to the height of the vegetation; 8-to-10-years-old willow or cottonwood trees intergrow with some weeds and brush (none of the vegetation in foliage) where the hydraulic radius exceeds 0.607 m.;or mature row crops such as small vegetables, or mature field crops where depth flow is at least twice the height of the vegetation.
Very Large	0.050-0.100	Turf grass growing where the average depth of flow is less than half the height of the vegetation; or moderate to dense brush, or heavy stand of timber with few down trees and little undergrowth where depth of flow is below branches, or mature field crops where depth of flow is less than the height of the vegetation.
Extreme	0.100-0.200	Dense bushy willow, mesquite, and saltcedar(all vegetation in full foliage), or heavy stand of timber, few down trees, depth of reaching branches.

Assume grass is equal to or less than 0.05 metres in height

n_4 = 0.055	When water depth is < 0.03m	(water depth less than height of grass)
n_4 = 0.03	When water depth is ~ 0.05m	(water depth equal in height to grass)
n_4 = 0.005	When water depth is ~ 0.07m	(water depth less than twice height of grass)
n_4 = 0.005	When water depth is > 0.1m	(water depth more than twice height of grass)

Final 'n' Value

$n = m (n_b + n_1 + n_2 + n_3 + n_4)$

n = 0.096	When water depth is < 0.03m
n = 0.071	When water depth is ~ 0.05m
n = 0.041	When water depth is ~ 0.07m
n = 0.03	When water depth is > 0.1m

Manning's 'n' Calculations

Prepared by: D. Fedczyna **Date:** 8/11/2016
Checked by: **Date:**

The following provides Manning's' n roughness coefficient calculations based on the modified Cowan method documented in the USGS Paper 2339: "Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains' (Arcement & Schneider). The approach was adopted for direct rainfall modelling as it can account for the higher effective roughness likely to be encountered at shallow flow depths

Overview

Manning's 'n' is calculated using the modified Cowan method based on the following formula:

$n = m (n_b + n_1 + n_2 + n_3 + n_4)$

Where: n_b = a base value of n for the floodplain's natural bare soil surface
n_1 = a correction factor for the effect of surface irregularities
n_2 = a value for variations in shape and size of the floodplain cross-section (assumed to be 0.0)
n_3 = a value for obstructions
n_4 = a value for vegetation on the floodplain
m = a correction factor for sinuosity (assumed to be 1.0)

Description of Surface / Material Type

Material Type - Impervious (concrete, road, car parking area)

n_b Calculation

n_b is extracted from the following table:

Table 1. Base Values of Manning's *n*

Bed Material	Median Size of bed material (in millimeters)	Base *n* Value: Straight Uniform Channel[1]	Base *n* Value: Smooth Channel[2]
Sand Channels			
Sand[3]	0.2	0.012	--
	.3	.017	--
	.4	.020	--
	.5	.022	--

	.6 .8 1.0	.023 .025 .026	-- -- --
Stable Channels and Flood Plains			
Concrete	--	0.012-0.018	0.011
Rock Cut	--	--	.025
Firm Soil	--	0.025-0.032	.020
Coarse Sand	1-2	0.026-0.035	--
Fine Gravel	--	--	.024
Gravel	2-64	0.028-0.035	--
Coarse Gravel	--	--	.026
Cobble	64-256	0.030-0.050	--
Boulder	>256	0.040-0.070	--

[Modified from Aldridge & Garret, 1973, Table 1 --No data
1Benson & Dalrymple --No data
[2] For indicated material; Chow(1959)
[3] Only For Upper regime flow where grain roughness is predominant

Assume "Concrete"

n_b = 0.012

n_1 Calculation (Degree of Irregularity)

n_1 is extracted from the following table:

Smooth	0.000	Compares to the smoothest, flattest flood-plain attainable in a given bed material.
Minor	0.001-0.005	Is a Flood Plain Slightly irregular in shape. A few rises and dips or sloughs may be more visible on the flood plain.
Moderate	0.006-0.010	Has more rises and dips. Sloughs and hummocks may occur.
Severe	0.011-0.020	Flood Plain very irregular in shape. Many rises and dips or sloughs are visible. Irregular ground surfaces in pasture land and furrows perpendicular to the flow are also included.

Assume smooth

n_1 = 0

n_3 Calculation (Effect of Obstructions)

n_3 is extracted from the following table:

Negligible	0.000-0.004	Few scattered obstructions, which include debris deposits, stumps, exposed roots, logs, piers, or isolated boulders, that occupy less than 5 percent of the cross-sectional area.
Minor	0.040-0.050	Obstructions occupy less than 15 percent of the cross-sectional area.
Appreciable	0.020-0.030	Obstructions occupy from 15 percent to 50 percent of the cross-sectional area.

Assume minimal obstructions

n_3 = 0.002

n_4 Calculation (Effect of Vegetation)

n_4 is largely driven by the height of flow relative to the height of vegetation as defined in the following table:

Small	0.001-0.010	Dense growths of flexible turf grass, such as Bermuda, or weeds growing where the average depth of flow is at least two times the height of the vegetation; supple tree seedlings such as willow, cottonwood, arrow-weed, or saltcedar growing where the average depth of flow is at least three times the height of the vegetation.

		three times the height of the vegetation.
Medium	0.010-0.025	Turf grass growing where the average depth of flow is from one to two times the height of the vegetation; moderately dense stemy grass, weeds, or tree seedlings growing where the average depth of flow is from two to three times the height of the vegetation; brushy, moderately dense vegetation, similar to 1-to-2-year-old willow trees in the dormant season..
Large	0.025-0.050	Turf grass growing where the average depth of flow is about equal to the height of the vegetation; 8-to-10-years-old willow or cottonwood trees intergrow with some weeds and brush (none of the vegetation in foliage) where the hydraulic radius exceeds 0.607 m.;or mature row crops such as small vegetables, or mature field crops where depth flow is at least twice the height of the vegetation.
Very Large	0.050-0.100	Turf grass growing where the average depth of flow is less than half the height of the vegetation; or moderate to dense brush, or heavy stand of timber with few down trees and little undergrowth where depth of flow is below branches, or mature field crops where depth of flow is less than the height of the vegetation.
Extreme	0.100-0.200	Dense bushy willow, mesquite, and saltcedar(all vegetation in full foliage), or heavy stand of timber, few down trees, depth of reaching branches.

n_4 = 0.02	When water depth is < 0.005m	(Water in contact with aggregate)
n_4 = 0.001	When water depth is > 0.005m	(Water above aggregate height)

Final 'n' Value

$n = m (n_b + n_1 + n_2 + n_3 + n_4)$

n = 0.034	When water depth is < 0.005m
n = 0.015	When water depth is > 0.005m

Manning's 'n' Calculations

Prepared by: D. Fedczyna **Date:** 8/11/2016
Checked by: **Date:**

The following provides Manning's' n roughness coefficient calculations based on the modified Cowan method documented in the USGS Paper 2339: "Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains' (Arcement & Schneider). The approach was adopted for direct rainfall modelling as it can account for the higher effective roughness likely to be encountered at shallow flow depths

Overview

Manning's 'n' is calculated using the modified Cowan method based on the following formula:

$n = m (n_b + n_1 + n_2 + n_3 + n_4)$

Where: n_b = a base value of n for the floodplain's natural bare soil surface

n_1 = a correction factor for the effect of surface irregularities

n_2 = a value for variations in shape and size of the floodplain cross-section (assumed to be 0.0)

n_3 = a value for obstructions

n_4 = a value for vegetation on the floodplain

m = a correction factor for sinuosity (assumed to be 1.0)

Description of Surface / Material Type

Material Type - Sand
Beach and back of dune areas

n_b Calculation

n_b is extracted from the following table:

Table 1. Base Values of Manning's *n*

Bed Material	Median Size of bed material (in millimeters)	Base *n* Value: Straight Uniform Channel[1]	Base *n* Value: Smooth Channel[2]
Sand Channels			
Sand[3]	0.2	0.012	--
	.3	.017	--
	.4	.020	--
	.5	.022	--

	.6	.023	--
	.8	.025	--
	1.0	.026	--
Stable Channels and Flood Plains			
Concrete	--	0.012-0.018	0.011
Rock Cut	--	--	.025
Firm Soil	--	0.025-0.032	.020
Coarse Sand	1-2	0.026-0.035	--
Fine Gravel	--	--	.024
Gravel	2-64	0.028-0.035	--
Coarse Gravel	--	--	.026
Cobble	64-256	0.030-0.050	--
Boulder	>256	0.040-0.070	--

[Modified from Aldridge & Garret, 1973, Table 1 --No data
1Benson & Dalrymple --No data
[2] For indicated material; Chow(1959)
[3] Only For Upper regime flow where grain roughness is predominant

Assume median size of 0.2mm diameter sand

n_b = 0.012

n_1 Calculation (Degree of Irregularity)

n_1 is extracted from the following table:

Smooth	0.000	Compares to the smoothest, flattest flood-plain attainable in a given bed material.
Minor	0.001-0.005	Is a Flood Plain Slightly irregular in shape. A few rises and dips or sloughs may be more visible on the flood plain.
Moderate	0.006-0.010	Has more rises and dips. Sloughs and hummocks may occur.
Severe	0.011-0.020	Flood Plain very irregular in shape. Many rises and dips or sloughs are visible. Irregular ground surfaces in pasture land and furrows perpendicular to the flow are also included.

Assume "minor" to cater for gradual terrain undulations across dune and beach

n_1 = 0.003

n_3 Calculation (Effect of Obstructions)

n_3 is extracted from the following table:

Negligible	0.000-0.004	Few scattered obstructions, which include debris deposits, stumps, exposed roots, logs, piers, or isolated boulders, that occupy less than 5 percent of the cross-sectional area.
Minor	0.040-0.050	Obstructions occupy less than 15 percent of the cross-sectional area.
Appreciable	0.020-0.030	Obstructions occupy from 15 percent to 50 percent of the cross-sectional area.

Negligible obstruction present along beach and dune

n_3 = 0.004

n_4 Calculation (Effect of Vegetation)

n_4 is largely driven by the height of flow relative to the height of vegetation as defined in the following table:

Small	0.001-0.010	Dense growths of flexible turf grass, such as Bermuda, or weeds growing where the average depth of flow is at least two times the height of the vegetation; supple tree seedlings such as willow, cottonwood, arrow-weed, or saltcedar growing where the average depth of flow is at least three times the height of the vegetation.

Medium	0.010-0.025	Turf grass growing where the average depth of flow is from one to two times the height of the vegetation; moderately dense stemy grass, weeds, or tree seedlings growing where the average depth of flow is from two to three times the height of the vegetation; brushy, moderately dense vegetation, similar to 1-to-2-year-old willow trees in the dormant season..
Large	0.025-0.050	Turf grass growing where the average depth of flow is about equal to the height of the vegetation; 8-to-10-years-old willow or cottonwood trees intergrow with some weeds and brush (none of the vegetation in foliage) where the hydraulic radius exceeds 0.607 m.;or mature row crops such as small vegetables, or mature field crops where depth flow is at least twice the height of the vegetation.
Very Large	0.050-0.100	Turf grass growing where the average depth of flow is less than half the height of the vegetation; or moderate to dense brush, or heavy stand of timber with few down trees and little undergrowth where depth of flow is below branches, or mature field crops where depth of flow is less than the height of the vegetation.
Extreme	0.100-0.200	Dense bushy willow, mesquite, and saltcedar(all vegetation in full foliage), or heavy stand of timber, few down trees, depth of reaching branches.

n_4 = 0.001	When water depth is < 0.01m	(negligible vegetation on dune/beach)
n_4 = 0.001	When water depth is ~ 0.02m	(negligible vegetation on dune/beach)
n_4 = 0.001	When water depth is ~ 0.05m	(negligible vegetation on dune/beach)
n_4 = 0.001	When water depth is > 0.1m	(negligible vegetation on dune/beach)

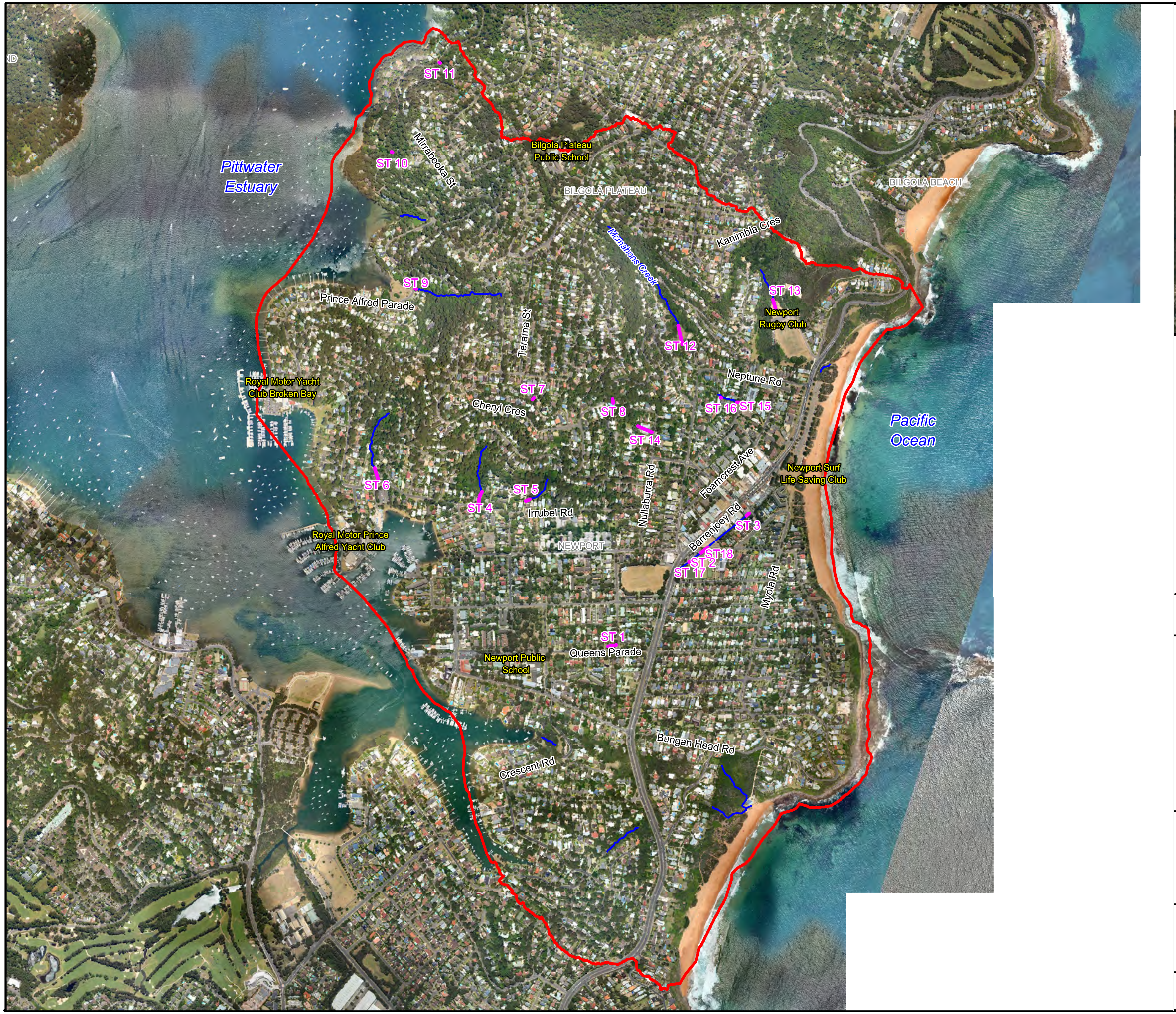
Final 'n' Value

$n = m (n_b + n_1 + n_2 + n_3 + n_4)$

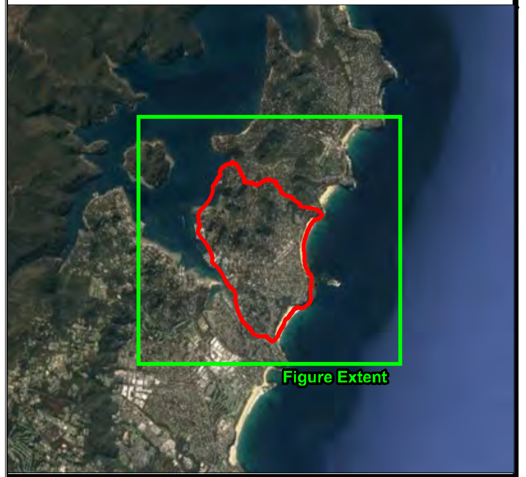
n = 0.03	When water depth is < 0.01m
n = 0.03	When water depth is ~ 0.02m
n = 0.025	When water depth is ~ 0.05m
n = 0.014	When water depth is > 0.1m

APPENDIX D

BLOCKAGE ASSESSMENT



NORTHERN BEACHES COUNCIL



LEGEND

- ST 1 Blockage Liable Structure
- Newport Study Area
- Watercourse

Notes:

Aerial photograph date: 2014

N
W E
S

Scale 1:13,000 (at A3)

0 0.4 0.8 Km

Appendix D1: Blockage Liable Structure Locations

Prepared By:

Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: AppD - Hydraulic Structure Locations.wor

STRUCTURE BLOCKAGE ASSESSMENT

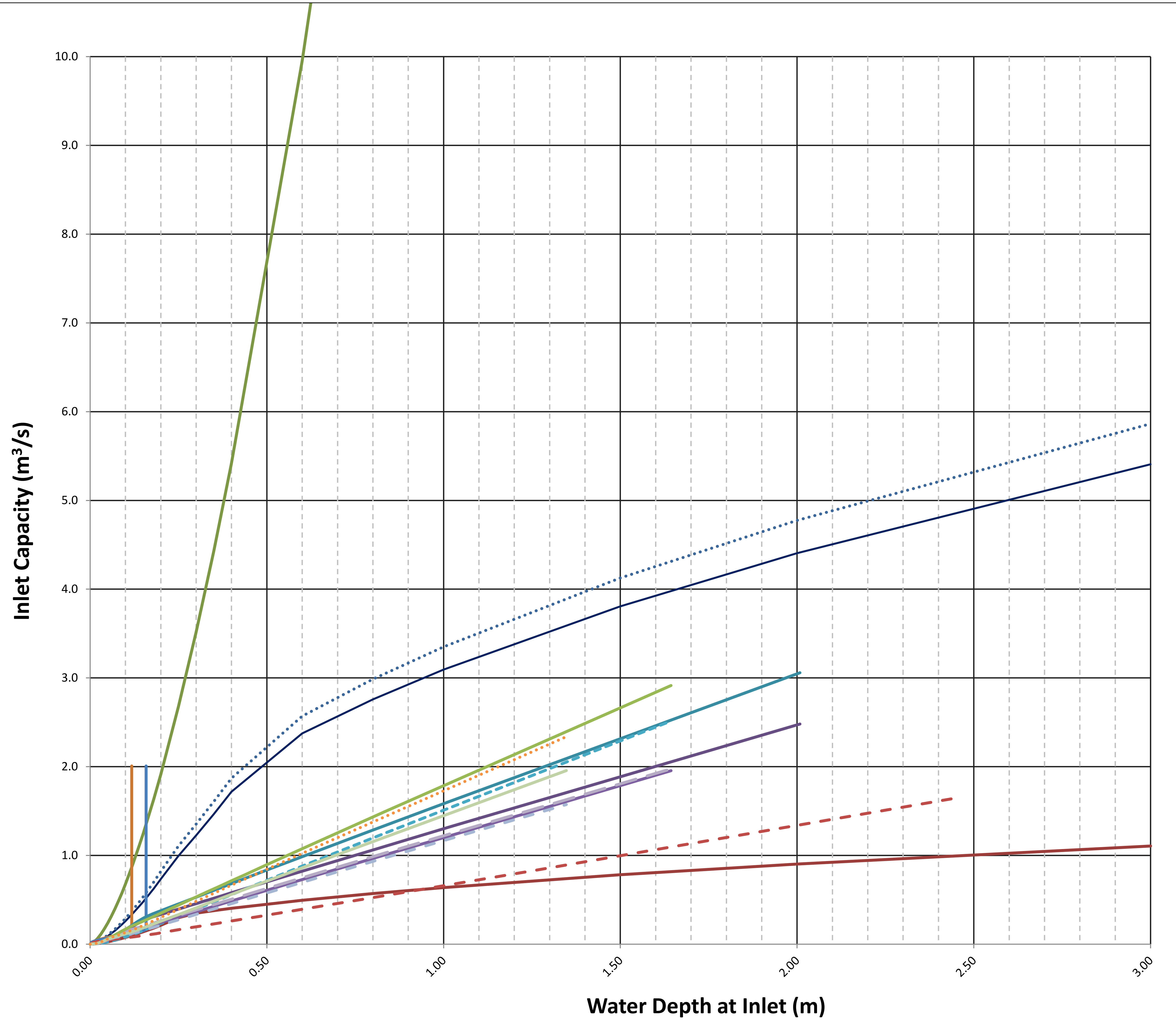
Newport Flood Study

Structure ID	Roadway	Structure Type	Structure Dimensions			Land Use Across Upstream Catchment	Max. L10 (m)	Control Dimension	Main Stream Slope (%)	Debris Availability (L, M, H)	Debris Mobility (L, M, H)	Debris Transportability (L, M, H)	Debris Potential	Debris Potential at Structure	Adjustment for AEP			Design Blockage Level		
			Dia/Width/Span	Height	Cells / Spans										AEP >5%	AEP 5%-0.5%	AEP < 0.5%	AEP >5%	AEP 5%-0.5%	AEP < 0.5%
ST 1	Upstream of Bishop St	Box Culvert	0.375	0.375	1	16% Grass, 46% Trees, 11% Impervious, 26% Buildings	3.00	W<L	3.16	M	M	H	**MMH**	Medium	Low	Medium	High	25%	50%	100%
ST 2	The Boulevarde	Box Culvert	1.2	1.2	2	40% Impervious, 49% Grass, 11% Trees	3.00	W<L	0.27	H	M	L	**HML**	Medium	Low	Medium	High	25%	50%	100%
ST 3	Bramley Ave	Box Culvert	2.72	2.72	2	19% Impervious, 24% Grass, 27% Trees, 29% Buildings	3.00	W<L	0.55	H	M	L	**HML**	Medium	Low	Medium	High	25%	50%	100%
ST 4	80 Irrubel Rd	Pipe Culvert	1.05	N/A	1	58% Trees, 11% Impervious, 15% Grass, 16% Buildings	3.00	W<L	20.01	H	M	H	**HMH**	High	Medium	High	High	50%	100%	100%
ST 5	Rear of 60 Irrubel Rd	Pipe Culvert	0.75	N/A	1	18% Grass, 10% Impervious, 56% Trees, 16% Buildings	3.00	W<L	22.74	H	M	H	**HMH**	High	Medium	High	High	50%	100%	100%
ST 6	126A Irrubel Rd	Pipe Culvert	0.75	N/A	1	67% Trees, 11% Grass, 16% Buildings, 6% Impervious	3.00	W<L	17.2	H	M	H	**HMH**	High	Medium	High	High	50%	100%	100%
ST 7	7 Kemble Pl	Pipe Culvert	0.375	N/A	1	53% Trees, 22% Buildings, 3% Impervious, 22% Grass	3.00	W<L	23.47	L	M	H	**LMH**	Medium	Low	Medium	High	25%	50%	100%
ST 8	Belinda Pl	Pipe Culvert	0.6	N/A	1	20% Buildings, 15% Grass, 11% Impervious, 54% Trees	3.00	W<L	29.79	H	M	H	**HMH**	High	Medium	High	High	50%	100%	100%
ST 9	Prince Alfred Pde	Pipe Culvert	1.2	N/A	1	13% Impervious, 12% Grass, 56% Trees, 19% Buildings	3.00	W<L	23.35	H	M	H	**HMH**	High	Medium	High	High	10%	25%	50%
ST 10	170 Prince Alfred Pde	Pipe Culvert	0.375	N/A	1	26% Buildings, 12% Grass, 49% Trees, 13% Impervious	3.00	W<L	28.52	H	M	H	**HMH**	High	Medium	High	High	50%	100%	100%
ST 11	Hudson pde	Pipe Culvert	0.6	N/A	1	72% Trees, 9% Impervious, 5% Grass, 14% Buildings	3.00	W<L	43.11	H	M	H	**HMH**	High	Medium	High	High	50%	100%	100%
ST 12	Howell Cl Reserve	Pipe Culvert	1.35	N/A	1	15% Grass, 13% Impervious, 18% Buildings, 54% Trees	3.00	W<L	15.02	H	M	H	**HMH**	High	Medium	High	High	50%	100%	100%
ST 13	Newport Rugby Club Field	Pipe Culvert	0.75	N/A	1	10% Impervious, 16% Grass, 59% Trees, 14% Buildings	3.00	W<L	22.15	H	M	H	**HMH**	High	Medium	High	High	50%	100%	100%
ST 14	Upstream Nullaburra Rd	Pipe Culvert	0.9	N/A	1	7% Impervious, 15% Grass, 61% Trees, 16% Buildings	3.00	W<L	14.87	M	M	H	**MMH**	Medium	Low	Medium	High	25%	50%	100%
ST 15	Ocean Avenue	Pipe Culvert	1.05	N/A	3	20% Grass, 40% Trees, 13% Impervious, 27% Buildings	3.00	W<L	1.76	M	M	M	**MMM**	Medium	Low	Medium	High	25%	50%	100%
ST 16	5 Ismona Ave Bridge	Bridge	4.5	1.65	1	15% Impervious, 49% Trees, 18% Grass, 18% Buildings	3.00	L<W<3L	1.96	M	M	M	**MMM**	Medium	Low	Medium	High	0%	10%	20%
ST 17	Newport Bowling Club Bridge	Bridge	3.5	1.15	1	15% Impervious, 43% Trees, 21% Buildings, 21% Grass	3.00	L<W<3L	1.34	M	M	M	**MMM**	Medium	Low	Medium	High	0%	10%	20%
ST 18	Downstream of The Boulevarde	Bridge	3.5	1.3	1	30% Buildings, 23% Grass, 34% Trees, 14% Impervious	3.00	L<W<3L	0	L	M	L	**LML**	Low	Low	Low	Medium	0%	0%	10%

APPENDIX E

STORMWATER INLET CAPACITY CURVES

NORTHERN BEACHES COUNCIL



LEGEND

- 0.24m2 Grate in Sag
- 18.5m2 Grate in Sag
- Combination Inlet (2.4m lintel, 0.75m2 Grate) in Sag
- Combination Inlet (3m lintel, 0.75m2 Grate) in Sag
- 0.45m2 Grate on 2.5% Grade
- 0.75m2 Grate on 2.5% Grade
- Combination Inlet (2.4m lintel, 0.75m2 Grate) on 2.5% Grade
- Combination Inlet (3m lintel, 0.75m2 Grate) on 2.5% Grade
- 3.2m Kerb Inlet on 5% Grade
- Combination Inlet (2.4m lintel, 0.45m2 Grate) on 5% Grade
- Combination Inlet (2.4m Lintel, 0.75m2 Grate) on 5% Grade
- Combination Inlet (3m Lintel, 0.75m2 Grate) on 5% Grade
- Combination Inlet (3.6m Lintel, 0.75m2 Grate) on 5% Grade
- Combination Inlet (2.4m Lintel, 0.75m2 Grate) on 10% Grade
- Combination Inlet (3m Lintel, 0.75m2 Grate) on 10% Grade
- Combination Inlet (3.6m Lintel, 0.75m2 Grate) on 10% Grade

Notes:

Inlet capacity curves do not consider blockage.

Figure E1: Inlet Capacity Curves

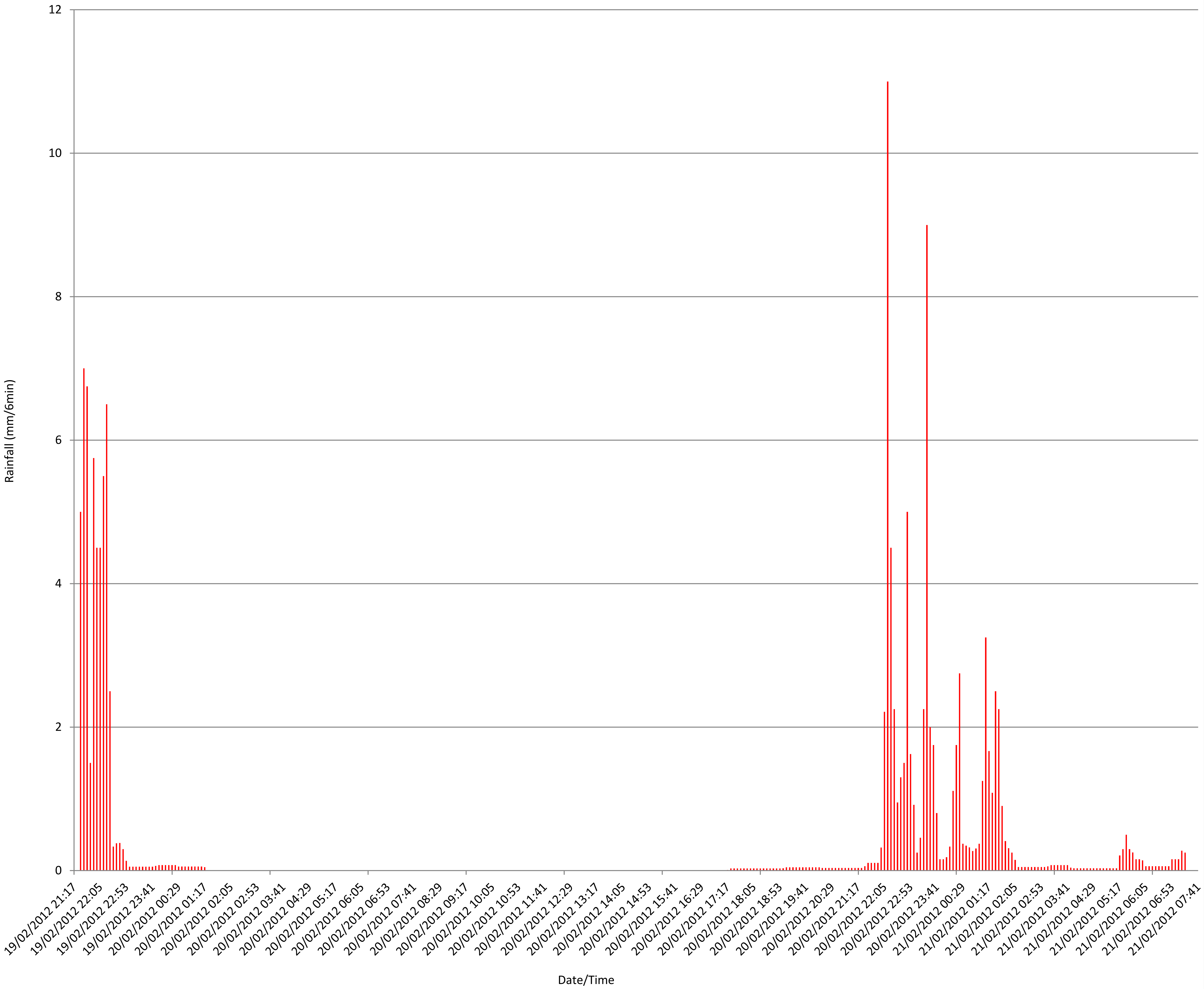
Prepared By:

Catchment Simulation Solutions
Suite 2.01, 210 George Street
Sydney, NSW, 2000

File Name: Inlet Capcacity Curves.xls

APPENDIX F

HISTORIC RAINFALL INPUTS



NORTHERN BEACHES COUNCIL

LEGEND:

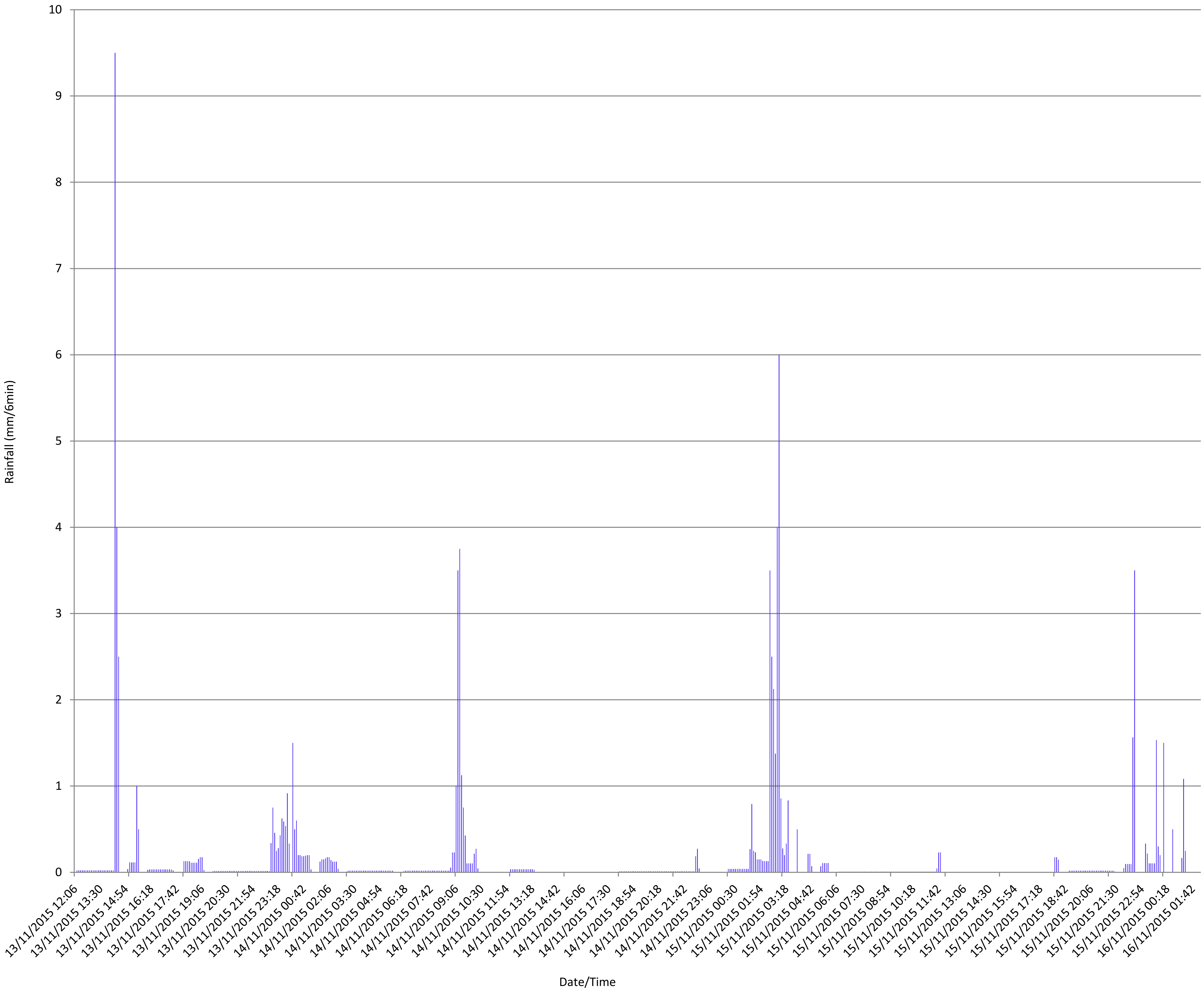
Avalon (Gauge #566145)

Notes:

Figure F1: Continuous Rainfall Data for the February 2012 event

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George Street
Sydney, NSW, 2000

File Name: Historic_Pluviographs.xls



NORTHERN BEACHES
COUNCIL

LEGEND:

■ Avalon (Gauge #566145)

Notes:

Figure F2:
Continuous Rainfall Data for the November 2015 event

Prepared By:
Catchment Simulation Solutions
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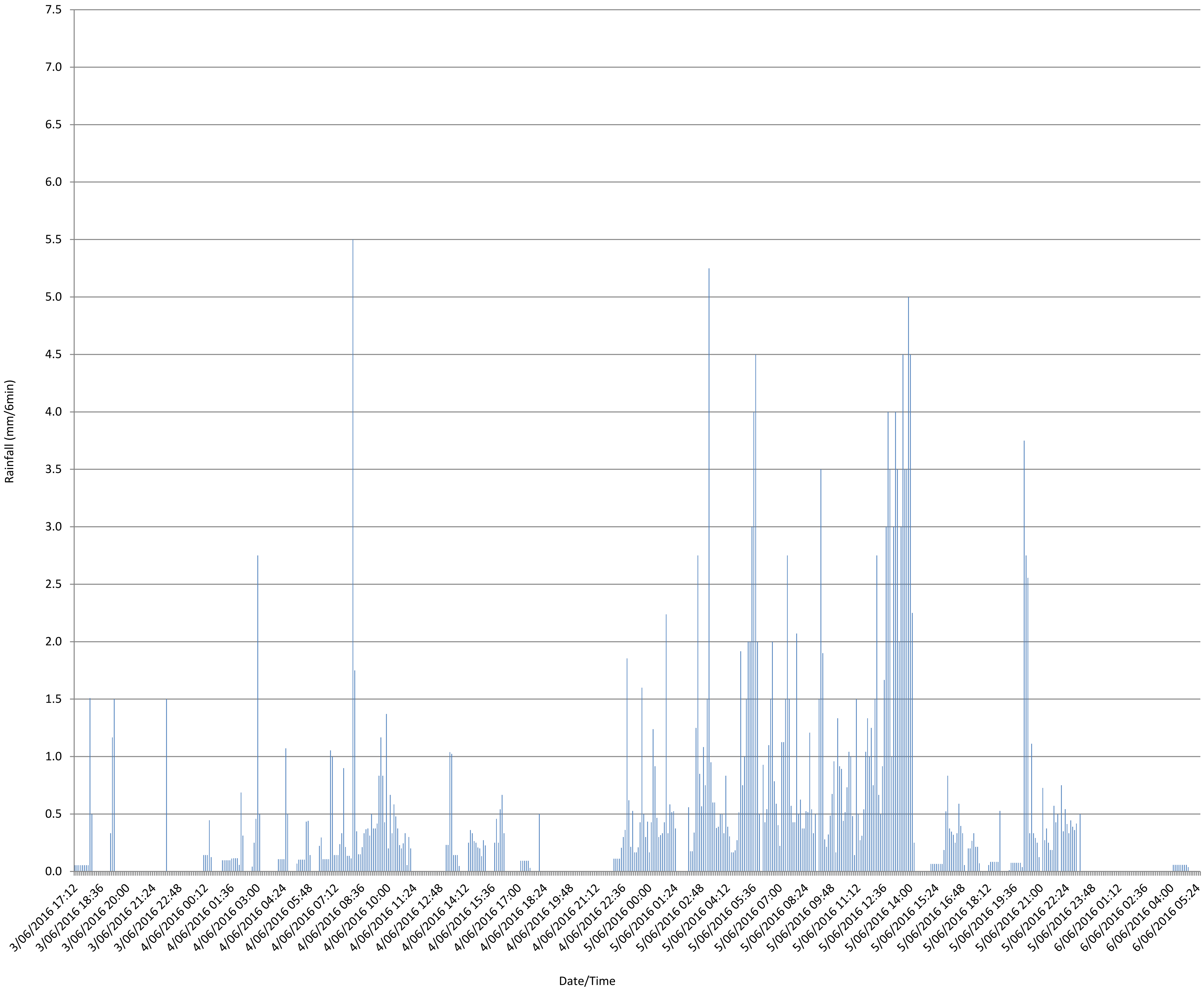
Sydney, NSW, 2000

File Name: Historic_Pluviographs.xls



NORTHERN BEACHES COUNCIL

LEGEND:

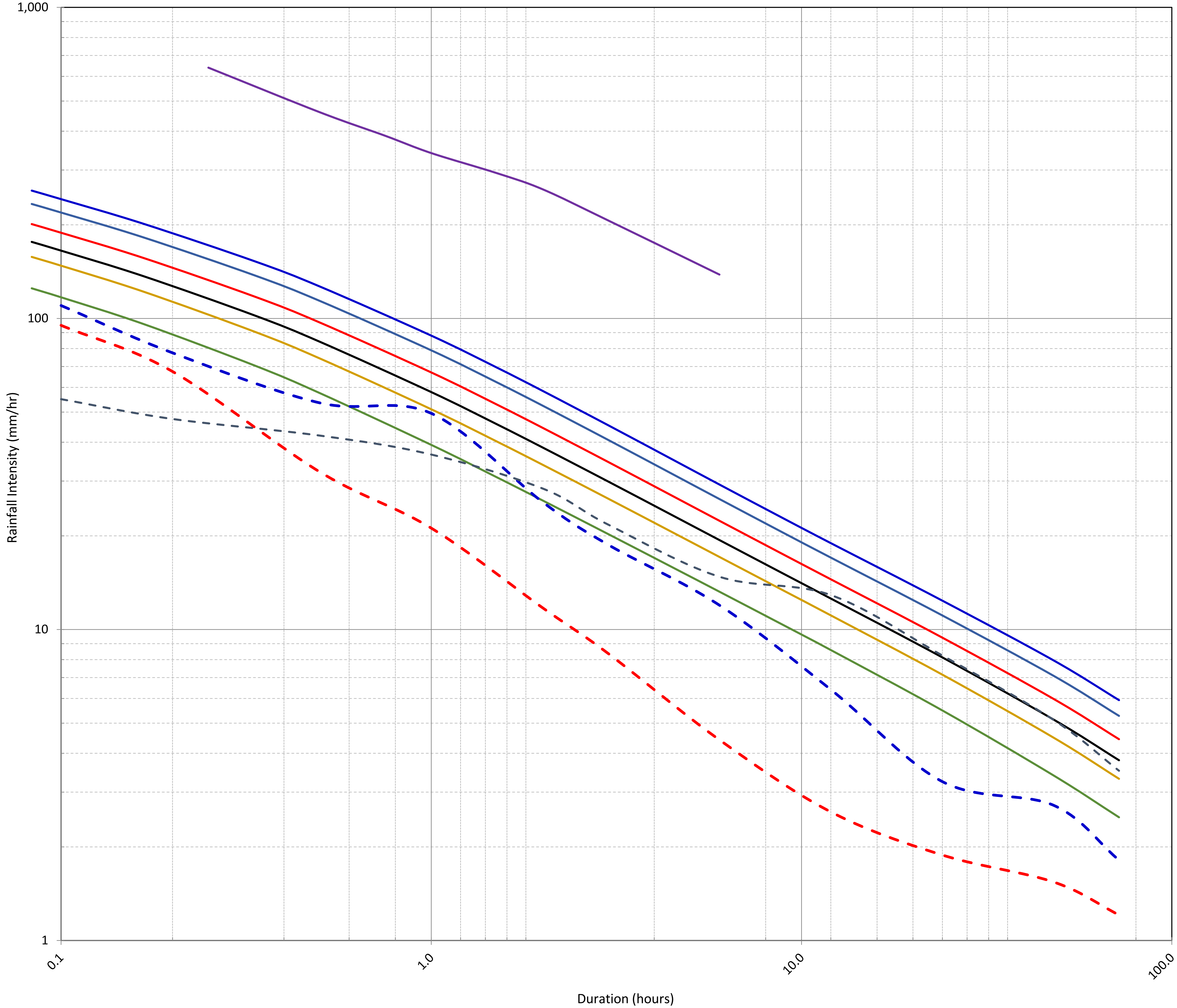
Newport (Gauge #566188)

Notes:

Figure F3: Continuous Rainfall Data for the June 2016 event

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George Street
Sydney, NSW, 2000

File Name: Historic_Pluviographs.xls



NORTHERN BEACHES COUNCIL

LEGEND:

- PMP
- 1% AEP
- 2% AEP
- 5% AEP
- 10% AEP
- 20% AEP
- 2 year ARI
- 2012 Rainfall
- 2015 Rainfall
- 2016 Rainfall

Notes:
Intensity - Frequency - Duration Curves are derived from Australian Rainfall and Runoff 1987

Figure F4: Design Intensity - Frequency - Duration Curves Vs Historic Rainfall

Prepared By:
Catchment Simulation Solutions
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Sydney, NSW, 2000

File Name: IFD Comparison.xlsx

APPENDIX G

EXTREME RAINFALL CALCULATIONS

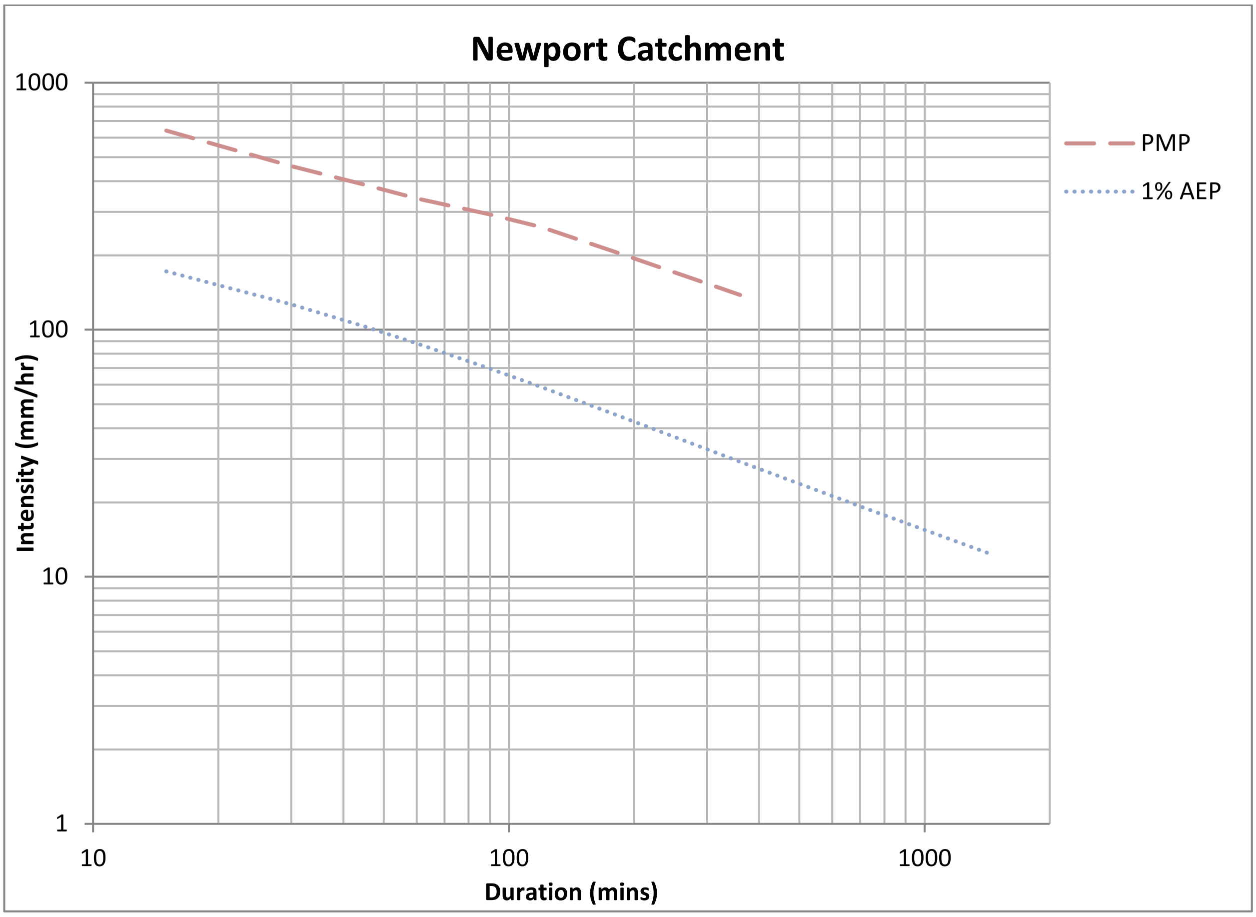
Estimation of 0.1% AEP Rainfall

Overview

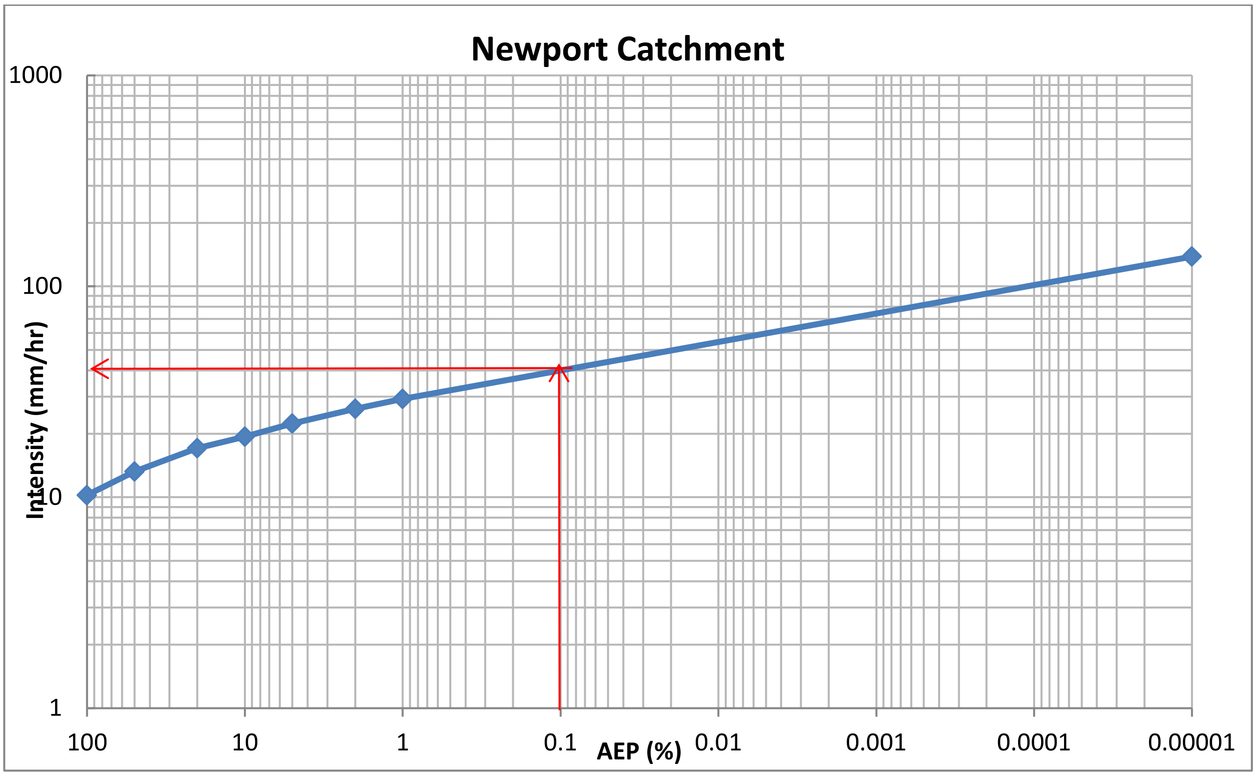
The 0.1% AEP rainfall was estimated as part of the Newport Flood Study. The calculations were completed in accordance with procedures set out in 'Australian Rainfall & Runoff- A Guideline to Flood Estimation' (Engineers Australia, 1998) for extreme rainfall. A summary of the calculation technique is provided below.

Calculations

The 1% AEP rainfall intensities were plotted on a chart for a range of different storm durations. The Probable Maximum Precipitation intensities were also included on the chart. A nominal ARI of 10,000,000 years was adopted for the PMP in accordance with Chapter 8 of the Bureau of Meteorology's Generalised Short Duration Method (GSDM) for catchments with areas of less than 100 km^2 (Bureau of Meteorology, 2003). The resulting chart is provided below.



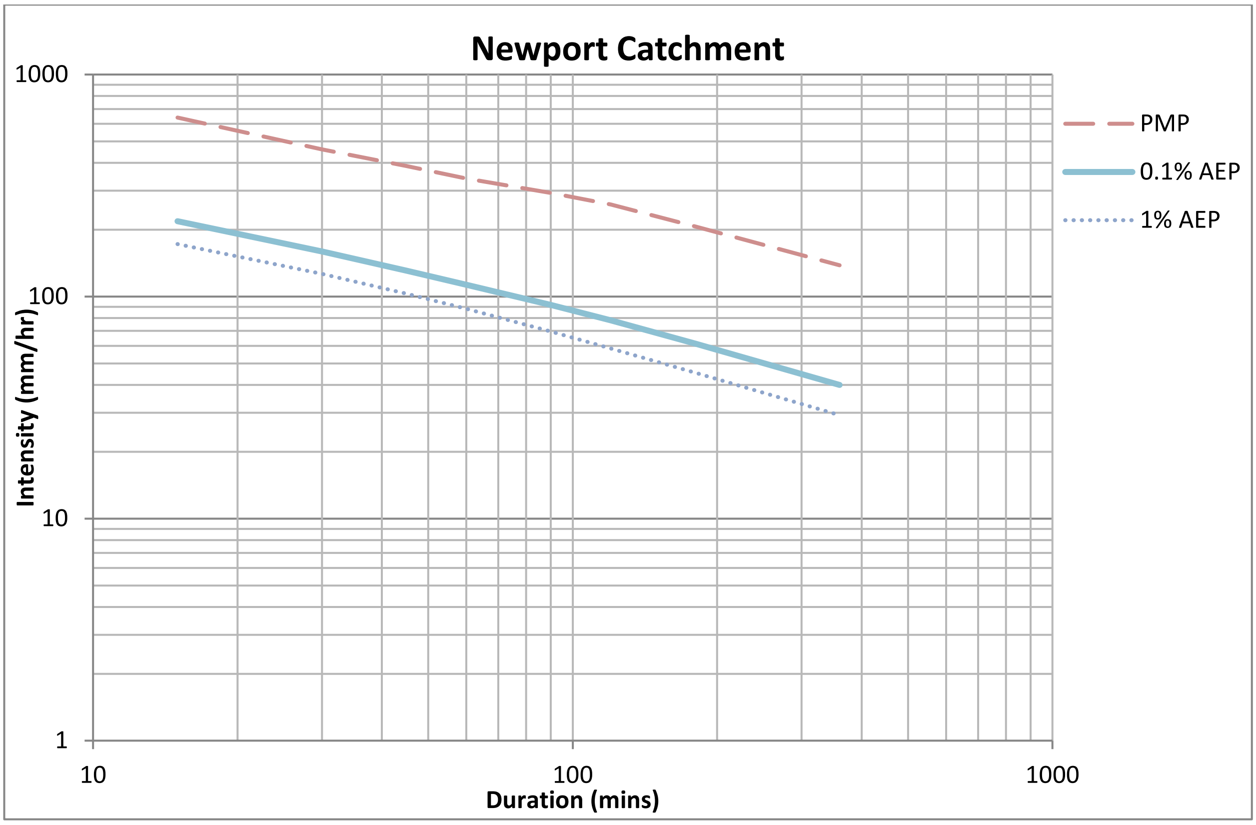
The 6 hour rainfall intensities were extracted from the above charts and were plotted against ARI. The resulting chart is presented below (note: log scales are applied to both X and Y axis).



6 hour rainfall intensities for the 0.1% AEP event was extracted from the above chart. This produced the following 6 hour intensity values:

- 0.1% AEP, 6 hour intensity = 40 mm/hr

The 0.1% AEP, 6 hour rainfall intensity was included on the original IFD chart and a line was drawn from this point parallel to the 1% AEP and PMF IFD lines (refer blue line in chart below). This line represents IFD curve for the 0.1% AEP storm.



The 0.1% AEP intensities were subsequently extracted from the chart for a range of durations:

Storm Duration	**0.1% AEP Intensity** (mm/hr)
15 mins	218
30 mins	160
1 hour	113
2 hours	78
3 hours	61
6 hours	40

GSDM CALCULATION SHEET

LOCATION INFORMATION

Catchment Newport | Area 4.56 km^2

State New South Wales | Duration Limit 6.0 hrs

Latitude 33.6547^0S | Longitude 151.3148^0E

Portion of Area Considered:

Smooth, **S** = 0.00 (0.0 - 1.0) | Rough, **R** = 1.00 (0.0 - 1.0)

ELEVATION ADJUSTMENT FACTOR (EAF)

Mean Elevation 44 m

Adjustment for Elevation (-0.05 per 300m above 1500m) 0.00

EAF = **1.00** (0.85 – 1.00)

MOISTURE ADJUSTMENT FACTOR (MAF)

MAF = **0.71** (0.40-1.00)

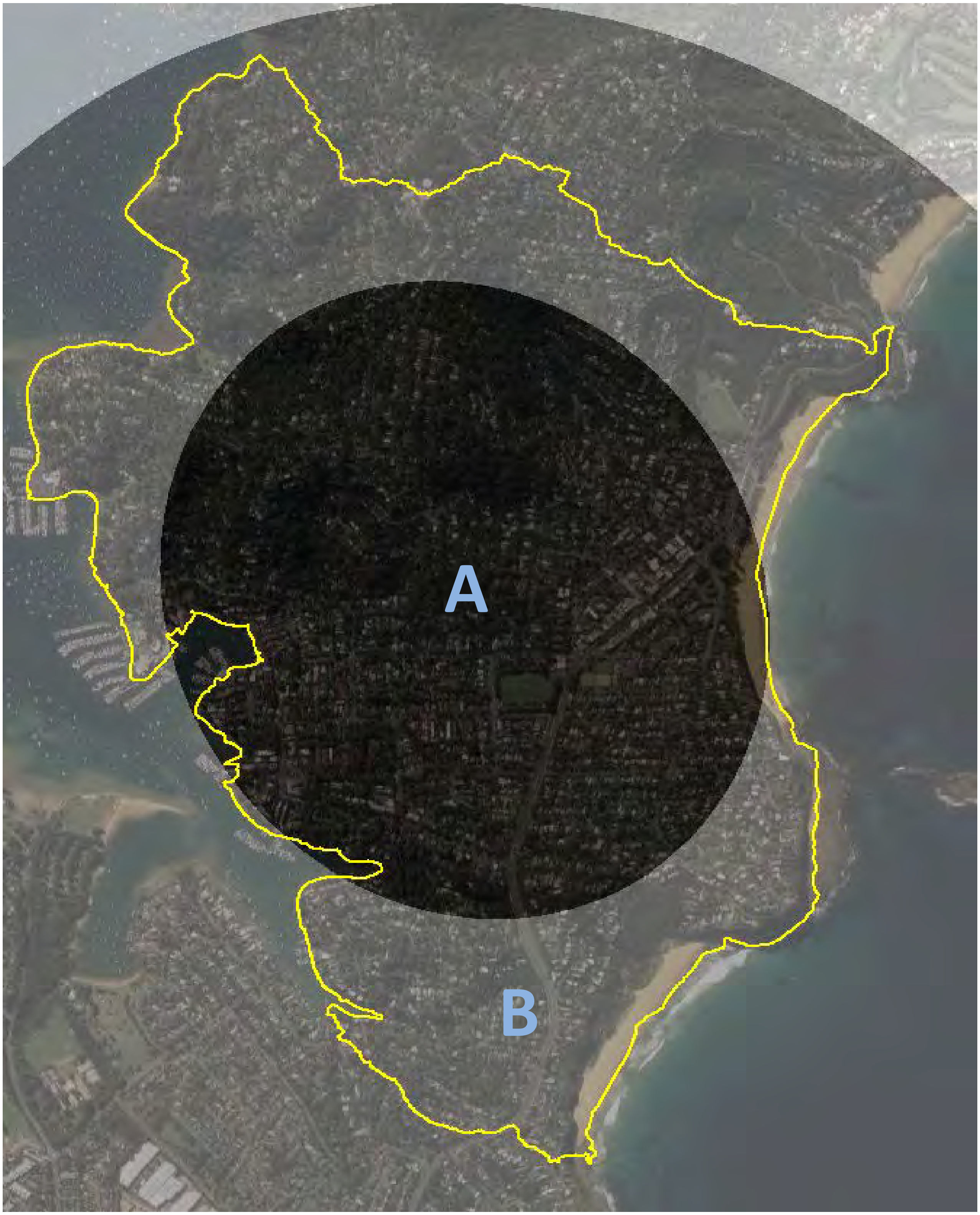
PMP VALUES (mm)

Duration (hours)	Initial Depth -Smooth (D_S)	Initial Depth -Rough (D_R)	PMP Estimate = (D_SxS + D_RxR) x MAF x EAF	Rounded PMP Estimate (nearest 10 mm)
0.25	224	224	159	160
0.50	327	327	232	230
0.75	414	414	294	290
1.00	482	482	342	340
1.50	550	620	440	440
2.00	615	726	515	520
2.50	655	800	568	570
3.00	690	877	623	620
4.00	755	1004	713	710
5.00	814	1104	784	780
6.00	862	1171	831	830

Prepared By ______________________ Date 16/11/2016

Checked By ______________________ Date ______________

GSDM SPATIAL DISTRIBUTION



GSDM SPATIAL DISTRIBUTION

DURATION = 0.25 Hours							
Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse ($mm.km^2$)	Rainfall Volume between Ellipses ($mm.km^2$)	Mean Rainfall Depth between ellipses (mm)
A	2.53	2.53	232	165	418	418	165
B	2.03	4.56	224	159	725	307	151
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

DURATION = 0.50 Hours							
Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse ($mm.km^2$)	Rainfall Volume between Ellipses ($mm.km^2$)	Mean Rainfall Depth between ellipses (mm)
A	2.53	2.53	336	239	605	605	239
B	2.03	4.56	327	232	1058	454	223
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

GSDM SPATIAL DISTRIBUTION (continued)

DURATION = 0.75 Hours

Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse ($mm.km^2$)	Rainfall Volume between Ellipses ($mm.km^2$)	Mean Rainfall Depth between ellipses (mm)
A	2.53	2.53	425	302	765	765	302
B	2.03	4.56	414	294	1342	577	284
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

DURATION = 1.0 Hours

Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse ($mm.km^2$)	Rainfall Volume between Ellipses ($mm.km^2$)	Mean Rainfall Depth between ellipses (mm)
A	2.53	2.53	494	350	887	887	350
B	2.03	4.56	482	342	1560	673	332
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

GSDM SPATIAL DISTRIBUTION (continued)

DURATION = 1.5 Hours							
Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse ($mm.km^2$)	Rainfall Volume between Ellipses ($mm.km^2$)	Mean Rainfall Depth between ellipses (mm)
A	2.53	2.53	637	452	1145	1145	452
B	2.03	4.56	620	440	2008	864	425
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

DURATION = 2.0 Hours							
Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse ($mm.km^2$)	Rainfall Volume between Ellipses ($mm.km^2$)	Mean Rainfall Depth between ellipses (mm)
A	2.53	2.53	745	529	1339	1339	529
B	2.03	4.56	726	515	2350	1011	498
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

GSDM SPATIAL DISTRIBUTION (continued)

DURATION = 2.5 Hours

Ellipse	Catchment Area Between Ellipse (km²)	Catchment Area Enclosed by Ellipse (km²)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse (mm.km²)	Rainfall Volume between Ellipses (mm.km²)	Mean Rainfall Depth between ellipses (mm)
A	2.53	2.53	822	584	1478	1478	584
B	2.03	4.56	800	568	2591	1113	548
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

DURATION = 3.0 Hours

Ellipse	Catchment Area Between Ellipse (km²)	Catchment Area Enclosed by Ellipse (km²)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse (mm.km²)	Rainfall Volume between Ellipses (mm.km²)	Mean Rainfall Depth between ellipses (mm)
A	2.53	2.53	902	641	1622	1622	641
B	2.03	4.56	877	623	2840	1218	600
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

GSDM SPATIAL DISTRIBUTION (continued)

DURATION = 4.0 Hours							
Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse ($mm.km^2$)	Rainfall Volume between Ellipses ($mm.km^2$)	Mean Rainfall Depth between ellipses (mm)
A	2.53	2.53	1031	732	1854	1854	732
B	2.03	4.56	1004	713	3253	1399	689
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

DURATION = 5.0 Hours							
Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse ($mm.km^2$)	Rainfall Volume between Ellipses ($mm.km^2$)	Mean Rainfall Depth between ellipses (mm)
A	2.53	2.53	1136	807	2043	2043	807
B	2.03	4.56	1104	784	3576	1533	755
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

GSDM SPATIAL DISTRIBUTION (continued)

DURATION = 6.0 Hours							
Ellipse	**Catchment Area Between Ellipse (km^2)**	**Catchment Area Enclosed by Ellipse (km^2)**	**Initial Mean Rainfall Depth (mm)**	**Adjusted Mean Rainfall Depth (mm)**	**Rainfall Volume enclosed by Ellipse ($mm.km^2$)**	**Rainfall Volume between Ellipses ($mm.km^2$)**	**Mean Rainfall Depth between ellipses (mm)**
A	2.53	2.53	1201	853	2160	2160	853
B	2.03	4.56	1171	831	3792	1632	804
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Appendix H

Stage Hydrographs

NORTHERN BEACHES COUNCIL

LEGEND

1 Flow Hydrograph Locations

1 Stage Hydrograph Locations

Newport Study Area

Notes:

Aerial photograph date: 2014

N
W E
S

Scale 1:13,000 (at A3)

0 0.4 0.8

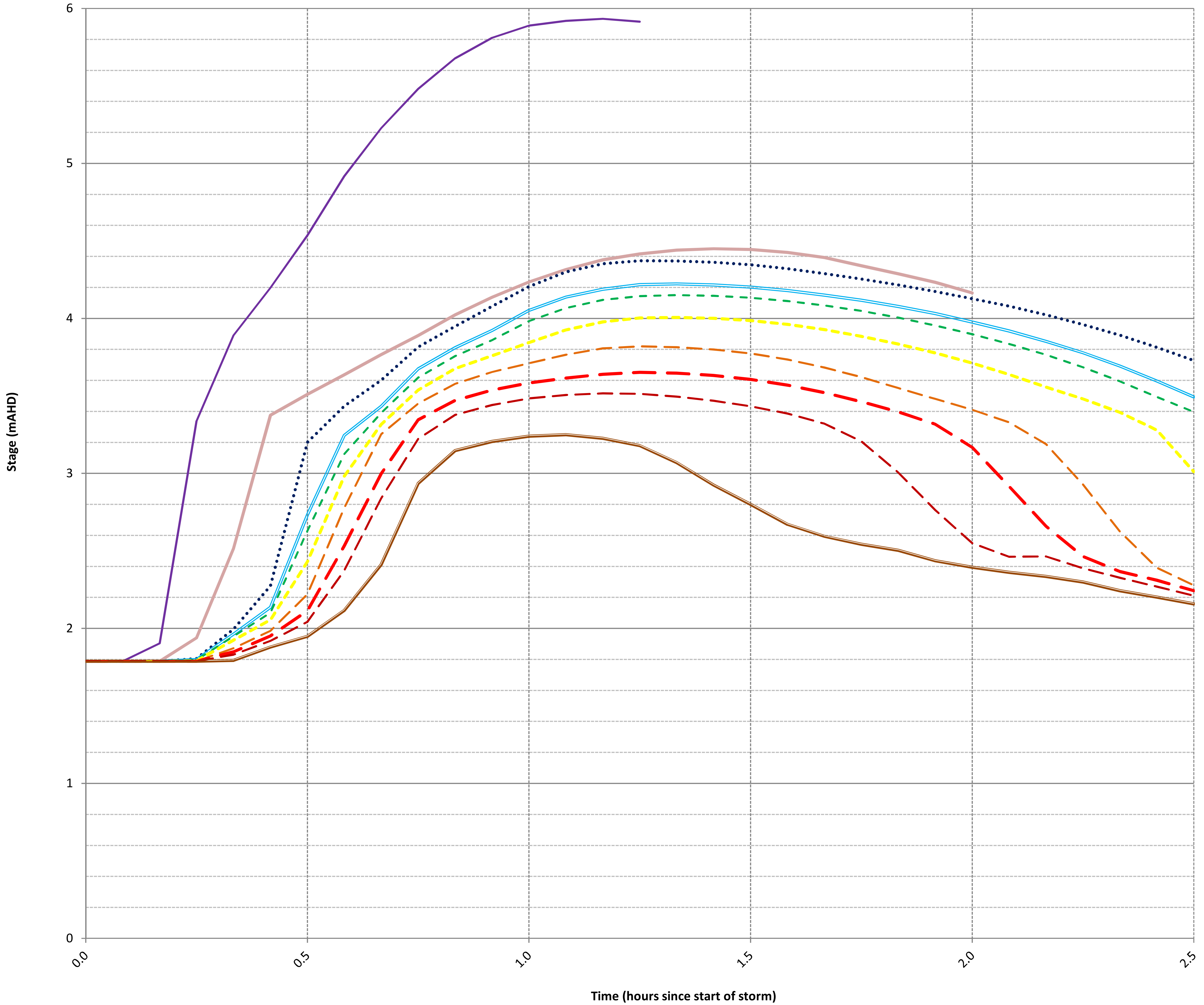
Km

Figure H1: Stage and Flow Hydrograph Reporting Locations

Prepared By:

Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: AppH - Stage and Flow Hydrogrpah Locations.wor



NORTHERN BEACHES COUNCIL

LEGEND:

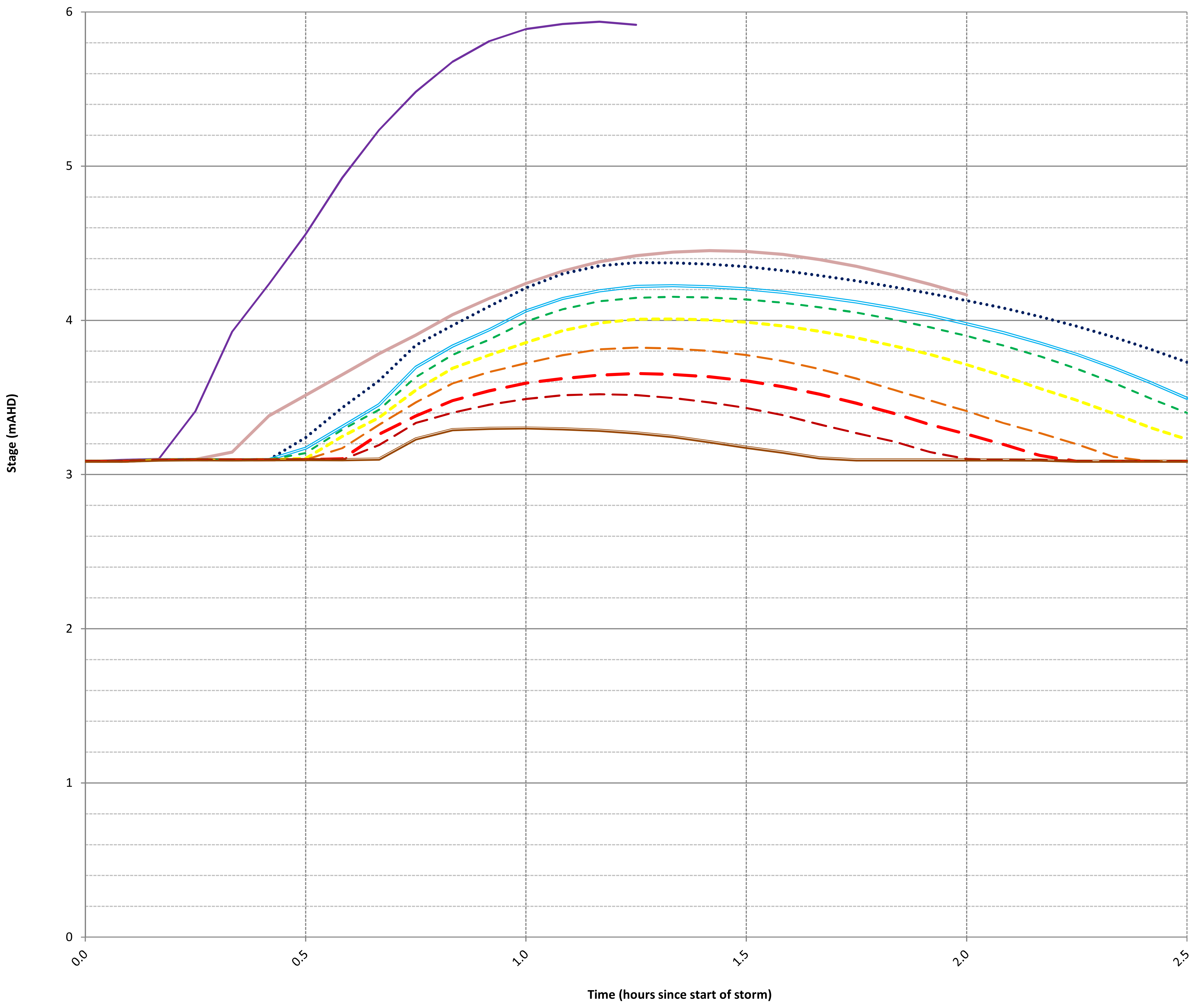
- PMF Stage Hydrograph
- 0.1% AEP Stage Hydrograph
- 0.2% AEP Stage Hydrograph
- 0.5% AEP Stage Hydrograph
- 1% AEP Stage Hydrograph
- 2% AEP Stage Hydrograph
- 5% AEP Stage Hydrograph
- 10% AEP Stage Hydrograph
- 20% AEP Stage Hydrograph
- 1 in 2 Year ARI Stage Hydrograph

Notes:
A number of different storm durations were simulated for each design flood. The stage hydrograph presented in this figure represents the storm duration that produces the highest peak design flood level at this location.

Figure H.1 Design Stage Hydrographs at Location #1 (Drainage channel upstream of The Boulevard)

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George Street
Sydney, NSW, 2000

File Name: Design Stage Hydrographs.xlsx



NORTHERN BEACHES COUNCIL

LEGEND:

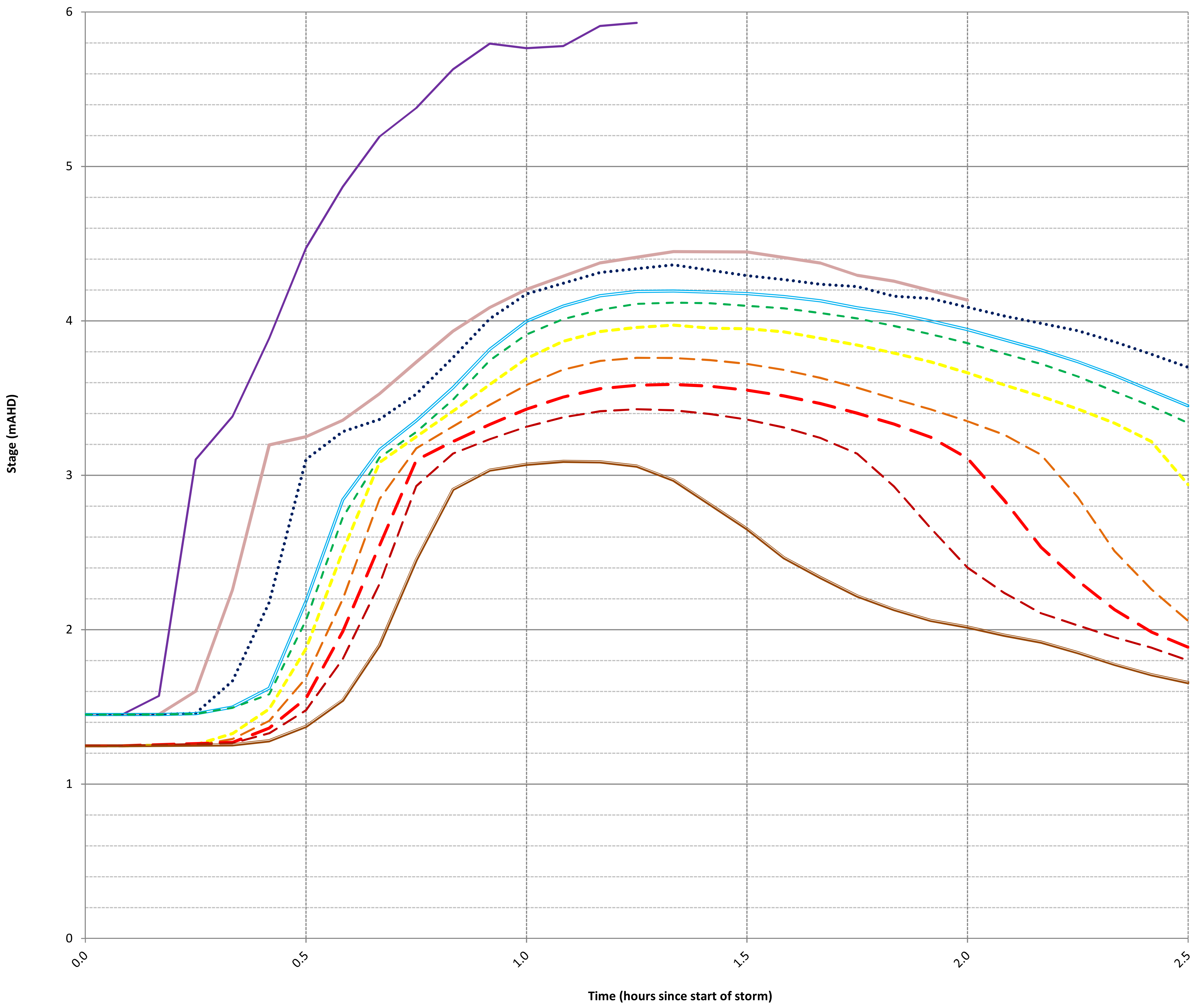
- PMF Stage Hydrograph
- 0.1% AEP Stage Hydrograph
- 0.2% AEP Stage Hydrograph
- 0.5% AEP Stage Hydrograph
- 1% AEP Stage Hydrograph
- 2% AEP Stage Hydrograph
- 5% AEP Stage Hydrograph
- 10% AEP Stage Hydrograph
- 20% AEP Stage Hydrograph
- 1 in 2 Year ARI Stage Hydrograph

Notes:
A number of different storm durations were simulated for each design flood. The stage hydrograph presented in this figure represents the storm duration that produces the highest peak design flood level at this location.

Figure H.2
Design Stage Hydrographs at Location #2 (Barrenjoey Road at the intersection of The Boulevard)

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George Street
Sydney, NSW, 2000

File Name: Design Stage Hydrographs.xlsx



NORTHERN BEACHES COUNCIL

LEGEND:

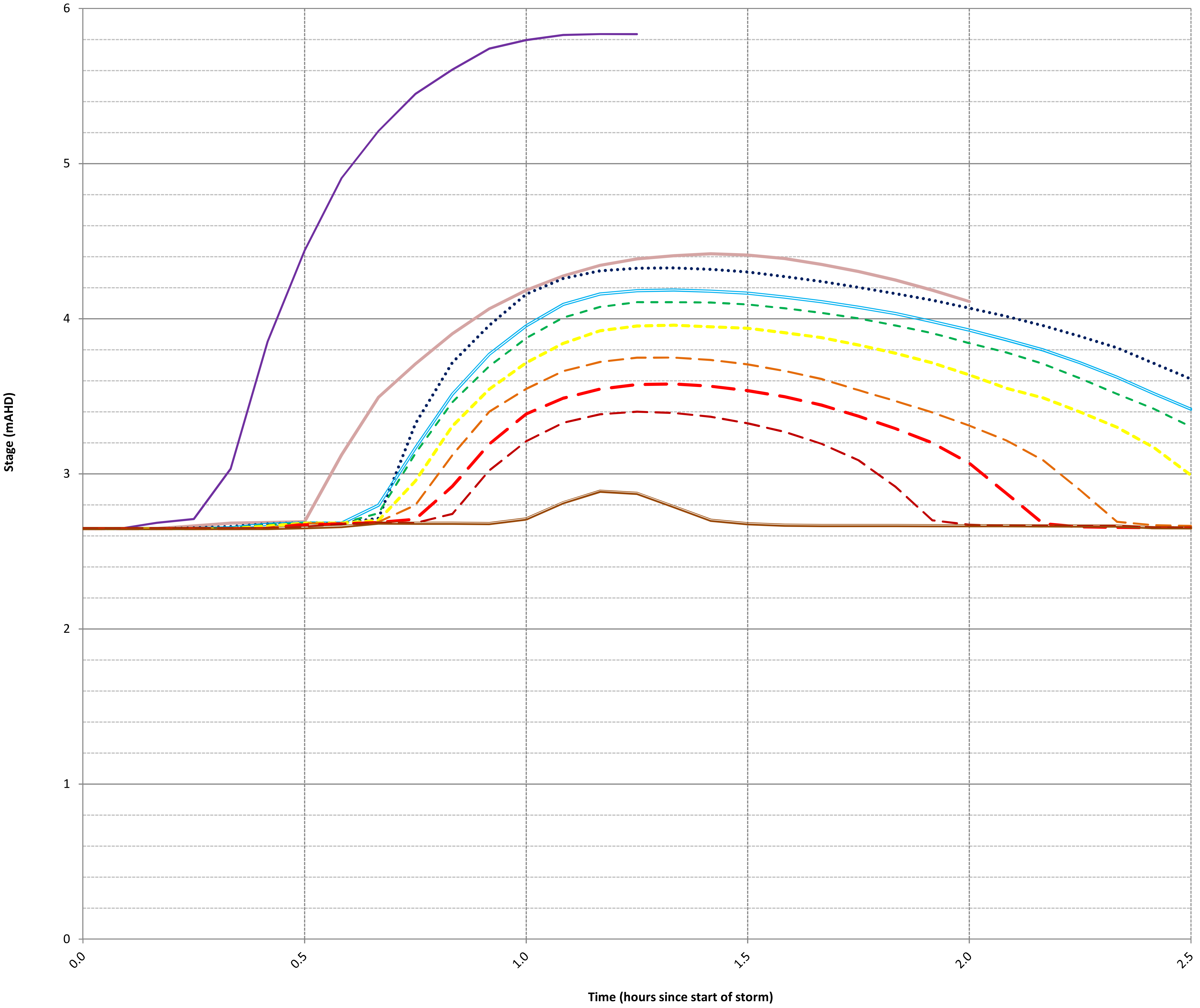
- PMF Stage Hydrograph
- 0.1% AEP Stage Hydrograph
- 0.2% AEP Stage Hydrograph
- 0.5% AEP Stage Hydrograph
- 1% AEP Stage Hydrograph
- 2% AEP Stage Hydrograph
- 5% AEP Stage Hydrograph
- 10% AEP Stage Hydrograph
- 20% AEP Stage Hydrograph
- 1 in 2 Year ARI Stage Hydrograph

Notes:
A number of different storm durations were simulated for each design flood. The stage hydrograph presented in this figure represents the storm duration that produces the highest peak design flood level at this location.

Figure H.3
Design Stage Hydrographs at Location #3 (Drainage channel upstream of Bramley Ave)

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George Street
Sydney, NSW, 2000

File Name: Design Stage Hydrographs.xlsx



NORTHERN BEACHES COUNCIL

LEGEND:

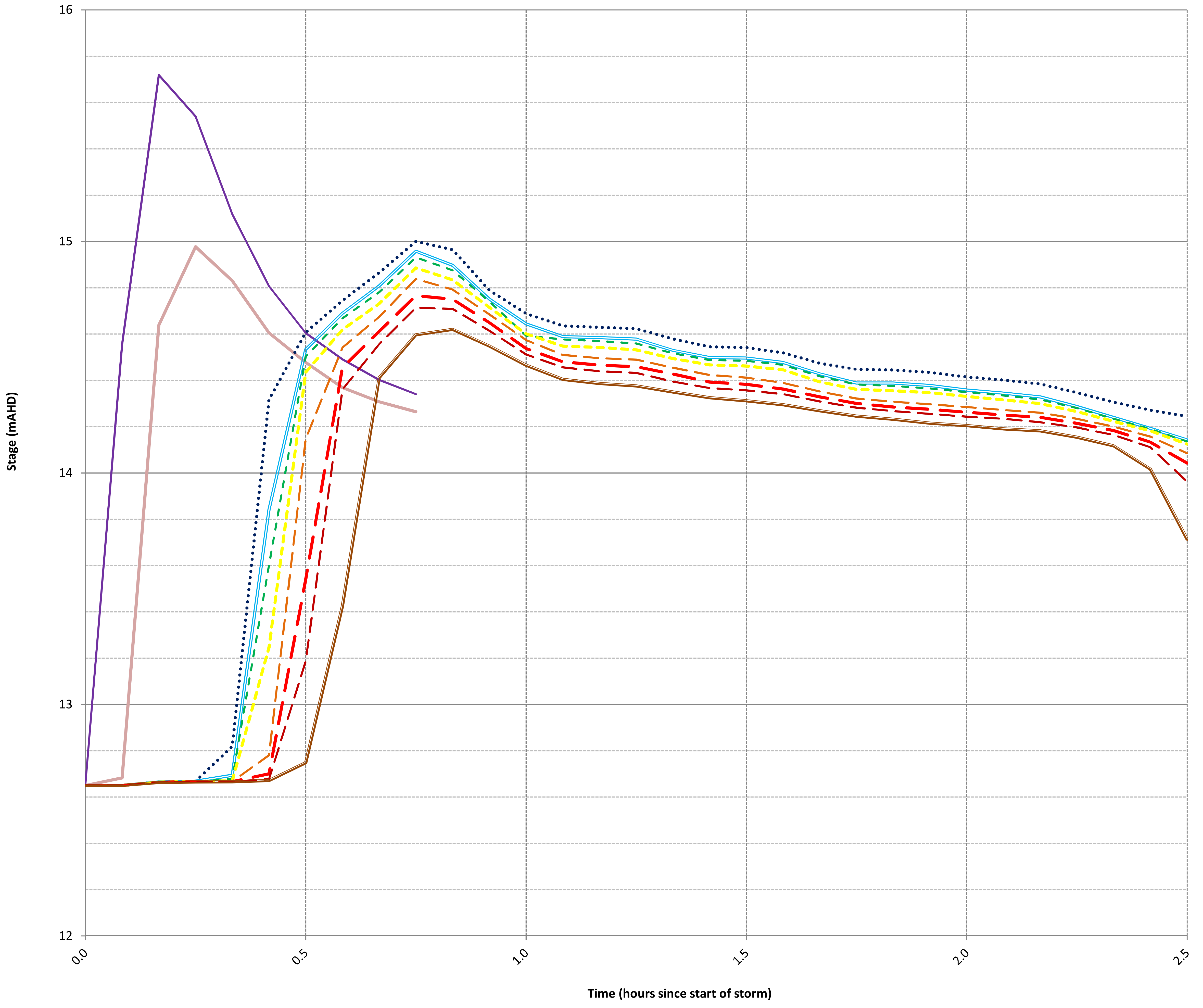
- PMF Stage Hydrograph
- 0.1% AEP Stage Hydrograph
- 0.2% AEP Stage Hydrograph
- 0.5% AEP Stage Hydrograph
- 1% AEP Stage Hydrograph
- 2% AEP Stage Hydrograph
- 5% AEP Stage Hydrograph
- 10% AEP Stage Hydrograph
- 20% AEP Stage Hydrograph
- 1 in 2 Year ARI Stage Hydrograph

Notes:
A number of different storm durations were simulated for each design flood. The stage hydrograph presented in this figure represents the storm duration that produces the highest peak design flood level at this location.

Figure H.4
Design Stage Hydrographs at Location #4 (Coles Parade Carpark)

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George Street
Sydney, NSW, 2000

File Name: Design Stage Hydrographs.xlsx



NORTHERN BEACHES COUNCIL

LEGEND:

- PMF Stage Hydrograph
- 0.1% AEP Stage Hydrograph
- 0.2% AEP Stage Hydrograph
- 0.5% AEP Stage Hydrograph
- 1% AEP Stage Hydrograph
- 2% AEP Stage Hydrograph
- 5% AEP Stage Hydrograph
- 10% AEP Stage Hydrograph
- 20% AEP Stage Hydrograph
- 1 in 2 Year ARI Stage Hydrograph

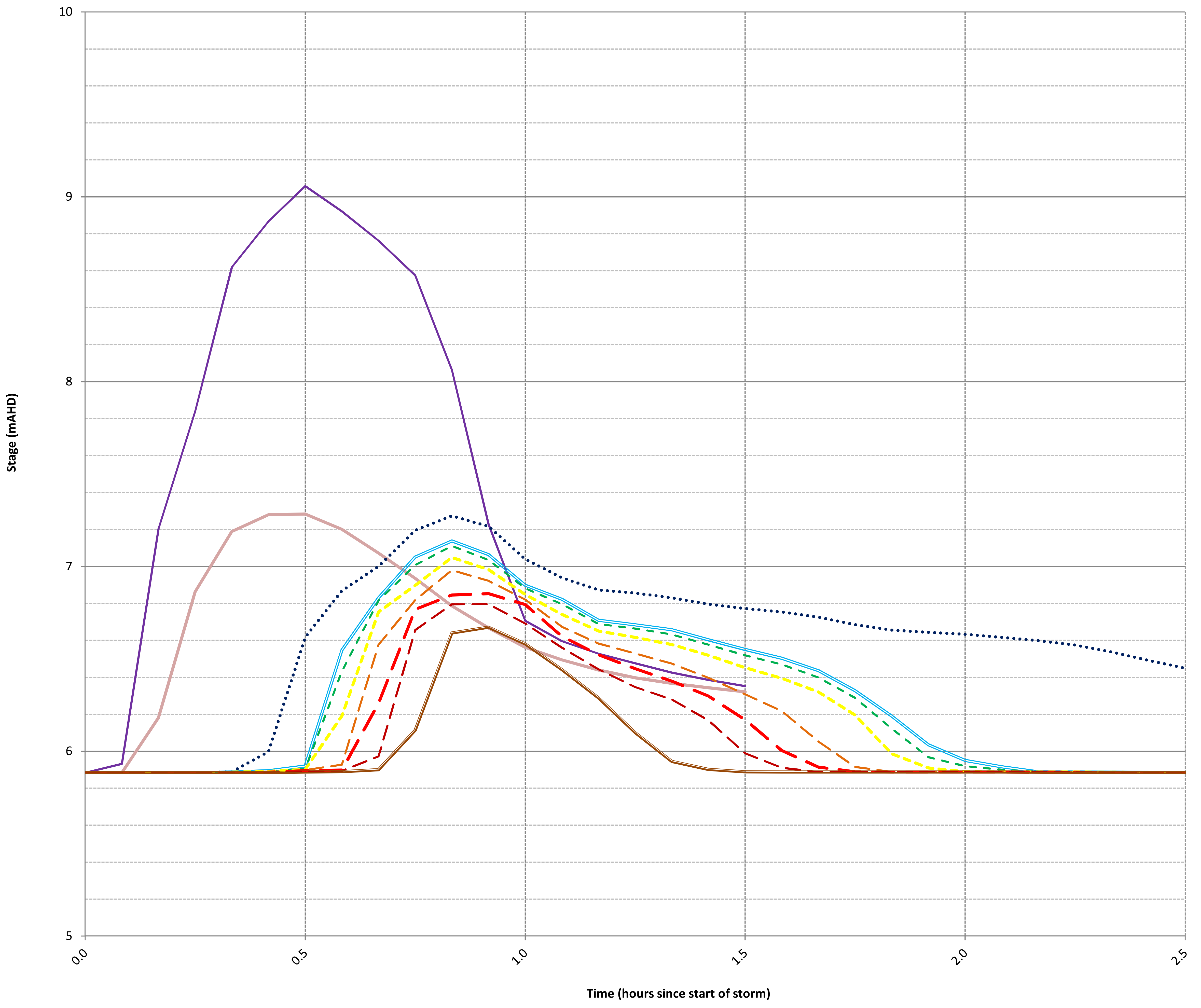
Notes:

A number of different storm durations were simulated for each design flood. The stage hydrograph presented in this figure represents the storm duration that produces the highest peak design flood level at this location.

Figure H.5
Design Stage Hydrographs at Location #5 (Howell Close Culvert Inlet)

Prepared By:
CatchmentSimulationSolutions
Suite 2.01, 210 George Street
Sydney, NSW, 2000

File Name: Design Stage Hydrographs.xlsx



NORTHERN BEACHES COUNCIL

LEGEND:

- PMF Stage Hydrograph
- 0.1% AEP Stage Hydrograph
- 0.2% AEP Stage Hydrograph
- 0.5% AEP Stage Hydrograph
- 1% AEP Stage Hydrograph
- 2% AEP Stage Hydrograph
- 5% AEP Stage Hydrograph
- 10% AEP Stage Hydrograph
- 20% AEP Stage Hydrograph
- 1 in 2 Year ARI Stage Hydrograph

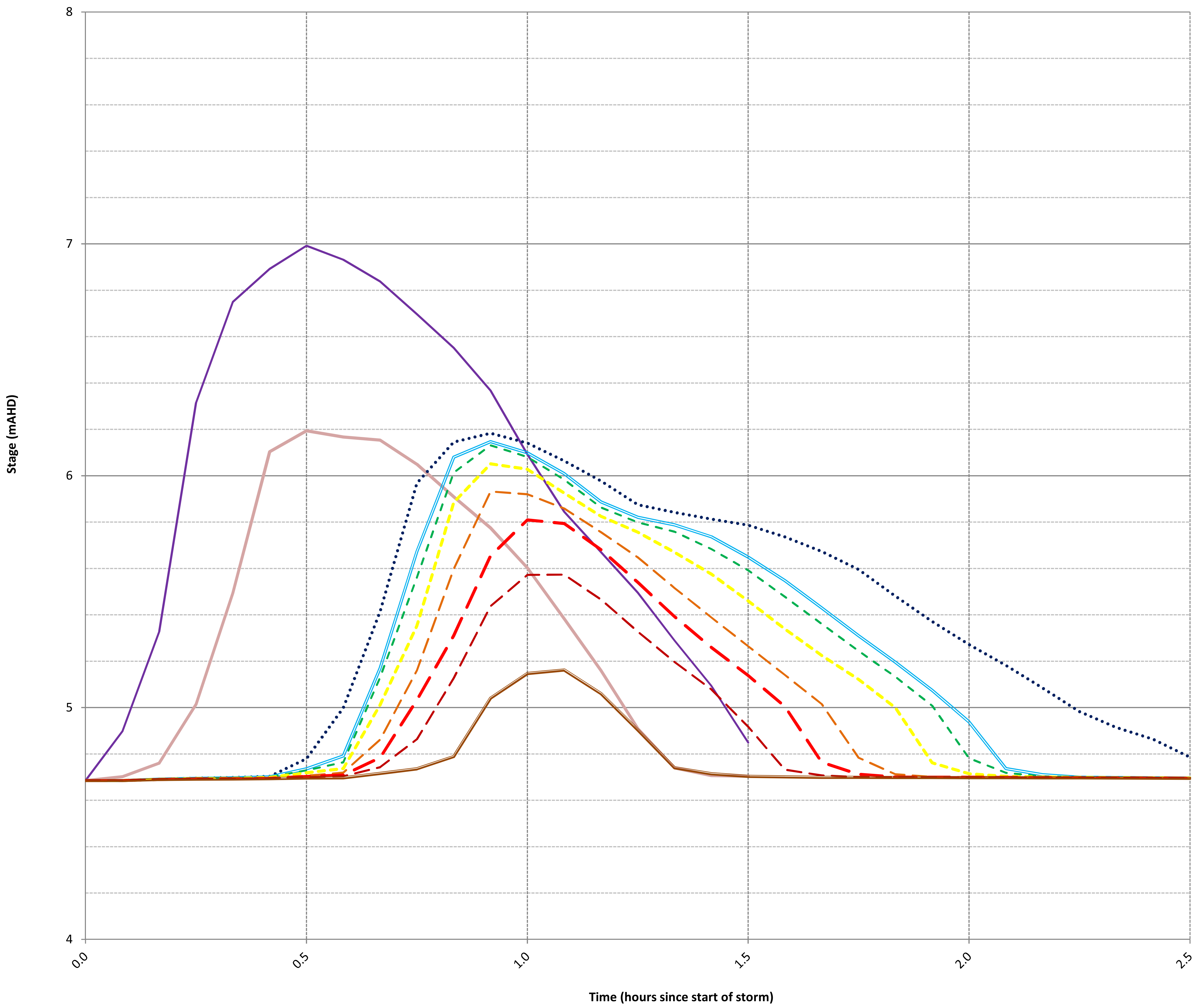
Notes:

A number of different storm durations were simulated for each design flood. The stage hydrograph presented in this figure represents the storm duration that produces the highest peak design flood level at this location.

Figure H.6
Design Stage Hydrographs at Location #6 (Drainage channel upstream of Ocean Ave)

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George Street
Sydney, NSW, 2000

File Name: Design Stage Hydrographs.xlsx



NORTHERN BEACHES COUNCIL

LEGEND:

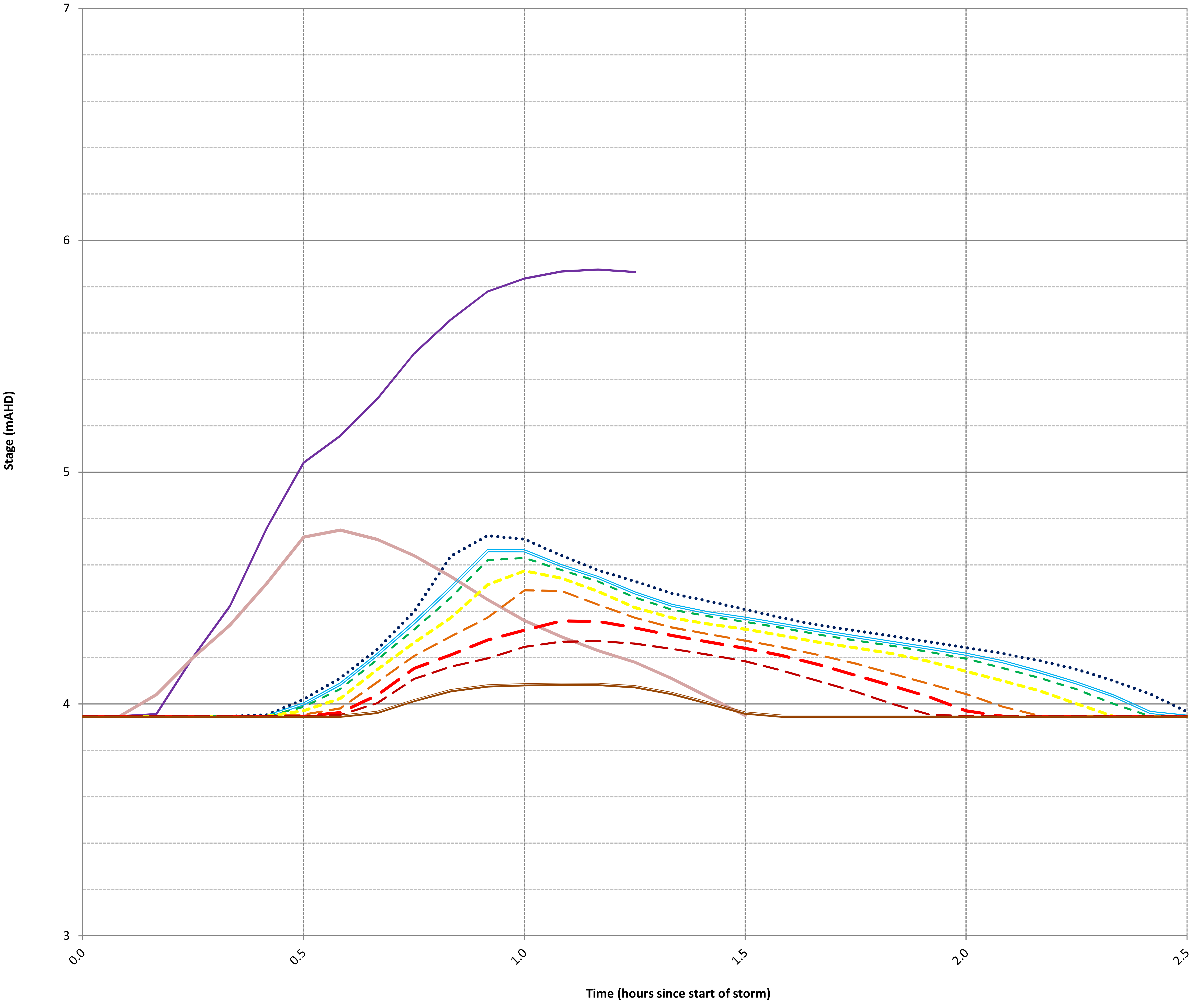
- PMF Stage Hydrograph
- 0.1% AEP Stage Hydrograph
- 0.2% AEP Stage Hydrograph
- 0.5% AEP Stage Hydrograph
- 1% AEP Stage Hydrograph
- 2% AEP Stage Hydrograph
- 5% AEP Stage Hydrograph
- 10% AEP Stage Hydrograph
- 20% AEP Stage Hydrograph
- 1 in 2 Year ARI Stage Hydrograph

Notes:
A number of different storm durations were simulated for each design flood. The stage hydrograph presented in this figure represents the storm duration that produces the highest peak design flood level at this location.

Figure H.7
Design Stage Hydrographs at Location #7
(Foamcrest Avenue road reserve)

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George Street
Sydney, NSW, 2000

File Name: Design Stage Hydrographs.xlsx



NORTHERN BEACHES COUNCIL

LEGEND:

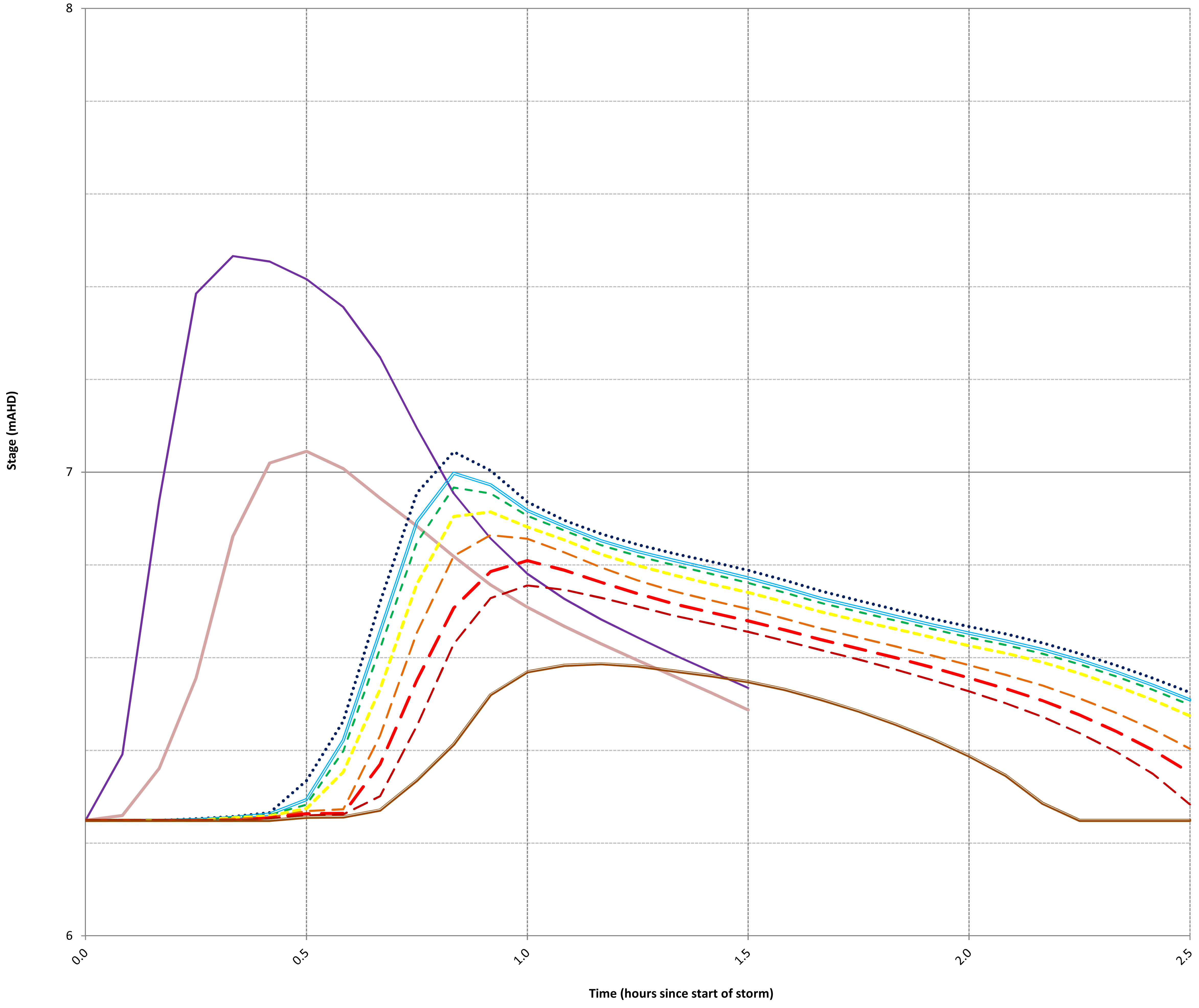
- PMF Stage Hydrograph
- 0.1% AEP Stage Hydrograph
- 0.2% AEP Stage Hydrograph
- 0.5% AEP Stage Hydrograph
- 1% AEP Stage Hydrograph
- 2% AEP Stage Hydrograph
- 5% AEP Stage Hydrograph
- 10% AEP Stage Hydrograph
- 20% AEP Stage Hydrograph
- 1 in 2 Year ARI Stage Hydrograph

Notes:
A number of different storm durations were simulated for each design flood. The stage hydrograph presented in this figure represents the storm duration that produces the highest peak design flood level at this location.

Figure H.8
Design Stage Hydrographs at Location #8
(Barrenjoey Rd at the intersection of Coles Pde)

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George Street
Sydney, NSW, 2000

File Name: Design Stage Hydrographs.xlsx



NORTHERN BEACHES COUNCIL

LEGEND:

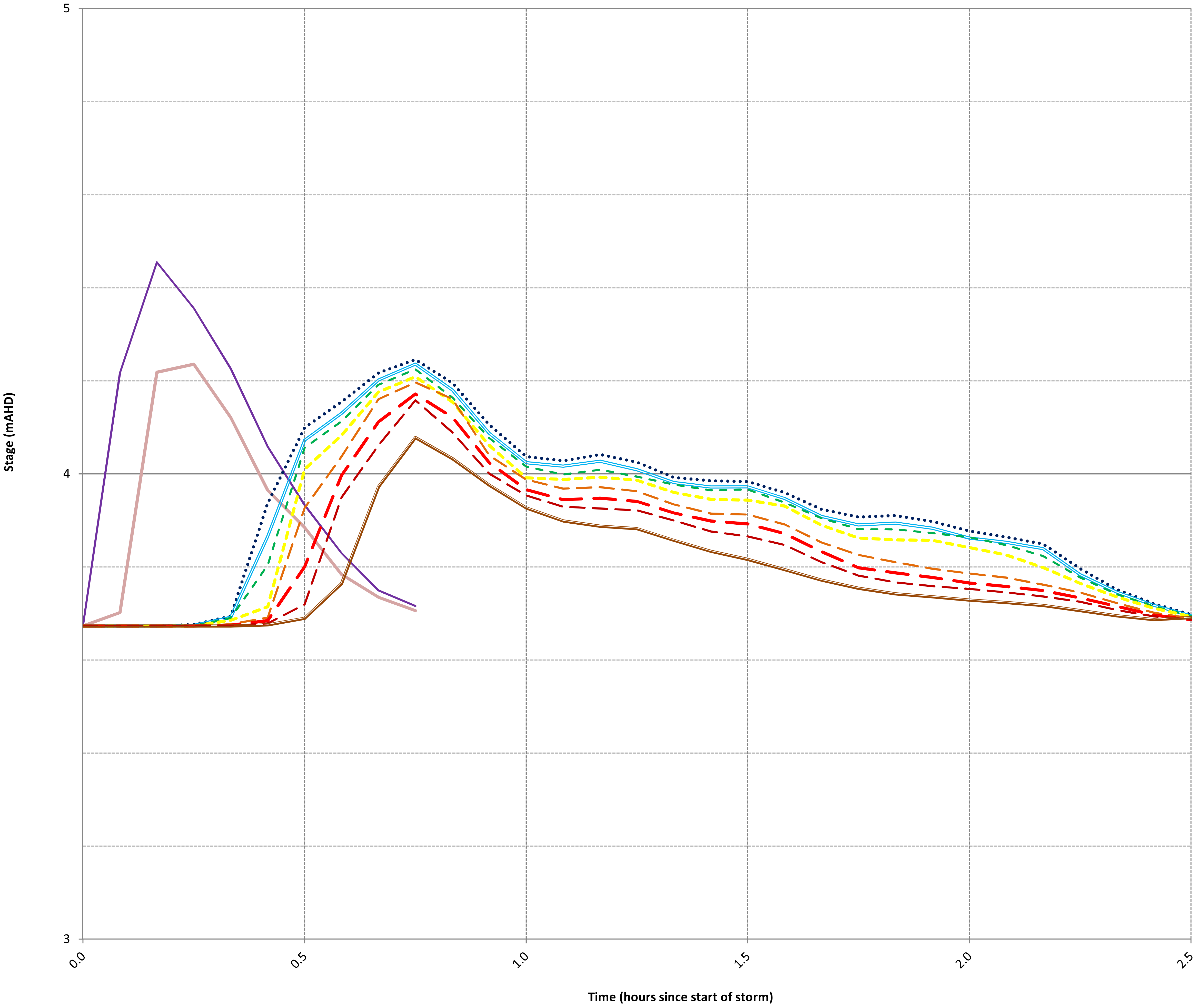
- PMF Stage Hydrograph
- 0.1% AEP Stage Hydrograph
- 0.2% AEP Stage Hydrograph
- 0.5% AEP Stage Hydrograph
- 1% AEP Stage Hydrograph
- 2% AEP Stage Hydrograph
- 5% AEP Stage Hydrograph
- 10% AEP Stage Hydrograph
- 20% AEP Stage Hydrograph
- 1 in 2 Year ARI Stage Hydrograph

Notes:
A number of different storm durations were simulated for each design flood. The stage hydrograph presented in this figure represents the storm duration that produces the highest peak design flood level at this location.

Figure H.9
Design Stage Hydrographs at Location #9 (Barrenjoey Rd adjacent 409 Barrenjoey Rd apartments)

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George Street
Sydney, NSW, 2000

File Name: Design Stage Hydrographs.xlsx



NORTHERN BEACHES COUNCIL

LEGEND:

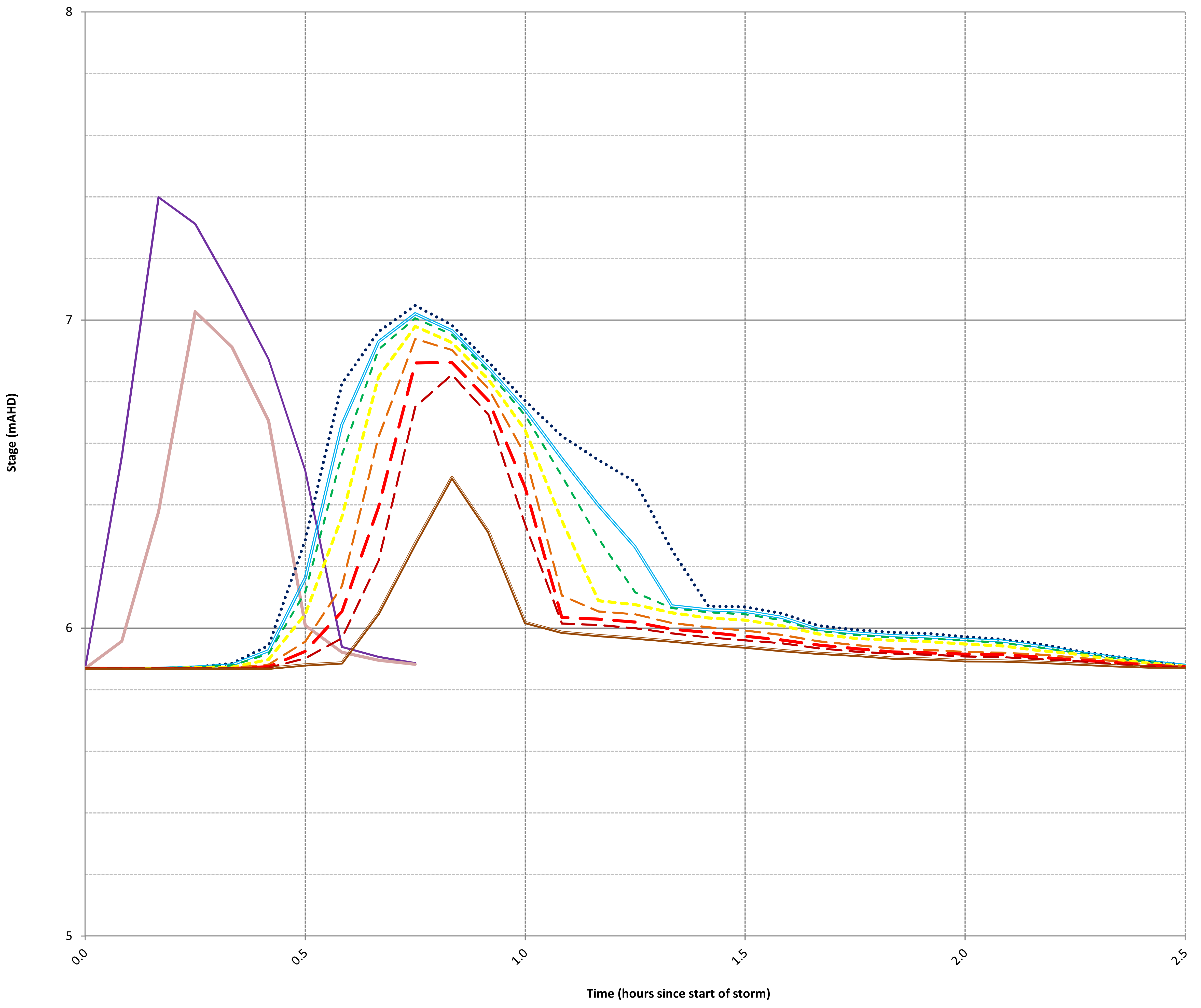
- PMF Stage Hydrograph
- 0.1% AEP Stage Hydrograph
- 0.2% AEP Stage Hydrograph
- 0.5% AEP Stage Hydrograph
- 1% AEP Stage Hydrograph
- 2% AEP Stage Hydrograph
- 5% AEP Stage Hydrograph
- 10% AEP Stage Hydrograph
- 20% AEP Stage Hydrograph
- 1 in 2 Year ARI Stage Hydrograph

Notes:
A number of different storm durations were simulated for each design flood. The stage hydrograph presented in this figure represents the storm duration that produces the highest peak design flood level at this location.

**Figure H.10
Design Stage Hydrographs at Location #10
(Prince Alfred Pde sag adjacent Florence Park)**

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George Street
Sydney, NSW, 2000

File Name: Design Stage Hydrographs.xlsx



NORTHERN BEACHES COUNCIL

LEGEND:

- PMF Stage Hydrograph
- 0.1% AEP Stage Hydrograph
- 0.2% AEP Stage Hydrograph
- 0.5% AEP Stage Hydrograph
- 1% AEP Stage Hydrograph
- 2% AEP Stage Hydrograph
- 5% AEP Stage Hydrograph
- 10% AEP Stage Hydrograph
- 20% AEP Stage Hydrograph
- 1 in 2 Year ARI Stage Hydrograph

Notes:
A number of different storm durations were simulated for each design flood. The stage hydrograph presented in this figure represents the storm duration that produces the highest peak design flood level at this location.

Figure H.11
Design Stage Hydrographs at Location #11 (Irrubel Rd sag adjacent Crystal St)

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George Street
Sydney, NSW, 2000

File Name: Design Stage Hydrographs.xlsx

Appendix I

XP-RAFTS Verification Model

XP-RAFTS Validation Model

General

The XP-RAFTS software was used to develop a hydrologic computer model of the Newport catchment to assist with the validation of the TUFLOW computer model. XP-RAFTS is a lumped hydrologic software product that is developed by XP Software (XP Software, 2009) and is used extensively across Australia for simulating rainfall-runoff processes and producing design discharge estimates. The following sections provide a summary of the model development process and the outcomes of the model validation.

Hydrologic Model Development

Subcatchment Parameterisation

The Newport catchment was subdivided into 265 subcatchments based on the alignment of major flow paths and topographic divides. The subcatchments were delineated with the assistance of the CatchmentSIM software (Catchment Simulation Solutions, 2011) using a 2 metre Digital Elevation Model (DEM). The subcatchment layout is presented in **Figure I1**.

The Newport catchment incorporates significant urban areas that are relatively impervious. Urbanisation effectively separates the catchment into two hydrologic systems, i.e.,:

- rapid rainfall response and low infiltration potential across impervious areas (e.g.; roads, driveways, buildings); and,
- slower rainfall response and high infiltration potential across pervious areas (e.g.; bushland, grass).

In recognition of the differing characteristics of the two hydrologic systems, each XP-RAFTS subcatchment was subdivided into two sub-areas. The first sub-area was used to represent the pervious sections of the subcatchment and the second sub-area was used to represent the impervious sections of the subcatchment. The division of each subcatchment into pervious and impervious sub-areas allows different rainfall losses and roughness coefficients to be specified, thereby providing a more realistic representation of rainfall-runoff processes from the two different hydrologic systems.

Key hydrologic properties including area and average vectored slope were calculated automatically for each subcatchment using CatchmentSIM. The adopted subcatchment slopes and areas are provided in **Table I1**.

The catchment was also subdivided into different land use types based on the remote sensing outputs that were used for assigning material types in the TUFLOW model. Percentage impervious and Manning's 'n' values were assigned to each land use and are summarised in **Table I2**. The percentage impervious and Manning's 'n' values were subsequently used to calculate weighted average percentage impervious and 'n' values for each subcatchment.

Table I1 - XP-RAFTS INPUT PARAMETERS

Subcatchment ID	Sub-Area	Area [ha]	Catchment Slope [%]	Percentage Impervious [%]	Mannings 'n'
1	1	0.56	40.56	0	0.136
	2	0.19	40.56	100	0.015
2	1	0.56	12.82	0	0.157
	2	0.11	12.82	100	0.015
3	1	0.64	50.93	0	0.131
	2	0.23	50.93	100	0.015
4	1	0.46	23.44	0	0.121
	2	0.25	23.44	100	0.015
5	1	0.88	23.44	0	0.101
	2	0.61	23.44	100	0.015
6	1	0.10	17.12	0	0.169
	2	0.01	17.12	100	0.015
7	1	0.86	19.07	0	0.150
	2	0.16	19.07	100	0.015
8	1	1.37	38.51	0	0.126
	2	0.55	38.51	100	0.015
9	1	0.93	12.58	0	0.131
	2	0.29	12.58	100	0.015
10	1	0.43	1.79	0	0.106
	2	0.21	1.79	100	0.015
11	1	0.31	1.78	0	0.067
	2	0.35	1.78	100	0.015
12	1	0.78	12.47	0	0.105
	2	0.47	12.47	100	0.015
13	1	0.18	2.83	0	0.074
	2	0.21	2.83	100	0.015
14	1	0.26	3.84	0	0.117
	2	0.12	3.84	100	0.015
15	1	0.48	12.94	0	0.078
	2	0.48	12.94	100	0.015
16	1	1.38	41.45	0	0.128
	2	0.47	41.45	100	0.015
17	1	0.97	17.35	0	0.106
	2	0.29	17.35	100	0.015
18	1	1.09	6.35	0	0.091
	2	0.92	6.35	100	0.015
19	1	0.39	14.63	0	0.074
	2	0.37	14.63	100	0.015
20	1	1.25	12.09	0	0.110
	2	0.49	12.09	100	0.015
21	1	0.60	13.17	0	0.121
	2	0.24	13.17	100	0.015
22	1	1.49	23.73	0	0.127
	2	0.61	23.73	100	0.015
23	1	0.72	10.65	0	0.101
	2	0.48	10.65	100	0.015

Subcatchment ID	Sub-Area	Area [ha]	Catchment Slope [%]	Percentage Impervious [%]	Mannings 'n'
24	1	0.48	22.26	0	0.104
	2	0.31	22.26	100	0.015
25	1	1.97	30.08	0	0.130
	2	0.75	30.08	100	0.015
26	1	1.39	8.56	0	0.079
	2	0.93	8.56	100	0.015
27	1	0.24	33.02	0	0.112
	2	0.13	33.02	100	0.015
28	1	1.37	10.58	0	0.133
	2	0.38	10.58	100	0.015
29	1	0.84	14.12	0	0.100
	2	0.40	14.12	100	0.015
30	1	0.45	4.06	0	0.111
	2	0.25	4.06	100	0.015
31	1	0.24	22.95	0	0.095
	2	0.19	22.95	100	0.015
32	1	2.23	27.02	0	0.124
	2	1.01	27.02	100	0.015
33	1	1.05	9.21	0	0.109
	2	0.63	9.21	100	0.015
34	1	0.57	7.87	0	0.068
	2	0.55	7.87	100	0.015
35	1	1.35	24.45	0	0.118
	2	0.47	24.45	100	0.015
36	1	1.74	27.22	0	0.100
	2	0.89	27.22	100	0.015
37	1	1.06	7.45	0	0.080
	2	0.69	7.45	100	0.015
38	1	0.59	8.07	0	0.095
	2	0.46	8.07	100	0.015
39	1	0.58	8.29	0	0.079
	2	0.38	8.29	100	0.015
40	1	0.85	14.99	0	0.125
	2	0.35	14.99	100	0.015
41	1	1.35	25.82	0	0.131
	2	0.40	25.82	100	0.015
42	1	1.44	24.58	0	0.120
	2	0.49	24.58	100	0.015
43	1	0.85	16.13	0	0.085
	2	0.59	16.13	100	0.015
44	1	0.20	16.70	0	0.075
	2	0.21	16.70	100	0.015
45	1	1.27	34.83	0	0.120
	2	0.44	34.83	100	0.015
46	1	0.37	6.24	0	0.070
	2	0.29	6.24	100	0.015
47	1	1.01	18.22	0	0.103
	2	0.46	18.22	100	0.015

Subcatchment ID	Sub-Area	Area [ha]	Catchment Slope [%]	Percentage Impervious [%]	Mannings 'n'
48	1	1.79	11.51	0	0.097
	2	1.09	11.51	100	0.015
49	1	2.21	23.46	0	0.131
	2	0.91	23.46	100	0.015
50	1	4.62	23.60	0	0.143
	2	1.11	23.60	100	0.015
51	1	0.53	21.60	0	0.122
	2	0.21	21.60	100	0.015
52	1	0.96	15.61	0	0.113
	2	0.58	15.61	100	0.015
53	1	2.90	20.24	0	0.158
	2	0.49	20.24	100	0.015
54	1	1.77	35.99	0	0.125
	2	0.68	35.99	100	0.015
55	1	1.28	8.37	0	0.089
	2	0.95	8.37	100	0.015
56	1	0.26	43.23	0	0.173
	2	0.01	43.23	100	0.015
57	1	0.51	35.50	0	0.113
	2	0.18	35.50	100	0.015
58	1	2.63	26.33	0	0.151
	2	0.32	26.33	100	0.015
59	1	0.24	17.71	0	0.102
	2	0.11	17.71	100	0.015
60	1	0.22	22.65	0	0.122
	2	0.12	22.65	100	0.015
61	1	3.95	25.77	0	0.130
	2	1.36	25.77	100	0.015
62	1	0.61	16.62	0	0.092
	2	0.42	16.62	100	0.015
63	1	1.65	25.55	0	0.115
	2	0.82	25.55	100	0.015
64	1	1.23	9.32	0	0.087
	2	0.86	9.32	100	0.015
65	1	0.93	31.56	0	0.101
	2	0.23	31.56	100	0.015
66	1	1.07	14.12	0	0.068
	2	0.92	14.12	100	0.015
67	1	0.74	12.17	0	0.096
	2	0.56	12.17	100	0.015
68	1	1.39	25.95	0	0.096
	2	0.77	25.95	100	0.015
69	1	1.96	27.00	0	0.122
	2	0.69	27.00	100	0.015
70	1	0.17	6.57	0	0.091
	2	0.02	6.57	100	0.015
71	1	1.80	12.97	0	0.114
	2	0.14	12.97	100	0.015

Subcatchment ID	Sub-Area	Area [ha]	Catchment Slope [%]	Percentage Impervious [%]	Mannings 'n'
72	1	1.75	17.05	0	0.107
	2	0.58	17.05	100	0.015
73	1	0.71	9.27	0	0.077
	2	0.78	9.27	100	0.015
74	1	0.47	15.31	0	0.087
	2	0.44	15.31	100	0.015
75	1	0.31	17.94	0	0.086
	2	0.37	17.94	100	0.015
76	1	0.19	8.28	0	0.081
	2	0.18	8.28	100	0.015
77	1	1.33	32.64	0	0.109
	2	0.65	32.64	100	0.015
78	1	0.53	24.87	0	0.116
	2	0.23	24.87	100	0.015
79	1	2.40	18.93	0	0.112
	2	0.88	18.93	100	0.015
80	1	0.90	23.30	0	0.122
	2	0.34	23.30	100	0.015
81	1	0.84	3.89	0	0.070
	2	0.22	3.89	100	0.015
82	1	0.97	10.80	0	0.084
	2	0.51	10.80	100	0.015
83	1	1.61	9.58	0	0.117
	2	0.10	9.58	100	0.015
84	1	1.62	15.03	0	0.087
	2	0.97	15.03	100	0.015
85	1	1.02	6.08	0	0.088
	2	0.73	6.08	100	0.015
86	1	0.87	8.99	0	0.090
	2	0.62	8.99	100	0.015
87	1	1.51	7.74	0	0.085
	2	0.55	7.74	100	0.015
88	1	0.96	5.35	0	0.070
	2	0.07	5.35	100	0.015
89	1	0.33	24.80	0	0.094
	2	0.20	24.80	100	0.015
90	1	0.59	36.24	0	0.125
	2	0.18	36.24	100	0.015
91	1	0.47	22.98	0	0.097
	2	0.32	22.98	100	0.015
92	1	1.22	14.54	0	0.107
	2	0.78	14.54	100	0.015
93	1	0.63	18.64	0	0.077
	2	0.43	18.64	100	0.015
94	1	1.12	33.17	0	0.130
	2	0.47	33.17	100	0.015
95	1	0.78	5.28	0	0.067
	2	0.52	5.28	100	0.015

Subcatchment ID	Sub-Area	Area [ha]	Catchment Slope [%]	Percentage Impervious [%]	Mannings 'n'
96	1	0.56	1.63	0	0.058
	2	0.31	1.63	100	0.015
97	1	0.29	41.42	0	0.159
	2	0.05	41.42	100	0.015
98	1	1.09	3.86	0	0.090
	2	0.51	3.86	100	0.015
99	1	1.57	23.56	0	0.113
	2	0.58	23.56	100	0.015
100	1	0.48	19.04	0	0.093
	2	0.25	19.04	100	0.015
101	1	0.65	8.35	0	0.069
	2	0.52	8.35	100	0.015
102	1	0.99	27.10	0	0.133
	2	0.23	27.10	100	0.015
103	1	1.28	28.14	0	0.136
	2	0.43	28.14	100	0.015
104	1	0.73	5.25	0	0.086
	2	0.51	5.25	100	0.015
105	1	1.17	29.10	0	0.105
	2	0.52	29.10	100	0.015
106	1	0.50	33.44	0	0.105
	2	0.21	33.44	100	0.015
107	1	0.53	13.49	0	0.123
	2	0.21	13.49	100	0.015
108	1	0.98	12.20	0	0.091
	2	0.65	12.20	100	0.015
109	1	0.25	18.77	0	0.100
	2	0.16	18.77	100	0.015
110	1	0.41	16.08	0	0.133
	2	0.16	16.08	100	0.015
111	1	1.19	26.58	0	0.108
	2	0.48	26.58	100	0.015
112	1	0.54	40.82	0	0.134
	2	0.12	40.82	100	0.015
113	1	0.89	3.70	0	0.071
	2	0.78	3.70	100	0.015
114	1	0.49	15.72	0	0.137
	2	0.09	15.72	100	0.015
115	1	0.55	19.14	0	0.093
	2	0.23	19.14	100	0.015
116	1	0.73	0.41	0	0.061
	2	0.58	0.41	100	0.015
117	1	0.80	20.82	0	0.112
	2	0.36	20.82	100	0.015
118	1	0.49	28.53	0	0.119
	2	0.18	28.53	100	0.015
119	1	3.00	10.65	0	0.113
	2	1.18	10.65	100	0.015

Subcatchment ID	Sub-Area	Area [ha]	Catchment Slope [%]	Percentage Impervious [%]	Mannings 'n'
120	1	0.75	24.49	0	0.122
	2	0.24	24.49	100	0.015
121	1	1.84	13.23	0	0.138
	2	0.48	13.23	100	0.015
122	1	0.67	2.96	0	0.068
	2	0.87	2.96	100	0.015
123	1	0.37	11.89	0	0.111
	2	0.17	11.89	100	0.015
124	1	0.35	14.96	0	0.128
	2	0.13	14.96	100	0.015
125	1	0.38	5.93	0	0.092
	2	0.24	5.93	100	0.015
126	1	0.58	16.24	0	0.117
	2	0.21	16.24	100	0.015
127	1	0.19	13.84	0	0.060
	2	0.24	13.84	100	0.015
128	1	1.05	5.72	0	0.097
	2	0.54	5.72	100	0.015
129	1	0.95	2.13	0	0.058
	2	1.06	2.13	100	0.015
130	1	1.06	23.22	0	0.109
	2	0.28	23.22	100	0.015
131	1	1.17	12.58	0	0.093
	2	0.74	12.58	100	0.015
132	1	0.49	3.20	0	0.101
	2	0.25	3.20	100	0.015
133	1	0.66	1.89	0	0.051
	2	1.12	1.89	100	0.015
134	1	1.33	5.20	0	0.098
	2	0.69	5.20	100	0.015
135	1	1.21	31.77	0	0.137
	2	0.29	31.77	100	0.015
136	1	0.44	3.29	0	0.077
	2	0.41	3.29	100	0.015
137	1	0.72	3.26	0	0.070
	2	0.67	3.26	100	0.015
138	1	0.67	0.81	0	0.061
	2	0.30	0.81	100	0.015
139	1	0.63	2.19	0	0.042
	2	0.96	2.19	100	0.015
140	1	2.87	10.91	0	0.095
	2	1.57	10.91	100	0.015
141	1	0.48	3.72	0	0.052
	2	0.00	3.72	100	0.015
142	1	0.69	0.45	0	0.059
	2	0.36	0.45	100	0.015
143	1	0.61	16.56	0	0.086
	2	0.39	16.56	100	0.015

Subcatchment ID	Sub-Area	Area [ha]	Catchment Slope [%]	Percentage Impervious [%]	Mannings 'n'
144	1	1.45	12.49	0	0.121
	2	0.58	12.49	100	0.015
145	1	2.55	10.54	0	0.132
	2	0.66	10.54	100	0.015
146	1	0.28	2.64	0	0.034
	2	0.43	2.64	100	0.015
147	1	2.65	14.31	0	0.120
	2	0.95	14.31	100	0.015
148	1	0.61	15.81	0	0.136
	2	0.13	15.81	100	0.015
149	1	1.37	1.64	0	0.061
	2	1.28	1.64	100	0.015
150	1	1.69	9.79	0	0.117
	2	0.73	9.79	100	0.015
151	1	0.36	2.81	0	0.050
	2	0.65	2.81	100	0.015
152	1	0.46	6.77	0	0.095
	2	0.25	6.77	100	0.015
153	1	1.11	1.43	0	0.057
	2	0.93	1.43	100	0.015
154	1	1.15	7.59	0	0.103
	2	0.60	7.59	100	0.015
155	1	0.81	2.24	0	0.068
	2	0.62	2.24	100	0.015
156	1	1.58	3.17	0	0.048
	2	1.42	3.17	100	0.015
157	1	1.09	7.76	0	0.075
	2	0.96	7.76	100	0.015
158	1	0.73	2.42	0	0.084
	2	0.41	2.42	100	0.015
159	1	0.79	4.87	0	0.086
	2	0.48	4.87	100	0.015
160	1	2.65	3.32	0	0.103
	2	1.15	3.32	100	0.015
161	1	0.21	4.15	0	0.062
	2	0.25	4.15	100	0.015
162	1	0.35	4.81	0	0.107
	2	0.14	4.81	100	0.015
163	1	0.25	6.73	0	0.106
	2	0.13	6.73	100	0.015
164	1	0.17	4.47	0	0.090
	2	0.06	4.47	100	0.015
165	1	0.69	6.37	0	0.090
	2	0.48	6.37	100	0.015
166	1	1.39	5.68	0	0.081
	2	0.99	5.68	100	0.015
167	1	2.67	1.12	0	0.076
	2	0.62	1.12	100	0.015

Subcatchment ID	Sub-Area	Area [ha]	Catchment Slope [%]	Percentage Impervious [%]	Mannings 'n'
168	1	1.12	1.91	0	0.068
	2	1.08	1.91	100	0.015
169	1	1.35	5.95	0	0.087
	2	0.94	5.95	100	0.015
170	1	0.25	4.50	0	0.102
	2	0.15	4.50	100	0.015
171	1	0.48	6.32	0	0.102
	2	0.28	6.32	100	0.015
172	1	1.28	2.12	0	0.074
	2	1.04	2.12	100	0.015
173	1	0.75	3.85	0	0.084
	2	0.62	3.85	100	0.015
174	1	1.84	2.78	0	0.094
	2	1.03	2.78	100	0.015
175	1	1.27	2.61	0	0.079
	2	0.87	2.61	100	0.015
176	1	1.78	2.41	0	0.096
	2	0.92	2.41	100	0.015
177	1	1.99	5.17	0	0.115
	2	0.86	5.17	100	0.015
178	1	1.69	4.05	0	0.094
	2	0.93	4.05	100	0.015
179	1	1.63	3.08	0	0.083
	2	1.14	3.08	100	0.015
180	1	1.26	5.28	0	0.079
	2	1.04	5.28	100	0.015
181	1	1.98	3.96	0	0.098
	2	1.06	3.96	100	0.015
182	1	0.34	4.85	0	0.063
	2	0.37	4.85	100	0.015
183	1	1.47	6.18	0	0.088
	2	1.09	6.18	100	0.015
184	1	0.74	4.18	0	0.084
	2	0.64	4.18	100	0.015
185	1	0.83	3.58	0	0.085
	2	0.57	3.58	100	0.015
186	1	0.76	9.57	0	0.076
	2	0.68	9.57	100	0.015
187	1	1.09	4.72	0	0.081
	2	0.80	4.72	100	0.015
188	1	0.28	8.51	0	0.087
	2	0.26	8.51	100	0.015
189	1	0.58	7.21	0	0.069
	2	0.55	7.21	100	0.015
190	1	3.07	4.17	0	0.096
	2	1.89	4.17	100	0.015
191	1	1.45	6.38	0	0.089
	2	0.87	6.38	100	0.015

Subcatchment ID	Sub-Area	Area [ha]	Catchment Slope [%]	Percentage Impervious [%]	Mannings 'n'
192	1	1.37	4.79	0	0.080
	2	0.84	4.79	100	0.015
193	1	0.14	6.90	0	0.050
	2	0.29	6.90	100	0.015
194	1	0.50	10.20	0	0.086
	2	0.33	10.20	100	0.015
195	1	1.12	12.69	0	0.092
	2	0.82	12.69	100	0.015
196	1	0.61	11.53	0	0.074
	2	0.47	11.53	100	0.015
197	1	0.48	11.54	0	0.097
	2	0.32	11.54	100	0.015
198	1	0.68	6.43	0	0.101
	2	0.50	6.43	100	0.015
199	1	0.25	8.31	0	0.063
	2	0.26	8.31	100	0.015
200	1	1.60	12.88	0	0.109
	2	0.76	12.88	100	0.015
201	1	1.89	8.58	0	0.089
	2	1.32	8.58	100	0.015
202	1	0.60	6.27	0	0.085
	2	0.54	6.27	100	0.015
203	1	1.16	12.21	0	0.081
	2	1.17	12.21	100	0.015
204	1	0.57	4.71	0	0.078
	2	0.48	4.71	100	0.015
205	1	0.24	5.96	0	0.067
	2	0.35	5.96	100	0.015
206	1	0.99	16.05	0	0.095
	2	0.52	16.05	100	0.015
207	1	1.64	7.52	0	0.111
	2	0.81	7.52	100	0.015
208	1	0.62	15.17	0	0.092
	2	0.39	15.17	100	0.015
209	1	0.51	15.79	0	0.078
	2	0.40	15.79	100	0.015
210	1	1.25	12.65	0	0.109
	2	0.54	12.65	100	0.015
211	1	1.22	13.93	0	0.110
	2	0.52	13.93	100	0.015
212	1	2.12	12.60	0	0.134
	2	0.40	12.60	100	0.015
213	1	0.75	13.59	0	0.114
	2	0.31	13.59	100	0.015
214	1	0.29	8.46	0	0.081
	2	0.27	8.46	100	0.015
215	1	1.00	15.15	0	0.099
	2	0.38	15.15	100	0.015

Subcatchment ID	Sub-Area	Area [ha]	Catchment Slope [%]	Percentage Impervious [%]	Mannings 'n'
216	1	1.63	21.78	0	0.085
	2	0.94	21.78	100	0.015
217	1	0.99	22.01	0	0.130
	2	0.20	22.01	100	0.015
218	1	0.69	9.93	0	0.112
	2	0.32	9.93	100	0.015
219	1	2.19	18.28	0	0.114
	2	0.54	18.28	100	0.015
220	1	2.04	11.57	0	0.116
	2	0.44	11.57	100	0.015
221	1	0.56	4.40	0	0.059
	2	0.79	4.40	100	0.015
222	1	1.69	12.98	0	0.120
	2	0.58	12.98	100	0.015
223	1	1.89	18.47	0	0.149
	2	0.36	18.47	100	0.015
224	1	1.57	10.44	0	0.113
	2	0.54	10.44	100	0.015
225	1	1.64	13.25	0	0.115
	2	0.69	13.25	100	0.015
226	1	0.38	11.90	0	0.120
	2	0.14	11.90	100	0.015
227	1	2.18	8.79	0	0.115
	2	0.69	8.79	100	0.015
228	1	1.21	9.79	0	0.120
	2	0.43	9.79	100	0.015
229	1	1.17	10.54	0	0.117
	2	0.48	10.54	100	0.015
230	1	0.48	11.28	0	0.122
	2	0.18	11.28	100	0.015
231	1	0.38	14.33	0	0.130
	2	0.14	14.33	100	0.015
232	1	0.96	14.32	0	0.130
	2	0.31	14.32	100	0.015
233	1	3.17	10.84	0	0.118
	2	1.09	10.84	100	0.015
234	1	0.48	5.27	0	0.062
	2	0.61	5.27	100	0.015
235	1	1.23	36.46	0	0.108
	2	0.78	36.46	100	0.015
236	1	3.13	26.98	0	0.138
	2	1.14	26.98	100	0.015
237	1	2.97	20.63	0	0.120
	2	1.61	20.63	100	0.015
238	1	1.97	22.69	0	0.092
	2	1.48	22.69	100	0.015
239	1	0.99	55.54	0	0.074
	2	0.22	55.54	100	0.015

Subcatchment ID	Sub-Area	Area [ha]	Catchment Slope [%]	Percentage Impervious [%]	Mannings 'n'
240	1	2.31	24.44	0	0.093
	2	1.97	24.44	100	0.015
241	1	0.92	13.80	0	0.068
	2	0.12	13.80	100	0.015
242	1	1.38	6.94	0	0.049
	2	0.28	6.94	100	0.015
243	1	3.37	16.77	0	0.089
	2	2.16	16.77	100	0.015
244	1	1.35	9.74	0	0.033
	2	0.26	9.74	100	0.015
245	1	0.67	9.52	0	0.030
	2	0.12	9.52	100	0.015
246	1	3.64	13.92	0	0.075
	2	3.71	13.92	100	0.015
247	1	2.26	5.11	0	0.032
	2	0.50	5.11	100	0.015
248	1	2.36	6.19	0	0.077
	2	1.70	6.19	100	0.015
249	1	2.40	37.93	0	0.049
	2	0.79	37.93	100	0.015
250	1	3.57	10.39	0	0.086
	2	3.22	10.39	100	0.015
251	1	3.44	30.14	0	0.075
	2	1.57	30.14	100	0.015
252	1	2.61	12.61	0	0.094
	2	1.87	12.61	100	0.015
253	1	1.40	11.76	0	0.119
	2	0.55	11.76	100	0.015
254	1	3.91	15.61	0	0.087
	2	2.78	15.61	100	0.015
255	1	1.60	52.62	0	0.073
	2	0.87	52.62	100	0.015
256	1	1.34	60.20	0	0.058
	2	0.68	60.20	100	0.015
257	1	0.55	7.92	0	0.037
	2	0.13	7.92	100	0.015
258	1	0.51	3.86	0	0.035
	2	0.32	3.86	100	0.015
259	1	1.21	9.55	0	0.053
	2	0.30	9.55	100	0.015
260	1	2.32	6.74	0	0.090
	2	1.25	6.74	100	0.015
261	1	2.50	10.62	0	0.085
	2	1.00	10.62	100	0.015
262	1	0.80	15.23	0	0.076
	2	0.09	15.23	100	0.015
263	1	1.77	9.97	0	0.051
	2	0.32	9.97	100	0.015

Subcatchment ID	Sub-Area	Area [ha]	Catchment Slope [%]	Percentage Impervious [%]	Mannings 'n'
264	1	1.71	15.57	0	0.062
	2	0.55	15.57	100	0.015
265	1	2.76	20.37	0	0.057
	2	0.95	20.37	100	0.015
_junc_1	1	0.00	0.00	0	0.035
_junc_20	1	0.00	0.00	0	0.035
_junc_23	1	0.00	0.00	0	0.035
_junc_24	1	0.00	0.00	0	0.035
_junc_29	1	0.00	0.00	0	0.035
_junc_34	1	0.00	0.00	0	0.035
_junc_46	1	0.00	0.00	0	0.035
_junc_47	1	0.00	0.00	0	0.035
_junc_48	1	0.00	0.00	0	0.035
_junc_58	1	0.00	0.00	0	0.035
_junc_70	1	0.00	0.00	0	0.035
_junc_72	1	0.00	0.00	0	0.035
_junc_74	1	0.00	0.00	0	0.035
_junc_78	1	0.00	0.00	0	0.035
_junc_79	1	0.00	0.00	0	0.035
_junc_92	1	0.00	0.00	0	0.035
_junc_108	1	0.00	0.00	0	0.035
_junc_109	1	0.00	0.00	0	0.035
_junc_116	1	0.00	0.00	0	0.035
_junc_118	1	0.00	0.00	0	0.035
_junc_122	1	0.00	0.00	0	0.035
_junc_123	1	0.00	0.00	0	0.035
_junc_136	1	0.00	0.00	0	0.035
_junc_137	1	0.00	0.00	0	0.035
_junc_138	1	0.00	0.00	0	0.035
_junc_142	1	0.00	0.00	0	0.035
_junc_154	1	0.00	0.00	0	0.035
_junc_170	1	0.00	0.00	0	0.035
_junc_176	1	0.00	0.00	0	0.035
_junc_181	1	0.00	0.00	0	0.035
_junc_183	1	0.00	0.00	0	0.035
_junc_189	1	0.00	0.00	0	0.035
_junc_191	1	0.00	0.00	0	0.035
_junc_193	1	0.00	0.00	0	0.035

The adopted pervious and impervious areas and weighted 'n' values for each subcatchment are also provided in **Table I1**.

Table I2 Adopted Impervious Percentage and Manning's 'n' Values for Hydrologic Model

Land Use Description	Hyrdologic roughness	Impervious (%)
Impervious	0.015	100
Buildings	0.010	100
Watercourses	0.070	100
Water	0.035	100
Grass	0.030	0
Sand	0.025	0
Trees	0.190	0

Stream Routing

In addition to local subcatchment runoff, most subcatchments will also carry flow from upstream catchments along the main flow path. The flow along these flowpaths in XP-RAFTS is represented using a "link" between successive subcatchment "nodes".

For this study, time delay lag routing was employed to represent the routing of runoff along the main watercourses into downstream subcatchments. The time delay value for each subcatchment was calculated using a modified version of the Bransby-Williams formula (Queensland Government, 2007).

Rainfall Loss Model

During a typical rainfall event, not all of the rain falling on a catchment is converted to runoff. Some of the rainfall may be intercepted and stored by vegetation, some may be stored in small depressions and some may infiltrate into the underlying soils.

To account for rainfall "losses" of this nature, the hydrologic model incorporates a rainfall loss model. For this study, the "Initial-Continuing" loss model was adopted, which is recommended in *"Australian Rainfall and Runoff – A Guide to Flood Estimation"* (Engineers Australia, 1987) for eastern NSW.

This loss model assumes that a specified amount of rainfall is lost during the initial saturation/wetting of the catchment (referred to as the 'Initial Loss'). Further losses are applied at a constant rate to simulate infiltration/interception once the catchment is saturated (referred to as the 'Continuing Loss Rate'). The initial and continuing losses are deducted from the total rainfall over the catchment, leaving the residual rainfall to be distributed across the catchment as runoff.

Initial and continuing losses were applied to each material type based on standard design values documented in *'Australian Rainfall and Runoff – A Guide to Flood Estimation' (Engineers Australia, 1987)* and are summarised in **Table I3**. All rainfall losses are consistent with those adopted in the TUFLOW model.

Table I3 Adopted XP-RAFTS Rainfall Loss Values

Material Description	Rainfall Losses	
	Initial Loss *(mm)*	Continuing Loss Rate *(mm/hr)*
Impervious	1.0	0.0
Buildings	1.0	0.0
Watercourses	1.0	0.0
Water	0.0	0.0
Grass	10.0	1.8
Sand	10.0	5.0
Trees	10.0	1.8

Results

The XP-RAFTS hydrologic models were then used to simulate the 1% AEP storm for a range of design storm durations. Peak 1% AEP discharges were extracted from the model and compared to the TUFLOW hydraulic model at common locations. A summary of the flow comparison results is provided in **Table I4**, and complete results for all subcatchments in the Newport Catchment is contained in **Table I5**.

Table I4 Comparison between XP-RAFTS and TUFLOW 1%AEP peak discharges in the Newport Catchment

XP-RAFTS Subcatchment	Peak 1% AEP Flow (m^3/s)		
	XP-RAFTS	TUFLOW	Difference
_junc_46	6.46	6.61	0.16
_junc_123	2.80	3.22	0.42
167	9.84	11.25	1.41
_junc_142	3.93	3.88	-0.06
79	14.41	16.38	1.96
_junc_58	4.83	5.77	0.94
16	1.85	2.11	0.27

The comparison provided in **Table I4** shows the TUFLOW model produces peak flows are that are typically within 15% of the XP-RAFTS model, with the biggest discrepancy being 16%. This is considered to be a reasonable level of agreement and indicates that the TUFLOW model is providing a reasonable representation of hydrologic processes across the Newport Catchment.

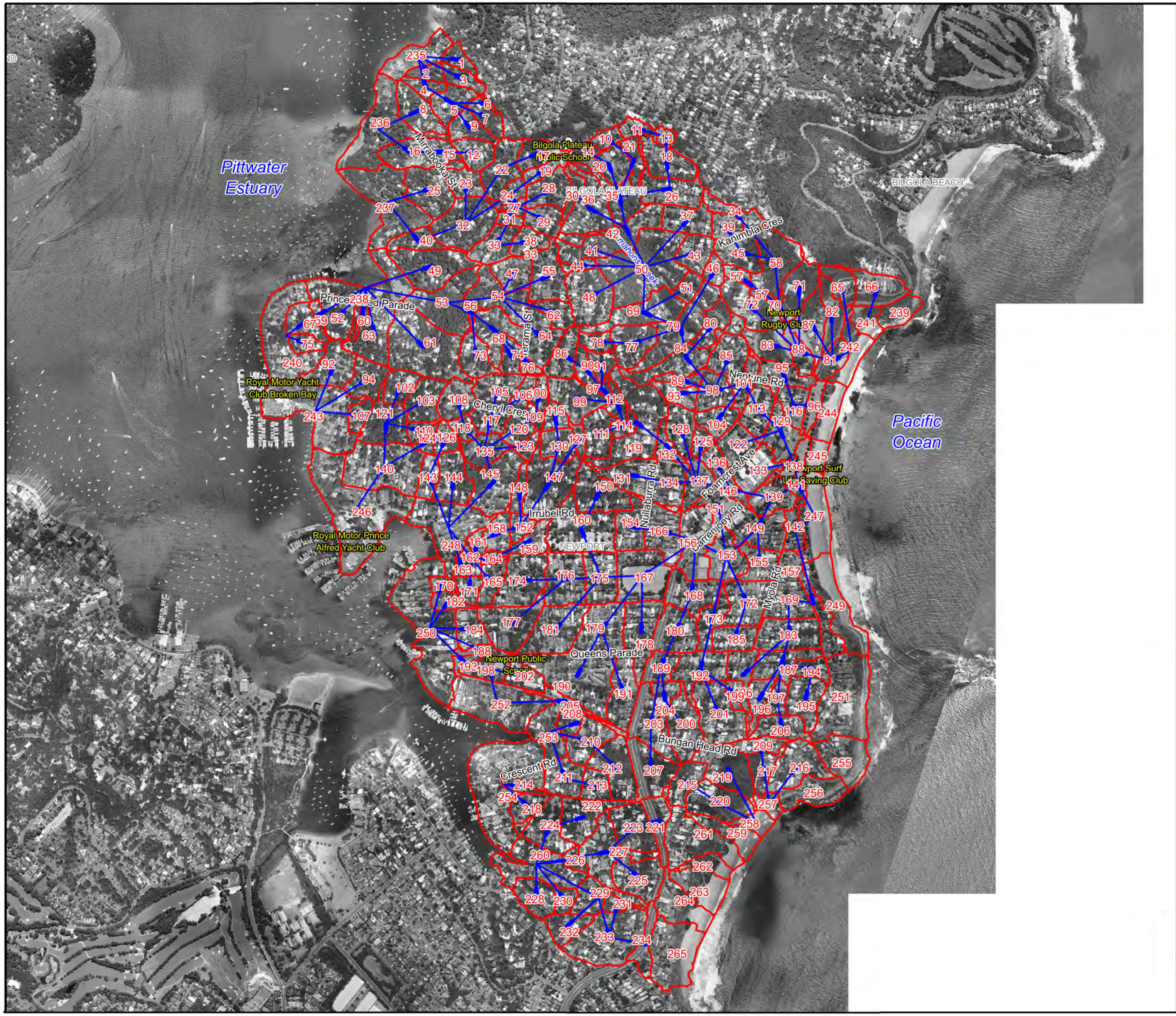
Table I5 - PEAK DESIGN FLOOD DISCHARGES - 100 Year ARI

Subcatchment ID	Peak Discharge (m^3/s)									
	15 min	30 min	45 min	60 min	90 min	120 min	180 min	270 min	360 min	540 min
1	0.29	0.36	0.33	0.38	**0.40**	0.36	0.26	0.23	0.17	0.15
2	0.13	0.18	0.20	0.22	**0.25**	0.24	0.20	0.17	0.15	0.13
3	0.36	0.45	0.40	0.46	**0.48**	0.43	0.30	0.26	0.19	0.17
4	1.25	1.50	1.43	1.75	**1.89**	1.79	1.36	1.21	0.99	0.86
5	1.01	1.26	1.18	1.46	**1.63**	1.54	1.19	1.03	0.84	0.73
6	0.03	0.04	0.04	0.04	**0.05**	0.05	0.04	0.03	0.02	0.02
7	0.23	0.29	0.32	0.35	**0.41**	0.40	0.31	0.27	0.22	0.20
8	0.65	0.86	0.79	0.96	**1.01**	0.90	0.66	0.57	0.43	0.38
9	0.30	0.35	0.36	0.41	**0.48**	0.45	0.36	0.31	0.26	0.23
10	0.16	0.16	0.14	0.18	**0.20**	0.18	0.13	0.14	0.12	0.10
11	0.26	0.26	0.23	0.28	**0.32**	0.29	0.20	0.18	0.14	0.12
12	0.43	0.49	0.43	0.56	**0.61**	0.54	0.41	0.35	0.28	0.25
13	0.41	0.41	0.37	0.45	**0.50**	0.46	0.32	0.28	0.23	0.20
14	0.10	0.11	0.10	0.12	**0.14**	0.12	0.10	0.09	0.08	0.07
15	0.80	0.93	0.82	1.02	**1.11**	1.01	0.73	0.63	0.49	0.43
16	1.38	1.61	1.53	1.80	1.83	**1.85**	1.34	1.15	0.90	0.79
17	0.36	0.46	0.44	0.56	**0.61**	0.56	0.42	0.35	0.28	0.25
18	1.06	1.10	0.97	1.16	**1.30**	1.21	0.91	0.81	0.66	0.58
19	0.37	0.42	0.35	0.43	**0.45**	0.41	0.26	0.23	0.17	0.15
20	0.55	0.64	0.62	0.75	**0.87**	0.82	0.63	0.54	0.45	0.40
21	0.38	0.41	0.41	0.48	0.49	**0.54**	0.39	0.34	0.30	0.26
22	0.87	1.10	1.10	1.37	**1.53**	1.42	1.10	0.92	0.74	0.65
23	0.43	0.47	0.41	0.54	**0.59**	0.52	0.40	0.34	0.27	0.24
24	2.53	2.83	2.54	3.21	**3.50**	3.29	2.44	2.15	1.75	1.53
25	0.79	1.02	0.94	1.19	**1.32**	1.20	0.91	0.77	0.60	0.53
26	1.72	1.87	1.71	2.05	**2.30**	2.18	1.64	1.43	1.17	1.02
27	0.93	1.04	0.95	1.22	**1.35**	1.23	0.96	0.86	0.72	0.62
28	0.37	0.43	0.46	0.51	**0.59**	0.57	0.46	0.41	0.37	0.32
29	0.41	0.48	0.44	0.57	**0.62**	0.55	0.41	0.35	0.28	0.24
30	0.20	0.20	0.19	0.24	**0.29**	0.24	0.20	0.18	0.15	0.13
31	1.08	1.16	0.99	1.33	**1.49**	1.34	0.99	0.85	0.69	0.60
32	4.46	5.25	4.97	6.23	**6.63**	6.39	4.71	4.21	3.44	3.00
33	0.87	0.95	0.83	1.09	**1.23**	1.11	0.85	0.73	0.60	0.52
34	0.49	0.54	0.46	0.59	**0.62**	0.56	0.38	0.33	0.25	0.22
35	2.96	3.38	3.24	3.88	**4.22**	4.14	3.14	2.76	2.30	2.00
36	1.15	1.38	1.23	1.55	**1.65**	1.47	1.08	0.95	0.73	0.64
37	0.60	0.65	0.56	0.76	**0.85**	0.74	0.57	0.48	0.39	0.34
38	0.38	0.42	0.36	0.48	**0.53**	0.47	0.35	0.30	0.23	0.21
39	0.37	0.40	0.36	0.46	**0.50**	0.45	0.32	0.28	0.21	0.19
40	4.65	5.58	5.32	6.62	**6.98**	6.78	5.00	4.51	3.66	3.21
41	0.48	0.60	0.59	0.77	**0.84**	0.77	0.58	0.49	0.39	0.34
42	4.50	5.12	4.93	5.92	**6.41**	6.24	4.70	4.17	3.43	2.99
43	0.58	0.67	0.59	0.75	**0.78**	0.70	0.49	0.43	0.32	0.28
44	0.22	0.25	0.20	0.24	**0.25**	0.24	0.14	0.13	0.09	0.08
45	0.89	1.08	1.01	1.27	**1.36**	1.24	0.90	0.77	0.59	0.52
46	0.26	0.31	0.27	0.34	**0.36**	0.33	0.23	0.20	0.15	0.13
47	0.48	0.58	0.54	0.70	**0.75**	0.67	0.50	0.42	0.33	0.29
48	0.94	1.03	0.90	1.23	**1.38**	1.22	0.93	0.79	0.63	0.55
49	0.87	1.04	0.98	1.26	**1.43**	1.30	1.00	0.85	0.69	0.60
50	7.32	8.59	8.88	10.53	11.05	**11.44**	8.68	7.70	6.41	5.57
51	0.26	0.31	0.29	0.36	**0.38**	0.35	0.25	0.22	0.17	0.15
52	0.53	0.59	0.52	0.69	**0.76**	0.67	0.51	0.43	0.34	0.30
53	5.33	6.27	5.86	7.41	**7.92**	7.46	5.51	4.83	3.88	3.39
54	3.01	3.33	3.11	3.94	**4.22**	4.06	2.96	2.52	2.04	1.79
55	0.79	0.84	0.71	0.96	**1.10**	0.95	0.71	0.61	0.49	0.43
56	1.98	2.36	2.12	2.58	**2.72**	2.48	1.77	1.53	1.16	1.02
57	0.29	0.36	0.32	0.37	**0.38**	0.34	0.24	0.21	0.15	0.14
58	1.97	2.26	2.20	2.74	**2.93**	2.91	2.13	1.81	1.48	1.30
59	0.14	0.18	0.16	0.19	**0.20**	0.18	0.12	0.11	0.08	0.07
60	0.13	0.18	0.16	0.19	**0.19**	0.18	0.12	0.10	0.08	0.07
61	1.36	1.60	1.63	1.95	**2.26**	2.10	1.65	1.40	1.16	1.01
62	0.43	0.49	0.43	0.53	**0.56**	0.50	0.35	0.31	0.23	0.20
63	0.81	1.00	0.92	1.17	**1.26**	1.11	0.84	0.71	0.55	0.48
64	0.74	0.81	0.69	0.93	**1.05**	0.90	0.68	0.58	0.46	0.40
65	0.42	0.56	0.52	0.61	**0.62**	0.57	0.40	0.35	0.26	0.23
66	0.87	1.01	0.87	1.10	**1.14**	1.02	0.69	0.60	0.45	0.39
67	0.49	0.55	0.48	0.62	**0.67**	0.60	0.44	0.38	0.29	0.26
68	1.25	1.56	1.45	1.68	**1.77**	1.64	1.18	1.02	0.77	0.68
69	7.99	9.62	9.89	11.73	12.15	**12.48**	9.48	8.55	7.07	6.17
70	2.27	2.55	2.49	3.08	3.27	**3.32**	2.42	2.05	1.67	1.47
71	0.34	0.54	0.59	0.65	0.70	**0.71**	0.57	0.48	0.42	0.36
72	0.62	0.77	0.75	0.97	**1.08**	0.99	0.76	0.64	0.51	0.45
73	0.66	0.70	0.59	0.77	**0.82**	0.75	0.51	0.44	0.33	0.29
74	0.41	0.47	0.40	0.49	**0.52**	0.47	0.31	0.28	0.20	0.18
75	0.36	0.39	0.32	0.39	**0.41**	0.38	0.24	0.21	0.15	0.13
76	0.16	0.18	0.16	0.21	**0.22**	0.19	0.13	0.11	0.08	0.07
77	0.94	1.22	1.11	1.36	**1.42**	1.29	0.94	0.81	0.61	0.54
78	0.29	0.35	0.32	0.39	**0.40**	0.36	0.26	0.23	0.17	0.15
79	9.09	11.53	11.97	13.86	14.11	**14.41**	11.04	10.20	8.39	7.33
80	0.39	0.48	0.46	0.57	**0.62**	0.56	0.42	0.35	0.28	0.24
81	3.97	5.46	5.75	6.78	6.71	**7.05**	5.33	4.91	4.02	3.52
82	0.50	0.58	0.53	0.68	**0.75**	0.66	0.50	0.42	0.33	0.29

Subcatchment ID	Peak Discharge (m³/s)									
	15 min	30 min	45 min	60 min	90 min	120 min	180 min	270 min	360 min	540 min
83	0.26	0.41	0.46	0.53	0.52	**0.55**	0.44	0.41	0.35	0.30
84	9.58	12.50	13.03	14.88	15.00	**15.30**	11.78	11.11	9.10	7.96
85	0.60	0.63	0.53	0.71	**0.80**	0.70	0.54	0.47	0.38	0.33
86	0.53	0.59	0.50	0.67	**0.74**	0.65	0.49	0.42	0.33	0.29
87	0.53	0.62	0.64	0.76	**0.90**	0.81	0.64	0.53	0.45	0.39
88	3.39	4.43	4.56	5.43	5.54	**5.72**	4.33	3.79	3.14	2.75
89	0.67	0.73	0.68	0.79	0.79	**0.80**	0.54	0.48	0.36	0.31
90	0.79	0.90	0.81	1.00	**1.08**	1.00	0.74	0.64	0.50	0.44
91	0.36	0.41	0.36	0.43	**0.45**	0.41	0.27	0.24	0.18	0.16
92	0.69	0.77	0.67	0.90	**1.01**	0.87	0.66	0.56	0.44	0.39
93	0.48	0.56	0.48	0.58	**0.60**	0.54	0.37	0.32	0.24	0.21
94	0.53	0.67	0.63	0.79	**0.83**	0.74	0.54	0.46	0.35	0.31
95	0.47	0.51	0.44	0.58	**0.64**	0.57	0.43	0.36	0.29	0.25
96	0.25	0.26	0.24	0.32	**0.36**	0.32	0.25	0.22	0.19	0.16
97	1.23	1.46	1.31	1.59	**1.70**	1.54	1.12	0.97	0.75	0.66
98	10.35	13.65	14.35	16.25	16.26	**16.71**	12.90	12.22	10.06	8.82
99	0.64	0.81	0.79	0.98	**1.07**	0.96	0.72	0.61	0.48	0.42
100	0.31	0.36	0.32	0.39	**0.40**	0.36	0.25	0.22	0.16	0.14
101	10.46	13.84	14.76	16.63	16.67	**17.14**	13.31	12.53	10.45	9.18
102	0.34	0.43	0.42	0.53	**0.59**	0.55	0.41	0.34	0.27	0.24
103	0.49	0.61	0.59	0.76	**0.84**	0.76	0.57	0.48	0.38	0.33
104	0.41	0.46	0.38	0.51	**0.57**	0.51	0.39	0.34	0.27	0.24
105	0.61	0.78	0.73	0.88	**0.91**	0.81	0.58	0.50	0.38	0.33
106	0.31	0.38	0.33	0.38	**0.40**	0.36	0.25	0.22	0.16	0.14
107	0.21	0.27	0.25	0.32	**0.35**	0.32	0.24	0.21	0.16	0.14
108	0.59	0.67	0.59	0.76	**0.84**	0.73	0.55	0.46	0.36	0.32
109	0.46	0.56	0.50	0.60	**0.63**	0.57	0.39	0.34	0.25	0.22
110	0.16	0.22	0.21	0.26	**0.28**	0.26	0.19	0.16	0.13	0.11
111	0.57	0.72	0.68	0.84	**0.88**	0.78	0.57	0.49	0.37	0.33
112	2.04	2.48	2.29	2.86	**3.04**	2.79	2.03	1.76	1.37	1.20
113	10.51	13.95	14.94	16.87	16.92	**17.44**	13.61	12.74	10.71	9.43
114	2.65	3.20	3.05	3.74	**3.86**	3.80	2.77	2.37	1.87	1.64
115	0.31	0.37	0.34	0.40	**0.42**	0.37	0.27	0.23	0.17	0.15
116	0.74	0.83	0.84	1.09	**1.18**	1.07	0.87	0.78	0.67	0.60
117	1.21	1.50	1.44	1.70	**1.77**	1.68	1.21	1.04	0.79	0.70
118	0.81	0.92	0.84	1.04	**1.12**	1.04	0.77	0.65	0.51	0.45
119	3.35	4.02	4.02	4.88	4.96	**5.14**	3.83	3.33	2.75	2.39
120	0.74	0.88	0.84	1.01	**1.07**	1.00	0.73	0.62	0.47	0.42
121	1.31	1.63	1.79	2.13	**2.34**	2.23	1.73	1.50	1.26	1.09
122	0.64	0.66	0.57	0.72	**0.79**	0.74	0.49	0.43	0.34	0.30
123	0.17	0.22	0.20	0.25	**0.27**	0.25	0.18	0.16	0.12	0.11
124	0.14	0.19	0.18	0.22	**0.24**	0.22	0.16	0.14	0.11	0.09
125	0.20	0.23	0.21	0.28	**0.31**	0.28	0.20	0.18	0.14	0.12
126	0.26	0.30	0.28	0.35	**0.38**	0.35	0.26	0.23	0.18	0.15
127	0.25	0.26	0.22	0.26	**0.27**	0.25	0.15	0.13	0.10	0.09
128	0.45	0.49	0.44	0.56	**0.64**	0.56	0.45	0.40	0.34	0.29
129	10.90	14.73	16.00	18.13	18.17	**18.83**	14.90	13.84	11.94	10.56
130	0.69	0.83	0.82	0.99	**1.05**	0.99	0.72	0.61	0.47	0.41
131	0.66	0.75	0.66	0.88	**0.98**	0.85	0.64	0.54	0.42	0.37
132	3.40	4.18	4.22	5.08	5.15	**5.33**	3.98	3.50	2.88	2.51
133	0.81	0.82	0.73	0.89	**0.97**	0.90	0.57	0.51	0.39	0.35
134	1.14	1.23	1.13	1.44	**1.65**	1.47	1.14	1.00	0.84	0.73
135	3.29	3.93	3.79	4.56	**4.78**	4.56	3.30	2.87	2.23	1.95
136	0.31	0.32	0.28	0.38	**0.42**	0.38	0.27	0.24	0.19	0.16
137	4.20	6.01	6.28	7.26	7.07	**7.41**	5.63	5.29	4.40	3.84
138	10.98	14.83	16.14	18.37	18.46	**19.18**	15.35	14.10	12.32	10.93
139	14.67	20.19	22.76	24.78	24.57	**25.26**	20.33	20.50	18.04	16.01
140	2.19	2.88	3.19	3.69	3.79	**3.88**	3.10	2.70	2.31	2.01
141	20.54	29.95	34.24	39.35	**40.14**	39.88	34.16	33.12	29.76	26.72
142	3.80	4.86	5.06	5.87	5.81	**6.01**	4.62	4.32	3.64	3.17
143	0.67	0.79	0.71	0.87	**0.93**	0.83	0.61	0.53	0.40	0.35
144	0.54	0.61	0.60	0.72	**0.85**	0.78	0.61	0.52	0.44	0.38
145	3.57	4.59	4.53	5.35	**5.59**	5.40	3.95	3.59	2.87	2.49
146	4.29	6.24	6.62	7.59	7.35	**7.71**	5.92	5.60	4.67	4.09
147	1.54	1.90	1.95	2.31	2.35	**2.49**	1.89	1.60	1.34	1.17
148	0.18	0.22	0.24	0.28	**0.32**	0.31	0.24	0.20	0.16	0.14
149	11.97	15.51	16.85	19.06	19.46	**19.62**	14.91	15.42	13.52	12.10
150	0.63	0.69	0.67	0.81	**0.95**	0.87	0.68	0.60	0.51	0.44
151	0.49	0.52	0.43	0.56	**0.60**	0.55	0.35	0.30	0.23	0.20
152	1.83	2.31	2.40	2.81	2.85	**3.03**	2.29	1.98	1.65	1.44
153	11.78	15.14	16.13	18.39	18.74	**18.81**	14.16	14.84	12.85	11.47
154	0.52	0.55	0.50	0.64	**0.73**	0.64	0.51	0.45	0.38	0.33
155	0.47	0.50	0.42	0.55	**0.61**	0.55	0.40	0.37	0.30	0.26
156	10.69	12.64	12.75	15.06	**15.64**	15.57	11.57	12.02	10.49	9.23
157	3.77	4.80	4.92	5.72	5.64	**5.83**	4.48	4.17	3.48	3.02
158	1.90	2.52	2.64	3.09	3.11	**3.28**	2.50	2.23	1.86	1.63
159	0.39	0.44	0.37	0.50	**0.56**	0.49	0.38	0.34	0.28	0.24
160	1.45	1.50	1.30	1.72	**1.96**	1.75	1.35	1.36	1.20	1.02
161	1.94	2.62	2.75	3.21	3.23	**3.38**	2.58	2.34	1.95	1.70
162	2.57	3.59	3.86	4.41	4.31	**4.49**	3.58	3.28	2.79	2.43
163	0.12	0.13	0.12	0.16	**0.19**	0.17	0.12	0.10	0.08	0.07
164	0.43	0.49	0.44	0.57	**0.63**	0.57	0.44	0.39	0.32	0.28
165	0.39	0.44	0.37	0.50	**0.56**	0.49	0.37	0.32	0.26	0.23
166	1.11	1.18	1.15	1.35	1.48	**1.56**	1.17	1.03	0.88	0.77

Subcatchment ID	Peak Discharge (m^3/s)									
	15 min	30 min	45 min	60 min	90 min	120 min	180 min	270 min	360 min	540 min
167	7.54	8.04	7.71	9.35	**10.15**	9.84	7.25	7.42	6.60	5.77
168	2.72	3.45	3.53	4.22	**4.31**	4.17	3.20	3.25	2.73	2.39
169	3.40	4.32	4.34	5.22	5.19	**5.39**	4.07	3.69	3.07	2.68
170	0.12	0.13	0.12	0.15	**0.18**	0.16	0.12	0.10	0.09	0.08
171	0.23	0.27	0.24	0.32	**0.35**	0.31	0.24	0.21	0.17	0.15
172	1.05	1.10	1.00	1.11	1.26	**1.27**	0.94	0.88	0.76	0.66
173	2.04	2.27	2.06	2.62	**2.91**	2.69	2.06	1.87	1.54	1.34
174	0.78	0.78	0.69	0.87	**0.96**	0.87	0.62	0.61	0.54	0.47
175	4.56	4.70	4.29	5.33	**5.88**	5.56	4.11	4.19	3.72	3.21
176	1.46	1.49	1.30	1.63	**1.82**	1.65	1.17	1.15	1.04	0.89
177	0.70	0.71	0.61	0.80	**0.91**	0.80	0.63	0.63	0.55	0.47
178	0.74	0.75	0.65	0.83	**0.95**	0.85	0.63	0.60	0.53	0.45
179	2.64	2.68	2.60	3.08	**3.39**	3.31	2.34	2.29	2.00	1.71
180	2.59	3.03	3.03	3.71	**3.85**	3.75	2.83	2.76	2.35	2.04
181	1.53	1.54	1.35	1.73	**1.96**	1.74	1.33	1.31	1.15	0.99
182	0.30	0.35	0.29	0.38	**0.40**	0.37	0.24	0.21	0.16	0.14
183	3.18	3.83	3.77	4.65	4.64	**4.86**	3.60	3.15	2.63	2.30
184	0.49	0.52	0.44	0.58	**0.64**	0.58	0.42	0.37	0.30	0.26
185	0.44	0.47	0.39	0.53	**0.59**	0.53	0.39	0.36	0.30	0.26
186	0.60	0.65	0.55	0.73	**0.78**	0.70	0.49	0.42	0.32	0.28
187	2.53	2.82	2.63	3.39	**3.56**	3.49	2.51	2.19	1.77	1.55
188	0.22	0.26	0.23	0.29	**0.31**	0.28	0.19	0.16	0.12	0.11
189	2.21	2.46	2.47	3.04	**3.26**	3.10	2.38	2.22	1.92	1.67
190	1.43	1.44	1.28	1.58	**1.80**	1.60	1.17	1.11	0.98	0.84
191	0.73	0.76	0.66	0.88	**1.02**	0.88	0.69	0.60	0.50	0.43
192	1.85	1.96	1.72	2.23	**2.56**	2.32	1.79	1.55	1.29	1.12
193	0.24	0.25	0.22	0.26	**0.27**	0.25	0.15	0.13	0.10	0.09
194	1.02	1.13	0.98	1.31	**1.44**	1.29	0.93	0.79	0.62	0.54
195	0.72	0.80	0.70	0.93	**1.02**	0.89	0.65	0.55	0.43	0.38
196	0.46	0.52	0.45	0.57	**0.59**	0.53	0.37	0.32	0.24	0.21
197	0.76	0.87	0.82	1.04	**1.13**	1.04	0.77	0.65	0.51	0.45
198	0.80	0.86	0.74	0.98	**1.10**	1.00	0.73	0.63	0.51	0.45
199	0.24	0.28	0.23	0.30	**0.31**	0.28	0.18	0.16	0.11	0.10
200	0.68	0.77	0.73	0.94	**1.08**	0.95	0.75	0.63	0.52	0.45
201	1.08	1.15	0.97	1.35	**1.52**	1.35	1.01	0.87	0.70	0.61
202	0.43	0.47	0.40	0.53	**0.58**	0.52	0.38	0.32	0.25	0.22
203	1.50	1.63	1.47	1.83	**2.00**	1.85	1.37	1.23	1.02	0.88
204	0.75	1.01	0.94	1.20	**1.31**	1.16	0.91	0.87	0.69	0.61
205	0.28	0.31	0.26	0.34	**0.35**	0.33	0.20	0.18	0.13	0.12
206	0.52	0.62	0.56	0.73	**0.79**	0.69	0.51	0.44	0.34	0.30
207	0.67	0.71	0.64	0.81	**0.93**	0.83	0.66	0.59	0.51	0.44
208	0.40	0.46	0.41	0.51	**0.54**	0.48	0.35	0.30	0.23	0.20
209	0.42	0.48	0.41	0.50	**0.51**	0.47	0.31	0.28	0.20	0.18
210	0.86	1.05	1.19	1.30	**1.50**	1.49	1.17	1.04	0.91	0.78
211	0.76	0.91	0.89	1.08	**1.25**	1.16	0.90	0.75	0.62	0.54
212	0.43	0.59	0.67	0.74	**0.82**	0.81	0.66	0.60	0.53	0.45
213	0.33	0.37	0.35	0.44	**0.49**	0.45	0.35	0.29	0.24	0.21
214	0.23	0.28	0.24	0.31	**0.32**	0.29	0.19	0.17	0.13	0.11
215	0.42	0.51	0.48	0.62	**0.68**	0.62	0.46	0.39	0.31	0.27
216	1.00	1.22	1.08	1.34	**1.40**	1.25	0.88	0.77	0.57	0.50
217	0.71	0.83	0.79	0.94	0.96	**0.96**	0.70	0.59	0.47	0.41
218	0.29	0.34	0.31	0.40	**0.45**	0.41	0.32	0.27	0.22	0.19
219	0.63	0.80	0.87	1.02	**1.18**	1.12	0.87	0.73	0.60	0.52
220	0.84	1.05	1.15	1.37	1.44	**1.45**	1.13	0.99	0.83	0.72
221	0.62	0.65	0.55	0.71	**0.76**	0.71	0.46	0.40	0.30	0.27
222	0.55	0.64	0.68	0.79	**0.93**	0.86	0.68	0.58	0.49	0.42
223	1.00	1.10	1.08	1.37	**1.57**	1.44	1.10	0.94	0.78	0.68
224	0.97	1.14	1.27	1.38	**1.64**	1.60	1.26	1.08	0.94	0.81
225	0.63	0.72	0.71	0.88	**1.02**	0.92	0.73	0.61	0.51	0.44
226	0.14	0.20	0.18	0.23	**0.25**	0.23	0.17	0.15	0.12	0.10
227	1.82	2.21	2.43	2.89	2.98	**3.11**	2.42	2.16	1.87	1.61
228	0.40	0.46	0.46	0.53	**0.62**	0.58	0.46	0.41	0.35	0.30
229	2.06	2.36	2.42	2.82	3.13	**3.19**	2.42	2.20	1.85	1.61
230	0.18	0.23	0.21	0.27	**0.30**	0.28	0.21	0.18	0.15	0.13
231	0.15	0.20	0.18	0.23	**0.25**	0.23	0.17	0.15	0.12	0.10
232	0.33	0.38	0.39	0.45	**0.53**	0.49	0.39	0.33	0.28	0.24
233	1.40	1.61	1.58	1.89	2.11	**2.18**	1.65	1.47	1.25	1.08
234	0.49	0.53	0.44	0.58	**0.61**	0.57	0.37	0.32	0.24	0.22
235	2.62	3.05	2.98	3.43	3.72	**3.73**	2.78	2.41	1.94	1.70
236	2.94	3.30	3.37	3.99	4.36	**4.43**	3.31	2.80	2.26	1.98
237	5.77	7.69	7.61	9.06	9.08	**9.16**	6.82	6.29	5.22	4.54
238	8.57	10.87	10.99	12.98	12.86	**13.38**	10.20	8.92	7.48	6.52
239	0.70	0.73	0.63	0.71	**0.75**	0.68	0.42	0.37	0.27	0.24
240	2.59	2.89	2.50	3.24	**3.44**	3.11	2.13	1.85	1.40	1.23
241	1.23	1.42	1.27	1.55	**1.60**	1.51	1.03	0.89	0.68	0.59
242	4.31	6.08	6.48	7.49	7.29	**7.73**	5.88	5.57	4.60	4.00
243	3.10	3.54	3.23	4.21	**4.70**	4.22	3.24	2.73	2.19	1.91
244	0.73	0.89	0.77	0.89	**0.92**	0.83	0.56	0.49	0.36	0.31
245	0.42	0.47	0.40	0.45	**0.47**	0.43	0.27	0.24	0.18	0.15
246	4.77	5.35	5.40	6.19	**7.03**	6.81	5.39	4.63	3.92	3.41
247	21.63	32.19	37.27	42.76	**43.57**	43.38	37.41	36.23	32.88	29.63
248	6.75	10.05	10.51	11.97	**12.03**	11.99	9.42	8.82	7.34	6.35
249	1.79	1.91	1.62	1.85	**1.95**	1.77	1.11	0.98	0.71	0.62
250	3.77	3.98	3.36	4.51	**5.00**	4.47	3.25	2.81	2.25	1.97

Subcatchment ID	Peak Discharge (m^3/s)									
	15 min	30 min	45 min	60 min	90 min	120 min	180 min	270 min	360 min	540 min
251	1.98	2.43	2.21	2.64	**2.73**	2.42	1.73	1.51	1.12	0.98
252	2.49	2.72	2.34	3.09	**3.47**	3.09	2.35	2.02	1.63	1.43
253	2.39	2.82	2.91	3.44	**3.89**	3.74	2.87	2.55	2.14	1.86
254	2.83	3.13	2.75	3.62	**4.04**	3.57	2.70	2.30	1.83	1.60
255	1.37	1.48	1.23	1.43	**1.51**	1.36	0.86	0.76	0.55	0.49
256	1.28	1.24	1.14	1.22	**1.30**	1.20	0.70	0.62	0.45	0.40
257	1.86	2.25	2.09	2.53	**2.65**	2.48	1.79	1.55	1.19	1.04
258	1.65	2.03	2.22	2.63	2.74	**2.86**	2.19	1.90	1.60	1.39
259	0.53	0.69	0.65	0.77	**0.79**	0.72	0.52	0.45	0.34	0.30
260	5.32	6.94	7.59	8.75	9.09	**9.35**	7.22	6.90	5.81	5.05
261	0.95	1.15	1.09	1.36	**1.57**	1.43	1.11	0.94	0.77	0.67
262	0.32	0.38	0.37	0.43	**0.44**	0.43	0.30	0.26	0.20	0.17
263	0.74	0.88	0.87	1.03	**1.07**	0.99	0.71	0.62	0.46	0.41
264	0.82	1.06	0.99	1.17	**1.20**	1.09	0.78	0.68	0.50	0.44
265	1.48	1.87	1.69	1.97	**2.03**	1.80	1.28	1.12	0.83	0.73
_junc_1	0.77	0.98	0.89	1.06	**1.12**	1.04	0.75	0.66	0.51	0.44
_junc_108	3.56	4.56	4.66	5.54	5.56	**5.76**	4.31	3.87	3.19	2.78
_junc_109	10.94	14.78	16.07	18.30	18.35	**19.04**	15.21	14.01	12.20	10.82
_junc_116	20.54	29.94	34.21	39.31	**40.08**	39.82	34.09	33.08	29.70	26.66
_junc_118	21.61	32.15	37.21	42.63	**43.29**	43.06	37.05	36.04	32.54	29.35
_junc_122	14.64	20.15	22.70	24.64	24.41	**25.08**	20.06	20.34	17.80	15.77
_junc_123	1.72	2.11	2.18	2.58	2.64	**2.80**	2.12	1.80	1.51	1.32
_junc_136	2.62	3.68	3.96	4.51	4.41	**4.58**	3.67	3.37	2.86	2.49
_junc_137	0.81	0.89	0.79	1.03	**1.16**	1.05	0.81	0.71	0.58	0.51
_junc_138	10.44	12.14	12.01	14.42	**15.06**	14.98	11.07	11.57	10.00	8.76
_junc_142	2.90	3.03	2.98	3.60	3.87	**3.93**	2.86	2.69	2.30	1.99
_junc_154	2.95	3.23	3.08	3.90	3.98	**4.14**	3.00	2.55	2.09	1.83
_junc_170	1.88	2.12	2.19	2.62	**2.88**	2.68	2.13	1.98	1.71	1.48
_junc_176	1.61	1.94	2.08	2.34	**2.75**	2.65	2.07	1.79	1.53	1.32
_junc_181	1.57	1.96	1.83	2.22	**2.36**	2.16	1.58	1.36	1.04	0.91
_junc_183	1.48	1.84	2.01	2.34	2.46	**2.58**	1.99	1.69	1.43	1.24
_junc_189	1.95	2.37	2.58	3.08	3.16	**3.34**	2.60	2.29	1.98	1.71
_junc_191	2.20	2.53	2.60	3.05	3.36	**3.42**	2.59	2.37	2.00	1.74
_junc_193	1.73	1.99	1.97	2.31	2.64	**2.67**	2.04	1.80	1.52	1.33
_junc_20	3.67	4.35	3.94	5.06	**5.58**	5.19	3.94	3.39	2.76	2.41
_junc_23	1.93	2.16	1.90	2.48	**2.77**	2.50	1.95	1.70	1.41	1.23
_junc_24	0.79	0.91	0.86	1.07	**1.21**	1.12	0.87	0.77	0.64	0.56
_junc_29	3.96	4.57	4.31	5.18	**5.73**	5.54	4.21	3.67	3.03	2.64
_junc_34	4.97	5.59	5.48	6.58	**7.04**	7.01	5.28	4.62	3.82	3.33
_junc_46	4.79	5.59	5.07	6.47	**6.94**	6.46	4.72	4.04	3.20	2.81
_junc_47	1.96	2.14	1.83	2.42	**2.71**	2.36	1.75	1.50	1.18	1.04
_junc_48	2.23	2.49	2.43	3.02	3.21	**3.25**	2.37	2.00	1.64	1.43
_junc_58	2.98	3.75	3.80	4.56	4.72	**4.83**	3.63	3.13	2.59	2.26
_junc_70	10.22	13.41	13.99	15.88	15.92	**16.35**	12.60	11.93	9.78	8.56
_junc_72	3.64	4.93	5.12	6.09	6.10	**6.38**	4.80	4.29	3.54	3.10
_junc_74	1.10	1.30	1.17	1.41	**1.52**	1.38	1.02	0.88	0.68	0.59
_junc_78	0.71	0.77	0.66	0.90	**1.01**	0.89	0.68	0.59	0.48	0.42
_junc_79	1.82	2.22	2.04	2.57	**2.77**	2.47	1.84	1.58	1.23	1.08
_junc_92	2.52	3.03	2.87	3.52	**3.64**	3.57	2.60	2.22	1.74	1.53



NORTHERN BEACHES COUNCIL

LEGEND

XP-RAFTS Node-Link

1 XP-RAFTS Subcatchment Boundaries

Notes:

Aerial photograph date: 2014

N W E S

Scale 1:13,000 (at A3)

0 0.4 0.8 Km

Figure I1: Newport XP-RAFTS Subcatchment Layout

Prepared By:

Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: Appl - Newport XP-RAFTS Subcatchment Layout.wor

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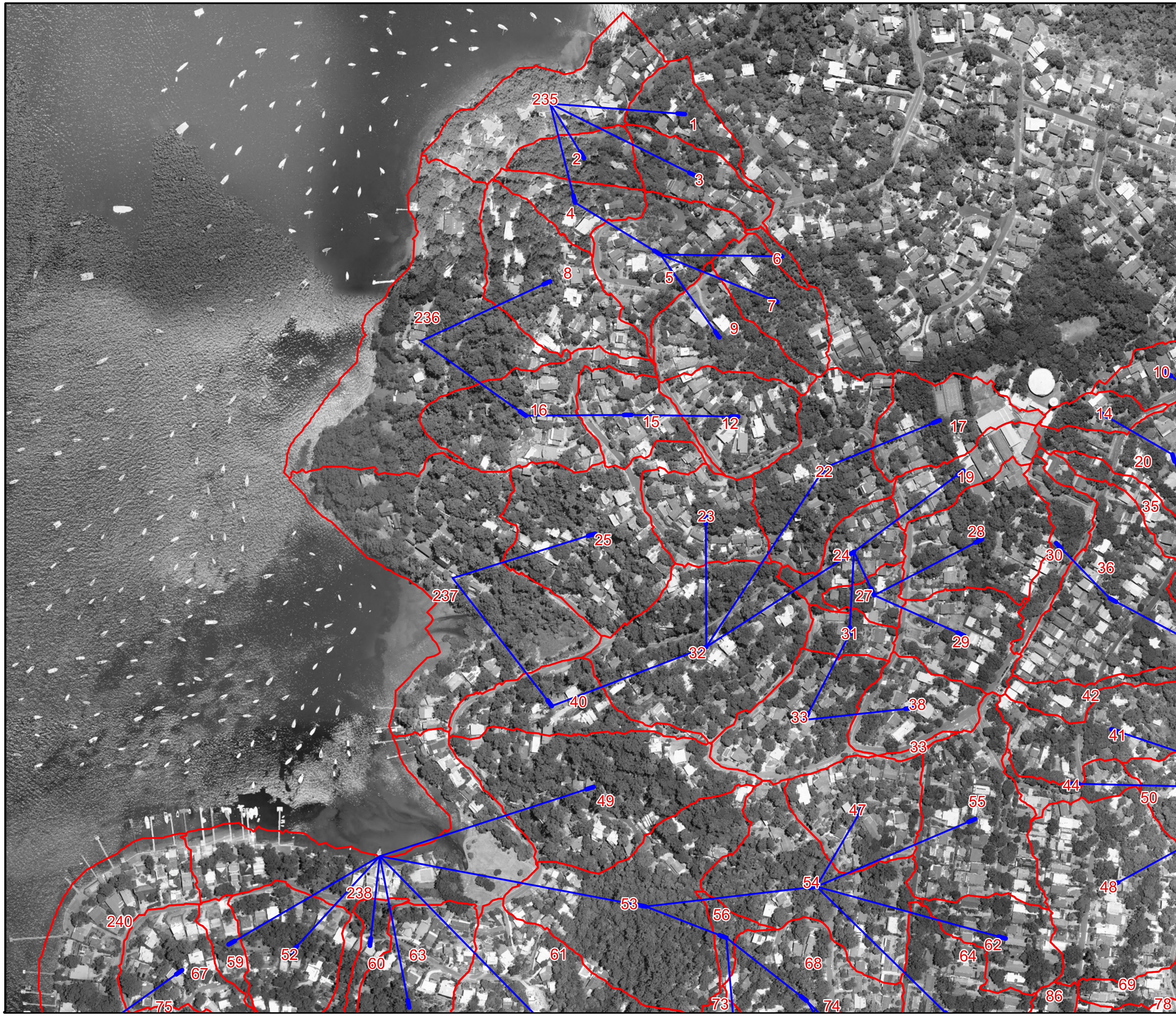

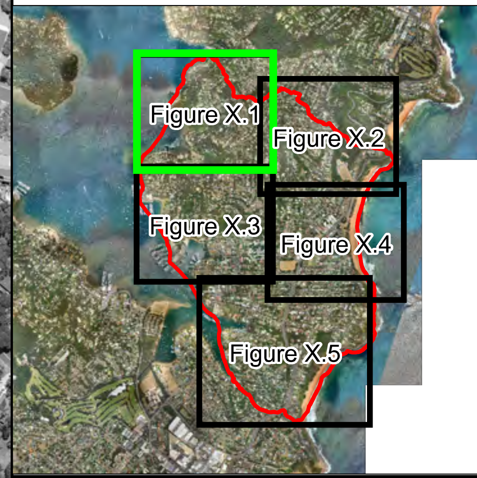

LEGEND

XP-RAFTS Node-Link

1 XP-RAFTS Subcatchment Boundaries

Notes:

Aerial photograph date: 2014

N
W E
S

Scale 1:4,000 (at A3)

0 0.1 0.2
Km

Figure I1.1: Newport XP-RAFTS Subcatchment Layout

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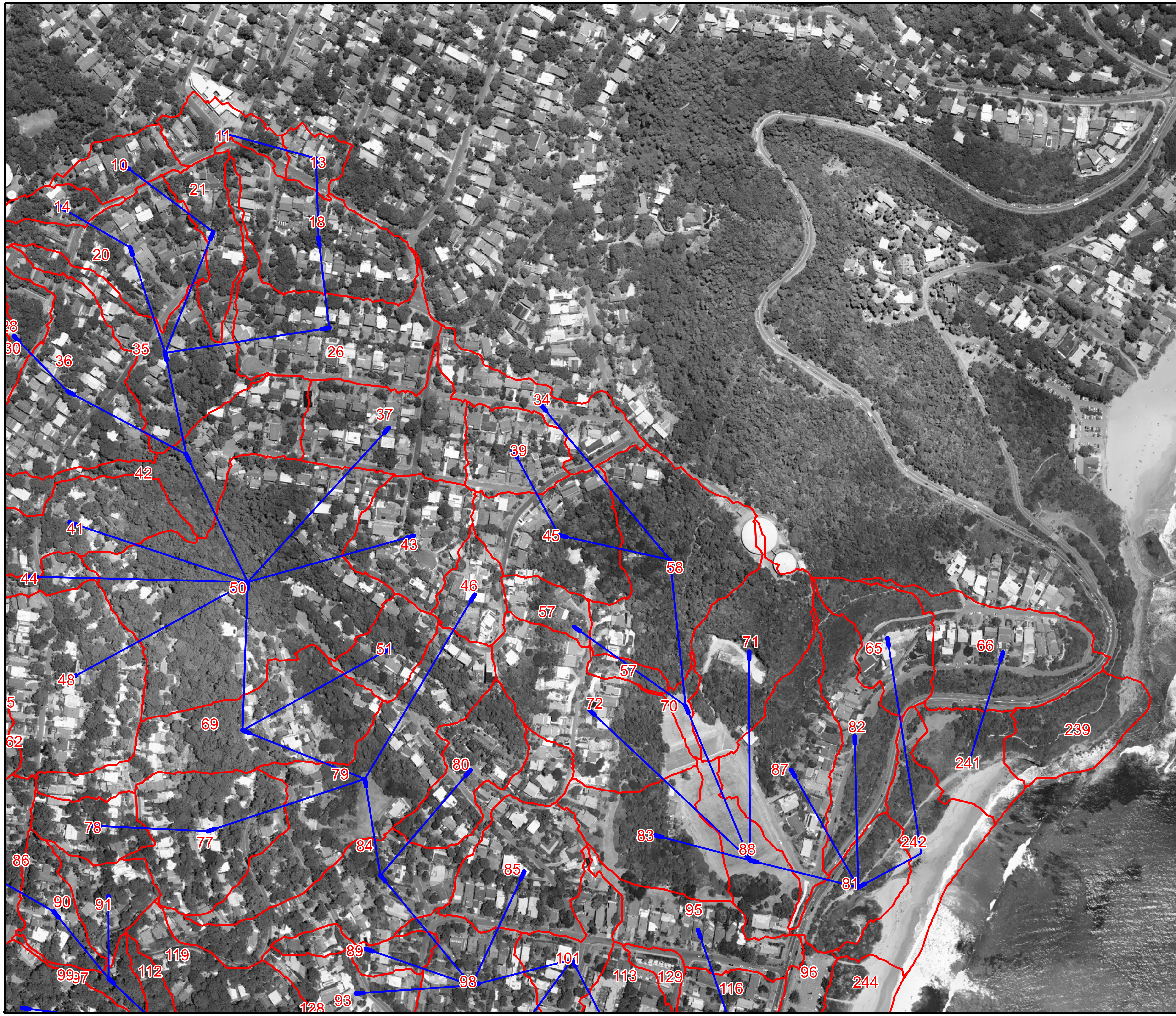
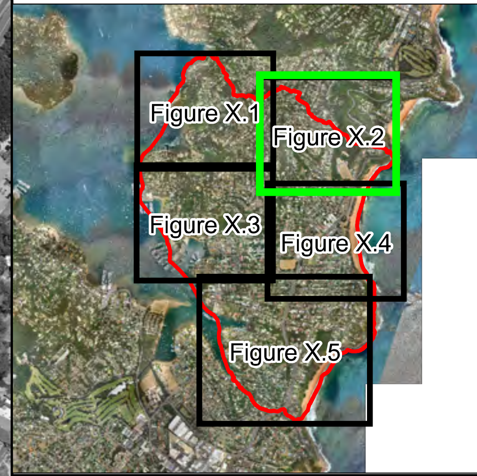
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: Appl - XP-RAFTS Subcatch Layout.wor



NORTHERN BEACHES COUNCIL



LEGEND

XP-RAFTS Node-Link

1 XP-RAFTS Subcatchment Boundaries

Notes:

Aerial photograph date: 2014

N W E S

Scale 1:4,000 (at A3)

0 0.1 0.2 Km

Figure I1.2: Newport XP-RAFTS Subcatchment Layout

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Catchment Simulation Solutions
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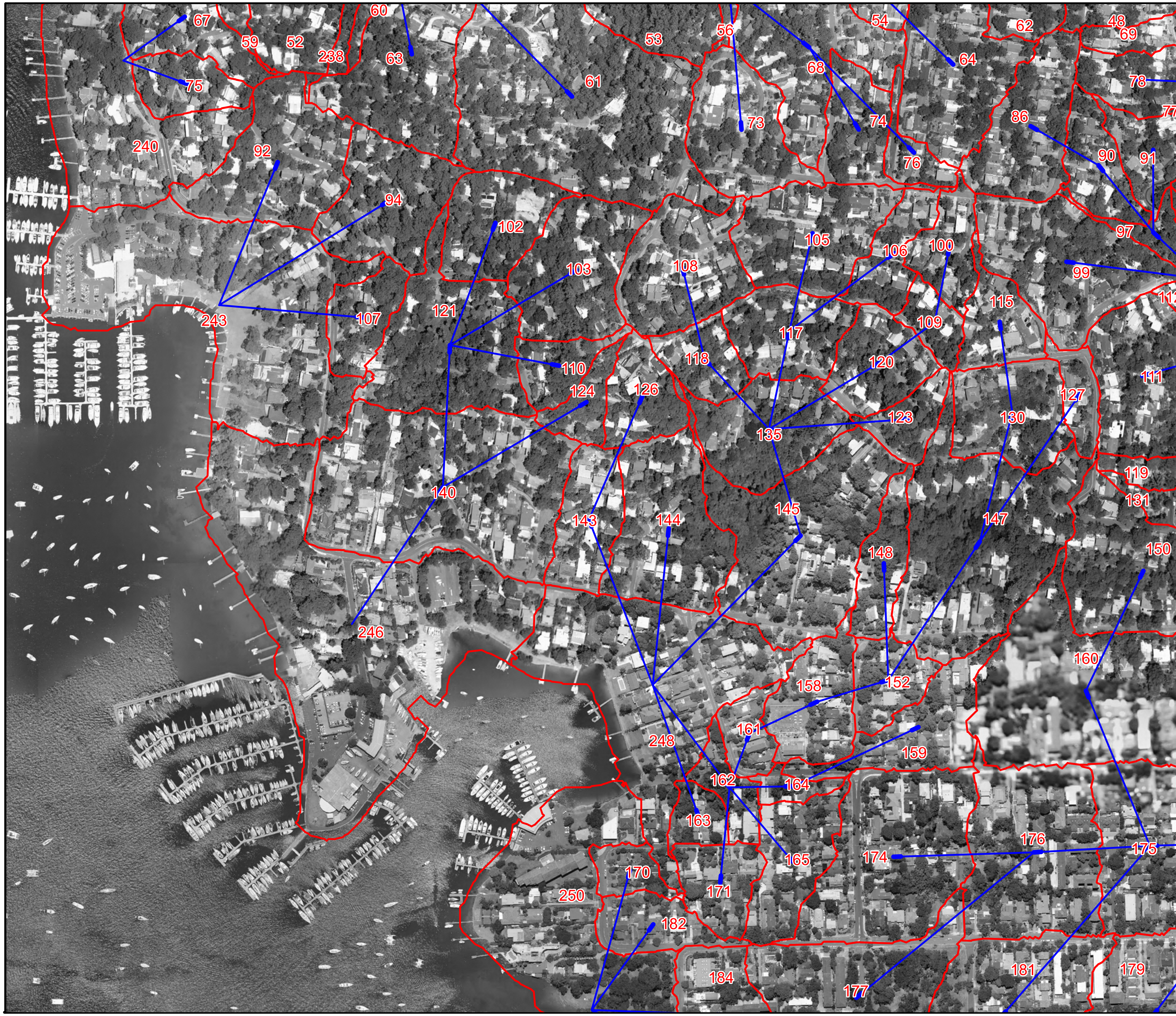
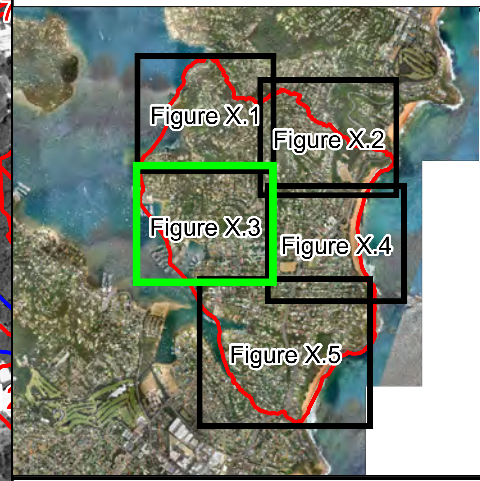
Sydney, NSW 2000

File Name: Appl - XP-RAFTS Subcatch Layout.wor



NORTHERN BEACHES COUNCIL



LEGEND

XP-RAFTS Node-Link

1 XP-RAFTS Subcatchment Boundaries

Notes:

Aerial photograph date: 2014

N
W E
S

Scale 1:4,000 (at A3)

0 0.1 0.2 Km

Figure I1.3: Newport XP-RAFTS Subcatchment Layout

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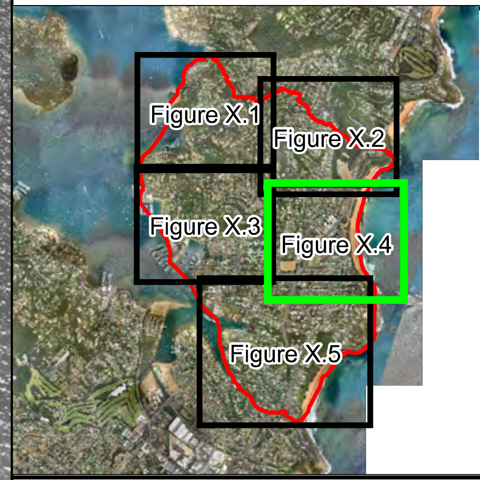
Sydney, NSW 2000

File Name: Appl - XP-RAFTS Subcatch Layout.wor

NORTHERN BEACHES COUNCIL



LEGEND

XP-RAFTS Node-Link

1 XP-RAFTS Subcatchment Boundaries

Notes:

Aerial photograph date: 2014

N
W E
S

Scale 1:4,000 (at A3)

0 0.1 0.2 Km

Figure I1.4: Newport XP-RAFTS Subcatchment Layout

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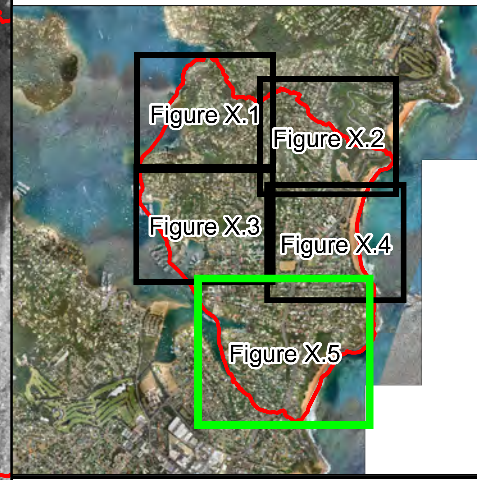
Sydney, NSW 2000

File Name: Appl - XP-RAFTS Subcatch Layout.wor

NORTHERN BEACHES COUNCIL



LEGEND

XP-RAFTS Node-Link

1 XP-RAFTS Subcatchment Boundaries

Notes:

Aerial photograph date: 2014

N W E S

Scale 1:5,000 (at A3)

0 0.15 0.3 Km

Figure I1.5: Newport XP-RAFTS Subcatchment Layout

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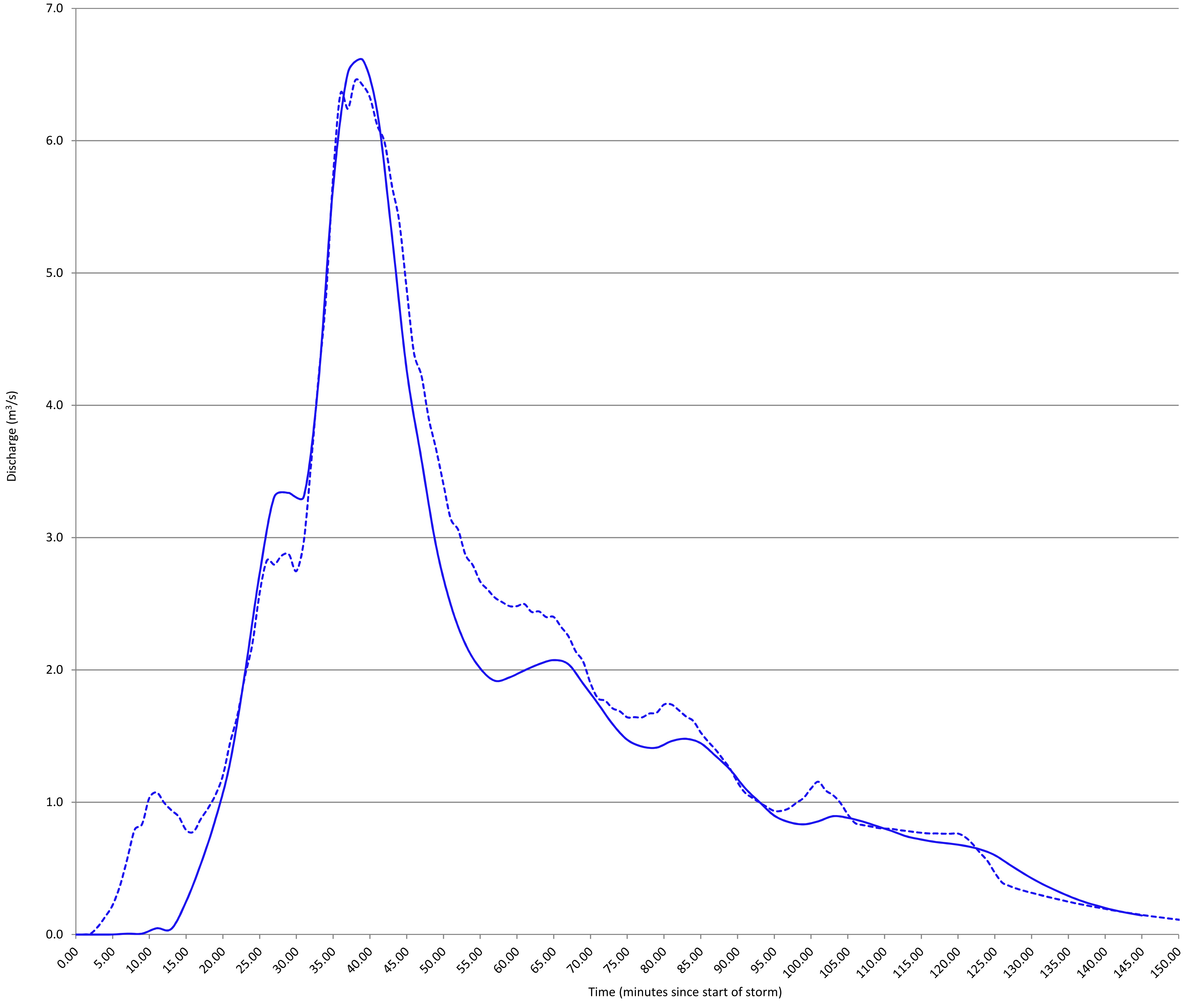
Sydney, NSW 2000

File Name: Appl - XP-RAFTS Subcatch Layout.wor



NORTHERN BEACHES COUNCIL

LEGEND:

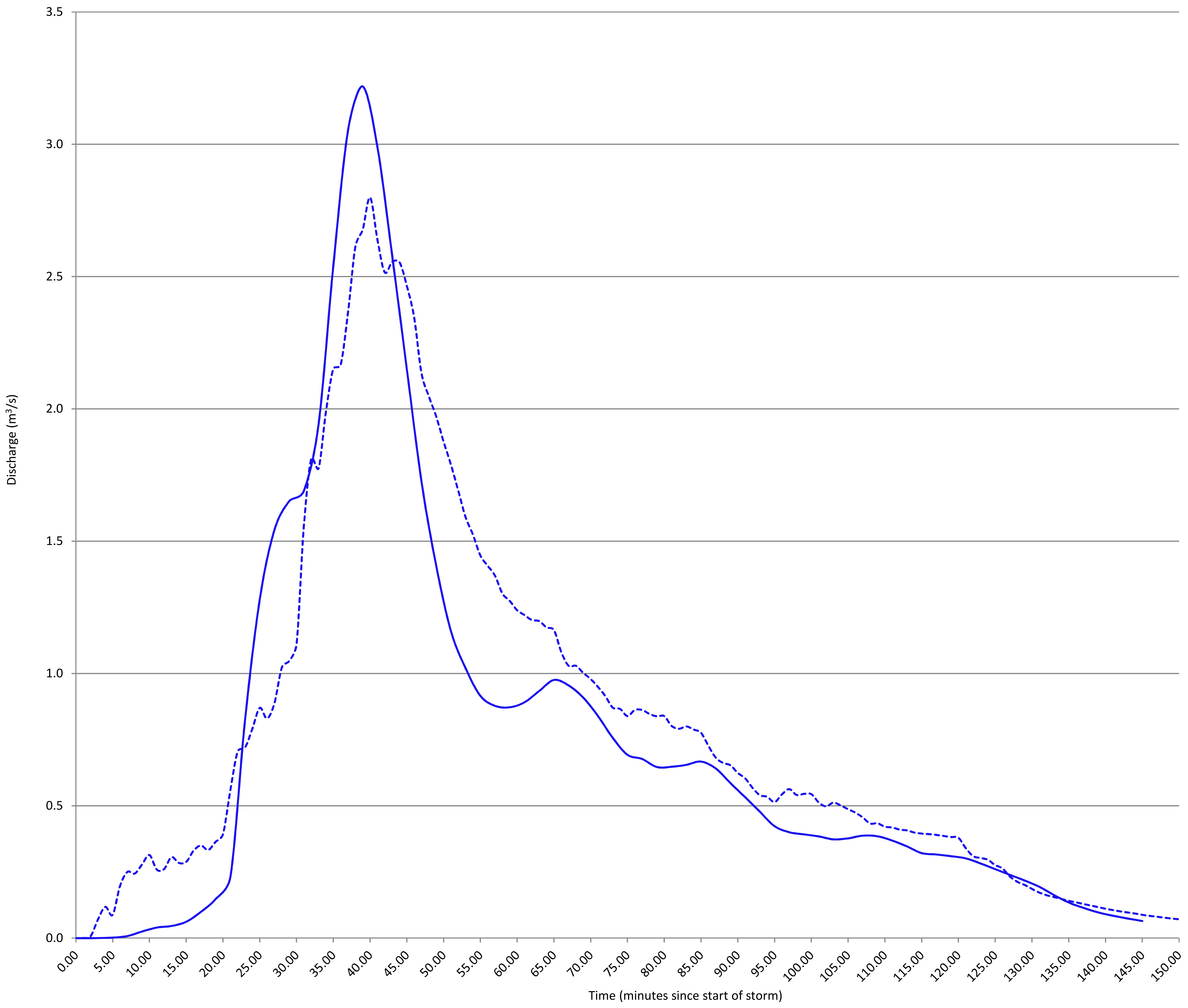
- 100 Year ARI (2 hour storm) XP-RAFTS hydrograph (dashed line)
- 100 Year ARI (2 hour storm) TUFLOW hydrograph (solid line)

Notes:
Hydrograph extracted Newport XP-RAFTS Subcatchment _junc_46

Figure I2: Comparison Between XP-RAFTS and TUFLOW Discharge Hydrographs near De Lauret Avenue.

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George Street
Sydney, NSW, 2000

File Name: Hydrograph Comparisons.xlsx



NORTHERN BEACHES COUNCIL

LEGEND:

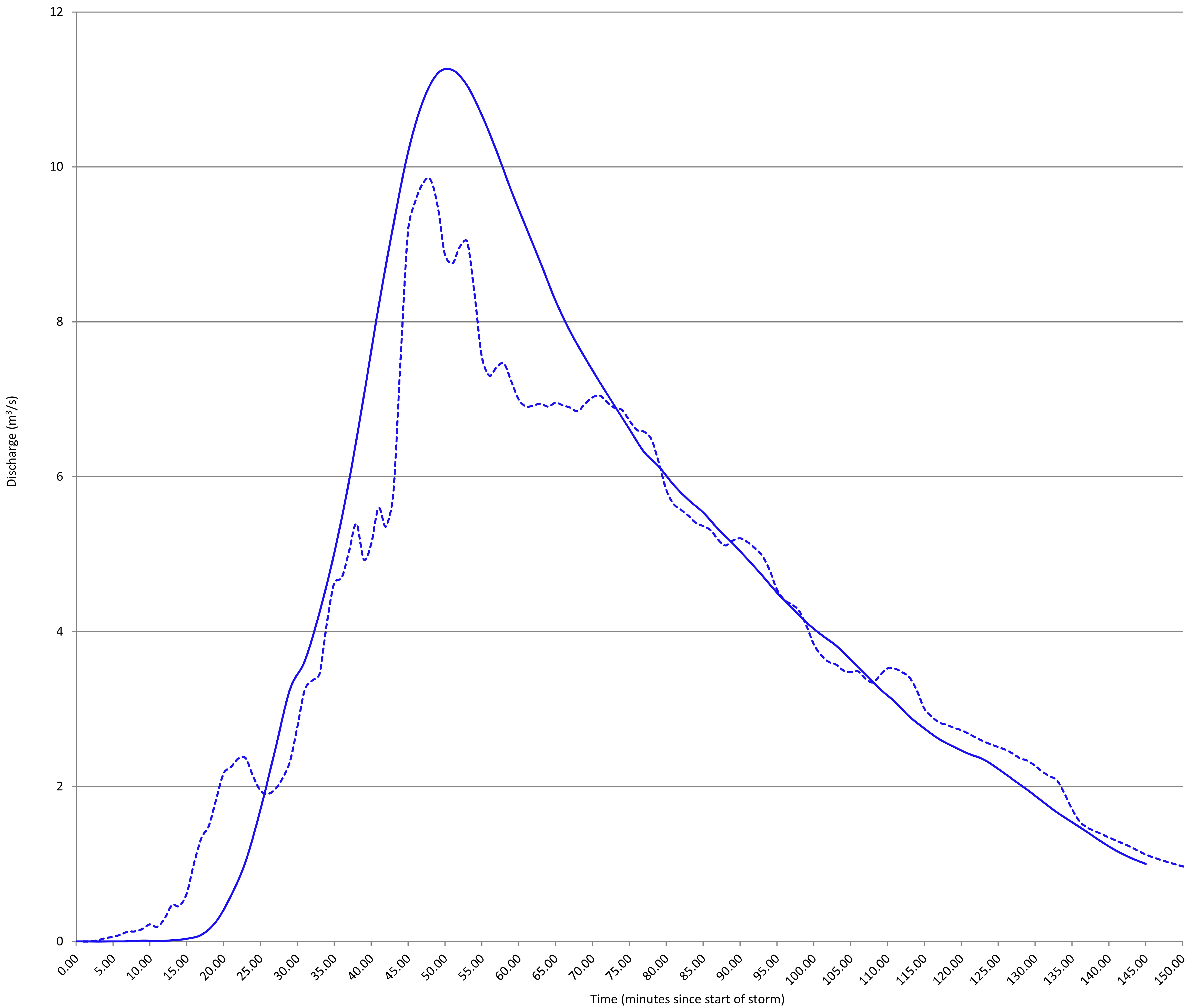
- 100 Year ARI (2 hour storm) XP-RAFTS hydrograph
- 100 Year ARI (2 hour storm) TUFLOW hydrograph

Notes:
Hydrograph extracted from Newport XP-RAFTS Subcatchment _junc_123

Figure I3: Comparison Between XP-RAFTS and TUFLOW Discharge Hydrographs at Irrubel Road near King Street.

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George Street
Sydney, NSW, 2000

File Name: Hydrograph Comparisons.xlsx



NORTHERN BEACHES COUNCIL

LEGEND:

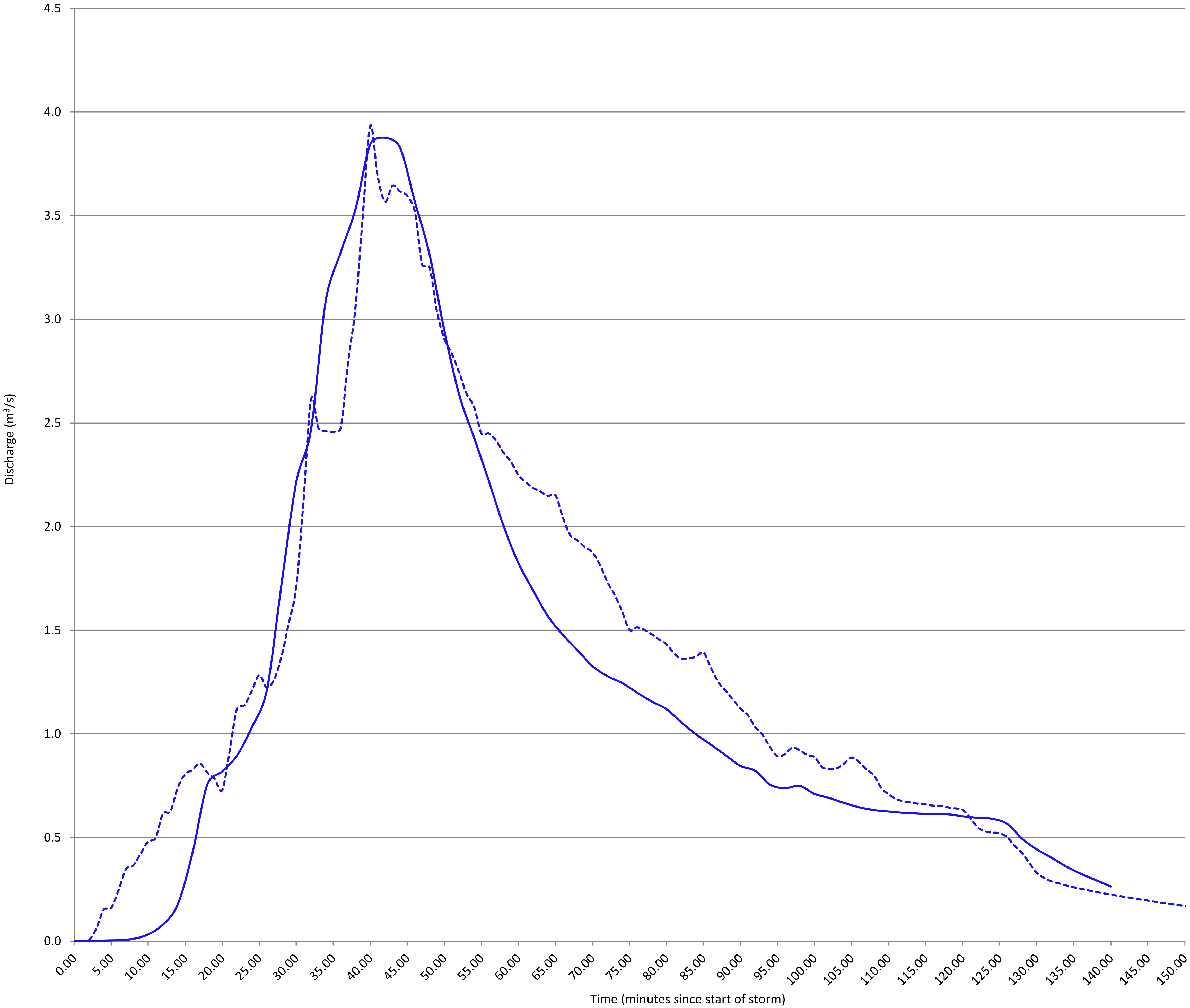
- 100 Year ARI (2 hour storm) XP-RAFTS hydrograph (dashed line)
- 100 Year ARI (2 hour storm) TUFLOW hydrograph (solid line)

Notes:
Hydrograph extracted from Newport XP-RAFTS Subcatchment 167

Figure I4:
Comparison Between XP-RAFTS and TUFLOW Discharge Hydrographs at Newport Park.

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George Street
Sydney, NSW, 2000

File Name: Hydrograph Comparisons.xlsx



NORTHERN BEACHES COUNCIL

LEGEND:

- - - - 100 Year ARI (2 hour storm) XP-RAFTS hydrograph

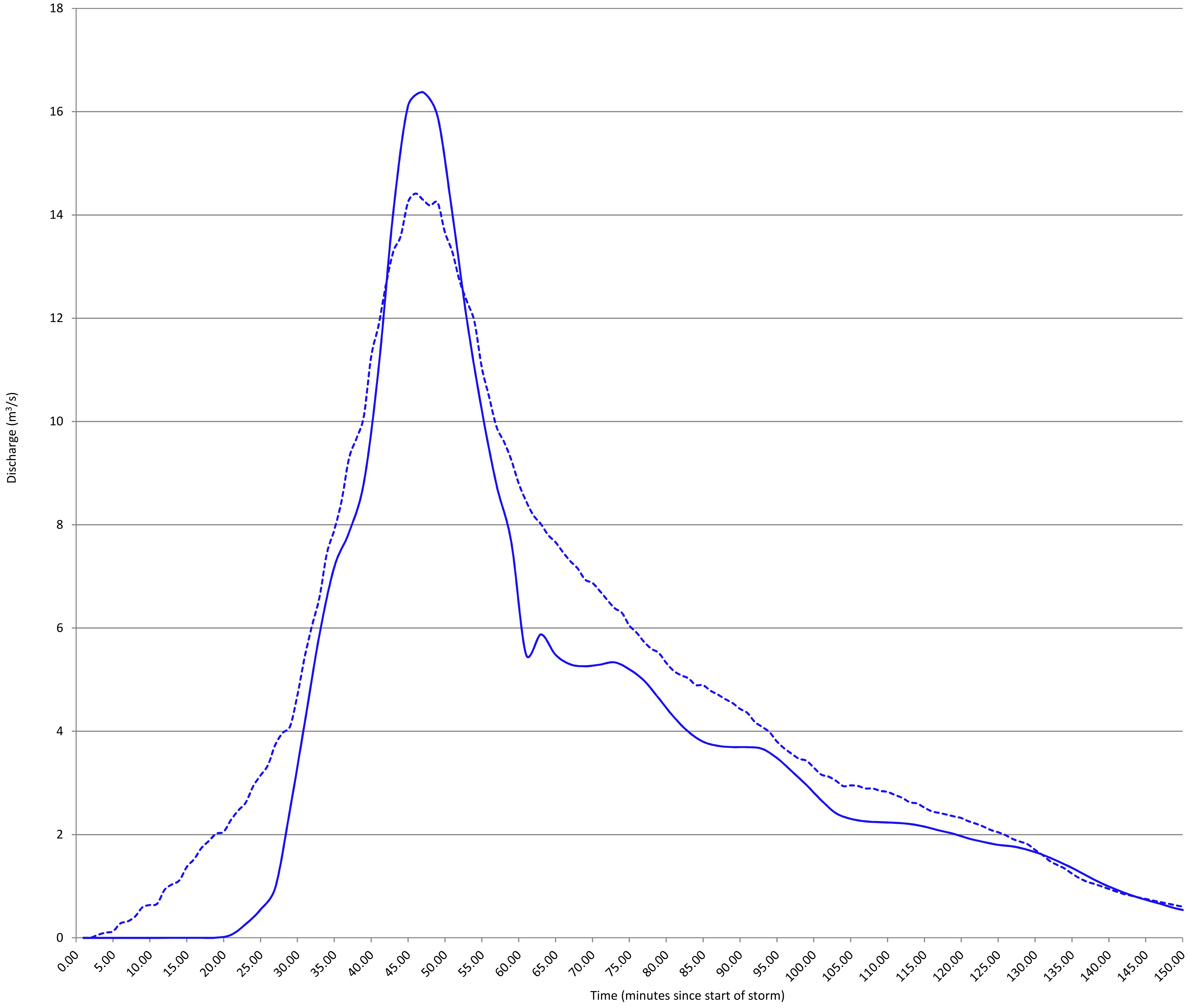
—— 100 Year ARI (2 hour storm) TUFLOW hydrograph

Notes:
Hydrograph extracted from Newport XP-RAFTS Subcatchment _junc_142

Figure I5: Comparison Between XP-RAFTS and TUFLOW Discharge Hydrographs at Palm Road.

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George Street
Sydney, NSW, 2000

File Name: Hydrograph Comparisons.xlsx



NORTHERN BEACHES COUNCIL

LEGEND:

- - - - 100 Year ARI (2 hour storm) XP-RAFTS hydrograph

—— 100 Year ARI (2 hour storm) TUFLOW hydrograph

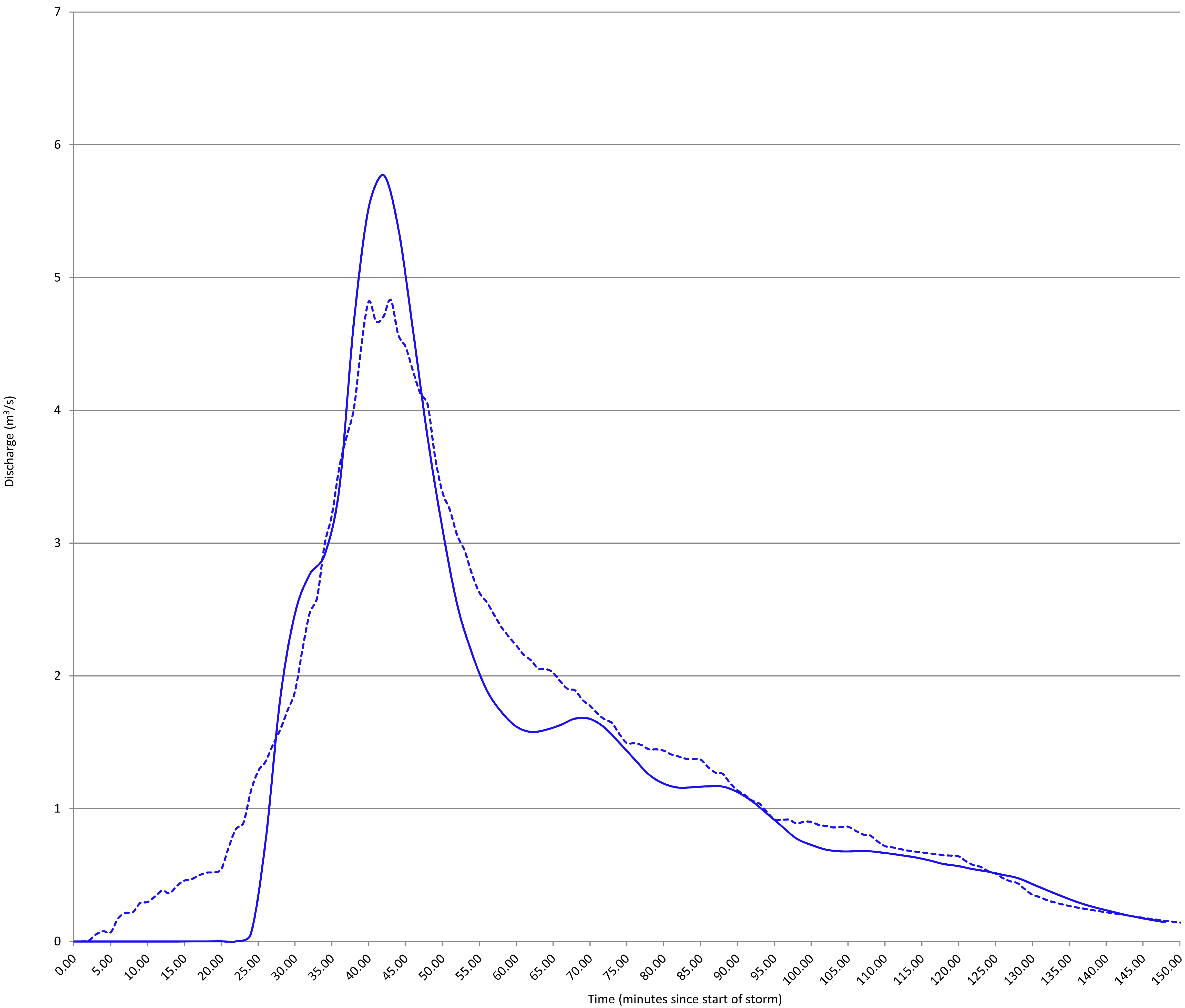
Notes:
Hydrograph extracted from Newport XP-RAFTS Subcatchment 79

Figure I6: Comparison Between XP-RAFTS and TUFLOW Discharge Hydrographs at Howell Close Reserve.

Prepared By:

Catchment Simulation Solutions
Suite 2.01, 210 George Street
Sydney, NSW, 2000

File Name: Hydrograph Comparisons.xlsx



NORTHERN BEACHES COUNCIL

LEGEND:

- - - - 100 Year ARI (2 hour storm) XP-RAFTS hydrograph

—— 100 Year ARI (2 hour storm) TUFLOW hydrograph

Notes:
Hydrograph extracted from Newport XP-RAFTS Subcatchment _junc_58

Figure I7: Comparison Between XP-RAFTS and TUFLOW Discharge Hydrographs upstream of Newport Rugby Fields.

Prepared By:
Catchment Simulation Solutions
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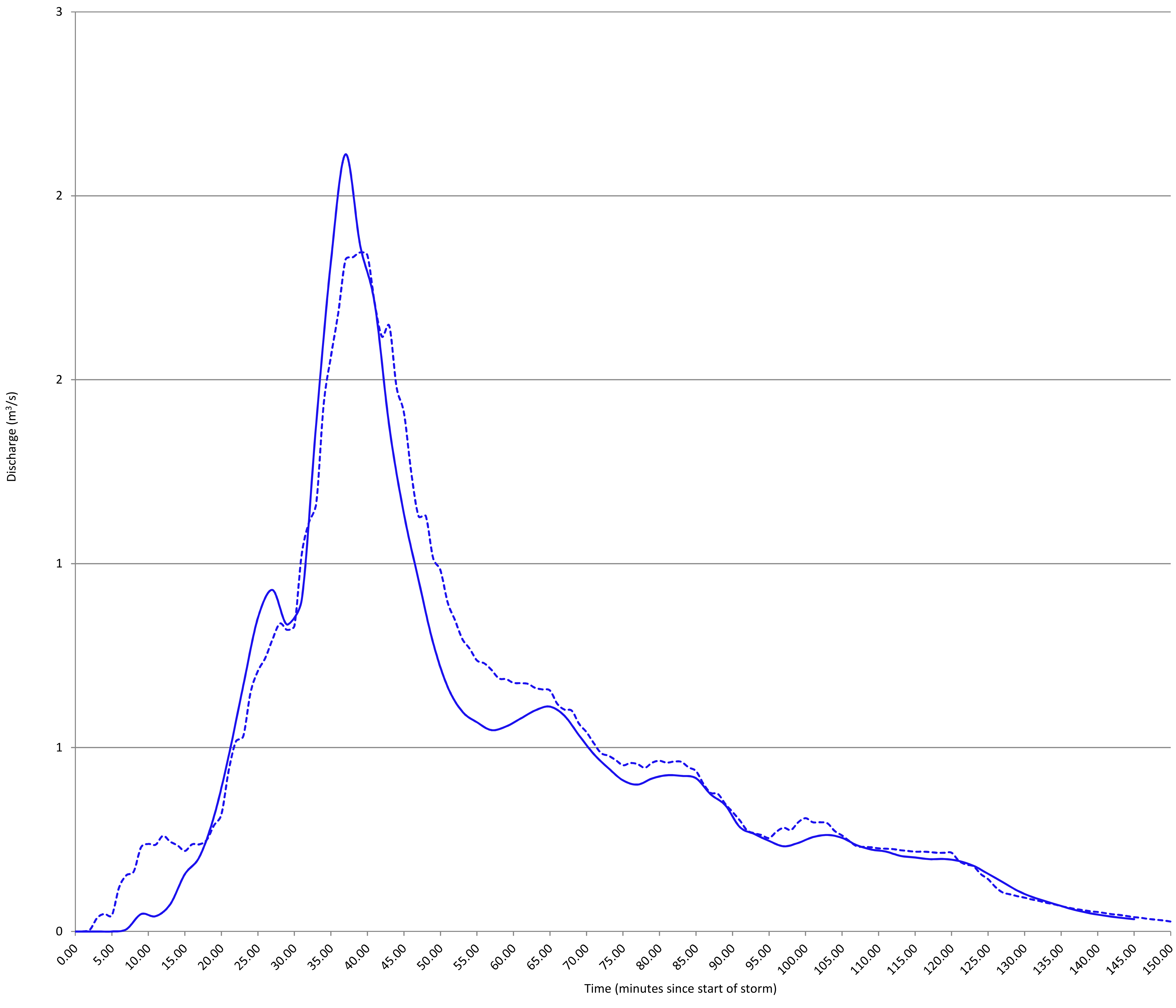
File Name: Hydrograph Comparisons.xlsx



NORTHERN BEACHES COUNCIL

LEGEND:

100 Year ARI (2 hour storm) XP-RAFTS hydrograph (dashed line)

100 Year ARI (2 hour storm) TUFLOW hydrograph (solid line)

Notes:
Hydrograph extracted from Newport XP-RAFTS Subcatchment 16

Figure I8:
Comparison Between XP-RAFTS and TUFLOW Discharge Hydrographs at Prince Alfred Parade cul-de-sac.

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Sydney, NSW, 2000

File Name: Hydrograph Comparisons.xlsx

Appendix J

Sensitivity Results Comparison

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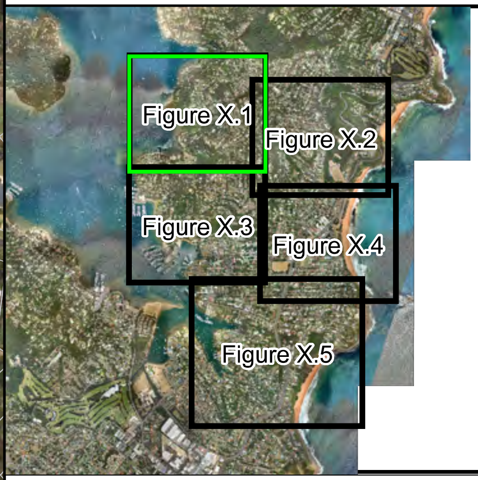


LEGEND

- Flood Level Comparison Point

Notes:
Aerial photograph date: 2014

N
W E
S

Scale 1:4,000 (at A3)

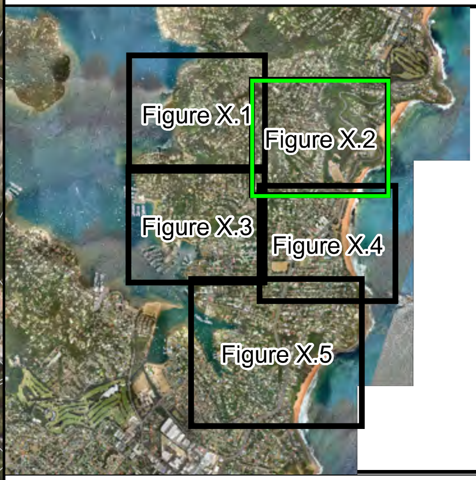
0 0.1 0.2
Km

Figure J1.1:
Locations for Flood Level Sensitivity Comparison

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigJ1.1 - Locations for FL.wor

NORTHERN BEACHES COUNCIL



LEGEND

Flood Level Comparison Point

Notes:
Aerial photograph date: 2014

N
W E
S

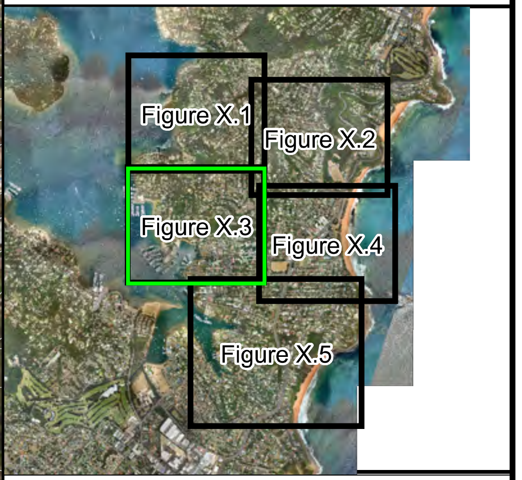
Scale 1:4,000 (at A3)
0 0.1 0.2
Km

**Figure J1.2:
Locations for Flood Level Sensitivity Comparison**

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigJ1.2 - Locations for FL.wor

NORTHERN BEACHES COUNCIL



LEGEND

Flood Level Comparison Point

Notes:
Aerial photograph date: 2014

N
W E
S

Scale 1:4,000 (at A3)

0 0.1 0.2
Km

Figure J1.3: Locations for Flood Level Sensitivity Comparison

Prepared By:
Catchment Simulation Solutions
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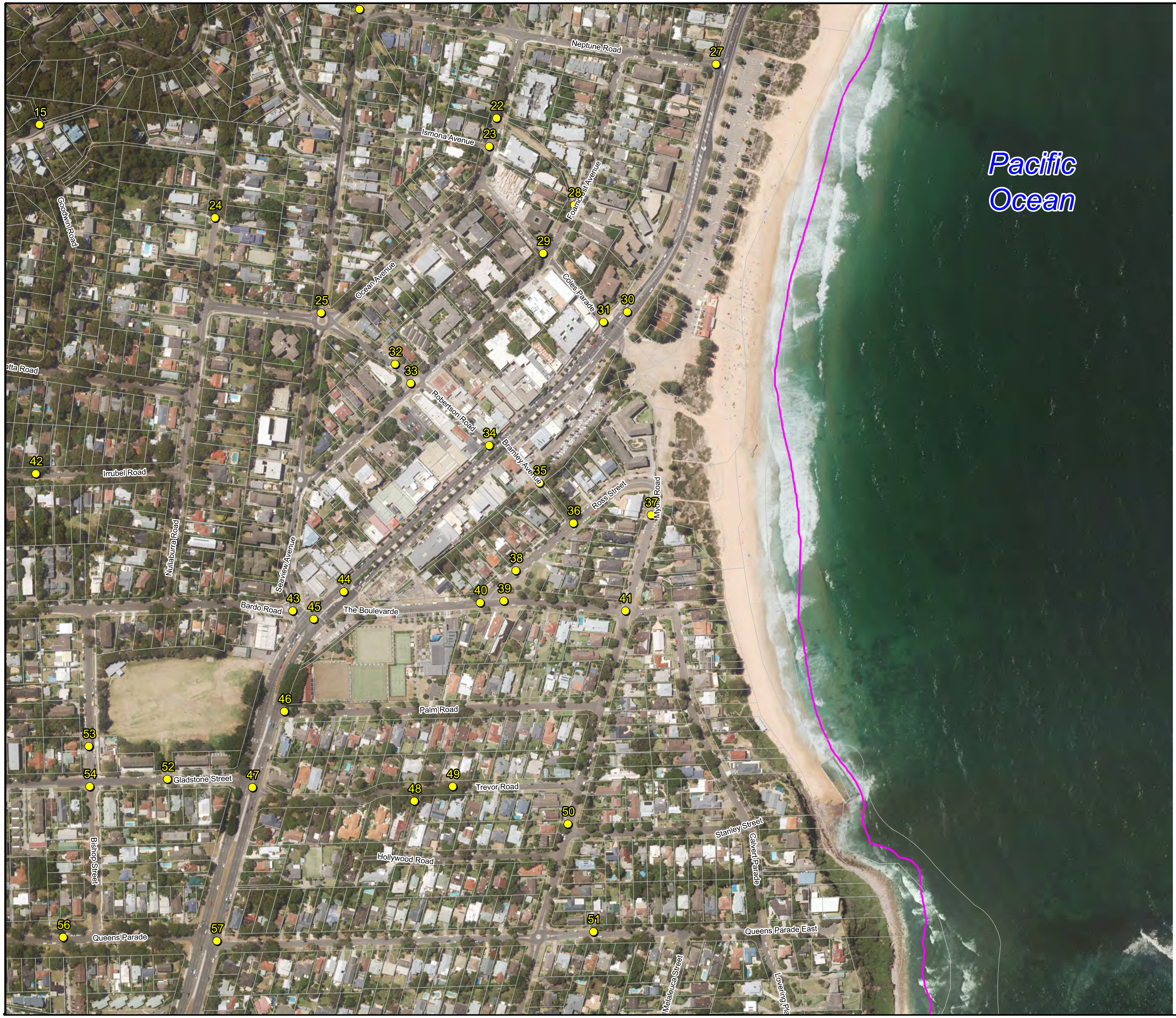
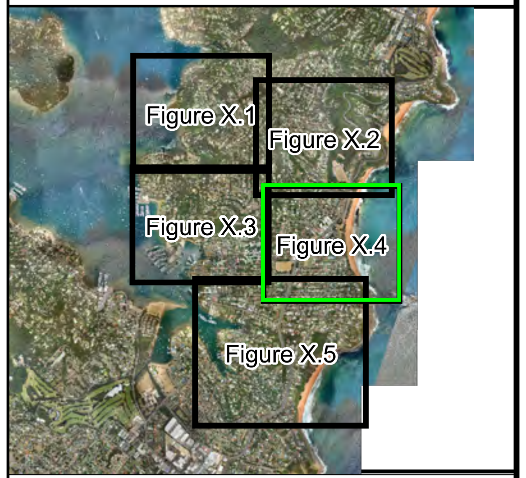
Sydney, NSW 2000

File Name: FigJ1.3 - Locations for FL.wor

NORTHERN BEACHES COUNCIL





LEGEND

Flood Level Comparison Point

Notes:
Aerial photograph date: 2014

N
W E
S

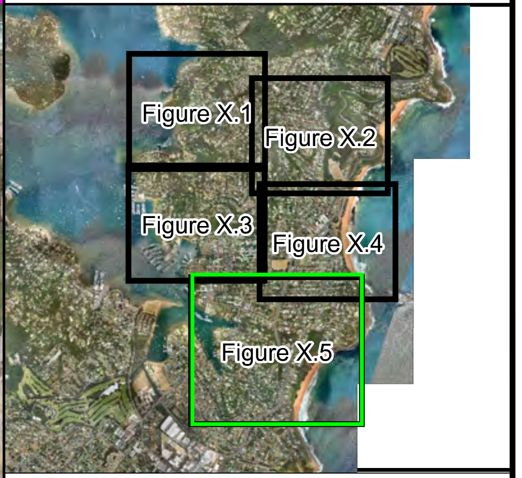
Scale 1:4,000 (at A3)
0 0.1 0.2
Km

Figure J1.4: Locations for Flood Level Sensitivity Comparison

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigJ1.4 - Locations for FL.wor

NORTHERN BEACHES COUNCIL



LEGEND

- Flood Level Comparison Point

Notes:
Aerial photograph date: 2014

N
W E
S

Scale 1:5,000 (at A3)

0 0.15 0.3
Km

Figure J1.5:
Locations for Flood Level Sensitivity Comparison

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: FigJ1.5 - Locations for FL.wor

Table J1 Peak Floodwater Stage Comparions at Key Locations within the Newport Catchment between Existing and 30% Increase in Rainfall Intensity with 0.9m Ocean Level Rise

ID	Location Description	Peak Stage (mAHD)																										
		Design	30% Increase in Rainfall Intensity with 0.9m Ocean level Rise	Difference	Design	30% Increase in Rainfall Intensity with 0.9m Ocean level Rise	Difference	Design	30% Increase in Rainfall Intensity with 0.9m Ocean level Rise	Difference	Design	30% Increase in Rainfall Intensity with 0.9m Ocean level Rise	Difference	Design	30% Increase in Rainfall Intensity with 0.9m Ocean level Rise	Difference	Design	30% Increase in Rainfall Intensity with 0.9m Ocean level Rise	Difference	Design	30% Increase in Rainfall Intensity with 0.9m Ocean level Rise	Difference	Design	30% Increase in Rainfall Intensity with 0.9m Ocean level Rise	Difference	Design	30% Increase in Rainfall Intensity with 0.9m Ocean level Rise	Difference
		20% AEP			10% AEP			5% AEP			2% AEP			1% AEP			0.5% AEP			0.2% AEP			0.1% AEP			PMF		
1	Southern end of Hudson Parade	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	27.54	27.57	0.03	27.55	27.58	0.03	27.56	27.59	0.03	27.55	27.59	0.04	27.71	27.76	0.05
2	Prince Alfred Parade 10m NorthWest of intersection with Loomba St	32.02	32.09	0.07	32.09	32.11	0.02	32.08	32.09	0.01	32.08	32.08	0.00	32.09	32.12	0.03	32.06	32.11	0.05	32.12	32.13	0.01	32.10	32.15	0.04	32.26	32.30	0.04
3	Loomba St 20m East of intersection with Prince Alfred Parade	40.49	40.57	0.08	40.61	40.66	0.04	40.66	40.76	0.10	40.68	40.96	0.28	40.75	40.94	0.19	40.86	41.16	0.31	40.98	41.10	0.11	40.88	41.31	0.42	41.14	41.32	0.18
4	Prince Alfred Parade 80m SouthWest of intersection with Loomba St	24.04	24.13	0.09	24.06	24.15	0.09	24.14	24.16	0.02	24.13	24.18	0.05	24.17	24.17	0.00	24.18	24.20	0.03	24.17	24.24	0.07	24.19	24.23	0.04	24.28	24.30	0.02
5	Prince Alfred Parade 220m East of intersection with Elvina Avenue	4.14	4.19	0.05	4.17	4.21	0.04	4.20	4.25	0.05	4.22	4.27	0.05	4.24	4.30	0.06	4.25	4.31	0.06	4.27	4.33	0.06	4.27	4.32	0.06	4.46	4.52	0.06
6	Prince Alfred Parade 210m West of intersection with Elvina Avenue	16.22	16.24	0.02	16.23	16.25	0.02	16.24	16.26	0.02	16.25	16.27	0.02	16.25	16.27	0.02	16.26	16.28	0.02	16.26	16.29	0.02	16.26	16.29	0.03	16.38	16.41	0.03
7	Mirrabooka St 40m North of intersection with Loomba St	81.65	81.81	0.16	81.74	81.87	0.13	81.82	81.92	0.10	81.86	81.96	0.11	81.90	81.99	0.09	81.92	82.02	0.10	81.95	82.04	0.09	81.91	82.03	0.11	82.29	82.37	0.08
8	Cooinda Place 15m North of intersection with Loomba St	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	86.55	86.59	0.04	86.56	86.60	0.04	86.57	86.61	0.04	86.57	86.60	0.04	86.74	86.78	0.05
9	Lower Plateau Rd 190m North of intersection with Plateau Rd	119.30	119.32	0.02	119.31	119.34	0.02	119.33	119.35	0.02	119.33	119.36	0.02	119.34	119.36	0.02	119.35	119.37	0.02	119.35	119.38	0.02	119.35	119.37	0.02	119.45	119.48	0.03
10	Algona St 100m SouthEast of intersection with Loomba St	99.73	99.75	0.02	99.74	99.76	0.03	99.75	99.78	0.03	99.76	99.79	0.03	99.77	99.80	0.03	99.78	99.81	0.03	99.79	99.82	0.03	99.78	99.82	0.04	99.90	99.94	0.04
11	Birubi Cres 135m North of intersection with Raymond Rd	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	108.81	108.84	0.03	108.82	108.85	0.03	108.83	108.86	0.03	108.84	108.87	0.03	108.84	108.87	0.03	108.99	109.02	0.03
12	Cheryl Cres 200m South of intersection with Mountview Place	N/A	N/A	N/A	N/A	N/A	N/A	91.66	91.67	0.02	91.66	91.68	0.02	91.67	91.70	0.03	91.67	91.70	0.03	91.68	91.71	0.04	91.68	91.72	0.04	91.87	91.93	0.06
13	Cheryl Cres 270m West of intersection with Belinda Place	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	94.62	94.68	0.06
14	Corner of Raymond Road and York Terrace	N/A	N/A	N/A	N/A	N/A	N/A	132.10	132.12	0.03	132.11	132.13	0.03	132.12	132.14	0.03	132.12	132.15	0.03	132.13	132.16	0.03	132.12	132.15	0.03	132.24	132.28	0.03
15	North East end of Belinda Place	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	70.02	70.08	0.05	70.04	70.09	0.05	70.03	70.08	0.05	70.24	70.37	0.14
16	The Outlook 27m East of intersection with Daly St	N/A	N/A	N/A	126.67	126.70	0.03	126.68	126.70	0.02	126.69	126.71	0.02	126.70	126.72	0.01	126.70	126.72	0.02	126.71	126.73	0.02	126.70	126.73	0.02	126.80	126.84	0.04
17	Monterey Rd 100m West of intersection with Farview Rd	N/A	N/A	N/A	N/A	N/A	N/A	108.55	108.59	0.04	108.56	108.60	0.03	108.58	108.61	0.03	108.58	108.62	0.03	108.60	108.63	0.03	108.58	108.62	0.04	108.71	108.75	0.04
18	60m SouthEast of Western end of Kanimbla Crescent	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	90.57	90.63	0.06
19	Kanimbla Cres 20m NorthEast of intersection with Monterey Road	109.22	109.23	0.01	109.23	109.24	0.02	109.24	109.25	0.01	109.24	109.25	0.01	109.24	109.26	0.02	109.25	109.26	0.01	109.25	109.27	0.01	109.25	109.27	0.02	109.32	109.34	0.02
20	North West end of Hillslope Road	43.30	43.33	0.03	43.32	43.35	0.04	43.33	43.37	0.04	43.35	43.38	0.03	43.36	43.41	0.04	43.37	43.41	0.04	43.38	43.42	0.04	43.38	43.42	0.04	43.54	43.56	0.02
21	Howell Close 10m North of intersection with Neptune Road	11.14	11.26	0.11	11.19	11.30	0.11	11.28	11.37	0.09	11.32	11.41	0.09	11.36	11.47	0.10	11.38	11.49	0.12	11.41	11.54	0.14	11.41	11.53	0.12	13.02	13.47	0.46
22	Ocean Avenue 30m North of intersection with Ismona Avenue	6.57	6.73	0.16	6.63	6.81	0.18	6.75	6.90	0.15	6.82	7.03	0.21	6.88	7.17	0.30	6.92	7.24	0.32	7.12	7.48	0.36	7.16	7.52	0.36	9.34	9.83	0.48
23	Intersection of Ismona Avenue and Ocean Avenue	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	9.22	9.67	0.45
24	Nullaburra Rd 90m North of intersection with Robertson Rd	18.48	18.50	0.02	18.49	18.52	0.02	18.51	18.56	0.05	18.53	18.59	0.06	18.55	18.60	0.05	18.56	18.61	0.05	18.60	18.67	0.07	18.60	18.67	0.08	18.96	19.11	0.15
25	Roundabout at intersection of Robertson Road and Ocean Avenue	N/A	N/A	N/A	12.43	12.48	0.05	12.45	12.52	0.06	12.47	12.55	0.08	12.50	12.58	0.08	12.52	12.59	0.07	12.53	12.62	0.09	12.54	12.63	0.09	12.88	12.94	0.06
26	Burke Street 60m North of intersection with Attunga Road	14.72	14.76	0.04	14.74	14.79	0.04	14.77	14.82	0.05	14.79	14.83	0.04	14.81	14.86	0.05	14.82	14.87	0.05	14.83	14.88	0.05	14.83	14.89	0.06	15.08	15.15	0.07
27	Intersection of Barrenjoey Road and Neptune Road	6.75	6.87	0.12	6.81	6.93	0.12	6.88	7.01	0.13	6.94	7.06	0.12	6.99	7.11	0.12	7.02	7.13	0.11	7.05	7.16	0.11	7.05	7.15	0.10	7.45	7.54	0.09
28	Foamcrest Avenue 60m North of intersection with Coles Parade	5.56	5.93	0.36	5.82	6.05	0.24	5.94	6.15	0.21	6.06	6.21	0.15	6.13	6.25	0.11	6.15	6.29	0.13	6.20	6.35	0.15	6.22	6.39	0.17	7.05	7.45	0.40
29	Intersection of Foamcrest Avenue and Coles Parade	N/A	N/A	N/A	N/A	N/A	N/A	6.06	6.13	0.07	6.07	6.17	0.10	6.12	6.21	0.09	6.13	6.24	0.11	6.17	6.27	0.10	6.20	6.30	0.10	6.96	7.36	0.40
30	Barrenjoey Road 20m North of intersection with Coles Parade	4.27	4.50	0.23	4.36	4.58	0.22	4.51	4.67	0.16	4.58	4.73	0.15	4.65	4.80	0.15	4.68	4.82	0.15	4.73	4.87	0.14	4.76	4.91	0.14	5.88	6.13	0.25
31	Intersection of Barrenjoey Road and Coles Parade	4.27	4.50	0.23	4.36	4.57	0.22	4.51	4.67	0.16	4.58	4.73	0.15	4.65	4.80	0.15	4.67	4.82	0.15	4.73	4.87	0.14	4.76	4.90	0.14	5.89	6.14	0.25
32	Robertson Road 25m NorthWest of intersection with Foamcrest Avenue	9.36	9.42	0.06	9.39	9.46	0.07	9.42	9.49	0.07	9.46	9.53	0.07	9.48	9.56	0.08	9.50	9.58	0.08	9.52	9.60	0.08	9.54	9.63	0.09	10.00	10.13	0.13
33	Intersection of Robertson Road and Foamcrest Avenue	8.92	8.96	0.04	8.94	8.98	0.04	8.96	9.00	0.04	8.98	9.02	0.04	9.00	9.05	0.05	9.01	9.06	0.05	9.02	9.07	0.05	9.04	9.09	0.05	9.37	9.46	0.09
34	Intersection of Barrenjoey Road and Robertson Road	4.77	4.87	0.10	4.82	4.91	0.10	4.87	4.95	0.08	4.91	4.99	0.08	4.95	5.03	0.08	4.95	5.04	0.09	4.99	5.06	0.07	5.01	5.08	0.06	5.89	6.17	0.28
35	Bramley Avenue 55m SouthEast of intersection with Barrenjoey Road	3.43	3.82	0.39	3.58	4.00	0.43	3.79	4.19	0.40	3.99	4.37	0.38	4.13	4.57	0.44	4.21	4.64	0.43	4.36	4.77	0.41	4.45	4.85	0.41	5.91	6.16	0.26
36	Intersection of Bramley Avenue and Ross Street	3.45	3.82	0.37	3.59	4.00	0.41	3.79	4.20	0.41	3.99	4.37	0.39	4.14	4.56	0.41	4.22	4.62	0.40	4.36	4.74	0.38	4.45	4.85	0.40	5.92	6.19	0.27
37	Myola Road 105m North of intersection with The Boulevarde	N/A	N/A	N/A	N/A	N/A	N/A	4.10	4.17	0.07	4.13	4.34	0.22	4.16	4.53	0.37	4.18	4.59	0.42	4.33	4.70	0.38	4.42	4.82	0.40	5.85	6.09	0.24
38	Ross Street 45m NorthWest of intersection with The Boulevarde	3.46	3.82	0.36	3.60	4.00	0.41	3.80	4.20	0.41	3.99	4.37	0.38	4.14	4.56	0.42	4.22	4.62	0.40	4.36	4.75	0.38	4.45	4.84	0.39	5.93	6.11	0.18
39	The Boulevarde 15m NorthWest of intersection with Ross Street	3.46	3.82	0.36	3.60	4.01	0.41	3.80	4.21	0.41	3.99	4.37	0.38	4.14	4.56	0.42	4.22	4.63	0.41	4.36	4.76	0.40	4.46	4.86	0.40	5.96	6.17	0.20
40	Intersection of The Boulevarde and Ross Street	3.46	3.82	0.36	3.60	4.00	0.41	3.80	4.20	0.40	3.99	4.37	0.38	4.14	4.56	0.42	4.22	4.63	0.41	4.36	4.76	0.40	4.46	4.86	0.40	6.05	6.26	0.21
41	Intersection of The Boulevarde and Myola Road	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5.89	6.16	0.27
42	Irrubel Road 160m West of intersection with Nullaburra Road	28.58	28.61	0.03	28.60	28.62	0.02	28.61	28.63	0.02	28.62	28.64	0.02	28.63	28.65	0.02	28.63	28.65	0.02	28.64	28.65	0.02	28.63	28.65	0.02	28.73	28.75	0.02
43	Intersection of Seaview Avenue and Bardo Road	N/A	N/A	N/A	3.91	4.03	0.12	3.92	4.22	0.30	4.02	4.38	0.36	4.16	4.56	0.40	4.24	4.62	0.38	4.38	4.73	0.36	4.46	4.83	0.37	5.91	6.19	0.28
44	Intersection of Barrenjoey Road and The Boulevarde	3.52	3.85	0.33	3.65	4.02	0.37	3.83	4.22	0.38	4.02	4.38	0.36	4.16	4.56	0.40	4.23	4.62	0.38	4.38	4.73	0.36	4.46	4.83	0.37	5.91	6.19	0.29
45	Barrenjoey Road 40m SouthWest of intersection with The Boulevarde	3.53	3.85	0.32	3.66	4.02	0.37	3.83	4.22	0.38	4.02	4.38	0.36	4.16	4.56	0.40	4.23	4.62	0.38	4.38	4.73	0.36	4.46	4.83	0.37	5.91	6.19	0.28
46	Intersection of Barrenjoey Road and Palm Road	4.13	4.19	0.06	4.16	4.22	0.06	4.18	4.26	0.08	4.22	4.41	0.19	4.23	4.59	0.36	4.26	4.65	0.39	4.41	4.77	0.36	4.49	4.85	0.36	5.93	6.22	0.28
47	Intersection of Barrenjoey Road and Trevor Road	7.02	7.08	0.06	7.02	7.07	0.05	7.07	7.08	0.01	7.08	7.10	0.02	7.07	7.10	0.03	7.07	7.09	0.02	7.09	7.09	0.00	7.09	7.09	0.00	7.17	7.23	0.06
48	Hollywood Road 10m SouthWest of intersection with Trevor Road	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	9.49	9.52	0.03	9.49	9.52	0.03	9.67	9.71	0.03
49	Trevor Road 40m East of intersection with Hollywood Road	8.66	8.69	0.03	8.68	8.72	0.04	8.70	8.74	0.04	8.71	8.76	0.04	8.73	8.78	0.05	8.74	8.80	0.06	8.75	8.81	0.06	8.76	8.82	0.06	9.11	9.26	0.15
50	Intersection of Stanley Street and Myola Road	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	12.67	12.75	0.08
51	Queens Parade East 60m East of intersection with Myola Road	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	17.61	17.65	0.04	17.62	17.67	0.04	17.63	17.68	0.05	17.81	17.87	0.06
52	Gladstone Street 90m West of intersection with Barrenjoey Road	5.13	5.15	0.02	5.14	5.16	0.02	5.15	5.17	0.02	5.16	5.18	0.02	5.17	5.19	0.02	5.17	5.19	0.02	5.18	5.21	0.03	5.17	5.20	0.02	5.94	6.23	0.29
53	Bishop Street 35m North of intersection with Gladstone Street	4.86	4.97	0.10	4.91	5.02	0.11	4.97	5.08	0.11	5.02	5.13	0.10	5.07	5.16	0.09	5.09	5.18	0.09	5.12	5.22	0.10	5.14	5.24	0.10	5.95	6.24	0.29
54	Intersection of Bishop Street and Gladstone Street	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5.58	5.60	0.02	5.59	5.60	0.01	5.58	5.60	0.02	5.96	6.25	0.29
55	Woolcott Street 25m North of intersection with Gladstone Street	5.64	5.76	0.11	5.70	5.81	0.11	5.76	5.87	0.11	5.82	5.93	0.11	5.85	5.98	0.12	5.89	6.00	0.12	5.92	6.04	0.12	5.94	6.06	0.13	6.57	6.77	0.19
56	Queens Parade 35m West of intersection with Bishop Street	N/A	N/A	N/A	N/A	N/A	N/A	14.18	14.20	0.03	14.19	14.22	0.03	14.20	14.22	0.03	14.21	14.23	0.03	14.21	14.24	0.03	14.21	14.25	0.03	14.35	14.39	0.04
57	Intersection of Barrenjoey Road and Queens Parade East	17.15	17.27	0.12	17.18	17.25	0.07	17.28	17.33	0.05	17.29	17.34	0.05	17.31	17.37	0.06	17.33	17.37	0.04	17.32	17.41	0.09	17.28	17.36	0.07	17.35	17.40	0.05
58	Irrubel Road 25m East of intersection with Crystal Street	6.83	6.94	0.11	6.89	6.98	0.09	6.95	7.02	0.07	6.98	7.05	0.07	7.01	7.08	0.07	7.02	7.09	0.07	7.04	7.12	0.07	7.04	7.11	0.08	7.40	7.51	0.11
59	Nooal Street 25m South of intersection with Irrubel Road	2.69	2.76	0.07	2.72	2.81	0.09	2.79	2.93	0.14	2.84	3.01	0.16	2.90	3.11	0.21	2.93	3.15	0.22	3.00	3.22	0.23	2.98	3.23	0.25	4.53	5.35	0.82
60	Irrubel Road 35m East of intersection with King Street	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	15.60	15.65	0.04	15.62	15.66	0.04	15.63	15.67	0.04	15.65	15.68	0.03	15.65	15.69	0.04	16.04	16.42	0.38
61	King Street 50m South of intersection with Irrubel Road	12.15	12.22	0.07	12.19	12.26	0.07	12.23	12.30	0.07	12.26	12.32	0.06	12.28	12.35	0.06	12.30	12.36	0.06	12.32	12.38	0.06	12.31	12.39	0.08	12.86	13.12	0.26
62	Bardo Road 110m West of intersection with King Street	6.67	6.73	0.06	6.70	6.75	0.05	6.73	6.77	0.04	6.75	6.80	0.04	6.77	6.82	0.05	6.78	6.82	0.04	6.79	6.84	0.05	6.80	6.84	0.05	6.98	7.03	0.04
63	King Street 100m South of intersection with Bardo Road	9.29	9.34	0.04	9.31	9.35	0.04	9.34	9.37	0.03	9.35	9.39	0.04	9.37	9.40	0.04	9.38	9.41	0.04	9.38	9.42	0.04	9.37	9.41	0.04	9.60	9.67	0.06
64	Western End of Queens Parade	1.83	1.88	0.05	1.84	1.89	0.05	1.86	1.90	0.04	1.88	1.91	0.03	1.89	2.36	0.48	1.89	2.36	0.47	1.90	2.37	0.47	1.89	2.37	0.47	1.98	2.36	0.38
65	Crescent Road 15m North East of intersection with Wiruna Crescent	8.82	8.92	0.10	8.87	8.96	0.09	8.92	9.01	0.09	8.95	9.04	0.09	8.99	9.08	0.08	9.01	9.10	0.09	9.03	9.12	0.09	9.02	9.11	0.09	9.46	9.59	0.13
66	Crescent Road 200m North West of intersection with Yachtsmans Paradise	N/A	N/A	N/A	N/A	N/A	N/A	8.62	8.64	0.02	8.63	8.65	0.02	8.63	8.67	0.03	8.63	8.68	0.04	8.64	8.69	0.05	8.64	8.68	0.04	8.85	8.92	0.07
67	Intersection of Yachtsmans Paradise and Crescent Road	7.50	7.53	0.03	7.52	7.56	0.04	7.53	7.59	0.05	7.55	7.61	0.05	7.57	7.63	0.06	7.59	7.65	0.07	7.61	7.68	0.07	7.62	7.71	0.09	7.85	7.96	0.11
68	Suncrest Ave 80m North of intersection with Cecil Road	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	15.02	15.06	0.04	15.03	15.07	0.04	15.04	15.08	0.04	15.04	15.08	0.04	15.21	15.27	0.06
69	Yachtsmans Paradise 70m South West of intersection with Crescent Road	5.66	5.81	0.15	5.74	5.87	0.13	5.82	5.94	0.12	5.87	5.99	0.12	5.92	6.05	0.12	5.95	6.07	0.12	5.99	6.12	0.13	5.97	6.09	0.12	6.59	6.81	0.21

Table J2 Peak Discharge Comparions at Key Locations within the Newport Catchment between Existing and 30% Increase in Rainfall Intensity with 0.9m Ocean Level Rise

ID	Location Description	Peak Discharge (m^3/s)																										
		Design	30% Increase in Rainfall Intensity with 0.9m Ocean level Rise	Difference	Design	30% Increase in Rainfall Intensity with 0.9m Ocean level Rise	Difference	Design	30% Increase in Rainfall Intensity with 0.9m Ocean level Rise	Difference	Design	30% Increase in Rainfall Intensity with 0.9m Ocean level Rise	Difference	Design	30% Increase in Rainfall Intensity with 0.9m Ocean level Rise	Difference	Design	30% Increase in Rainfall Intensity with 0.9m Ocean level Rise	Difference	Design	30% Increase in Rainfall Intensity with 0.9m Ocean level Rise	Difference	Design	30% Increase in Rainfall Intensity with 0.9m Ocean level Rise	Difference	Design	30% Increase in Rainfall Intensity with 0.9m Ocean level Rise	Difference
		20% AEP			10% AEP			5% AEP			2% AEP			1% AEP			0.5% AEP			0.2% AEP			0.1% AEP			PMF		
1	De Lauret Avenue	4.03	5.36	1.33	4.70	6.21	1.51	5.42	7.38	1.96	6.17	8.10	1.93	6.90	9.23	2.33	7.36	9.77	2.41	7.99	10.66	2.67	7.78	10.48	2.70	28.52	37.90	9.38
2	Irrubel Road near King Street	1.85	2.54	0.69	2.16	2.93	0.76	2.57	3.44	0.87	2.90	3.82	0.92	3.22	4.37	1.15	3.35	4.59	1.24	3.76	4.96	1.20	3.82	5.10	1.28	12.78	16.67	3.89
3	Palm Road	6.21	8.79	2.57	7.40	10.33	2.93	8.89	12.39	3.49	10.41	14.09	3.68	11.91	15.80	3.89	12.69	16.51	3.83	13.86	18.14	4.28	14.82	18.69	3.88	36.78	43.61	6.84
4	Newport Park	2.43	3.42	0.99	2.93	4.07	1.14	3.48	4.89	1.41	4.05	5.64	1.59	4.64	6.41	1.77	4.98	6.85	1.86	5.58	7.52	1.94	5.86	7.78	1.92	16.56	21.32	4.76
5	Howell Close Reserve	9.33	13.29	3.95	10.96	15.16	4.20	13.44	17.72	4.28	14.91	19.75	4.84	16.85	22.35	5.50	17.89	23.87	5.98	19.44	26.34	6.90	18.63	25.56	6.94	63.84	84.65	20.81
6	Upstream of Newport Rugby Fields	3.32	4.63	1.31	3.92	5.23	1.30	4.66	6.21	1.55	5.14	7.06	1.92	5.85	8.17	2.32	6.20	8.61	2.41	6.90	9.34	2.44	6.93	9.34	2.41	22.07	29.47	7.40
7	Prince Alfred Parade cul-de-sac	1.17	1.64	0.46	1.37	1.87	0.51	1.66	2.31	0.65	1.70	2.51	0.82	2.10	2.79	0.68	2.35	2.90	0.55	2.47	3.03	0.56	2.21	2.95	0.74	6.60	8.90	2.30

APPENDIX K

SUMMARY OF PUBLIC SUBMISSIONS

Newport Flood Study Public Submissions and Actions Summary

#	Summary of Submission	Action to Address Submission
1	Wants FAQs to include what will be done to fix the flooding problems, and wants to know why the current body of work does not include this	FAQ included on Council website. Letter prepared outlining that potential mitigation measures will be reviewed as part of a future options assessments.
2	Suggests flood mapping was not realistic in vicinity of site. Also notes uncontrolled release of water from upstream property and suggests road repair option for local road.	Site visit completed. PMF extent refined in vicinity of site. Water releases and road repair suggestions forwarded to relevant sections of Council to action
3	Notes that flooding in Myola/Ross St is caused by insufficient number and size of drains, and that debris also causes the flooding issues.	Request for additional maintenance of local drainage infrastructure forwarded to Council's stormwater section for actioning
4	Raises concerns that the property is within the FPL. However water that overtops the gutter would flow downhill away from property and not impact it. Asks if complete blockage of the drain was assumed and could be the cause of the inclusion in the FPL?	Site visit completed. Flood mapping refined in vicinity of property. However, FPA (which includes freeboard allowance) and PMF is sufficiently high to extend into front of property.
5	States that based on infomation provided at community infomation sessions, that property will be removed from the FPA. Requests confirmation that this has occurred	Site visit completed. PMF mapping refined which excludes property from PMF. Letter prepared confirming property was removed
6	Alludes to some on-site drainage issues at property. Suggests that the downstream drainage capacity could be the problem.	Letter provided outlining that property level drainage infrastructure is not included in flood model. Lack of downstream drainage capacity forwarded to Council's stormwater section for consideration
7	Considers flood mapping is unrealistic in vicinity of 2 properties. Would like a field visit on-site	Site visit completed. Flood mapping updated. Revised mapping shows one property not impacted during any flood and the edge of the other property only impacted by FPA and PMF
8	Does not believe property is flood liable	Property only impacted during the PMF. A site visit confirmed water is likely to overtop the driveway of an upstream property and spill into backyard. However inundation shallow even during PMF. No changes made
9	States that property is very elevated and inundation is unlikely even during PMF. Requests mapping be updated.	Site visit completed and confirm property was well elevated above adjoining creek. Flood mapping updated
10	Does not see the point of the PMF flood when the 1:100 and FPA exists. Does not understand why their property is identified but neighbouring property is not.	Letter prepared explaining the purpose of the PMF in the flood study (e.g., primarily for sensitive land uses). Site visit completed and confirmed subject property is located adjacent to and lower than roadway sag point while neighbouring property is more elevated. Flood mapping appears realistic. No changes made.
11	Believes the property has never been impacted by flood. Requests site visit and review of flood affectation as it will impact insurance premiums and property value.	Site visit completed and confirmed majority of property is elevated. However, front of property adjoining road is lower lying and there is potential for FPA and PMF to extend across front property boundary. Mapping generally seems reasonable, however, some refinement of the mapping was completed to reflect retaining wall not picked up in model
12	Suggests model is not sufficiently detailed for site specific outcomes. Suggests Council should take responsibility for overland flooding remediation works, instead of applying development controls to private landholders. They object to being identified as flood liable unless Council put remediation works in place.	Site visit completed and confirm site grades up rapidly from road frontage. Vegetation likely reducing reliability of LiDAR in this area. Therefore flood mapping refined. FPA and PMF not extend <1m inside of site boundary, therefore, will no longer be identified as a flood control lot
13	Have never experienced flooding on roadway or in house, only across back of property. The previous studies did not identify the property as flood prone, however this one does, what has changed?	Letter prepared explaining that new study is more detailed and include additional overland flow impediment such as buildings and fences which are evident in this area. Only impacted during the PMF. Mapping appears realistic so no changes made
14	Notes that changes to RPAYC Crystal St Carpark and Irrubel Rd kerb and gutter have recently occurred and would not be reflected in LiDAR information. Requests site visit to confirm and mapping to be updated .	Site visit was completed and confirmed new kerb and gutter in Irrubel Road as well as regrading across the RPAYC car park, which would reduce inundation extents across subject properties. Flood mapping updated
15	States that the FPA on the property does not seem correct as the areas affected are elevated and would not allow water to pond. The building is also elevated and would not be impacted. Request a site visit be completed and FPA removed from property.	Site visit completed and confirmed property is unlikely to be impacted during small floods. However, once freeboard is added, it would be sufficient to extend across site boundary (but remain well clear of building). Mapping generally appears to be realistic, however, mapping was refined based on the outcomes of the field visit
16	The site drains in an easterly /south-easterly direction and the ponding shown on the site does not occur. A request to remove the ponding and flood affectation is made.	Site visit completed. Confirmed inundation of site would not occur during more frequent floods. Refinement of FPA was completed to reflect flow obstructions located across adjoining site. However, PMF extent appears realistic as it would be sufficient high to overtop gutter and flow across site.
17	Generally happy with flood mapping extent although inundation extent on eastern side of the existing house is likely overestimated	Site visit completed and flood mapping updated to reduce inundation extent on eastern side of house
18	Extent of inundation in mapping was exaggerated and encouraged Council/CSS to undertake a review of the channel to confirm.	Site visit completed and confirmed that area is significantly vegetated and LiDAR does not reliably reflect existing channel across site. Flood mapping updated
19	Believes that there may be some additional stormwater pits in Trevor Road and Hollywood Rd that are omitted from the model	Site visit completed and confirmed all pits are accounted for in the model