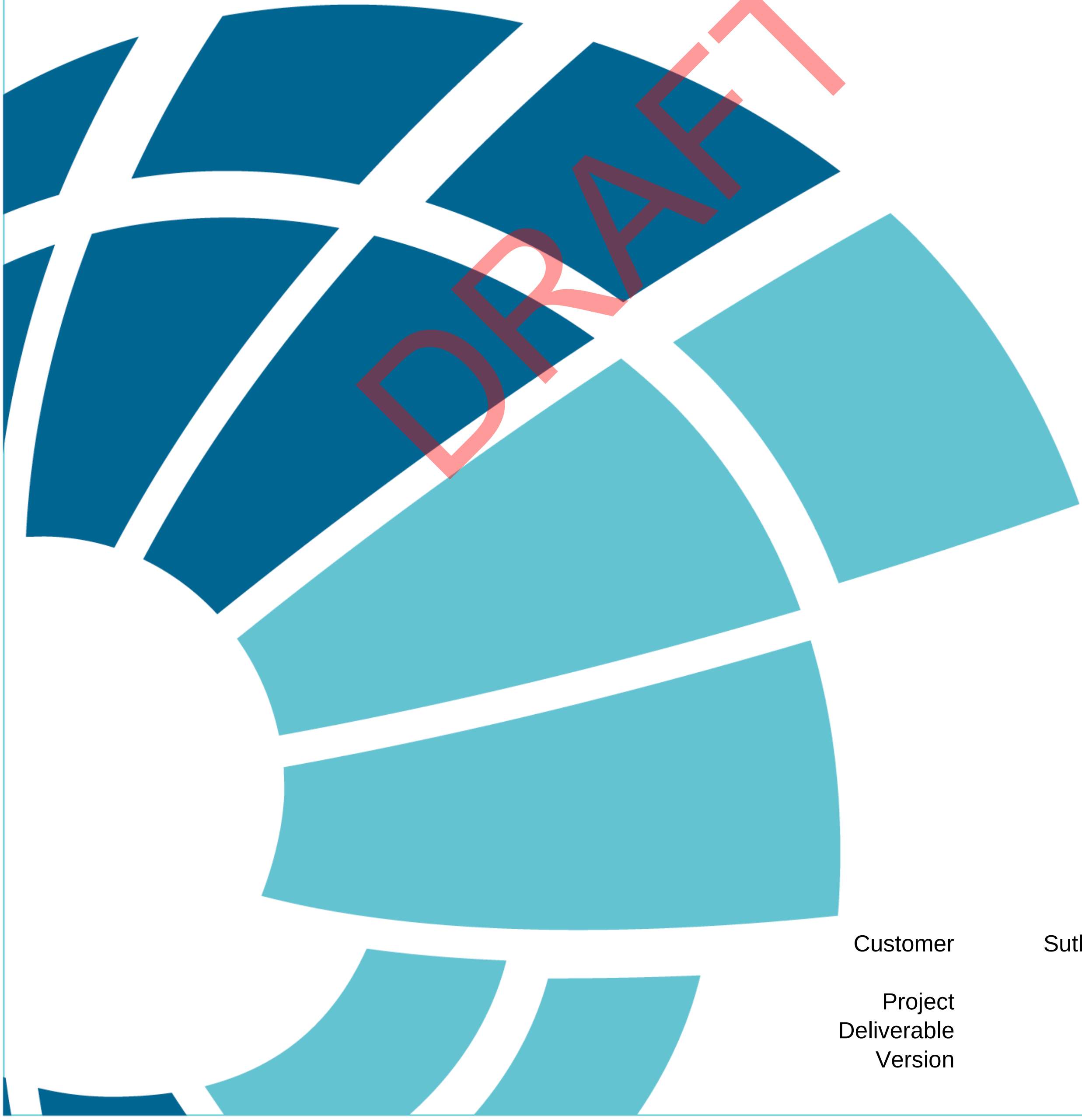
Sutherland Shire Overland Flood Study

Volume 1: Report and Appendices (Draft Report)



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Author	Melissa Adam, Nam Nguyen, Jacquie Hannan
Reviewed By	Jacquie Hannan
Project Manager	Jacquie Hannan

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Sutherland Shire
ssc@ssc.nsw.gov.au
(02) 9710 0333

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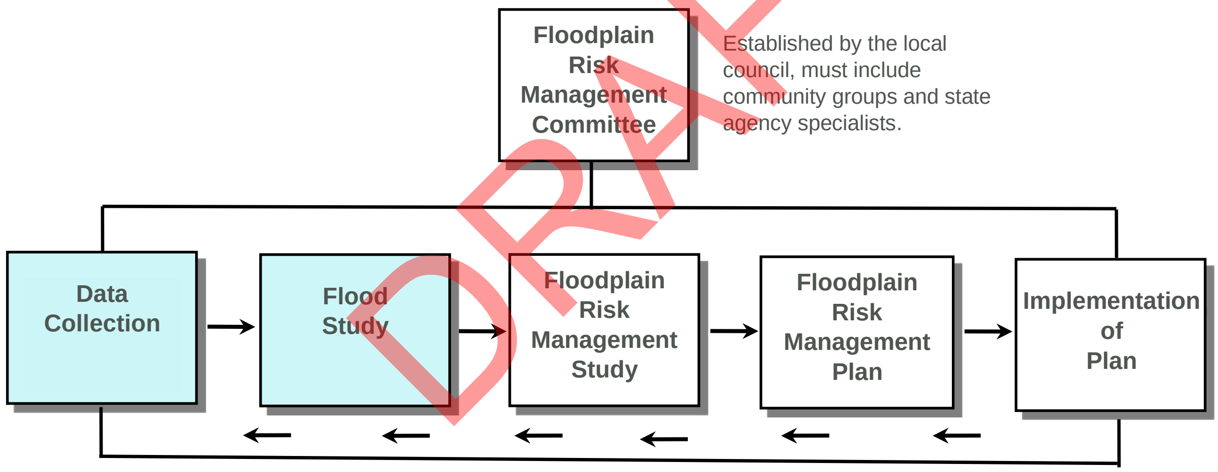
Foreword

Flooding in NSW is managed in accordance with the NSW Government's Flood Prone Land Policy. The Policy is directed towards providing solutions to existing flooding problems in developed areas, understanding potential future impacts on flood risk, and ensuring that new development is compatible with its flood risk exposure and does not create additional flooding problems in other areas.

The NSW Government's 'Floodplain Development Manual' (2005) supports the Policy by defining the responsibilities, roles and processes for the management of flood prone land in NSW. Under the Policy, the management of flood liable land is the responsibility of the local authority, in this case Sutherland Shire Council, with technical and financial support from the NSW Government. This includes the development and implementation of local flood studies and floodplain risk management studies and plans to define and manage flood risk. These are prepared through the staged approach defined by the NSW Floodplain Management process shown in Figure 1.

The Sutherland Shire Overland Flood Study represents Stages 1 and 2 of the process and aims to compile relevant data and provide an understanding of flood behaviour in the study area. It has been undertaken under the NSW Floodplain Management Program, in accordance with the NSW Government's Flood Prone Land Policy, and has received NSW Government financial support.



Compilation of existing data and collection of additional data. Usually undertaken by consultants appointed by the council.	Defines the nature and extent of the flood problem, in technical rather than map form. Usually undertaken by consultants appointed by the council.	Determines options in consideration of social, ecological and economic factors relating to flood risk. Usually undertaken by consultants appointed by the council.	Preferred options publicly exhibited and subject to revision in light of responses. Formally approved by the council after public exhibition and any necessary revisions due to public comments.	Flood, response and property modification measures including mitigation works, planning controls, flood warnings, flood readiness and response plans, environmental rehabilitation, ongoing data collection and monitoring.

Figure 1. Stages of the Floodplain Management Process (Source: 'Floodplain Development Manual' (2005))

Acknowledgements

Sutherland Shire Council has prepared this document with financial assistance from the NSW and Commonwealth Governments through the Natural Disaster Resilience Program. This document does not necessarily represent the opinions of the NSW or Commonwealth Governments.

The assistance of the following parties in providing data, guidance and support to the study is appreciatively acknowledged:

- Sutherland Shire Council
- NSW Department of Planning and Environment
- State Emergency Service
- Community within the study area.

Executive Summary

Background

The Sutherland Shire Overland Flood Study has been undertaken by BMT Commercial Pty Ltd (“BMT) for Sutherland Shire Council (“Council”) to define the overland flood behaviour and associated flood risk within the urban areas of the Sutherland LGA that ultimately drain to the Georges River to the east and west of the Woronora River outlet, Woronora River and Port Hacking (a total catchment area of approximately 253 km^2). The study area and associated major catchments are shown in Figure 2. Please note that this study excludes the Gwawley Bay, Woolooware Bay, Bundeena Creek and Kurnell township catchments previously studied by Council, as well as the eastern portion of the LGA within the Royal National Park that drains east to the Pacific Ocean.

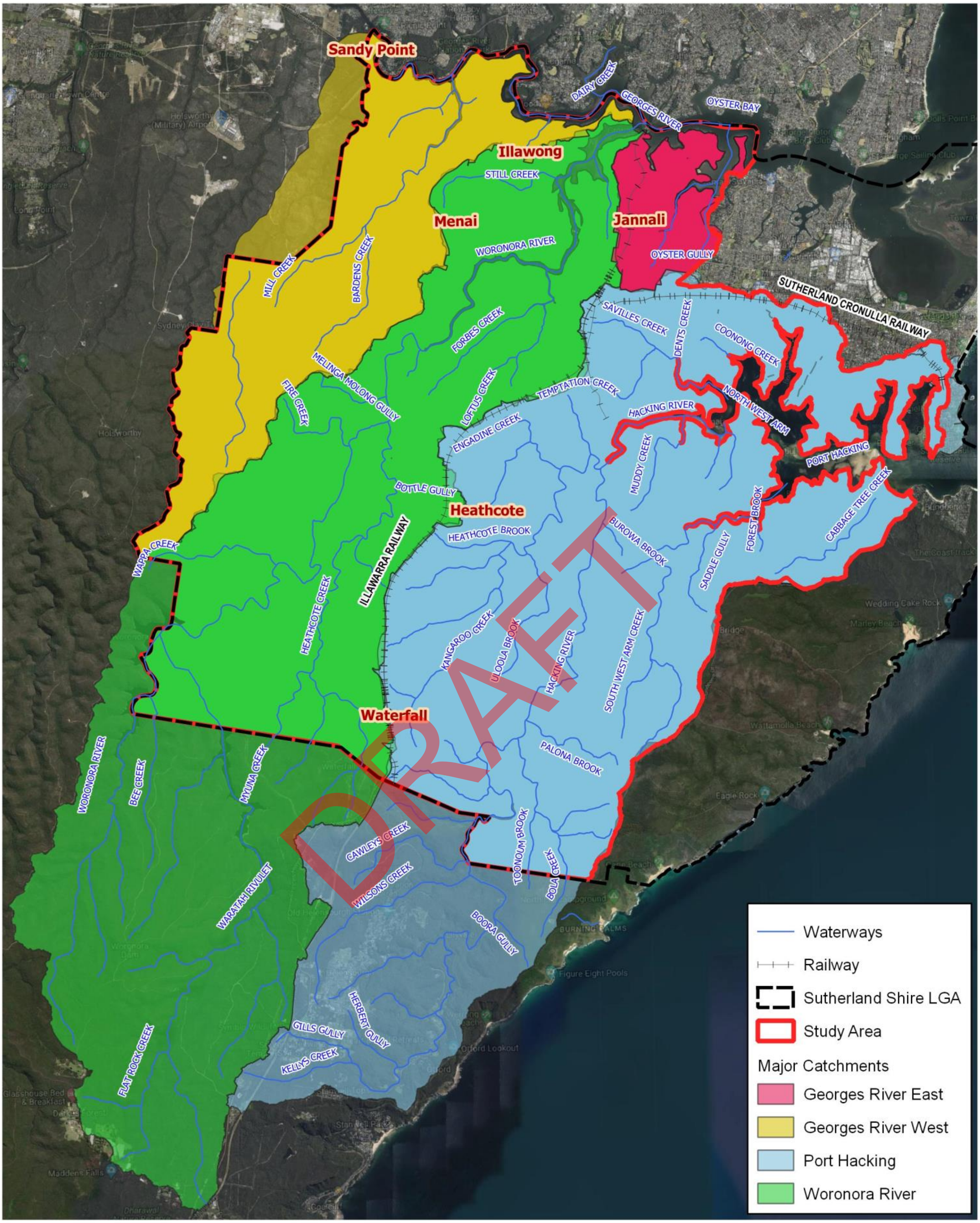
It is noted that the focus of this flood study is local overland flood conditions within the urban areas of the study catchments. The potential interaction of overland flows with receiving watercourses at the outlet of the catchments was also considered, however specific consideration of riverine flooding within the Woronora River and Georges River was beyond the scope of this study.

The outputs of this study will assist in Council’s management of flood risk by identifying and assessing the existing and potential future flood risk (i.e. incorporating climate change), and informing strategic land use policy, flood-related development controls, and flood emergency management planning and response within the study area. It forms an initial stage towards the development of a comprehensive Floodplain Risk Management Study and Plan that will ultimately guide the direction of future floodplain risk management activities across these catchments with the specific aim of reducing the risk to life, property and infrastructure associated with overland flooding.

The project was completed based on best practice guidance and methodologies for flood studies in NSW and in accordance with the project requirements defined by Council and the Department of Planning and Environment (DPE).

The Flood Study is presented in the following two volumes:

- Volume 1: Report and Appendices (this document)
- Volume 2: Flood Mapping.



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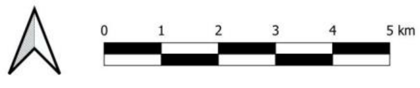

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Community Consultation

Community consultation was completed via a number of different consultation methods at various points within the Flood Study process. This included:

- Study webpage established in September 2021 for the duration of the study and made available via Council's online community engagement portal (Overland Flood Study | Join the Conversation - Sutherland Shire Council (nsw.gov.au)).
- A social media release prepared by Council to advertise the study, community questionnaire and webpage on social media.
- Community questionnaire to gather relevant flood information from the community, including photographs, observed flood depths and descriptions of flood behaviour within the study area. The questionnaire was accessible through Council's online community engagement portal from 15 September to 15 October 2021. Three submissions to the online questionnaire were received.
- Public exhibition.

Overall, these community consultation activities have:

- Informed the community about the preparation of the Flood Study and its likely outcome, as a precursor to the development of a floodplain risk management study and plan.
- Provided an opportunity to collect information on the community's flood experience and their concerns on flooding issues.
- Maintained community engagement with the study and its outcomes.

Model Development and Verification

New hydrologic and hydraulic models were developed to define overland flood behaviour across the study area based on detailed and contemporary topographic data, latest modelling techniques and current best practice guidance (i.e. Australian Rainfall & Runoff 2019 (ARR2019)). This included:

- Hydrologic model of the four (4) major catchments within the study area, i.e. Woronora River, Georges River East, Georges River West and Port Hacking catchments, using the Watershed Bounded Network Model (WBNM) software. The outputs of the hydrologic modelling defined the flow hydrographs inputted into the hydraulic model.
- Two-dimensional (2D) hydraulic models of the urban floodplains within the Woronora River, Georges River East, Georges River West and Port Hacking catchments using the TUFLOW software. The results of these models define design flood conditions such as flood extents, levels, depths and velocities as outputs.

The WBNM and TUFLOW models were verified against available historical flow and flood information for events that occurred in May 2003, April 2015, February 2020 and March 2021 to confirm key model parameters and the capability of the models for producing reliable estimates of flood behaviour. Overall, the outcomes of the model verification indicated that the models provide consistently good outcomes across the four historical floods used for model verification, and provide suitable tools for estimating design flood behaviour across the study area.

Design Flood Simulation and Mapping

The verified WBNM and TUFLOW models were used to simulate a range of design flood magnitudes ranging from more frequent events to very rare events and define overland flood conditions. Specifically, this included the following design floods: 20%, 10% 5%, 2%, 1%, 0.5% and 0.2% Annual Exceedance Probability (AEP) floods and probable maximum flood (PMF).

The design modelling outputs were used to develop a comprehensive set of design flood maps to visualise the potential flood behaviour and associated flood risks across the study area. This includes peak flood level, depth, velocity, hazard and flood function mapping. These mapping outputs are presented in Volume 2: Flood Mapping.

Summary of Flood Behaviour

Overland flow within the study catchments is caused by short duration, intense rainfall events (i.e. high rainfall totals over short time periods typically in the order of hour(s) or less) and when the rainfall within a catchment falls onto impervious or saturated areas, is unable to infiltrate into the ground and instead becomes runoff which contributes to overland flow. This behaviour is most easily observable on “hard surfaces” (e.g. roads, houses and pavements) within the urban environment, where very little rain is able to infiltrate and runoff quickly turns into rapid overland flow or ponding. However, this type of runoff can also occur in more pervious areas, during intense periods of rainfall capable of exceeding the infiltration capacity of the soil.

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

During smaller magnitude floods, such as the 20% AEP to 5% AEP, overland flow flooding in urban areas is typically contained within defined waterways and roadway corridors. However, during larger magnitude events, such as the 2% AEP flood and larger, property inundation occurs in some parts of the study area when overland flow from an upstream catchment area drains through a property to its discharge point or when flow within a roadway overtops the layback / kerb and drains through a property.

Flood modelling results were also reviewed to identify several key flood locations or flooding “hotspots” with a concentration of flood impacted properties or significant inundation as a result of overland flow flooding. Where feasible, future investigations and potential floodplain risk management activities should be aimed at reducing the flood risk in these hotspot locations. It is noted that across the study area, the largest number of hotspots were identified within the Port Hacking catchment (relative to other major catchments within the study area).

Sensitivity and Climate Change Assessment

Sensitivity analyses were undertaken to assess the potential impact of variation in model parameters on predicted design flood behaviour. Sensitivity tests included changes to:

- Hydraulic roughness (Manning’s n value)
- Hydraulic structure blockage (both globally and structure-specific blockage)

The results of the sensitivity assessment indicated that flood levels were most sensitive to changes in hydraulic structure blockage.

The potential impacts of climate change, including increased rainfall intensity and sea level rise, were also assessed. The results of the climate change assessment indicate that climate change does have the potential to increase the existing flood risk.

Whilst it is acknowledged that there is still considerable uncertainty associated with climate change predictions and current information suggests rainfall intensity is not predicted to reach the upper limits considered as part of this study until at least approximately 2090, potential changes in climate conditions should be closely monitored as there is potential for impacts to overland flood levels across the urban floodplain.

Information to Support Decisions

Flood planning and emergency response information, including definition of the Flood Planning Area (FPA), Flood Control Lots, Flood Risk Precincts and Flood Emergency Response Classifications (FERCs), was also be developed based on the predicted flood characteristics and will aid in Council's decision making within the floodplain. These mapping outputs are presented in Volume 2: Flood Mapping.

Notably, the derivation of a FPA and identification of flood control lots has been undertaken based on a methodology determined and agreed with Council (refer Sections 9.2 and 9.3), noting that the FPA was based on the application of a flood planning level (FPL) equivalent to the 1% AEP flood level plus 0.5 m freeboard. This has identified properties within Council's GIS cadastral lot database that are:

- FPA and PMF tagged
- PMF tagged only (i.e. within the PMF extent but beyond the FPA extent)

The number of flood control lots identified in the study area is listed in Table 1.

Table 1. Flood Control Lots within the Study Area

Flood Control Lot Tagging	Number of Lots Tagged (Total Cadastral Lots within Modelled Extent = 48,612)
FPA	6,886
PMF	9,741

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1 Introduction

1.1 Background

The Sutherland Shire is a 370km^2 Local Government Area (LGA) on the southern extent of the Sydney Metropolitan Area. A number of major waterways traverse or bound the LGA, including the Georges River, Woronora River and Port Hacking.

Following severe flooding in 2003, Sutherland Shire Council ("Council") completed an initial, assessment of major overland flooding across the LGA, as documented in the 'Initial Subjective Assessment of Major Flooding' (Bewsher, 2004). The study recommended a prioritised action plan for future catchment-scale flood studies and floodplain management studies. Since 2012, Council have completed overland flood studies and floodplain risk management studies and plans for the four highest priority catchments determined by the Bewsher (2004), including the Woolooware Bay, Gwawley Bay, Bundeena Creek and Kurnell township catchments. However, Council has limited knowledge of overland flow conditions and flood risk across the remaining areas of the LGA.

Accordingly, Council engaged BMT Commercial Australia Pty Ltd ("BMT") to undertake the Sutherland Shire Overland Flood Study to develop catchment-wide flood models and define the historical, existing and future overland flood risk across the urban areas of the LGA that have not been included in recent detailed flood studies. It forms an initial stage towards the development of a comprehensive Floodplain Risk Management Study and Plan that will ultimately guide the direction of future floodplain risk management activities across these portions of the LGA.

The outcomes of this overland flood study will enable the identification of the relative magnitude of flood-related problems across the study area and provide Council with a basis to prioritise floodplain risk management activities. The improved definition of flood behaviour will also aid in Council's management of flood risk, including flood related land use planning and development controls, and emergency management within the study area.

1.2 Study Area

The study covers a total area of approximately 253 km^2 within the Sutherland Shire LGA and includes the catchments that ultimately drain to the Georges River (to the east and west of the Woronora River outlet), Woronora River and Port Hacking. The study area excludes the Gwawley Bay, Woolooware Bay, Bundeena Creek and Kurnell township catchments which have previously been studied by Council, as well as the eastern portion of the LGA within the Royal National Park that drains east to the Pacific Ocean. The four major catchments that form the study area are shown in Figure 1.1and details of these catchments are provided in Table 1.1.

Table 1.1 Major Catchments within the Study Area

Major Catchment	Total Area (km^2)	Area within the LGA (km^2)	Sub-catchments
Georges River East	8.9	8.9	Coronation Bay, Oyster Bay, Oyster Creek and Carina Bay
Georges River West	49.9	41.4	Great Moon Bay and Mill Creek

Major Catchment	Total Area (km^2)	Area within the LGA (km^2)	Sub-catchments
Woronora River	160.5	83.4	Bonnet Bay, Mandowie Creek, Forbes Creek, Loftus Creek, Still Creek, Audrey Bay, Bottle Creek and Crescent Creek
Port Hacking	161.3	119.4	Hacking River, Savilles Creek, Dents Creek, Ewey Creek, North West Arm, Kangaroo Creek, Gymea Bay, Yowie Bay, Turriell Bay, Burraneer Bay, Gunnamatta Bay and South West Arm

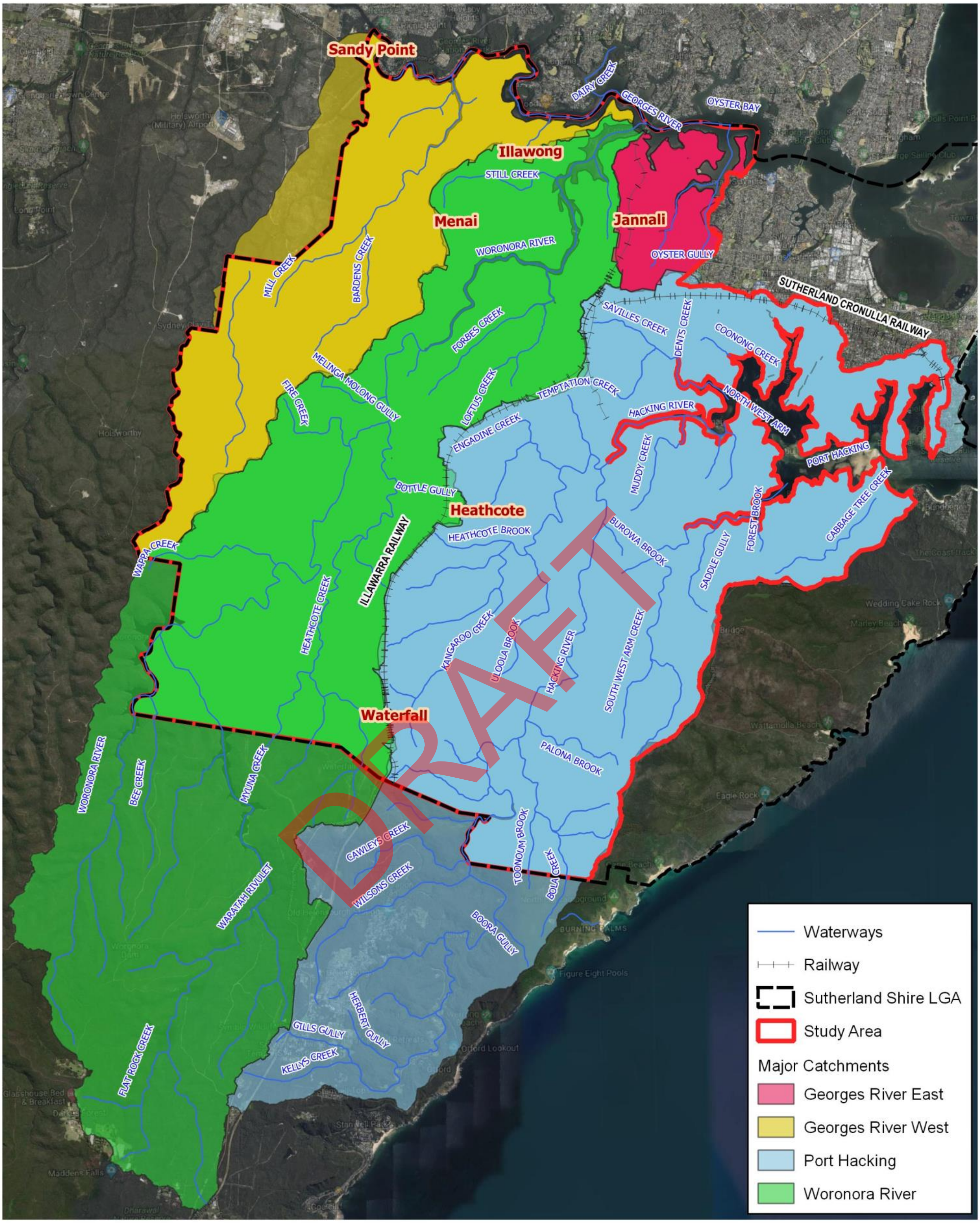
The Port Hacking, Woronora River and Georges River West catchments cover relatively large areas that originate in the heavily vegetated areas of the Royal National Park and/or Heathcote National Park and typically drain from south to north towards these major watercourses. The Georges River East catchment is significantly smaller than the other catchments and drains the urban areas of Jannali, Como, Oyster Bay and Kareela.

The lower portions of the Port Hacking, Woronora River and Georges River West catchments, as well as the entire Georges River East catchment, predominantly comprise urbanised areas consisting of a mix of residential, commercial and industrial properties. There are also several open spaces (e.g. Kareela Golf Course, Kareela Playing Fields, Como Oval and Como Pleasure Grounds) particularly in the lower reaches of the Georges River East catchment. The study area is traversed by major transport routes including the Princes Highway, Kingsway, The Boulevarde and Illawarra Railway Line (refer Figure 1.1).

The urban areas of the catchments are typically drained by a Council-owned sub-surface stormwater network that either connects into a series of open creeks and waterways that ultimately drain to the major receiving watercourses of the Georges River, Woronora River and Port Hacking or discharges directly to these major watercourses. During periods of heavy rainfall, there is potential for the capacity of the stormwater system to be exceeded. In these circumstances, the excess water travels overland and may result in inundation of roadways and adjoining properties. There is also potential for floodwaters to overtop the banks of the creek network and inundate the adjoining floodplain where open watercourse sections drain through urban areas. For this study, the definition of flood behaviour is primarily focussed on the developed areas within the study extent, which predominantly comprise highly urbanised residential, commercial and industrial areas with scattered open space.

During major flooding, the lower parts of the catchments can also be inundated by backwater from the Georges River, Woronora River and Port Hacking. Elevated water levels in these watercourses also inhibits drainage of the study area following a major flood event. Although flooding of these watercourses and its potential to interact with floodwaters from the local catchments was considered as part of the study, riverine flooding and any tidal inundation of watercourses and overland urban areas is not the focus of the study.

Flooding in the area has occurred in the past, including in 1990, 1998, 2003, 2013, 2015 and 2016. Most recently, heavy and intense rainfall in February 2020 and March 2021 resulted in flooding in urbanised areas.



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1.3 Objectives and Scope of this Study

The primary objective of the Sutherland Shire Overland Flood Study is to define overland flood behaviour across the urbanised portions of the study area under historical, existing and future conditions (incorporating potential impacts of climate change). The study is focussed on local overland flood conditions within the urban areas of the study catchments. The potential interaction of overland flows with receiving watercourses at the outlet of the catchments was also considered, however it is noted that the specific consideration of riverine flooding within the Woronora River and Georges River was beyond the scope of this study.

Overland flooding typically occurs during short duration, intense rainfall events when:

- Rainfall is converted to overland runoff and runs across the local catchment before entering a watercourse, channel or stormwater system.
- The capacity of local watercourses, channels and stormwater networks are exceeded by local catchment runoff and flow is discharged from these systems as floodwaters.

Property inundation may occur as a result of the above mechanisms when overland flow from an upstream catchment area drains through a property on its way to its discharge point or when flow within a roadway overtops the layback / kerb and drains through a property.

An improved appreciation of overland flood behaviour will aid in Council's management of flood risk, including informing flood impact assessment, strategic land use, flood-related development control, stormwater management and flood emergency response. It will also enable the identification of flooding "hot spots" and the relative magnitude of flood-related problems to provide Council with a basis upon which to undertake a prioritised program of future flood risk management activities.

The general approach and methodology used to achieve the study objectives align with best practice guidance and methodologies for flood studies in NSW and in accordance with the requirements defined by Council and the Department of Planning and Environment (DPE) for this project. Specifically, this study includes:

- compilation and review of relevant data, including site inspections
- development of computer based hydrologic and hydraulic models
- calibration and validation of the computer models to assess their ability to reliably reproduce historical flood behaviour
- simulation of design 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% Annual Exceedance Probability (AEP) events and the Probable Maximum Flood (PMF) for existing topographic and development conditions
- determination of design flood conditions within the study area
- development of a comprehensive set of design flood maps (e.g. peak flood level, depth, velocity, hazard and flood function mapping) based on the outputs of the modelling
- assessment of potential climate change impacts
- assessment of the sensitivity of the flood models to changes in parameters
- identification of flooding "hot spots" and prioritised list of areas for future, detailed flood studies
- preparation of information to assist in future floodplain management, land use planning and emergency response, including:
  - properties impacted by flooding

  - Flood Planning Area (FPA) for application of land use development controls
  - Flood Risk Precincts to guide land use planning for future development
  - SES Flood Emergency Response Classification of Communities
  - identification of flooding “hot spots” and prioritised list of areas for future, detailed flood studies.

This flood study has been completed in conjunction with representatives from both Council and NSW Department of Planning and Environment (DPE). All stages of the study have been overseen by the Floodplain Management Committee, which includes representatives from the NSW Department of Planning and Environment, State Emergency Service (SES), local community representatives, Councillors and Council staff.

1.4 Limitations and Assumptions

Please note the following limitations and assumption that apply to this flood study:

- This is a catchment-wide flood study that has been undertaken to determine the flood risk across the study area.
- The level of accuracy associated with available data inputs and modelling outputs is considered adequate for this flood study.
- The flood models developed for this flood study provide a mechanism that can be:
  - updated with more contemporary data should it become available in the future (e.g. stormwater network data, infrastructure and development details, etc)
  - modified to include site-specific data (e.g. detailed site survey) should more localised and/or detailed flood risk information be required as part of future studies (e.g. site-specific flood assessment, feasibility assessment for mitigation works, etc).
- Whilst this study considers the potential interaction of overland flows with receiving watercourses at the outlet of the catchments, specific consideration of riverine flooding within the Woronora River and Georges River was beyond the scope of this flood study.
- In preparing this report, BMT has relied upon and presumed accurate, information (or absence thereof) provided by Sutherland Shire Council. Except as otherwise stated in this report, BMT has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete, then it is possible that our observations and conclusions as expressed in this report may change.

1.5 Report Structure

This report comprises two volumes:

- Volume 1 (this document) contains the report text and appendices including:
  - Section 1 provides background to the study, describes the study area, and outlines the study objectives and limitations
  - Section 2 details the data collection and review
  - Section 3 describes the community consultation process
  - Section 4 details the development of the hydrologic and hydraulic models
  - Section 5 details the model verification process and outcomes
  - Section 6 details the design flood modelling approach
  - Section 7 details the design flood results

  - Section 8 details the sensitivity and climate change assessment
  - Section 9 provides information to support decision making, including flood planning and emergency response outputs
  - Section 10 provides the study conclusions and recommendations
  - Section 11 provides the list of references used in the study
  - Section 12 provides a glossary of key terms used within this report
- Volume 2 contains all flood mapping for this study.

[This report provides details of work completed to date. Any methodology and findings contained herein represent draft results and are not final.]

2 Data Collection and Review

2.1 Overview

The initial stage in this flood study involved the collection and review of relevant data, including:

- Previous studies (Section 2.2)
- GIS data (Section 2.3)
- Hydrologic data (Section 2.4)
- Topographic data (Section 2.5)
- Stormwater network data (Section 2.6)
- Land-use planning information (Section 2.7)
- Building footprints (Section 2.8)
- Engineering plans (Section 2.8)
- Historical flood information (Section 2.10)
- Site inspections (Section Figure 1.1).

A description of each dataset and synopsis of its relevance to the current study is provided below.

2.2 Previous Studies

2.2.1 Woronora River Flood Study (Public Works, 1991)

The ’Woronora River Flood Study’ was undertaken to determine the design flood levels for the Woronora River for the 1%, 2% and 5% AEP events, as well as an extreme flood.

The study included the development of a RORB hydrologic model for the 174 km^2 catchment draining to the Georges River confluence and considered the impact of the Woronora Dam, which controls runoff from a 78.2 km^2 area within the catchment. A MIKE-11 one-dimensional (1D) unsteady flow hydraulic model stretching from the Needles to the Georges River confluence, and covering a river length of approximately 10.8 km, was developed to define flood conditions within the Woronora River. The models were calibrated using data from the April 1988 event and verified against historical flood data from events in 1933, 1956, 1965, 1969 and 1974.

Design flood modelling was undertaken using the calibrated models and in accordance with Australian Rainfall and Runoff 1987 (AR&R1987) guidelines. Rainfall estimates for the extreme event were obtained from the Bureau of Meteorology's Bulletin 51. The study also included a sensitivity analysis for the 1% AEP flood to assess the potential impact of increased river channel roughness, variations in downstream Georges River levels and higher Woronora River bed levels.

Peak design flood levels were extracted from the ‘Woronora River Flood Study’ (Public Works, 1991) at each MIKE-11 cross-section and used to inform the downstream boundary conditions for the Woronora River catchment as part of this study. This is discussed further in Section 6.5.1.

2.2.2 Initial Subjective Assessment of Major Flooding (Bewsher, 2004)

Bewsher Consulting was commissioned by Sutherland Shire Council to undertake an initial subjective assessment of major flooding in the Sutherland Shire LGA. The aim of the study was to strategically assess 82 major drainage systems and 19 waterways, and to present a prioritised action plan to investigate and manage these risks through future flood studies and floodplain risk management studies/plans. The study adopted the following approach:

- Preliminary hydrologic and hydraulic analyses involving the preparation of 1% AEP and ‘extreme flood’ flows using the Urban Rational Method in accordance with Australian Rainfall and Runoff 1987 (adapted for Sutherland Shire Council in the SSC Urban Drainage Design Manual). Areas and extents of inundation were estimated by application of the open channel flow equation to cross sections derived from Council data.
- Interrogation of Council’s Customer Response Management System (CRMS) database, which contained 730 flood complaint entries, primarily relating to 13 May 2003 storm event.
- Review of expert knowledge of flood risk in the area.

About 4,000 properties within the LGA (and 2,500 within this flood study’s extent) were identified as being impacted in the 1% AEP flood. The “top 10” priorities areas for further, more detailed flood risk studies were determined as:

1. Gwawley Bay
2. Kurnell township
3. Woolooware Bay catchment (referred to in this report as the Botany Bay catchment)
4. Bundeena Creek
5. Oyster Creek
6. Dents Creek (and lower Savilles Creek)
7. Ewey Creek
8. Unnamed Woronora River tributary (Sutherland/Woronora)
9. Kareela Creek
10. Carina Creek.

It should be noted that flood studies and floodplain risk management studies were completed between 2012 and 2021 (or are still currently underway) for the top four (4) identified priority areas.

Earlier studies were also completed for the Dents Creek, Ewey Creek and Oyster Creek catchments between 2001 and 2010 (refer Sections 2.2.3 to 2.2.8). These studies were based on consideration of riverine flooding and are based on now outdated modelling methodologies (e.g. 1D hydraulic modelling of watercourses and floodplains) and industry guidance (e.g. AR&R1987).

Therefore, this study considers overland flooding within the remaining six higher priority areas, as well as other lower priority areas that were identified through the initial subjective assessment and for which recent detailed studies have not been completed.

2.2.3 Dents Creek Flood Study (Sutherland Shire Council, 2001)

The ‘Dents Creek Flood Study’ was undertaken by Council to determine the flood behaviour along the 1.4 km section of Dents Creek between President Avenue (Gymea) and the confluence with Savilles Creek. The study included the development of a HEC-RAS (1D) hydraulic model of the creek that was used to define the flood characteristics for the 20%, 5% and 1% AEP events, as well as the PMF.

The findings of the study identified 111 properties inundated during the PMF and 92 properties impacted by the 1% AEP flood. It recommended that the flood study be extended upstream along

Savilles Creek and downstream along North West Arm to identify any additional properties that may be affected by flooding along these adjoining reaches of Dents Creek (refer Section 2.2.4).

The HEC-RAS model from this study was provided by Council. Cross-sections and associated creek invert levels were extracted from this model for use in this study. Hydraulic structure details for the Dents Creek crossings at President Avenue, Rulwalla Place and Avenel Place to No. 60 North West Arm Road were also extracted to define the size and configuration of these structures.

2.2.4 Dents Creek (North West Arm) Flood Study (Sutherland Shire Council, 2004)

This study was undertaken by Council as an extension to the earlier ‘Dents Creek Flood Study’ (2001). The HEC-RAS model developed in 2001 was extended to also include the 2.4 km section of North West Arm from the confluence of Dents Creek and Savilles Creek downstream to Fernhill Place (Grays Point). The extended HEC-RAS model was used to define the flood characteristics for the 20%, 5% and 1% AEP floods, as well as the PMF. Flood risk mapping (low, medium and high) was also prepared.

The HEC-RAS model from this study was provided by Council. Cross-sections and associated creek invert levels were extracted from this model for use in this study. Hydraulic structure details for the North West Arm Road at Savilles Creek was also extracted to define the size and configuration of this structure.

2.2.5 Ewey Creek Flood Study (Sutherland Shire Council, 2004)

The ‘Ewey Creek Flood Study’ was undertaken by Council to determine the flood behaviour along the 2.3 km length of Ewey Creek from Manchester Road (Gymea) to the western head of Yowie Bay. The study included the development of a HEC-RAS (1D) hydraulic model of the creek that was used to define flood characteristics for a range of flood events up to and including the PMF. The findings of the study identified 189 properties inundated by the PMF and 99 properties with the Flood Planning Area (FPA), as defined by a Flood Planning Level (FPL) of the 1% AEP flood level plus 0.5 m freeboard.

The HEC-RAS model from this study was provided by Council. Cross-sections and associated creek invert levels were extracted from this model for use in this study.

2.2.6 Oyster Creek Flood Study (Webb, McKeown & Associates, 2005)

Webb, McKeown & Associates completed the ‘Oyster Creek Flood Study’ for Council in 2005. Oyster Creek has a catchment area of approximately 3.5 km^2 draining to Oyster Bay on the Georges River and 2.4 km^2 draining to Bates Drive. The catchment lies within the suburbs of Sutherland, Kirrawee, Jannali, Kareela and Oyster Bay.

Flooding of roads and residential properties between Box Road and Bates Drive had occurred in the past. Flooding within the Oyster Creek catchment may occur as a result of a number of flood mechanisms (occurring in isolation, or in combination) including:

- Elevated water levels in Oyster Bay due to persistent rain over the entire Georges River catchment and an elevated ocean level.
- Elevated water levels within Oyster Creek as a result of intense rain over the Oyster Creek catchment. The levels in the creek may also be affected by constrictions (e.g. culverts, blockages, vegetation).
- Local runoff over a small area accumulating (ponding) in low spots (such as may occur in Buderim Avenue). Generally, this occurs in areas which are relatively flat with little potential for drainage. This type of flooding may be exacerbated by inadequate local drainage provisions and elevated water levels at the downstream outlet of the urban drainage system. Detailed analysis of this type of flooding was outside the scope of Webb, McKeown & Associates (2005).

A WBNM hydrologic model was established to represent the entire catchment draining to Oyster Bay and the Georges River. A MIKE-11 (1D) hydraulic model was developed to represent the creek from the downstream limit of Oyster Bay to the upstream limit about 170 m upstream of Box Road (i.e. 1.9 km upstream of Oyster Bay). Both models were calibrated (where possible) to historical flood data and subsequently used to determine design flood levels.

The WBNM and MIKE-11 models were used to simulate the 10%, 5%, 2%, 1%, 0.2% AEP and PMF events in order to define the flood behaviour within the creek and adjoining floodplain. Hydraulic and hazard categorisation was also defined for the 1% AEP flood.

2.2.7 Oyster Creek Floodplain Risk Management Study (Webb, McKeown & Associates, 2005)

This study was undertaken by Webb, McKeown & Associates on behalf of Council to identify and assess floodplain management measures for the Oyster Creek floodplain.

Based on the results of the ‘Oyster Creek Flood Study’ (Webb, McKeown & Associates, 2005), the floodplain management study determined that up to 21 buildings within the catchment would be inundated under PMF conditions. The Average Annual Damages (AAD) were estimated to be $125,000 (in 2005 dollars), assuming 100% blockage of the Bates Drive and Box Road culverts.

A list of possible floodplain risk management measures was initially developed for consideration, and these measures were then assessed in terms of the associated reduction in social, ecological, environmental, cultural and economic impacts. Structural measures that were considered included channel widening, vegetation clearing, dredging of creek channel, levees, debris structure to mitigate culvert blockage and slot at Bates Drive culverts.

The relatively small number of buildings inundated in the 1% AEP event (i.e. 13 properties assuming 100% blockage, or only seven properties if 0% blockage of the Bates Drive and Box Road culverts was assumed), meant that higher-cost management measures could not be supported purely on economic grounds. The most cost effective measure was determined to be flood proofing (if possible) for individual buildings upon renovation or re-building of structures.

However, the outcomes of study’s community consultation activities indicated that residents considered that some flood modification works should be undertaken even if not supported by benefit/cost analysis or normal Government funding requirements for floodplain management. This included:

- measures to reduce blockage of the Bates Drive culverts
- stream clearing, if only for aesthetic and social reasons
- dredging
- construction of a slot in the base of the Bates Drive culverts
- reactivation of the Management Plan for the creek.

2.2.8 Oyster Creek Revised Flood Study (WMAwater, 2010)

The ‘Oyster Creek Revised Flood Study’ was completed in 2010 to update the design flood data to reflect the management works undertaken by Sutherland Shire Council following the ‘Oyster Creek Floodplain Risk Management Plan’ (WMAwater, 2005).

Detailed survey was undertaken and indicated the extent of the floodplain works and altered conditions within the catchment. The MIKE-11 model developed for the previous Oyster Creek studies was updated to include the following completed works:

- construction of a debris deflector at the Box Road footbridge

- stream clearing immediately downstream of the footbridge
- creek widening and bank stabilisation between the Box Road footbridge and Bates Drive
- installation of a flood marker in Carvers Road Reserve.

This MIKE-11 model was used to simulate the 10%, 5%, 2%, 1%, 0.2% AEP and PMF events, and the impacts of these works on the previously defined flood conditions was established. Overall, the study found that the implemented mitigation works had reduced the 1% AEP flood levels by up to 0.5 m, resulting in lower FPLs in some areas and reduced future flood damages.

As this study represents the most recent flood-related investigation completed for Oyster Creek, the detailed channel and floodplain survey from this study was provided by Council and used to define the topography across relevant areas of the floodplain, as well as channel invert elevations for this overland flood study. Structure details were also extracted from the MIKE-11 model for the Bates Drive and Box Road culverts.

2.2.9 Lower Georges River Floodplain Risk Management Study and Plan (Bewsher Consulting, 2011)

In 2011, Bewsher Consulting completed the ‘Lower Georges River Floodplain Risk Management Study’. This study was an update of the earlier ‘Georges River Floodplain Risk Management Study and Plan’ (Bewsher Consulting, 2004) and covered an extended reach of the river. Only riverine flooding originating from the Georges River was considered. The study area included floodplain areas of the Georges River in the Liverpool City, Fairfield City, Bankstown and Sutherland Shire LGAs.

A MIKE-11 computer model of the Georges River, from Botany Bay to upstream of Liverpool, was established as part of the study. This includes the Georges River floodplain downstream of Alfords Point Bridge, including the Woronora River and foreshore areas of the Georges River catchments within the extent of the Sutherland Shire Overland Flood Study. The MIKE-11 model was used to verify results from the previous study and to test the impact of development and other works that had occurred in the floodplain since the mid-1980s. The MIKE-11 model was used to define flood behaviour, including flow rates, flood levels, velocities and flood hazard information.

As there had been no previous studies to define design flood levels in the Georges River for the area downstream of Picnic Point, the results of the MIKE-11 model provide the only flood level estimates for the Georges River within the Sutherland Shire LGA. Flooding in these lower reaches of the Georges River result from high river flows and elevated water levels in Botany Bay arising from storm tide conditions.

Modelling of flood conditions in the lower river assumed that both the 1% AEP river flows and 5% AEP river flows coincide with a mean high water level in Botany Bay. However, 5% AEP and 1% AEP storm tides of 1.5 and 1.7 mAHD were adopted as the maximum peak flood levels where these tidal levels exceeded predicted riverine flood levels. The PMF assessment assumed that PMF river flows coincide with an extreme storm tide level (assumed peak tidal level of 2.0 mAHD). Peak design flood levels were extracted from the ‘Georges River Floodplain Risk Management Study & Plan’ (Bewsher Consulting, 2011) and used to inform the downstream boundary conditions for the Georges River (east and west) catchments (discussion further in Section 6.5.1). These peak flood levels are listed in Table 2.1.

The study estimated that 44 residential properties (and 18 homes) would be flooded within the Sutherland Shire LGA in the 1% AEP flood, with these properties located in Sandy Point and Illawong. No industrial/commercial properties were predicted to be impacted.

Table 2.1 Georges River Flood Levels (Source: 'Georges River Floodplain Risk Management Study & Plan' (2004))

Location	5% AEP Flood Level (mAHD)	1% AEP Flood Level (mAHD)
Alfords Point	2.1	2.7
Alfords Point Bridge	2.05	2.6
Moon Point	1.8	2.3
Illawong	1.6	2.05
Confluence with Woronora River	1.5	1.8
Como Railway Bridge	1.5	1.7
Captain Cook Bridge (Taren Point)	1.5	1.7

2.3 Geographic Information System (GIS) Data

A number of digital Geographic Information System (GIS) layers were also provided by Council to assist with this flood study, including:

- study area extent
- cadastral lot boundaries
- locations of community hall, schools and childcare centres
- drainage infrastructure including pits and pipes
- drainage catchments
- emergency management data including evacuation centres, vulnerable assets, sea level rise for 2100
- environmental management including watercourses assessment lines
- current flood risk mapping
- roadway data (used for roadway labels)
- kerb layer
- cycle facilities (i.e. cycle paths)
- locations and details of water quality devices and catchments.

In general, the GIS layers provide a suitable basis for preparing report figures and informing the development of hydrologic and hydraulic models. Further details on the outcomes of the review of the stormwater drainage network layers is provided in Section 2.6.

2.4 Hydrologic Data

2.4.1 Rainfall Data

Rainfall data provides a high-quality dataset for use in the model calibration and validation process. It is used to define when historical rainfall events occurred, as well as the temporal (i.e. time varying) patterns and rainfall depths for these events. The Bureau of Meteorology (BoM), Water NSW (WNSW) and Sydney Water (SW) operate an extensive network of rainfall gauges across the east coast of NSW and within the greater Sydney Metropolitan Area. The two different rainfall gauge data types available are:

- Daily rainfall data recorded over a 24 hour period to 9:00 am which provides an overview of the total amount of rainfall that occurred. There are 4 daily gauges within the catchment and an additional 29 daily rainfall gauges surrounding the catchment (only 19 are currently operational).
- Sub-daily rainfall data (continuous or pluviograph) recorded in small depth and time increments (less than 1 mm and usually a 5/6 min time increments). There are 7 sub-daily gauges within the catchment and additional sub-daily gauges located within a 10 km radius from the catchment boundary to the north and west and 14 km radius to the south (where rainfall gauges are comparatively sparser outside the Sydney Metropolitan Area). Of the 25 sub-daily gauges, 23 are currently operational.

The full list of rainfall stations and their respective period of record are provided in Table 2.2 and Table 2.3. The locations of the closest gauges are shown in Figure 2.1.

For overland catchments, the duration of rainfall that produces overland flooding is typically less than 6 hours and therefore often unable to be captured by a sub-daily gauge. Overall, there is sufficient gauges both within the catchment and surrounding areas to enable a reasonable representation of rainfall and historical temporal patterns across the study area.

Table 2.2 Daily Rainfall Gauges in the Vicinity of the Study Area

Station No.	Station Name	Record Period	Authority	Distance from catchment centroid (km)
66078	Lucas Heights (ANSTO)	1969 – current	BOM	4.6
66176	Audley (Royal National Park)	1899 - current	BOM	5.0
68263	Holsworthy Defence AWS	1968 - current	BOM	10.1
66204	Oyster Bay	1929 - current	BOM	11.0
66161	Holsworthy Aerodrome AWS	1904 - current	BOM	11.7
68160	Campbelltown	1995 - current	BOM	12.7
66014	Cronulla South Bowling Club	1982 - 2014	BOM	13.1
66181	Oatley (Woronora Parade)	1998 - current	BOM	13.5
66148	Peakhurst Golf Club	1958 - current	BOM	13.7
67117	Holsworthy Control Range	1941 - 2013	BOM	14.1
66058	Sans Souci (Public School)	1942 - 2015	BOM	14.9
68231	Ruse (Denison Street)	1998 - 2014	BOM	15.1
66054	Revesby (Paten Street)	2000 - current	BOM	15.3
66190	Ingleburn (Sackville Street)	1956 - 2010	BOM	15.7
66168	Milperra Bridge	1895 - 2015	BOM	17.5
68024	Darkes Forest (Kintyre)	1952 - 2016	BOM	18.2
66137	Bankstown Airport AWS	1992 - 2019	BOM	18.7

Station No.	Station Name	Record Period	Authority	Distance from catchment centroid (km)
66072	Kurnell (Caltex Oil Refinery)	1894 - 2012	BOM	20.2
68159	Wedderburn (Booalbyn)	1992 - 2011	BOM	20.7
67020	Liverpool	1926 - 2017	BOM	21.5
66037	Sydney Airport AMO	1995 - 2011	BOM	21.5
66050	Potts Hill Reservoir	1894 - current	BOM	21.8
66036	Marrickville Golf Club	1964 - current	BOM	22.0
66194	Canterbury Racecourse AWS	1974 - current	BOM	22.0
66070	Strathfield Golf Club	1988 - current	BOM	22.9
66164	Rookwood (Hawthorne Ave)	1963 - current	BOM	23.5
66051	Little Bay	1966 - current	BOM	24.9
66000	Ashfield Bowling Club	2007 - current	BOM	25.0
68216	Menangle Bridge (Nepean River)	2007 - current	BOM	25.2
66195	Sydney Olympic Park	1992 - current	BOM	26.3
68101	Woonona (Popes Rd)	1962 - 2016	BOM	30.3
68200	Douglas Park (St Marys Towers)	2001 - 2012	BOM	30.9
68228	Bellambi AWS	1981 - current	BOM	32.4

Table 2.3 Sub-Daily Rainfall Gauges in the Vicinity of the Study Area

Station No.	Station Name	Record Period	Authority	Distance from catchment centroid (km)
566093	Engadine Bowling Club	1991 - current	SW	2.6
566056	Yarrawarrah	1983 - current	SW	4.0
566075	Barden Ridge Dam	2012 - current	SW	6.8
566175	Menai Reservoir (Replacement)	2014 - current	SW	7.0
566092	Sutherland Bowling Club	1991 - current	SW	9.2
566174	Helensburgh WS0049	2014 - current	SW	11.3
566098	Caringbah Bowling Club	1991 - current	SW	13.5
566031	Revesby Bowling Club	2005 - current	SW	14.5
566047	Mortdale Bowling Club	1977 - current	SW	14.6
566072	Kyle Bay Bowling Club	2010 - current	SW	14.9
566078	South Cronulla Bowling Cl	1990 - current	SW	15.8
567078	Glenfield WWTP	N/A - current	SW	16.1

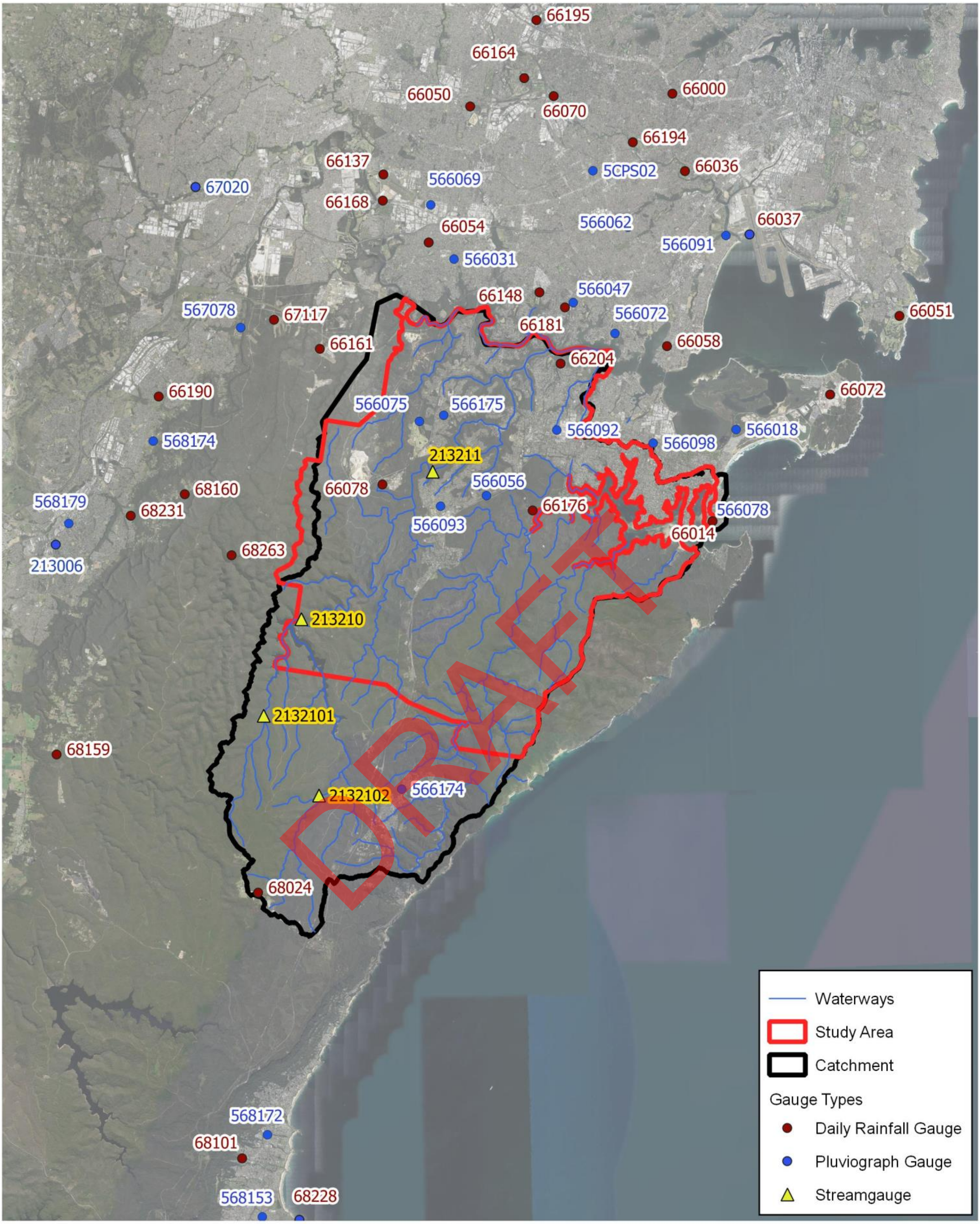
Station No.	Station Name	Record Period	Authority	Distance from catchment centroid (km)
566069	Bankstown Trotting Club	N/A - current	SW	17.1
568174	Helensburgh	N/A - current	SW	17.6
566018	Cronulla WRP	1979 - current	SW	18.2
213006	Fishers Ghost Creek @ Bradbury Park	1945 - 2019	Water NSW	18.6
566062	Bexley Bowling Club	1987 - current	SW	19.4
5CPS02	Belmore BC	N/A - current	SW	20.7
67020	Liverpool	2001 - 2013	BoM	21.5
66037	Sydney Airport AMO	1886 - current	BoM	21.5
568179	Campbelltown Bowling Club	N/A - current	SW	21.7
566091	Kyeemagh RSL Club	1991 - current	SW	22.8
568172	Bulli - Woonona Bowling	1990 - current	SW	29.5
68228	Bellambi AWS	1988 - current	BoM	32.4
568153	Bellambi Bowling Club	1987 - current	SW	33.4

2.4.2 Stream Gauge Data

There are four stream gauges within the catchment, all located within the Woronora River catchment. Three are located in the upper catchment and one is further downstream on Woronora River near Engadine. Details of the gauges are provided in Table 2.4, with locations shown in Figure 2.1.

Table 2.4 Stream Gauges in the Vicinity of the Study Area

Station No.	Station Name	Record Period	Data Type	Authority	Max. Gauge Depth (m)
213211	Woronora River at the Needles North Engadine	1992 - current	Level Flow	WaterNSW	2.856
213210	Woronora River at Woronora Dam	1966 - current	Level	WaterNSW	N/A
2132101	Woronora River at Fire Rd 9F	2007 - current	Level Flow	WaterNSW	0.420
2132102	Waratah River at Fire Rd No 95	2007 - current	Level Flow	WaterNSW	0.985



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RAINFALL AND STREAM GAUGES

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2.5 Topographic Data

Aerial topographic survey, also known as LiDAR (Light Detection and Ranging) survey, covering the catchment was downloaded from the Elvis Geographic Website. The survey was captured by the NSW Government's Land and Property Information (LPI) for a number of different regions (Port Hacking, Wollongong, Sydney and Penrith) and dates (February 2011, April 2013 and April 2020), as listed in Table 2.5 and shown in Figure 2 2.

Table 2.5 LiDAR Datasets Covering the Catchment

ID Number	Region	Date Collected
1	Sydney	April 2020
2	Wollongong	April 2020
3	Port Hacking	April 2020
4	Wollongong	April 2013
5	Port Hacking	April 2013
6	Penrith	April 2020
7	Wollongong	February 2011
8	Wollongong	April 2013

The April 2020 LiDAR datasets cover the majority of the study catchments, with the exception of the upstream catchment extents of the Woronora River and Port Hacking. However, topographic definition in these areas can be provided by earlier LiDAR datasets such as the Wollongong LiDAR collected in 2011 and 2013.

The April 2020 LiDAR data was supplied at a 1 m grid resolution, with a stated horizontal accuracy of +/- 0.8 m @ 95% confidence and a vertical accuracy of +/- 0.3 m @ 95% confidence. LiDAR generally provides a good representation of the variation in ground surface elevations in the catchment; however, the datasets can provide a less reliable representation of the terrain in areas of high vegetation density or in close proximity to buildings.

As a means to verify the accuracy of the LiDAR, the ground surface elevations from the April 2020 LiDAR datasets were compared against available standard survey marks (SSM's) downloaded from Spatial Services (refer Figure 2 2). Across the catchment, there were 36 SSM's where the data was able to be verified against Survey Mark Sketches. It was determined that 61% of the surveyed marks lie within +/- 0.2 m of the LiDAR ground elevations. The largest difference between the SSM and LiDAR elevation was determined to be 0.78 m and occurs at a point adjacent to overhanging tree canopies which may have impacted on the reliability of LiDAR elevation capture at that point. However, the elevation at this point was determined to be within approximately 0.07 m of the April 2013 LiDAR elevation. Considering the vertical accuracy, confidence limits and resolution of the available topographic data, the simulated flood levels presented in this flood study will be limited to one decimal place so as not to imply a higher level of model accuracy than the adopted topographic data allows.

A Digital Elevation Model (DEM) of the study catchments was developed from these LiDAR datasets, as shown in Figure 2.2. It can be seen that the combination of the 2020 LiDAR datasets (where available) with the earlier 2011 and 2013 LiDAR data covers the entire study area and can be used to define the topography across all catchment areas for the hydrologic model development. Meanwhile, the urban areas within the catchments are covered entirely by the 2020 LiDAR data.

As the 2020 LiDAR datasets were collected relatively recently and considering that the 2011 and 2013 LiDAR datasets are typically only used in undeveloped areas of the catchments, this DEM provides a sufficiently detailed and reliable representation of contemporary topographic and development conditions for developing the hydrologic and hydraulic models for this flood study.

2.6 Stormwater Network Data

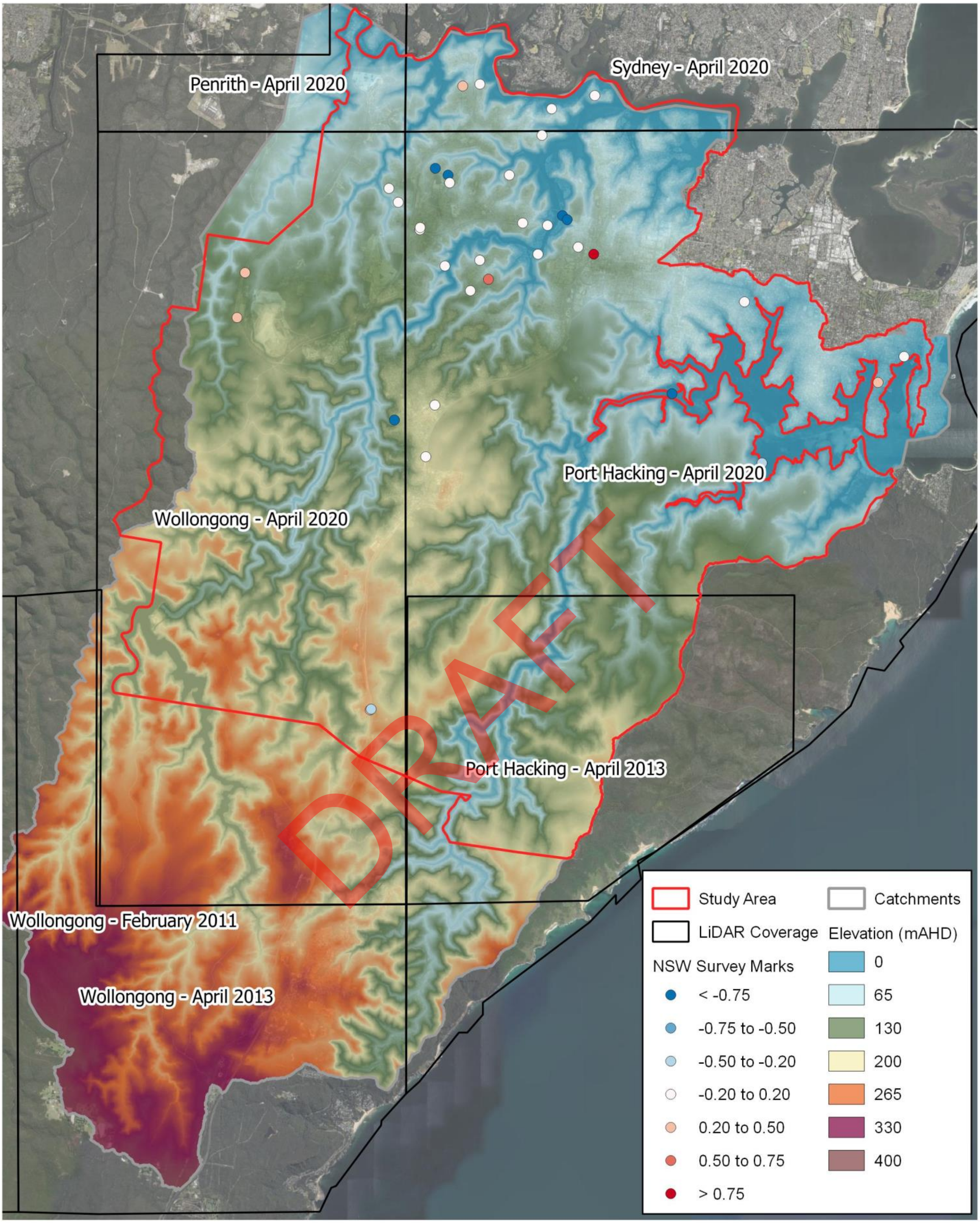
A GIS database comprising an extensive network of stormwater drainage infrastructure was provided by Council in August 2020. This database provides the location, alignment and attributes of Council owned stormwater pipes and culverts, as well as the locations and attributes of stormwater pits/inlets. A summary of this data is provided in Table 2.6.

Table 2.6 Summary of Council's Pit and Pipe Database

Asset Type	Data Provided	Number of Assets
Pit	Location, Pit ID, Installation Date, Type (sag pit, junction pit, gully pit, grated pit, surface inlet, headwall), Dimensions.	24,211
Pipe	Location, Length, Installation Date, Dimensions, Depth to Invert (Upstream and Downstream), Material of structure, Type (pipe, channel, gully)	23,744

A detailed review of these layers was completed to confirm if the available information was sufficient to include a representation of the stormwater system within the flood model. In general, the pit and pipe layers provide sufficient information. However, the following limitations were identified:

- Pipe asset database included non-pipes (i.e. open channels, rock channel, gullies, etc) that were filtered out, resulting in approximately 21,700 pipe assets remaining in the GIS layer.
- Invert elevations are not provided in either dataset. Depth to invert is included for less than 10% of assets and in these cases, invert levels were estimated (and verified) by interrogating the overlying LiDAR elevation data and subtracting the specified depth to invert. Where the pit/pipe depths were not provided, invert elevations were estimated using the following approach:
    - Invert elevation = LiDAR elevation – 0.6 m cover – pipe diameter
- A limited number of pipes did not include size/diameter data. The details of these pipes were either provided by Council (where available), sourced from engineering plans, estimated through visual or desktop assessment (e.g. Google Street View), or assumed based on upstream/downstream pipe details.
- 10% of pipes in the database (i.e. approximately 2,160 pipes) have a diameter less than or equal to 300 mm. Only pipe diameters equal to or greater 375 mm were included in the hydraulic flood models, except where required to maintain continuity of the piped system.
- Lengths of the pipes within the database were found to be inconsistent with the actual pipe length at various locations. The line length within the GIS database was used to define the pipe length in the modelling.



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CATCHMENT TOPOGRAPHY

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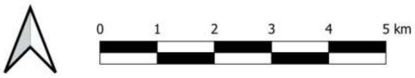

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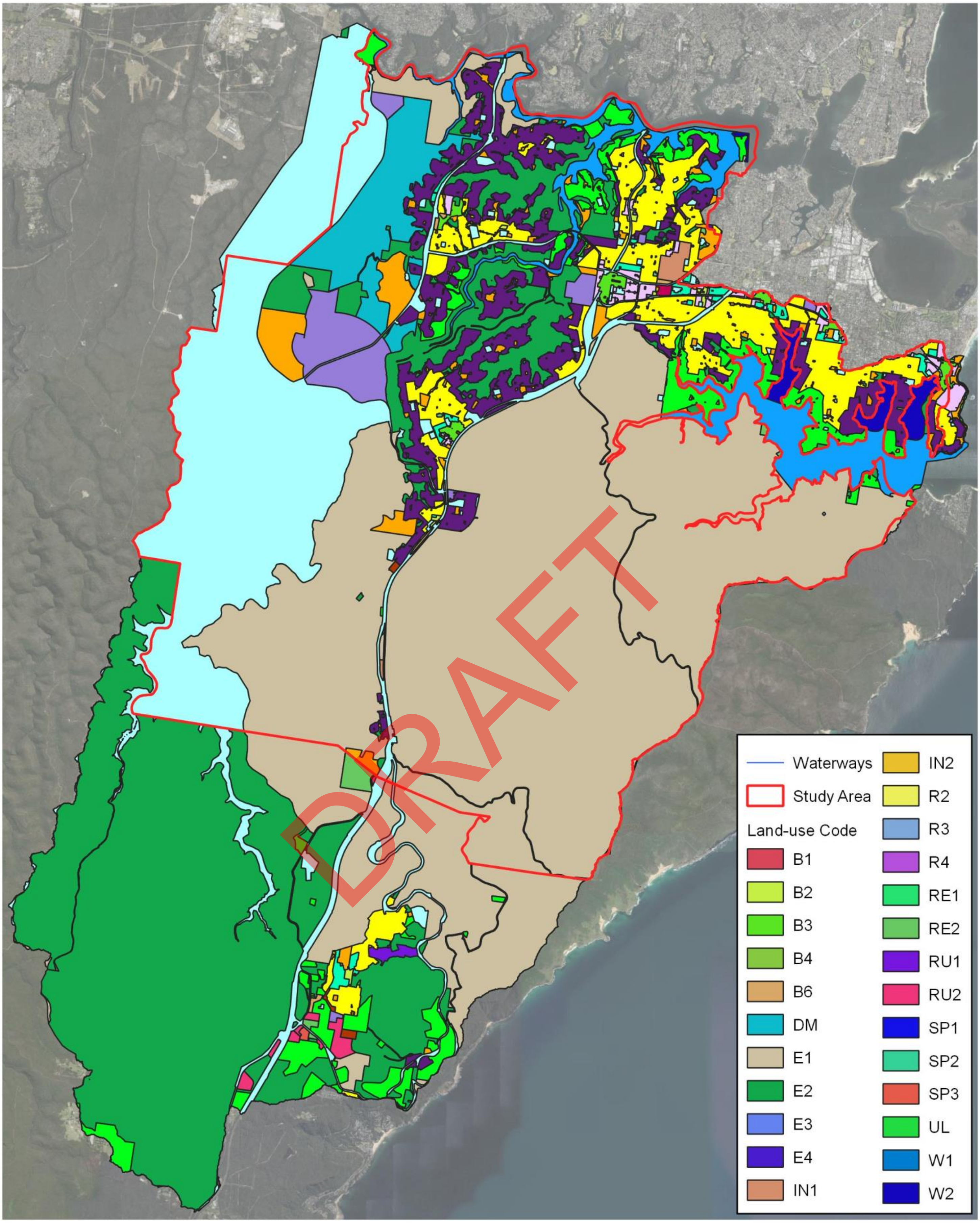
2.7 Land Use Planning Information

NSW Planning Environmental Planning Instrument (EPI) datasets were provided by the Department of Planning and Environment (DPE). This data includes land use planning information that provides a means to distinguish between land use types across the study area and enable spatial variation of distinct hydrologic (e.g. rainfall losses) and hydraulic properties (e.g. Manning’s roughness parameter ‘n’). The land use zones are shown in Figure 2.3. Table 2.7 lists the zonings and the associated categorisation of land use types that were used for assigning land surfaces (e.g. refer Section 4.2.4) and hydraulic roughness properties (refer Section 4.3.5) for the flood modelling for this study.

Table 2.7 Land Use Zones and Associated Land Use Types

Code	Land Use Zone	Area (ha)	Land Use Type(s)
B1	Neighbourhood Centre	7	Lot Commercial / Road
B2	Local Centre	27	Lot Commercial / Road
B3	Commercial Core	109	Lot Commercial / Road
B4	Mixed Use	10	Lot Commercial / Road
B6	Enterprise Corridor	21	Lot Commercial / Road
DM	Deferred Matter	847	Dense Vegetation / Grass / Waterbody
E1	National Parks and Nature Reserves	14,766	Dense Vegetation / Grass / Waterbody
E2	Environmental Conservation	9,281	Dense Vegetation / Grass / Waterbody
E3	Environmental Management	1,235	Lot Low Density / Grass / Waterbody
E4	Environmental Living	1,994	Lot Low Density / Road
IN1	General Industrial	58	Lot Commercial / Road
IN2	Light Industrial	18	Lot Commercial
R2	Low Density Residential	1,814	Lot Low Density / Road / Grass
R3	Medium Density Residential	142	Lot Low Density / Road / Grass
R4	High Density Residential	179	Lot High Density / Road / Grass
RE1	Public Recreation	700	Dense Vegetation / Grass / Waterbody
RE2	Private Recreation	82	Lot Low Density / Grass
RU1	Primary Production	34	Outside of hydraulic model extent
RU2	Rural Landscape	78	Outside of hydraulic model extent
SP1	Special Activities	582	Lot Low Density / Dense Vegetation / Grass
SP2	Infrastructure	5,308	Railway / Road / Lot Commercial
SP3	Tourist	7	Outside of hydraulic model extent
UL	Unzoned Land	13	Outside of hydraulic model extent
W1	Natural Waterways	969	Waterbody
W2	Recreational Waterways	205	Waterbody



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LAND-USE PLANNING

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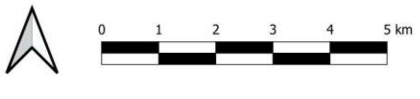

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2.8 Building Footprints

Council provided the Geoscape[2] building footprint dataset created by PSMA Australia Ltd and dated September 2022. This dataset consists of a digital outline of building roof structures across the study area using remote sensing imagery and includes any building structure over 9 m^2.

A visual assessment of the building footprints was undertaken against buildings shown in aerial imagery for the study area. In general, this dataset was determined to be representative of the building extents and locations, however there are data gaps in areas of dense vegetation and tree canopy cover.

Overall, this data provides a means to represent the localised blockages associated within buildings across the study area and will be incorporated into the hydraulic model.

2.9 Engineering Plans

2.9.1 Monash Road Subdivision

Council provided two design plans for civil works proposed for the subdivision of lots at 287 Alfords Point Road (DA 12/0446) dated 11 November 2013 and 313 Alfords Point Road (DA 13/0529), Menai dated 13 September 2014.

The civil works plans provide details on the subdivision of lots, road layouts, changes to vegetation, proposed stormwater drainage, earthworks and terrain survey. Proposed stormwater drainage details include the layout of the network and swale, stormwater pipe and stormwater pit dimensions.

These plans have been used to supplement existing data, where required, during the model development process including incorporation of the proposed stormwater network and drainage swales, and assigning Manning ‘n’ roughness values. It is assumed that the April 2020 LiDAR captures the design terrain.

2.9.2 Other Plans

Council provided survey and/or work-as-executed plans for the following structures:

- Princes Highway Sutherland Bypass Via Acacia Rd & Merton St (Dept Main Roads, 1973)
- Foch Avenue Drainage, Gymea (Sutherland Shire Council, 2012)
- Waratah Street West, Sutherland (Sutherland Shire Council, 1986)
- Drainage Pit 3 Details at Ch180 Wilson Pde, Heathcote (Steve Whelan & Associated, 1982)
- Blacket Street proposed widening and piping works (Sutherland Shire Council, 1985)
- Culvert at Oakwood Street, Sutherland (RTA, 2000)
- Adjustment of Ex Council Drainage - 35 Walker Avenue, Gymea (AKY Civil Engineering, 2008)
- Proposed Townhouse Development 372-376 President Avenue, Gymea (Jones Nicholson Pty Ltd, 2015)
- IP&S Survey Section President Avenue, Caringbah (Sutherland Shire Council, 2012)
- Yurunga Avenue, Caringbah South Drainage Upgrade (Sutherland Shire Council, 2018)
- 28-30 Marina Crescent, Gymea Bay Remedial Drainage Works, (Sutherland Shire Council, 2021)

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[2] Geoscape Buildings

- Ellesmere Road, Gymea Bay Stormwater Upgrade and Associated Works (Sutherland Shire Council, 2021)
- No. 78 Ellesmere Road, Gymea Bay Stage 2 Works Concept Design (Sutherland Shire Council, 2021)
- Binney Street (no. 9) Caringbah South Drainage Upgrade (Sutherland Shire Council, 2021).

These plans generally include information describing the size/dimensions of the structures including invert elevations and are sufficiently detailed for including a representation of these structures in the flood models.

2.10 Historical Flood Information

2.10.1 Council's Flood Database

Flooding complaints from Council's Customer Response Management System (CCRM) were provided for four (4) historical floods that occurred in May 2003, April 2015, February 2020 and March 2021. This data is discussed below.

May 2003

A database comprising a total of 505 complaints in the study area was provided for the May 2003 event. Due to the large number of records in the data, the complaints were filtered into the following categories:

- flooding above floor level (35)
- flooding on property (77)
- flooding in parks/playground/other local areas (7)
- flooding on adjacent roadways (11)
- stormwater maintenance issues (e.g. related to broken culverts, blocked/not functioning drains, water dripping from roof, open drains issues) (233)
- other complaints (e.g. damage, buildings complaint, risks management) (142).

Figure 2.5 shows the spatial distribution and categorisation of the submissions across the catchment.

April 2015

Council provided a database of 286 complaints for the April 2015 event. This database includes Council's classification of the reported flooding which has been used as the basis for filtering records to those relevant to flooding due to heavy rainfall. Out of 286 submissions, 29 complaints are classified as flood-related and the locations of these complaints across the study catchment are shown in Figure 2.6.

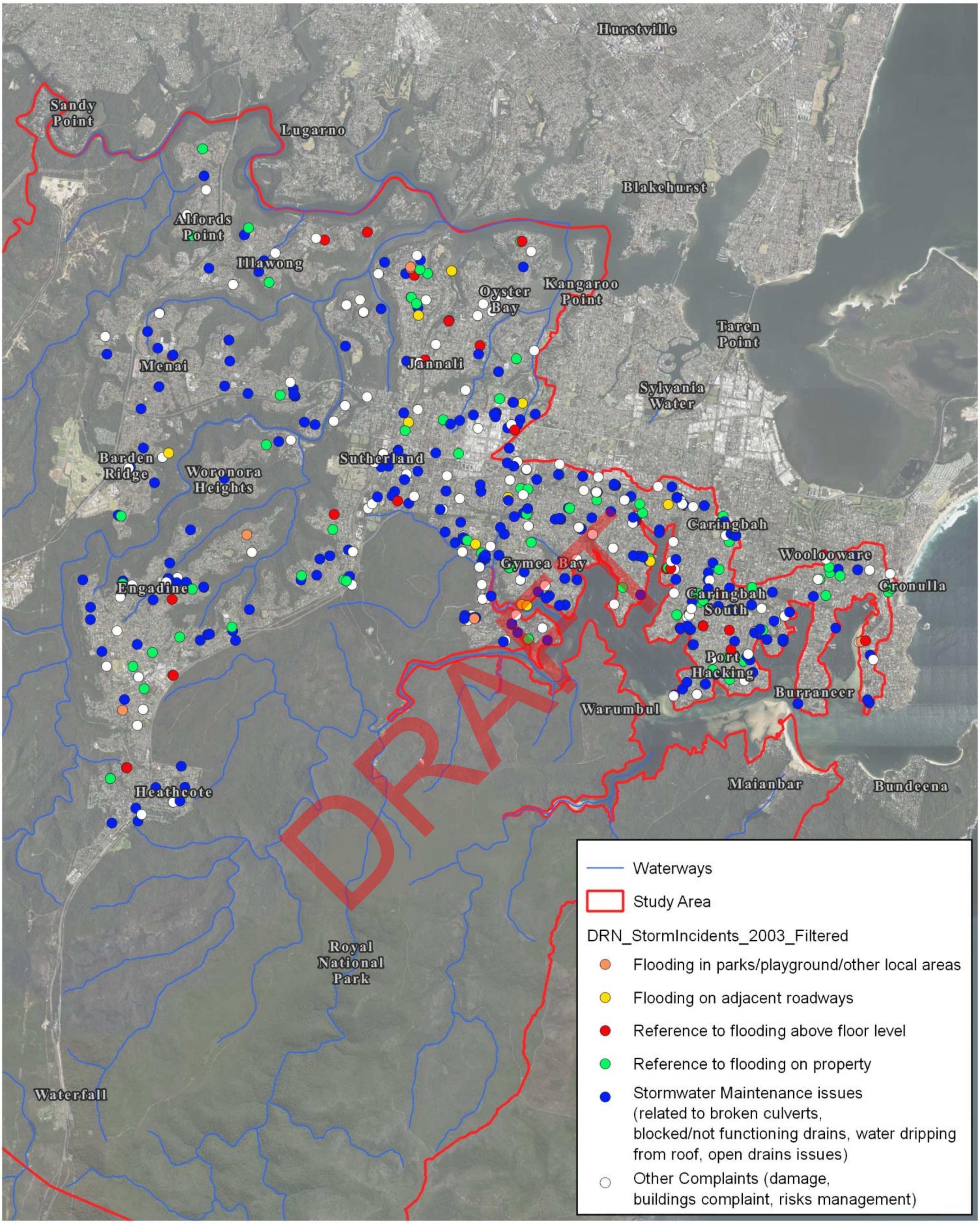
February 2020

For the February 2020 event, a database of 86 flooding complaints was provided by Council. The database included information on flooding, required maintenance on drainage infrastructure, blocking of pits or headwalls and broken pits. Complaints were subsequently categorised based on the issue reported and it was determined that 9 locations were reported to be due to flooding during heavy rainfall. The locations of overland flooding complaints for this event are shown in Figure 2.6.

Council also provided photographs of flooding at four locations within the study area, including President Avenue and North West Arm Road (Gymea), Ellesmere Road (Gymea), Kareela Golf Course (Kareela) and Gymea Bay Road (Gymea Bay).

March 2021

For the March 2021 event, Council provided details of flood-related complaints at five properties within the study area, including photographic and/or video records of flooding during the event at these locations (where available). The locations of overland flooding complaints for this event are shown in Figure 2.6.



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HISTORIC FLOOD DATABASE - MAY 2003 EVENT

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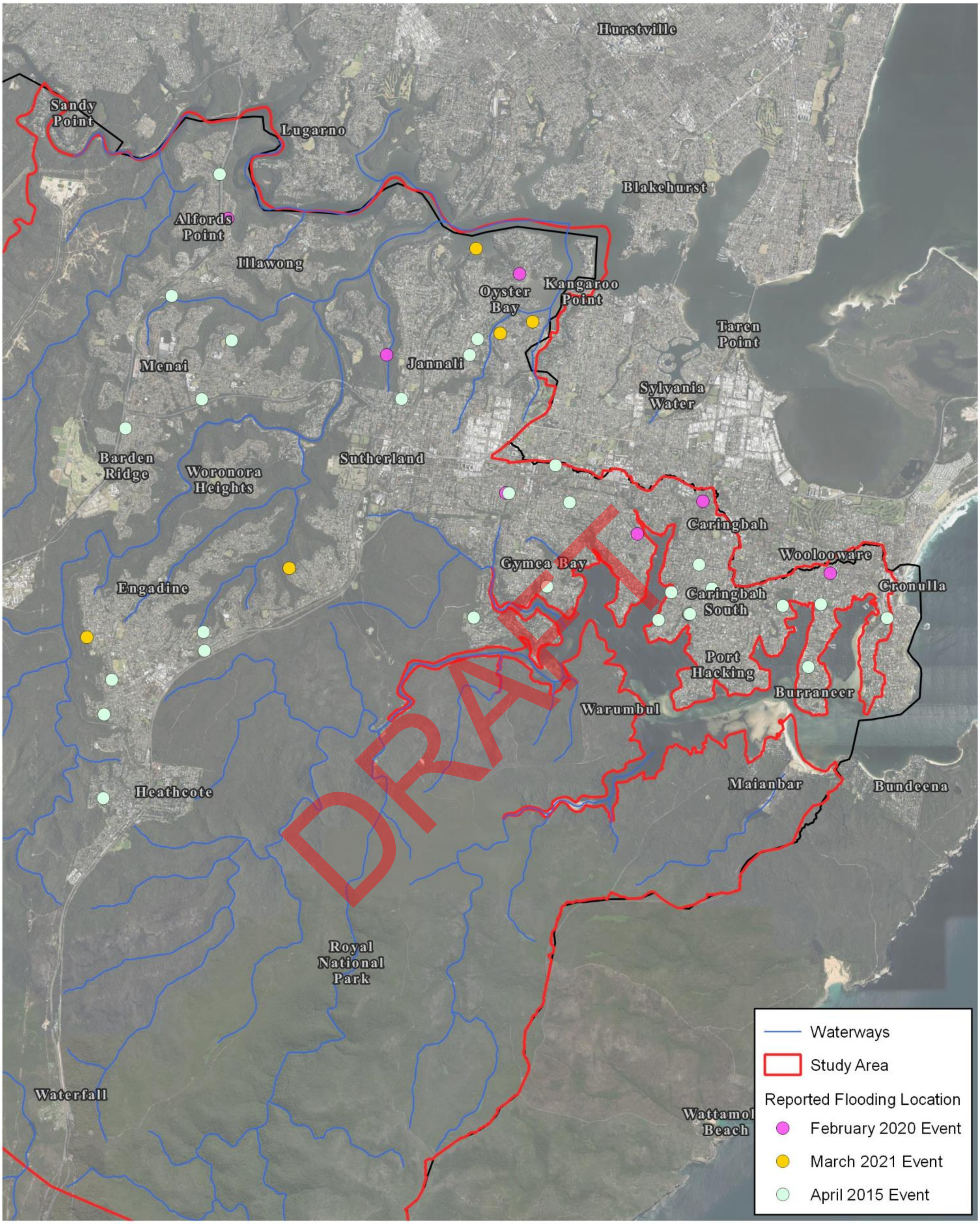

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HISTORIC FLOOD DATABASE - APRIL 2015, FEBRUARY 2020, MARCH 2021

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2.10.2 Data from other Sources

Historical flood information (e.g. photographic and video evidence) was also requested from the local SES units of the NSW State Emergency Service (SES). However, no information could be sourced.

2.11 Site Inspections

Site inspections are undertaken during the early project phase to gain an appreciation of local hydraulic features and their potential influence on the flood behaviour. Some of the key observations accounted for during the site inspections include:

- presence of structural hydraulic controls such as bridges, culverts, roadway and railway embankments, as well as natural topographical controls such as channel constrictions or steep reaches
- general nature of the catchment landforms, vegetation type and coverage and the presence of significant flow paths
- location of existing development and infrastructure in the study area.

BMT completed a site visit with Council on the 1 October 2020 to inspect the following five known areas of flooding issues (i.e. “hotspots”) reported by Council:

- Binney Street to Mirral Road (Caringbah South) (refer Figure 2.7)
- Gymea Bay Road (Gymea) (refer Figure 2.8)
- North Attunga Road and Forest Road (Yowie Bay) (refer Figure 2.9)
- Attunga Road and Wonga Road (Yowie Bay) (refer Figure 2.10)
- North West Arm Road and Hovea Place (Grays Point) (refer Figure 2.11).

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

Figure 2.7 View Looking South along Binney Street, Caringbah South

Figure 2.8 View Looking North-west along Gymea Bay Road, Gymea

Figure 2.9 View Looking West at Intersection of North Attunga Road and Forest Road, Yowie Bay

Figure 2.10 View Looking East at Intersection of Wonga Road and Attunga Road, Yowie Bay

Figure 2.11 Looking North from North West Arm Road (near Hovea Place) at Drainage Channel

3 Community Consultation

3.1 Purpose

Council recognises that community consultation is an important component of the Flood Study. Therefore, the community was consulted during the preparation of the flood study. The consultation with the community aimed to:

- inform the community about the study
- gather information from the community on their flood experiences within the study catchments
- develop and maintain community confidence in the study results.

The consultation was completed via a number of different consultation methods at various points within the flood study, as detailed in the following sections.

3.2 Study Webpage

A study webpage was established for the duration of the study and made available via Council's online community engagement portal since September 2021:

Overland Flood Study | Join the Conversation - Sutherland Shire Council (nsw.gov.au)

The webpage was developed by Council to provide the community with an overview of the study, purpose and objectives of the study, timeline for the project and an opportunity to respond to the questionnaire online.

3.3 Media Release and Community Questionnaire

A social media release was prepared by Council to advertise the study, community questionnaire and webpage on social media (e.g. Facebook).

The community questionnaire sought to collect information on the community's past flood experiences and concerns. More specifically, the focus of the questionnaire was to gather relevant flood information from the community, including photographs, observed flood depths and descriptions of flood behaviour within the study area. Photographs and/or comments relating to flood behaviour contained within the responses were extracted to assist with the model validation process. The questionnaire was accessible through Council's online community engagement portal between 15 September and 15 October 2021.

There were a total of 103 views of the webpage during the community engagement period. Three submissions to the online questionnaire were received via the webpage, including two responses and three pins placed to indicate locations of past flood experiences in Heathcote (2) and Gymea Bay (1). This represents a very low response rate when compared to the typical response rates for other similar flood studies undertaken in NSW. The responses to the questionnaire indicate that shallow flooding was experienced at two locations in Heathcote in the past and particularly during the recent March 2021 event. The respondent indicated overland flow was observed to be due to blocked drains.

No historical flood photographs were provided by any respondents.

3.4 Public Exhibition of Draft Flood Study Report

[To be completed following Public Exhibition]

4 Model Development

4.1 Types of Models

The urbanised nature of the study area creates a complex hydrologic and hydraulic flow regime. This is due to the mixture of pervious and impervious surfaces, as well as a combination of open waterways, overland flow paths, cross-drainage structures and piped stormwater systems.

Computer models are the most common and efficient tools for assessing flood behaviour within a catchment. Separate hydrologic and hydraulic models were developed for this study, whereby:

- The hydrologic model transforms rainfall into runoff across the catchment and produces the flows which form the inflow boundaries of the hydraulic model.
- The hydraulic model simulates the distribution and movement of the runoff (or flow) across the floodplain, overland flow paths and within the stormwater network, and predicts flood characteristics such as flood levels, depths and velocities.

Information on the topography and characteristics of the catchments and floodplains are built into the hydrologic and hydraulic models. Recorded historical flood data, including rainfall and flood levels, are used to calibrate and validate the models, if possible. Alternatively, models can be verified where there is limited quantity and uncertainty over the accuracy of historical flood information (such as for this study). Once suitably calibrated (or verified), the models can be used to simulate design events and derive design flood conditions (e.g. peak flood extents, flood depths, flood levels, discharges and flow velocities) that can be used to produce flood maps and define flood risk.

This section describes the development of the hydrologic and hydraulic models for this study. Specific details of the application of these models as part of the model verification and design modelling process are provided in Section 5 and Section 6.

4.2 Hydrologic Model

4.2.1 Modelling Approach

The Watershed Bounded Network Model (WBNM) software was used to develop a hydrologic model to simulate the catchment rainfall-runoff processes across the study catchments. WBNM is widely used throughout Australia and simulates a catchment and its tributaries as a series of sub-catchment areas linked together to replicate the rainfall and runoff process through a stream network. Input data includes the definition of physical catchment characteristics including:

- catchment area
- catchment pervious/impervious surfaces
- spatial and temporal variations in the distribution, intensity and amount of rainfall
- antecedent moisture conditions (dryness/wetness) of the catchment (i.e. initial and continuing losses).

The default runoff routing and linearity parameters are based on data from 54 catchments in Queensland, NSW, Victoria and South Australia (Boyd, 2005). The output from the hydrologic model is a series of flow hydrographs that form the inflow boundaries for the hydraulic model.

For this flood study, a single WBNM hydrologic model was developed that includes all four (4) major sub-catchments (i.e. Woronora River, Georges River West, Georges River East and Port Hacking catchments). This model includes the full catchment areas draining to the outlets of each catchment, including both contributing catchment areas upstream of the LGA boundary and sub-catchments within the study area. The following sections discuss the model development and adopted parameters.

4.2.2 Catchment Delineation and Parameterisation

The four major catchments within the study area were delineated into sub-catchments based on the alignment of watercourses, topographic divides, and locations of key infrastructure and associated cross drainage structures (e.g. culverts and bridges), as defined by the DEM developed for this study (refer Section 2.5 and Figure 2.2) and GIS data (refer Section 2.3). The extent of the hydraulic model was also considered within the sub-catchment delineation to ensure the availability of inflow information at upstream boundary locations and appropriate locations within the hydraulic model extent.

Figure 4.1 shows the delineated WBNM sub-catchments determined for this study. The total number of sub-catchments within each catchment and average sub-catchment size within urban and non-urban areas of the catchments are listed in Table 4.1.

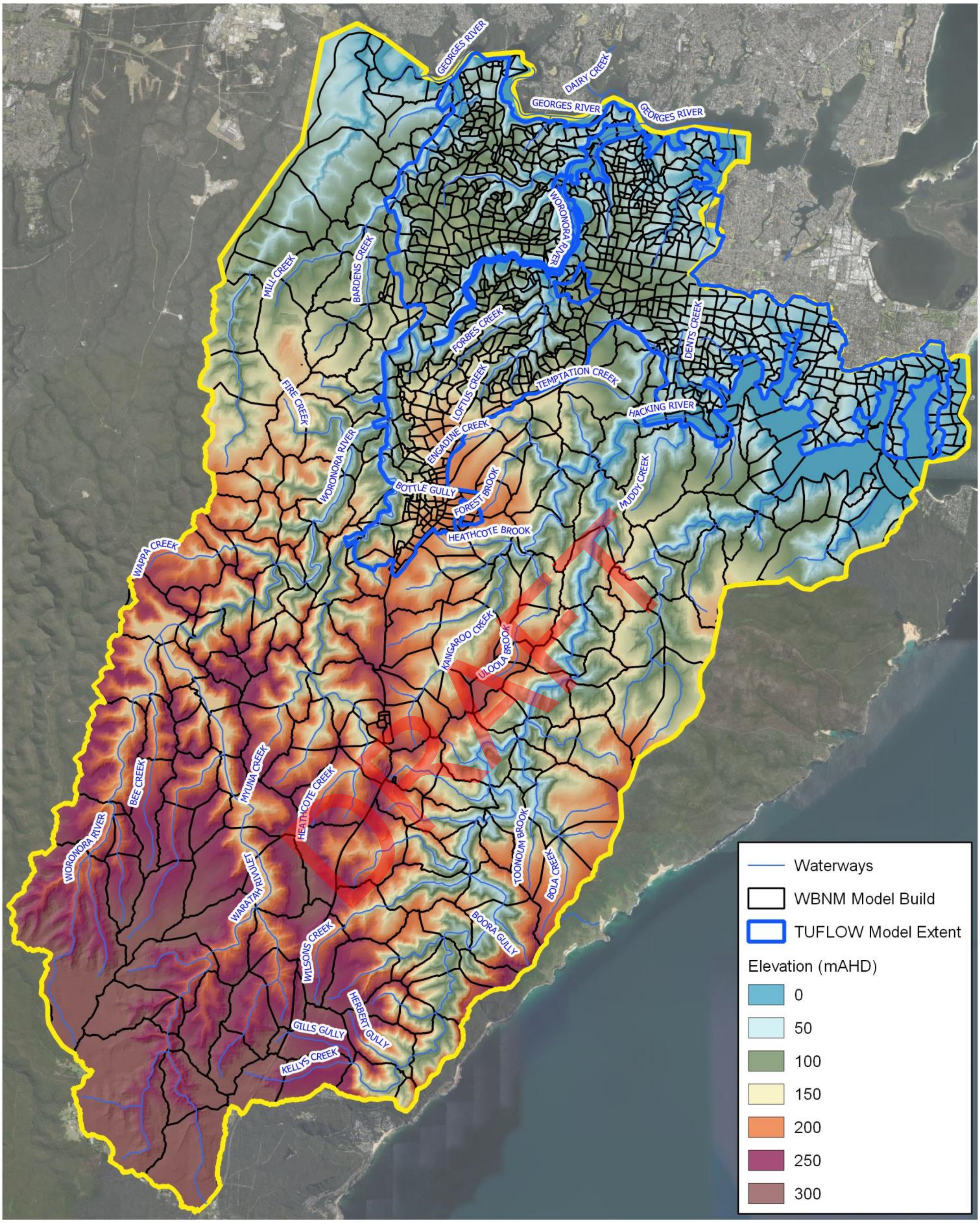
Table 4.1 Number and Average Size of Sub-catchments

Major Catchment	No. of Sub-catchments	Sub-catchment Size – Urban Areas (km^2)	Sub-catchment Size – Non-urban Areas (km^2)
Georges River East	138	0.005 to 0.20	0.14 to 0.29
Georges River West	142	0.007 to 0.22	0.05 to 3.32
Woronora River	514	0.010 to 0.23	0.03 to 9.48
Port Hacking	410	0.006 to 0.31	0.34 to 3.37

4.2.3 Catchment Parameters

The model input parameters adopted for each sub-catchment within the WBNM model are:

- Lag factor (termed C) of 1.6. This factor can be used to accelerate or delay the runoff response to rainfall. This influences the shape of the hydrograph as well as the channel routing properties that affect routing speed and attenuation.
- Stream flow routing factor of 1.0 for natural streams and 0.33 for urban areas, which can speed up or slow-down in-channel flows occurring through each sub-catchment.
- Impervious area lag factor of 0.15.
- Percentage of catchment area with a pervious/impervious surfaces varied based on land uses as defined in Section 4.2.4.
- Rainfall losses calculated as initial and continuing losses to represent infiltration. These vary for historical and design events and the adopted values are discussed in Section 5 and Section 6.



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WBNM MODEL SUBCATCHMENT LAYOUT

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4.2.4 Impervious/Pervious Areas

Based on ARR 2019 guidelines, rainfall losses within a hydrologic model are differentiated based upon the land surface type. The definitions of each land surface type are provided below:

- Effective Impervious Area (EIA): Incorporates the area of the catchment that generates a rapid runoff response in rainfall events, which includes:
    - Directly Connected Impervious Area (DCIA): Impervious area with a hydraulic connection to the drainage network. Examples of such areas include roof area, driveway or main sealed road.
    - Indirectly Connected Impervious Area (ICIA): Impervious area with a contribution of discharges from an impervious area onto a pervious area which rapidly saturates. Examples include footpaths adjacent to nature strips, paved backyard areas next to a garden bed, part of driveway, areas that are unlikely to be directly connected with any drainage network but likely to flow onto pervious surfaces.
- Urban Pervious Area (UPA): Consisting of parkland and bushland that do not interact with impervious areas.

DCIA, ICIA, EIA (i.e. DCIA + ICIA) and UPA components were estimated based on analysis of aerial photography to calculate typical pervious/impervious percentages within each land use category, as listed in Table 4.2 (refer further details in A.1). This enabled the estimation of resultant EIA within each sub-catchment based on the contributing areas from each land use zone.

Table 4.2 Pervious/Impervious Area Percentages for Land Use Zones

Land Use Code	Land Use Zone	% DCIA	% ICIA	Total % EIA	%UPA
E1	National Parks and Nature Reserves	2%	0%	2%	98%
E3	Environmental Management	49%	12%	61%	39%
E2	Environmental Conservation	2%	0%	2%	98%
B2	Local Centre	80%	10%	90%	10%
B1	Neighbourhood Centre	80%	10%	90%	10%
B4	Mixed Use	80%	17%	97%	3%
B3	Commercial Core	85%	10%	95%	5%
B6	Enterprise Corridor	90%	9%	99%	1%
RE2	Private Recreation	13%	2%	15%	85%
RU2	Rural Landscape	10%	5%	15%	85%
IN1	General Industrial	80%	10%	90%	10%
RE1	Public Recreation	5%	5%	10%	90%
IN2	Light Industrial	90%	5%	95%	5%
UL	Unzoned Land	0%	0%	0%	100%
E4	Environmental Living	51%	4%	55%	45%
R2	Low Density Residential	53%	7%	60%	40%
R4	High Density Residential	58%	12%	70%	30%

Land Use Code	Land Use Zone	% DCIA	% ICIA	Total % EIA	%UPA
R3	Medium Density Residential	55%	5%	60%	40%
W1	Natural Waterways	100%*	0%	100%	0%
SP1	Special Activities	7%	3%	10%	90%
W2	Recreational Waterways	100%*	0%	100%	0%
RU1	Primary Production	10%	5%	15%	85%
SP3	Tourist	20%	5%	25%	75%
SP2	Infrastructure	30%	0%	30%	70%
SP22	Infrastructure 02	10%	0%	10%	90%
DM	Deferred Matter	0%	0%	0%	100%

***Note: Waterways are 100% impervious since rainfall will contribute directly to runoff.**

4.3 Hydraulic Model

4.3.1 Modelling Approach

Four separate hydraulic models were developed for each for the major catchments within the study area (i.e. Woronora River, Georges River East, Georges River West and Port Hacking catchments) using the TUFLOW modelling software. TUFLOW was developed by BMT and is the most widely used 1D/2D flood modelling software in Australia.

The overland flow regime in urban environments is typically characterised by inundation of urban development with interconnecting and varying flow paths at varying depths. Road networks often convey a considerable proportion of floodwaters due to the hydraulic efficiency of the road surface compared to residential properties. Integrated 1D/2D TUFLOW models were created to model the dynamic interactions between waterways and floodplains, complex overland flow paths, converging and diverging of flows through structures, and the interaction between surface and sub-surface flow (i.e. stormwater drainage system).

This has involved the schematisation of the study area based on the following key model features:

- floodplain and overland flow areas represented in the 2D domain
- open watercourse channels are represented within the 2D model
- culvert structures represented as 1D elements dynamically linked to the 2D domain
- noise walls along major roadways represented as solid obstructions in the 2D model
- kerbside enforcement within the 2D model topography
- bridges represented as either 1D elements or 2D layered flow constrictions
- stormwater drainage network represented as 1D elements, dynamically linked to the 2D domain
- hydrologic inflows derived using the WBNM model applied as upstream and local inflows
- water levels within receiving watercourses applied as tailwater conditions.

The development of the hydraulic models and adopted parameters are discussed in the following sections.

4.3.2 Model Extent

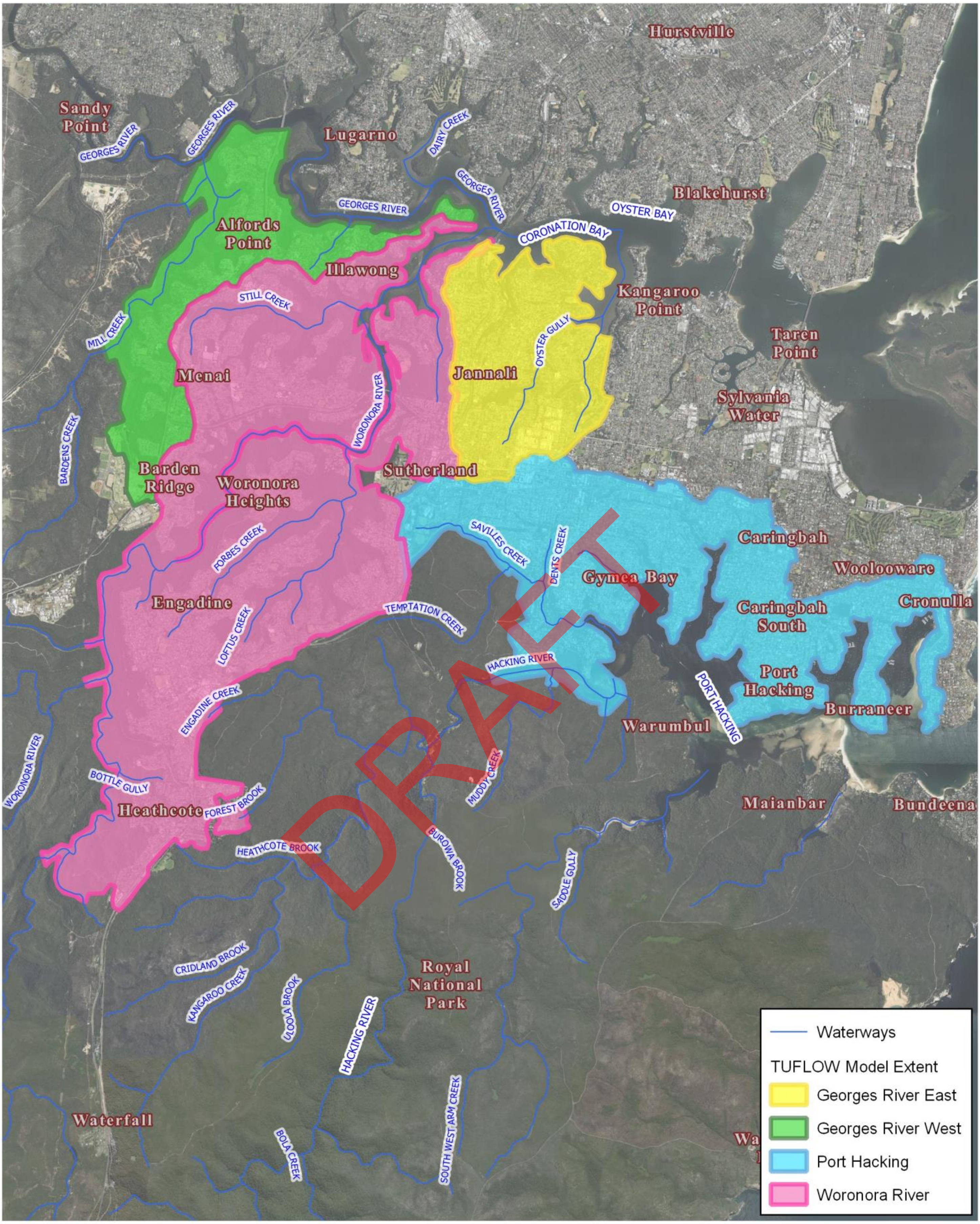
The hydraulic model for this flood study was developed using TUFLOW (Version 2020-10-AD). The TUFLOW Heavily Parallelised Compute (HPC) solver was used for this study, enabling more detailed models to be simulated in practical simulation times. This TUFLOW version includes the scale independent sub-grid turbulence scheme.

The 2D domain for each catchment was determined to extend across the urbanised portion of each catchment within the LGA boundary, as shown in Figure 4.2. The total area modelled within the TUFLOW 2D domains covers approximately 90.37 km^2, including the following separate model areas:

- Georges River West: 11.56 km^2
- Woronora River: 44.96 km^2
- Georges River East: 9.21 km^2
- Port Hacking: 24.64 km^2.

As discussed, these models drain into either the Woronora River, Georges River or Port Hacking. The TUFLOW model of the Woronora River catchment incorporates the river and its adjoining floodplain to ensure the interaction between local catchment flows and flows along the Woronora River is represented.

However, the Georges River and Port Hacking form the downstream boundaries of the Georges River West, Georges River East and Port Hacking model areas. Therefore, the Georges River and Port Hacking have not been included in the model domain. Flooding from these watercourses is represented within the model by defining a suitable downstream stage (i.e. water level) hydrograph.



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TUFLOW MODEL EXTENTS

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4.3.3 Grid Size

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 study 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 floodplain topography and characteristics and associated flood behaviour relative to a larger grid size. However, a smaller grid size will take longer to perform all of the necessary hydraulic computations. Therefore, a significant component of the model development involved optimising the grid size within the model whilst ensuring that practical simulation times are maintained.

TUFLOW's Quadtree feature has been used to vary the grid cell size across the model domain in the Woronora River TUFLOW model only. This process has prioritised allocating higher resolution to urban areas and for areas that benefit hydraulically from a high resolution. Specifically the grid cell sizes adopted are:

- Georges River East TUFLOW model: uniform 2 m grid cell size
- Georges River West TUFLOW model: uniform 2 m grid cell size
- Woronora River TUFLOW model: 2/4/8 m grid cell size. A grid cell size of 2 m was used across urban areas of the model. Larger grid cell sizes (e.g. 4 m and 8 m) were only applied in non-urbanised areas of the model, including within the Woronora River.
- Port Hacking TUFLOW model: uniform 2 m grid cell size.

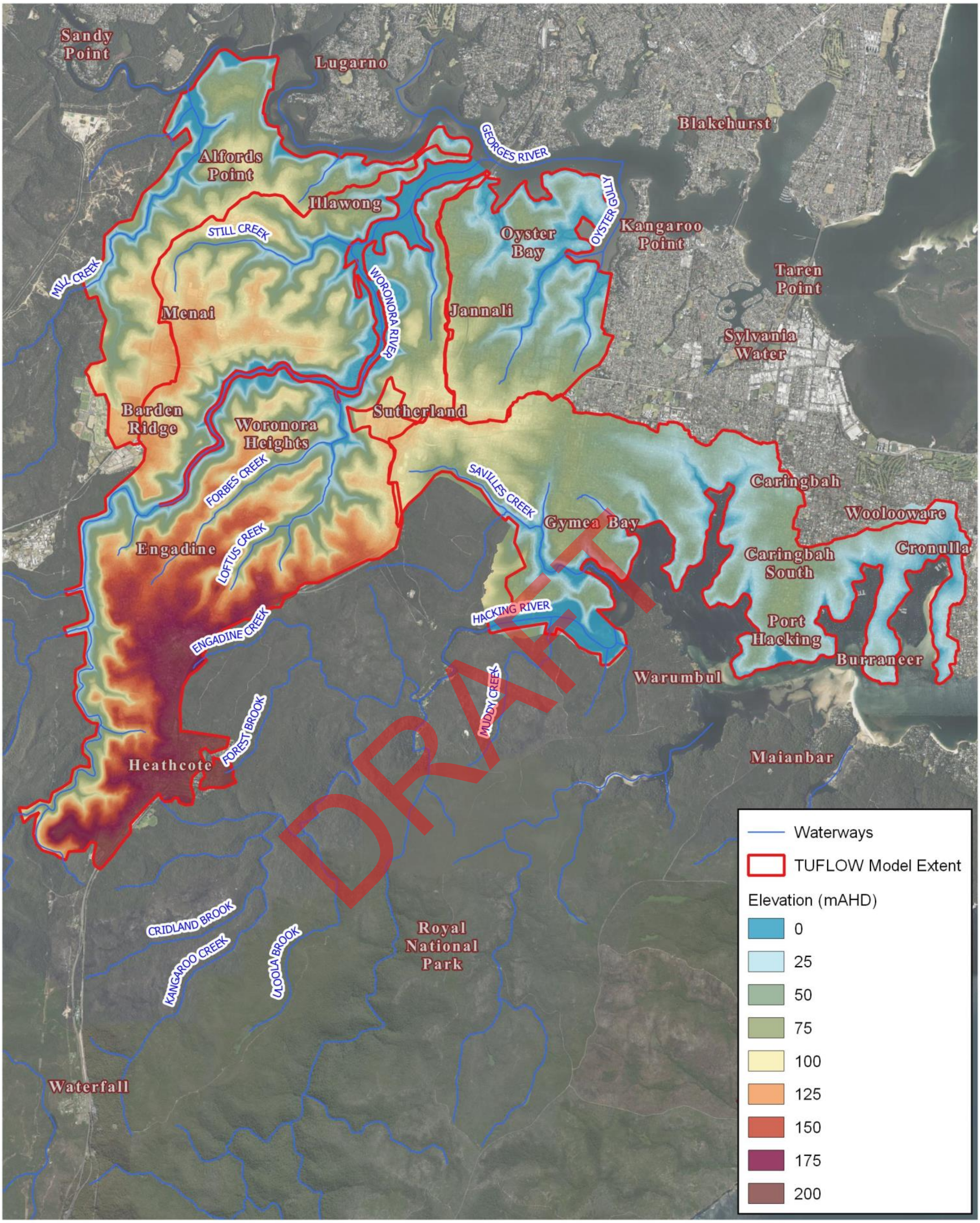
4.3.4 Topography

A high-resolution DEM was derived for the study area based on LiDAR data (refer Section 2.5). The ground surface elevations for the TUFLOW model grid points were sampled directly from this DEM and formed the base topography used in the 2D model.

Where available, additional topographic data was used to define more detailed and localised variations in topography, including:

- Detailed survey of the Oyster Creek floodplain from the 'Oyster Creek Flood Study Review' (WMAwater, 2010) in the Georges River East TUFLOW model.
- Minimum bed elevations within Ewey and Dents Creek were defined by channel inverts extracted from the HEC-RAS models within the Port Hacking TUFLOW model. These elevations were compared against LIDAR elevations along creek sides and banks to ensure appropriate transition between elevations from these two datasets.
- Key embankments (e.g. railway, highway, etc) were incorporated into the model as breaklines.
- Kerb and gutters are also important in conveying flow along roadways in urban areas, particularly in smaller (more frequent) events. However, it is difficult to reliably capture these features even using a 2 m grid cell size. Therefore, the locations of gutters were defined by Council's GIS kerb layer for Council roads across the entire study area, and manually digitised for roads operated and maintained by TfNSW or new roads within the study area (e.g. The Kingsway, Princes Highway, River Road / Linden Street, The Grand Parade and roadways within Monash Estate). Gutters were incorporated into the model by the reducing ground surface elevations along the approximate alignment of the gutters by 150 mm.

The resulting topography of the hydraulic models is presented in Figure 4.3.



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TUFLOW MODEL TOPOGRAPHY

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4.3.5 Hydraulic Roughness

Manning's n values are used to describe the variation in flow resistance afforded by different surface materials / land uses (e.g. trees, grass, roads, etc) within the extents of the TUFLOW models. These are specified based on land use categorisation (see Section 2.7). Aerial photography and GIS cadastral, land use planning and roadways layers were used as the basis for defining the land use category across the study area. The land use types used to assign the hydraulic roughness across the model are shown in Figure 4.4.

For each land use category, appropriate industry standard values of Manning's 'n' values have been applied and refined as part of the model verification process. A single set of Manning's n values was applied for modelling verification events and subsequently used for modelling design flood events. Adopted Manning's 'n' values are listed in Table 4.3.

Table 4.3 Adopted Manning's 'n' Values

Land Use Type	Manning's 'n' value
Maintained Grass	0.035
Roads	0.02
Railway	0.05
Low Density Residential Lot	0.04
High-density Residential Lot	0.03
Commercial Lot	0.03
Maintained Vegetation (e.g. grass)	0.035
Dense Vegetation	0.10
Waterbody	0.02
Open Channels	0.04

4.3.6 Representation of Buildings and Localised Obstructions

The representation of buildings is important in areas conveying significant volumes of flow or experiencing significant ponding depth. There are various ways to approach the modelling of buildings. The methods that are typically considered for an urban study include:

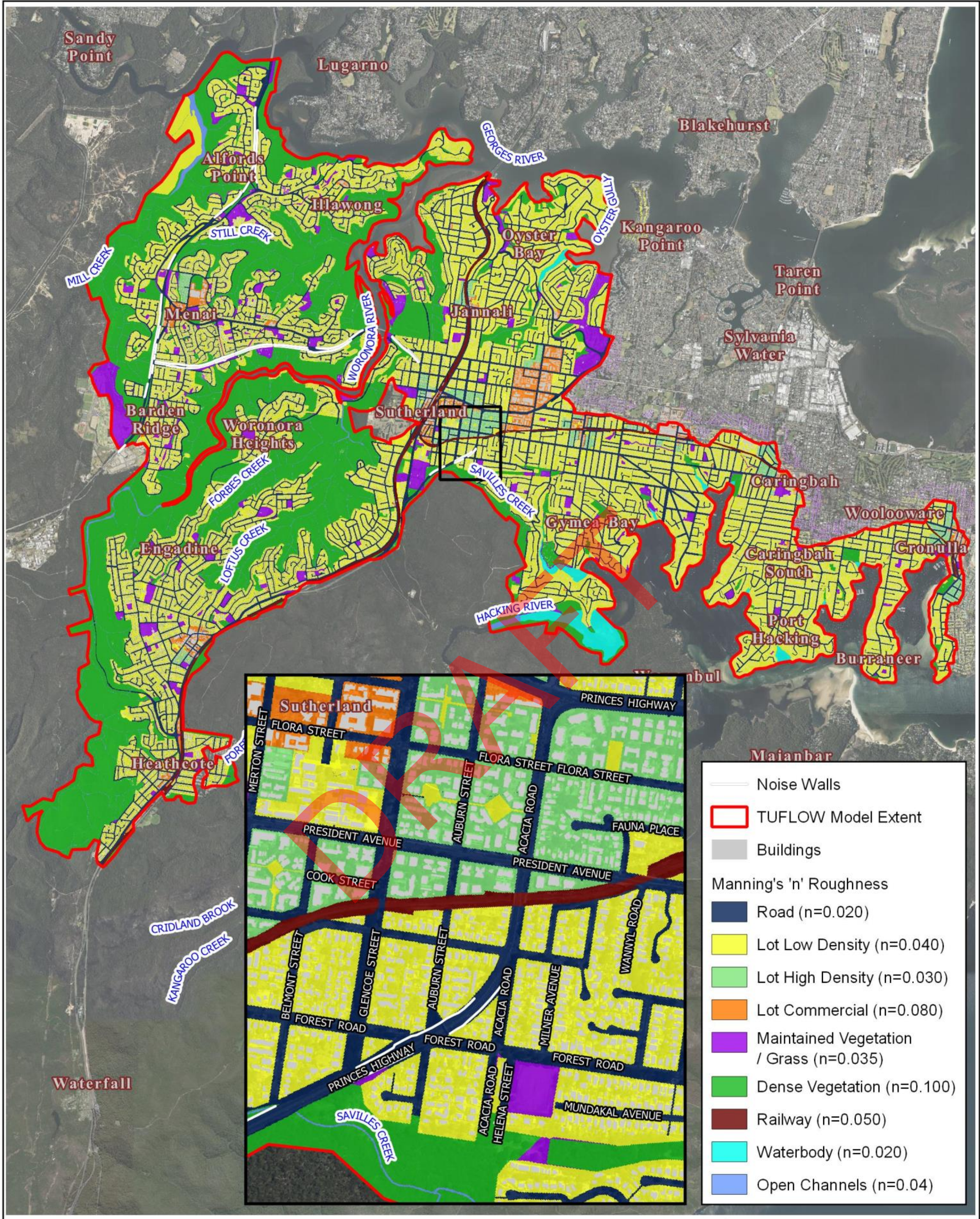
1. Buildings are represented with 2-3 sides of the building in addition to applying a higher Manning's 'n' value and raising ground levels facing the flow direction from the ground. This assumption allows for the energy dissipation of water flowing through and around the buildings, and the storage effects of the buildings being inundated.
2. Buildings are represented by removing the building footprints from the active model area. This assumption means that floodwater does not pass through and must flow around buildings, considering the energy dissipation of water moving around the structure. Storage effects are not considered. This approach was used for the 'Woolooware Bay Flood Study' (WMAwater, 2014).
3. Buildings are represented in the TUFLOW model as a high Manning's 'n' value which considers the energy dissipation of water flowing through and around the building. This approach also includes the storage effects of the building being inundated. This approach was used for the 'Bundeena Creek Flood Study' (Advisian, 2014) (Manning's 'n' value of 1) and 'Gwawley Bay Flood Study' (Bewsher, 2012) (Manning's 'n' value of 20).
4. Buildings are represented in the TUFLOW model by increasing the ground levels of the building. A standard depth (i.e. 0.3 metres) would be adopted as the area between ground level and floor level which is applied to all buildings across the study area, which generally accounts for 1-2 steps up into a property.
5. Various combinations of the above.

Method 2 above was adopted for representing buildings within the TUFLOW models and is consistent with the approach used in the 'Woolooware Bay Flood Study' (WMAwater, 2014) and 'Woolooware Bay Floodplain Risk Management Study and Plan' (WMAwater, 2022). This approach is considered appropriate for use in this study due to the short-duration, intense flash flooding nature of overland flow flooding in the study area. Figure 4.4 shows the representation of buildings within the TUFLOW model.

Building footprints were defined using the Geoscape building footprint dataset discussed in Section 2.8. Given this dataset provides a digital outline of building roof structure, building outlines were buffered 1m inside the roof outline to reflect typical overhang of eaves and to enable better representation of flow paths between buildings, particularly where buildings are located in close alignment.

Various noise wall structures situated along Alfords Point Road, Bangor Bypass, River Road and the Princes Highway were manually digitised using aerial photography and Google Street View (refer locations and alignments shown in Figure 4.4) and incorporated within the TUFLOW model as solid obstructions.

Smaller localised obstructions within or bordering private property, such as urban fences (e.g. Colorbond or wood paling fences), were not explicitly represented within the hydraulic model. Rather, these obstructions have been incorporated into the adopted Manning's 'n' roughness value for urban development land use across the study area (i.e. residential and commercial lots), due to their propensity to fail during large flood events.



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HYDRAULIC ROUGHNESS ZONES, BUILDINGS AND NOISE WALL STRUCTURES

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4.3.7 Hydraulic Structures

There are several culvert and bridge structures throughout the study area to enable cross-drainage under major roadways and railway lines. These structures vary in terms of size and configuration, with varying degrees of influence on local hydraulic behaviour. Incorporation of structures into the TUFLOW models enables the simulation of hydraulic losses associated with structures and their influence on flood behaviour.

Culverts were modelled as 1D structures embedded within the 2D domain. Dimensions and invert elevations for circular or rectangular culverts were included directly in the TUFLOW model. An entrance loss coefficient of 0.5 and an exit loss coefficient of 1.0 were adopted for all culverts as recommended by ‘TUFLOW Classic/HPC User Manual’ (BMT, 2018).

Bridges were either modelled as:

- 2D layered flow constriction structures in the 2D domain with based on the underlying model DEM defining the channel elevations beneath the bridge; or
- 1D structures embedded within the 2D domain where the available waterway area beneath the bridge deck was specified using a cross-section of the underlying channel.

Energy losses were defined using a water height versus loss coefficient relationship that was developed based upon procedures outlined in ‘Hydraulics of Bridge Waterways’ (Bradley, 1978).

The adopted structure details (e.g. invert elevations, structure dimensions, bridge obvert, deck level, etc) were defined based on the following data sources:

- Structure details extracted from hydraulic modelling files from previous flood studies (refer Section 2.2)
- Work-as-executed and/or design plans provided by Council
- Structure dimensions and levels supplied by Council
- Council’s stormwater (and structure) network data (refer Section 2.6).

Where no existing data was available from the above sources to define invert levels at inlets and outlets of hydraulic structures, elevations were estimated based on DEM values and minimum cover requirements.

4.3.8 Stormwater System

The stormwater system can play a significant role in defining flood behaviour across urbanised areas, particularly during more frequent flood events. Therefore, a representation of the stormwater system was included in the TUFLOW models to simulate the conveyance of flows by the stormwater system below ground and overland flows in 2D once the capacity of the stormwater system is exceeded.

Within each TUFLOW model, the stormwater system for all pipes with diameter equal to or greater than 375 mm was incorporated as a 1D drainage network, dynamically linked to the 2D domain at specified pit locations. Figure 4.5 shows the 1D stormwater network representation included the hydraulic modelling.

The properties of the stormwater system (e.g. pit types/sizes, pipe lengths/diameters) were defined by data within Council’s stormwater network GIS database, where available. A limited number of pipes did not include size/diameter data. The details of these pipes were either provided by Council (where available), sourced from engineering plans or assumed based on upstream pipe details.

Invert elevations were not included in Council's stormwater network database. Therefore, invert elevations within the models were defined based on:

- Work-as-executed or design plans, where available.
- Interrogation of the overlying LiDAR elevation data and subtracting the specified depth to invert, in instances where pit/pipe depths were provided. Note that less than 10% of assets in Council's database had depth to invert data.
- Estimated invert elevations using the following approach in instances where the pit/pipe depths were not provided:
    - Invert elevation = LiDAR elevation – 0.6m cover – pipe diameter.

Pit inlet capacities were modelled using lintel opening lengths and grate sizes based on the data provided. Pit inlet dimensions were assumed where data was not available, based on most common pit type within the study area or based on data for nearby pits.

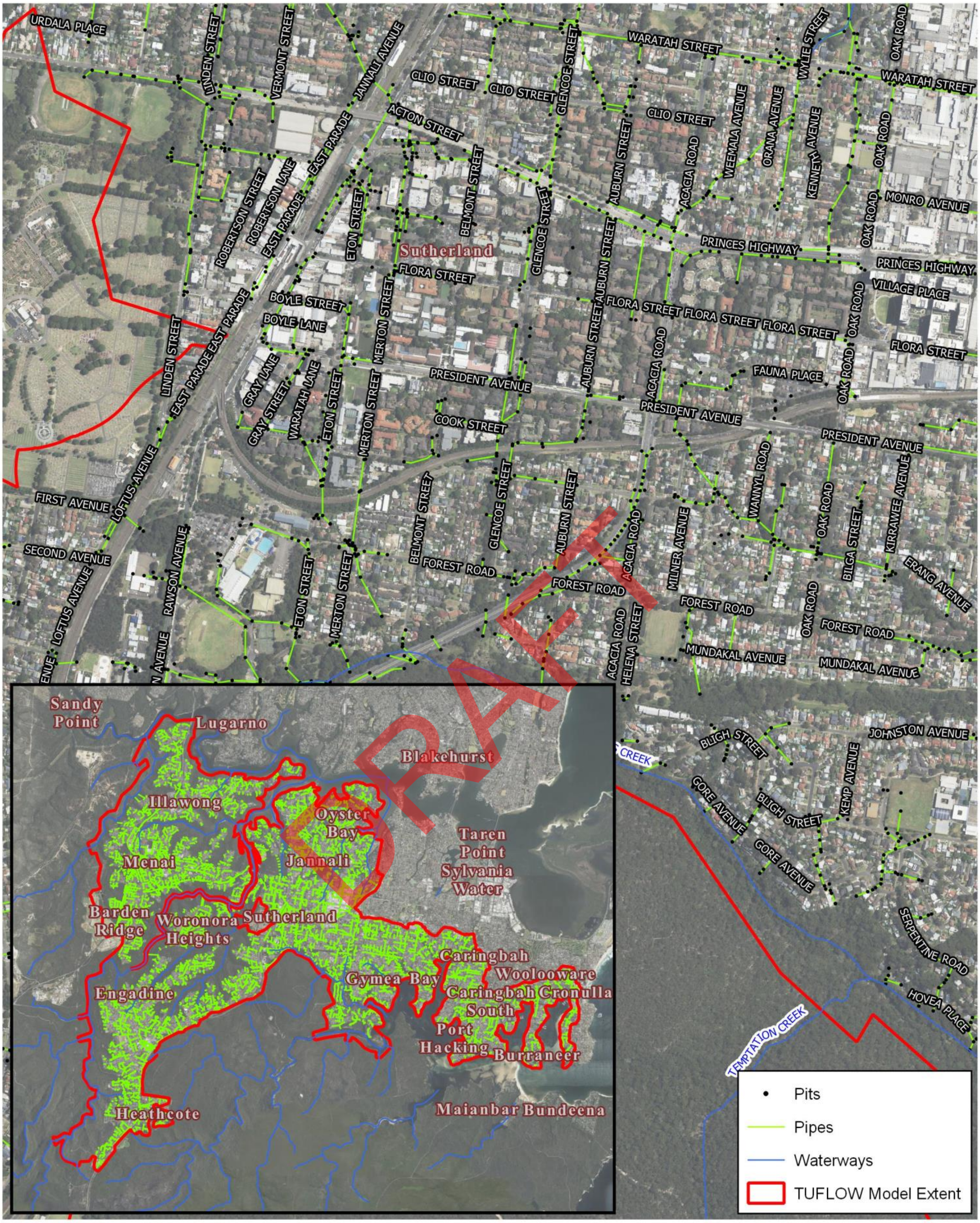
For the majority of the magnitude of events under consideration in the study, the pipe drainage system capacity is anticipated to be exceeded, with the major proportion of flow conveyed in overland flow paths. Therefore, any limitations in the available pipe data or model representation of the drainage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

Hydraulic "losses" throughout the stormwater system are estimated in TUFLOW using the Engelhund loss approach (BMT, 2018). 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.

Once all stormwater pits were included in the TUFLOW model, inlet capacity curves were used to define the pit inflow capacity with respect to water depth for each pit type. The inlet capacity curves account for:

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



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STORMWATER NETWORK

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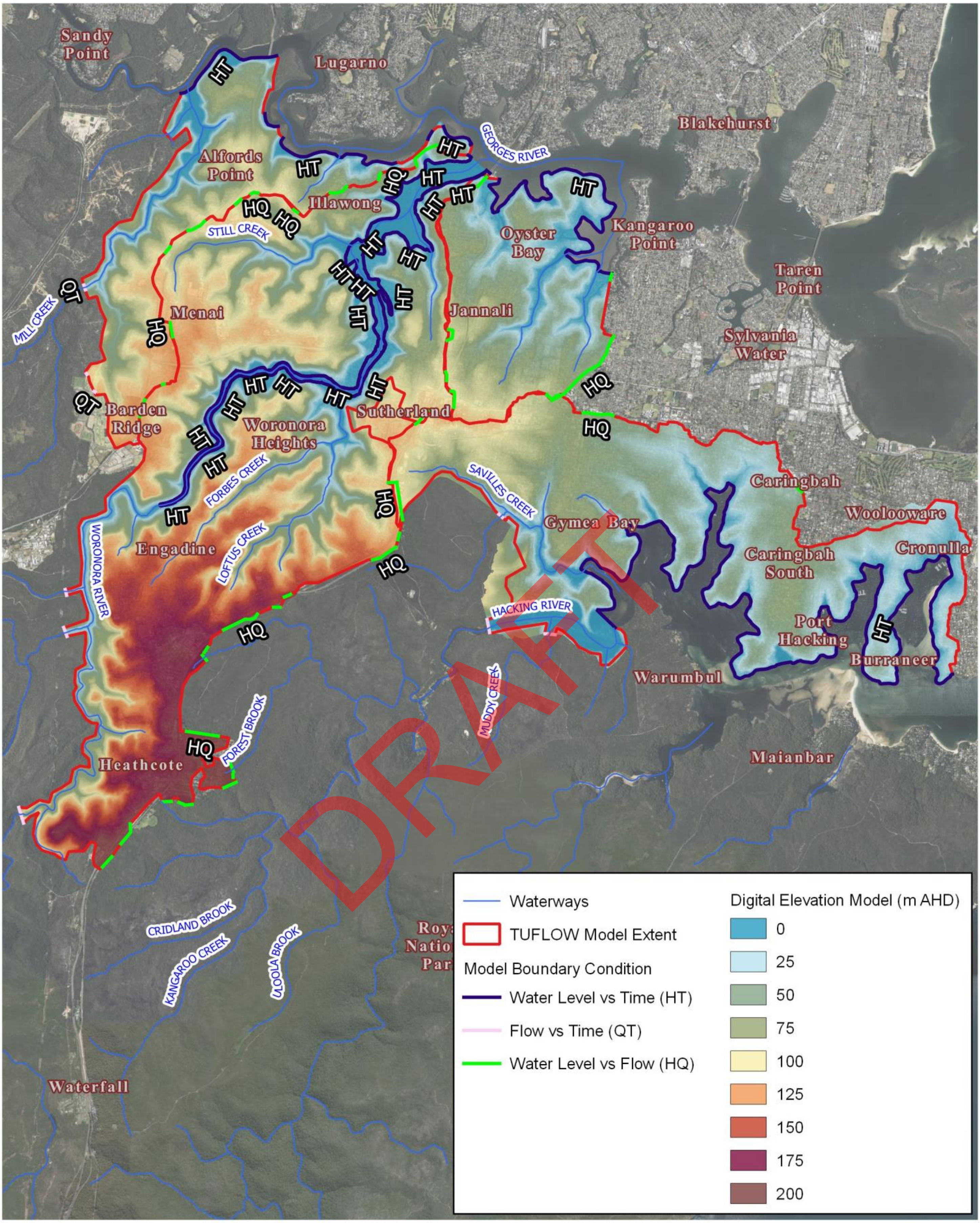
4.3.9 Model Boundary Conditions

The specification of suitable boundary conditions that account for design flows into the system and tailwater conditions at the outlet of the system is a critical component of flood simulations. The boundary conditions used for the TUFLOW model include:

- Upstream boundary conditions: For the Georges River West, Port Hacking and Woronora River TUFLOW models, flow hydrographs (i.e. flow vs time (QT)) from the WBNM model were applied at the upstream boundary of the model extents (noting that the Georges River East catchment does not have any contributing upstream catchment that does not lie within the TUFLOW model extent) (refer locations shown in Figure 4.6). The hydrographs for historical and design events were derived from the results of the WBNM hydrologic model developed for the study (discussed further in Section 5 and Section 6).
- Local Inflow conditions: Local catchment runoff hydrographs derived by the WBNM model were applied directly to the hydraulic models as inflow hydrographs. For sub-catchments with modelled stormwater drainage, the inflows were applied directly to the 2D domain where the cells are connected to the 1D stormwater network (i.e. inflows are directly applied to the top of the pit inlet). The advantage of this method is that any blockage assigned to a pit will be appropriately modelled. For sub-catchment areas containing no stormwater drainage network, the catchment runoff is applied directly to the 2D domain, being applied to the outlet of the catchment. The hydrographs for historical and design events were derived from the results of the WBNM hydrologic model developed for the study (discussed further in Section 5 and Section 6).
- Downstream boundary conditions: For the respective models, tailwater conditions were applied based on water (or tidal) levels within the receiving watercourse (discussed further in Section 5 and Section 6) or stage-flow relationship at the locations shown in Figure 4.6 as follows:
  - HT: The water level at the boundary, which can be specified as a static or varying water level over time (i.e. stage hydrograph). As shown in Figure 4.6, HT boundaries were included along the Woronora River banks and outlets to the Georges River and Port Hacking.
  - HQ: A normal depth condition where the stage-discharge relationship is automatically calculated based on a specified water surface slope that is assumed to be equal to the topographic gradient (i.e. uniform flow).



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TUFLOW MODEL BOUNDARY

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5 Model Verification

5.1 Overview

Computer flood models are approximations of very complex processes and are generally developed using parameters that may not be known with a high degree of certainty and/or are subject to natural variability. This includes catchment roughness (i.e. Manning's n values), initial/continuing losses, and loss coefficients and blockage at culverts, bridges, pipes and stormwater pits. Accordingly, hydrologic and hydraulic models should be calibrated and/or validated against available historical flow and flood level information to establish the values of key model parameters and confirm that the models are capable of adequately representing real world flood behaviour.

The selection of suitable historical events for calibration of the computer models is largely dependent on available historical flood information (e.g. rainfall, flow and flood level data). Ideally, the calibration and validation process should cover a range of flood magnitudes to demonstrate the suitability of the model for the range of design event magnitudes considered.

5.2 Approach

Calibration data is the data available for historical floods that can be used to compare against modelling results. It is typically necessary to have the following datasets to enable full calibration of hydrologic and hydraulic models:

- Pluviograph (also referred to as sub-daily or continuous) rainfall data describing the temporal and spatial distribution of rainfall across each catchment for historical floods, particularly for short duration, intense rainfall often associated with overland flow flooding that often has high spatial variability.
- Stream gauge data describing the time variation in flows/stages at discreet locations for historical floods.
- Historical flood marks describing the peak level/depth that water reached during historical floods (e.g. surveyed debris marks and anecdotal data such as eyewitness accounts, photos and videos).

No surveyed flood marks are available within the study area to provide historical flood levels and depths to any great degree of certainty, and there are no stream gauges within three (3) of the study catchments that provided recorded historical flows or levels. Therefore, formal calibration of the flood models was not possible.

However, review of available data highlighted flood events in May 2003, April 2015, February 2020 and March 2021 with sufficient data to support a model verification process, including:

- Two available stream gauges (Stations 213102 and 213211) located in the study area to complete calibration of the hydrologic model developed for the Woronora River catchment. Data at Woronora River at the Needles – North Engadine (Station 213211) was selected as this gauge lies within the study area. No specific calibration of the hydrologic modelling of the George River East, Georges River West and Port Hacking catchments is possible.
- Suitable daily and pluviograph rainfall records available either within or in close proximity to the study area to enable the determination of the total rainfall, and both spatial and temporal variability of rainfall across the catchments for these recent flood events.
- Historical flood information at discrete locations across the study area. This information includes reported/known locations of inundation, descriptions of flood behaviour and photographic/video

records of flood conditions. Whilst the quantity and spread of data throughout the study area is limited, it does provide some indication of extent and depth of inundation, and locations of some of the more severely inundated areas during these events.

Therefore, it was possible to undertake a “pseudo” verification of the of the computer models for the four identified flood events by routing recorded rainfall from available rain gauges through the hydrologic model. The flows from the hydrologic model were then routed through the hydraulic model. The performance of the models was assessed by comparing modelled outputs to recorded data in terms of:

- Shape, timing and peak flows of the hydrograph recorded at the Woronora River at the Needles – North Engadine (Station 213211) stream gauge
- Correlation between known/reported flood locations and predicted flood extents
- Comparison of photographs of historical flooding with predicted flood extents and depths.

The verification process and results of the WBNM and TUFLOW modelling for these historical events are presented in the following sections.

5.3 May 2003 Event

5.3.1 Hydrologic Modelling

Rainfall

Heavy rain on the morning of 13 May 2003 led to severe flooding across the Sutherland Shire (Bewsher, 2004). This was reported to result in property and above floor flooding, road closures and associated property damage.

The recorded daily totals for active gauges for the 6-day period between 13 May 2003 and 18 May 2003 (for the 24 hours to 9am) are shown in Table 5.1. Ten sub-daily gauges and 20 daily gauges within the study catchments, wider LGA and surrounding areas were operational during this event, providing sufficient data to define spatial and temporal variability of rainfall.

Table 5.1 Recorded Daily Rainfall Totals for June 2016 Events

Station No.	Station Name	Station Type	Daily Rainfall to 9am (mm)						Total Rainfall (mm)
			13 May	14 May	15 May	16 May	17 May	18 May	
566018	Cronulla WRP	Pluvio	62	145	66.5	64	33.5	6.5	377.5
566078	South Cronulla Bowling Club	Pluvio	48	109	59.5	74	25.5	13	329.0
566088	Malabar WWTP	Pluvio	43	85.5	56	53.5	34	8.5	280.5
566091	Kyeemagh RSL Club	Pluvio	35	104.5	51	44.5	40	13	288.0
566092	Sutherland Bowling Club	Pluvio	74	119.5	54	48.5	27	25	348.0
566098	Caringbah Bowling Club	Pluvio	72	155.5	42.5	63	24	21.5	378.5
567078	Glenfield WWTP	Pluvio	16.5	56.5	16.5	29	12	26	156.5
568162	Balgownie Reservoir	Pluvio	32.5	101	78	46.5	48	13	319.0
568172	Bulli - Woonona Bowling Club	Pluvio	35	112	62.5	49	35	12	305.5
5CPS02	Belmore BC	Pluvio	35	92	32	28	18.5	14	219.5

Station No.	Station Name	Station Type	Daily Rainfall to 9am (mm)						Total Rainfall (mm)
			13 May	14 May	15 May	16 May	17 May	18 May	
66036	Marrickville Golf Club	Daily	30.0	85.0	43.0	37.0	26.0	15.0	236.0
66037	Sydney Airport AMO	Daily	32.0	94.2	48.8	44.2	34.0	9.0	262.2
66058	Sans Souci (Public School)	Daily	45.0	114.0	47.0	45.0	18.0	15.0	284.0
66078	Lucas Heights (ANSTO)	Daily	27.8	74.6	42.2	56.4	22.0	29.2	252.2
66137	Bankstown Airport AWS	Daily	30.0	59.0	17.0	24.0	14.0	18.0	162.0
66148	Peakhurst Golf Club	Daily	32.0	113.0	46.0	32.0	21.0	15.0	259.0
66164	Rockwood (Hawthorne Ave)	Daily	54.2	75.0	36.0	26.5	20.0	14.4	226.1
66168	Milperra Bridge (Georges River)	Daily	26.0	60.0	19.0	25.0	13.0	15.0	158.0
66176	Audley (Royal National Park)	Daily	51.0	143.0	42.0	55.0	32.0	42.0	365.0
66194	Canterbury Racecourse AWS	Daily	39.2	84.8	36.2	29.4	21.4	14.4	225.4
66204	Oyster Bay (Green Point Road)	Daily	30.0	101.0	59.0	43.5	18.2	21.4	273.1
68160	Campbelltown (Kentlyn (Georges River Road)	Daily	39.0	45.0	29.0	39.0	9.0	11.0	172.0
66014	Cronulla South Bowling Club	Daily	54.0	117.0	64.0	76.0	28.6	16.6	356.2
66054	Revesby (Paten Street)	Daily	22.6	80.8	23.4	29.4	20.0	21.2	197.4
66072	Kurnell (Caltex Oil Refinery)	Daily	35.6	81.4	71.4	73.8	31.8	3.0	297.0
66181	Oatley (Woronora Parade)	Daily	30.0	108.8	56.6	37.8	21.0	17.8	272.0
66195	Sydney Olympic Park	Daily	38.0	77.0	34.0	29.0	14.0	16.0	208.0
67020	Liverpool	Daily	26.0	34.0	19.0	35.6	8.6	23.8	147.0
67117	Holsworthy Control Range	Daily	16.0	62.0	22.0	29.0	11.0	28.0	168.0
68231	Ruse (Denison Street)	Daily	21.0	32.2	28.4	26.2	18.0	8.0	133.8

Whilst there is spatial variability in terms of relative daily rainfall depths across the region, the gauges within the study area indicate total rainfall of approximately 270 to 380 mm between 13 May and 18 May 2003. It can be seen in Table 5.1 that the largest total rainfall in the study area was recorded at Caringbah Bowling Club (Station 566098), with 378.5 mm over the 6-day period and 270 mm in the 3 days from 12 May and 15 May 2013. The most significant rainfall depths across the area (i.e. up to 155.5 mm) were recorded on 13 May 2003 (i.e. 24-hour to 9am on 14 May 2003).

Based on proximity to sub-catchments and general consistency with daily gauges, five sub-daily gauges were used to define the rainfall depth and temporal pattern for the modelling of the May 2003 event. Analysis was undertaken on these gauges, with the rainfall pattern based on 3-hourly rainfall hyetograph shown in Figure B.1 (A.1). This figure provides an insight into the temporal and spatial distribution of the rain and the intensity of the rainfall throughout the event, indicating:

- Persistent and substantial rain fell at all five gauges during this period.

- A generally similar pattern of rainfall between the gauges (particularly within the LGA) and therefore a spatially consistent rainfall pattern across the area.
- Some spatial variability in rainfall depths between the gauges, however an intense period of rainfall is noted at all gauges on 13 May 2003.
- Intense bursts of rain (i.e. higher rainfall depths during short periods) were recorded within these 6 days.
- The majority of rainfall occurred on 13 May 2003, with the heaviest rainfall recorded between 6am and 12pm.

Intensity-Frequency-Duration (IFD) calculations using the Rainfall IFD Data System published by the BoM were used to calculate the AEP of recorded rainfall, as presented in Figure B.2 (A.1). In order to gain an appreciation of the relative intensity and magnitude of the May 2003 event within this region of southern Sydney, the recorded rainfall depths at the five sub-daily gauges used for analysis were compared with design IFD rainfall curves, as presented in Figure B.2 (A.1).

The AEPs across the gauges indicate a range of storm magnitudes across the LGA. The rainfall recorded at Caringbah Bowling Club (Station 566098) and Sutherland Bowling Club (Station 566092) was approximately equivalent to or larger than 1% AEP for durations between 1 hour and 6 hours. Therefore, the high intensity rainfall recorded at these gauges during the main burst of the event (i.e. the morning of 13 May 2003) is estimated to exceed a 1% AEP magnitude storm event. For durations from 6 hours to 24 hours, the rainfall recorded at the gauges during this event was generally between 20% and 1% AEP.

A rainfall surface grid (i.e. isohyet grid) provides a visual and spatial representation of the recorded rainfall across the catchment during an event. Figure B.3 (A.1) shows the isohyet grid illustrating the spatial variability in rainfall during the 6-day event in May 2003 using the following method:

- Combining the available daily and sub-daily rainfall totals for the event based on the closest, active gauges to the catchment. If a gauge has both daily and sub-daily rainfall total available, the sub-daily total will be used for the analysis.
- The rainfall grid was generated by interpolating the "natural neighbour" of the total rainfall at each gauge location.

Figure B.3 (A.1) indicates that higher rainfall depths were recorded in the eastern portion of the LGA, including the Port Hacking catchment.

The catchment average rainfall was applied to each sub-catchment by sampling the rainfall surface grid. Each sub-catchment used the closest available sub-daily gauge or similar topographic characteristics to define the temporal pattern. This approach was used for all historical events used for model verification.

Rainfall Losses

The conceptual model known as the "Initial Loss – Continuing Loss model" has been adopted for this study, 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 or wetting of the catchment (referred to as the "Initial Loss"). Further losses are applied at a constant rate to simulate infiltration and 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 catchments include extensive urban areas that are relatively impervious and 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. Accordingly, different initial and continuing losses were applied to the WBNM for pervious and impervious areas.

For historical events, the pervious initial loss was based on antecedent catchment conditions (i.e. catchment wetness and rainfall prior to the modelled storm burst), noting that there had been dry weather conditions with little (<1 mm daily total) or no rain recorded at local rain gauges in the 5 days preceding the 2003 event. The following losses were applied:

- Pervious areas:
  - Initial Loss = 65 mm
  - Continuing Loss = 0.5 mm/hr
- Impervious areas:
  - Initial Loss = 1 mm.

No losses were assumed across waterbodies within the catchments as any rain falling on water will directly contribute runoff to that waterbody (i.e. no potential for interception of infiltration).

Comparison with Historical Flow Data

The WBNM model was used to simulate rainfall-runoff behaviour for the 3 days between 9am 12 May 2003 and 9am 15 May 2003 based on the rainfall and rainfall loss information presented in the preceding sections. This enabled discharge hydrographs to be generated for each sub-catchment.

Recorded flows at Woronora River at the Needles – North Engadine (Station 213211) provide the principal verification dataset available for the hydrologic model for this event. A comparison of recorded and modelled flow hydrographs for the May 2003 event at this gauge is shown in Figure 5.1. It can be seen from Figure 5 1 that the WBNM model was able to reliably replicate the general shape of the hydrograph and magnitude of the first peak and the subsequent rises of the gauge flow.

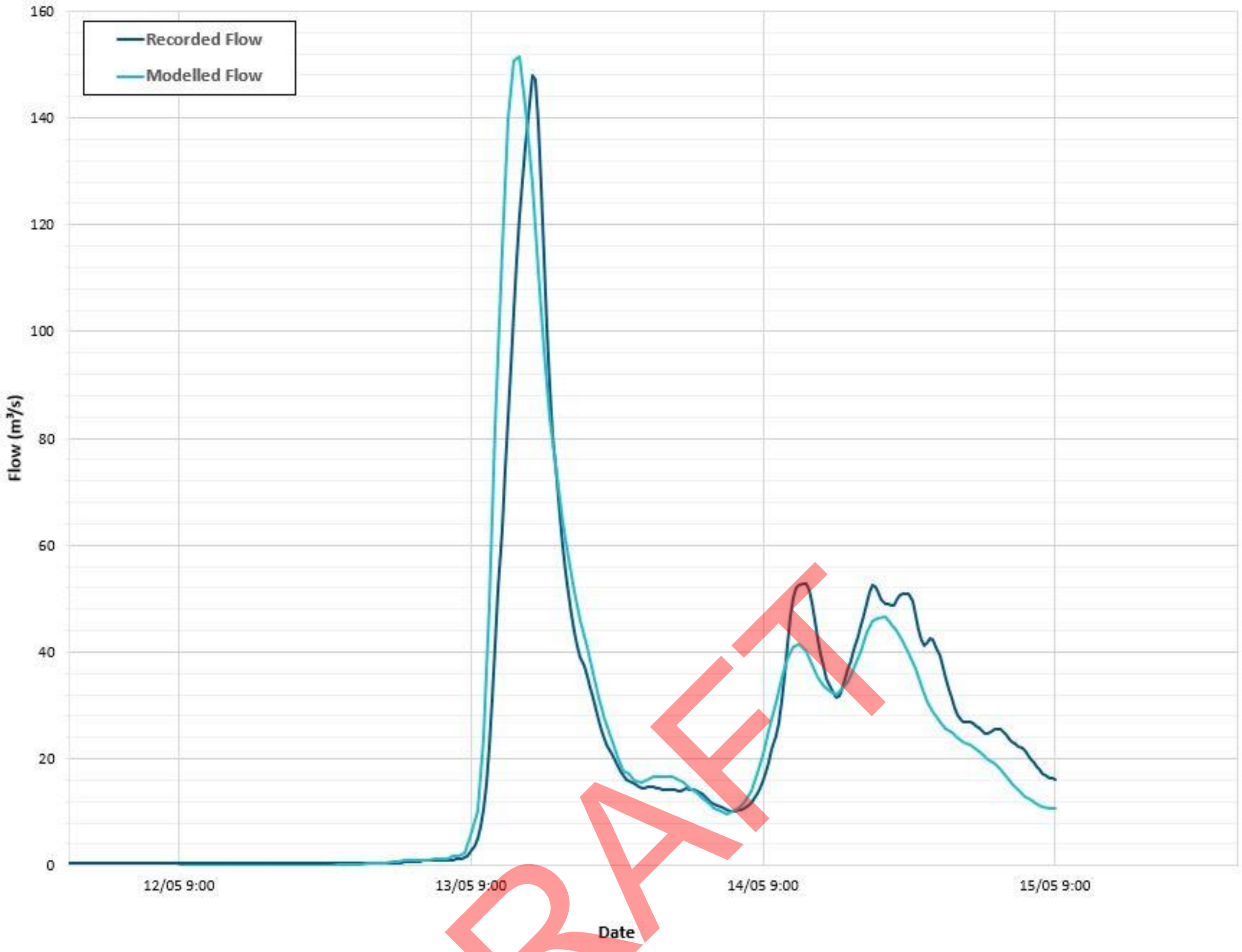


Figure 5.1 Comparison of Gauged and Modelled Flow for May 2003 Event for Woronora River at the Needles – North Engadine (Station 213211)

5.3.2 Hydraulic Modelling

Inflow Boundary Conditions
The discharge hydrographs generated by the WBNM model were used to define inflows across each TUFLOW model area for the May 2003 flood simulation.

Downstream Boundary Condition
In most instances, tidal water level conditions will not be critical in determining overland flood levels in the local catchments. For simulation of all historical events, a static water level of 1.4 mAHD was adopted and corresponds to maximum water level during a representative High High Water Springs (Solstice Spring) (HHWS(SS)) level from 'Floodplain Risk Management Guide: Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterway' (OEH, 2015). This same approach was applied to all historical events discussed in the following sections.

Historical Flood Data
There are no stream gauges within the TUFLOW model extents that can provide recorded water levels, nor any surveyed flood marks from the event. Therefore, historical flood data is limited to flood complaints following the 13 May 2003 event. As discussed in Section 2.10.1, this included a total of 505 complaints that were categorised based on issue, location and flooding type to filter the complaints to

130 potential overland flood locations. These correspond to locations of complaints of flooding above floor level, flooding on property, flooding in public spaces and flooding within roadways.

Comparison with Reported Flooding Locations
The TUFLOW models were used to simulate flood conditions from 9am 12 May to 9am 15 May 2003. The simulated peak flood depths and distribution of inundation during this event are presented in Figure A-1.A to Figure A-1.J in Volume 2: Flood Mapping.

The available data does not provide definitive flood levels, but rather indicative locations of flooding and observations of flow paths and inundation extent. Therefore, only qualitative verification of the model could be completed by comparing the distribution of reported flooding locations from Council's database with the extent of flooding predicted by the results of the TUFLOW hydraulic models. This approach is considered suitable for the broadscale nature of this study.

Comparison of reported flooding locations with the extent of inundation predicted by the TUFLOW models indicates reasonable correlation between reported flooding locations and predicted flood extent for this event.

5.4 April 2015 Event

5.4.1 Hydrologic Modelling

Rainfall
During the April 2015 event, rain fell over a 3-day period with the most significant rainfall recorded over a short period of time between 12am and 12pm on 22 April 2015.

The recorded daily totals (for the 24 hours to 9am) between 21 April and 23 April 2015 are shown in Table 5.2. Twenty-three sub-daily gauges and 14 daily gauges within the study area or wider local region were operational during this event, providing sufficient data to define spatial and temporal variability of rainfall.

Table 5.2 Recorded Daily Rainfall Totals for June 2016 Events

Station No.	Station Name	Station Type	Daily Rainfall to 9am (mm)			Total Rainfall (mm)
			21 April	22 April	23 April	
566018	Cronulla WRP	Pluvio	84.5	82.5	61	228.0
566031	Revesby Bowling Club	Pluvio	74.5	71.5	54	200.0
566047	Mortdale Bowling Club	Pluvio	99	98	71.5	268.5
566056	Yarrawarrah	Pluvio	100.5	135.5	50	286.0
566062	Bexley Bowling Club	Pluvio	131.5	91	69.5	292.0
566069	Bankstown Trotting Club	Pluvio	79.5	77.5	61.5	218.5
566072	Kyle Bay Bowling Club	Pluvio	65.5	67.5	77	210.0
566075	Barden Ridge Dam	Pluvio	84	92.5	58.5	235.0
566078	South Cronulla Bowling Club	Pluvio	72	88	91	251.0
566088	Malabar WWTP	Pluvio	91.5	111	52	254.5

Station No.	Station Name	Station Type	Daily Rainfall to 9am (mm)			Total Rainfall (mm)
			21 April	22 April	23 April	
566091	Kyeemagh RSL Club	Pluvio	82	65.5	68	215.5
566092	Sutherland Bowling Club	Pluvio	90	123	72	285.0
566093	Engadine Bowling Club	Pluvio	100	131.5	36	267.5
566098	Caringbah Bowling Club	Pluvio	74	87.5	71	232.5
566174	Helensburgh WS0049	Pluvio	71.5	116	17.5	205.0
566175	Menai Reservoir	Pluvio	108.5	112	57	277.5
567078	Glenfield WWTP	Pluvio	76.5	67	47.5	191.0
568153	Bellambi Bowling Club	Pluvio	74.5	81	40	195.5
568162	Balgownie Reservoir	Pluvio	81.5	89.5	37.5	208.5
568172	Bulli - Woonona Bowling Club	Pluvio	73	80	31	184.0
568174	Eagleview Rd Reservoir, Minto	Pluvio	73	64.5	16.5	154.0
568179	Campbelltown Bowling Club	Pluvio	83.5	64.5	8	156.0
5CPS02	Belmore BC	Pluvio	140	91.5	57.5	289.0
66036	Marrickville Golf Club	Daily	123.0	104.0	59.0	286.0
66037	Sydney Airport AMO	Daily	88.6	72.8	70.8	232.2
66058	Sans Souci (Public School)	Daily	90.0	85.0	78.0	253.0
66070	Strathfield Golf Club	Daily	109.0	108.0	54.0	271.0
66078	Lucas Heights (ANSTO)	Daily	95.0	102.6	28.8	226.4
66137	Bankstown Airport AWS	Daily	79.0	72.8	61.0	212.8
66148	Peakhurst Golf Club	Daily	84.0	81.0	70.0	235.0
66161	Holsworthy Aerodrome AWS	Daily	67.0	70.2	47.6	184.8
66164	Rockwood (Hawthorne Ave)	Daily	134.0	115.2	60.6	309.8
66168	Milperra Bridge (Georges River)	Daily	59.0	58.0	52.0	169.0
66176	Audley (Royal National Park)	Daily	74.0	116.0	64.0	254.0
66194	Canterbury Racecourse AWS	Daily	123.0	101.8	57.2	282.0
66204	Oyster Bay (Green Point Road)	Daily	75.0	106.0	64.2	245.2
68160	Campbelltown (Kentlyn (Georges River Road)	Daily	80	77	12	169

It can be seen in Table 5.2 that the largest total rainfall in the study area was recorded at Yarrawarrah (Station 566056), with a total of 286 mm over the 3-day period. Nearby gauges including Sutherland

Bowling Club (Station 566092) and Menai Reservoir (Station 566175) also recorded similar significant rainfall totals of 285 mm and 277.5 mm, respectively.

Based on proximity to sub-catchments and general consistency with daily gauges, 11 sub-daily gauges were used to define the rainfall depth and temporal pattern for the April 2015 event model verification. Analysis was undertaken on these gauges, with the rainfall pattern shown in Figure B.4 to Figure B.6 (enclosed in A.1) as a 3-hourly hyetograph. This indicates:

- Persistent and substantial rain fell at these gauges during this period.
- A generally similar pattern and depth of rainfall between the gauges (particularly within the LGA), indicating spatially and temporally consistent rainfall across the area.
- Intense bursts of rain (i.e. higher rainfall depths during short periods) were recorded across these 3 days. In particular, high intensity rainfall and significant depths were recorded in the study area during the morning of 22 April 2015.

In order to gain an appreciation of the relative intensity and magnitude of the April 2015 event, the recorded rainfall depths at the 11 sub-daily gauges used for analysis were compared with design IFD rainfall curves, as presented in Figure B.7 (A.1). This indicates a range of storm magnitudes across the LGA. For durations between 30 minutes and 6 hours, the rainfall event was typically equivalent to between 20% AEP and 5% AEP for gauges within the study area.

Figure B.8 (A.1) shows the isohyet grid illustrating the spatial variability in rainfall during the 3-day event in April 2015 (see Section 5.3.1.1 for method of creating the isohyet grid). This figure indicates that higher rainfall depths were recorded in the central portion of the LGA, including in the Woronora River catchment.

Rainfall Losses

For this historical event, the pervious initial loss was based on antecedent catchment conditions (i.e. catchment wetness and rainfall prior to the modelled storm burst), noting that there had been low daily rainfall totals (1-2 mm) recorded at local rain gauges in the 3 days preceding the 2015 event . The following losses were applied:

- Pervious areas:
  - Initial Loss = 50 mm
  - Continuing Loss = 0.5 mm/hr
- Impervious areas:
  - Initial Loss = 1 mm.

No losses were assumed across waterbodies within the catchments as any rain falling on water will directly contribute runoff to that waterbody (i.e. no potential for interception of infiltration).

Comparison with Historical Flow Data

The WBNM model was used to simulate rainfall-runoff behaviour for the April 2015 event based on the rainfall and rainfall loss information presented in the preceding sections. This enabled discharge hydrographs to be generated for each sub-catchment.

A comparison of recorded and modelled flow hydrographs at Woronora River at the Needles – North Engadine (Station 213211) for the April 2015 event at this gauge is shown in Table 5.2. The WBNM model was able to replicate the multiple peaks along the rising and falling limbs of the recorded flow hydrograph, as well as the time of the peak. However, it was unable to match the magnitude of the recorded peak flows which was possibly the result of localised, intense rainfall bursts that were not captured by the sub-daily rainfall gauges available for this event, debris accumulation at the gauge location or flow releases from the Woronora Dam upstream of this gauge.

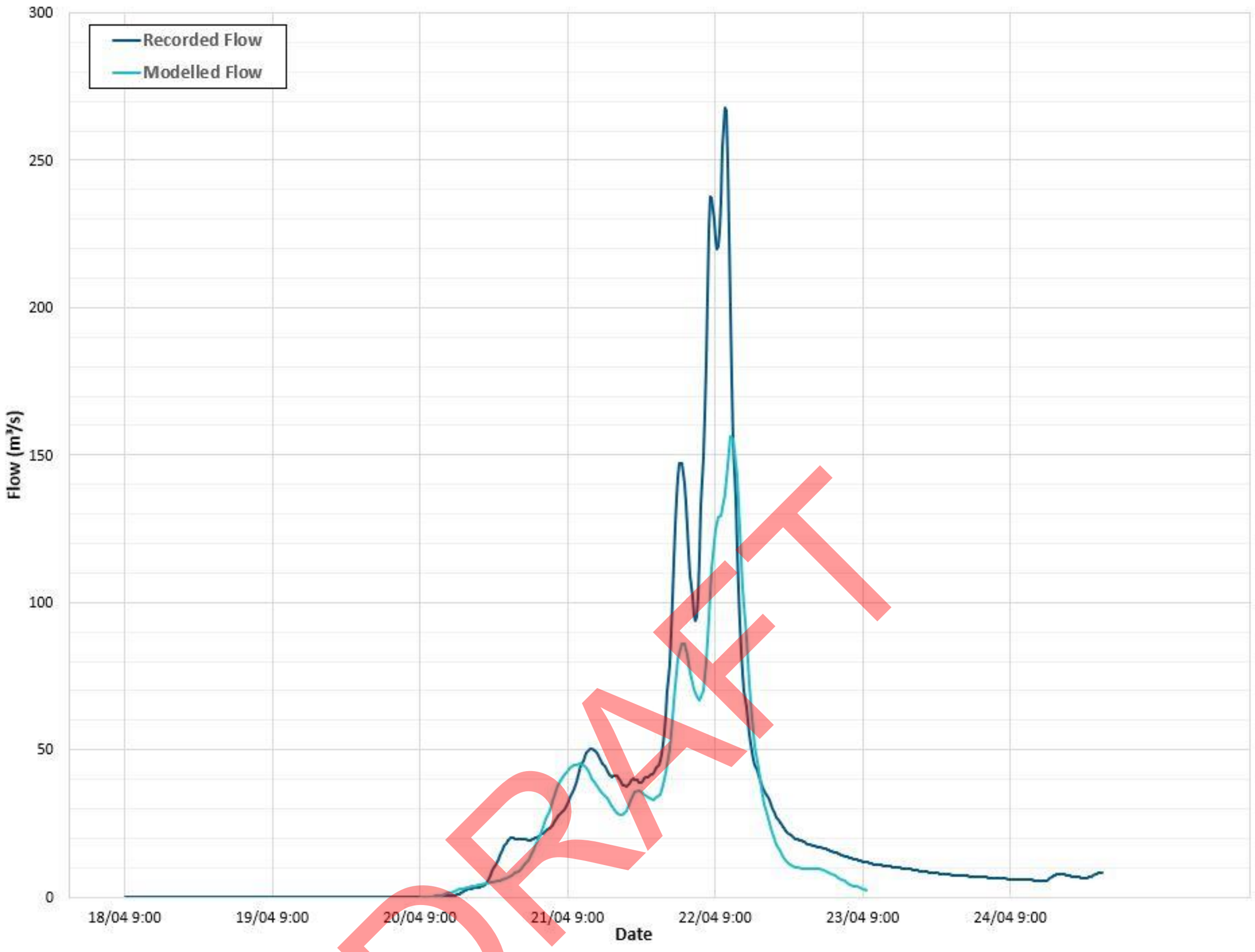


Figure 5.2 Comparison of Gauged and Modelled Flow for April 2015 Event for Woronora River at the Needles – North Engadine (Station 213211)

5.4.2 Hydraulic Modelling

Inflow Boundary Conditions

The discharge hydrographs generated by the WBNM model were used to define inflows across each TUFLOW model area for the April 2015 flood simulation.

Historical Flood Data

There are no stream gauges situated within the TUFLOW model extents that can provide recorded water levels, nor any surveyed flood marks from this event. Therefore, historical flood data is limited to flood complaints data following the April 2015 event. As discussed in Section 2.10.1, this included complaints at 29 potential overland flood locations.

Comparison with Reported Flooding Locations

The TUFLOW models were used to simulate flood conditions for 3 days from 9am 20 April to 9am 23 April 2015. The simulated peak flood depths and distribution of inundation during this event are presented in Figure A-2.A to Figure A-2.J in Volume 2: Flood Mapping.

Due to available data limitations, only qualitative verification of the model could be completed by comparing the distribution of reported flooding locations from Council's database with the extent of flooding predicted by the results of the TUFLOW hydraulic models. Comparison of reported flooding locations with the flood extent predicted by the TUFLOW models indicates good correlation between reported flooding locations and predicted flood extent for this event.

5.5 February 2020 Event

5.5.1 Hydrologic Modelling

Rainfall

In February 2020, NSW experienced approximately two weeks of prolonged rainfall with intermittent heavy rainfall bursts. The February 2020 event occurred as a result of an east coast low between 7 February and 10 February 2020.

The recorded daily totals (for the 24 hours to 9am) covering the 3-day period from 9:00am on 7 February 2020 to 9:00am on 10 February are provided in Table 5.3. Twenty-three sub-daily gauges and 12 daily gauges within the study area or wider local region were operational during this event, providing sufficient data to define spatial and temporal variability of rainfall.

Table 5.3 Recorded Daily Rainfall Totals for the February 2020 Event

Station No.	Station Name	Station Type	Daily Rainfall to 9am (mm)			Total Rainfall (mm)
			8 Feb	9 Feb	10 Feb	
566018	Cronulla WRP	Pluvio	46	43.5	105.5	195.0
566031	Revesby Bowling Club	Pluvio	47.5	90	191	328.5
566047	Mortdale Bowling Club	Pluvio	63.5	91	171	325.5
566056	Yarrawarrah	Pluvio	60	86	171.5	317.5
566062	Bexley Bowling Club	Pluvio	72	104.5	183	359.5
566069	Bankstown Trotting Club	Pluvio	47	91.5	166.5	305.0
566072	Kyle Bay Bowling Club	Pluvio	52	59	141	252.0
566075	Barden Ridge Dam	Pluvio	54	80.5	178.5	313.0
566078	South Cronulla Bowling Club	Pluvio	46	43	91.5	180.5
566088	Malabar WWTP	Pluvio	34	67	148	249.0
566091	Kyeemagh RSL Club	Pluvio	43.5	64	114	221.5
566092	Sutherland Bowling Club	Pluvio	64	82.5	160.5	307.0
566093	Engadine Bowling Club	Pluvio	59	78.5	174.5	312.0
566098	Caringbah Bowling Club	Pluvio	46.5	51.5	129	227.0
566174	Helensburgh WS0049	Pluvio	96.5	67.5	181.5	345.5
566175	Menai Reservoir	Pluvio	64.5	88	185.5	338.0
567078	Glenfield WWTP	Pluvio	48	69	179.5	296.5

Station No.	Station Name	Station Type	Daily Rainfall to 9am (mm)			Total Rainfall (mm)
			8 Feb	9 Feb	10 Feb	
568153	Bellambi Bowling Club	Pluvio	85	54	128	267.0
568162	Balgownie Reservoir	Pluvio	99	40.5	125.5	265.0
568172	Bulli - Woonona Bowling Club	Pluvio	58.5	76.5	130.5	265.5
568174	Eagleview Rd Reservoir, Minto	Pluvio	33.5	59.5	151	244.0
568179	Campbelltown Bowling Club	Pluvio	41.5	50	176.5	268.0
5CPS02	Belmore BC	Pluvio	59.5	89.5	183.5	332.5
66036	Marrickville Golf Club	Daily	65.0	78.0	194.0	337.0
66037	Sydney Airport AMO	Daily	60.0	77.8	161.0	298.8
66058	Sans Souci (Public School)	Daily	51.0	39.0	100.0	190.0
66078	Lucas Heights (ANSTO)	Daily	57.2	70.4	169.8	297.4
66137	Bankstown Airport AWS	Daily	40.8	79.2	159.6	279.6
66148	Peakhurst Golf Club	Daily	67.0	100.0	225.0	392.0
66161	Holsworthy Aerodrome AWS	Daily	48.6	61.0	183.2	292.8
66168	Milperra Bridge (Georges River)	Daily	42.0	88.0	153.0	283.0
66176	Audley (Royal National Park)	Daily	57.0	69.0	161.0	287.0
66194	Canterbury Racecourse AWS	Daily	74.8	74.2	189.2	338.2
66204	Oyster Bay (Green Point Road)	Daily	67.6	62.0	174.0	303.6
68263	Holsworthy Defence AWS	Daily	56.8	59.2	224.2	340.2

Within the LGA, Menai Reservoir (Station 566175) recorded both the highest daily total and highest total rainfall depth during the 3-day period, with 185.5 mm recorded in the 24-hours to 9am on 10 February 2020 and a 3-day total of 338 mm.

Based on proximity to sub-catchments and general consistency with daily gauges, 11 sub-daily gauges were used to define the rainfall depth and temporal pattern for the February 2020 event model verification. Analysis was undertaken on these gauges, with the rainfall pattern shown in Figure B.8 to Figure B.10 (Annex B) as a 2-hourly hyetograph. This indicates:

- Persistent and substantial rain fell at all 11 gauges during this period.
- Intense bursts of rain (i.e. higher rainfall depths during short periods) were recorded within these 3 days.
- Some spatial rainfall variability across the study area. Whilst patterns of rainfall are generally consistent across gauges in the southern, central and western areas of the study area (e.g. refer Engadine Bowling Club, Barden Ridge Dam and Menai Reservoir gauge), rainfall patterns in the eastern part of the LGA (e.g. Caringbah Bowling Club and South Cronulla Bowling Club) vary from rainfall patterns across other areas of the LGA.
- The majority of rainfall occurred on 9 February 2020 (i.e. 24-hours to 9am on 10 February 2020).

In order to gain an appreciation of the relative intensity and magnitude of the February 2020 event, the recorded rainfall depths at the 11 sub-daily gauges used for analysis were compared with design IFD rainfall curves, as presented in Figure B.11 (Annex B).

The annual exceedance probability across the gauges indicate a similar magnitude storm event across southern, central and western parts of the LGA for durations greater than 4.5 hours, in particular. For durations between 6 hours and 24 hours, Figure B.11 (Annex B) indicates the rainfall recorded during the February 2020 event was generally between 50% and 2% AEP. The two gauges in the east of the LGA (i.e., Caringbah Bowling Club and South Cronulla Bowling Club) indicate a comparatively lower AEP magnitude of between 10% and 50% AEP for durations longer than 6 hours.

Figure B.12 (Annex B) shows the isohyet grid illustrating the spatial variability in rainfall during the 3-day event in February 2020 (see Section 5.3.1.1 for method of creating the isohyet grid). This figure indicates that higher rainfall depths were recorded in the central and western parts of the LGA, including in the Georges River West and Woronora River catchments.

Rainfall Losses

For this historical event, the pervious initial loss was based on antecedent catchment conditions (i.e. catchment wetness and rainfall prior to the modelled storm burst), noting that there had been substantial and consistent rainfall (daily totals up to 12 mm) recorded at local rain gauges in the 5 days preceding the 2020 event. The following losses were applied:

- Pervious areas:
    - Initial Loss = 15 mm
    - Continuing Loss = 3.5 mm/hr
- Impervious areas:
    - Initial Loss = 1 mm.

No losses were assumed across waterbodies within the catchments as any rain falling on water will directly contribute runoff to that waterbody (i.e. no potential for interception of infiltration).

Comparison with Historical Flow Data

The WBNM model was used to simulate rainfall-runoff behaviour for the February 2020 event based on the rainfall and rainfall loss information presented in the preceding sections. This enabled discharge hydrographs to be generated for each sub-catchment.

A comparison of recorded and modelled flow hydrographs at Woronora River at the Needles – North Engadine (Station 213211) for the February 2020 event at this gauge is shown in Figure 5.3. The results indicate a good agreement between the initial response, timing, peak and shape of the modelled flow hydrograph to recorded conditions.

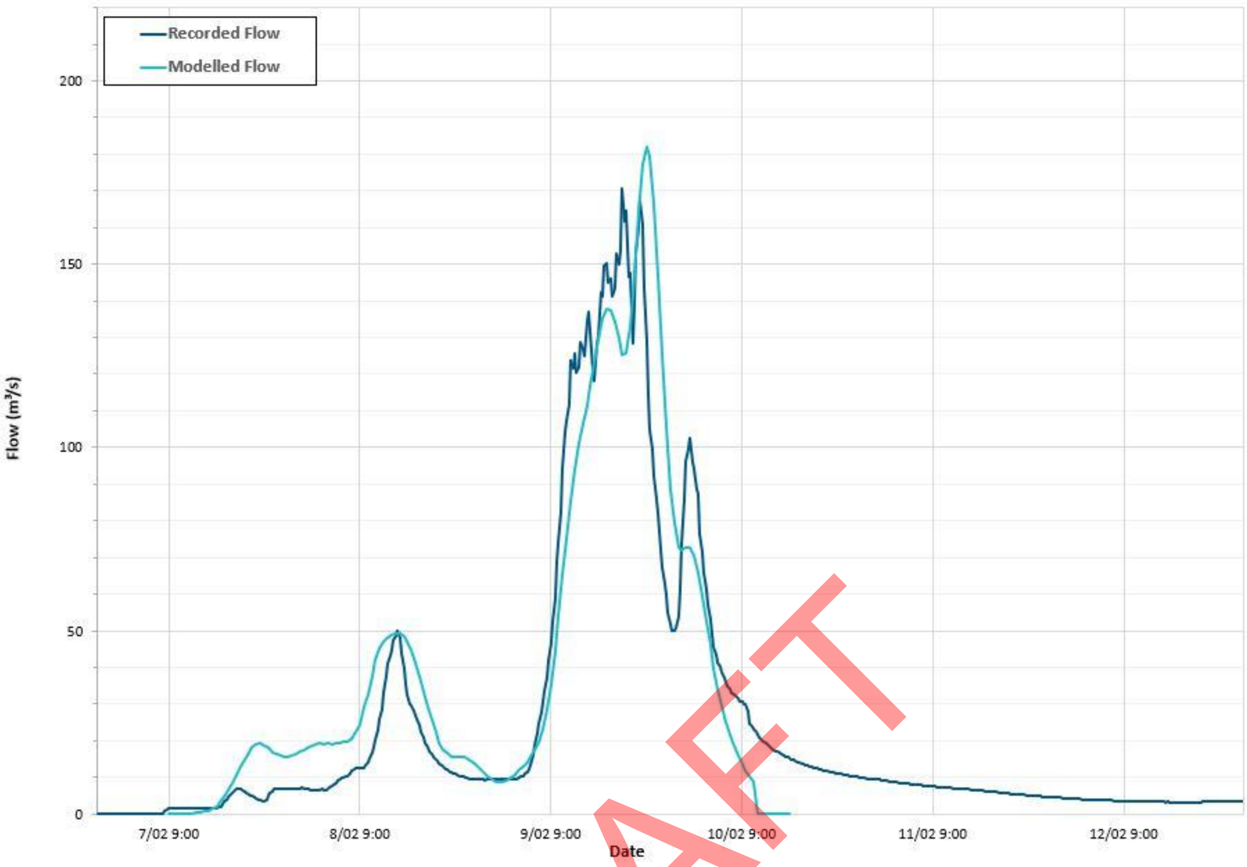


Figure 5.3 Comparison of Gauged and Modelled Flow for February 2020 Event for Woronora River at the Needles – North Engadine (Station 213211)

5.5.2 Hydraulic Modelling

Inflow Boundary Conditions

The discharge hydrographs generated by the WBNM model were used to define inflows across each TUFLOW model area for the February 2020 flood simulation.

Historical Flood Data

There are no stream gauges situated within the TUFLOW model extents that can provide recorded water levels, nor any surveyed flood marks from this event. Therefore, historical flood data is limited to flood complaints data following the February 2020 event. As discussed in Section 2.10.1, this included complaints at nine potential overland flood locations, as well as four (4) photographs taken during this event.

Council also provided details of the following five (5) known areas of flooding issues during this event (i.e. “hotspots”):

- Attunga Road and Wonga Road (Yowie Bay)
- Binney Street to Mirral Road (Caringbah South)
- Gymea Bay Road (Gymea)
- North Attunga Road and Forest Road (Yowie Bay)
- North West Arm Road and Hovea Place (Gray Point).

Comparison with Reported Flooding Locations

The TUFLOW models were used to simulate flood conditions for the 3 days from 9am 8 February to 9am 10 February 2020. The simulated peak flood depths and distribution of inundation during this event are presented in Figure A-3.A to Figure A-3.J in Volume 2: Flood Mapping.

Due to available data limitations, only qualitative verification of the model could be completed by comparing the distribution of reported flooding locations from Council's database with the extent of flooding predicted by the results of the TUFLOW hydraulic models. Comparison of reported flooding locations with the flood extent predicted by the TUFLOW models indicates good correlation between reported flooding locations and predicted flood extent for this event.

The results of the modelling show that floodwaters are predicted to be largely contained to waterways and open drainage channels, with overland flows concentrated along roadways. More significant overland flooding is predicted in several locations within the study area, including the following five known areas of flooding issues (i.e. "hotspots") listed above.

Comparisons of photographs depicting significant flooding during the February 2020 event with the predicted flood depths from the TUFLOW modelling provide a good representation of observed historical flood behaviour, as demonstrated in Figure 5.4, Figure 5.5 and Figure 5.6 (with the indicative location of the photograph shown as a red dot).

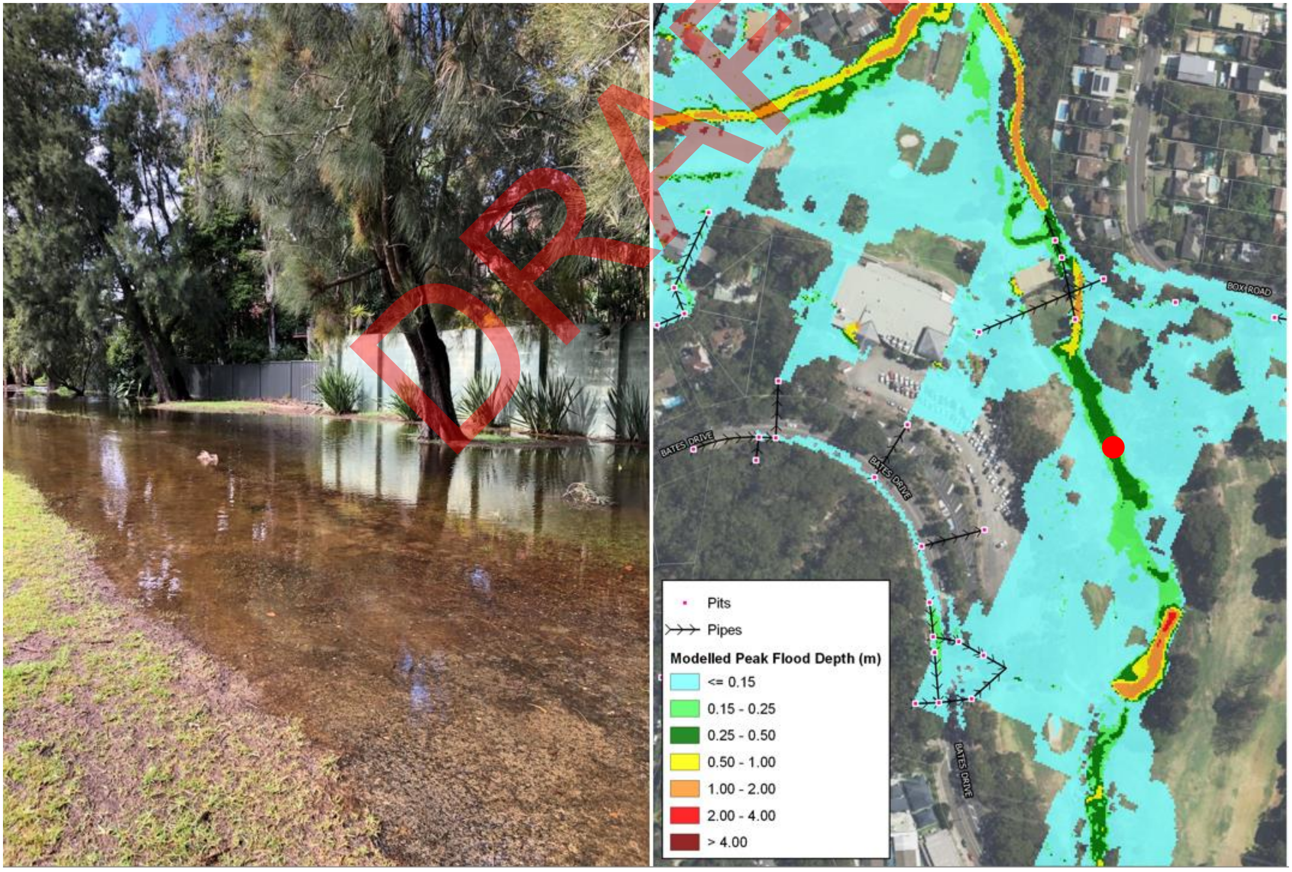


Figure 5.4 Photograph and Predicted Flood Depths for February 2020 Event – Kareela Golf Course, Bates Drive (Kareela)

Figure 5.5 Photograph and Predicted Flood Depths for February 2020 Event – Corner President Avenue and North West Arm Road (Gymea)

Figure 5.6 Photograph and Predicted Flood Depths for February 2020 Event – Ellesmere Road (Gymea Bay)

5.6 March 2021 Event

5.6.1 Hydrologic Modelling

Rainfall

Extreme multi-day rainfall and flooding affected many parts of eastern and central Australia from 17 March to 26 March 2021 as a result of a blocking high pressure system became established in the Tasman Sea, directing a strong, low pressure trough off north-western Australia south-east towards the NSW coast over the 10-day period.

The recorded daily totals (for the 24 hours to 9am) between 20 March to 24 March 2021 are provided in Table 5.4. Twenty-three sub-daily gauges and 14 daily gauges within the study area or wider local region were operational during this event, providing sufficient data to define spatial and temporal variability of rainfall.

Table 5.4 Recorded Daily Rainfall Totals for the March 2021 Event

Station No.	Station Name	Station Type	Daily Rainfall to 9am (mm)					Total Rainfall (mm)
			20 March	21 March	22 March	23 March	24 March	
566018	Cronulla WRP	Pluvio	31.5	47.5	28.5	43.5	30.0	181.0
566031	Revesby Bowling Club	Pluvio	35.5	105.0	26.5	48.5	24.0	239.5
566047	Mortdale Bowling Club	Pluvio	44.5	110.5	33.0	50.0	30.0	268.0
566056	Yarrawarrah	Pluvio	40.5	76.5	43.0	48.5	36.0	244.5
566062	Bexley Bowling Club	Pluvio	45.5	120.0	27.5	48.0	28.5	269.5
566069	Bankstown Trotting Club	Pluvio	41.0	103.5	29.5	49.5	24.0	247.5
566072	Kyle Bay Bowling Club	Pluvio	36.0	93.5	32.0	49.0	32.0	242.5
566075	Barden Ridge Dam	Pluvio	43.5	83.0	33.0	46.0	29.0	234.5
566078	South Cronulla Bowling Club	Pluvio	27.5	47.5	40.0	47.0	31.0	193.0
566088	Malabar WWTP	Pluvio	43.0	72.5	21.5	44.5	29.5	211.0
566091	Kyeemagh RSL Club	Pluvio	40.0	91.0	26.0	37.0	23.5	217.5
566092	Sutherland Bowling Club	Pluvio	50.5	62.5	36.5	45.5	29.0	224.0
566093	Engadine Bowling Club	Pluvio	37.5	77.0	41.0	50.0	34.0	239.5
566098	Caringbah Bowling Club	Pluvio	38.0	48.0	26.0	40.5	28.0	180.5
566174	Helensburgh WS0049	Pluvio	23.0	87.5	39.5	38.0	30.0	218.0
566175	Menai Reservoir	Pluvio	50.5	91.0	37.5	53.0	34.5	266.5
567078	Glenfield WWTP	Pluvio	31.0	109.0	37.5	56.0	23.0	256.5
568153	Bellambi Bowling Club	Pluvio	15.0	51.0	67.5	33.0	28.0	194.5
568162	Balgownie Reservoir	Pluvio	23.5	60.5	60.0	38.0	31.0	213.0
568172	Bulli - Woonona Bowling Club	Pluvio	15.5	51.0	82.0	32.5	27.0	208.0
568174	Eagleview Rd Reservoir, Minto	Pluvio	23.0	88.0	32.5	50.0	25.0	218.5
568179	Campbelltown Bowling Club	Pluvio	28.5	94.0	44.0	48.0	28.0	242.5
5CPS02	Belmore BC	Pluvio	59.0	100.0	25.0	50.0	28.5	262.5
66036	Marrickville Golf Club	Daily	55.0	107.0	24.0	42.0	25.0	253.0
66037	Sydney Airport AMO	Daily	37.2	110.0	30.0	34.8	24.6	236.6
66058	Sans Souci (Public School)	Daily	29.0	40.0	25.0	34.0	21.0	149.0
66078	Lucas Heights (ANSTO)	Daily	32.4	73.0	42.0	46.6	36.7	230.7

Station No.	Station Name	Station Type	Daily Rainfall to 9am (mm)					Total Rainfall (mm)
			20 March	21 March	22 March	23 March	24 March	
66137	Bankstown Airport AWS	Daily	34.6	92.0	41.6	47.8	26.2	242.2
66148	Peakhurst Golf Club	Daily	46.0	110.0	43.0	47.0	36.0	282.0
66161	Holsworthy Aerodrome AWS	Daily	36.4	96.4	36.6	49.0	29.6	248.0
66176	Audley (Royal National Park)	Daily	31.0	71.0	41.0	44.0	47.0	234.0
66194	Canterbury Racecourse AWS	Daily	56.8	100.4	25.0	44.8	26.2	253.2
66204	Oyster Bay (Green Point Road)	Daily	31.6	96.4	33.4	44.2	32.2	237.8
68160	Campbelltown (Kentlyn (Georges River Road)	Daily	26.0	97.0	47.0	50.0	35.0	255.0
68263	Holsworthy Defence AWS	Daily	39.6	83.0	36.4	45.6	38.6	243.2

It can be seen in Table 5.4 that the largest total rainfall in the study area was recorded at Menai Reservoir (Station 566175), with a total of 266.5 mm over the 5-day period. Nearby gauges including Yarrawarrah (Station 566056) and Engadine Bowling Club (Station 566093) also recorded similar significant rainfall totals of 244.5 mm and 239.5 mm, respectively. Higher daily rainfall totals were recorded on 20 March 2021.

Based on proximity to sub-catchments and general consistency with daily gauges, 11 sub-daily gauges were used to define the rainfall depth and temporal pattern for the March 2021 event model verification. Analysis was undertaken on these gauges, with the rainfall pattern shown in Figure B.13 to Figure B.15 (enclosed in A.1) as a 2-hourly hyetograph. This indicates:

- Persistent and substantial rain fell at these gauges during this period.
- A generally similar pattern and depths of rainfall between the gauges (particularly within the LGA), indicating spatially and temporally consistent rainfall across the area.
- Intense bursts of rain (i.e. higher rainfall depths during short periods) were recorded across these 5 days, for example there was a period of heavy downpour recorded between 3am and 5pm on 20 March 2021.

In order to gain an appreciation of the relative intensity and magnitude of the March 2021 event, the recorded rainfall depths at the 11 sub-daily gauges used for analysis were compared with design IFD rainfall curves, as presented in Figure B.16 (A.1). This indicates a range of storm magnitudes across the LGA. The rainfall event was typically equivalent to between 63.2% AEP and 40% AEP for gauges in the central and western parts of the study area. For gauges to the east of the study area (e.g. Caringbah Bowling Club), this storm is predicted to have a lower magnitude AEP of less than 63.2% for all storm durations.

Figure B.17 (A.1) shows the isohyet grid illustrating the spatial variability in rainfall during the 5-day event in March 2021 (see Section 5.3.1 for method of creating the isohyet grid). Figure B.17 (A.1) indicates that higher rainfall depths were recorded in the north-western portion of the LGA, including in the Georges River West and Woronora River catchments.

Rainfall Losses

For this historical event, the pervious initial loss was based on antecedent catchment conditions (i.e. catchment wetness and rainfall prior to the modelled storm burst), noting that there had been minor to moderate daily rainfall totals (1-24 mm) recorded at local rain gauges during the 6 days preceding the 2021 event and no rain on one day during that period. The following losses were applied:

- Pervious areas:
  - Initial Loss = 30 mm
  - Continuing Loss = 0.5 mm/hr
- Impervious areas:
  - Initial Loss = 1 mm.

No losses were assumed across waterbodies within the catchments as any rain falling on water will directly contribute runoff to that waterbody (i.e. no potential for interception of infiltration).

Comparison with Historical Flow Data

The WBNM model was used to simulate rainfall-runoff behaviour for the March 2021 event based on the rainfall and rainfall loss information presented in the preceding sections. This enabled discharge hydrographs to be generated for each sub-catchment.

A comparison of recorded and modelled flow hydrographs at Woronora River at the Needles – North Engadine (Station 213211) for the March 2021 event at this gauge is shown in Figure 5 6. The results indicate a good agreement between the initial response, timing and shape of the modelled flow hydrograph to recorded conditions.

Whilst the WBNM model is not reproducing the magnitude of the peaks, this is possibly the result of localised, intense rainfall bursts that were not captured by the sub-daily rainfall gauges available for this event, debris accumulation at the gauge location or flow releases from the Woronora Dam upstream of this gauge.

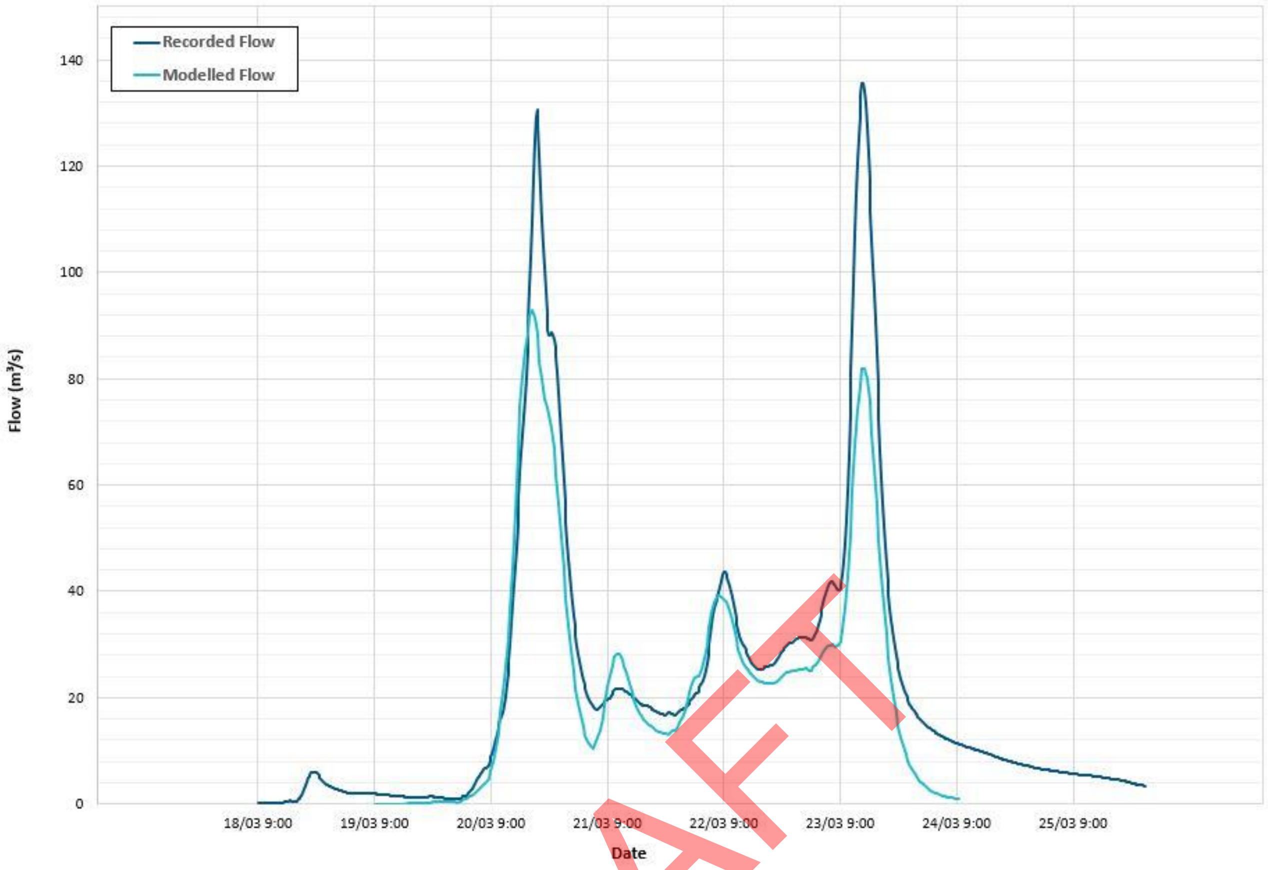


Figure 5.7 Comparison of Gauged and Modelled Flow for March 2021 Event for Woronora River at the Needles – North Engadine (Station 213211)

5.6.2 Hydraulic Modelling

Inflow Boundary Conditions

The discharge hydrographs generated by the WBNM model were used to define inflows across each TUFLOW model area for the March 2021 flood simulation.

Historical Flood Data

There are no stream gauges situated within the TUFLOW model extents that can provide recorded water levels, nor any surveyed flood marks from this event. Therefore, historical flood data is limited to flood complaints data following the March 2021 event. As discussed in Section 2.10.1, this included complaints at five potential overland flood locations.

Comparison with Reported Flooding Locations

The TUFLOW models were used to simulate flood conditions for 5 days from 9am 19 March to 9am 24 March 2021. The simulated peak flood depths and distribution of inundation during this event are presented in Figure A-4.A to Figure A-4.J in Volume 2: Flood Mapping.

Due to available data limitations, only qualitative verification of the model could be completed by comparing the distribution of reported flooding locations from Council’s database with the extent of flooding predicted by the results of the TUFLOW hydraulic models. Comparison of reported flooding locations with the flood extent predicted by the TUFLOW models indicates good correlation between reported flooding locations and predicted flood extent for this event.

5.7 Overall Findings of Model Verification

The WBNM model was able provide a reasonable representation of the general hydrograph shape and/or magnitude of peak flows recorded at Woronora River at the Needles – North Engadine (Station 213211) for all four modelled historical events. However, it should be noted that overland flows, not mainstream flows within the Woronora River, are the primary focus of this study. Therefore, comparison of recorded and modelled flows at this gauge only serve as an indication of the general performance of the WBNM model at that location, rather than at all locations across the overland flow sub-catchments.

The comparison of the reported flooding locations with the predicted flood inundation extents and overland flow path locations demonstrate that the TUFLOW models are able to provide a reliable reproduction of observed flood conditions during the 2003, 2015, 2020 and 2021 events.

Overall, the outcomes of the model validation presented in this section indicate that the WBNM and TUFLOW models provide consistently good verification outcomes across the four historical floods used for verification and provide suitable tools for estimating design flood behaviour across the study area.

Further to this, a sensitivity analysis has been undertaken to assess the influence of the adopted model parameters on predicted flood conditions (refer Section 8).

6 Design Flood Modelling

6.1 Design Floods

Design floods are hypothetical flood events with a given probability of occurrence and are used for floodplain risk management. The probability of occurrence is the chance that the flood may occur or be exceeded in any one year and is termed the Annual Exceedance Probability (AEP). A 1% AEP flood is a flood that statistically has a 1% chance of occurring or being exceeded in any given year. This is also sometimes stated as a '1 in 100' chance of occurrence in any given year.

Prior to ARR2019, these statistical design floods were typically referred to by their Average Recurrence Interval (ARI) with this terminology being phased out in ARR2019. Table 6.1lists the AEPs considered in this study and their equivalent ARIs. In this report the AEP terminology, expressed as a percentage, has been used to describe probability of occurrence.

Table 6.1 Design Flood Terminology

AEP %	AEP 1 in Y	Comments
Extreme Flood / PMF		A probabilistic or statistical estimate of flood or combination of floods, which represent an extreme scenario.
0.2%	500	A probabilistic or statistical estimate of flood or combination of floods likely to occur on average once every 500 years or with a 0.2% probability of occurring in any given year
0.5%	200	As for the 0.2% AEP flood but with a 0.5% probability or 1 in 200 chance of occurring in any one year.
1%	100	As for the 0.2% AEP flood but with a 1% probability or 1 in 100 chance of occurring in any one year.
2%	50	As for the 0.2% AEP flood but with a 2% probability or 1 in 50 chance of occurring in any one year.
5%	20	As for the 0.2% AEP flood but with a 5% probability or 1 in 20 chance of occurring in any one year.
10%	10	As for the 0.2% AEP flood but with a 10% probability or 1 in 10 chance of occurring in any one year.
20% AEP	5	As for the 0.2% AEP flood but with a 20% probability or 1 in 5 chance of occurring in any one year.

6.2 Approach

Design floods for the hydraulic model were derived using the following inputs, with further details provided in the following sections:

- Design flood inflows from upstream catchments and local catchments within the TUFLOW model extent - WBNM hydrologic modelling derived flows based on ARR2019 design inputs.
- Downstream boundary applied based on water (or tidal) levels within the receiving watercourse.

6.3 Hydrologic Modelling

6.3.1 Overview of ARR 2019

The ARR 2019 guidelines comprise significant changes to the previous AR&R 1987 guideline. Some of the key changes in ARR 2019 include:

- Intensity-Frequency-Duration (IFD) 2016 design rainfalls – revised IFD rainfall estimates underpin the ARR 2019 guidelines. The updated IFD, developed by BoM, includes an additional 30 years of rainfall data as well as in increase in the number of available pluviograph and daily rainfall gauges (600 to 2280 pluvio gauges and 7500 to 8074 daily gauges).
- Areal reduction factors (ARFs) – revised equations have been developed as part of ARR 2019 with regionalised parameters to define ARFs for catchments based on catchment area and storm duration.
- Design rainfall losses – estimation of initial and continuing loss rates (as applied in the hydrologic model) are provided in ARR 2019 as gridded spatial data. Representative losses for catchments are extracted from the database. This is a significant change from the previous approach (AR&R 1987) in which basic ranges were recommended for broad areas that is eastern or western NSW.
- Pre-burst rainfall – ARR 2019 provides procedures for the consideration of pre-burst rainfalls for consideration along with design initial losses. The procedures provide for generation of tabular outputs of pre-burst rainfall for the catchment of interest based on a combination of storm duration and return period.
- Temporal patterns – the change in temporal patterns represents one of the most significant differences from the ARR 2019 guidelines. Each design duration now has an ensemble of 10 temporal patterns as opposed to a single temporal pattern for each duration for AR&R 1987.

The ARR 2019 parameters are sourced via the ARR Data Hub (https://data.arr-software.org/). An ARR 2019 Data Hub report was downloaded at the location of the centroid within each sub-catchment, enabling the application of spatially variation hydrologic inputs across the study catchments. A sample of one of these ARR 2019 Data Hub reports is included in Annex C.

6.3.2 IFD Design Rainfall

Design rainfall grids (based on the 2016 IFDs) were obtained from the BoM website for a range of AEP/duration combinations. The IFD grids have a grid cell spacing of 0.025 decimal spacing (an area of approx. 2.8 km^2). The total catchment area of approximately 385 km^2 is covered by approximately 137 grid cells.

Spatial variability in design rainfall depth is present across the overall study catchment, with a typical trend of increasing rainfall depths from north to south and west to east across the study catchments. Specifically, IFD rainfall depths are highest in the southern portion of the catchment (over the area upstream of Woronora Dam and lowest in the north-west of the study area.

6.3.3 At-Site IFD Analysis

As part of this study, “at-site” gauge data has been compared against the 2016 IFD design rainfalls supplied by BoM to establish if:

- There is a significant bias between the two datasets
- 2016 IFD design rainfall potentially overestimates or underestimates likely catchment rainfall conditions.

Historical rainfall data was supplied by Sydney Water for five pluviographs located within the study area and with the longest period of record. A summary of each pluviograph and its period of record is shown in Table 6.2.

Table 6.2 Rainfall Gauges Used For At-Site Rainfall Analysis

Gauge Name	Station Number	Period of Record	Length of Record (years)	Data Quality Rating (%)
Yarrawarrah	566056	1983 - current	40	31.18%
Caringbah Bowling Club	566098	1991 - current	32	54.35%
Sutherland Bowling Club	566092	1991 - current	32	64.35%
South Cronulla Bowling Club	566078	1991 - current	32	46.81%
Cronulla	566018	1979 - current	44	50.56%

However, these five gauged datasets are not considered appropriate for use in this assessment given that:

- The periods of record are not sufficient to provide a conclusive pattern, particularly for larger magnitude storms which have an average recurrence interval that significantly exceeds the period of record (i.e. 1% AEP and larger).
- For some gauges, the quality rating of the datasets is compromised due to missing years of record, quality of data collected at the gauge, etc.

Nevertheless, in order to provide a comparison between 2016 IFDs and at-site IFDs, the annual maximum rainfall depth for all design durations at the Sutherland Bowling Club gauge was used to produce an annual maximum series (AMS). The TUFLOW FLIKE software was then used to fit a probability distribution through the AMS depths (using a GEV probability model with an LH moments inference method). The probability distribution for this gauge was then compared against the 2016 IFDs as shown in Figure 6.1.

As shown in Figure 6.1, the results of the at-site rainfall analysis for the Sutherland Bowling Club gauge indicate that the 2016 IFDs:

- Are similar to at-site IFDs for the 20% AEP to 5% AEP events
- May underestimate expected rainfall depths for larger events such as the 2% AEP and 1% AEP events
- May overestimate expected rainfall depths for frequent events such as the 63.2% and 50% AEP events.

However, given the deficiencies of the gauge data (i.e. period of record and quality), as well as the spatial variability in rainfall across the large study area versus the distribution of available pluviographs, it was not considered appropriate to apply at-site IFDs for this study nor to scale the 2016 IFDs in accordance with the findings of at-site IFD analysis. Therefore, 2016 IFDs have formed the basis of rainfall data inputs for the Sutherland Shire Overland Flood Study.

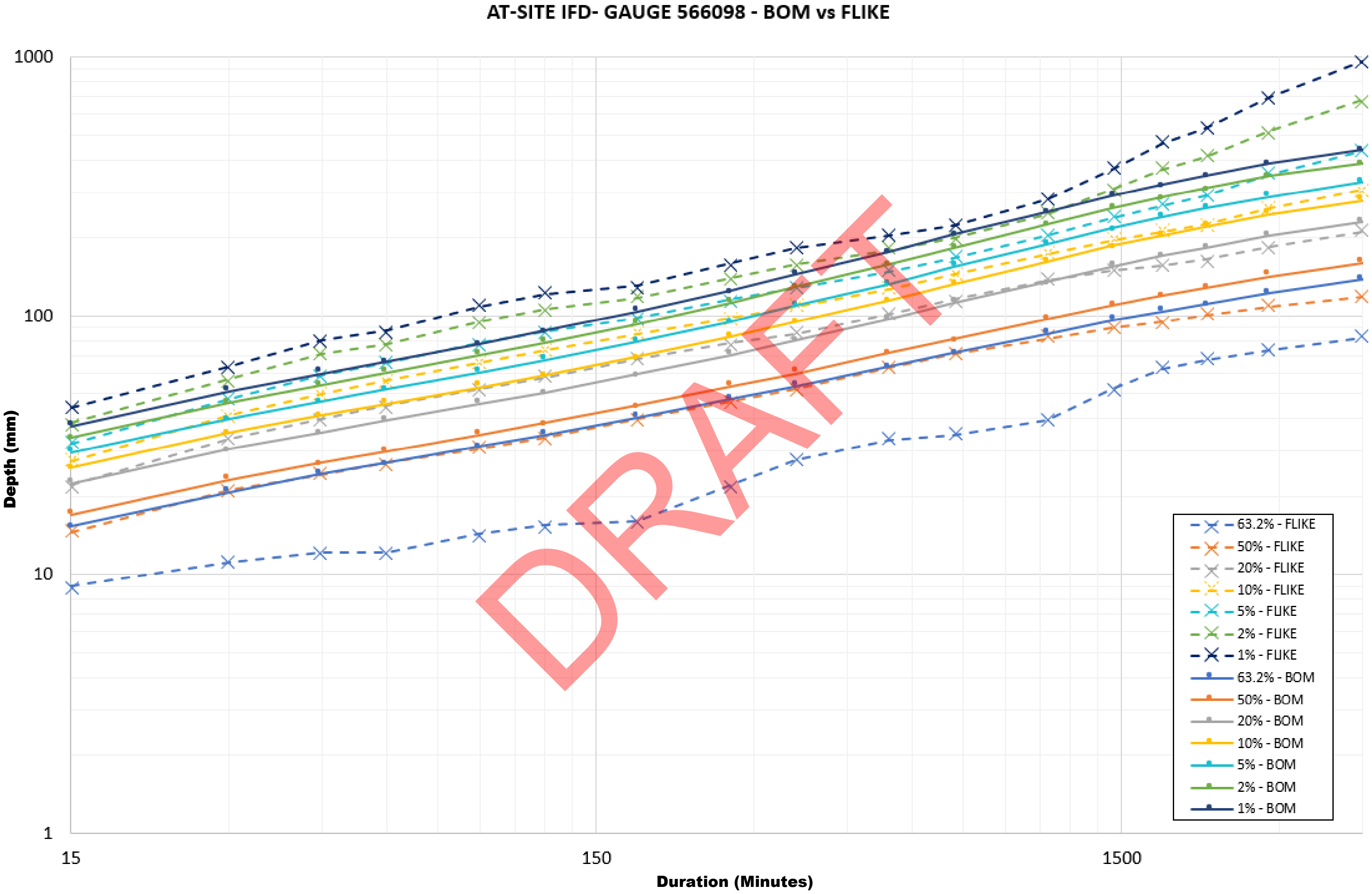


Figure 6.1 At-site Rainfall vs 2016 IFD Comparison for Sutherland Bowling Club Gauge

6.3.4 Areal Reduction Factors

The design rainfall intensities presented in the preceding section are only applicable for catchment areas of up to 1 km^2. An Areal Reduction Factors (ARF) considers how the rainfall depth varies across a catchment under the assumption that larger catchments will not experience a uniform rainfall depth over the entire area. Equations have been developed as part of ARR 2019 with regionalised parameters to define event specific ARFs for catchments, based on catchment area and storm duration. ARFs are only applied to catchments larger than 1 km^2.

Whilst the study area is made up of four major catchments that cover a total area of approximately 253 km^2 within the LGA, ARF estimates should be based on the catchment areas of the smaller sub-catchment systems rather than the whole study area or study catchment.

One of the main difficulties in applying ARFs for a flood study such as this is the fact that the contributing catchment area varies considerably across the study area. For example, the contributing catchment areas vary from less than 1 km^2 at the upstream end of each major sub-catchment (and smaller localised catchments) up to >10 km^2. Therefore, to fully apply the correct areal reductions factors, it would be necessary to calculate the catchment area draining to the outlet of each sub-catchment, determine the reduction factor for each sub-catchment then adjust the rainfall intensities individually for each sub-catchment. This would result in a significant increase in the number of design storms that need to be simulated with associated increases in simulation times and processing effort.

Therefore, it was considered more appropriate to select a single representative contributing catchment area to develop a single set of areal reduction factors for application to the study area. As a first step, the sub-catchments where the contributing catchment area was less than versus greater than 1 km^2 (i.e. the area threshold where reduction factors begin to be applied) was investigated. This analysis showed that most sub-catchments within the urban areas of interest, have a contributing upstream catchment of less than 1 km^2. Therefore, application of no areal reductions would be appropriate for the majority of the study area.

Whilst application of no ARF across the downstream sections of the catchment may result in design discharges being slightly overestimated, this is not considered unreasonable considering that the reduction factors for the critical durations would typically be less than 10% (and in most cases less than 5%). Therefore, the reductions would not change peak discharges along waterways and overland flow paths significantly. Based on this assessment, it was considered reasonable to apply no areal reduction factors to the point rainfall intensities as the majority of the study area comprises catchments areas that are less than 1 km^2 and the reduction factors for other areas would be relatively small.

6.3.5 Rainfall Losses

In early February 2019, the NSW Office of Environment Heritage (OEH) released the ‘Review of ARR Design Inputs for NSW’ (OEH, 2019) to address concerns that the standard ARR2019 method and parameters may be providing for an underestimation bias when deriving design event peak flows in NSW. It includes preliminary advice on changes required to address the bias associated with initial and continuing loss rates.

The document also outlines a recommended 5-level hierarchical approach to the selection of rainfall losses for NSW catchments, as presented in Table 6.3. Based on this approach, it was determined that Approach 5 is appropriate for this assessment given no other information was available.

Table 6.3 Hierarchy of Loss Approach from Most (1) to Least Preferred (5)

Approach	Data to use	Storm Initial Loss	Pre-burst (transformational)	IL Burst	Continuing Loss
1	Current Study	Average Calibration	Not required or back calculated using $IL_{Storm} - IL_{Burst}$	Calculated using Equation 6*	Average Calibration
2	Other Studies within the Catchment	Average Calibration	Not required or back calculated using $IL_{Storm} - IL_{Burst}$	Calculated using Equation 6*	Average Calibration
3	Neighbouring Studies	Average Calibration	Not required or back calculated using $IL_{Storm} - IL_{Burst}$	Calculated using Equation 6*	Average Calibration
4	FFA (Flood Frequency Analysis)	NSW FFA reconciled initial loss	Not required or back calculated using $IL_{Storm} - IL_{Burst}$	Probability Neutral Burst Loss	NSW FFA reconciled continuing losses
5	ARR Data Hub	ARR Data Hub initial loss	Not required or back calculated using $IL_{Storm} - IL_{Burst}$	Probability Neutral Burst Loss	ARR Data Hub continuing losses multiplied x 0.4

Note: * Equation 6 as predicted in 'Review of ARR Design Inputs for NSW' (OEH, 2019)

In accordance with the 'Review of ARR Design Inputs for NSW' (OEH, 2019), the following modifications to the ARR Data Hub loss values are recommended for NSW catchments:

- Adoption of the revised Probability Neutral Burst Initial Loss as provided through the ARR Data Hub.
- A multiplication factor of 0.4 should be applied to the ARR Data Hub continuing loss.

6.3.6 Temporal Patterns

The ARR 2019 temporal patterns provide one of the most significant changes in the approach to design flow estimation from AR&R 1987, with an ensemble of ten temporals patterns used instead of a single temporal pattern for each AEP and duration combination.

As per ARR2019 recommendations, an ensemble of ten temporal patterns for each duration has been modelled for each AEP flood event as part of this assessment. The ten temporal patterns vary in terms of their distribution and variability (comprising front, middle and back loaded storms) and can result in a wide range of flood behaviour within the catchment.

6.4 Probable Maximum Precipitation

The Probable Maximum Precipitation (PMP) is used to derive the Probable Maximum Flood (PMF) event. The definition of the PMP is *"the theoretical maximum precipitation for a given duration under modern meteorological conditions*" (WMO, 2009). The ARI of a PMP/PMF event ranges between 10^4 and 10^7 years and is beyond the "credible limit of extrapolation" (Pilgrim, 1987). That is, it is not possible to use rainfall depths determined for the more frequent events (1% AEP and less) to extrapolate the PMP. For this study, the PMP has been estimated using the Generalised Short Duration Method (GSDM) procedures outlined in 'The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method (BoM, 2003), which is appropriate for durations up to 360 minute (6 hours) and considered suitable for small catchments (less than 1,000 km^2).

According to the GSDM, the design spatial distribution for the PMP storm assumes a virtually stationary storm diagram (with the shape of a group of ellipses) that can be oriented in any direction with respect to the catchment. Due to the shape and size of the study area, two groups of ellipses were considered to obtain the best fit for the spatial distribution of rainfall. The mean rainfall depth obtained for each sub-catchment from the two groups of ellipses for all durations up to 360 minutes were enveloped and applied to the WBNM model to produce inflow hydrographs. These hydrographs were then applied to the TUFLOW model to determine the critical duration(s) for the PMF event. The storm durations assessed included 15, 30, 45, 60, 90, 120, 150, 180, 270, 300, and 360-minute durations.

The rainfall for each duration was estimated following the GSDM methodology and using one temporal pattern as shown in Figure 6.2. This pattern was scaled to the appropriate duration and rainfall total for each storm duration.

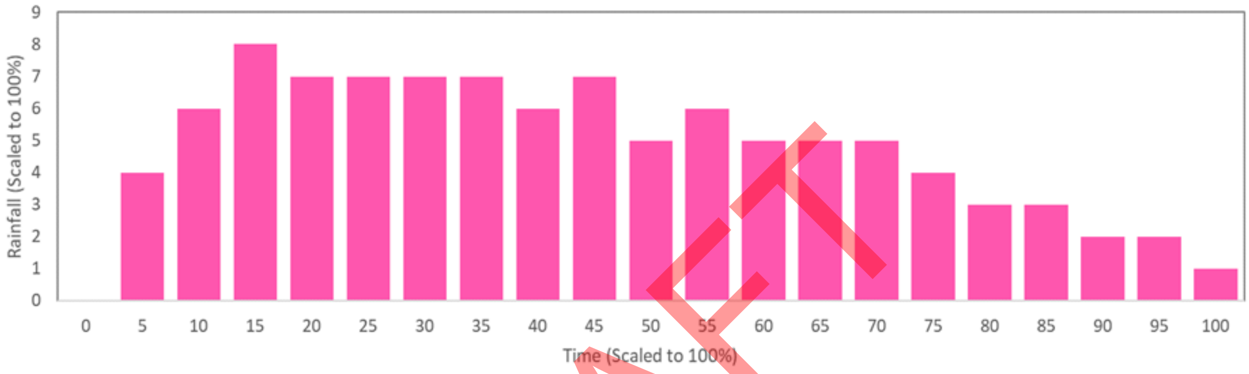


Figure 6.2 PMP Temporal Pattern

6.5 Hydraulic Modelling

6.5.1 Downstream Boundary Conditions

As discussed, the study catchments ultimately drain to either the Georges River (to the east and west of the Woronora River outlet), Woronora River or Port Hacking either via a series of channel confluences and piped networks or overland via the vegetated areas draining down to these waterways. During major riverine flooding, the lower parts of the study catchments could be inundated by backwater flooding from the Georges River, Woronora River and Port Hacking, and elevated water levels within these receiving waterways may also interact with floodwaters from local catchments and creeks, as well as potentially inhibiting drainage of overland flows into receiving waterways. Whilst consideration of joint probability of coincident flooding from both catchment runoff and backwater impacts from the Georges River, Woronora River and Port Hacking is required, a full joint probability analysis is beyond the scope of this study.

However, it is recognised that peak overland flood conditions (i.e. the primary focus of this study) may not coincide with peak riverine or ocean flood conditions. It is also noted that overland flow flooding (not riverine flooding and tidal inundation) of urban areas is the focus of this study. Thus, simple combinations of standard design AEP local catchment rainfall and riverine or ocean events were modelled, as presented in Table 6.4, with these combinations based on dominant rainfall event magnitudes (i.e. larger rainfall AEP events in combination with smaller ocean or riverine AEP events and consistent with the rainfall event conditions considered ‘Woolooware Bay Floodplain Risk Management Study and Plan’ (WMAwater, 2022).

The downstream boundary (or “tailwater”) conditions of the four (4) TUFLOW models were defined by either tidal or riverine design flood levels as follows:

- Port Hacking TUFLOW model: Design ocean levels adopted in the ‘Woolooware Bay Floodplain Risk Management Study and Plan’ (WMAwater, 2022) and consistent with other similar studies previously completed by Council.
- Georges River East and West TUFLOW models: Design flood levels for riverine Georges River flooding, as defined by the ‘Lower Georges River Floodplain Risk Management Study and Plan’ (Bewsher Consulting, 2011).
- Woronora River TUFLOW model: Design flood levels for riverine Woronora River flooding, as defined by the ‘Woronora River Flood Study’ (Public Works, 1991).

Table 6.4 Adopted Peak Tailwater Levels for Combined Local Catchment and Oceanic/Riverine Conditions

Design Flood	Local Catchment Rainfall Event	Ocean or Riverine Event	Downstream Boundary Level (mAHD)			
			Port Hacking	Georges River East	Georges River West	Woronora River
20% AEP	20% AEP	20% AEP	1.1	1.1*	1.1*	1.1*
10% AEP	10% AEP	10% AEP	1.3	1.3*	1.3*	1.3*
5% AEP	5% AEP	5% AEP	1.5	1.5	Alfords Point 2.1 Moon Point 1.8 Illawong 1.6	1.5 – 5.7
2% AEP	2% AEP	5% AEP	1.5	1.5		1.5 – 5.7
1% AEP	1% AEP	5% AEP	1.5	1.5		1.5 – 5.7
0.5% AEP	0.5% AEP	5% AEP	1.5	1.5		1.5 – 5.7
0.2% AEP	0.2% AEP	5% AEP	1.5	1.5		1.5 – 5.7
PMF	PMF	1% AEP	1.5	1.5	Alfords Point 2.7 Moon Point 2.3 Illawong 2.05	1.75 – 6.7

Note: *No record available. Estimated as part of this study

6.5.2 Blockage Assumptions

Blockage of Hydraulic Structures

ARR 2019 includes guidance regarding the procedure to estimate blockage levels of structure inlets for design flood modelling (refer Book 6: Flood Hydraulics – Chapter 6 Blockage of Hydraulic Structures). The ARR 2019 assessment procedure includes classification of the following mechanisms:

- Debris type and dimensions (including identification of the average length of the longest 10% of the debris that could arrive at the site (termed as L^{10}). In line with the value suggested in ARR 2019 an L^{10} of 1.5m has been adopted for this study.
- Debris availability in the study area
- Debris mobility
- Debris transportability.

A classification is applied to each of the above components and the combination of these classifications provides a debris potential classification of either Low, Medium or High.

This assessment has also adopted an AEP adjusted scaling of the 'most-likely' inlet blockage based upon the magnitude of a design event. That is, more frequent flood events are likely to have lower blockages than a rarer event. The ARR 2019 blockage assessment sheet is included in Annex D.

In addition to the structure blockage condition, industry standard pipe and culvert losses have been applied at all relevant conduits in the TUFLOW hydraulic model, specifically:

- An entry and exit loss of 0.5 and 1.0 respectively
- Height and width contraction coefficients of 0.6 and 0.9 for culverts and 0 and 1.0 for pipes.

Pit Inlet Blockages

Temporary blockage of pit inlets may occur during a storm as a result of the pit entry being restricted by either a vehicle parking over the grate or vegetation covering/blocking the inlet. For this study, a 50% inlet blockage was adopted for all pit inlets, as agreed with Council, and noting this is consistent with the assumption for the neighbouring 'Woolooware Bay Floodplain Risk Management Study and Plan' (WMAwater, 2022).

6.5.3 Critical Duration and Temporal Pattern Assessment

The critical duration (and its associated mean temporal pattern) was selected through assessment of the peak flood levels across the catchment predicted by the modelling. This analysis was completed for each of the temporal pattern bins associated with the selected design events (i.e. frequent, intermediate and rare storm events).

The following method was adopted to undertake the critical duration assessment:

1. Using WBNM to run an ensemble of temporal patterns from the 15-minute duration to the 720-minute duration. This included 13 durations; 15, 20, 25, 30, 45, 60, 90, 120, 180, 270, 360, 540 and 720-minute.
2. Applying the hydrographs from the WBNM model to the TUFLOW models. In total, 130 TUFLOW runs were completed for each temporal pattern bin for each design flood from 20% AEP to 0.2% AEP.
3. For each duration and AEP combination, determine the temporal pattern that provided the level that was one above the mean of the ensemble of ten temporal patterns.
4. Once a representative mean temporal pattern was identified for each duration, the duration or combination of durations providing the peak flood level was identified to be the critical duration(s) for the study area.

The procedures for ARR2019 provide for the selection of the temporal pattern that gives the peak flow closest to the mean of the peak flows from all ten temporal patterns via the WBNM model output. This method was used to find the critical temporal pattern for each storm duration.

A critical storm duration assessment was then undertaken to establish the critical storm duration that produces the highest mean peak flood level for the study area across the modelled storm durations using TUFLOW model outputs. Please note that the critical duration selection process focussed on urban overland flow areas across the entire study area, i.e. considering locations across all the four (4) modelled catchments at once rather than a separate assessment for each model area. A summary of the critical storm duration and temporal pattern for each AEP design storm event is presented in Table 6.5.

It can be seen in Table 6.5 that shorter durations (i.e. less than 1 hour) are typically critical across the catchment due to the urbanised nature of the study area, lack of major storage and steeper terrain gradients in some areas.

Table 6.5 Critical Storm Duration and Temporal Pattern Selection

Design Storm (AEP)	Storm Duration (min) - Temporal Pattern
20%	45mins - TP4549 60mins - TP4581 120mins - TP4641
10%	20mins - TP4440 30mins - TP4512 60mins - TP4573
5%	15mins - TP4414 20mins - TP4440 60mins - TP4565 90mins - TP4590
2%	10mins - TP4361 20mins - TP4404 45mins - TP4528 60mins - TP4559
1%	10mins - TP4356 20mins - TP4428 45mins - TP4528 60mins - TP4557
0.5%	20mins - TP4404 30mins - TP4504 60mins - TP4463
0.2%	10mins - TP4354 20mins - TP4429 45mins - TP4534
PMF	15mins 30mins 45mins

7 Design Flood Conditions

7.1 Design Flood Modelling and Mapping

The TUFLOW models were used to simulate the 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP floods and PMF. As discussed in Section 6, multiple storm durations were simulated for each modelled design flood. As a result, a range of modelling results were generated for each modelled design flood that were subsequently merged to form a "design flood envelope". This involved extracting and comparing peak flood levels, depth and velocities at each TUFLOW grid cell and adopting the highest value for each flood characteristic.

Due to the nature of modelling overland flows, the direct (or "raw") outputs of the design flood simulations produced by the TUFLOW models predict very shallow water depths across a significant portion of the study area. Therefore, it was considered necessary for the raw modelling results to be "filtered" to remove sheet flow from the design flood extents such that:

- Only defined overland flow paths and areas subject to more significant flood depth and/or flood hazard (i.e. overland flooding) are included; and
- Areas subject to negligible inundation (i.e. "nuisance flooding" or stormwater rather than overland flooding) are excluded.

Filtering of modelling results is typically undertaken utilising a threshold assessment of flood conditions – namely flood depth, flow velocity and/or velocity-depth product (i.e. V x D) in isolation or in combination – followed by the removal of isolated or disconnected areas of overland flow flooding (i.e. "flood islands").

The adopted filtering methodology and criteria used for this study is outlined below :

1. *Removal of areas where depth of inundation is less than 0.15 m*

   A minimum depth threshold of 0.15 m is typically adopted as common practice in overland flood studies completed across Sydney. This threshold is considered appropriate for adoption in this study for the following reasons:

   - Council's standard kerb height is generally 0.15 m. Therefore, water depths less than 0.15 m will typically be contained within road carriageways and not spill over kerbs and travel overland through properties. It is noted that a gutter depth of 0.15 m was reinforced within the TUFLOW models.
   - The National Construction Code 2022 requires the floor level of buildings in poorly drained areas to be elevated 0.15 metres above the finished ground level. Accordingly, there is limited chance of over floor flooding when water depths are less than 0.15 m.
   - The quoted vertical accuracy of the DEM used to define the underlying topography within the TUFLOW models is 0.3 m. Therefore, a depth threshold of 0.15 m lies at the median of the vertical accuracy of the main topographic data source.

2. *Reinstating areas where velocity ≥ 0.5 m/s and depth ≥ 0.1 m*

   Inclusion of this criteria was considered appropriate to ensure that areas of faster moving water (i.e. with flow velocity greater than or equal to 0.5 m/s) that is not very shallow (i.e. greater than 100 mm) are retained. Blockage of these types of flows along overland flow paths has the potential to impact on local flood behaviour.

3. *Removal of isolated ponding areas less than 100 m^2*

   Isolated ponding areas or “flood islands” (i.e. disconnected areas of overland flow flooding) were removed to ensure that the modelling results only depict defined and typically continuous overland flow paths.

The above filtering is hereafter referred to as “Primary Filtering” for flood mapping and flood planning purposes, noting that “Secondary Filtering” is discussed and applied in reference to flood control lot tagging (refer Section 9.3).

A series of design flood maps showing peak flood depths (and extent), levels and velocities for the full range of modelled design floods were prepared using the primary filtered modelling results and are provided in Map Set B in Volume 2: Flood Mapping.

7.2 Description of Flood Behaviour

Overland flow within the study catchments is caused by short duration, intense rainfall events (i.e. high rainfall totals over short time periods typically in the order of hour(s) or less) and when the rainfall within a catchment falls onto impervious or saturated areas, is unable to infiltrate into the ground and instead becomes runoff which contributes to overland flow. This behaviour is most easily observable on “hard surfaces” (e.g. roads, houses and pavements) within the urban environment, where very little rain is able to infiltrate and runoff quickly turns into rapid overland flow or ponding. However, this type of runoff can also occur in more pervious areas, during intense periods of rainfall capable of exceeding the infiltration capacity of the soil.

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

During smaller magnitude floods, such as the 20% AEP to 5% AEP, overland flow flooding in urban areas is typically contained within defined waterways and roadways. However, during larger magnitude events, such as the 2% AEP flood and larger, property inundation occurs when overland flow from an upstream catchment area drains through a property to its discharge point or when flow within a roadway overtops the layback / kerb and drains through a property.

7.3 Key Flood Locations

Key flood locations or flooding “hotspots” are areas with a concentration of flood impacted properties or significant inundation predicted by the flood modelling results. Where feasible, it is recommended that future investigations and potential floodplain risk management activities should be aimed at mitigating the flood risk at these locations.

Flooding “hotspots” were identified within the study area based on consideration of:

- Major overland flow paths
- Areas that are flood impacted in a range of design flood magnitudes, including more frequent design floods such as the 20% AEP
- Locations with multiple flood impacted properties during the 1% AEP flood (or more frequent AEPs)
- Reported/known flooding locations from Council’s database.

Identified hotspot locations are presented in Figure 7.1 (with reference to the annotations below) and dsiucssed in the following sections.

7.3.1 Georges River West Catchment

One (1) flooding hotspot was identified in the Georges River West catchment, as follows:

- Fowler Road and Shand Close, Illawong (G-01) – Upstream runoff causes ponding at the low point of Fowler Road near Batavia Place Reserve. The overland flow path runs north-easterly and drains into a small channel parallel to Old Ferry Road, eventually leading to Ocean Place. This flow inundates properties and creates ponding within roadways along its course reaching peak depths up to 0.5 m in the 20% AEP flood.

7.3.2 Woronora River Catchment

Inundation of roads and properties within the suburbs of Woronora and the low lying areas of Bonnet Bay is primarily caused by riverine flooding from the Woronora River. Since this study is focussed on overland flow flooding within the catchment, only the following four (4) overland flow flooding hotspots were identified:

- Linden Street, Sunbury Street and Tudar Road, Sutherland (W-01) – Overland flow originates upstream of Galga Street and flows northwards along Linden Street, before draining through private properties, continuing north along Tudar Road and ultimately discharging into the bushland reserve on the eastern side of Tudar Road. This overland flow path leads to inundation of roadways and properties in this area. During the 20% AEP flood, depths of up to 0.5 m are predicted at the intersection of Linden Street and Sunbury Street.
- Amiens Avenue to Anzac Avenue playing fields, Engadine (W-02) – In events as frequent as the 20% AEP, several properties downstream of Amiens Avenue are impacted by flooding and peak 20% AEP floodwater depths up to 0.4 m are predicted. This is primarily due to the stormwater network operating at full capacity along this flow path during events of this magnitude (and larger). This flow path then drains northwards and results in inundation of Anzac Avenue, the adjoining playing field and Achilles Road before discharging into Forbes Creek. Flooding is predicted to result in hazardous conditions on Achilles Road due to the accumulation of floodwaters within this roadway.
- Princes Highway to Boundary Road, Heathcote (W-03) – Runoff accumulates at the low point of the Princes Highway and flows in a north-westerly direction through properties and towards Boundary Road, also inundating Lindsay Gordon Place.
- Intersection of Garvan Road and Princes Highway (W-04) - Significant ponding is predicted within the roadway in events as frequent as the 20% AEP flood, with peak 20% AEP water depths up to 0.8 m and higher depths predicted in larger floods.

7.3.3 Georges River East Catchment

Five (5) flooding hotspots were identified in the Georges River East catchment, as follows:

- Intersection of Binya Place and Como Parade, Como (E-01) – During frequent rainfall events, stormwater runoff exceeding the capacity of the local stormwater network inundates Binya Place and nearby properties, reaching depths of up to 0.5 m. The overland flow then drains to under the railway line before flowing in a north-easterly direction, eventually discharging into Scylla Bay Oval.
- Cowan Street and Como Road, Oyster Bay (E-02) – Due to the full capacity of the stormwater network in this area, an overland flow path leads to inundation of roadways and properties between Cowan Street and Como Road, eventually discharging at the low point of Oyster Bay Oval. In the 20% AEP event, flood depths of up to 0.5 m and velocities of up to 1.7 m/s are observed along Como Road, resulting in the isolation of properties along Scylla Road.

- Glencoe Street and The Boulevarde to Wattle Road, Sutherland (E-03) – Overland flow follows the drainage network from the low point of Glencoe Street and continues through properties before ponding on The Boulevarde, reaching depths of up to 0.5 m in the 20% AEP flood. This flow then drains northwards through properties along Wattle Road.
- Upstream of Oyster Gully to The Boulevarde and Tea Tree Place, Kirrawee (E-04) – Runoff accumulates along this overland flow path and typically follows the alignment of stormwater network, discharging into the upstream section of Oyster Gully located north-west of Birch Place. This flow path breaks out into properties from more frequent events, with floodwater depths of up to 0.4 m during the 20% AEP flood. Additionally, ponding occurs within The Boulevarde near Kiewa Place and Tea Tree Place before discharging to the downstream section of Oyster Gully.
- Upstream of intersection between Oyster Bay Road and Sage Avenue, Oyster Bay (E-05) – Overland flows drain in an easterly direction parallel to Oyster Bay Road and inundate properties along its course.

7.3.4 Port Hacking Catchment

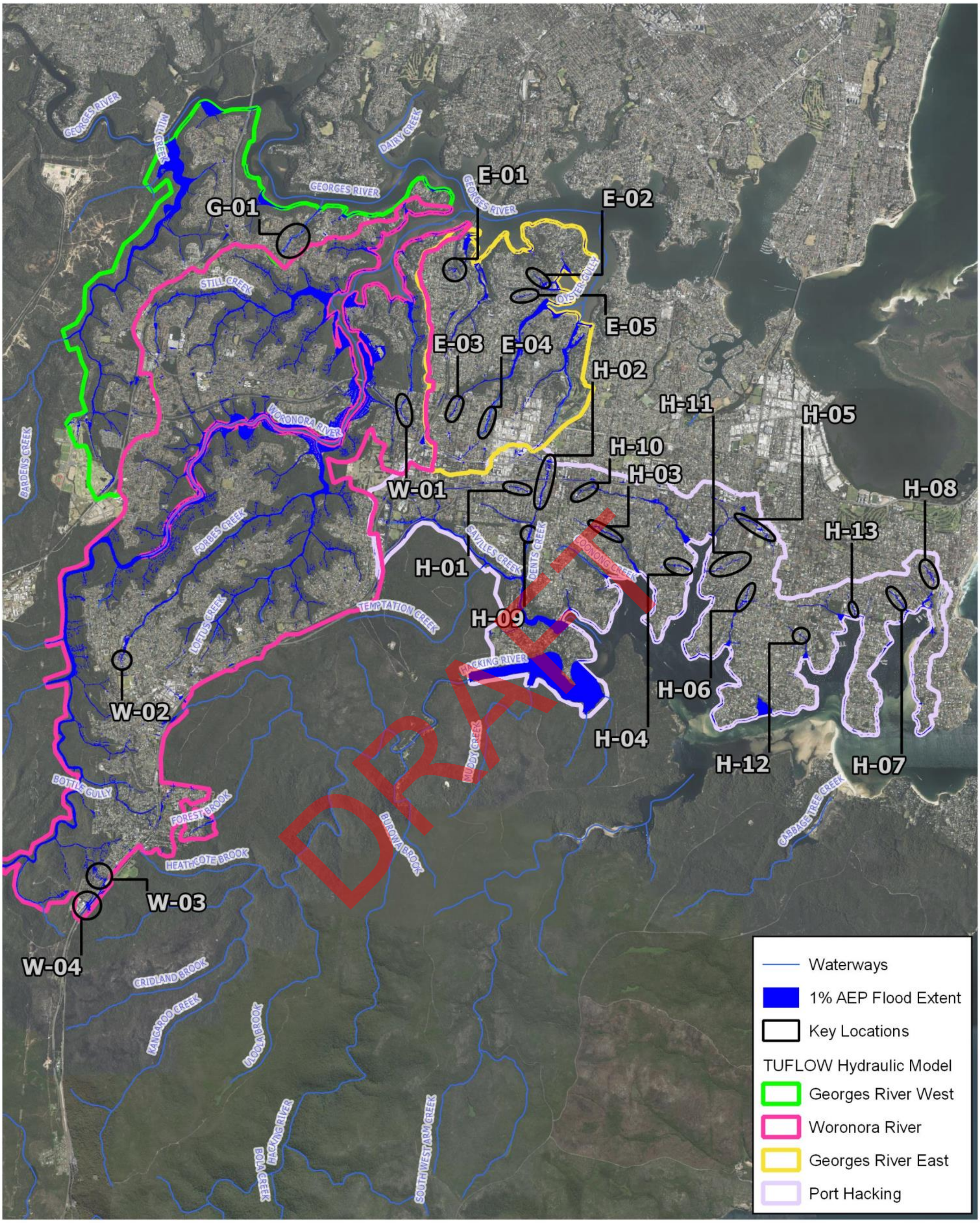
Eight (8) flooding hotspots were identified in the Georges River East catchment, as follows:

- Bath Road and Bidurgal Lane, Gymea (H-01) – Overland flows from the sag point in Bath Road drain through properties towards Balgang Avenue and Bidurgal Lane. During the 20% AEP flood, peak depths of 0.5 m are predicted in this area.
- The Kingsway and President Avenue, upstream of Dents Creek (H-02) – Overland flow originates from Foch Avenue and Hotham Road, resulting in ponding at the sag point adjacent to Gymea TAFE on The Kingsway. During frequent events, such as the 20% AEP, peak depths up to 1m are predicted within this sag point. Subsequently, the flow drains southward towards Dents Creek, inundating numerous downstream properties and parts of President Avenue along its course.
- Sylvania Road and Alkaringa Road, upstream of Alcheringa Gully (H-03) – A high-velocity overland flow path originates in the sag point on Sylvania Road, leading to the inundation of properties before discharging into Alcheringa Gully. During the 20% AEP flood, the flow velocities of up to 2 m/s and depths of 0.5 m are predicted within properties along Wyangala Place.
- Wonga Road Reserve to Kalang Lane, Yowie Bay (H-04) – Runoff from the upstream catchment of Wonga Road Reserve accumulates within the low point in this reserve adjacent to the intersection of Wonga Road and Attunga Road, before draining into the stormwater network. Overland flow surcharging from pits along Wonga Road is predicted to drain across properties and through Kalang Reserve towards Kalang Lane. During the 20% AEP flood, depths of up to 0.3 meters and velocities up to 2.5 m/s are predicted within properties along Wonga Road. There were several complaints regarding flood damage to properties in this area during the 2003 flood event.
- President Avenue, Caringbah Commercial Centre (H-05) – Runoff generated upstream of Glen Mcgrath Oval drains to the low point of President Avenue (adjacent to commercial properties within this commercial centre) and leading to high-depth ponding that cuts off this road. During the 20% AEP flood, there is a 0.5 m depth at this location, whilst in the 1% AEP event, the extent of road inundation is significantly larger with peak depths of up to 1 m. This flow path also impacts properties between Willarong Road, Curtis Street, and Taren Road.
- Castelnau Street to Telopea Avenue and towards Crescent Road, Caringbah South (H-06) – Runoff from the Castelnau Street area drains south through residential properties towards Telopea Avenue, before eventually discharging into a channel extending from Ash Avenue to downstream of Crescent Road. When the stormwater network reaches capacity, overland flows cause inundation of properties and roadways along its flow path. For example, peak 20% AEP flood depths of up to 0.5 meters are predicted in Wilga Road, with high flow velocities also impacting properties upstream of Ash Avenue during this more frequent AEP event.

- Intersection of Trickett Road and Hill Street towards Gunnamatta Bay, Cronulla(H-07) – An overland flow path originates at the intersection of Trickett Road and Hill Street, and follows the alignment of the stormwater network and discharges into Gunnamatta Bay. When the network reaches its full capacity, resultant overland flow inundates properties along its path, with high velocities of 2 m/s downstream of Burraneer Bay Road and water depths of up to 0.6 m in the 20% AEP event.
- Kurnell Road to the intersection of Gosport Street and The Kingsway, Cronulla (H-08) – In events from the 20% AEP event, several properties between Kurnell Road and Gosport Street are predicted to be inundated when the stormwater network reaches its full capacity. The flow path follows a south-easterly direction and results in ponding at the intersection of Gosport Street and The Kingsway, with peak 20% AEP depths of up to 0.5 m. Further downstream, the stormwater network overflows, leading to significant inundation at the roundabout at Wilbar Avenue and Purley Place, with ponding of up to 0.6 m predicted during the 20% AEP event.

Whilst not flooding hotspots, it is noted that there are other minor overland flow paths that result from the full capacity of the stormwater network and cause inundation to roads and properties in various areas. These areas may warrant further investigation by Council when considering possible mitigation measures in this catchment and include:

- Intersection of Wanganui Road and North West Arm Road, Kirrawee (H-09)
- Premier Street and Manchester Road before the channel upstream of Yowie Gully, Gymea (H-10)
- Babbin Place to west of Burraneer Bay Road, Caringbah South (H-11)
- Upstream of the intersection of Lehan Plaza and Parthenia Street, Dolans Bay (H-12)
- Dominic Street to Willaburra Road and Bayview Road, Burraneer (H-13).



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KEY FLOOD LOCATIONS

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7.4 Provisional Flood Hazard

7.4.1 Overview

Flood hazard defines the potential impact that flooding will have on vehicles, people and structures across different areas of the floodplain. The key factors influencing flood hazard (or risk) are:

- Size of the flood
- Rate of rise and effective warning time
- Community awareness
- Flood depth and velocity
- Duration of inundation
- Obstructions to flow
- Access and evacuation.

The consideration of the depth and velocity of floodwaters in isolation is referred to as the “provisional flood hazard” and is determined on the basis of the predicted flood depth, velocity and velocity-depth product (V x D). This is achieved through the analysis of flood modelling results.

For this study, the variation in provisional flood hazard across the floodplain was defined based on classification criteria from both ‘Australian Disaster Resilience Handbook 7 Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia’ (AIDR, 2017) and ‘Floodplain Development Manual: the management of flood liable land’ (NSW Government, 2005). This is outlined in the following sections.

7.4.2 AIDR (2017) Flood Hazard

The variation in flood hazard is characterised in AIDR (2017) based on the composite six-tiered hazard classification that corresponds to the potential vulnerability of people, cars and structures based upon the depth and velocity of floodwaters. The six hazard classifications are summarised in Table 7.1 and shown in Figure 7.2.

Table 7.1 Best Practice Provisional Flood Hazards (AIDR, 2017)

Hazard	Criteria	Description
H1	Depth < 0.3 m and Velocity < 2.0 m/s and Velocity*Depth ≤ 0.3 m^2/s	Generally safe for vehicles, people and buildings.
H2	Depth < 0.5 m and Velocity < 2.0 m/s and Velocity*Depth ≤ 0.6 m^2/s	Unsafe for small vehicles.
H3	Depth < 1.2 m and Velocity < 2.0 m/s and Velocity*Depth ≤ 0.6 m^2/s	Unsafe for small vehicles , children and the elderly.
H4	Depth < 2.0 m and Velocity < 2.0 m/s and Velocity*Depth ≤ 1.0 m^2/s	Unsafe for vehicles and people.
H5	Depth < 4.0 m and Velocity < 4.0 m/s and Velocity*Depth ≤ 4.0 m^2/s	Unsafe for vehicles and people. All building types vulnerable to structural damage. Some less robust building types vulnerable to failure.
H6	Depth > 4.0 m OR Velocity > 4.0 m/s OR Velocity*Depth > 4.0 m^2/s	Unsafe for vehicles and people. All building types considered vulnerable to failure.

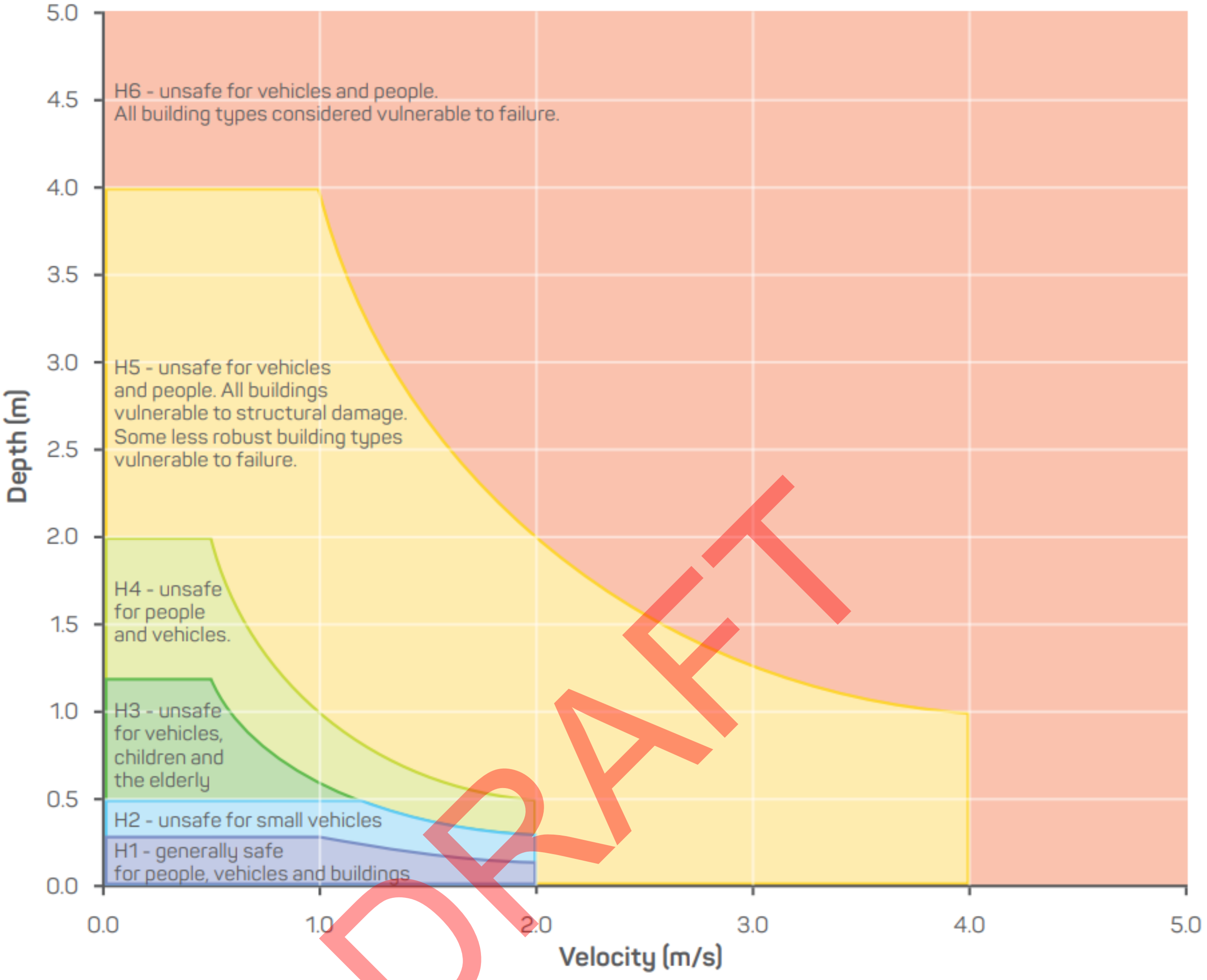


Figure 7.2 Combined Flood Hazard Curves

Peak depth, velocity and velocity-depth product outputs from the TUFLOW modelling were used to map the variation in flood hazard across the catchments. Provisional hazard mapping for the study area is provided in Map Set C in Volume 2: Flood Mapping for all modelled floods. It is noted that the primary filtered modelling results (refer Section 7.1) have been used to develop this mapping.

7.4.3 FDM (2005) Flood Hazard

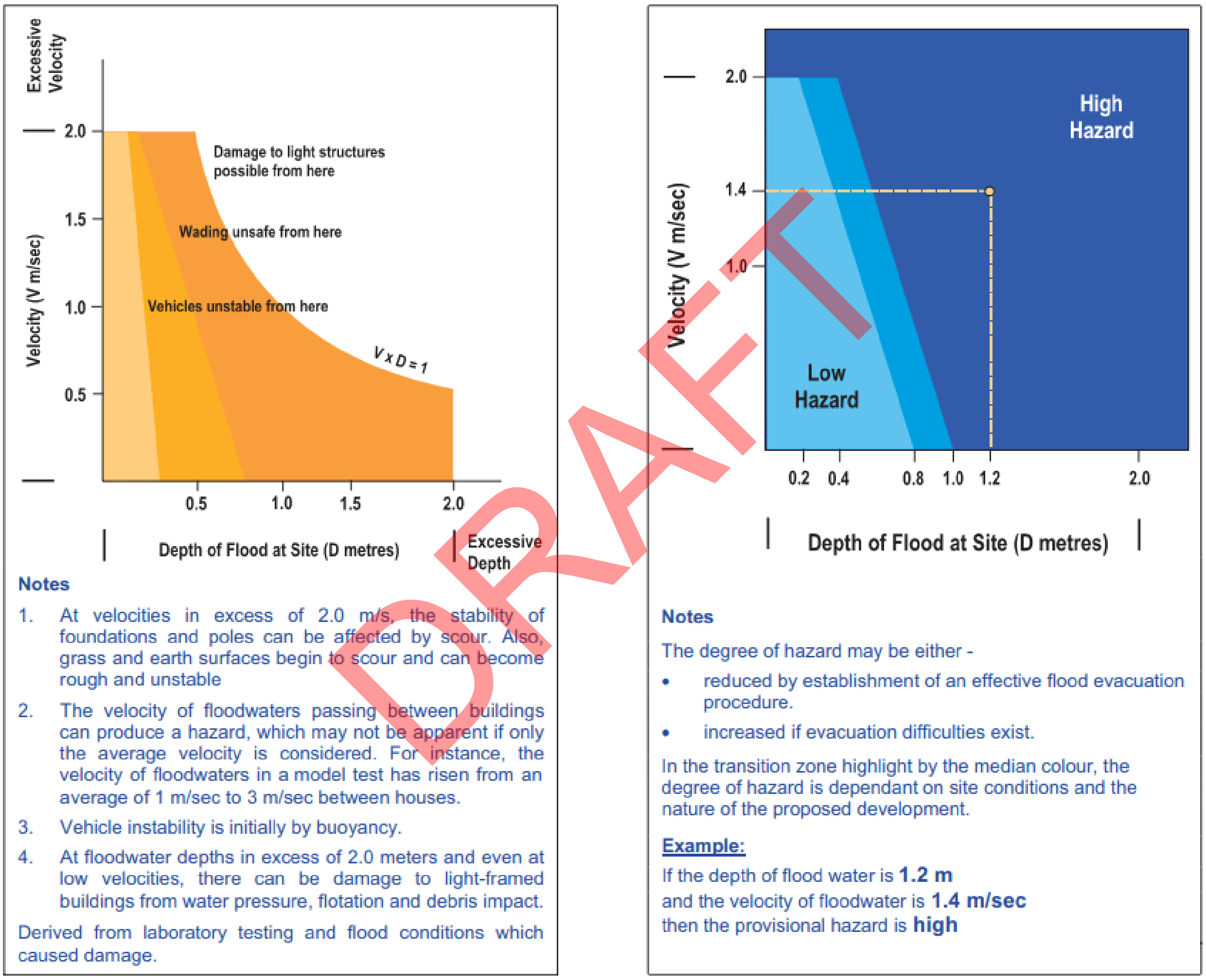
The NSW Government's Floodplain Development Manual (NSW Government, 2005) defines flood hazard categories as follows:

- High hazard – possible danger to personal safety; evacuation by trucks is difficult; able-bodied adults would have difficulty in wading to safety; potential for significant structural damage to buildings.
- Low hazard – should it be necessary; trucks could evacuate people and their possessions; able-bodied adults would have little difficulty in wading to safety.

It also includes a "transition zone" between the low and high hazard categories (referred to in the mapping as "medium" hazard). The provisional hazard categories can subsequently be modified based on consideration of the other factors listed above to form true hazard categories. However, this does not typically occur until the preparation of a Floodplain Risk Management Study and Plan.

Figures L1 and L2 in the ‘Floodplain Development Manual’ (NSW Government, 2005) are used to determine provisional hazard categorisations within flood liable land based on this approach. These figures are reproduced in Figure 7.3.

The provisional hazard is included in the mapping series provided for all modelled events in Map Set C of Volume 2: Flood Mapping. It is noted that the primary filtered modelling results (refer Section 7.1) have been used to develop this provisional hazard mapping.



Notes

1. At velocities in excess of 2.0 m/s, the stability of foundations and poles can be affected by scour. Also, grass and earth surfaces begin to scour and can become rough and unstable
2. The velocity of floodwaters passing between buildings can produce a hazard, which may not be apparent if only the average velocity is considered. For instance, the velocity of floodwaters in a model test has risen from an average of 1 m/sec to 3 m/sec between houses.
3. Vehicle instability is initially by buoyancy.
4. At floodwater depths in excess of 2.0 meters and even at low velocities, there can be damage to light-framed buildings from water pressure, flotation and debris impact.

Derived from laboratory testing and flood conditions which caused damage.

Notes

The degree of hazard may be either -

- reduced by establishment of an effective flood evacuation procedure.
- increased if evacuation difficulties exist.

In the transition zone highlight by the median colour, the degree of hazard is dependant on site conditions and the nature of the proposed development.

Example:

If the depth of flood water is **1.2 m**
and the velocity of floodwater is **1.4 m/sec**
then the provisional hazard is **high**

Figure 7.3 Provisional Flood Hazard Categorisation (Source: NSW Government, 2005)

7.5 Flood Function

Flood function categories (also referred to as hydraulic categories) defined in the ‘Floodplain Development Manual: Flood Risk Management Guideline FB02’ (DPE, 2023) are:

- **Floodway -** Areas that convey a significant portion of the flow. These are areas that, even if partially blocked, would cause a significant increase in flood levels or a significant redistribution of flood flows, which may adversely affect other areas.

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

There are no prescriptive methods for determining what parts of the floodplain constitute floodways, flood storages and flood fringes. Descriptions of these terms within the ‘Floodplain Development Manual’ (DPE, 2023) are essentially qualitative in nature and the definition of flood behaviour and associated impacts is likely to vary from one floodplain to another depending on the circumstances and nature of flooding within the catchment.

For this study, the multi-criterion approach considering peak flood depths, velocities and the velocity-depth product listed in Table 7.2 was adopted to derive the floodway, flood storage and flood fringe. Hydraulic category mapping for all modelled design floods is included in Map Set D in Volume 2: Flood Mapping. It is noted that the primary filtered modelling results (refer Section 7.1) have been used to develop the flood function mapping.

Table 7.2 Hydraulic Categories

Classification	Criteria	Definition
Floodway	[Velocity * Depth ≥ 0.25 m^2/s AND Velocity ≥ 0.5 m/s AND Depth ≥ 0.1 m] OR [Velocity > 1.0 m/s AND Depth ≥ 0.1 m]	Areas and flow paths where a significant proportion of floodwaters are conveyed.
Flood Storage	Depth ≥ 0.3 m	Areas where floodwaters accumulate before being conveyed downstream. These areas are important for detention and attenuation of flood peaks.
Flood Fringe	Remaining Flood Extent Depth < 0.3 m	Areas that are low-velocity backwaters within the floodplain. Filling of these areas generally has little consequence to overall flood behaviour.

8 Sensitivity and Climate Change Assessment

8.1 Sensitivity Assessment

8.1.1 Overview

Computer flood models require the adoption of several modelling parameters that may not be known with a high degree of certainty or are subject to natural variation (e.g. summer vs. winter vegetation). Calibration and/or verification is completed, where possible, in an effort to ensure the adopted model parameters generate reliable estimates of flood conditions. The model verification completed for this study is discussed in Section 5.

As inputs can impact on the results generated by the models, it is important to understand how any uncertainties in key model input parameters or changes to parameters (e.g. due to climate change) may impact on the results predicted by the models. Accordingly, a sensitivity assessment was undertaken using the TUFLOW models in order to observe changes to predicted design flood behaviour when varying the model parameters listed in Table 8.1 (noting no other modification outside the changes to the listed parameters were undertaken). In defining sensitivity tests, consideration has been given to the most appropriate parameters considering catchment properties and simulated design flood behaviour.

Table 8.1 Sensitivity Assessment Criteria

Sensitivity Assessment Scenario	Details	Design Floods
Hydraulic roughness (Manning's n)	+ 20% Manning's 'n' values - 20% Manning's 'n' values	1% AEP PMF
Hydraulic structure / pit inlet blockage	100% Blockage	1% AEP PMF

The rationalisation for each of these sensitivity tests, as well as adopted model parameters and results are summarised in the following sections.

8.1.2 Hydraulic Roughness

Whilst the adopted hydraulic roughness values are within typical recommended ranges, the inherent variability and uncertainty in hydraulic roughness warrants consideration of the relative impact on adopted design flood conditions. Sensitivity tests on the TUFLOW model results to modified hydraulic roughness (Manning's 'n') were undertaken by applying a 20% increase and a 20% decrease in the adopted values for the 1% AEP flood, with adopted values listed in Table 8.2.

Table 8.2 Hydraulic Roughness Values for Sensitivity Assessment

Land Use Type	Manning's 'n' value	20% Increase in Manning's 'n'	20% Decrease in Manning's 'n'
Maintained Grass	0.035	0.042	0.028
Roads	0.02	0.024	0.016
Railway	0.05	0.06	0.04
Low Density Residential Lot	0.04	0.048	0.032

Land Use Type	Manning’s ‘n’ value	20% Increase in Manning’s ‘n’	20% Decrease in Manning’s ‘n’
High-density Residential Lot	0.03	0.036	0.024
Commercial Lot	0.03	0.036	0.024
Maintained Vegetation (e.g. grass)	0.035	0.042	0.028
Dense Vegetation	0.10	0.12	0.08
Waterbody	0.02	0.024	0.016
Open Channels	0.04	0.048	0.032

The results of the sensitivity assessment are provided in Map Set E in Volume 2: Flood Mapping. It is noted that the primary filtering method (refer Section 7.1) has been applied to this mapping.

Whilst the modified hydraulic roughness values do result in some changes to the predicted peak water levels along watercourses, there is minimal impact on inundation extents in urban areas where shallow, higher velocity flows are present.

8.1.3 Hydraulic Structure Blockage

As discussed in Section 6.5.2, structure and pit inlet blockage are an important consideration in the modelling of design floods. Blockage sensitivity was assessed based on full (i.e. 100%) blockage for all structures across the study area. This includes all cross-drainage structures, pit inlets and headwalls across the study area.

The results of the sensitivity assessment are provided in Map Set E in Volume 2: Flood Mapping. It is noted that the primary filtering method (refer Section 7.1) has been applied to this mapping. This mapping indicates that the full blockage scenario generally results in peak flood level increases immediately upstream of cross-drainage structures and corresponding localised decreases downstream of the structures.

8.2 Climate Change

8.2.1 Climate Change Guidance

Guidance on climate change assessment is provided in ARR2019. As outlined in Book 1 Chapter 6 of ARR 2019, there are multiple aspects of design flood estimation that are likely to be impacted by climate change, including:

- rainfall IFD relationships
- temporal patterns
- continuous rainfall sequences
- antecedent conditions
- coincident flooding extremes.

However, individual impacts of any single aspect have not been subject to comprehensive study. As such, ARR 2019 recommends a focus on potential changes in rainfall intensity and sea level rise for the assessment of the likely impacts of climate change. As the study area is tidally impacted, both sea level rise and rainfall intensity are considered relevant to this Flood Study. Although there is considerable uncertainty associated with the impact that climate change may have on rainfall levels, in particular, it was considered important to provide an assessment of the potential impact that climate change may have on the existing flood risk across the catchment.

Book 1, Chapter 6 of ARR 2019 outlines a six-step approach to be used to incorporate climate change risks into the estimation of design flood conditions. The six steps and their application in this study are outlined below:

- *Step 1: Set the Effective Service Life or Planning Horizon* – A 2090 planning horizon has been assumed.
- *Step 2: Set the Design Flood Standard* – The 1% AEP flood has been adopted as the design standard.
- *Step 3: Consider the Purpose and Nature of the Asset or Activity and Consequences of its Failure* – The consequences of increased frequency of exposure and damage are considered to be high in this case.
- *Step 4: Carry out a Climate Change Risk Screening Analysis* – Marginal increase in peak flood levels are expected in events rarer than the 1% AEP (i.e. the 0.5% AEP and 0.2% AEP) across the majority of the catchment. However, larger peak flood level increase are expected in certain locations.
- *Step 5: Consider Climate Change Projections and their Consequences* – ARR 2019 recommends assessment of Representative Concentration Pathway (RCP) 4.5 and RCP 8.5 scenarios.
- *Step 6: Consider Statutory Requirements* – Impacts of climate change are discussed in this chapter.

The ARR Data Hub provides a series of Interim Climate Change Factors for locations across Australia, these are presented in Table 8.3.

Table 8.3 Climate Change Sensitivity Scenarios (Rainfall Increase in %)

Year	RCP 4.5	RCP 6	RCP 8.5
2030	0.869 (4.3%)	0.783 (3.9%)	0.983 (4.9%)
2040	1.057 (5.3%)	1.014 (5.1%)	1.349 (6.8%)
2050	1.272 (6.4%)	1.236 (6.2%)	1.773 (9.0%)
2060	1.488 (7.5%)	1.458 (7.4%)	2.237 (11.5%)
2070	1.676 (8.5%)	1.691 (8.6%)	2.722 (14.2%)
2080	1.810 (9.2%)	1.944 (9.9%)	3.209 (16.9%)
2090	1.862 (9.5%)	2.227 (11.5%)	3.679 (19.7%)

8.2.2 Modelled Climate Change Events

With consideration of the above process and table, in consultation with Council and in line with the climate change assessment undertaken in the neighbouring Woolooware Bay catchment, the following climate change event simulations were undertaken for the 1% AEP flood and PMF:

- Rainfall increase events:
  - 10% increase in rainfall intensity (considered to approximate the 2090 RCP 4.5 scenario)
  - 20% increase in rainfall intensity (considered to approximate the 2090 RCP 8.5 scenario)
  - 30% increase in rainfall intensity.

- Sea level rise (SLR) events:
  - 0.39 m sea level rise for 2070 (applied to design tailwater conditions for the design 1% AEP flood and PMF events as listed in Table 8.4)
  - 0.72 m sea level rise for 2100 (applied to design tailwater conditions for the design 1% AEP flood and PMF events as listed in Table 8.4).

Table 8.4 Tailwater Conditions for Sea Level Rise Events

Climate Change Event	Local Catchment Rainfall Event	Adopted Sea Level Rise Tailwater Condition
1% AEP + SLR 2070	1% AEP	5% AEP Level + 0.39 m
1% AEP + SLR 2090	1% AEP	5% AEP Level + 0.72 m
PMF + SLR 2070	PMF	1% AEP Level + 0.39 m
PMF + SLR 2090	PMF	1% AEP Level + 0.72 m

It is noted that no combined increased rainfall intensity and sea level rise scenarios were considered as part of this assessment.

8.2.3 Results of Rainfall Increase Events

The change in peak 1% AEP flood and PMF levels associated with the adopted 10%, 20% and 30% increases in rainfall intensities are presented in Map Set F in Volume 2: Flood Mapping. It is noted that the primary filtering method (refer Section 7.1) has been applied to this mapping.

A 10% rainfall increase generally results in widespread 1% AEP peak flood level increases of up to 0.1 m within defined watercourses, with smaller increases of up to 0.05 m within urban overland flow paths. Peak flood level increases are largest in locations immediately upstream of major cross-drainage structures, with notable increases in the storage areas at Garnet Road and Bates Drive (0.2 m increase) and upstream of the railway line between Gymea and Miranda Station (0.2 m increase). In the PMF event, an increase of up to 0.2 m is predicted within defined watercourses, with the widespread increases of up to 0.05 m across urban overland flooding areas.

A 20% rainfall increase generally results in widespread 1% AEP peak flood level increases of up to 0.3 m within defined watercourses, with smaller increases of up to 0.08 m within urban overland flow paths. Peak flood level increases are largest in locations immediately upstream of major cross-drainage structures, with notable increases in the storage areas at Garnet Road and Bates Drive (0.35 m increase) and upstream of the railway line between Gymea and Miranda Station (0.3 m increase). In the PMF event, an increase of up to 0.35 m is predicted within defined watercourses, with the widespread increases of up to 0.1 m across urban overland flooding areas.

A 30% rainfall increase generally results in widespread 1% AEP peak flood level increases of up to 0.4 m within defined watercourses, with smaller increases of up to 0.1 m within urban overland flow paths. Peak flood level increases are largest in locations immediately upstream of major cross-drainage structures, with notable increases in the storage areas at Garnet Road and Bates Drive (0.4 m increase) and upstream of the railway line between Gymea and Miranda Station (0.45 m increase). In the PMF event, an increase of up to 0.4 m is predicted within defined watercourses, with the widespread increases of up to 0.2 m across urban overland flooding areas.

8.2.4 Results of Sea Level Rise Events

The change in peak 1% AEP flood and PMF levels associated with the modelled sea level rise conditions are presented in Map Set F in Volume 2: Flood Mapping. It is noted that the primary filtering method (refer Section 7.1) has been applied to this mapping.

This mapping indicates that minimal peak 1% AEP and PMF overland flow flood level impacts are predicted as a result of sea level rise within urban overland flooding areas across all catchments. This is because these urban areas are typically elevated above the level of tidally influenced watercourses such as Port Hacking and the Georges River. However, some increases in peak flood levels and extents are predicted along tidal boundaries and within tidally influenced creeks (e.g. Oyster Gully), particularly within the Georges River East catchment.

8.2.5 Discussion

This assessment has shown that climate change induced rainfall does have the potential to increase the existing flood risk and potential impacts of future floods within this study area, with more significant impacts on overland flow flooding within this study area predicted to be associated with climate induced rainfall increases rather than sea level rise.

It needs to be acknowledged that there is still considerable uncertainty associated with climate change predictions. Although current information suggests rainfall intensity is not predicted to reach the upper limits considered as part of this study until at least 2090, potential changes in climate conditions should be closely monitored as the catchment is predicted to be sensitive to increases in flood producing rainfalls and there is potential for impacts to flood levels across the floodplain.

9 Information to Support Decision Making

9.1 Overview

Land use planning and development controls are key mechanisms by which Council can reduce flood risk, provide guidance on where appropriate development can occur, manage areas impacted by flooding and protect increasing numbers of people located within the floodplain. Such mechanisms will influence future development (and redevelopment) and therefore the benefits will accrue gradually over time. Without comprehensive floodplain planning, existing problems may be exacerbated and opportunities to reduce flood risk to people, property and public infrastructure may be missed.

Flood emergency response measures are key to managing the continuing and residual flood risk to the community. They seek to modify the response of the emergency services and the community to residual flood risk by providing information, education and awareness about the nature of flooding so that informed decisions can be made before, during and after a flood.

The following sections discuss key outputs of this flood study related to flood planning and emergency response, including the preliminary flood planning area, flood control lot tagging, flood risk precincts and flood emergency response classifications.

9.2 Preliminary Flood Planning Area

9.2.1 Overview

The Flood Planning Level (FPL) is an important flood risk management tool that is used for flood planning purposes and is defined in best practice guidelines ‘Floodplain Development Manual’ (NSW Government, 2005), ‘Floodplain Risk Management Manual’ (DPE, 2023) and ‘Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia, Handbook 7’ (AIDR, 2017). The FPL defines the level below which a Council places restrictions on development as a means of managing future flood risk. It is derived through a combination of the flood level for the Defined Flood Event (DFE) plus an adopted freeboard (refer Figure 9.1). The area of land below the FPL and subject to flood related development controls is the Flood Planning Area (FPA).

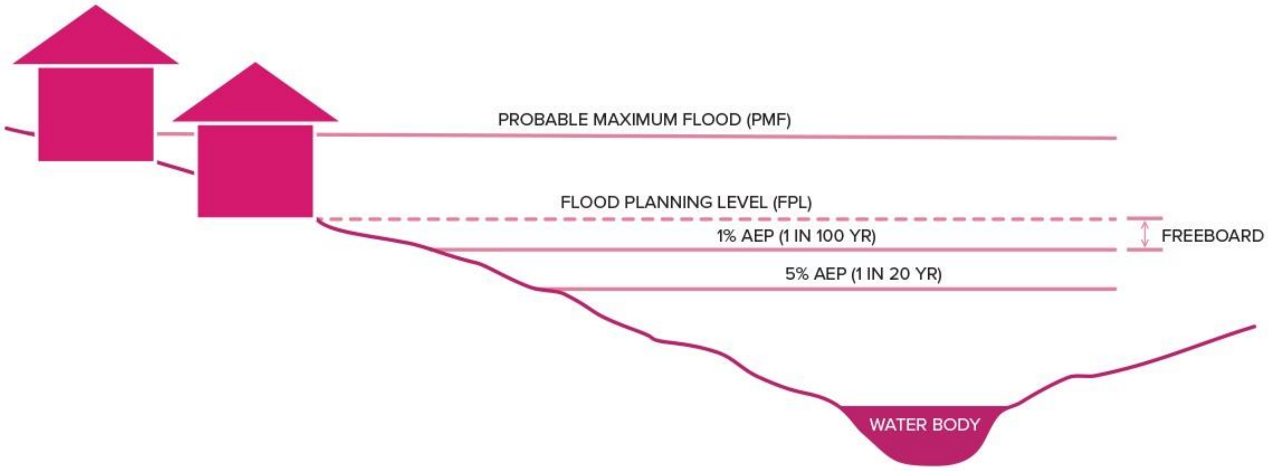


Figure 9.1 Typical Relationship between FPL, DFE and Freeboard
(Source: Flooding | City of Ryde (nsw.gov.au))

9.2.2 Defining the Preliminary FPL and FPA

The 1% AEP flood, which has 1% chance of being equalled or exceeded in any one year, is the typical DFE used across NSW for flood planning and development control purposes. Sutherland Shire Council has consistently adopted the 1% AEP flood as the DFE for determining the FPL across its LGA.

Freeboard is a factor of safety expressed as the height above the design flood level. It is added to flood levels to provide reasonable certainty of achieving the desired level of service expected from setting a DFE (NSW Government, 2023), with consideration of the following:

- Differences in flood level due to local factors (e.g. wave action, small flow paths less than model grid size).
- Uncertainties in flood level estimates and predicted flood conditions, as the model does not include objects which may increase or impact overland flows (such as vehicles, power poles, electricity substations etc). Estimates may also be sensitive to changes in model parameters and conditions such as pit blockage, surface roughness, etc, and model calibration and/or verification may be limited by suitable data availability.
- Changes in rainfall patterns and intensity as a result of climate change.
- Cumulative impact of infill development on existing zoned land.

The above factors may either result in a variation between flood modelling results and actual flood conditions, or a variation between existing flood risk and potential future flood risk that is accounted for in the freeboard.

The NSW Government Department of Planning and Environment Guide ‘Understanding and Managing Flood Risk: Flood Risk Management Guide’ (2023) identifies that *“The typical freeboard used for flooding from waterways in New South Wales is 0.5 metres”* and *“A lower level of freeboard, 0.3 metres, is generally considered acceptable where there is very shallow water and where the influence of [uncertainties] is limited. This is generally limited to some areas affected by local overland flooding.”*

Whilst a lower freeboard value of 0.3 m was considered given the shallow depths of overland flow flooding across the study area, a 0.5 m freeboard value was proposed by Council for this study for consistency with Council’s Development Control Plan (DCP) 2015, other previous studies completed in the LGA and typical freeboard values adopted by Councils across NSW. The suitability of the freeboard was also assessed relative to the results of the sensitivity assessment for the 1% AEP flood. It was determined that the impact of changes in modelling parameters and/or climate change lie within the 0.5 m freeboard tolerance, with predicted peak flood level impacts across local overland flooding areas typically less than 0.3 m. Accordingly, FPLs across the study area were derived from the 1% AEP flood level + 0.5 m freeboard.

The FPA was then defined by applying the FPL directly to the topographic data to determine the extent of the FPA (i.e. defined by intersecting the FPL with the surface topography) and clipping this area to the PMF extent as this represents the limit of the floodplain. Mapping of the resultant FPA extent is shown in Map Set G in Volume 2: Flood Mapping.

9.3 Flood Control Lots

Flood control lots are identified as flood liable and subject to Section 10.7 notification. This indicates to Council that these lots are subject to flood-related development controls due to their potential to be flood affected and should development of the lots occur, flooding will need to be considered and Council’s Local Environment Plan, Development Control Plan and any other relevant flood related policies will apply.

In 2021, the updated NSW Flood Prone Land Package came into effect. The package recommended a modification to the notation of flood affected lots to include both those below the FPL (as identified above) and additionally land above the FPL but below the PMF level. Under the Flood Prone Land Package, flood affected lots are now to be notated on Section 10.7 certificates as either affected in the FPL (Part 7.1) or the PMF (Part 7.2).

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 defined flood event (in this study the 1% AEP event), up to and including the PMF event should be addressed in a floodplain risk management study. Whilst planning decisions around building conditions such as floor heights and structural stability generally focus on the 1% AEP event, events up to the PMF are of greater importance when considering issues such as emergency response management. PMF tagging identifies properties where greater consideration of flood risk is required, in particular for development associated with critical or sensitive land uses (e.g. child and aged care, schools, medical facilities, etc).

Accordingly, flood control lot tagging has been undertaken to identify properties within Council's GIS cadastral lot database that are:

- FPA and PMF tagged
- PMF tagged only (i.e. within the PMF extent but beyond the FPA extent).

Initial preliminary flood control lot tagging was undertaken based on the intersection of cadastral lots with either the FPA or PMF extents. "Secondary Filtering" criterion was then applied to eliminate lots that are only marginally affected along property boundaries. This was achieved by applying a 1 m buffer within a lot and removing any properties where the FPA or PMF extent is limited to areas outside the buffer within a cadastral lot.

Resultant flood control lot mapping is provided in Map Set G in Volume 2: Flood Mapping. The number of flood control lots identified in the study area is listed in Table 9.1. Please note that these values are not final and are subject to change based on further review by BMT and Council.

Table 9.1 Flood Control Lots within the Study Area

Flood Control Lot Tagging	Number of Lots Tagged (Total Cadastral Lots within the TUFLOW Model Extent = 48,612)	% of Lots Tagged vs Total Lots in TUFLOW Model Extent
FPA	6,886	14%
PMF	9,741	20%

9.4 Flood Risk Precincts

Sutherland Shire Council's requirements for development within its floodplain are defined within the Sutherland Shire Council Development Control Plan 2015. Chapter 40 of the DCP introduces the concept of "Flood Risk Precincts", which divides the floodplain accordingly to the potential flood hazard and risk to people and property. This flood risk precinct classification, in turn, determines which flood-related development controls are applicable for a particular parcel of land. The three flood risk precincts documented within the DCP are summarised in Table 9.2.

Table 9.2 Flood Risk Precinct Definitions (Source: DCP 2015)

Flood Risk Precinct	Description
High	High Flood Risk is defined as an area of land below the 1% AEP flood level that is either subject to a high hydraulic hazard or where there are significant evacuation difficulties. On land with high flood risk, there is possible danger to personal safety; evacuation by trucks would be difficult; able-bodied adults would have difficulty wading to safety; and there is a potential for significant structural damage to buildings.
Medium	Medium Flood Risk is the area below the 1% AEP flood that is not subject to a high hydraulic hazard and where there are no significant evacuation difficulties. In this precinct there would still be a significant risk of flood damage or risk to life, but these damages and risks can be minimised by the application of appropriate development controls.
Low	Low Flood Risk is all land that could potentially be inundated (i.e. within the extent of the PMF) but not identified as either a high flood risk or a medium flood risk precinct (refer above). The low flood risk precinct is that area above the 1% AEP flood level and most land uses would be permitted within this precinct.

To aid Council in defining the spatial extent of each flood risk precinct across the study catchments, Flood Risk Precinct mapping was prepared based on the outcomes of the design flood simulations and FDM (2005) hazard mapping. The flood risk precinct maps are provided in Map Set H in Volume 2: Flood Mapping.

The majority of the study area is generally classified as Low and Medium Flood Risk Precincts. High Flood Risk Precincts are typically limited to low lying areas surrounding major receiving watercourses and along local creeks.

9.5 Flood Emergency Response Classifications

The NSW State Emergency Service (SES) has formal responsibility for emergency management operations in response to flooding in NSW. Other organisations typically assist, as required, including the Bureau of Meteorology, Council, Police, Fire Brigade, Ambulance and community groups.

The SES classifies communities according to the impact that flooding has on them. The primary purpose for doing this is to assist SES in the planning and implementation of response strategies. Flood impacts relate to where the normal functioning of services is altered due to a flood, either directly or indirectly, and relates specifically to the operational issues of evacuation, resupply and rescue. Flood emergency response classifications are listed below, with definitions extracted from 'Flood Emergency Response Classification of the Floodplain' (AIDR, 2017).

- Flooded Isolated Elevated (FIE) – Areas flooded in the PMF and isolated from community evacuation facilities by floodwaters or impossible terrain where there is a substantial amount of land elevated above the PMF.
- Flooded Isolated Submerged (FIS) — Areas flooded in the PMF and isolated from community evacuation facilities by floodwaters or impossible terrain where all land will be fully submerged in the PMF after becoming isolated.
- Overland Escape Route (FEO) – Areas that are flooded in the PMF but not isolated from community evacuation facilities, where evacuation relies upon overland escape routes that rise out of the floodplain.

- Rising Road (FER) – Areas that are flooded in the PMF but not isolated from community evacuation facilities, where evacuation routes from the area follow roads that rise out of the floodplain.
- Indirect Consequence (NIC) – Areas outside the limit of flooding which are not inundated and do not lose road access but which may be indirectly affected as a result of flooding.

The classification of communities is designed for use on broad or precinct basis. The study area was delineated into a series of local areas (or precincts) related to local flood behaviour and overland flow paths. The flood classification process was undertaken using the AIDR (2017) flowchart reproduced in Figure 9.2) to identify the flood classification for each precinct for the PMF and is presented in Map Set I in Volume 2: Flood Mapping.

Due to the nature of overland flow flooding and the terrain within the study area, the majority of areas only impacted by overland flooding are generally classified as either Isolated Elevated, Overland Escape or Rising Road areas. Isolated Submerged areas are typically limited to low lying areas surrounding receiving watercourses, most notably the Woronora River, and adjacent to local creeks.

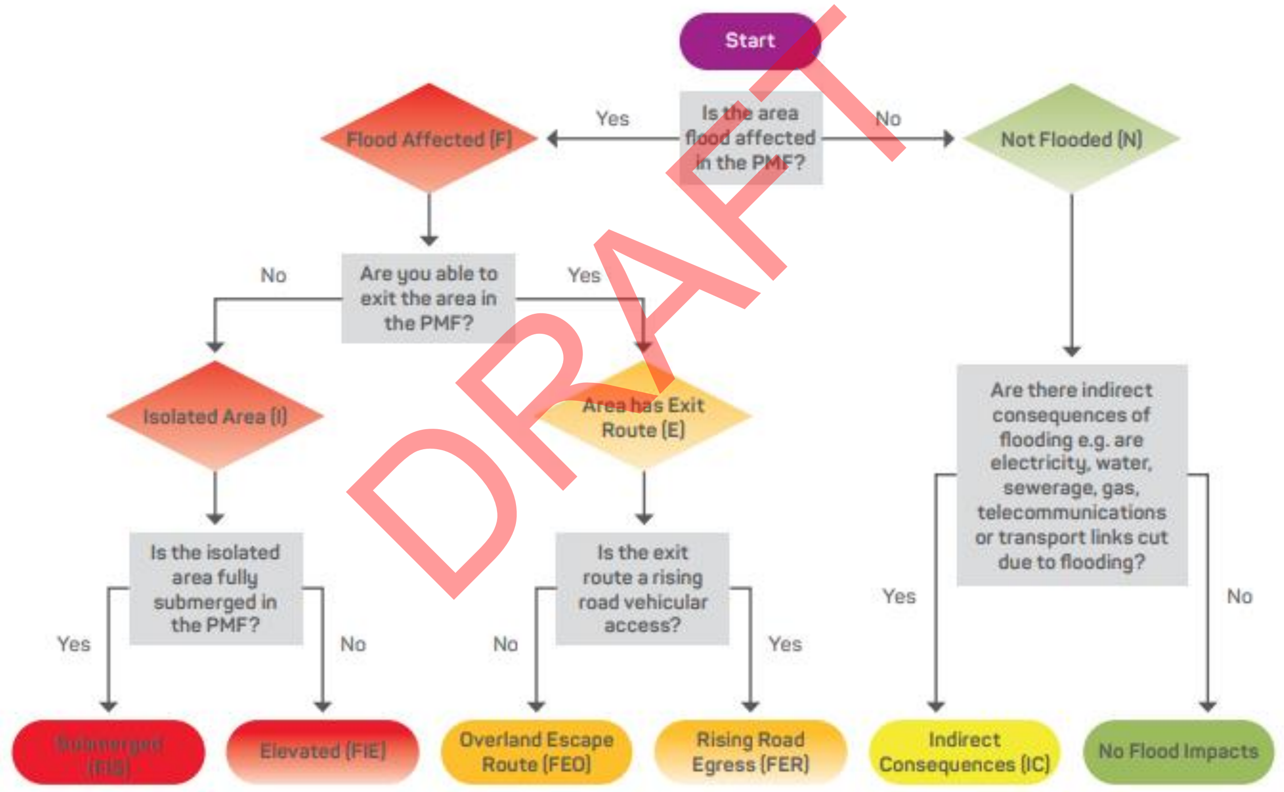


Figure 9.2 Flow chart for Determining Flood Emergency Response Classifications (AIDR, 2017)

9.6 Pipe Capacity Assessment

A stormwater network pipe capacity assessment was undertaken using the one-dimensional (1D) TUFLOW results for each modelled design flood, with pipe capacity considered in terms of the design flood during which the pipe is first full (>99%) or “at capacity”. Please note that this assessment was undertaken using design flood modelling results that apply the blockage assumptions outlined in Section 6.4.2. The resultant pipe capacity assessment is shown in Map Set J in Volume 2: Flood Mapping and a breakdown of the percentage of pipes that are at capacity for modelled design floods is provided in Table 9.3.

Table 9.3 Percentage (%) of Pipes at Capacity During Design Floods

Design Flood	% of Pipe Network at Capacity
20% AEP	54%
10% AEP	58%
5% AEP	62%
2% AEP	65.5%
1% AEP	67.7%
0.5% AEP	70.7%
0.2% AEP	76.9%
PMF	89.3%
Not “at capacity” in any design floods	10.7%

The assessment shows that 54% of pipes in the model are operating at capacity during the 20% AEP flood. Above the 1% AEP, more than 70% of pipes in the study area’s stormwater network are at capacity.

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

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

10 Conclusions

The Sutherland Shire Overland Flood Study was completed to define the historical, existing and potential future climate overland flood conditions across the urban areas of the Sutherland LGA that ultimately drain to the Georges River, Woronora River and Port Hacking

Flood behaviour was predicted for a range of design floods based on a WBNM hydrologic and TUFLOW hydraulic models developed for the study catchments as part of this Flood Study. These models were verified qualitatively using anecdotal flood information for historical events that was provided by the community and Council.

The WBNM and TUFLOW models were used to simulate a range of design events including the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP floods and PMF. The potential impacts of climate change, including increased rainfall intensity and sea level rise, were also assessed. The modelling results were used to prepare design flood mapping, incorporating peak flood depth, flood velocity, flood hazard and flood function (refer Volume 2: Flood Mapping).

Overall it was found that during smaller magnitude floods, such as the 20% AEP to 5% AEP, overland flow flooding in urban areas is typically contained within defined waterways and roadway corridors. However, during larger magnitude events, such as the 2% AEP flood and larger, property inundation occurs in some parts of the study area when overland flow from an upstream catchment area drains through a property to its discharge point or when flow within a roadway overtops the layback / kerb and drains through a property. Several flooding hotspots across urban overland flooding areas were also determined based on the results of the flood models, with the largest number of hotspots identified within the Port Hacking catchment (relative to other major catchments within the study area).

Flood planning and emergency response information, including definition of the Flood Planning Area (FPA), Flood Control Lots, Flood Risk Precincts, and Flood Emergency Response Classifications (FERCs), has also be developed based on the predicted flood characteristics (refer Volume 2: Flood Mapping).

Overall, the outputs of this flood study provide an improved understanding of overland flood behaviour that will aid in Council’s management of flood risk and establish the basis for subsequent floodplain management activities.

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12 Glossary

afflux	The change in water level from existing conditions resulting from a change in the watercourse or floodplain – e.g. construction of a new bridge.
Annual Exceedance Probability (AEP)	The chance of a flood of a given size (or larger) occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (i.e. a 1 in 20 chance) of a peak discharge of 500 m^3/s (or larger) occurring in any one year (also see Average Recurrence Interval).
Australian Height Datum **(AHD)**	National survey datum corresponding approximately to mean sea level.
astronomical tide	Astronomical tide is the cyclic rising and falling of the Earth's oceans water levels resulting from gravitational forces of the Moon and the Sun acting on the Earth.
attenuation	Weakening in force or intensity.
Average Recurrence Interval (ARI)	The long-term average number of years between the occurrence of a flood as big as (or larger than) the selected event. For example, floods with a discharge as great as (or greater than) the 20yr ARI design flood will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event. (see also annual exceedance probability)
Australian Rainfall and Runoff (AR&R)	Engineers Australia publication pertaining to rainfall and flooding investigations in Australia.
calibration	The adjustment of model confuguration and key parameters to best fit an observed data set.
catchment	The catchment at a particular point is the area of land that drains to that point.
critical duration	The critical duration is the design storm duration which provides the highest peak water levels for a given design flood (e.g. 1% AEP) at a given location. For example, if the following design durations were modelled - 2-hour, 6-hour, 9-hour and 12-hour – and the 9-hour duration resulted in the highest peak water level at a given location then the critical duration for that location would be 9-hours.
design flood event	A hypothetical flood representing a specific likelihood of occurrence (for example the 100yr ARI or 1% AEP flood).
development	Existing or proposed works that may or may not impact upon flooding. Typical works are filling of land, and the construction of roads, floodways and buildings.

discharge	The rate of flow of water measured in tems of vollume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
Extreme Flood	An extreme flood deemed to be the maximum flood likely to occur (for this study the Extreme Flood event was defined as three times the 1% AEP event).
flood	Relatively high river or creek flows, which overtop the natural or artificial banks, and inundate floodplains and/or coastal inundation resulting from super elevated sea levels and/or waves overtopping coastline defences.
flood behaviour	The pattern / characteristics / nature of a flood.
flood fringe	Land that may be affected by flooding but is not designated as floodway or flood storage.
flood hazard	The potential risk to life and limb and potential damage to property resulting from flooding. The degree of flood hazard varies with circumstances across the full range of floods.
flood level	The height or elevation of floodwaters relative to a datum (typically the Australian Height Datum). Also referred to as “stage”.
flood liable land	See flood prone land.
floodplain	Land adjacent to a river or creek that is periodically inundated due to floods. The floodplain includes all land that is susceptible to inundation by the probable maximum flood (PMF) or Extreme Flood event.
floodplain management	The co-ordinated management of activities that occur on the floodplain.
floodplain risk management plan	A document outlining a range of actions aimed at improving floodplain management. The plan is the principal means of managing the risks associated with the use of the floodplain. A floodplain risk management plan needs to be developed in accordance with the principles and guidelines contained in the NSW Floodplain Management Manual. The plan usually contains both written and diagrammatic information describing how particular areas of the floodplain are to be used and managed to achieve defined objectives.
Flood Planning Area (FPA)	The area of land below the Flood Planning Level and subject to flood related development controls.

Flood Planning Levels (FPLs)	Flood Planning Levels selected for planning purposes are derived from a combination of the adopted flood level plus freeboard, as determined in floodplain management studies and incorporated in floodplain risk management plans. Selection should be based on an understanding of the full range of flood behaviour and the associated flood risk. It should also take into account the social, economic and ecological consequences associated with floods of different severities. Different FPLs may be appropriate for different categories of landuse and for different flood plans. The concept of FPLs supersedes the “standard flood event”. As FPLs do not necessarily extend to the limits of flood prone land, floodplain risk management plans may apply to flood prone land beyond that defined by the FPLs.
flood prone land	Land susceptible to inundation by the probable maximum flood (PMF) or Extreme Flood event. Under the merit policy, the flood prone definition should not be seen as necessarily precluding development. Floodplain Risk Management Plans should encompass all flood prone land (i.e. the entire floodplain).
flood source	The source of the floodwaters. In this study, overland flow is the primary source of floodwaters.
flood storage	Floodplain area that is important for the temporary storage of floodwaters during a flood.
floodway	A flow path (sometimes artificial) that carries significant volumes of floodwaters during a flood.
freeboard	A factor of safety usually expressed as a height above the adopted flood level thus determing the flood planning level. Freeboard tends to compensate for factors such as wave action, localised hydraulic effects and uncertainties in the design flood levels.
geomorphology	The study of the origin, characteristics and development of land forms.
gauging (tidal and flood)	Measurement of flows and water levels during tides or flood events.
historical flood	A flood that has actually occurred.
hydraulic	The term given to the study of water flow in rivers, estuaries and coastal systems.
hydrodynamic	Pertaining to the movement of water
hydrograph	A graph showing how a river or creek’s discharge changes with time.
hydrographic survey	Survey of the bed levels of a waterway.
hydrologic	Pertaining to rainfall-runoff processes in catchments
hydrology	The term given to the study of the rainfall-runoff process in catchments.

hyetograph	A graph showing the depth of rainfall over time.
Intensity Frequency Duration (IFD) Curve	A statistical representation of rainfall showing the relationship between rainfall intensity, storm duration and frequency (probability) of occurrence.
LiDAR	Light Detection and Ranging –a remote sensing method used to generate ground surface elevation. Typically acquired through airborne surveys from which an aeroplane can cover large areas.
overland flow	Overland flow is surface run off before it enters a waterway. It is caused by rainfall which flows downhill along low points concentrating in gullies, channels, surface depressions and stormwater systems.
peak flood level, flow or velocity	The maximum flood level, flow or velocity that occurs during a flood event.
pluviometer	A rainfall gauge capable of continously measuring rainfall intensity
Probable Maximum Flood (PMF)	An extreme flood deemed to be the maximum flood likely to occur.
probability	A statistical measure of the likely frequency or occurrence of flooding.
Representative Concentration Pathway (RCP)	Prescribed pathway for greenhouse gas and aerosol concentrations, together with land use change, that are consistent with a set of broad climate outcomes used by the climate modelling community.
riparian	The interface between land and waterway. Literally means “along the river margins”.
runoff	The amount of rainfall from a catchment that actually ends up as flowing water in the river or creek.
stage	See flood level.
stage hydrograph	A graph of water level over time.
sub-critical	Refers to flow in a channel that is relatively slow and deep
topography	The shape of the surface features of land
velocity	The speed at which the floodwaters are moving. A flood velocity predicted by a 2D computer flood model is quoted as the depth averaged velocity, i.e. the average velocity throughout the depth of the water column. A flood velocity predicted by a 1D or quasi-2D computer flood model is quoted as the depth and width averaged velocity, i.e. the average velocity across the whole river or creek section.

validation	A test of the appropriateness of the adopted model configuration and parameters (through the calibration process) for other observed events.
water level	See flood level.

Annex A Estimation of Pervious/Impervious Areas and Percentages

A.1 Overview

This section provides a comprehensive overview of the approach and findings relevant to the estimation of pervious and impervious areas and percentages for different land use zones to be used in the WBNM hydrologic modelling for this study. This included the estimation of the following pervious/impervious areas:

- Total Area (TA): Selection of several blocks within relevant land use categories to establish the overall total area.
- Effective Impervious Area (EIA): The catchment area that generates rapid runoff in response to rainfall events and consisting of Directly Connected Impervious Area (DCIA) and Indirectly Connected Impervious Area (ICIA).
- Urban Pervious Area (UPA): Calculated by subtracting the Effective Impervious Area (EIA) and Indirectly Connected Impervious Area (ICIA) from the Total Area (TA).

The method used for estimating the Effective Impervious Area (EIA) involved visual inspection and/or GIS digitising of areas based on aerial photography and land use maps. This is discussed further for different land use zones in the following sections.

A.2 EIA for Specific Urban Residential Zones

A.1 illustrates that the urban residential zones, including environmental living, low-density residential and high residential areas, encompass a significant portion of the urban catchments in the study area. Recognising their significance, a more detailed analysis utilising GIS digitisation techniques was undertaken. This involved examining representative sub-areas within the catchment and employing aerial photography to map imperviousness more reliably. The estimated imperviousness derived from this mapping was then applied to the corresponding land use zoning maps for further analysis and assessment.

A.1 shows an illustrative sample area analysed for a residential land use zone. The assessment process involved evaluating each of these zones across relevant urban catchments, considering three to five distinct urban blocks within each zone. The final calculation of pervious/impervious areas was obtained by averaging the results from these five areas. The resulting estimates are summarised in A.1.

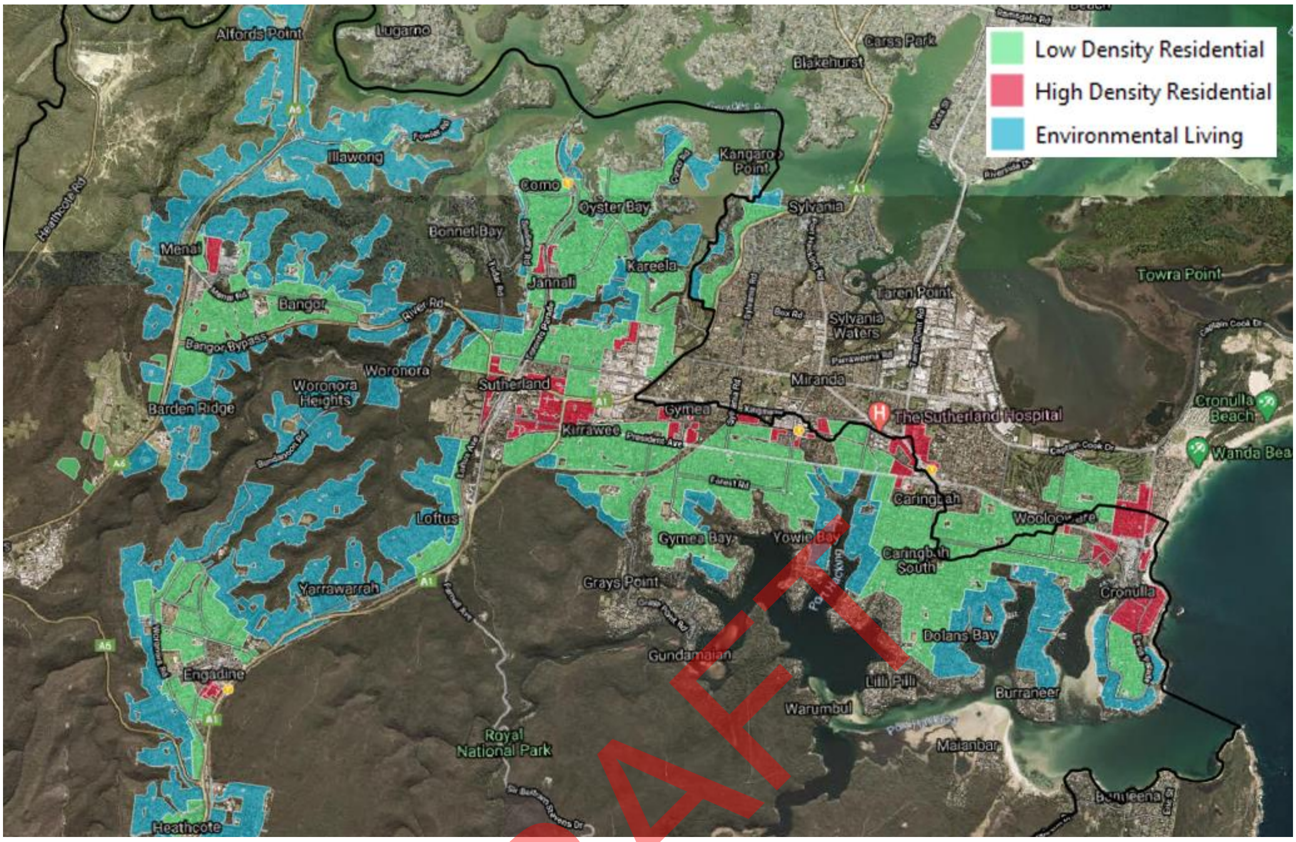
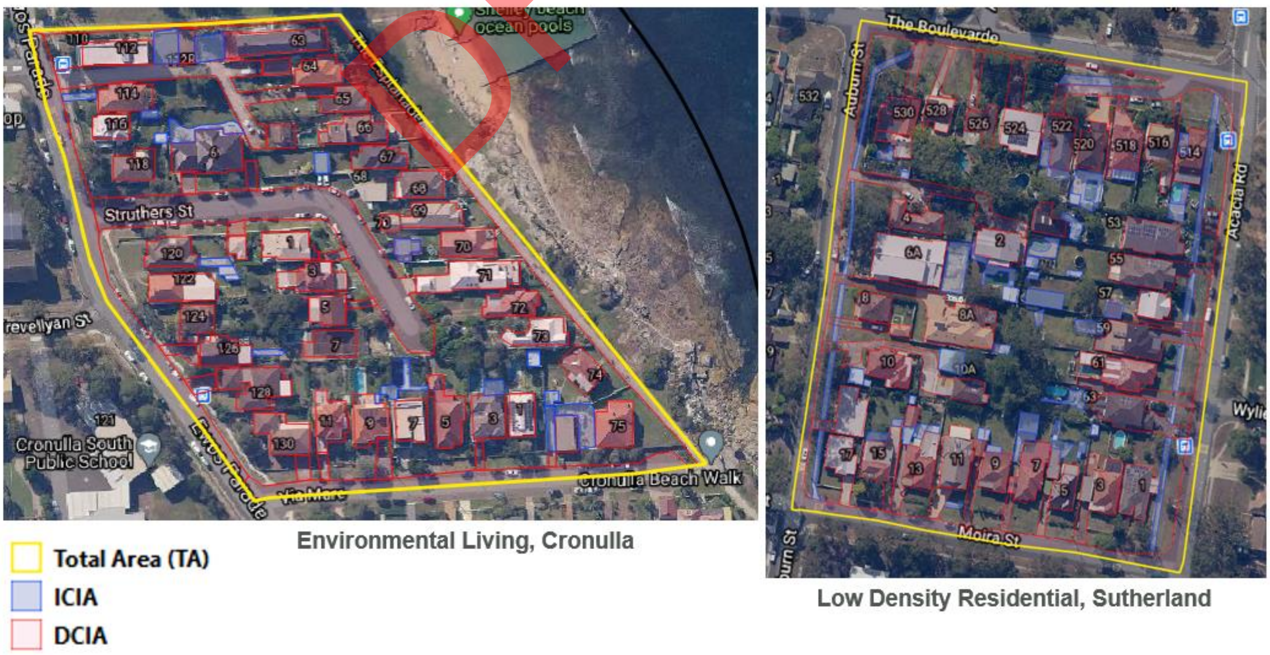


Figure A.1 Urbanised Land Use Zones within the Study Area



Environmental Living, Cronulla

Low Density Residential, Sutherland

Figure A.2 Example of Aerial Photography and Mapping

Table A.1. Results for Specific Urban Land Use Zones

Code	Class Description	Total Area	% of Catchment	DCIA	ICIA	UPA
E4	Environmental Living	19,936,624	5.18%	51%	4%	45%
R2	Low Density Residential	18,142,073	4.71%	53%	7%	40%
R4	High Density Residential	1,786,053	0.46%	58%	12%	30%

A.3 Estimation of EIA for General Land Use Zones

The estimation of pervious/impervious area for each sub-catchment was completed based on the percentage of Effective Impervious Area (EIA) assigned to each land use zoning. This process involved visually inspecting each land use zone located within the WBNM model catchments. The resulting calculations and findings are presented in Table A.2. and accompanied by comments that describe the outcomes of the visual inspection.

Table A.2. Summary of Land Uses and Estimated Percentage of Pervious and Impervious Areas

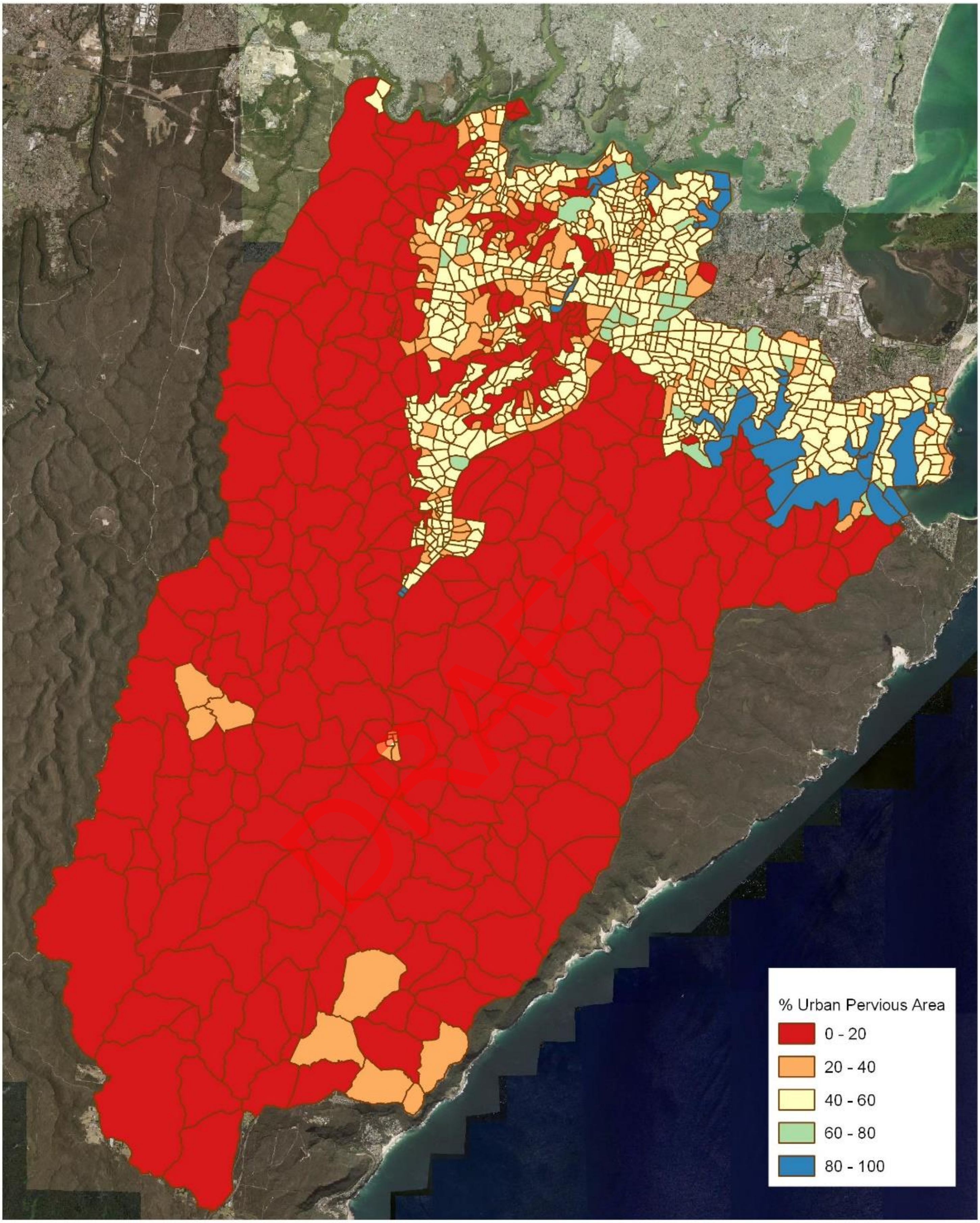
Code	Class Description	Total Area	% of Catchment	DCIA	ICIA	UPA	Comment
E1	National Parks and Nature Reserves	147,660,631	38.37%	2%	0%	98%	This zone should be 100% pervious, however, there is a minor portion of impervious surfaces such as waterways and roads.
E3	Environmental Management	12,345,207	3.21%	49%	12%	39%	Quite urbanised, large contribution to the catchment, digitised to estimate.
E2	Environmental Conservation	92,810,575	24.12%	2%	0%	98%	This zone should be 100% pervious, however, there is a minor portion of impervious surfaces such as waterways and roads.
B2	Local Centre	265,569	0.07%	80%	10%	10%	Predominantly buildings and roads
B1	Neighbourhood Centre	74,365	0.02%	80%	10%	10%	Predominantly buildings and roads
B4	Mixed Use	96,142	0.02%	80%	17%	3%	Visual inspection, mostly industrial building, little grass
B3	Commercial Core	1,089,360	0.28%	85%	10%	5%	Visual inspection, mostly industrial building, little grass
B6	Enterprise Corridor	212,757	0.06%	90%	9%	1%	Visual inspection, mostly industrial building, little grass
RE2	Private Recreation	815,205	0.21%	13%	2%	85%	Digitised a small area to determine percentage impervious
RU2	Rural Landscape	778,935	0.20%	10%	5%	85%	Visual inspection, rural residential with large building footprints/roofs
IN1	General Industrial	584,900	0.15%	80%	10%	10%	This zone seems mostly buildings, roofs and car parks, still a portion of grass
RE1	Public Recreation	6,995,646	1.82%	5%	5%	90%	Some buildings and car parks presented
IN2	Light Industrial	181,597	0.05%	90%	5%	5%	Visual inspection, mostly industrial buildings, little grass
UL	Unzoned Land	8,403	0.00%	0%	0%	100%	Mostly grassy
E4	Environmental Living	19,936,624	5.18%	51%	4%	45%	See Section A.1
R2	Low Density Residential	18,142,073	4.71%	53%	7%	40%	See Section A.1

Code	Class Description	Total Area	% of Catchment	DCIA	ICIA	UPA	Comment
R4	High Density Residential	1,786,053	0.46%	58%	12%	30%	See Section A.1
R3	Medium Density Residential	1,424,149	0.37%	55%	5%	40%	Estimated by digitising some areas
W1	Natural Waterways	9,690,064	2.52%	100%	0%	0%	Waterway classified as 100% impervious
SP1	Special Activities	5,818,278	1.51%	7%	3%	90%	Some buildings and roads in large pervious areas
W2	Recreational Waterways	2,045,259	0.53%	100%	0%	0%	Waterway classified as 100% impervious
RU1	Primary Production	336,275	0.09%	10%	5%	85%	Some buildings present
SP3	Tourist	66,506	0.02%	20%	5%	75%	Some buildings present
SP2	Infrastructure	21,565,048	5.60%	30%	0%	70%	Roadways, polygon also covers grassy roadside verges
SP22	Infrastructure 02	31,510,011	8.19%	10%	0%	90%	Added to better represent and increase % pervious for some catchments on north-west
DM	Deferred Matter	8,474,649	2.20%	0%	0%	100%	Mostly rural forest area
	No Class	114,648	0.03%	100%	0%	0%	To represent ocean areas

A.4 Estimation of Sub-catchment Pervious/Impervious Percentage

The estimation of pervious and impervious areas for each sub-catchment was determined by calculating the percentage of EIA associated with each land use zone. This calculation was completed individually for each sub-catchment.

Figure A.3 to Figure A.5 provide visual representations of the distribution of pervious and impervious areas across the various sub-catchments within the WBNM model.



Title:

HYDROLOGIC MODEL SET UP
EIA ASSESSMENT

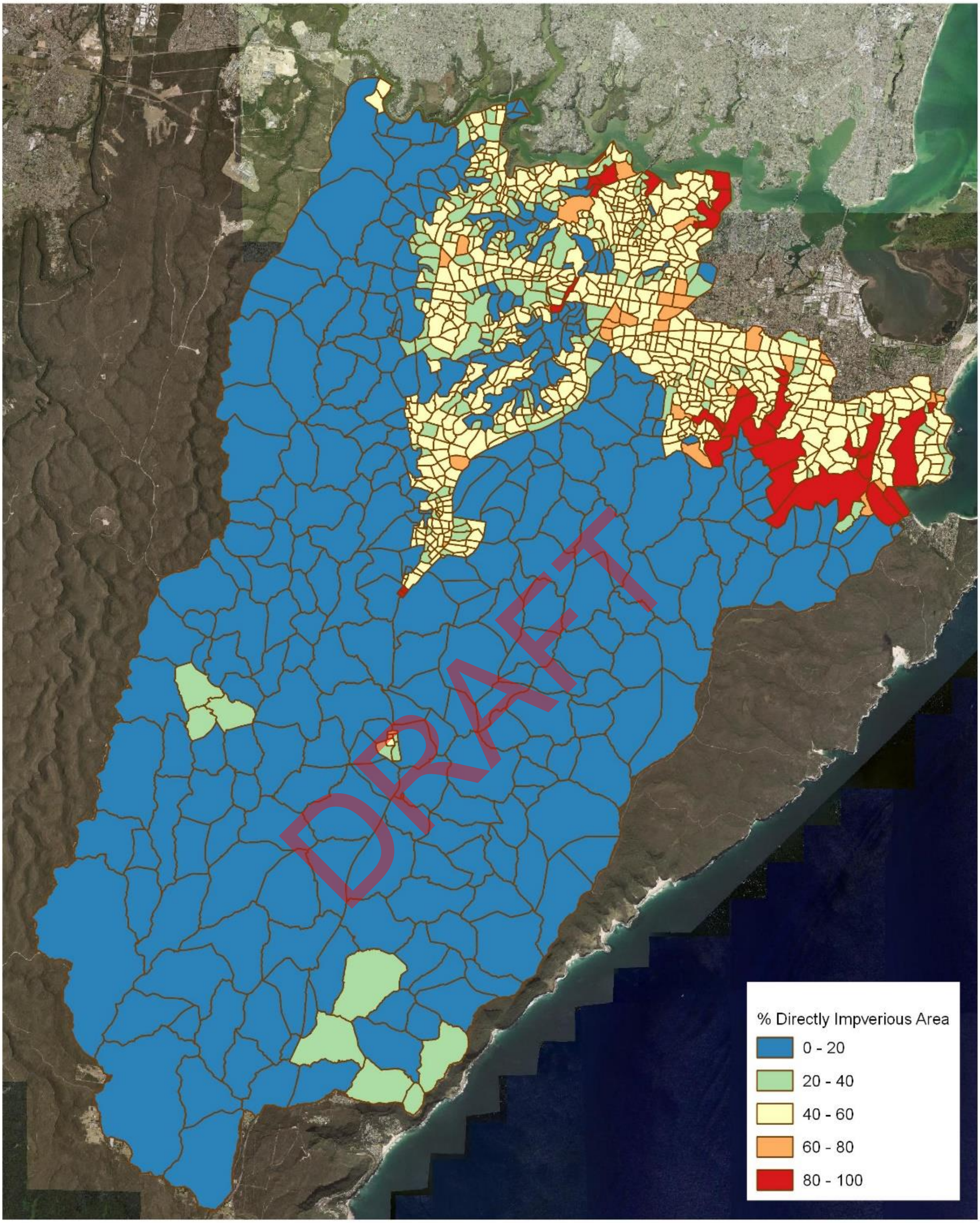
Figure: **A.3**

Rev: **A**

0 1 2 3 4 5 km

BMT

Filepath: S:\WATER\PROJECTS\A10089_Sutherland_Shire_Overland_FS\MI\Workspaces\Workspace_NN.qgz



Title:

HYDROLOGIC MODEL SET UP EIA ASSESSMENT

Figure: **A.4**

Rev: **A**

0 1 2 3 4 5 km

BMT

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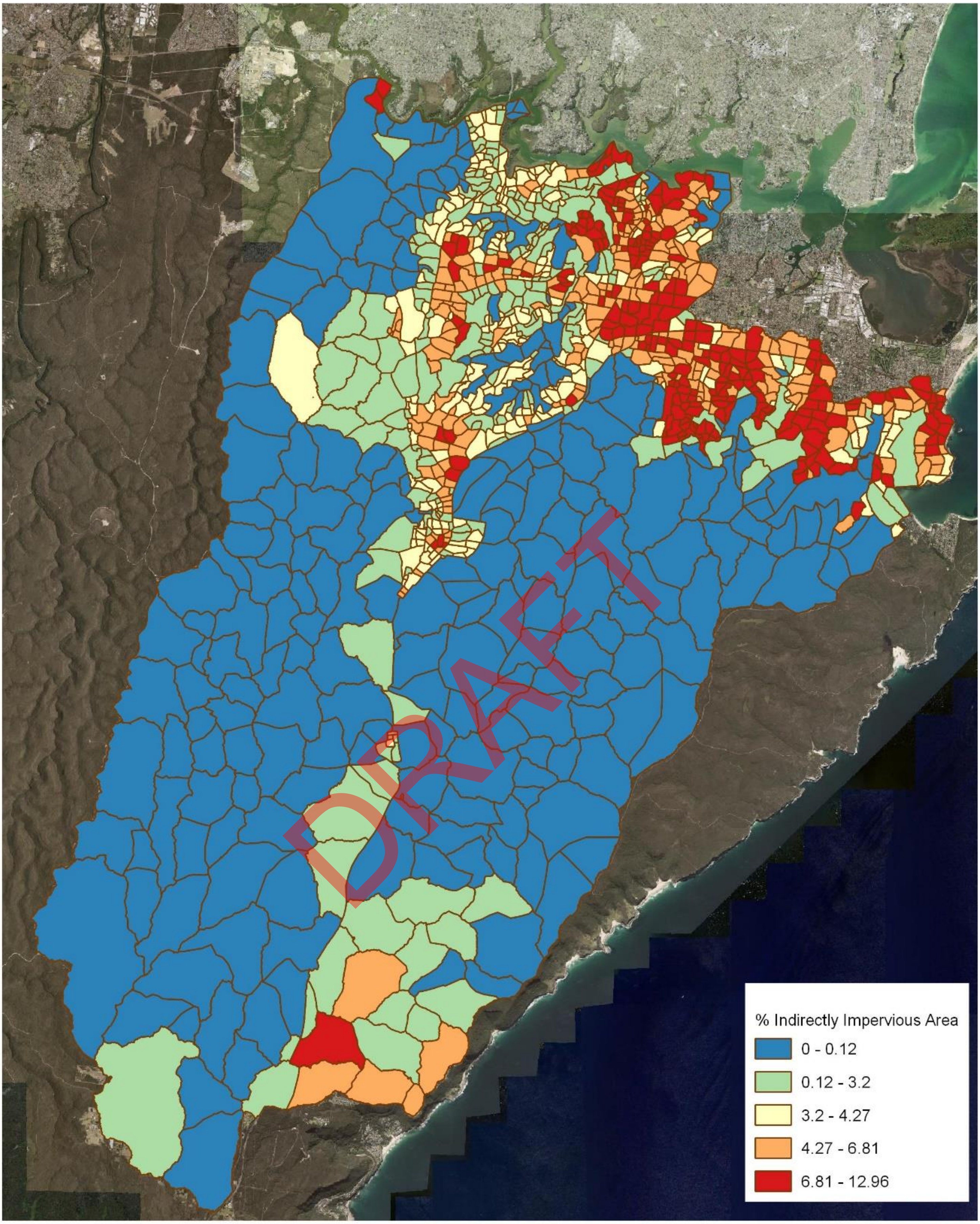


Title:

HYDROLOGIC MODEL SET UP EIA ASSESSMENT

Figure: **A.5**

Rev: **A**

BMT

Filepath: S:\WATER\PROJECTS\A10089_Sutherland_Shire_Overland_FS\MI\Workspaces\Workspace_NN.qgz

Annex B Historical Rainfall Data Assessment

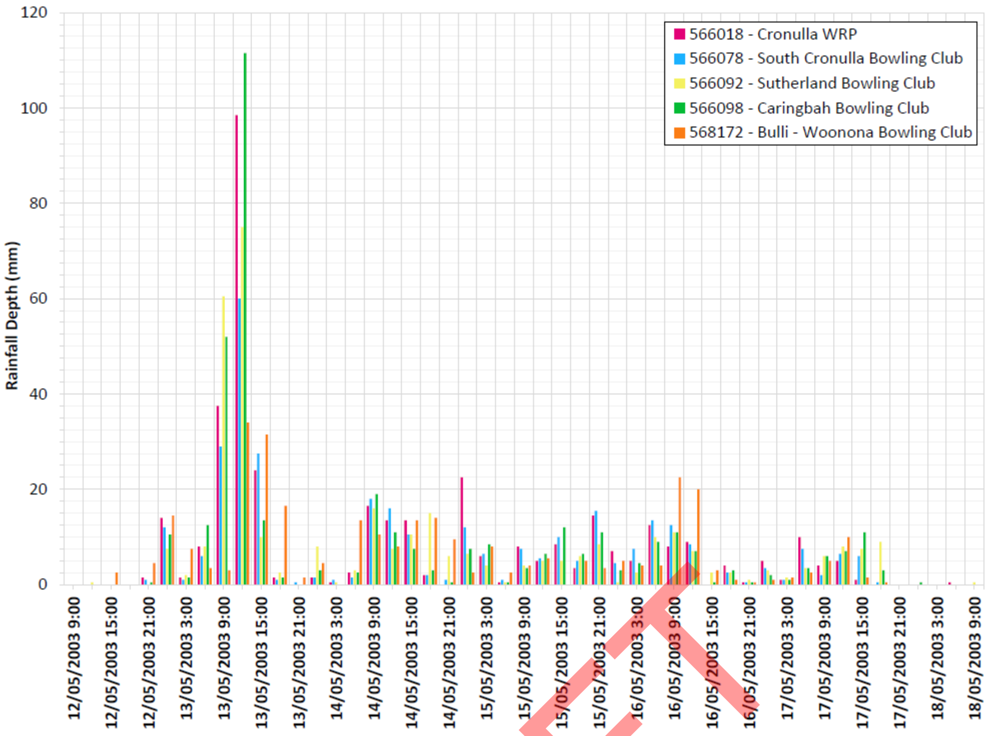


Figure B.1 Sub-Daily Hyetographs for the May 2003 Event (3-hourly Rainfall Data)

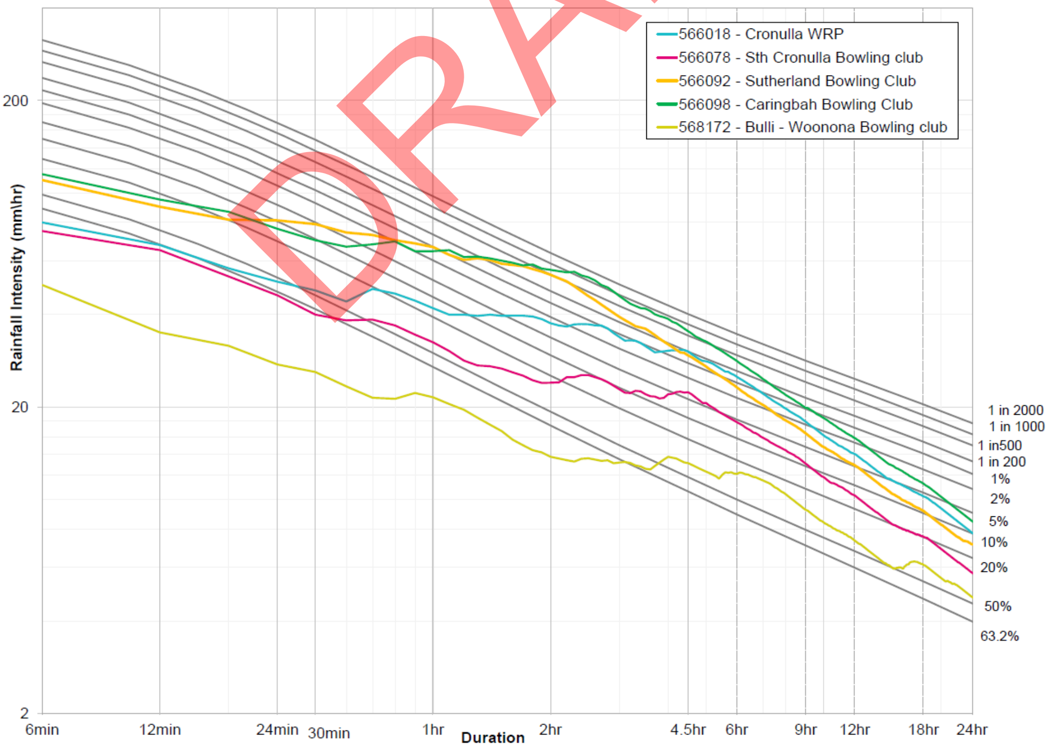
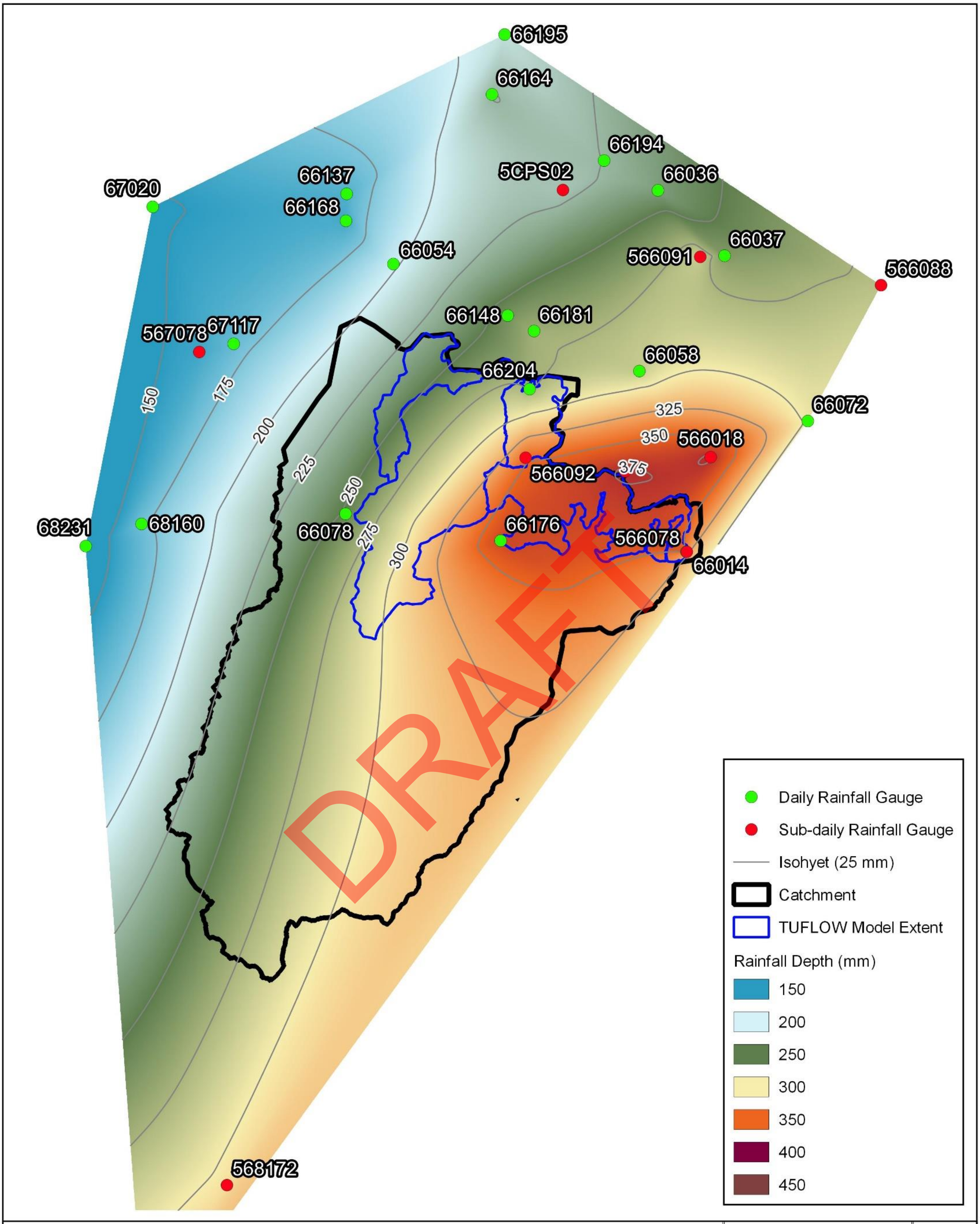


Figure B.2 Comparison of Recorded May 2003 Rainfall with IFD Relationships



Title:

HISTORICAL RAINFALL MAY 2003 EVENT

Figure:

B.3

Rev:

A

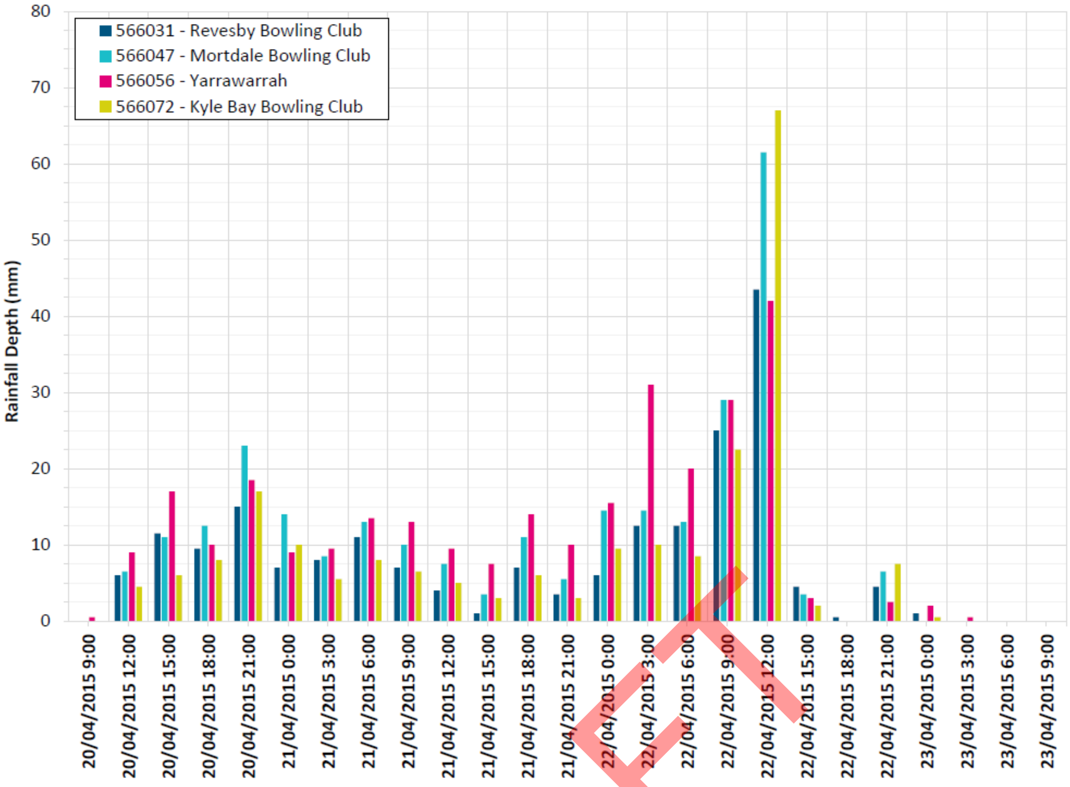


Figure B.4 Sub-Daily Hyetographs for the April 2015 Event (3-hourly Rainfall Data) (Plot 1)

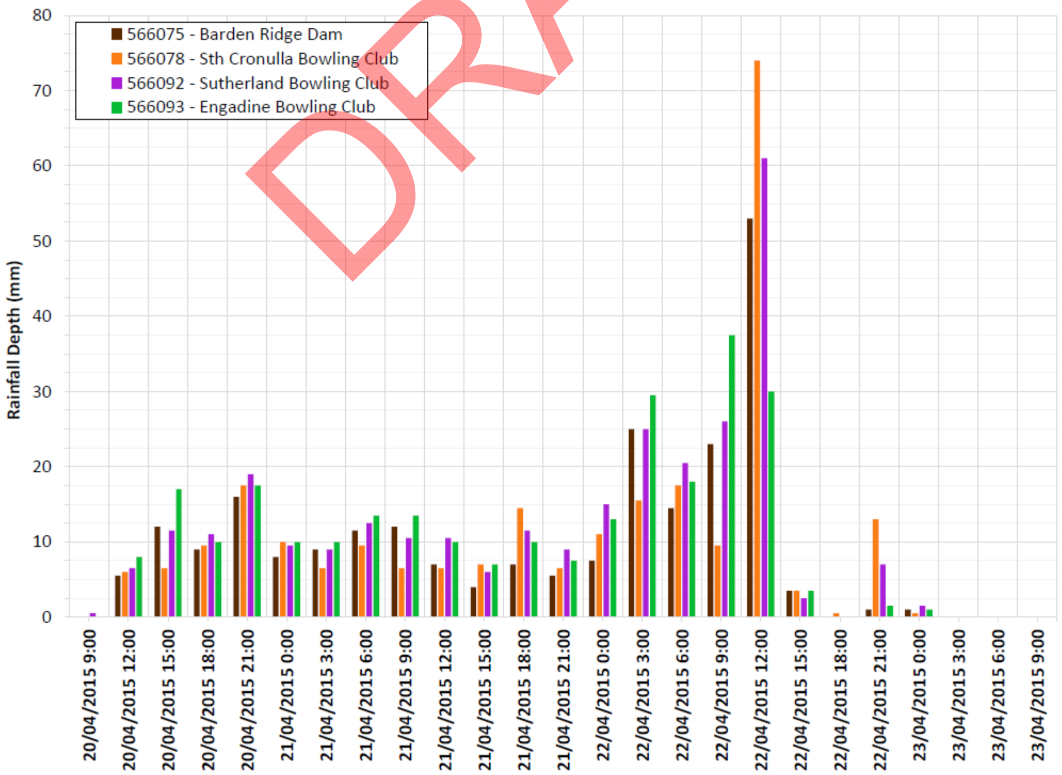


Figure B.5 Sub-Daily Hyetographs for the April 2015 Event (3-hourly Rainfall Data) (Plot 2)

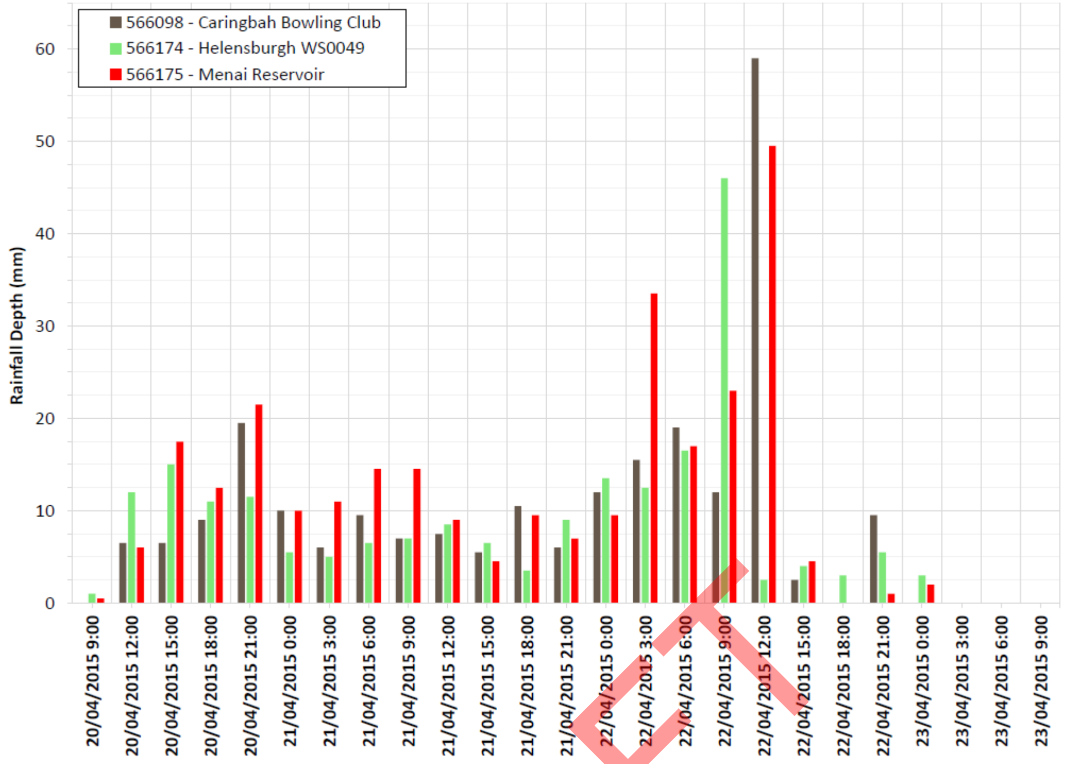


Figure B.6 Sub-Daily Hyetographs for the April 2015 Event (3-hourly Rainfall Data) (Plot 3)

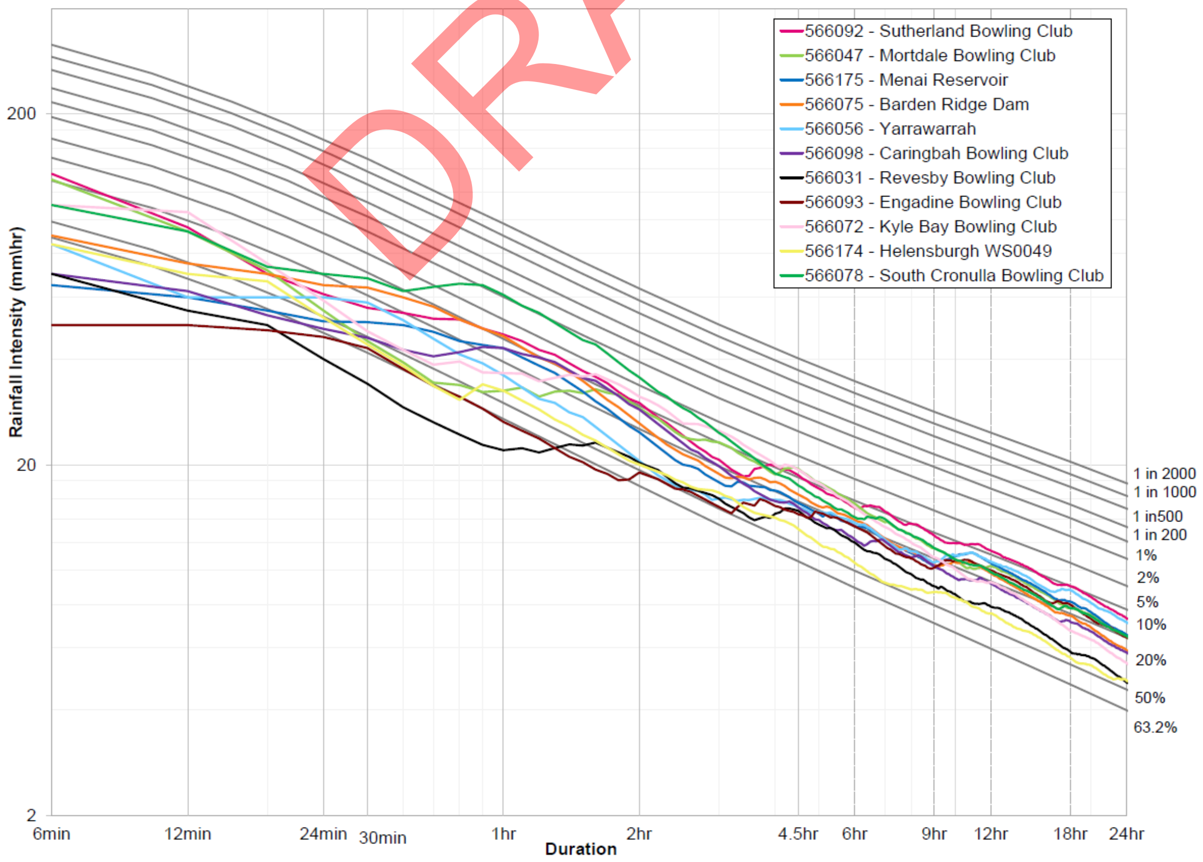
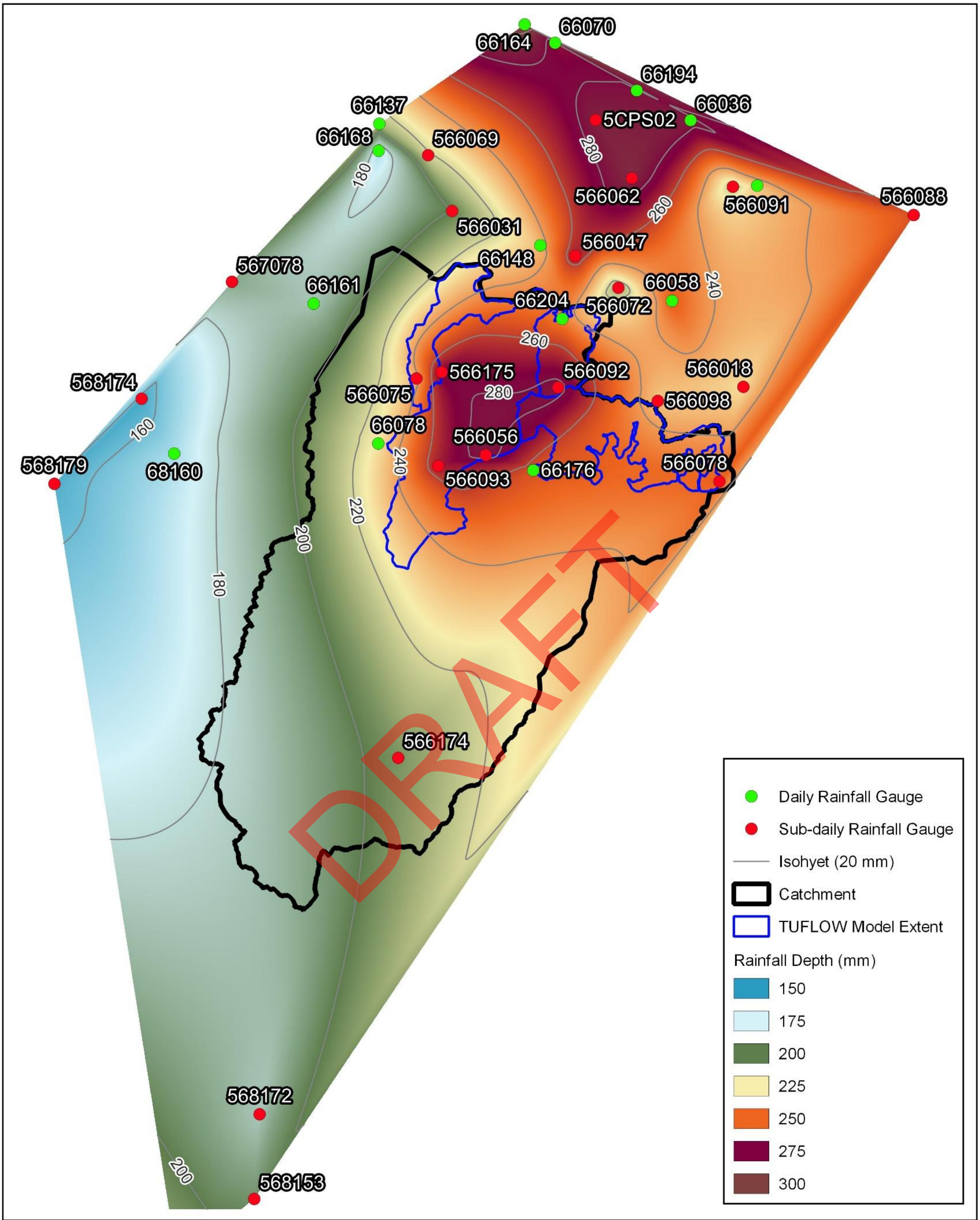


Figure B.7 Comparison of Recorded April 2015 Rainfall with IFD Relationships



Title:

HISTORICAL RAINFALL
APRIL 2015 EVENT

Figure:
B.8

Rev:
A

0 2 4 6 8 10 km

BMT

Filepath: S:\WATER\PROJECTS\A10089_Sutherland_Shire_Overland_FS\MI\QGIS\Stage2-2_Report\Report_Figure.qgz

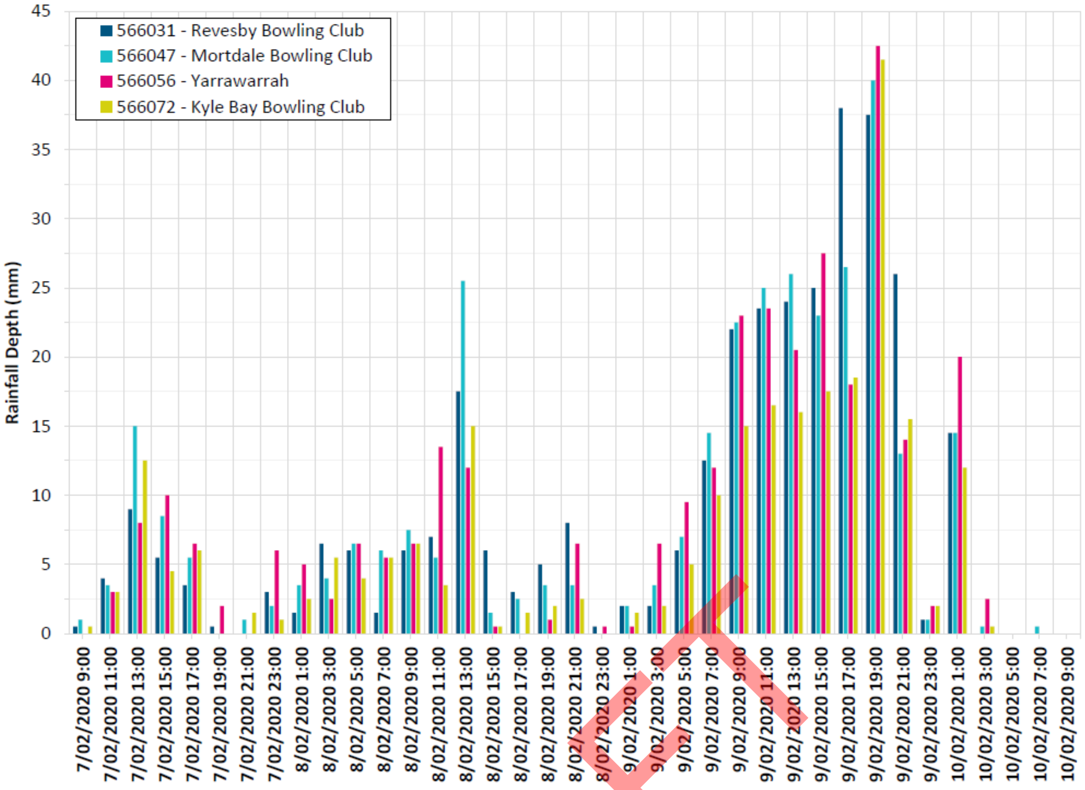


Figure B.8 Sub-Daily Hyetographs for the February 2020 Event (2-hourly Rainfall Data) (Plot 1)

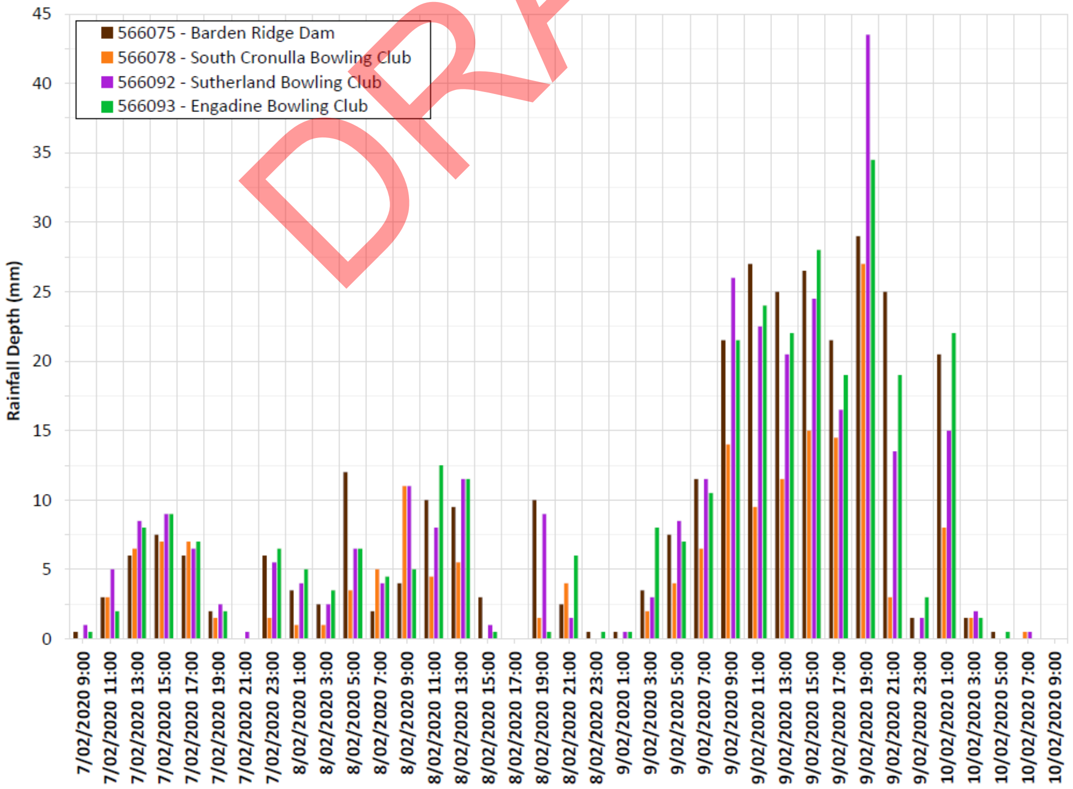


Figure B.9 Sub-Daily Hyetographs for the February 2020 Event (2-hourly Rainfall Data) (Plot 2)

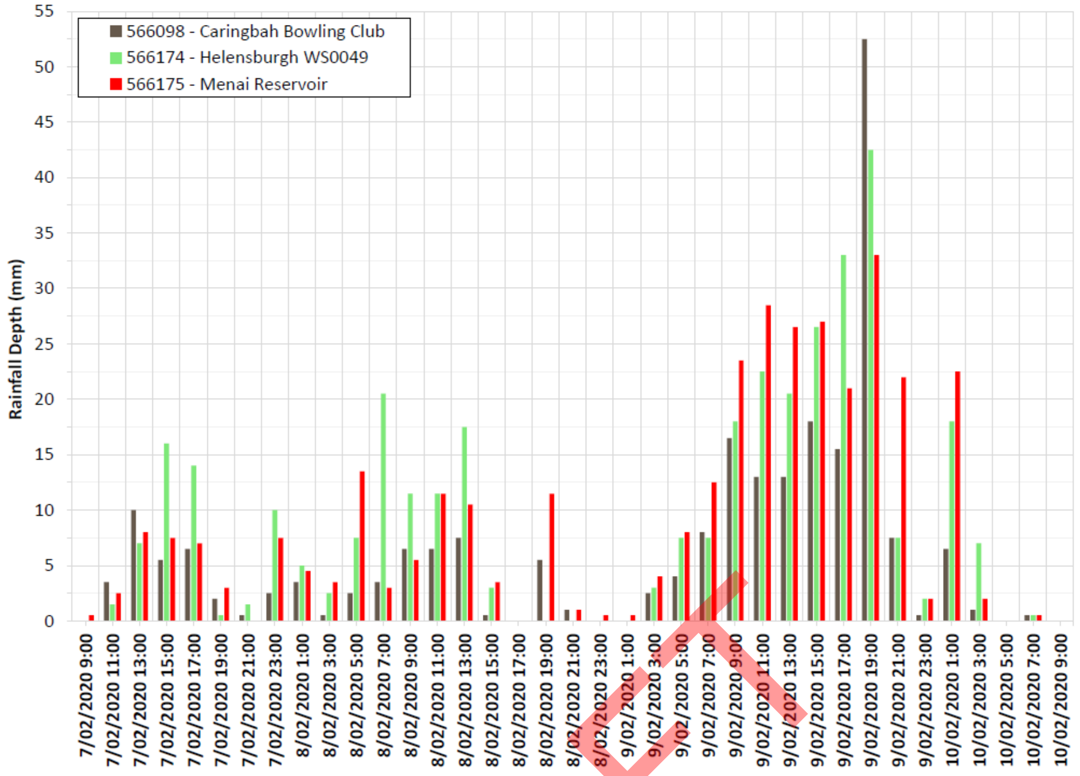


Figure B.10 Sub-Daily Hyetographs for the February 2020 Event (2-hourly Rainfall Data) (Plot 3)

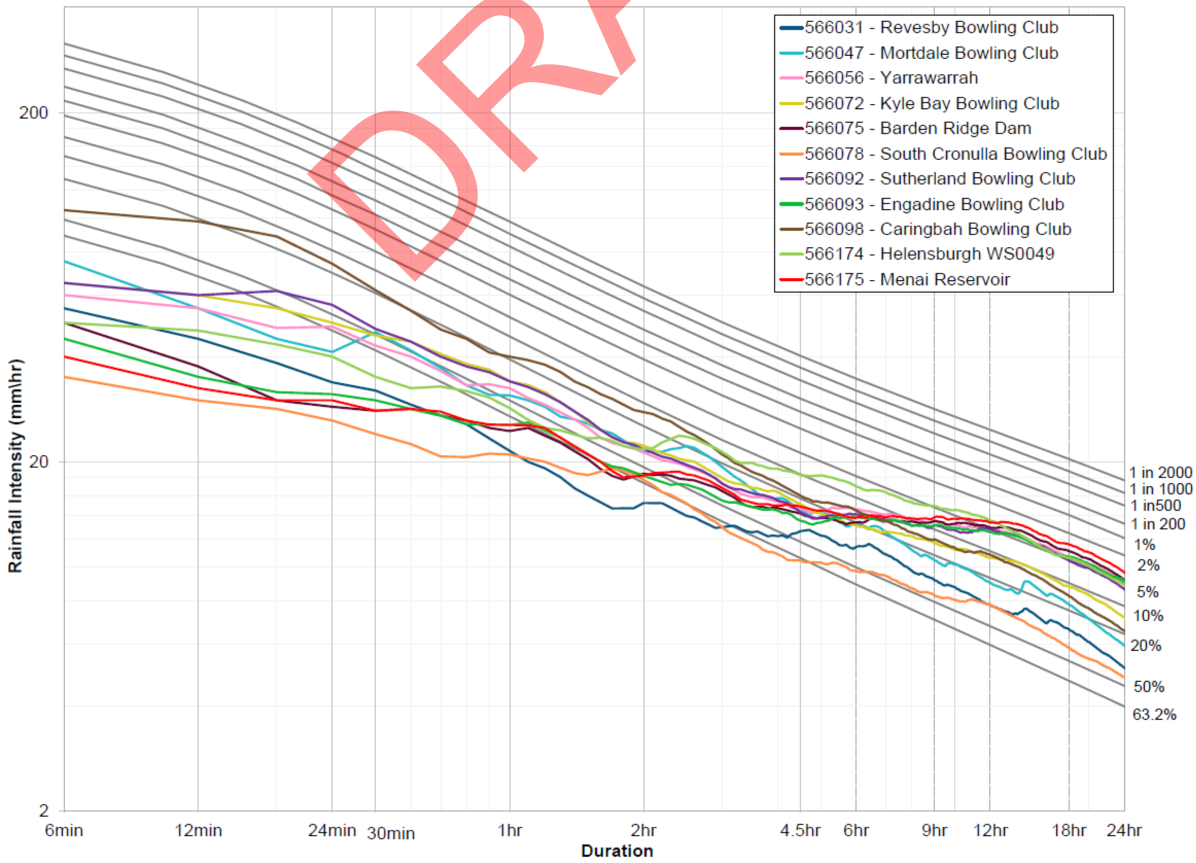
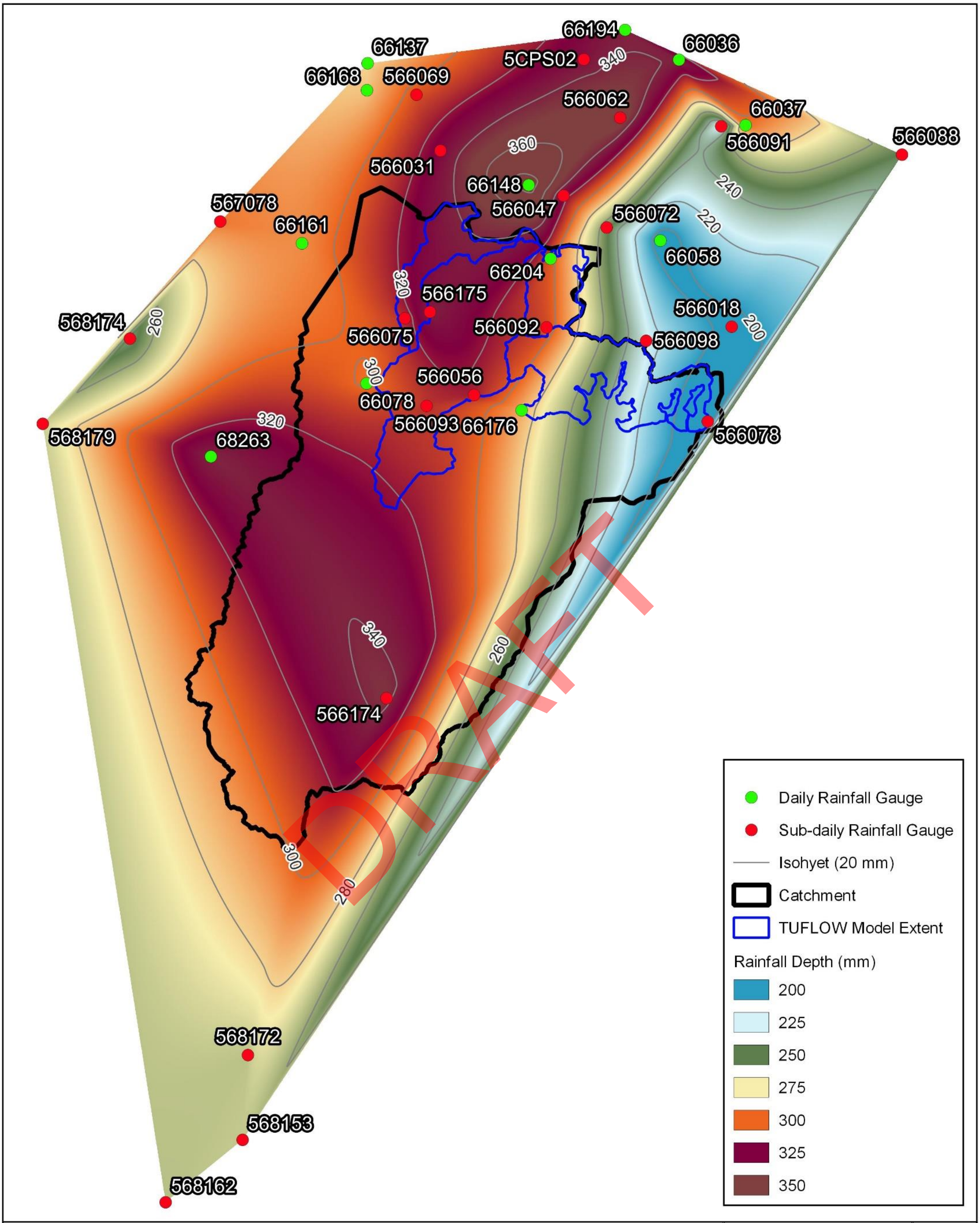


Figure B.11 Comparison of Recorded February 2020 Rainfall with IFD Relationships

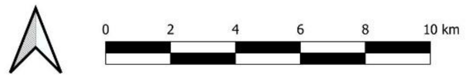


Title:

HISTORICAL RAINFALL FEBRUARY 2020 EVENT

Figure: **B.12**

Rev: **A**



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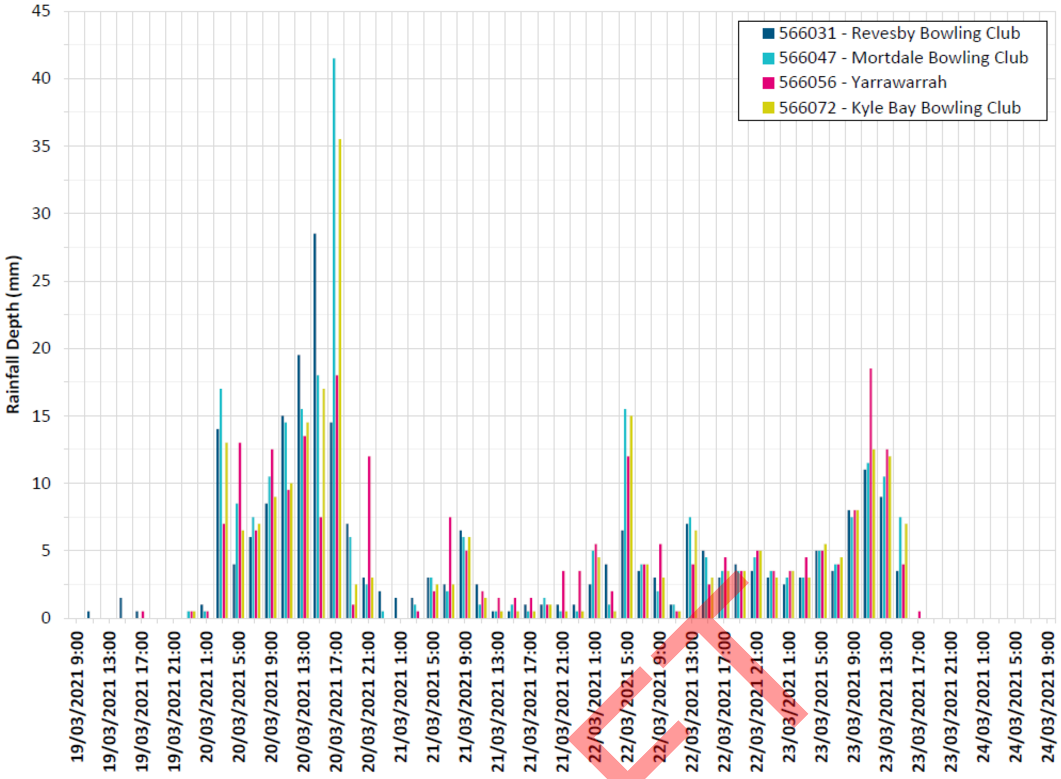


Figure B.13 Sub-Daily Hyetographs for the March 2021 Event (2-hourly Rainfall Data) (Plot 1)

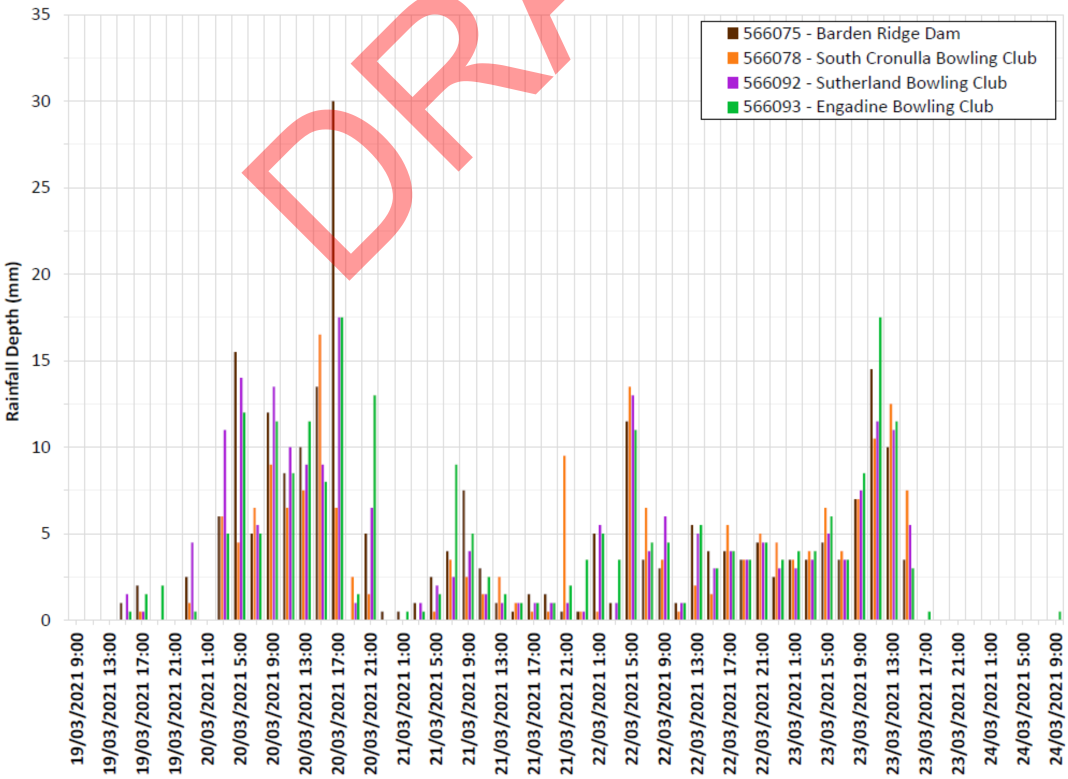


Figure B.14 Sub-Daily Hyetographs for the March 2021 Event (2-hourly Rainfall Data) (Plot 2)

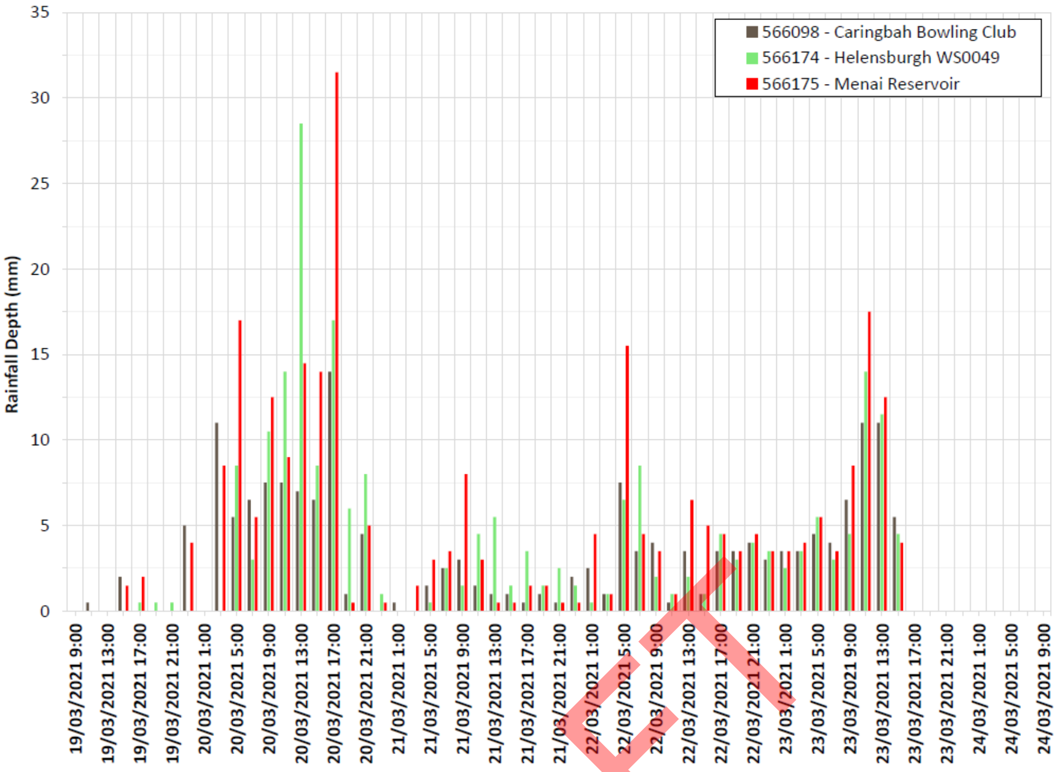


Figure B.15 Sub-Daily Hyetographs for the March 2021 Event (2-hourly Rainfall Data) (Plot 3)

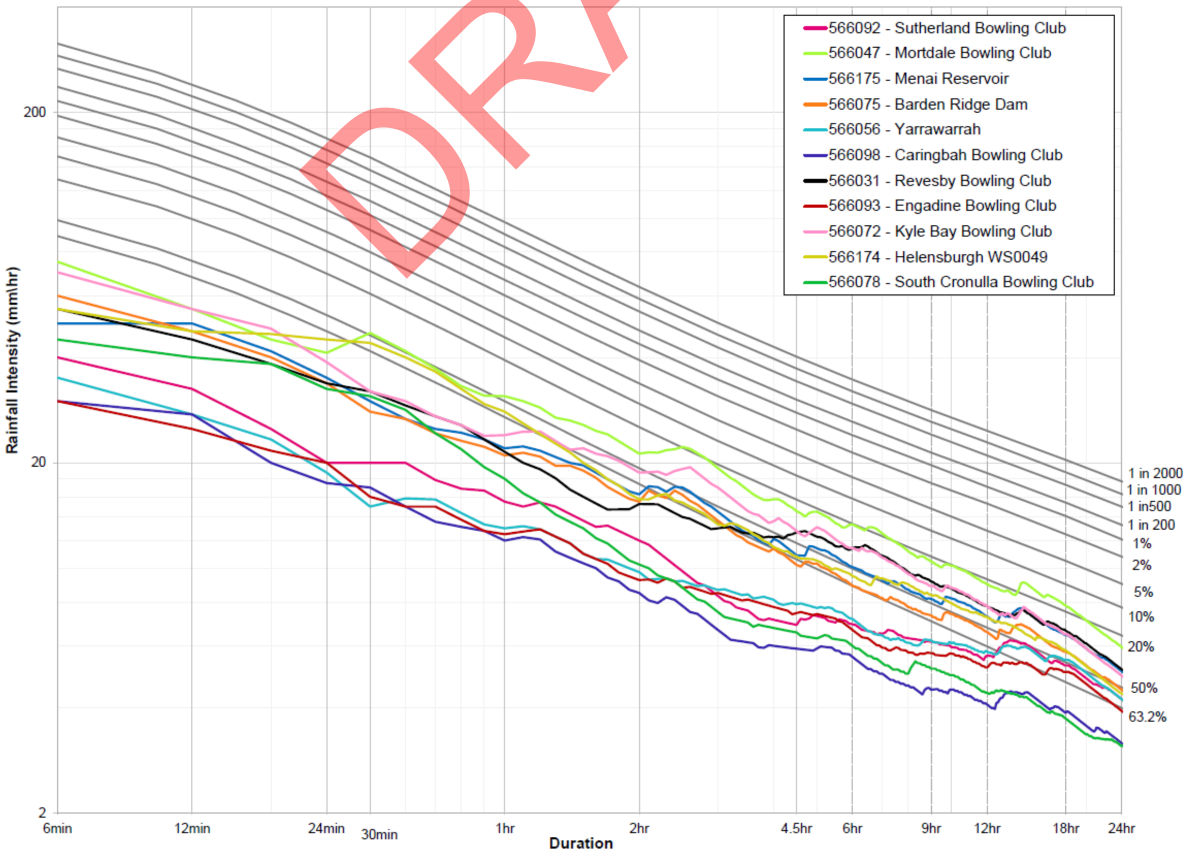
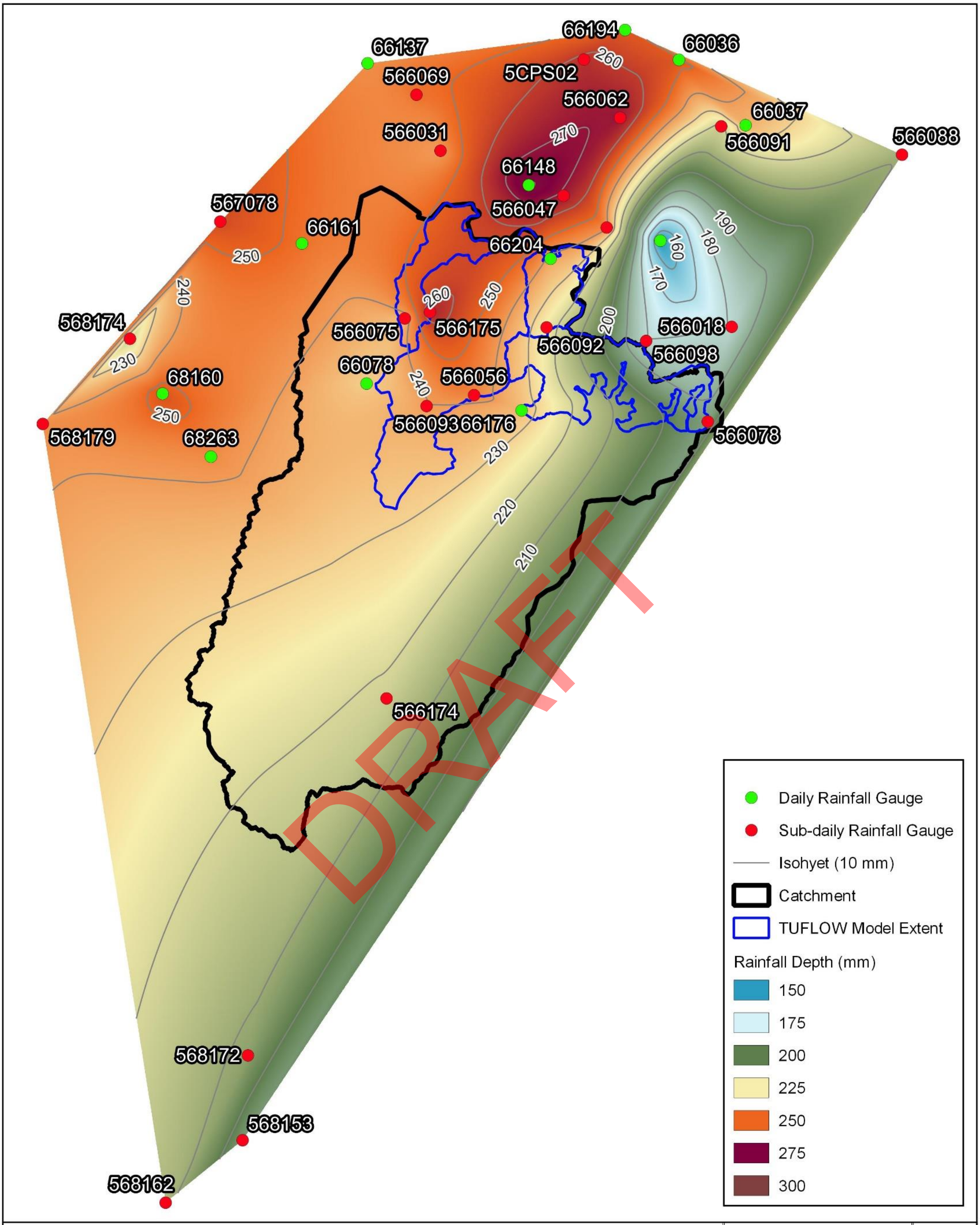


Figure B.16 Comparison of Recorded March 2021 Rainfall with IFD Relationships



Title:

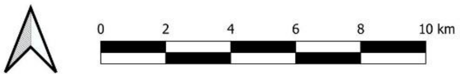
HISTORICAL RAINFALL MARCH 2021 EVENT

Figure:

B.17

Rev:

A



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Annex C Example ARR 2019 Datahub Report

```
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Latitude,-34.057000
Longitude,151.055000
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River Region
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Division,South East Coast (NSW)
River Number,14
River Name,Wollongong Coast
[RIVREG_META]
Time Accessed,27 May 2022 09:20AM
Version,2016_v1
[END_RIVREG]

ARF Parameters
[LONGARF]
Zone,SE Coast
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b,0.361
c,0.0
d,0.317
e,8.11e-05
f,0.651
g,0.0
h,0.0
i,0.0
[LONGARF_META]
Time Accessed,27 May 2022 09:20AM
Version,2016_v1
[END_LONGARF]

Storm Losses
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ID,13911.0
Storm Initial Losses (mm),32.0
Storm Continuing Losses (mm/h),2.2
[LOSSES_META]
Time Accessed,27 May 2022 09:20AM
Version,2016_v1
[END_LOSSES]

Temporal Patterns
[TP]
code,ECsouth
Label,East Coast South
[TP_META]
Time Accessed,27 May 2022 09:20AM
Version,2016_v2
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[END_TP]

Areal Temporal Patterns
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code,ECsouth
arealabel,East Coast South
[ATP_META]
Time Accessed,27 May 2022 09:20AM
Version,2016_v2
[END_ATP]

Median Preburst Depths and Ratios
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60 (1.0),12.1 (0.401),8.2 (0.207),5.6 (0.122),3.2 (0.060),1.8 (0.029),0.7 (0.010)
90 (1.5),9.1 (0.263),7.2 (0.158),6.0 (0.112),4.7 (0.078),2.7 (0.037),1.1 (0.014)
120 (2.0),12.3 (0.319),10.2 (0.199),8.7 (0.146),7.3 (0.108),4.9 (0.062),3.1 (0.036)
180 (3.0),6.7 (0.149),6.6 (0.111),6.6 (0.094),6.5 (0.081),7.4 (0.079),8.1 (0.077)
360 (6.0),15.9 (0.267),21.4 (0.265),25.0 (0.263),28.4 (0.259),23.1 (0.178),19.0 (0.131)
720 (12.0),5.3 (0.066),14.2 (0.127),20.0 (0.151),25.6 (0.166),35.6 (0.194),43.0 (0.209)
1080 (18.0),6.3 (0.066),11.1 (0.083),14.3 (0.088),17.3 (0.092),33.6 (0.150),45.8 (0.181)
1440 (24.0),1.2 (0.011),6.2 (0.041),9.6 (0.052),12.8 (0.059),23.6 (0.092),31.7 (0.109)
2160 (36.0),0.0 (0.000),2.2 (0.012),3.6 (0.016),5.0 (0.019),10.7 (0.035),15.1 (0.043)
2880 (48.0),0.0 (0.000),0.2 (0.001),0.4 (0.001),0.5 (0.002),4.1 (0.012),6.9 (0.018)
4320 (72.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),1.9 (0.005),3.4 (0.008)
[PREBURST_META]
Time Accessed,27 May 2022 09:20AM
Version,2018_v1
Note,Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.
[END_PREBURST]From preburst class

10% Preburst Depths
[PREBURST10]
min (h)\AEP(%),50,20,10,5,2,1
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90 (1.5),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000)
120 (2.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000)
180 (3.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000)
360 (6.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000)
720 (12.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000)
1080 (18.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000)
1440 (24.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000)
2160 (36.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000)
2880 (48.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000)
4320 (72.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000)
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Time Accessed,27 May 2022 09:20AM
Version,2018_v1
Note,Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.
[END_PREBURST10]From preburst class

25% Preburst Depths
```

```
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min (h)\AEP(%),50,20,10,5,2,1
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90 (1.5),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000)
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180 (3.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000)
360 (6.0),0.1 (0.002),0.1 (0.001),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000)
720 (12.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.5 (0.003),0.9 (0.004)
1080 (18.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),4.4 (0.019),7.6 (0.030)
1440 (24.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),1.5 (0.006),2.6 (0.009)
2160 (36.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000)
2880 (48.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.3 (0.001),0.5 (0.001)
4320 (72.0),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000),0.0 (0.000)
[PREBURST25_META]
Time Accessed,27 May 2022 09:20AM
Version,2018_v1
Note,Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain
unchanged.
[END_PREBURST25]From preburst class

75% Preburst Depths
[PREBURST75]
min (h)\AEP(%),50,20,10,5,2,1
60 (1.0),43.6 (1.450),38.5 (0.974),35.2 (0.764),32.0 (0.610),24.3 (0.399),18.5 (0.274)
90 (1.5),42.7 (1.229),37.7 (0.824),34.4 (0.645),31.3 (0.514),27.8 (0.392),25.2 (0.320)
120 (2.0),60.2 (1.559),52.1 (1.022),46.7 (0.784),41.5 (0.610),39.9 (0.501),38.6 (0.437)
180 (3.0),49.9 (1.108),47.7 (0.799),46.3 (0.661),44.9 (0.559),57.4 (0.610),66.7 (0.636)
360 (6.0),44.0 (0.736),61.6 (0.765),73.3 (0.770),84.5 (0.769),97.2 (0.751),106.8 (0.737)
720 (12.0),22.7 (0.281),43.3 (0.389),57.0 (0.429),70.1 (0.454),84.9 (0.463),96.0 (0.466)
1080 (18.0),25.8 (0.268),43.4 (0.323),55.1 (0.341),66.3 (0.352),81.3 (0.362),92.6 (0.366)
1440 (24.0),15.3 (0.141),27.1 (0.177),35.0 (0.190),42.5 (0.197),67.7 (0.263),86.5 (0.298)
2160 (36.0),7.6 (0.060),22.3 (0.123),32.1 (0.147),41.4 (0.161),53.0 (0.173),61.7 (0.178)
2880 (48.0),5.3 (0.038),9.8 (0.049),12.8 (0.053),15.7 (0.055),32.2 (0.094),44.5 (0.116)
4320 (72.0),0.1 (0.001),5.0 (0.022),8.2 (0.030),11.3 (0.035),35.5 (0.092),53.6 (0.123)
[PREBURST75_META]
Time Accessed,27 May 2022 09:20AM
Version,2018_v1
Note,Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain
unchanged.
[END_PREBURST75]From preburst class

90% Preburst Depths
[PREBURST90]
min (h)\AEP(%),50,20,10,5,2,1
60 (1.0),102.3 (3.406),106.1 (2.683),108.6 (2.359),110.9 (2.117),106.3 (1.744),102.8 (1.522)
90 (1.5),75.4 (2.170),87.1 (1.904),94.9 (1.778),102.4 (1.680),114.9 (1.618),124.4 (1.577)
120 (2.0),96.1 (2.490),120.1 (2.357),136.0 (2.284),151.2 (2.223),141.5 (1.780),134.3 (1.518)
180 (3.0),89.5 (1.988),122.9 (2.056),145.0 (2.070),166.2 (2.070),150.0 (1.593),137.8 (1.313)
360 (6.0),77.1 (1.290),107.6 (1.335),127.8 (1.343),147.2 (1.341),172.1 (1.328),190.8 (1.315)
720 (12.0),67.0 (0.829),88.4 (0.794),102.6 (0.773),116.2 (0.753),170.6 (0.931),211.5 (1.027)
1080 (18.0),72.9 (0.758),96.2 (0.715),111.6 (0.691),126.4 (0.671),165.5 (0.737),194.8 (0.771)
1440 (24.0),59.6 (0.549),76.2 (0.498),87.2 (0.473),97.8 (0.454),144.1 (0.560),178.9 (0.617)
2160 (36.0),47.7 (0.376),64.4 (0.356),75.4 (0.345),86.1 (0.335),107.6 (0.350),123.7 (0.357)
2880 (48.0),21.3 (0.153),38.9 (0.194),50.5 (0.207),61.7 (0.216),92.4 (0.270),115.3 (0.299)
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4320 (72.0),10.4 (0.066),18.7 (0.082),24.2 (0.088),29.4 (0.091),66.2 (0.172),93.8 (0.216)
[PREBURST90_META]
Time Accessed,27 May 2022 09:20AM
Version,2018_v1
Note,Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.
[END_PREBURST90]From preburst class

Interim Climate Change Factors
[CCF]
,RCP 4.5,RCP6,RCP 8.5
2030,0.869 (4.3%),0.783 (3.9%),0.983 (4.9%)
2040,1.057 (5.3%),1.014 (5.1%),1.349 (6.8%)
2050,1.272 (6.4%),1.236 (6.2%),1.773 (9.0%)
2060,1.488 (7.5%),1.458 (7.4%),2.237 (11.5%)
2070,1.676 (8.5%),1.691 (8.6%),2.722 (14.2%)
2080,1.810 (9.2%),1.944 (9.9%),3.209 (16.9%)
2090,1.862 (9.5%),2.227 (11.5%),3.679 (19.7%)

[CCF_META]
Time Accessed,27 May 2022 09:20AM
Version,2019_v1
Note,ARR recommends the use of RCP4.5 and RCP 8.5 values. These have been updated to the values that can be found on the climate change in Australia website.
[END_CCF]

Probability Neutral Burst Initial Loss
[BURSTIL]
min (h)\AEP(%),50.0,20.0,10.0,5.0,2.0,1.0
60 (1.0),21.1,11.2,10.8,12.0,11.4,10.8
90 (1.5),23.2,13.1,12.4,13.2,12.9,10.9
120 (2.0),18.9,11.9,12.2,12.4,11.5,9.3
180 (3.0),21.6,14.2,14.0,13.5,12.5,7.9
360 (6.0),21.1,14.1,14.3,12.2,11.1,5.0
720 (12.0),28.2,19.8,17.6,15.2,13.0,3.7
1080 (18.0),28.5,21.6,19.7,16.9,15.3,4.1
1440 (24.0),32.9,26.3,24.4,22.5,19.8,9.6
2160 (36.0),36.3,29.8,27.1,25.5,24.6,8.9
2880 (48.0),41.1,34.6,33.7,34.7,24.6,10.0
4320 (72.0),44.7,38.4,38.2,40.1,28.9,11.3
[BURSTIL_META]
Time Accessed,27 May 2022 09:20AM
Version,2018_v1
Note,As this point is in NSW the advice provided on losses and pre-burst on the
<a href="./nsw_specific">
 NSW Specific Tab of the ARR Data Hub
</a>
is to be considered.  In NSW losses are derived considering a hierarchy of approaches depending on the available loss information.  Probability neutral burst initial loss values for NSW are to be used in place of the standard initial loss and pre-burst as per the losses hierarchy.
[END_BURSTIL]
Transformational Pre-burst Rainfall
[PREBURST_TRANS]
min (h)\AEP(%),50.0,20.0,10.0,5.0,2.0,1.0
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60 (1.0),11.3,21.2,21.6,20.4,21.0,21.6
90 (1.5),9.2,19.3,20.0,19.2,19.5,21.5
120 (2.0),13.5,20.5,20.2,20.0,20.9,23.1
180 (3.0),10.8,18.2,18.4,18.9,19.9,24.5
360 (6.0),11.3,18.3,18.1,20.2,21.3,27.4
720 (12.0),4.2,12.6,14.8,17.2,19.4,28.7
1080 (18.0),3.9,10.8,12.7,15.5,17.1,28.3
1440 (24.0),0.0,6.1,8.0,9.9,12.6,22.8
2160 (36.0),0.0,2.6,5.3,6.9,7.8,23.5
2880 (48.0),0.0,0.0,0.0,0.0,7.8,22.4
4320 (72.0),0.0,0.0,0.0,0.0,3.5,21.1
[PREBURST_TRANS_META]
The tranformational pre-burst is intended for software suppliers in the NSW area and is simply the Initial Loss - Burst Initial Loss. It is not appropriate to use these values if considering a calibrated initial loss.
[END_PREBURST_TRANS]

[ENDTXT]
Temporal Pattern Raw Data
[STARTPATTERNS]
EventID, Duration, TimeStep, Region, AEP, Increments,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4380,10,5,East Coast (South),frequent,58.06,41.94,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4382,10,5,East Coast (South),frequent,52.13,47.87,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4384,10,5,East Coast (South),frequent,60.71,39.29,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4385,10,5,East Coast (South),frequent,51.51,48.49,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4386,10,5,East Coast (South),frequent,54.55,45.45,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4387,10,5,East Coast (South),frequent,39.3,60.7,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4388,10,5,East Coast (South),frequent,45,55,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4389,10,5,East Coast (South),frequent,49.56,50.44,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4390,10,5,East Coast (South),frequent,30.38,69.62,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4391,10,5,East Coast (South),frequent,45.3,54.7,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4369,10,5,East Coast (South),intermediate,55.22,44.78,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4370,10,5,East Coast (South),intermediate,64.14,35.86,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4372,10,5,East Coast (South),intermediate,50.55,49.45,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4373,10,5,East Coast (South),intermediate,42.72,57.28,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4374,10,5,East Coast (South),intermediate,47.92,52.08,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4375,10,5,East Coast (South),intermediate,48.92,51.08,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4376,10,5,East Coast (South),intermediate,49.41,50.59,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4377,10,5,East Coast (South),intermediate,46.47,53.53,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4378,10,5,East Coast (South),intermediate,52.27,47.73,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4379,10,5,East Coast (South),intermediate,59.29,40.71,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4354,10,5,East Coast (South),rare,60.56,39.44,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4355,10,5,East Coast (South),rare,61.2,38.8,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4356,10,5,East Coast (South),rare,50.88,49.12,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4357,10,5,East Coast (South),rare,49.43,50.57,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4361,10,5,East Coast (South),rare,43.58,56.42,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4363,10,5,East Coast (South),rare,58.18,41.82,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4364,10,5,East Coast (South),rare,49.51,50.49,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4365,10,5,East Coast (South),rare,58.87,41.13,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4366,10,5,East Coast (South),rare,34.23,65.77,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4368,10,5,East Coast (South),rare,41.94,58.06,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4417,15,5,East Coast (South),frequent,47.11,28.1,24.79,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4418,15,5,East Coast (South),frequent,45,32.5,22.5,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4419,15,5,East Coast (South),frequent,49.33,30.67,20,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4420,15,5,East Coast (South),frequent,33.72,30.44,35.84,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4421,15,5,East Coast (South),frequent,26.79,41.07,32.14,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4422,15,5,East Coast (South),frequent,26.35,37.75,35.9,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4423,15,5,East Coast (South),frequent,42.55,27.66,29.79,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4424,15,5,East Coast (South),frequent,38.1,30.95,30.95,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4425,15,5,East Coast (South),frequent,28.85,25,46.15,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4426,15,5,East Coast (South),frequent,32.81,20.31,46.88,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4381,15,5,East Coast (South),intermediate,45,32.5,22.5,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4408,15,5,East Coast (South),intermediate,47.17,24.53,28.3,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4409,15,5,East Coast (South),intermediate,53.74,22.93,23.33,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4410,15,5,East Coast (South),intermediate,24.57,45.61,29.82,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4411,15,5,East Coast (South),intermediate,35.8,20.9,43.3,,,

4412,15,5,East Coast (South),intermediate,34,42,24,,,

4413,15,5,East Coast (South),intermediate,29.34,48.03,22.63,,,

4414,15,5,East Coast (South),intermediate,33.66,36.51,29.83,,,

4415,15,5,East Coast (South),intermediate,27.5,27.55,44.95,,,

4416,15,5,East Coast (South),intermediate,25.37,29.85,44.78,,,

4358,15,5,East Coast (South),rare,27.09,36.04,36.87,,,

4392,15,5,East Coast (South),rare,43.48,34.78,21.74,,,

4393,15,5,East Coast (South),rare,47.14,31.43,21.43,,,

4396,15,5,East Coast (South),rare,50.62,22.22,27.16,,,

4397,15,5,East Coast (South),rare,37.63,36.63,25.74,,,

4398,15,5,East Coast (South),rare,41.16,29.61,29.23,,,

4400,15,5,East Coast (South),rare,28.13,39.06,32.81,,,

4401,15,5,East Coast (South),rare,34.35,38.93,26.72,,,

4403,15,5,East Coast (South),rare,20.46,26.98,52.56,,,

4407,15,5,East Coast (South),rare,27.25,23,49.75,,,

4445,20,5,East Coast (South),frequent,35.25,33.61,17.21,13.93,,

4446,20,5,East Coast (South),frequent,45.09,22.25,14.09,18.57,,

4448,20,5,East Coast (South),frequent,37.74,30.19,11.32,20.75,,

4449,20,5,East Coast (South),frequent,18.03,31.15,26.23,24.59,,

4450,20,5,East Coast (South),frequent,20.51,29.68,34.22,15.59,,

4451,20,5,East Coast (South),frequent,20.83,35.42,12.5,31.25,,

4452,20,5,East Coast (South),frequent,13.01,21.47,42.32,23.2,,

4453,20,5,East Coast (South),frequent,27.42,35.48,16.13,20.97,,

4454,20,5,East Coast (South),frequent,17.39,16.3,29.35,36.96,,

4455,20,5,East Coast (South),frequent,26.24,13.11,18.03,42.62,,

4383,20,5,East Coast (South),intermediate,32.67,30,16,21.33,,

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4434,20,5,East Coast (South),intermediate,31.17,37.66,16.88,14.29,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4435,20,5,East Coast (South),intermediate,41.67,13.89,11.11,33.33,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4436,20,5,East Coast (South),intermediate,14.12,35.32,28.75,21.81,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4437,20,5,East Coast (South),intermediate,25.26,27.33,25.3,22.11,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4438,20,5,East Coast (South),intermediate,27.55,33.67,19.39,19.39,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4439,20,5,East Coast (South),intermediate,21.3,20.41,26.27,32.02,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4440,20,5,East Coast (South),intermediate,22.33,22.32,23.54,31.81,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4441,20,5,East Coast (South),intermediate,14.82,22.22,12.96,50,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4444,20,5,East Coast (South),intermediate,20.62,12.69,37.37,29.32,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4359,20,5,East Coast (South),rare,13.08,23.54,31.33,32.05,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4367,20,5,East Coast (South),rare,22.66,43.56,17.78,16,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4371,20,5,East Coast (South),rare,39.41,22.03,6.36,32.2,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4399,20,5,East Coast (South),rare,15.19,34.91,25.11,24.79,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4404,20,5,East Coast (South),rare,34.05,13.5,17.79,34.66,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4427,20,5,East Coast (South),rare,23.88,26.06,27.02,23.04,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4428,20,5,East Coast (South),rare,14.79,35.65,26.65,22.91,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4429,20,5,East Coast (South),rare,26.2,18.72,28.7,26.38,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4432,20,5,East Coast (South),rare,28.18,3.9,16.54,51.38,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4433,20,5,East Coast (South),rare,20.78,32.47,18.18,28.57,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4480,25,5,East Coast (South),frequent,31.28,27.11,10.2,12.33,19.08,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4481,25,5,East Coast (South),frequent,36.11,18.43,11.33,10.74,23.39,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4483,25,5,East Coast (South),frequent,31.41,22.6,16.88,16.93,12.18,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4485,25,5,East Coast (South),frequent,14.81,27.78,25.93,16.67,14.81,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4486,25,5,East Coast (South),frequent,13.21,15.09,26.42,24.53,20.75,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4487,25,5,East Coast (South),frequent,19.68,27.89,28.68,14.57,9.18,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4488,25,5,East Coast (South),frequent,15.2,13.28,31.43,22.96,17.13,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4489,25,5,East Coast (South),frequent,24.14,18.97,22.41,13.79,20.69,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4490,25,5,East Coast (South),frequent,20.6,11.48,7.42,36.91,23.59,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
4494,25,5,East Coast (South),frequent,13.2,13.21,16.98,13.21,43.4,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
4447,25,5,East Coast (South),intermediate,11.62,39.84,19.67,12.46,16.41,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
4468,25,5,East Coast (South),intermediate,25.24,28.22,22.28,11.88,12.38,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
4470,25,5,East Coast (South),intermediate,19.45,36.11,15.28,6.94,22.22,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
4471,25,5,East Coast (South),intermediate,15.38,23.08,27.69,23.08,10.77,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
4472,25,5,East Coast (South),intermediate,23.92,21.53,19.62,16.75,18.18,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
4473,25,5,East Coast (South),intermediate,17.28,25.93,30.86,16.05,9.88,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
4474,25,5,East Coast (South),intermediate,25.97,21.92,16.15,11.41,24.55,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
4476,25,5,East Coast (South),intermediate,16.94,26.51,23.99,12.52,20.04,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
4477,25,5,East Coast (South),intermediate,14.81,14.8,14.8,20.12,35.47,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
4479,25,5,East Coast (South),intermediate,12.12,13.64,18.18,37.88,18.18,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
4394,25,5,East Coast (South),rare,20,13.33,31.43,20.95,14.29,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
4456,25,5,East Coast (South),rare,23.75,28.75,17.5,11.25,18.75,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
4458,25,5,East Coast (South),rare,14.61,35.96,22.47,13.48,13.48,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
4459,25,5,East Coast (South),rare,20.26,32.68,19.61,11.11,16.34,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
4460,25,5,East Coast (South),rare,23.4,11.44,28.53,26.51,10.12,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
4461,25,5,East Coast (South),rare,19.62,17.76,18.69,22.43,21.5,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
4462,25,5,East Coast (South),rare,7.54,25.64,26.01,23.75,17.06,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
4464,25,5,East Coast (South),rare,21.47,19.02,19.63,20.86,19.02,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
4466,25,5,East Coast (South),rare,23.51,11.95,11.95,17.93,34.66,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
4467,25,5,East Coast (South),rare,9.28,13.4,21.65,31.96,23.71,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
4484,30,5,East Coast (South),frequent,28.99,20.87,15.58,15.63,11.25,7.68,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
4516,30,5,East Coast (South),frequent,28.62,20.64,16.49,17.41,7.33,9.51,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
4517,30,5,East Coast (South),frequent,20.3,27.54,13.04,14.49,10.14,14.49,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
4518,30,5,East Coast (South),frequent,18.51,14.92,35.06,8.18,9.7,13.63,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
4519,30,5,East Coast (South),frequent,11.58,15.24,25,27.44,10.37,10.37,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4520,30,5,East Coast (South),frequent,10.01,12.51,12.5,37.9,13.54,13.54,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4521,30,5,East Coast (South),frequent,29.42,10.29,17.65,8.82,25,8.82,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4522,30,5,East Coast (South),frequent,18.51,22.7,19.96,18.57,11.57,8.69,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4523,30,5,East Coast (South),frequent,10.21,12.24,10.88,26.53,23.81,16.33,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4524,30,5,East Coast (South),frequent,12.67,12.68,18.31,9.86,22.54,23.94,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4506,30,5,East Coast (South),intermediate,16.02,26.72,20.61,12.98,12.98,10.69,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4507,30,5,East Coast (South),intermediate,28.07,19.37,13.44,11.46,14.62,13.04,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4508,30,5,East Coast (South),intermediate,17.18,25.55,20.26,13.22,14.1,9.69,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4509,30,5,East Coast (South),intermediate,15.06,21.08,24.1,19.28,13.25,7.23,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4510,30,5,East Coast (South),intermediate,9.74,14.99,19.72,27.46,15.92,12.17,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4511,30,5,East Coast (South),intermediate,12.79,12.79,24.42,17.44,23.26,9.3,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4512,30,5,East Coast (South),intermediate,17.07,21.95,19.51,17.07,12.2,12.2,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4513,30,5,East Coast (South),intermediate,12.71,17.46,26.98,11.11,22.22,9.52,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4514,30,5,East Coast (South),intermediate,10.25,10.26,10.26,18.28,30.44,20.51,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4515,30,5,East Coast (South),intermediate,8.29,12.52,13.7,9.69,29.74,26.06,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4402,30,5,East Coast (South),rare,7.64,9.29,24.59,27.87,19.13,11.48,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4457,30,5,East Coast (South),rare,20,24.21,14.74,9.47,15.79,15.79,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4495,30,5,East Coast (South),rare,23.53,25.02,18.34,9.66,10.36,13.09,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4497,30,5,East Coast (South),rare,22.98,24.14,20.31,14.18,3.45,14.94,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4498,30,5,East Coast (South),rare,12.58,17.02,24.01,19.18,13.47,13.74,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4500,30,5,East Coast (South),rare,20.07,17.67,16.87,12.45,14.06,18.88,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4502,30,5,East Coast (South),rare,8.44,22.67,17.33,33.78,10.67,7.11,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4503,30,5,East Coast (South),rare,20.99,13.32,19.99,17.67,12.49,15.54,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4504,30,5,East Coast (South),rare,14.81,9.26,15.74,16.67,26.85,16.67,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4505,30,5,East Coast (South),rare,10,11,16,21,32,10,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4545,45,5,East Coast (South),frequent,7.24,10.14,27.54,8.7,13.04,8.7,8.7,4.35,11.59,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4546,45,5,East Coast (South),frequent,7.22,21.4,20.86,9.42,7.21,6.4,7.77,9.04,10.68,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4547,45,5,East Coast (South),frequent,4.19,15.18,21.2,23.47,8.67,7.66,8.15,7.28,4.2,,,

4548,45,5,East Coast (South),frequent,4.1,4.11,5.48,9.59,20.55,21.92,16.44,12.33,5.48,,,

4549,45,5,East Coast (South),frequent,2.78,5.03,5.59,9.5,22.91,23.46,13.97,10.61,6.15,,,

4550,45,5,East Coast (South),frequent,9.22,12.06,7.8,16.31,14.18,17.02,11.35,4.26,7.8,,,

4551,45,5,East Coast (South),frequent,3.31,7.28,10.6,15.89,19.21,23.18,9.27,7.95,3.31,,,

4552,45,5,East Coast (South),frequent,4.33,8.59,9.29,20.48,18.75,13.34,11.37,9.62,4.23,,,

4553,45,5,East Coast (South),frequent,8.86,5.54,10.75,10.9,7.29,11.56,17.2,16.67,11.23,,,

4554,45,5,East Coast (South),frequent,13.23,11.64,2.12,3.7,3.7,13.76,21.16,17.99,12.7,,,

4478,45,5,East Coast (South),intermediate,11.15,11.15,11.15,15.16,26.72,7.51,2.73,5.28,9.15,,,

4536,45,5,East Coast (South),intermediate,10.01,11.43,14.29,27.14,15.71,5,3.57,7.14,5.71,,,

4537,45,5,East Coast (South),intermediate,12,16,14,16,11,12,6,8,5,,,

4538,45,5,East Coast (South),intermediate,12.82,19.81,13.08,12.91,12.91,12.91,5.58,4.99,4.99,,,

4539,45,5,East Coast (South),intermediate,9.23,10.77,16.92,10.77,6.15,9.23,12.31,13.85,10.77,,,

4540,45,5,East Coast (South),intermediate,10.46,11.05,11.05,11.72,11.72,11.72,15.4,7.79,9.09,,,

4541,45,5,East Coast (South),intermediate,11.92,10.38,14.62,18.46,9.62,7.31,12.69,11.92,3.08,,,

4542,45,5,East Coast (South),intermediate,4.91,22.13,11.48,3.28,11.48,16.39,10.66,15.57,4.1,,,

4543,45,5,East Coast (South),intermediate,9.99,10,1.67,4.17,7.5,14.17,14.17,25,13.33,,,

4544,45,5,East Coast (South),intermediate,5.25,10.93,3.89,8.24,6.76,11.42,14.82,19.86,18.83,,,

4362,45,5,East Coast (South),rare,11.31,16.04,20.76,14.15,14.15,5.44,6.51,6.51,5.13,,,

4496,45,5,East Coast (South),rare,5.68,6.58,19.39,20.62,15.11,7.96,8.54,10.79,5.33,,,

4525,45,5,East Coast (South),rare,7.76,18.16,17.68,19.12,10.51,10.04,4.78,6.69,5.26,,,

4526,45,5,East Coast (South),rare,10.36,14.72,17.06,16.72,11.71,9.36,7.36,7.36,5.35,,,

4527,45,5,East Coast (South),rare,4.47,6.39,11.5,12.46,11.5,12.14,13.1,15.34,13.1,,,

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4528,45,5,East Coast (South),rare,6.95,8.23,12.66,12.66,14.56,13.92,15.19,9.18,6.65,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4531,45,5,East Coast (South),rare,10.67,11.71,12.52,10.22,9.38,10.9,14.69,9.1,10.81,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4533,45,5,East Coast (South),rare,5.07,5.07,7.73,18.13,16,5.07,12.53,17.33,13.07,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4534,45,5,East Coast (South),rare,8.75,12.01,11.02,4.79,7.52,13.14,6.42,20.91,15.44,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4535,45,5,East Coast (South),rare,7.94,10.9,6.52,5.47,9,20.46,20.53,11.93,7.25,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4574,60,5,East Coast (South),frequent,20.52,14.11,21.79,7.69,7.69,0,0,0,0,0,21.79,6.41,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4575,60,5,East Coast (South),frequent,10.15,17.97,11.72,10.94,10.16,6.25,3.91,1.95,2.73,5.47,5.47,13.28,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4576,60,5,East Coast (South),frequent,19.14,17.02,14.89,10.64,8.51,4.26,5.32,3.19,4.26,1.6,4.79,6.38,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4577,60,5,East Coast (South),frequent,14.17,8.34,5.88,4.21,6.63,12.82,8.66,6.71,9.09,9.79,6,7.7,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4578,60,5,East Coast (South),frequent,7.21,3.09,7.22,7.22,12.37,7.22,11.34,7.22,9.28,11.34,14.43,2.06,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4579,60,5,East Coast (South),frequent,7.78,11.11,13.33,2.22,1.11,5.56,13.33,5.56,8.89,4.44,17.78,8.89,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4580,60,5,East Coast (South),frequent,18.94,9.85,8.33,8.33,3.79,6.82,6.06,4.55,6.82,11.36,9.85,5.3,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4581,60,5,East Coast (South),frequent,11.68,16.88,5.19,2.6,1.3,7.79,12.99,12.99,11.69,10.39,3.9,2.6,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4582,60,5,East Coast (South),frequent,3.19,4.11,4.92,6.04,8.33,9.42,5.49,7.16,13.97,22.64,10.38,4.35,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4583,60,5,East Coast (South),frequent,2.1,4.21,9.47,5.26,4.21,6.32,8.42,3.16,10.53,15.79,18.95,11.58,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4475,60,5,East Coast (South),intermediate,8.52,8.31,14.18,11.97,8.82,6.23,13.41,13.24,2.95,3.94,5.29,3.14,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4563,60,5,East Coast (South),intermediate,17.3,18.22,14.02,17.29,6.07,3.27,1.87,1.87,2.8,5.14,6.54,5.61,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4565,60,5,East Coast (South),intermediate,2.76,9.74,12.83,12.5,15.93,9.94,15.7,9.1,3.02,3.68,3.55,1.25,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4566,60,5,East Coast (South),intermediate,11.98,10.78,9.58,8.98,8.38,7.78,7.78,7.78,7.19,7.19,6.59,5.99,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4567,60,5,East Coast (South),intermediate,3.25,6.07,8.1,6.07,0.4,20.65,15.79,18.22,10.93,4.45,3.24,2.83,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4568,60,5,East Coast
(South),intermediate,5.33,7.61,3.43,5.32,6.84,19.01,17.87,12.55,5.7,5.7,7.22,3.42,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4569,60,5,East Coast
(South),intermediate,5.17,12.07,4.31,11.21,7.76,7.76,2.59,6.03,1.45,19.24,13.79,8.62,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4570,60,5,East Coast
(South),intermediate,6.44,12.04,9.23,12.74,8.84,6.27,8.39,6.84,5.85,7.29,8.18,7.89,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4572,60,5,East Coast
(South),intermediate,8.4,15.51,7.74,0.5,0.66,3.21,5.01,2.52,9.67,11.79,18.72,16.27,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4573,60,5,East Coast
(South),intermediate,6.44,6.43,7.14,7.14,10,7.14,3.57,5,7.86,17.86,15.71,5.71,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4360,60,5,East Coast
(South),rare,8.72,15.69,20.88,21.36,8.56,1.12,1.15,6.88,7.23,4.15,2.21,2.05,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4405,60,5,East Coast
(South),rare,10.42,5.88,5.61,14.82,5.87,7.74,15.09,5.07,5.61,13.48,5.34,5.07,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4463,60,5,East Coast
(South),rare,6.9,11.76,1.8,6.47,5.48,6.39,4.98,4.24,14.41,14.63,13.35,9.59,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4555,60,5,East Coast
(South),rare,9.81,13.75,12.38,10.22,7.66,10.81,7.86,10.61,5.5,3.54,3.73,4.13,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4556,60,5,East Coast
(South),rare,7.67,7.06,17.28,18.17,10.54,4.19,6.52,6.63,5.69,5.34,7.07,3.84,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4557,60,5,East Coast
(South),rare,4.13,6.51,7.1,7.69,8.88,11.83,13.61,13.02,13.02,5.92,5.33,2.96,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4558,60,5,East Coast
(South),rare,2.81,14.07,7.75,11.27,6.34,11.97,4.93,12.68,7.75,7.75,8.45,4.23,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4559,60,5,East Coast
(South),rare,4.44,5.9,9.04,9.78,6.64,7.75,9.59,13.65,12.18,8.12,7.93,4.98,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4560,60,5,East Coast
(South),rare,11.05,8.94,8.47,9.18,10.12,11.53,7.76,7.06,8.47,7.06,6.12,4.24,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4561,60,5,East Coast
(South),rare,5.6,6.54,2.34,2.34,4.21,4.21,9.81,18.22,15.89,13.08,7.01,10.75,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4600,90,5,East Coast
(South),frequent,3.07,7.15,6.13,11.22,18.37,9.18,4.08,2.04,3.06,3.06,3.06,6.12,6.12,6.12,1.02,3.06,2.04,5.1,,,,,,,,,,,,,,,,,,,,
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4602,90,5,East Coast
(South),frequent,3.77,9.6,10.92,10.8,10.6,9.34,3.5,13.5,9.19,3.42,2.47,1.72,1.72,1.72,2.21,2.18,1.67,1.67,,,,,,,,,,,,,,,,,,,,,,,,,
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4603,90,5,East Coast
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(South),frequent,2.89,4.82,8.65,7.69,13.46,12.5,6.73,7.69,4.81,2.88,3.85,1.92,4.81,2.88,4.81,5.77,0.96,2.88,,,,,,,,,,,,,,,,,,,,
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4604,90,5,East Coast
(South),frequent,3.62,8.44,7.24,4.82,12.05,6.02,4.82,8.43,6.02,2.41,6.02,6.02,3.61,2.41,2.41,4.82,4.82,6.02,,,,,,,,,,,,,,,,,,,,
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4605,90,5,East Coast
(South),frequent,0,3.4,6.81,13.64,6.82,4.55,1.14,4.55,6.82,9.09,6.82,11.36,3.41,6.82,2.27,4.55,5.68,2.27,,,,,,,,,,,,,,,,,,,,,,,,,
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4606,90,5,East Coast
(South),frequent,3.93,1.97,1.97,2.95,4.9,2.94,6.86,3.92,8.82,5.88,8.82,5.88,7.84,5.88,6.86,5.88,8.82,5.88,,,,,,,,,,,,,,,,,,,,,,,,
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4607,90,5,East Coast
(South),frequent,6.24,5.8,6.98,5.24,5.06,2.38,4.6,6.32,8.95,2.9,5.22,4.8,3.45,5.24,6.17,4.42,6.93,9.3,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4608,90,5,East Coast
(South),frequent,9.19,6.13,5.11,4.09,7.14,3.06,3.06,3.06,5.1,7.14,7.14,7.14,4.08,3.06,4.08,6.12,8.16,7.14,,,,,,,,,,,,,,,,,,,,,,,,
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4609,90,5,East Coast
(South),frequent,2.73,2.8,2.92,3.35,3.69,3.08,1.69,1.23,4.16,4.91,2.13,6.96,13.17,7.56,7.38,9.43,16.34,6.47,,,,,,,,,,,,,,,,,,,,
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4610,90,5,East Coast
(South),frequent,3.6,2.4,2,5.6,4.4,5.2,4.4,3.6,5.2,6.8,6.4,6.4,10.4,12,7.2,4,5.2,5.2,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4482,90,5,East Coast
(South),intermediate,19.61,10,6.15,5.83,12.7,8.61,4.19,0.94,0.66,1.08,0.6,0.36,0.36,7.07,4.37,2.64,4.91,9.92,,,,,,,,,,,,,,,,,,,
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4564,90,5,East Coast
(South),intermediate,3.94,13.21,13.93,10.71,13.21,4.64,2.5,1.43,1.43,2.14,3.93,5,4.29,6.43,5.36,2.14,2.5,3.21,,,,,,,,,,,,,,,,,
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4589,90,5,East Coast
(South),intermediate,4.74,16.56,11.29,9.95,7.16,11.43,5.72,4.54,4.63,4.52,2.82,1.25,3.65,4.54,2.98,2.04,1.09,1.09,,,,,,,,,,
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4590,90,5,East Coast
(South),intermediate,2,2.66,5.98,8.31,3.65,3.32,4.65,3.99,4.98,10.63,11.96,9.3,6.98,6.64,5.98,3.65,2.66,2.66,,,,,,,,,,,,,,,,,,,
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4592,90,5,East Coast
(South),intermediate,6.31,7.1,8.66,7.09,9.45,3.15,5.51,4.72,4.72,3.15,1.57,2.36,4.72,3.94,8.66,5.51,8.66,4.72,,,,,,,,,,,,,,,,,,
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4593,90,5,East Coast
(South),intermediate,3.41,3.87,3.94,6.17,7.03,4.47,4.24,5.77,3.94,6.26,8.14,9.81,9.9,6.89,2.97,4.85,4.89,3.45,,,,,,,,,,,,,,,,,,
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4594,90,5,East Coast
(South),intermediate,3.77,4.51,6.27,4.26,3.01,2.76,8.27,8.77,5.26,4.51,3.51,4.51,7.02,5.76,8.52,7.77,5.76,5.76,,,,,,,,,,,,,,
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4595,90,5,East Coast
(South),intermediate,10.25,9.03,2.25,4.02,3.71,8.9,4.97,4.89,4.3,3.72,7.29,5.36,2.51,3.38,6.51,6,4.45,8.46,,,,,,,,,,,,,,,,,,,,,
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4597,90,5,East Coast
(South),intermediate,4.1,13.31,5.46,12.97,5.46,1.71,1.02,0,0,0.34,0,0.68,2.73,10.24,11.95,15.7,10.92,3.41,,,,,,,,,,,,,,,,,,,,,
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4598,90,5,East Coast
(South),intermediate,7.99,5.47,7.99,7.98,1.26,0,0,0,0.42,0,12.61,7.98,3.78,12.18,5.88,10.5,6.72,9.24,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4395,90,5,East Coast
(South),rare,8.59,2.34,3.52,3.13,9.77,6.25,7.42,1.56,1.17,0.39,4.69,5.47,7.42,3.13,8.2,5.47,12.89,8.59,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4430,90,5,East Coast
(South),rare,4.83,10.89,7.79,11.94,10.97,10.08,4.96,1.49,4.79,3.82,2.98,1.7,2.2,7.59,4.39,1.92,3.44,4.22,,,,,,,,,,,,,,,,,,,,,,,,
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4465,90,5,East Coast
(South),rare,4.1,6.43,9,7.97,8.23,8.74,7.97,6.43,2.57,3.6,7.2,3.86,2.83,5.4,4.11,4.88,3.34,3.34,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4501,90,5,East Coast
(South),rare,5.55,8.14,7.17,6.84,5.05,5.7,7.65,5.05,5.37,4.72,5.05,5.7,7.82,4.56,4.56,3.58,3.58,3.91,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4532,90,5,East Coast
(South),rare,4.72,4.59,4.97,4.33,5.71,6.27,6.69,5.46,5.02,5.83,7.86,4.87,5.78,4.26,4.01,6.55,7.55,5.53,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4562,90,5,East Coast
(South),rare,1.26,2.31,6.97,5,5,4.29,5,1.79,1.79,3.21,3.21,7.5,13.93,12.14,10,5.36,8.21,3.03,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4584,90,5,East Coast
(South),rare,2.68,6.73,1.99,2.79,8.55,21.47,17.17,0.54,0.26,0.08,0.08,0.08,0.08,6.23,10.33,10.33,8.65,1.96,,,,,,,,,,,,,,,,,,,,
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4585,90,5,East Coast
(South),rare,5.24,15.73,7.67,0.85,0.19,0.19,0.19,0.19,2.3,14.19,9.66,11.12,4.16,4.25,7.36,5.92,6.6,4.19,,,,,,,,,,,,,,,,,,,,,,,,,,
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4586,90,5,East Coast
(South),rare,3.45,3.45,2.81,4.2,6.86,6.86,6.86,5.9,10.29,5.6,3.54,3.54,5.42,5.88,6.73,10.84,4,3.77,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4588,90,5,East Coast
(South),rare,2.92,4.13,4.28,4.13,2.91,7.03,7.8,9.02,8.72,4.74,5.81,9.17,4.43,4.89,5.2,5.5,5.5,3.82,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4632,120,5,East Coast
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(South),frequent,7.02,8.35,7.69,5.93,4.86,6.5,6.54,4.09,2.03,4.68,2.53,1.69,2.6,3.05,1.66,0,2.75,5.01,5.83,5.06,3.24,3.2
4,2.48,3.17,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4635,120,5,East Coast
(South),frequent,4.34,3.54,7.34,4.89,4.89,8.15,4.89,4.89,6.52,3.8,3.54,2.67,1.16,2.41,2.72,4.08,5.71,1.63,4.08,4.89,2.45
,4.35,3.8,3.26,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4636,120,5,East Coast
(South),frequent,11.18,10.45,10.24,9.34,4.64,4.99,3.3,0.61,0,0,0,0,0,0,0,0,0.18,2.3,1.87,17.7,6.81,12.69,2.64,1.06,,,,,,,,,
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4638,120,5,East Coast
(South),frequent,2.99,3.43,4.55,2.81,3.76,1.79,7.86,6.94,7.6,10.53,2.83,7.88,7.12,5.04,3.35,0.64,4.53,2,1.6,1.7,3.57,5.7
1,1.16,0.61,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4640,120,5,East Coast
(South),frequent,2.73,4.68,5.07,5.06,3.89,3.11,2.72,2.72,3.11,2.33,3.11,3.89,4.67,3.89,5.45,7.78,7,5.45,3.11,3.11,3.11,3
.11,5.06,5.84,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4641,120,5,East Coast
(South),frequent,0.72,4.42,7.65,7.65,11.18,7.65,1.77,0.99,2.28,2.61,2.61,7.98,21.18,2.07,2.64,2.94,2.94,0.99,2.54,1.77,
1.77,0.59,0.59,2.47,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4642,120,5,East Coast
(South),frequent,8.82,8.28,2.17,0,1.23,0,0,0,4.71,2.01,15.27,0,16.88,0.61,2.73,0.68,14.63,0,6.29,4.3,2.85,0,0,8.54,,,,,,,,,
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4643,120,5,East Coast
(South),frequent,3.32,5.11,8.14,4.34,3.48,2.4,1.5,0.77,0,0.47,1.2,5.2,7.58,4.85,5.3,2.73,3.61,6.1,8.27,5.56,5.56,5.56,5.0
2,3.93,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4644,120,5,East Coast
(South),frequent,9.88,14.28,16.48,2.24,0.09,0.09,0.09,0.09,0.09,0.09,0.09,0.09,0.09,0.09,0.09,0.09,0.64,1.56,5.49,4.95,
2.37,13.56,15.38,12.09,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4645,120,5,East Coast
(South),frequent,1.23,3.46,3.47,3.71,3.47,4.21,3.47,1.73,1.24,4.7,4.46,6.44,2.72,1.73,3.96,7.92,5.94,8.17,10.4,6.93,2.97
,3.96,2.72,0.99,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4621,120,5,East Coast
(South),intermediate,5.99,6.3,7.29,15.85,10.05,2.59,2.65,1.46,1.6,2.25,0.99,0,0.49,1.06,0.61,0.45,0.27,0,2.09,5.22,6.41,
5.06,9.49,11.83,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4622,120,5,East Coast
(South),intermediate,1.6,1.59,6.35,5.56,2.38,7.14,7.14,4.76,7.14,12.7,3.17,1.59,0.79,2.38,0.79,2.38,2.38,4.76,3.97,5.56,
2.38,7.94,2.38,3.17,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4623,120,5,East Coast
(South),intermediate,2.16,5.25,8.24,6.29,5.77,5.51,5.51,9.9,8.09,4.58,4.2,5.08,5.41,4.46,4.05,2.54,0.27,0,0,0.3,1.97,5.16
,4.48,0.78,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4624,120,5,East Coast
(South),intermediate,0.94,1.48,0.79,0.88,9.46,9.46,2.84,1.58,12.62,8.2,6.94,3.79,5.05,3.79,2.84,1.99,0.85,1.58,2.84,2.74
,1.36,4.1,8.2,5.68,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4625,120,5,East Coast (South),intermediate,0.58,1.16,1.72,1.72,2.3,1.72,8.05,8.62,7.47,6.32,4.02,2.87,4.6,2.3,3.45,2.3,2.3,4.02,5.17,7.47,4.6,2.87,6.9,7.47,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4626,120,5,East Coast (South),intermediate,2,4.58,2.29,2.87,4.3,4.87,2.87,5.44,10.6,6.59,3.72,2.58,9.74,4.87,4.87,3.44,2.87,2.01,0.57,9.74,2.87,2.29,2.01,2.01,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4628,120,5,East Coast (South),intermediate,3.44,2.3,4.31,2.59,8.62,4.02,5.17,3.45,4.6,5.46,3.74,3.45,5.75,3.45,3.45,2.87,5.17,5.75,6.9,5.17,4.02,3.45,2.01,0.86,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4629,120,5,East Coast (South),intermediate,3.73,3.75,4.75,5.86,4.44,3.67,5.08,5.47,6.09,4.71,4,4.23,4.45,5.43,5.36,4.81,3.7,2.26,4.03,2.59,2.65,2.77,2.71,3.46,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4630,120,5,East Coast (South),intermediate,5.99,4.28,3.43,4.27,3.42,4.27,3.42,1.71,2.56,4.27,1.71,0.85,0.85,0.85,3.42,4.27,6.84,8.55,13.68,7.69,2.56,3.42,3.42,4.27,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4631,120,5,East Coast (South),intermediate,4.38,7.45,6.13,2.19,0.44,7.02,7.46,5.26,0.88,0.88,0.44,0.44,0.88,0.88,1.32,0.44,0.44,1.32,3.07,4.82,10.09,10.53,10.96,12.28,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4431,120,5,East Coast (South),rare,0.96,0.63,4.22,9.5,6.79,10.4,9.56,8.79,4.33,1.3,4.17,3.33,2.6,1.48,1.92,6.61,3.83,1.67,3,3.68,3.11,4.41,2.4,1.31,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4499,120,5,East Coast (South),rare,6.12,5.83,7.19,6.63,3.69,3.38,4.13,2.47,1.05,0.69,0.43,0.25,0.14,0.33,3.61,4.23,4.47,5.45,7.38,10.4,8.31,5.84,5.96,2.02,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4571,120,5,East Coast (South),rare,7.04,5.4,7.44,5.16,3.66,4.9,3.99,3.42,4.25,4.78,4.6,3.71,5.8,5.01,4.49,3.94,3.04,1.58,1.34,2.39,3.14,3.32,3.71,3.89,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4611,120,5,East Coast (South),rare,4.21,5.78,2.62,2.36,2.1,2.62,4.99,7.35,12.86,14.7,10.24,2.1,0.79,1.18,1.57,0.92,0.96,1.67,1.57,3.67,5.77,2.36,2.1,5.51,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4613,120,5,East Coast (South),rare,2.54,11.96,17.34,8.97,2.99,1.2,1.49,8.07,1.79,1.2,2.39,0.6,0.6,0,0,0.6,5.38,5.38,1.99,2.79,5.98,8.37,4.78,3.59,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4614,120,5,East Coast (South),rare,2.07,2.58,2.57,1.54,1.03,3.6,3.08,8.74,2.57,6.68,4.11,6.68,10.8,9.25,8.74,6.68,2.06,0.77,0.77,3.08,5.14,4.63,1.03,1.8,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4615,120,5,East Coast (South),rare,6.32,6.88,5.02,4.78,4.53,3.58,3.03,2.62,0.7,3.85,4.76,5.5,5.92,4.22,3.23,2.92,3.34,4.18,3.94,2.97,4.71,5,3.5,4.5,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4617,120,5,East Coast

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(South),rare,7.53,12.55,8.58,2.62,2.62,1.19,0.76,0.45,1.11,1.29,0.77,4.16,6.38,6.38,6.38,6.22,8.84,7.93,7.93,3.86,1.13,0.59,0.45,0.28,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4618,120,5,East Coast (South),rare,0.67,0,1.34,7.38,4.03,4.7,2.68,3.36,0,2.68,6.71,4.03,0,10.07,6.04,2.01,3.36,11.41,3.36,4.03,2.68,7.38,5.37,6.71,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4619,120,5,East Coast (South),rare,2.79,2.13,2.66,5.09,1.94,1.87,0.79,1.7,3.41,3.9,2.55,2.38,2.2,0.95,1.78,6.52,9.67,7.95,6.74,7.75,5.73,3.5,8.89,7.11,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4646,180,15,East Coast (South),frequent,7.4,3.7,5.54,2.87,1.64,8.83,9.24,6.37,11.29,11.29,20.33,11.5,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4669,180,15,East Coast (South),frequent,12.46,19.92,29.46,7.47,7.88,4.15,3.73,1.66,2.07,4.98,2.49,3.73,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4670,180,15,East Coast (South),frequent,12.97,14.61,11.2,8.58,9.81,9.36,5.15,6.17,5.2,5.11,5.27,6.57,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4673,180,15,East Coast (South),frequent,11.6,11.71,8.92,10.4,8.47,1.74,8.05,7.98,0.72,6.53,10.93,12.95,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4674,180,15,East Coast (South),frequent,9.67,16.26,9.34,6.06,5.71,6.06,6.41,11.07,7.61,12.11,3.82,5.88,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4675,180,15,East Coast (South),frequent,9.64,6.57,12.68,8.01,6.38,9.24,10.89,8.73,4.65,10.19,7.66,5.36,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4676,180,15,East Coast (South),frequent,27.25,6.06,6.44,3.92,2.65,2.41,2.67,4.68,15.52,11.74,8.33,8.33,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4677,180,15,East Coast (South),frequent,4.2,4.77,9.23,13.66,8.24,8.52,6.53,6.61,14.64,11.39,5.15,7.06,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4679,180,15,East Coast (South),frequent,5.05,6.83,5.96,7.31,7.44,13.22,8.08,4.19,8.85,19.38,9.07,4.62,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4681,180,15,East Coast (South),frequent,15.04,12.03,6.02,0.75,1.5,2.26,6.77,13.53,19.55,16.54,4.51,1.5,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4627,180,15,East Coast (South),intermediate,7.25,8.96,16.84,11.94,9.81,4.05,11.09,3.84,4.48,3.41,11.51,6.82,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4639,180,15,East Coast (South),intermediate,8.78,6.68,17.9,16.97,12.39,5.73,5.49,5.97,4.17,2.93,7.62,5.37,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4658,180,15,East Coast (South),intermediate,9.31,0.51,14.54,16.92,15.06,10.76,11.32,2.06,2.68,3.1,5.31,8.43,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4659,180,15,East Coast (South),intermediate,5.66,2.85,9.95,5.43,13.45,18.58,7.71,9.09,9.14,9.54,4.67,3.93,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4662,180,15,East Coast
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(South),intermediate,9.93,1.99,1.32,2.65,3.31,9.27,20.53,16.56,2.65,8.61,14.57,8.61,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4663,180,15,East Coast
(South),intermediate,9.13,10.51,8.16,6.33,10.81,17.47,6.55,7.49,9.66,10.39,0.39,3.11,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4665,180,15,East Coast
(South),intermediate,5.66,8.64,9.16,10.92,10.58,5.74,14.8,9.61,7.16,3.59,6.54,7.6,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4666,180,15,East Coast
(South),intermediate,17.4,4.26,5.53,2.54,1.31,4.27,21.28,15.23,15.23,7.78,3.95,1.22,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4667,180,15,East Coast
(South),intermediate,6.23,4.94,5.41,8.47,5.65,9.18,8.24,6.12,10.35,15.53,11.3,8.58,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4668,180,15,East Coast
(South),intermediate,8.44,2.82,7.04,13.38,2.82,0,0,1.41,16.9,17.61,18.31,11.27,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4469,180,15,East Coast
(South),rare,21.52,11.11,11.81,8.3,9.42,5.77,1.69,2.39,4.78,9.14,5.91,8.16,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4599,180,15,East Coast
(South),rare,0.49,5.65,13.51,11.79,12.53,0.74,0.25,14.25,16.71,13.51,5.41,5.16,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4612,180,15,East Coast
(South),rare,10.2,5.09,10.75,27.17,2.92,2.48,4.97,7.36,9.06,3.77,6.98,9.25,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4647,180,15,East Coast
(South),rare,5.89,4.53,27.61,14.03,5.88,5.43,0.9,0.9,2.71,0.9,5.43,25.79,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4648,180,15,East Coast
(South),rare,6.99,10.29,10.29,5.35,9.67,9.26,7.41,7.41,7.61,9.67,5.56,10.49,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4649,180,15,East Coast
(South),rare,5.36,12.45,9.9,10.14,4.09,9.36,6.74,7.58,4.37,5.94,7.3,16.77,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4651,180,15,East Coast
(South),rare,3.56,7.24,4.29,13.79,19.27,7.77,5.59,15.5,11.37,3.25,1.34,7.03,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4652,180,15,East Coast
(South),rare,3.88,6.2,3.1,12.4,6.98,12.79,15.89,8.53,10.47,9.3,7.36,3.1,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4653,180,15,East Coast
(South),rare,11.35,2.56,9.95,6.01,13.71,8.78,9.21,13.04,9.53,8.33,3.28,4.25,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4656,180,15,East Coast
(South),rare,4.27,2.9,4.75,3.42,6.25,7.19,8.53,11.94,7.36,15.57,12.94,14.88,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

2749,270,15,East Coast
(South),frequent,7.91,4.67,4.35,2.32,2.49,5.51,3.12,3.12,2.5,5.11,2.11,9.08,5.56,9.32,8.12,10.83,8.42,5.46,,,,,,,,,,,,,,,,,,,,,,
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4706,270,15,East Coast
(South),frequent,2.55,7.33,20.15,22.71,2.93,0,0,0.37,0.73,5.49,2.56,8.06,12.09,4.4,3.3,3.3,3.66,0.37,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4707,270,15,East Coast
(South),frequent,5.32,7.09,2.96,4.14,14.2,20.12,10.65,2.96,0.59,1.78,1.78,2.37,1.18,0.59,5.33,6.51,9.47,2.96,,,,,,,,,,,,,,,,,,
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4708,270,15,East Coast
(South),frequent,3.72,0.89,9.98,14.23,9.28,7.13,5.25,5.25,5.05,4.06,4.78,3.71,8.04,5.99,3.91,2.77,3.81,2.15,,,,,,,,,,,,,,,,,,,,
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4709,270,15,East Coast
(South),frequent,4.27,5.04,4.84,8.53,8.72,7.36,2.13,3.29,3.68,3.49,3.88,4.07,6.01,7.56,6.2,8.53,7.75,4.65,,,,,,,,,,,,,,,,,,,,,,,,
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4711,270,15,East Coast
(South),frequent,5.34,4.54,4.8,4.13,4.93,3.07,4.93,10.4,8.28,11.21,6.8,5.73,3.47,3.2,3.78,5.79,4,5.6,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4712,270,15,East Coast
(South),frequent,4,2.4,1.6,3.2,6.4,3.2,7.2,18.4,5.6,4,7.2,16.8,4.8,2.4,2.4,0.8,4,5.6,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4715,270,15,East Coast
(South),frequent,3.64,5,8.78,4.97,4.44,5.2,5,5.85,8.75,5.66,1.95,2.48,3.43,4.28,6.67,6.86,7.9,9.14,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4717,270,15,East Coast
(South),frequent,7.31,5.11,4.28,4.58,3.04,8.58,8.79,9.34,10.14,6.76,4.76,5.37,5.18,3.23,2.37,1.95,5.2,4.01,,,,,,,,,,,,,,,,,,,,,,
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4718,270,15,East Coast
(South),frequent,3.3,3.29,1.97,5.92,5.26,1.97,1.97,0.66,1.97,4.61,3.29,15.79,7.89,6.58,5.92,4.61,19.74,5.26,,,,,,,,,,,,,,,,,,,,
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4664,270,15,East Coast
(South),intermediate,7.72,8.89,6.9,5.35,9.14,14.77,5.54,6.34,8.17,8.79,0.33,2.63,2.23,2.69,3.72,2.45,2.36,1.98,,,,,,,,,,,,,,,,
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4671,270,15,East Coast
(South),intermediate,3.33,10.82,12.18,9.34,7.16,8.18,7.81,4.3,5.14,4.34,4.26,4.4,5.48,3.78,2.68,1.79,2.13,2.88,,,,,,,,,,,,,,,,
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4695,270,15,East Coast
(South),intermediate,7.84,10.24,4.46,4.86,9.4,5.86,6.88,8.34,9.68,4.57,5.71,4.63,3.66,3.14,2.08,3.3,3.09,2.26,,,,,,,,,,,,,,,,,,
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4698,270,15,East Coast
(South),intermediate,5.56,3.44,6.09,6.61,6.09,7.67,8.73,3.44,5.29,5.82,7.94,6.35,2.77,4.62,3.97,4.76,5.29,5.56,,,,,,,,,,,,,,,,
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4699,270,15,East Coast
(South),intermediate,5.28,6.18,6.23,6.05,6.69,6.66,4.64,1.78,4.11,3.01,3.97,7.14,6.98,7.34,6.38,8.31,3.94,5.31,,,,,,,,,,,,,,,,
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4700,270,15,East Coast
(South),intermediate,1.7,1.53,2.94,4.13,3.21,7.32,7.86,9.94,7.18,2.44,8.31,11.42,5.74,5.65,6.26,3.78,6.08,4.51,,,,,,,,,,,,,,,,
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4701,270,15,East Coast
(South),intermediate,5.79,7.36,8.31,9.97,2.01,7.32,5.93,4.65,2.67,2.17,1.56,4.18,11.1,5.33,10.86,2.34,2.42,6.03,,,,,,,,,,,,,,
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4702,270,15,East Coast
(South),intermediate,5.11,4.6,6.64,7.65,5.61,5.1,4.08,6.12,5.1,10.2,5.61,3.57,5.61,6.12,2.55,1.53,1.02,13.78,,,,,,,,,,,,,,,,,,,,,
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4704,270,15,East Coast
(South),intermediate,5.31,2.66,2.48,1.16,2.81,4.64,8.11,5.63,6.79,5.96,2.81,4.97,8.77,8.94,6.62,5.79,10.76,5.79,,,,,,,,,,,,,,
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4705,270,15,East Coast
(South),intermediate,4.86,5.53,5.53,2.67,2.75,3.47,1.88,1.31,0.58,0.11,0.42,0.84,2.79,4.89,14.52,21.08,15.17,11.6,,,,,,,,,
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4616,270,15,East Coast
(South),rare,9.88,7.46,1.05,4.72,4.36,2.52,4.74,2.55,8.59,7.81,5.03,5.07,8.53,5.17,6.05,7.2,5.23,4.04,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4620,270,15,East Coast
(South),rare,2.76,4,3.4,2.09,9.39,4.78,5.97,0.51,2.22,4.97,5.98,2.79,5.46,4.32,5.6,14.76,10.29,10.71,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4650,270,15,East Coast
(South),rare,1.32,3.06,4.27,4.92,10.59,3.84,5.29,8.63,8.63,4.13,3.3,9.2,4.28,3.85,3.57,3.57,13.35,4.2,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4682,270,15,East Coast
(South),rare,9.25,21.2,8.15,8.15,3.26,0,0,0,6.52,14.13,0.54,2.17,5.98,8.15,8.7,2.17,1.09,0.54,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4683,270,15,East Coast
(South),rare,4.78,14.96,11.29,8.83,6.38,3.93,5.28,0.7,1.39,2.82,2.09,4.54,5.03,4.91,6.87,8.47,4.29,3.44,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4684,270,15,East Coast
(South),rare,4.13,4.82,10.42,15.83,10.55,5.77,6.71,2.13,6.45,4.81,3.08,3.31,3.05,3.24,7.57,3.97,2.67,1.49,,,,,,,,,,,,,,,,,,,,,,,,,
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4685,270,15,East Coast
(South),rare,8.15,2.86,6.94,5.31,5.31,7.35,5.31,4.9,2.45,2.45,3.27,7.35,5.71,5.71,8.57,6.53,5.71,6.12,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4686,270,15,East Coast
(South),rare,6.57,17.79,6.06,4.63,1.8,2.96,4.09,2.01,2.65,7.82,1.95,1.5,4.84,2.34,2.14,10.48,11.38,8.99,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4692,270,15,East Coast
(South),rare,21.49,12.11,2.34,1.56,1.17,0.39,1.95,3.13,5.86,5.86,7.81,5.47,3.91,10.94,5.86,5.86,1.56,2.73,,,,,,,,,,,,,,,,,,,,,,,,,
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4693,270,15,East Coast
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(South),rare,1,2.98,8.28,9.27,6.29,0.99,0.99,2.32,3.64,5.96,6.95,7.28,7.62,13.91,7.95,4.97,2.65,6.95,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4732,360,15,East Coast
(South),frequent,3.9,12.04,3.65,3.22,3.34,4.83,11.6,3.87,8.38,4.94,3.65,1.5,0.26,0.23,0.18,0.58,5.16,5.16,8.7,3.76,1.82,
1.09,6.75,1.39,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4734,360,15,East Coast
(South),frequent,7.09,3.87,1.55,2.99,6.55,2.45,5.66,1.85,16.33,3.66,2.3,5.13,2.08,0.27,1.37,5.65,5.92,3.32,0.73,0.59,9.1
5,6.78,2.12,2.59,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4735,360,15,East Coast
(South),frequent,5.27,5.27,5.26,4.09,5.26,7.6,8.19,5.85,5.26,4.68,4.68,3.51,2.34,2.92,2.34,1.75,2.92,3.51,2.92,2.34,1.17
,2.34,5.85,4.68,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4736,360,15,East Coast
(South),frequent,2.3,2.42,3.16,2.42,2.98,4.95,5.69,3.66,5.03,5.23,3.15,0,0,4.62,6.79,4.65,9.16,17.02,4.25,1.31,1.49,0.51
,0.38,8.83,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4737,360,15,East Coast
(South),frequent,3.1,5.72,4.32,2.34,2.65,1.43,2.16,5.6,4.04,2.73,1.94,3.09,6.57,5.95,4.34,3.37,5.09,3.37,3.24,6.68,6.68,
6.46,6.44,2.69,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4738,360,15,East Coast
(South),frequent,12.75,9.69,2.51,1.14,1.2,1.9,2.96,2.33,5.38,4.67,4.13,4.13,3.77,2.78,2.25,1.97,3.77,3.41,1.98,3.41,3.77
,3.95,6.82,9.33,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4739,360,15,East Coast
(South),frequent,3.04,3.15,3.65,3.65,4.01,6.2,6.74,5.29,9.84,5.83,7.29,8.75,2.92,1.7,1.22,0.87,2.41,0.8,1.51,1.48,2.39,3.
28,9.11,4.87,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4740,360,15,East Coast
(South),frequent,10.56,5.87,4.81,0.37,0.39,3.61,3.22,10.56,9.11,0.5,0,0,0.99,0.52,1.75,0.38,1.11,2.76,18.63,8.19,3.81,5.
23,3.36,4.27,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4741,360,15,East Coast
(South),frequent,2.95,2.36,2.36,2.37,2.37,3.55,2.96,2.96,2.37,2.37,3.55,2.37,1.78,4.14,4.14,4.73,5.92,2.96,5.33,4.73,6.5
1,10.65,10.06,6.51,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4742,360,15,East Coast
(South),frequent,2.43,3.04,3.04,3.04,2.44,3.66,2.44,3.66,3.05,1.83,1.83,2.44,2.44,4.27,4.27,3.66,3.05,6.71,6.71,6.71,7.9
3,11.59,5.49,4.27,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4591,360,15,East Coast
(South),intermediate,1.99,2.98,4.61,1.65,0.82,4.28,2.47,8.4,5.77,9.72,14,8.07,3.13,1.15,0.99,1.48,7.41,3.62,5.6,5.27,3.9
5,0.99,0.99,0.66,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4660,360,15,East Coast
(South),intermediate,1.87,2.52,3.52,3.76,6.43,5.29,12.67,11.1,4.4,6.5,7.41,5.88,3.04,2.93,2.07,1.5,0.82,1.06,2.61,3.91,2.
81,2.46,2.65,2.79,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4672,360,15,East Coast
(South),intermediate,3.01,9.73,10.96,8.4,6.44,7.36,7.02,3.87,4.63,3.9,3.83,3.95,4.93,3.4,2.41,1.61,1.91,2.59,1.77,2.29,1.
95,1.38,1.22,1.44,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4678,360,15,East Coast (South),intermediate,2.43,2.45,2.01,2.16,2.98,1.58,1.18,0.34,1.48,3.63,2.98,3.13,3.54,6.85,10.14,6.12,6.32,4.85,4.9,10.87,8.45,3.82,5.24,2.55,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4696,360,15,East Coast (South),intermediate,3.76,2.81,3.67,1.42,1.84,0.98,0.94,6.78,8.85,3.86,4.2,8.13,5.07,5.96,7.22,8.38,3.96,4.94,4.01,3.17,2.72,1.8,2.86,2.67,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4725,360,15,East Coast (South),intermediate,1.28,4.25,5.17,16.45,14.04,9.12,2.18,7.85,3.42,0.04,0.79,0.95,1.96,1.3,3.18,2.68,1.19,2.71,2.96,4.98,0.75,1.15,9.17,2.43,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4726,360,15,East Coast (South),intermediate,5.09,3.96,5.09,3.4,2.83,2.83,2.83,2.82,4.52,3.39,3.95,3.39,2.82,3.39,5.65,3.95,6.21,6.21,5.08,6.21,2.82,2.26,6.78,4.52,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4729,360,15,East Coast (South),intermediate,2.53,5.43,4.93,2.14,2.86,2.96,4.04,5.8,5.05,3.7,4.12,3.53,3.28,2.35,2.95,3.53,3.91,4.42,5.55,5.55,7.9,2.7,6.31,4.46,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4730,360,15,East Coast (South),intermediate,1.06,1.06,2.66,3.72,2.66,4.26,4.79,4.26,5.32,5.85,3.72,4.26,6.91,7.98,11.17,9.04,0,3.19,4.79,2.13,1.06,2.13,4.26,3.72,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4731,360,15,East Coast (South),intermediate,5.27,5.7,10.09,3.51,2.63,3.07,2.19,0.44,0,0,0.44,2.63,2.63,0.44,0,5.7,5.26,4.82,10.96,4.39,4.39,4.39,8.77,12.28,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4406,360,15,East Coast (South),rare,4.16,3.57,2.81,3.57,3.21,2.67,1.83,2.36,3.39,1.92,4.19,4.32,3.66,4.28,3.34,3.74,3.83,3.79,3.52,2.45,7.31,9.5,8.6,7.98,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4529,360,15,East Coast (South),rare,2.7,5.03,7.72,6.85,5.38,7.63,11.28,8.5,1.43,2.04,1.98,0.29,0.12,1.07,0.64,1.05,3.43,3.21,5.2,5.03,6.42,3.12,5.72,4.16,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4587,360,15,East Coast (South),rare,4.01,5.3,10.44,11.05,6.34,11.89,4.78,0.86,0.66,0.07,0.07,0.4,1.1,1.4,5.57,5.64,0.56,0.88,2.96,3.87,1.3,2.92,9.88,8.05,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4596,360,15,East Coast (South),rare,2.09,2.57,3.44,5.19,4.15,4.15,3.38,4.28,5.89,2.21,3.64,4.37,4.77,6.91,5.33,4.54,5.25,3.98,6.07,4.9,5.63,3.39,1.21,2.66,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4694,360,15,East Coast (South),rare,2.6,7.19,8.05,5.46,0.86,0.86,2.01,3.16,5.17,6.03,6.32,6.61,12.07,6.9,4.31,2.3,6.03,0.57,0.86,0.86,2.59,4.31,2.87,2.01,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4719,360,15,East Coast (South),rare,2.6,5.22,7.36,9.26,11.4,9.98,10.69,9.26,4.28,2.38,1.43,0.95,1.9,1.19,1.43,1.9,2.61,2.61,2.85,2.38,2.38,2.14,1.9,1.9,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4720,360,15,East Coast

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(South),rare,2.08,1.22,2.95,4.69,2.03,3.7,1.39,5.9,7.99,6.25,5.56,2.78,4.17,3.01,3.94,2.08,3.47,8.33,9.72,0.69,2.08,5.29,
5.12,5.56,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4721,360,15,East Coast
(South),rare,14.31,4.29,3,3,7.3,6.58,1,0.57,0.72,5.72,5.44,0.72,6.58,0.29,0.72,3.86,1.72,1.57,2.72,8.3,9.01,4.43,2,6.15,,,,
,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4722,360,15,East Coast
(South),rare,1.03,1.3,1.26,2.09,2.51,2.86,3.26,3.64,3.92,4.24,4.24,5.53,6.77,5.71,5.4,4.05,2.57,3.83,1.78,3.21,2.31,7.75,
15.1,5.64,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4723,360,15,East Coast
(South),rare,1.69,1.82,2.05,2.23,1.65,2.65,2.98,3.24,2.51,3.39,4.12,4.36,3.63,4.12,4.84,5.33,8.72,8.72,11.14,9.2,5.81,2.3
2,1.67,1.81,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4767,540,30,East Coast
(South),frequent,31.55,2.42,1.54,26.54,1.82,1.15,0.39,1.75,0.39,3.09,2.14,1.56,3.7,2.16,0.79,1.18,8.22,9.61,,,,,,,,,,,,,,,,,,,,
,,,,,,,,,,,,,,,,,,

4768,540,30,East Coast
(South),frequent,4.87,5.33,8.43,7.84,10.06,8.14,7.99,7.54,5.33,2.37,2.96,5.47,4.73,3.11,3.55,3.55,3.85,4.88,,,,,,,,,,,,,,,,,,,,
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4769,540,30,East Coast
(South),frequent,5.1,6.16,6.69,3.35,11.09,3.87,7.75,4.93,4.05,5.28,5.28,4.93,4.23,4.93,4.58,5.63,4.05,8.1,,,,,,,,,,,,,,,,,,,,,,,,
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4770,540,30,East Coast
(South),frequent,5.06,3.73,4.21,6.62,7.1,3.97,4.09,7.22,9.27,4.09,3.61,4.93,10.23,11.07,3.25,4.69,3.25,3.61,,,,,,,,,,,,,,,,,,,,
,,,,,,,,,,,,,,,,,,

4771,540,30,East Coast
(South),frequent,4.04,4.04,7.82,4.43,2.52,2.31,6.18,3.09,3.78,7.25,8.12,3.38,3.62,9.86,8.11,7.54,6.95,6.96,,,,,,,,,,,,,,,,,,,,,,
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4772,540,30,East Coast
(South),frequent,6.29,7,1.55,2.87,18.41,2.57,1.68,4.31,1.93,5.64,1.97,0.9,2.77,1.78,19.4,15.15,4.06,1.72,,,,,,,,,,,,,,,,,,,,,,,,,
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4773,540,30,East Coast
(South),frequent,5.66,3.6,1.88,1.23,8.33,3.59,6.22,10.34,6.21,6.97,5.23,8.71,5.45,5.45,5.23,6.1,5.77,4.03,,,,,,,,,,,,,,,,,,,,,,,,
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4774,540,30,East Coast
(South),frequent,2.39,3.81,3.81,1.43,7.14,1.43,1.43,7.14,6.19,5.71,3.33,6.67,5.71,4.76,10,20,4.29,4.76,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4775,540,30,East Coast
(South),frequent,4.42,2.3,2.68,3.36,2.35,8.66,4.68,3.01,5.59,6.48,7.24,7.65,1.67,3.93,6.17,6.57,13.83,9.41,,,,,,,,,,,,,,,,,,,,,,
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4776,540,30,East Coast
(South),frequent,4.95,1.1,9.01,2.02,1.47,1.29,13.24,1.1,2.94,2.94,8.46,5.15,13.24,2.76,6.43,4.23,6.25,13.42,,,,,,,,,,,,,,,,,,,,
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4697,540,30,East Coast (South),intermediate,5.16,3.13,2.95,3.62,3.33,3.63,4.98,4.33,2.5,3.42,11.59,9.39,9.51,11.1,7.98,5.63,3.78,3.97,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4756,540,30,East Coast (South),intermediate,13.84,28.19,1.06,0,0,1.06,6.91,0.53,6.91,2.66,2.13,7.45,0,0,4.26,14.89,7.45,2.66,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4757,540,30,East Coast (South),intermediate,28.92,15.36,6.11,1.32,0.99,0.17,0.5,2.98,9.26,7.77,3.64,5.29,6.45,4.3,1.82,1.32,0.99,2.81,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4759,540,30,East Coast (South),intermediate,8,6.36,4.6,6.77,7.4,8.75,2.79,3.88,4.94,3.22,4.13,2.41,7.13,5.49,5.13,3,10.04,5.96,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4760,540,30,East Coast (South),intermediate,2.92,1.59,1.49,2.81,11.09,14.59,5.83,3.05,2.19,2.55,3.71,5.32,4.9,3.99,5.59,19.39,5.99,3,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4761,540,30,East Coast (South),intermediate,6.47,6.35,7.26,5.88,5.15,3.82,5.26,7.43,7.12,6.19,6.81,6.96,3.25,3.25,6.18,4.18,4.8,3.64,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4763,540,30,East Coast (South),intermediate,4.62,4.5,1.52,4.82,4.78,8.72,3.03,6.64,7.01,6.06,3.24,2.15,7.61,6.88,8.43,6.79,6.82,6.38,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4764,540,30,East Coast (South),intermediate,6.43,4.94,6.43,4.95,6.44,4.95,9.41,2.97,0.99,0.99,2.48,1.98,8.91,6.93,12.38,8.42,5.94,4.46,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4765,540,30,East Coast (South),intermediate,4.5,2.52,2.15,3.28,4.83,2.88,1.39,5.09,6.78,7.01,6.9,4.36,13.47,13.58,6.41,5.46,4.34,5.05,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4766,540,30,East Coast (South),intermediate,8.01,0.47,2.59,2.83,0.71,4.72,14.39,4.01,1.42,6.37,3.54,5.66,12.03,13.44,10.38,3.54,3.77,2.12,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4442,540,30,East Coast (South),rare,5.64,3.75,4.3,8.33,8.6,3.23,2.96,2.96,2.69,19.09,9.14,5.11,2.69,2.69,2.96,1.61,5.38,8.87,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4530,540,30,East Coast (South),rare,4.61,5,10.57,8.75,16.02,3.37,2.17,0.67,1.4,3.21,8.17,7.91,7.26,2.92,2.79,7.07,2.92,5.19,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4601,540,30,East Coast (South),rare,4.57,4.3,6.72,2.96,12.1,6.45,6.45,3.76,3.23,3.76,3.49,5.65,7.26,6.99,4.84,4.03,6.18,7.26,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4657,540,30,East Coast

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(South),rare,3.66,4.38,3.05,3.3,5.6,3.23,1.86,3.65,4.15,5.24,8.52,10.46,15.45,8.98,1.35,4.04,11.28,1.8,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4743,540,30,East Coast
(South),rare,5.1,5.18,4.32,4.99,8.45,13.63,11.23,4.65,3.98,6.81,7.01,2.5,4.41,4.99,3.26,3.74,3.45,2.3,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
,,,,,,

4744,540,30,East Coast
(South),rare,6.58,3.99,4.39,5.97,5.48,5.69,5.39,6.82,9.13,5.03,8.28,4.08,4.35,4.09,4.57,5.39,1.74,9.03,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
,,,,,,,,

4745,540,30,East Coast
(South),rare,4.76,2.98,3.27,3.87,5.06,5.65,5.36,5.06,2.68,8.63,4.76,4.76,11.31,5.36,9.52,6.25,3.87,6.85,,,,,,,,,,,,,,,,,,,,,,,,,,,,
,,,,,,,,,,

4746,540,30,East Coast
(South),rare,3.4,3.36,3.89,3.59,3.74,3.9,4.1,5.41,6.05,6.49,8.51,8.82,7.47,6.51,3.87,8.99,6.67,5.23,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4750,540,30,East Coast
(South),rare,7.77,9.63,6.68,2.74,2.81,5.03,1.87,0.43,2.89,2.84,0.89,0.47,1.09,0.66,9.01,20.69,15.95,8.55,,,,,,,,,,,,,,,,,,,,,,,,,,
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4754,540,30,East Coast
(South),rare,4.06,3.59,3.16,5.64,4.14,5.32,2.68,5.33,5.53,6.14,5.51,5.13,8.39,3.2,7.59,9.29,4.23,11.07,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
,,,,,,,,

4802,720,30,East Coast
(South),frequent,2.97,3.29,5.15,2.89,3.36,2.76,2.75,5.51,11.01,16.32,5.04,5.16,4.18,4.29,0.82,3.68,4.7,1.99,1.75,2.73,1.
84,2.01,2.96,2.84,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4804,720,30,East Coast
(South),frequent,12.1,6.9,18.55,5.95,4.82,2.42,2.02,1.47,1.13,1.32,3.25,3.86,4.25,3.58,1.07,2.46,2.84,1.03,1.93,4.57,2.3
5,3.21,1.75,7.17,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4805,720,30,East Coast
(South),frequent,1.95,1.34,2.81,3.79,6.77,4.07,4.04,7.44,3.39,8.42,5.29,5,4.13,4.59,5.55,7.04,6.07,3.21,2.62,1.76,1.54,1
.29,4,3.89,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4806,720,30,East Coast
(South),frequent,6.25,9.73,3.09,2.63,2.41,2.59,9.73,1.57,2.36,2.24,11.68,3.24,4.04,4.06,1.95,3.68,2.89,4.46,3.32,3.48,3,
3.16,3.57,4.87,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4807,720,30,East Coast
(South),frequent,2.1,1.08,3.14,2.14,3.96,4.97,4.32,6.67,4.22,1.96,5.97,6.89,7.86,6.64,3.61,2.67,3.95,2.21,3.63,2.76,2.74
,4.16,8.7,3.65,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4808,720,30,East Coast
(South),frequent,4.19,5.74,2.11,3.02,3.93,3.67,3.28,3.34,2.53,5.73,6.05,4.93,3.74,1.9,4.23,3.86,2.63,2.82,3.1,4.51,6.78,
5.07,6.89,5.95,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4809,720,30,East Coast
(South),frequent,2.66,3.18,2.92,5.03,5.17,1.95,0.71,7.68,5.57,3.58,4.37,5.17,5.37,4.57,7.95,4.78,5.17,5.17,4.37,3.98,3.7
1,1.99,2.66,2.29,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
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4810,720,30,East Coast (South),frequent,2.82,1.92,2.38,3.68,2.11,3.07,3.01,2.77,3.06,2.34,2.68,3.52,4.16,5.16,8.84,4.28,4.13,6.59,11.27,9.78,5.91,1.59,1.97,2.96,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4811,720,30,East Coast (South),frequent,1.2,2.15,2.4,1.98,2.02,4.02,3.07,4.62,2.45,4.44,3.3,1.77,2.67,4.85,2.36,4.47,4.35,10.55,11.13,5.95,5.15,5.67,6.69,2.74,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4813,720,30,East Coast (South),frequent,2.83,2.13,1.76,2.3,4.34,4.56,4.2,2.33,2.44,3.73,1.99,1.56,2.36,1.13,3.25,3.56,4.45,7.19,3.89,8.74,7.47,13.94,7.94,1.91,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4703,720,30,East Coast (South),intermediate,2.42,2.14,2.14,2.41,2.94,2.67,3.21,5.08,7.49,5.61,5.35,8.02,4.81,6.15,2.14,7.75,2.94,0.53,5.35,2.94,5.61,5.61,4.28,2.41,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4788,720,30,East Coast (South),intermediate,2.69,0.22,5.45,7.99,12.88,6.06,0.23,2.71,6.4,7.4,4.34,6.94,1.65,2.53,5.37,0,3.43,0.91,6.8,3.39,2.57,1.97,6.12,1.95,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4789,720,30,East Coast (South),intermediate,4.84,6.69,3.93,4.39,4.39,3.46,5.08,12.47,6.7,4.16,3.23,2.77,2.08,1.39,2.31,1.85,0.23,3.93,3.23,4.62,5.54,3.7,4.62,4.39,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4790,720,30,East Coast (South),intermediate,3.1,4.68,3.65,4,4.13,4.14,4,3.84,3.27,6.96,4.25,5.24,5.51,5.76,4.22,3.68,2.09,2.72,2.26,4.9,3.55,4.71,4,5.34,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4791,720,30,East Coast (South),intermediate,3.47,4.62,1.15,1.15,3.46,1.15,1.92,5,5.77,11.92,11.15,5.77,5,4.62,3.08,5.77,3.08,3.85,2.31,5.38,2.69,3.08,0.38,4.23,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4792,720,30,East Coast (South),intermediate,5.07,10.71,3.45,2.42,1.98,1.88,1.83,4.32,2.53,3.69,5.52,3.33,2.35,5,3.79,5.52,4.14,4.14,8.46,4.31,5.87,4.26,2.47,2.96,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4793,720,30,East Coast (South),intermediate,2.71,4.75,3.89,2.3,1.8,1.66,2.32,1.84,4.09,5.38,6.12,4.8,1.98,11.19,4.82,8.15,3.93,3.01,4.06,8.67,5.06,3.04,1.56,2.87,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4794,720,30,East Coast (South),intermediate,0,0,0,31.24,7.39,2.84,1.14,0.57,0,0,0,0,0,0.57,0.57,6.25,0.57,0.57,2.27,14.77,13.64,9.66,5.68,2.27,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4800,720,30,East Coast (South),intermediate,2.67,2.41,6.22,3.6,11.05,1.56,4.41,2,0.79,3.6,2.39,0.22,2.25,3.42,7.47,1,5.22,2.29,7.92,12.11,8.65,4.92,0.61,3.22,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4801,720,30,East Coast (South),intermediate,2.38,0.8,0.66,2.99,2.22,2.56,4.27,4.94,3.64,4.74,5.4,4.61,4.09,3.84,5.12,7.17,8.7,7.42,5.9,5.63,3.57,1.71,3.92,3.72,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4443,720,30,East Coast
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(South),rare,2.01,3.82,2.92,2.92,4.04,3.15,3.15,6.07,8.54,3.37,2.25,2.7,2.25,8.99,14.16,4.49,2.47,2.47,2.25,1.57,4.27,6.0
7,3.6,2.47,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4654,720,30,East Coast
(South),rare,1.28,6.04,5.81,9.16,8.35,10.48,5.39,6.51,2.93,2.94,2.69,1.35,0.56,1.48,1.81,1.13,3.25,3.02,5.71,4.63,1.82,4.
6,5.79,3.27,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4724,720,30,East Coast
(South),rare,0.85,1.61,2.06,1.74,2.65,2.14,2.83,2.99,3.81,4.31,5.32,5.73,6.45,9.14,13.98,13.26,3.66,2.43,2.26,2.22,2.32,
2.97,2.75,2.52,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4747,720,30,East Coast
(South),rare,2.94,2.7,3.02,2.72,2.27,2.58,2.85,2.81,3.26,3.01,3.13,3.27,3.43,4.53,5.07,5.43,7.13,7.39,6.26,5.45,3.25,7.53
,5.58,4.39,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4751,720,30,East Coast
(South),rare,0.69,2.68,4.4,5.7,6.77,7.72,4.58,1.67,2.91,3.79,0.92,1.17,2.4,1.55,0.63,0.45,0.91,0.63,11.23,20.44,8.08,5.35
,3.98,1.35,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4758,720,30,East Coast
(South),rare,7.9,21.37,6.8,2.55,1.09,0.36,0.12,0.97,2.79,7.16,5.22,2.91,4,4.49,2.43,1.09,0.85,0.61,4,5.7,5.46,5.22,4.85,2.
06,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4777,720,30,East Coast
(South),rare,1.34,5.53,8.69,4.95,5.18,3.75,7.74,5.2,5.98,4.46,5.46,4.54,1.98,1.77,2.11,3.05,3.59,4.13,3.73,2.89,3.41,4.39
,4.72,1.41,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

4785,720,30,East Coast
(South),rare,11.44,5.72,8.25,0.95,0,0,0,0,0,0.63,2.54,11.75,2.22,4.44,8.25,11.43,7.3,5.4,3.49,5.4,2.22,2.54,2.54,3.49,,,,,,
,,,,,,,,,,,,,,,,,,,,,,,,,,

4786,720,30,East Coast
(South),rare,5.86,9.34,14.12,4.28,7.98,0.21,0,0,0.24,0.23,1.3,0.09,0,0,1.87,0.01,0,5.82,13.81,17.21,12.14,5.49,0,0,,,,,,,,,,
,,,,,,,,,,,,,,,,,,,,,,

4787,720,30,East Coast
(South),rare,3.22,4.03,3.88,4.4,2.53,2.82,2.29,2.53,3.14,2.86,3.68,3.39,3.23,3.57,2.77,3.1,3.78,4.72,8.47,9.13,6.26,7.51,
4.68,4.01,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

[ENDPATTERNS]
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Annex D ARR Blockage Assessment Form

BLOCKAGE ASSESMENT FORM

Australian Rainfall & Runoff

STRUCTURE :

OPENING WIDTH:......................m

DEBRIS TYPE/MATERIAL/L_{10}/SOURCE AREA - *There may be more than one material type to consider!*

Debris Type/Material	L_{10}	Source Area	How Assessed
Large tree branches	7-10m	Riverine/bushland Vegetation	Satellite Imagery

DEBRIS AVAILABILITY (HML) – *for the selected debris type/size and its source area*

Availability	Typical Source Area Characteristics	Notes
[✓ High]	• *Dense forest, thick vegetation, extensive canopy, difficult to walk through with considerable fallen limbs, leaves and high levels of floor litter.* • *Streams with boulder/cobble beds and steep bed slopes and banks showing signs of substantial past bed/bank movements.* • *Arid areas, where loose vegetation and exposed loose soils occur and vegetation is sparse.* • *Urban areas that are not well maintained and/or old paling fences, sheds, cars and/or stored loose material etc., are present on the floodplain close to the water course.*	densely vegetated area (e.g. woronora river)
Medium	• *State forest areas with clear understory, grazing land with stands of trees* • *Source areas generally falling between the High and Low categories.*	
Low	• *Well maintained rural lands and paddocks, with minimal outbuildings* • *Streams with moderate to flat slopes and stable beds and banks.* • *Arid areas where vegetation is deep rooted and soils resistant to scour* • *Urban areas that are well maintained with limited debris present in the source area.*	

DEBRIS MOBILITY (HML) - *for the selected debris type/size and its source area*

Mobility	Typical Source Area Characteristics	Notes
High	• *Steep source area with fast response times and high annual rainfall and/or storm intensities and/or source areas subject to high rainfall intensities with sparse vegetation cover.* • *Receiving streams that frequently overtop their banks.* • *Main debris source areas close to streams*	steep bank, medium rainfall intensities, mainly overland landscape
[✓ Medium]	• *Source areas generally falling between the High and Low categories.*	
Low	• *Low rainfall intensities and large, flat source areas.* • *Receiving streams that Infrequently overtop their banks.* • *Main source areas well away from streams*	

DEBRIS TRANSPORTABILITY (HML) - *for the selected debris type/size and stream characteristics*

Transportability	Typical Transporting Stream Characteristics	Notes
High	• *Steep bed slopes (> 3%).and/or high stream velocity ($V>2.5m/sec$)* • *Deep stream relative to vertical debris dimension ($D>0.5L_{10}$)* • *Wide streams relative to horizontal debris dimension. ($W>L_{10}$)* • *Streams relatively straight and free of constrictions/snag points.* • *High temporal variability in maximum stream flows*	Flat bed slopes (<1%) but velocity in 1%AEP fall between 1 to 2 m/s
[✓ Medium]	• *Streams generally falling between High and Low categories*	
Low	• *Flat bed slopes (< 1%).and/or low stream velocity ($V<1m/sec$)* • *Shallow stream relative to vertical debris dimension ($D<0.5L_{10}$)* • *Narrow streams relative to horizontal debris dimension.($W<L_{10}$)* • *Streams meander with frequent constrictions/snag points.* • *Low temporal variability in maximum stream flows*	

BLOCKAGE ASSESMENT FORM

Australian Rainfall & Runoff

SITE BASED DEBRIS POTENTIAL 1%AEP (HML) - *for the selected debris type/size arriving at the site*

Debris Potential	Combinations of the Above (any order)	Notes
DP_{High}	HHH or HHM	
[✓ DP_{Medium}]	MMM or HML or HMM or HLL	HMM
DP_{Low}	LLL or MML or MLL	Eg. MML, therefore DP_{Low} selected

AEP ADJUSTED SITE DEBRIS POTENTIAL (HML) - *for the selected debris type/size*

Event AEP	At Site 1% AEP Debris Potential			AEP Adjusted At Site Debris potential
	DP_{High}	[✓ DP_{Medium}]	DP_{Low}	
AEP > 5% *(frequent)*	Medium	Low	Low	Eg. Low
AEP 5% - AEP 0.5%	High	Medium	Low	Eg. Low
AEP < 0.5% *(rare)*	High	High	Medium	Eg. Medium

Debris Blockage

MOST LIKELY DESIGN INLET BLOCKAGE LEVEL (B_{DES}%) *for the selected debris type/size*

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

Event AEP	Bdes %
AEP > 5% *(frequent)*	Eg. Low – 0%
AEP 5% - AEP 0.5%	Eg. Low – 0%
AEP < 0.5% *(rare)*	Eg. Medium – 10%

Refer Guideline if opening H<0.33W

BLOCKAGE ASSESMENT FORM

Barrel Blockage

The following tables are only relevant to sites subject to a significant debris load of sediment. Where inlet blockage and barrel blockage are both likely, the blockage producing the greatest impact on flood behaviour should be used in design.

LIKELIHOOD OF SEDIMENT BEING DEPOSITED IN THE BARREL OR WATERWAY (HML)

Peak Velocity Through Structure (m/sec)	Mean Sediment Size Present				
	Clay/Silt 0.001 to 0.04 mm	Sand 0.04 to 2 mm	Gravel 2 to 63 mm	Cobbles 63 to 200 mm	Boulders >200 mm
>= 3	L	L	L	L	M
1.0 to < 3.0	L	L	L	M	M
0.5 to < 1.0	L	L	L	M	H
0.1 to < 0.5	L	L	M	H	H
< 0.1	L	M	H	H	H

Likelihood of Sediment: Eg. Medium

MOST LIKELY DESIGN BARREL BLOCKAGE (Bdes%) ***for sediment of a particular mean size is then;***

Likelihood That Deposition Occurs	AEP Adjusted Sediment Potential		
	High	**Medium**	**Low**
High	100%	60%	25%
Medium	60%	40%	15%
Low	25%	15%	0%

Event AEP	Bdes %
AEP > 5% (frequent)	Eg. Low – 15%
AEP 5% - AEP 0.5%	Eg. Low – 15%
AEP < 0.5% *(rare)*	Eg. Medium – 40%

For modelling blockage mechanism (type, location and timing), refer to Guideline Table 8

BLOCKAGE ASSESMENT FORM

STRUCTURE :

OPENING WIDTH:.......................m

DEBRIS TYPE/MATERIAL/L_{10}/SOURCE AREA - *There may be more than one material type to consider!*

Debris Type/Material	L_{10}	Source Area	How Assessed
Urban trash	1.5m	Urban areas	Satellite Imagery

DEBRIS AVAILABILITY (HML) – *for the selected debris type/size and its source area*

Availability	Typical Source Area Characteristics	Notes
High	• *Dense forest, thick vegetation, extensive canopy, difficult to walk through with considerable fallen limbs, leaves and high levels of floor litter.* • *Streams with boulder/cobble beds and steep bed slopes and banks showing signs of substantial past bed/bank movements.* • *Arid areas, where loose vegetation and exposed loose soils occur and vegetation is sparse.* • *Urban areas that are not well maintained and/or old paling fences, sheds, cars and/or stored loose material etc., are present on the floodplain close to the water course.*	
[✓ Medium]	• *State forest areas with clear understory, grazing land with stands of trees* • *Source areas generally falling between the High and Low categories.*	Well maintained urban Areas but Availability is high to also account for small tree branches and other non-urban debris
Low	• *Well maintained rural lands and paddocks, with minimal outbuildings* • *Streams with moderate to flat slopes and stable beds and banks.* • *Arid areas where vegetation is deep rooted and soils resistant to scour* • *Urban areas that are well maintained with limited debris present in the source area.*	

DEBRIS MOBILITY (HML) - *for the selected debris type/size and its source area*

Mobility	Typical Source Area Characteristics	Notes
High	• *Steep source area with fast response times and high annual rainfall and/or storm intensities and/or source areas subject to high rainfall intensities with sparse vegetation cover.* • *Receiving streams that frequently overtop their banks.* • *Main debris source areas close to streams*	
[✓ Medium]	• *Source areas generally falling between the High and Low categories.*	Medium
Low	• *Low rainfall intensities and large, flat source areas.* • *Receiving streams that Infrequently overtop their banks.* • *Main source areas well away from streams*	

DEBRIS TRANSPORTABILITY (HML) - *for the selected debris type/size and stream characteristics*

Transportability	Typical Transporting Stream Characteristics	Notes
High	• *Steep bed slopes (> 3%).and/or high stream velocity (V>2.5m/sec)* • *Deep stream relative to vertical debris dimension ($D>0.5L_{10}$)* • *Wide streams relative to horizontal debris dimension. ($W>L_{10}$)* • *Streams relatively straight and free of constrictions/snag points.* • *High temporal variability in maximum stream flows*	
[✓ Medium]	• *Streams generally falling between High and Low categories*	Medium
Low	• *Flat bed slopes (< 1%).and/or low stream velocity (V<1m/sec)* • *Shallow stream relative to vertical debris dimension ($D<0.5L_{10}$)* • *Narrow streams relative to horizontal debris dimension.($W<L_{10}$)* • *Streams meander with frequent constrictions/snag points.* • *Low temporal variability in maximum stream flows*	

BLOCKAGE ASSESMENT FORM

Australian Rainfall & Runoff

SITE BASED DEBRIS POTENTIAL 1%AEP (HML) - *for the selected debris type/size arriving at the site*

Debris Potential	Combinations of the Above (any order)	Notes
DP$_{High}$	HHH or HHM	
DP$_{Medium}$	MMM or HML or HMM or HLL	MMM
DP$_{Low}$	LLL or MML or MLL	Eg. MML, therefore DP$_{Low}$ selected

AEP ADJUSTED SITE DEBRIS POTENTIAL (HML) - *for the selected debris type/size*

Event AEP	At Site 1% AEP Debris Potential			AEP Adjusted At Site Debris potential
	DP$_{High}$	**DP$_{Medium}$**	**DP$_{Low}$**	
AEP > 5% *(frequent)*	Medium	Low	Low	Eg. Low
AEP 5% - AEP 0.5%	High	Medium	Low	Eg. Low
AEP < 0.5% *(rare)*	High	High	Medium	Eg. Medium

Debris Blockage

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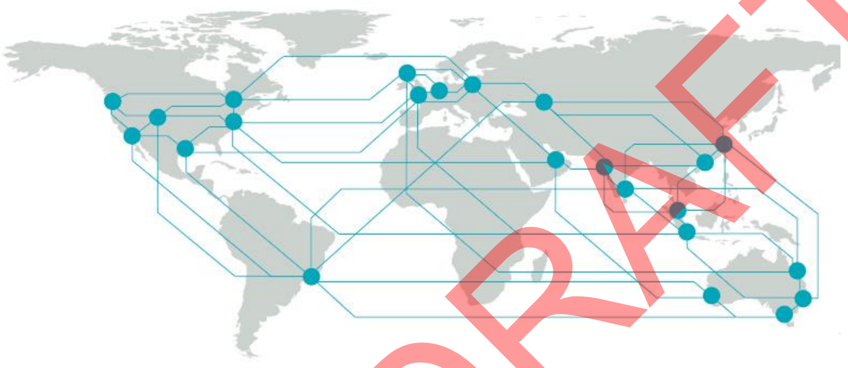

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Level 4
4-14 Foster Street
Surry Hills
NSW 2010
Australia
+61 2 8960 7755

Registered in Australia
Registered no. 010 830 421
Registered office
Level 5, 348 Edward Street,
Brisbane QLD 4000 Australia

For your local BMT office visit www.bmt.org

Contact us

enquiries@bmtglobal.com

www.bmt.org

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