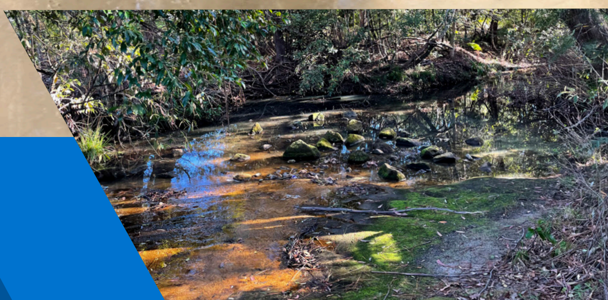
Central Coast Council

SOMERSBY AND KARIONG CATCHMENTS OVERLAND FLOW FLOOD STUDY



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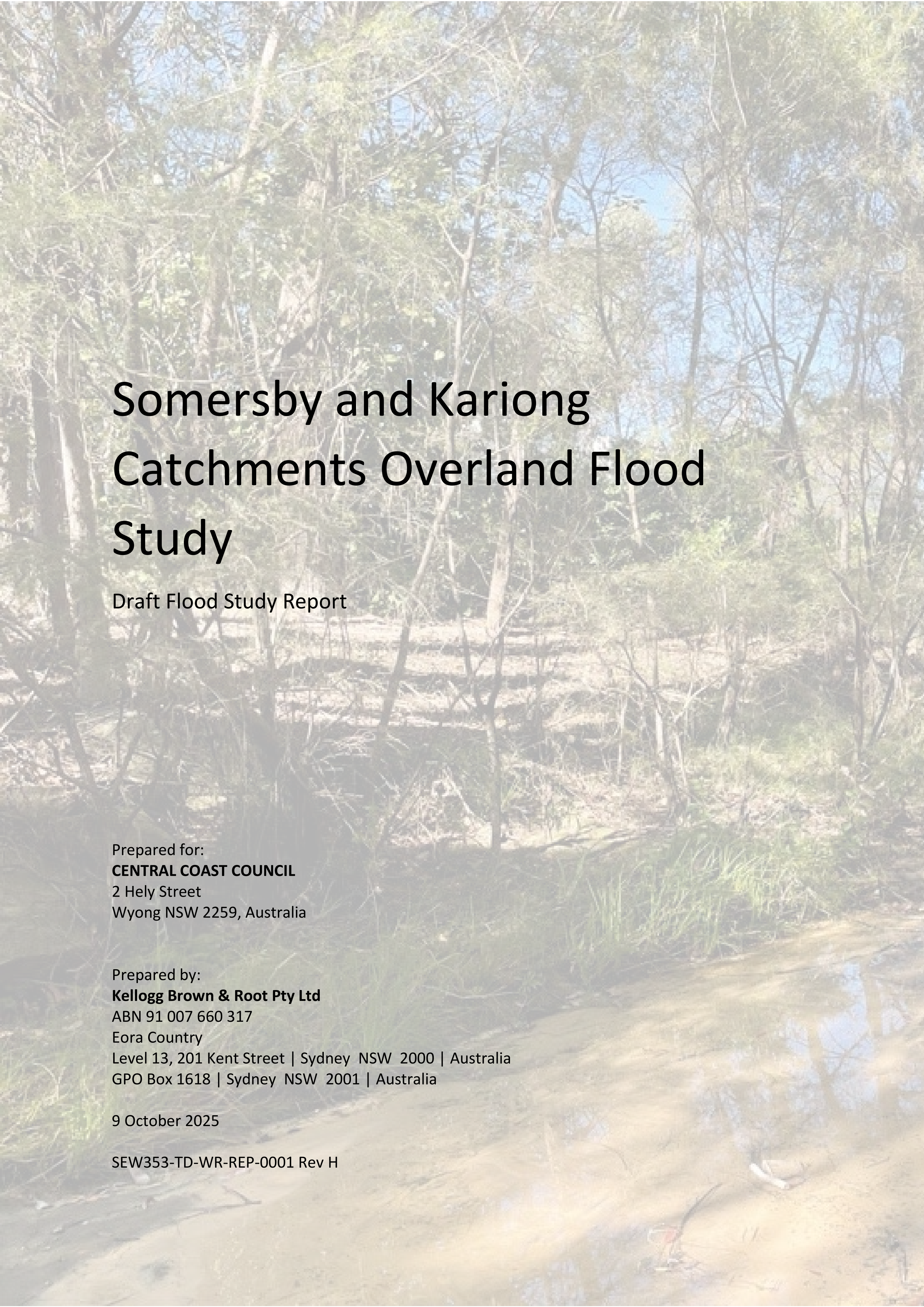

Somersby and Kariong Catchments Overland Flood Study

Draft Flood Study Report

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Revision History

Revision	Date	Comment	Signatures			
			Originated by	Checked by	Technical Approval	Project Approval
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Contents

List of Figures

List of Tables

List of Acronyms

AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ARI	Average Recurrence Interval
ARR	Australian Rainfall and Runoff
BOM	Bureau of Meteorology
DCP	Development Control Plan
DEM	Digital Elevation Model
DCCEEW	Department of Climate Change, Energy, the Environment and Water
CCC	Central Coast Council
FPA	Flood Planning Area
FRM	Flood Risk Management
GCC	Gosford City Council
GIS	Geographic Information System
LEP	Local Environmental Plan
LiDAR	Light Detection and Ranging
LGA	Local Government Area
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
RoG	Rainfall on Grid
TUFLOW	Two-Dimensional Unsteady Flow

Glossary

Terms and definitions as provided and/or interpreted from the NSW Flood Risk Management Manual 2023.

Term	Abbreviation	Definition
Annual Exceedance Probability	AEP	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage.
Australian Height Datum	AHD	A common national surface level datum often used as a referenced level for ground, floor and flood levels.
Average recurrence interval	ARI	The long-term average number of years between the occurrence of a flood equal to or larger in size than the selected event.
Defined flood event	DFE	The flood event selected as a general standard for the management of flooding to development.
Development Control Plan	DCP	The DCP provides detailed planning and design guidelines to support the planning controls in the Local Environmental Plan (LEP) and is prepared and adopted by Councils.
Flood		A natural phenomenon that occurs when water covers land that is normally dry. It may result from coastal inundation (excluding tsunamis) or catchment flooding, or a combination of both.
Flood (hydrologic and hydraulic) modelling		Hydrologic and hydraulic computer models to simulate catchment processes of rainfall, runoff, stream flow and distribution of flows across the floodplain or similar.
Flood Awareness		An appreciation of the likely effects of flooding, and a knowledge of the relevant flood warning, response and evacuation procedures facilitating prompt and effective community response to a flood threat.
Flood Constraints		Key constraints that flooding places on land.
Flood Damage		The tangible (direct and indirect) and intangible costs (financial, opportunity costs, clean-up) of flooding.
Flood Evacuation		The movement of people from a place of danger to a place of relative safety, and their eventual return.
Flood Impact and Risk Assessment	FIRA	A study to assess flood behaviour, constraints and risk, understand off-site flood impacts on property and the community resulting from the development, and flood risks to the development and its users.
Flood Plan (local or state)	Local (LFP)	A subplan of an Emergency Management plan that deals specifically with flooding; they can exist at state, zone and local levels.

Term	Abbreviation	Definition
Flood Planning Level	FPL	The combination of the flood level from the DFE and freeboard selected for FRM purposes.
Flood Prone Land		Land susceptible to flooding by the PMF event.
Flood Risk		Risk is based on the consideration of the consequences of the full range of flood behaviour on communities and their social settings, and the natural and built environment.
Flood Risk Management	FRM	The management of flood risk to communities.
Flood Risk Management Manual	FRMM	Guidance manual for the practice of Floodplain Risk Management within NSW that supports the delivery of the Flood Prone Land Policy through the Floodplain Management Program.
Flood Storage Areas		Areas of the floodplain that are outside floodways which generally provide for temporary storage of floodwaters during the passage of a flood and where flood behaviour is sensitive to changes that impact on temporary storage of water during a flood.
Flood Study		A comprehensive technical investigation of flood behaviour undertaken in accordance with the principles in the Flood Risk Management Manual and consistent with associated guidelines. A flood study defines the nature of flood behaviour and hazard across the floodplain by providing information on the extent, level and velocity of floodwaters, and on the distribution of flood flows considering the full range of flood events up to and including extreme events, such as the PMF.
Flood Warnings		Warnings issued when there is more certainty that flooding is expected, are more targeted and are issued for specific catchments.
Floodplain		Equivalent to flood prone land.
Floodways		Areas of the floodplain which generally convey a significant discharge of water during floods and are sensitive to changes that impact flow conveyance. They often align with naturally defined channels.
Flow		The rate of flow of water measured in volume per unit time; for example, cubic metres per second (m^3/s).
Freeboard		A factor of safety typically used in relation to the setting of minimum floor levels or levee crest levels.
Frequency		The measure of likelihood expressed as the number of occurrences of a specified event in a given time.
FRM Measures		Measures that can reduce flood risk.
FRM Options		The FRM measures that might be feasible for the management of a particular area of the floodplain.

Term	Abbreviation	Definition
FRM Plan		A management plan developed in accordance with the principles in the Flood Risk Management Manual and its supporting guidelines.
FRM Study		A management study developed in accordance with the principles in the Flood Risk Management Manual and its supporting guidelines.
Future Flood Risk		The risk future development and its users are exposed to as a result of its location on the floodplain.
Hazard		A source of potential harm or conditions that may result in loss of life, injury and economic loss due to flooding.
Hydraulics		The study of water flow in waterways and flow paths; in particular, the evaluation of flow parameters such as water level and velocity.
Hydrology		The study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
Likelihood of Occurrence		The likelihood that a specified event will occur.
Local Environment Plan	LEP	LEP's guide planning decisions for local government areas.
NSW Floodplain Management Program	The Program	The NSW Government's program of technical support and financial assistance to local councils to enable them to understand and manage their flood risk.
Prevention, preparedness, response and recovery		Involves: • prevention: to eliminate or reduce the level of the risk or severity of emergencies • preparedness: enhances the capacity of agencies and communities to cope with the consequences of emergencies • response: to ensure the immediate consequences of emergencies to communities are minimised • recovery: measures that support individuals and communities affected by emergencies in the reconstruction of physical infrastructure and restoration of physical, emotional, environmental and economic wellbeing.
Probability		A statistical measure of the expected chance of a flood.
Rainfall Intensity		The rate at which rain falls, typically measured in millimetres per hour (mm/h).
Residual Flood Risk		The risk to the existing and future community that remains with FRM, EM and land-use planning measures in place to address flood risk.
Risk		'The effect of uncertainty on objectives' (ISO 2018).

Term	Abbreviation	Definition
Runoff		The amount of rainfall that ends up as streamflow, also known as rainfall excess.
State Environmental Planning Policy	SEPP	Policies which guide planning for what development can occur on specific land in a state-wide context.
Scenario		A scenario may relate to current, historical or assumed future floodplain, catchment and climate conditions.
Velocity		The speed and direction of floodwaters, measured in metres per second (m/s).

Executive Summary

Central Coast Council (CCC) commissioned Kellogg Brown & Root (KBR) to undertake a comprehensive flood study for the Somersby and Kariong catchments. The primary objective of this study was to develop hydrologic and hydraulic models to assess flood risk across past, existing, and future catchment conditions. This report details flood modelling methodologies and mapping undertaken in line with industry standards. The approach to this study is in line with the Australian Rainfall and Runoff (ARR) Version 4.1 guideline, also known as Australian Rainfall and Runoff 2019. It Is noted that the ARR 4.2 guideline was released during the flood study program however the design event modelling was completed prior to its release. This study fulfills the objectives of the Flood Study phase of the New South Wales Government's Floodplain Management Process and provides a basis for future flood risk management processes.

As a part of this study, community consultation was undertaken providing multi-path communication between CCC, KBR, NSW State Government, State Emergency Services as well as the community. The community consultation included media releases, a project-specific website, community questionnaires, letters regarding the Flood Planning Area, Public Exhibition and a community drop-in session (the latter two elements are yet to be completed).

In conjunction with a detailed data review, KBR incorporated outcomes from community consultation to ensure the adopted modelling methodology reflected the needs and experiences of the local community. A combined hydrologic and hydraulic model was developed for the study area using the TUFLOW software suite, tailored to address the specific characteristics of the Somersby and Kariong catchments.

Hydrologic and hydraulic model calibration and validation were performed using historical flood events and community consultation data to ensure accuracy and reliability. Design flood events (20%, 10%, 5%, 2%, 1 in 100, 1 in 200 and 1 in 500 Annual Exceedance Probability (AEP) events) were simulated across multiple scenarios, including past, existing, and future catchment conditions, in accordance with the ARR 2019 guidelines. Additionally, the Probable Maximum Flood (PMF) event was modelled to assess extreme flood risks.

Sensitivity analyses were conducted on key model parameters to identify their influence on flood behaviour, while climate change assessments were undertaken to evaluate the potential impacts of increased rainfall intensities and future development within the catchment. A Flood Emergency Response Classification (FERC) assessment was also completed to identify areas requiring targeted emergency response measures.

The study further included the simulation and analysis of a future development scenario to assess the cumulative impacts of ongoing development within the catchments. These results provide a platform to guide CCC in flood risk management, future planning, and emergency response strategies.

The study has identified flooding associated with overland flow to be the dominant flooding mechanism within the study area. The relatively short catchment critical duration coupled with the rapid response times of the catchments suggest that the study area is at most risk to short duration and high intensity rainfall events. Overall, Somersby and Kariong is a relatively low risk catchment, with flooding generally constrained to flood storage basins and waterways. However, outcomes of the study have demonstrated that the study area is sensitive to stormwater infrastructure blockages. These impacts are further exacerbated with the increased rainfall intensities associated with the future changing climate.

The key recommendations/outcomes of the study are as follows:

- Integration of Study Outputs into Future Planning: The outputs of this study are to inform subsequent Floodplain Risk Management Studies (FRMS) and guide CCC's planning policies, including the review of Flood Planning Levels (FPL) and Flood Planning Areas (FPA).
- Refinement of Emergency Response Planning: The detailed information on flood behaviour can be used for further collaboration with emergency services to refine emergency response strategies. This includes improving transparency and enhancing local evacuation planning and flood warning systems.
- Future Climate Change Modelling: Climate change assessments can readily be updated to new guidelines and rainfall projections. This will ensure flood models remain current and reflect best practices in assessing projected climate impacts.
- Assessment of Future Development Scenarios: The impacts of future development scenarios on flood behaviour provides CCC with insight into the cumulative impacts of ongoing development and to support sustainable planning decisions.

This study provides CCC with reliable hydrologic and hydraulic modelling outputs to guide flood risk management initiatives, future planning strategies, and emergency preparedness efforts within the Somersby and Kariong catchments. The findings further enable CCC to make informed, evidence-based decisions to reduce the risks and impacts of flooding on the local community.

1 Introduction

The Somersby and Kariong Catchments Overland Flood Study was prepared for Central Coast Council (CCC). The study area forms part of the Central Coast Local Government Area (LGA), located 50 km north of Sydney. The Somersby and Kariong catchments cover an area of approximately 66.5 km^2 and primarily drain west towards the Hawkesbury River with a small area draining east to Brisbane Waters.

A ridgeline traverses through the study area to which a majority of development (residential and industrial) sits in close proximity. As such, the catchments experience overland flooding caused by short and intense rainfall events. CCC has previously developed flood models and undertaken drainage assessments across the catchments, however there is a lack of flood information to provide an in-depth understanding of the existing flood behaviour across the study area. In addition, a portion of the study area has been identified as a 'regionally significant growth area' as part of the Central Coast Regional Plan 2041 (DPE, 2022), highlighting the need to define the existing overland flooding behaviour to support planning procedures.

CCC engaged KBR to undertake the Somersby and Kariong Catchments Overland Flood Study to define the existing and future overland flooding across the study area. This in-depth understanding of flooding behaviour will, in turn, facilitate more effective flood risk management within the study area. This study, including the models developed, will be used in the assessment of development applications, provide information to emergency services, drainage assessments and other future planning decisions.

This study has been completed as a part of the NSW Government Floodplain Management Program, and has been funded by CCC, with both financial and technical support from the NSW Department Climate Change, Energy, Environment and Water (DCCEEW).

1.1 THE FLOODPLAIN MANAGEMENT PROCESS

As detailed in the NSW Flood Risk Management Manual (2023) (herein referred to as the Manual), the primary objective of the NSW Governments Flood Prone Land Policy is to reduce the impact of flooding and flood liability to landowners and occupiers of the floodplain and reduce the damages and losses resulting from floods. As with local land use planning processes, the responsibility for the management of flood liable land rests with local government/councils with support from DCCEEW.

The Manual defines the NSW Floodplain Management Process which includes five sequential steps as detailed in **Figure 1-1.** This study constitutes the ‘Flood Study’ step of the process and has been undertaken to define the existing flood risk and provide the basis for the planning studies in later steps.

While the Floodplain Management Process has been undertaken in various forms within the catchments, the purpose of this study is to revise the understanding of flooding in line with best practice methods and the changing nature of the catchments to enable a review of the floodplain risk management plan and associated options for the catchments in their entirety.

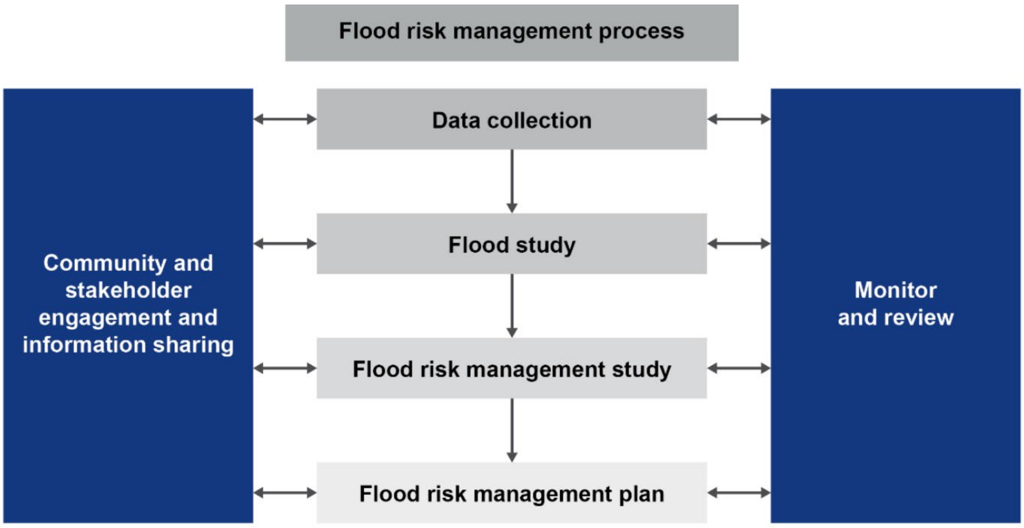


Figure 1-1: Steps of the Floodplain Management Process (extracted from Figure 2 of the Flood Risk Management Manual, 2023)

1.2 STUDY OBJECTIVES

The primary objective of this Flood Study is to define the flood behaviour under historical, existing and future conditions (including potential impacts of climate change) in the Somersby and Kariong study area, for a full range of design flood events. The study will provide information on flood levels, depths, velocities, flows, hydraulic categories and provisional hazard categories. Specifically, the study incorporates:

- Compilation and review of existing information relevant to the study and acquisition of additional data including survey as required.
- A community consultation and participation program to:
  - Identify local flooding concerns.
  - Collect information on historical flood behaviour.
  - Advise on the outcomes of the flood study and flood behaviour predictions.
  - Engage the community in the on-going floodplain management process.
- Development and calibration of suitable hydrological and hydraulic models.
- Determination of design flood conditions for a range of design events, including the 20%, 10%, 5%, 2%, 1 in 100, 1 in 200 and 1 in 500 Annual Exceedance Probability (AEP) events, and the Probable Maximum Flood (PMF).
- Assessment of the potential impact of climate change on the 1 in 100 AEP design flood event.
- The models and results produced in this study are intended to:
  - Outline the flood behaviour within the study area to aid in CCC's management of flood risk.
  - Form the basis for a subsequent floodplain risk management study, where detailed assessment of flood mitigation options and floodplain risk management measures will be undertaken.

1.3 REPORT STRUCTURE

This study is structured as follows:

- Section 1 – Introduction to the report and its purpose in the Floodplain Management Process.
- Section 2 – Summary of available data.
- Section 3 – Community consultation.
- Section 4 – Summary of hydrological and hydraulic model development.
- Section 5 – Model calibration and validation.
- Section 6 – Design modelling approach.
- Section 7 – Design modelling results.
- Section 8 – Model sensitivity assessment.
- Section 9 – Model verification
- Section 10 – Floodplain management planning
- Section 11 – Conclusions
- Section 12 – References.

1.4 STUDY AREA DESCRIPTION

The study area contains the suburbs of Somersby and Kariong as shown in **Figure 1-3**, and forms a part of the Mooney Mooney Creek catchment. The study area is comprised of several overland subcatchments that contribute flows to a number of major tributaries in the area, including Little Mooney Mooney Creek, Robinson Creek, Floods Creek, Piles Creek and Mooney Mooney Creek itself. The study area also contains a small section of the upper Narara Creek catchment that drains to Brisbane Water. The study area covers approximately 66.5 km^2.

The study area is divided by a natural ridgeline between the Piles Creek and Floods Creek subcatchments. The Central Coast Highway and the Pacific Motorway also cut across the Kariong upper catchment, acting as major hydraulic controls.

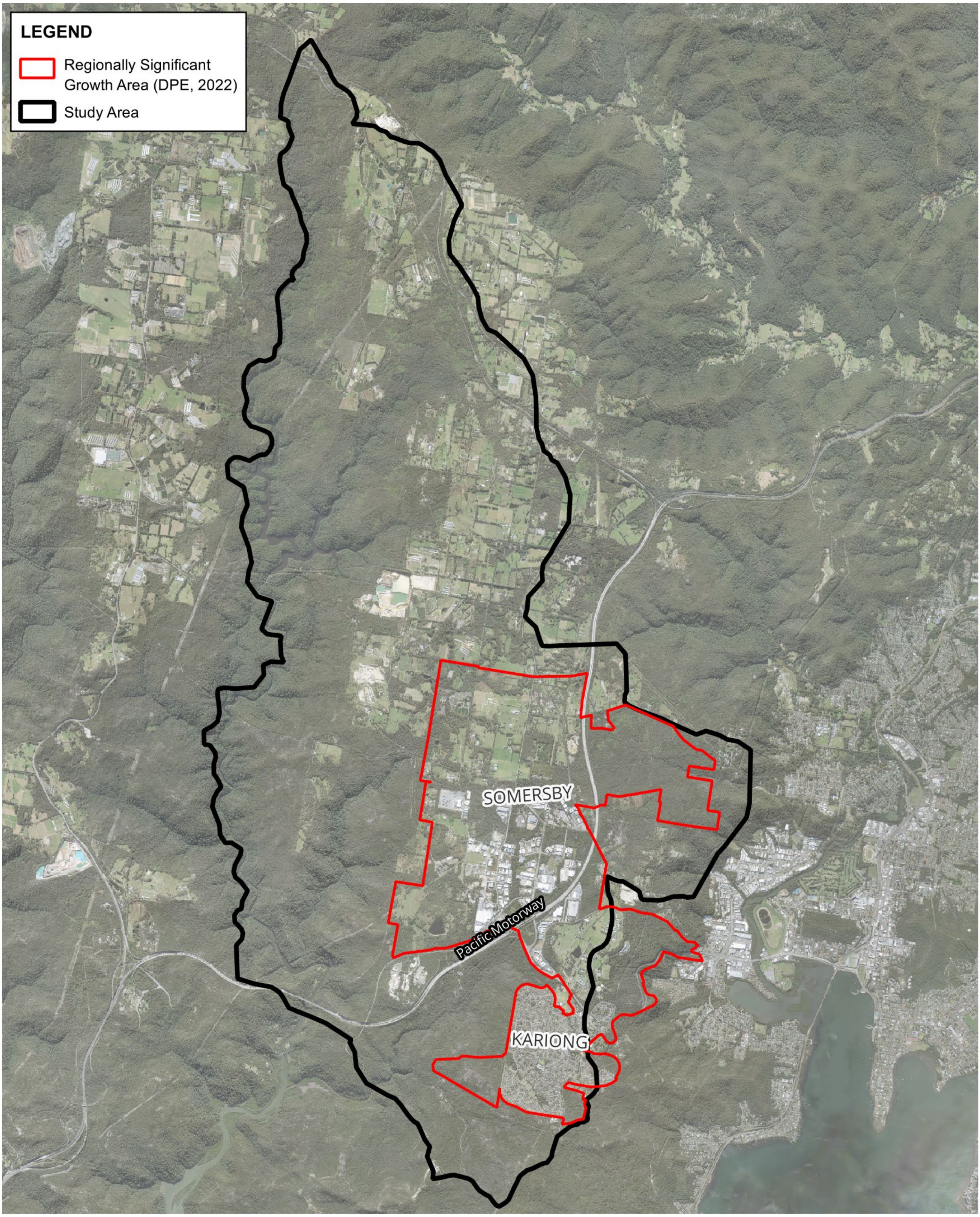
Figure 1-4 shows the study area topography and the tributaries local to the area. The study area extent follows a major ridgeline along the eastern boundary, with the highest point located in the north near the intersection of Peats Ridge Road and Wisemans Ferry Road at 309 m AHD. The topography generally grades south-west toward Mooney Mooney Creek in Brisbane Water National Park, which ultimately drains to Broken Bay via the Hawkesbury River. Most of the development is located within the relatively flat upper catchment. The topography quickly descends from the flat upper catchment into heavily vegetated bushland with steep incised valleys.

The Kariong study area is primarily characterised by residential land use in the upper catchment. This is interspersed with some commercial properties and educational institutions including Kariong Public School, Kariong Mountains High School and Ngaruki Gulgul Central School.

There are several green spaces, some of which also serve as flood storage basins. These basins include Peppermint Park and Kariong Oval which are previous flood mitigation works.

The upper catchment in the Somersby study area is primarily characterised by a developed industrial precinct in the south and primary production land use with large open green spaces in the north. Heavily vegetated trunk drainage channels are interspersed throughout the industrial precinct which convey flows to Piles Creek, which then flow under the Pacific Motorway to Mooney Mooney Creek.

The study area contains regionally significant growth areas as identified in the Central Coast Regional Plan 2041 (DPE, 2022). These are generally located in the developed upper reaches of the catchment, spanning from the Kariong residential precinct through to the Somersby Industrial and Primary Production areas further north. The extent of the regionally significant growth areas relevant to the study area is presented in **Figure 1-2**.



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Regionally Significant Growth Areas

Figure: 1-2

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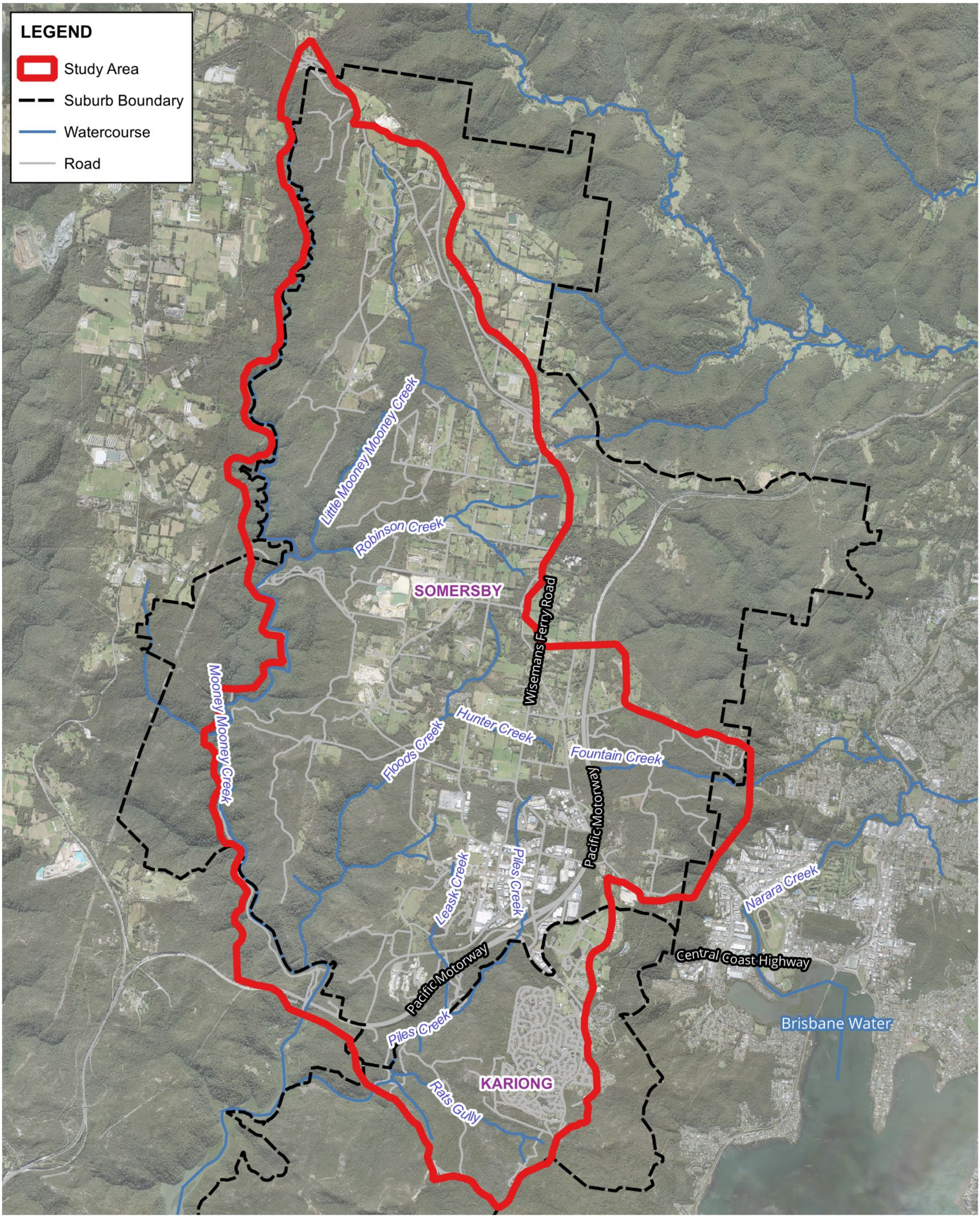

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Study Area Locality

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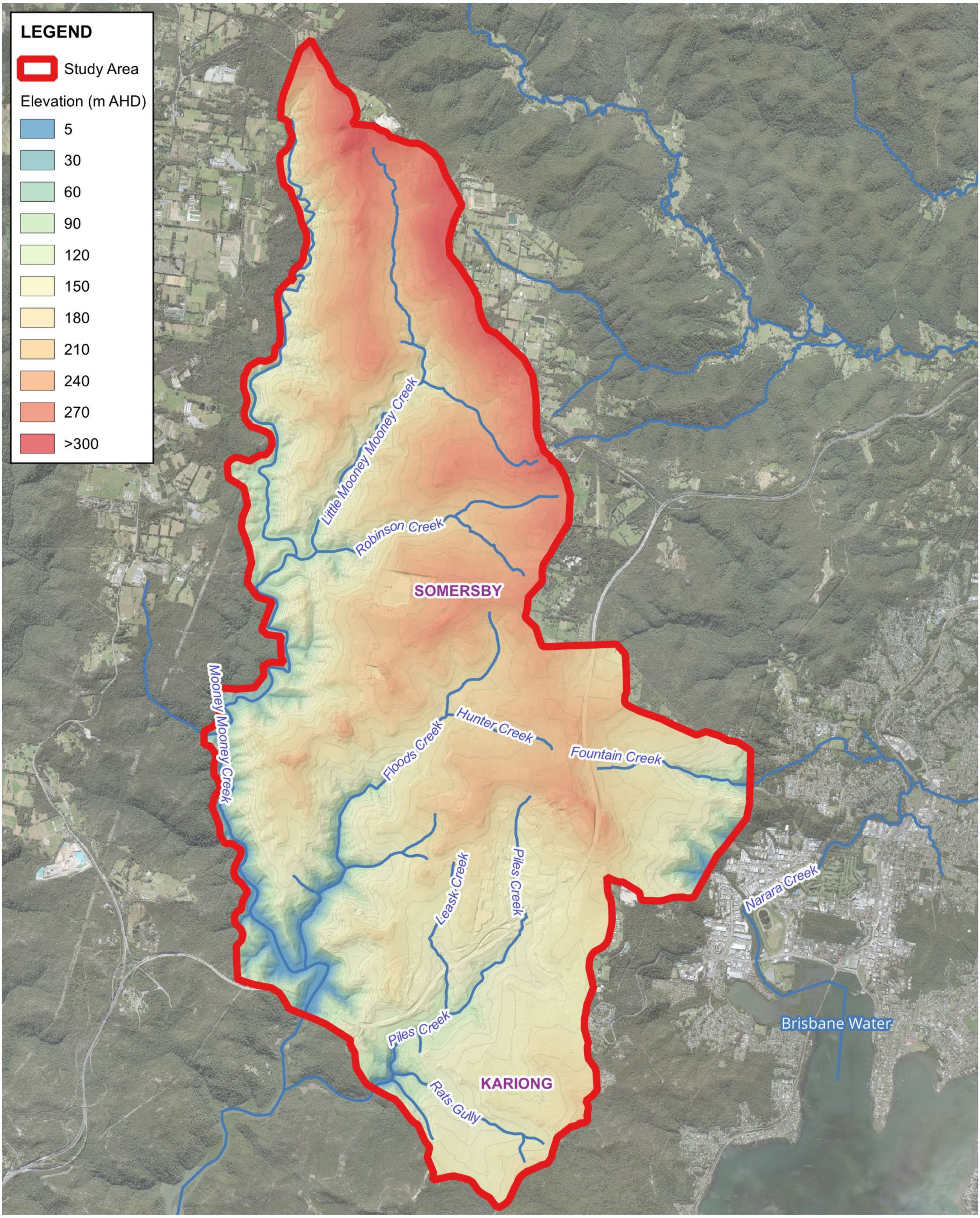

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Catchment Topography and Tributaries

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2 Compilation and Review of Available Data

The compilation and review of data were undertaken at the onset of the study in order to consolidate all relevant information and identify any gaps in data. The collection of data included reviewing information provided by CCC as well as other sources. A summary of the data reviewed for this study includes:

- Previous Studies undertaken within the study area or neighbouring catchments,
- Topographic Data,
- GIS Data,
- Rainfall Data; and
- Historical Flood Data.

2.1 REVIEW OF PREVIOUS STUDIES/INVESTIGATIONS

2.1.1 Kariong Trunk Drainage Review - Willing and Partners Consulting Engineers – July 1985

Willing and Partners Consulting Engineers (WPCE) was engaged by the Land Commission of NSW to undertake a review of the trunk drainage system in Development Project 99, Precinct 1 at Kariong and propose mitigation options. The relevant catchment map for the study area provided in the report is shown in **Figure 2-2**. This map also shows the existing trunk drainage at the time of the study, including detention Basins A and B upstream of Langford Drive at Guildford Street. **Figure 2-1** shows the location of these basins with 2019 aerial imagery.

The project was undertaken in response to the 8 November 1984 flood event, during which the local stormwater drainage assets near Tudawali Crescent and Rafferty Close surcharged, resulting in the inundation of some surrounding properties.

To assess the existing stormwater drainage, a RAFTS hydrologic model was developed to estimate design rainfall runoff and route it through the existing detention basins and stormwater infrastructure.

Two mitigation options were proposed:

- Combining Basin A and Basin B into a single detention basin and upgrade the outflow pipe to 1050 mm diameter RCP.
- Restricting outflow from the existing detention Basins to prevent surcharging of the downstream stormwater drainage pits and diverting flow from Milyerra Road to a different catchment so that flow to the basins is reduced.

The outflow restriction has been constructed following subsequent studies.

Figure 2-1: Location of Basin A and Basin B Reviewed in the Kariong Trunk Drainage Review (1985)

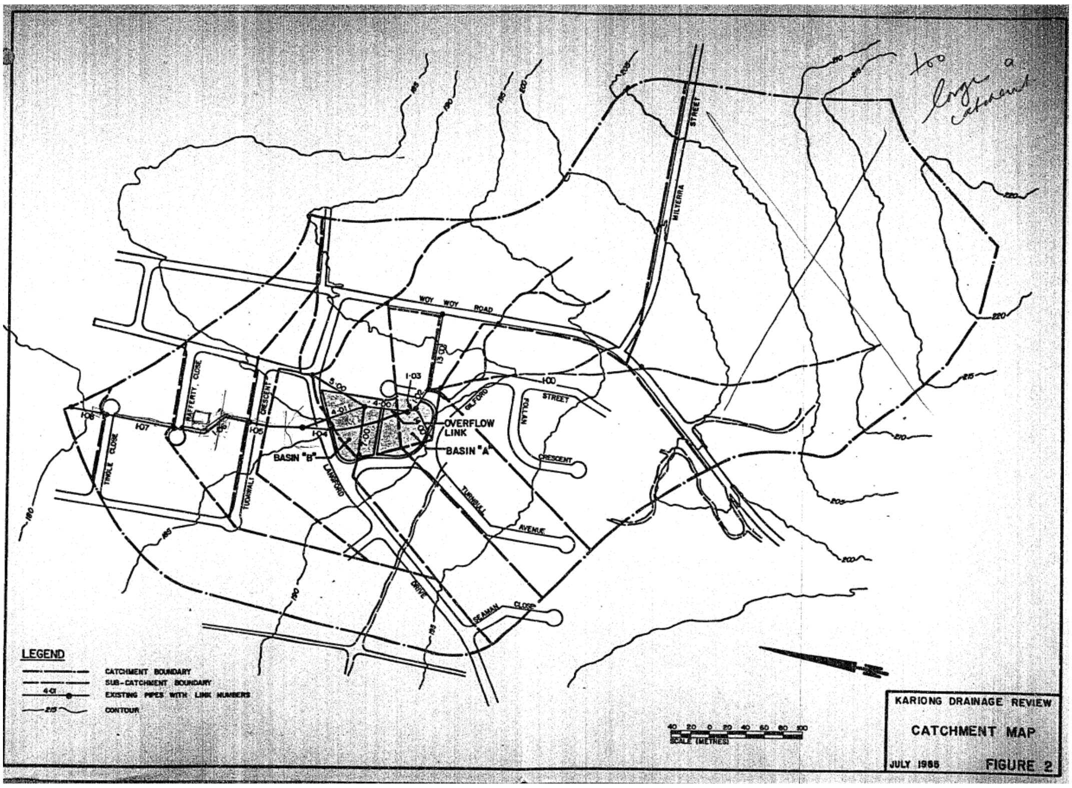


Figure 2-2: Map of Catchment Local to the Study Area - Extracted from the Kariong Trunk Drainage Review Report (Willing and Partners Consulting Engineers, 1985)

2.1.2 Kariong Trunk Drainage Upgrading - Willing and Partners Consulting Engineers – September 1986

WPCE was engaged by the NSW Department of Housing to build on the findings of the previous Kariong Trunk Drainage Review (Willing and Partners Consulting Engineers, 1985). Using the same modelling methodology as the previous 1985 review, the following outcomes were obtained:

- Restricting the outflow from Basin B using a 525 mm diameter pipe was sufficient to achieve the desired outcome. Increasing basin capacity was assessed to be unnecessary with this change.
- Restricting Basin B outflow using the 525 mm diameter pipe was estimated to result in ponding in the basin system less than 5 times per year.
- Proposed works to direct flows spilling from Basin B to Arunta Avenue included:
  - Relocating and raising the Basin B spillway.
  - Providing an embankment on the north side of Langford Drive.
  - Installing speed humps at the entrance to Rafferty Close and Tudawali Crescent to prevent the redirected flow on Arunta Avenue from causing surcharging in the local drainage pits of these two minor roads.
- In the scenario that all the above mitigation works are adopted, the basin system was estimated to prevent surcharging on Tudawali Road and not overtop the Basin B spillway in events up to and including the 10% AEP event.
- Replacing the drainage line between Rafferty Close and Tudawali Crescent with a more hydraulically efficient configuration, in addition to the above works, it was also estimated to prevent the local drainage pits on Tudawali Crescent from surcharging up to and including 5% AEP event.
- The Milyerra Road detention basin was estimated to require approximately 8,000 m^3 of storage to protect the downstream development from the 90 minute 1 in 100 AEP flood. However, it was noted that insufficient pit inlet capacity in the 90 minute 1 in 100 AEP storm may still lead to flooding. It was also noted that a larger storage volume for this proposed basin may be required in the case of a longer duration storm, in which storage effects become dominant over peak discharge effects.
- Constructing an additional detention basin on Milyerra Road, instead of diverting flows to the adjacent catchment as proposed in the previous review (Willing and Partners Consulting Engineers, 1985).

2.1.3 Project 99 - Kariong Northern Basin System - Nichols, Watts and Associates Pty. Ltd. - November 1987

Nichols, Watts and Associates Pty. Ltd. (NWA) was engaged by the Land Commission of NSW to undertake a design of a basin system located to the north-west of Curringa Road. The purpose was to ensure that proposed upstream development would not result in an increase in 1 in 5-year (~20% AEP event) runoff discharge from the catchment.

Basins 1 and 2 were designed to be suitable for active recreation, while Basin 3 was designed to be a ‘wet’ basin that makes use of an existing reservoir. The locations of these basins are shown in **Figure 2-3**.

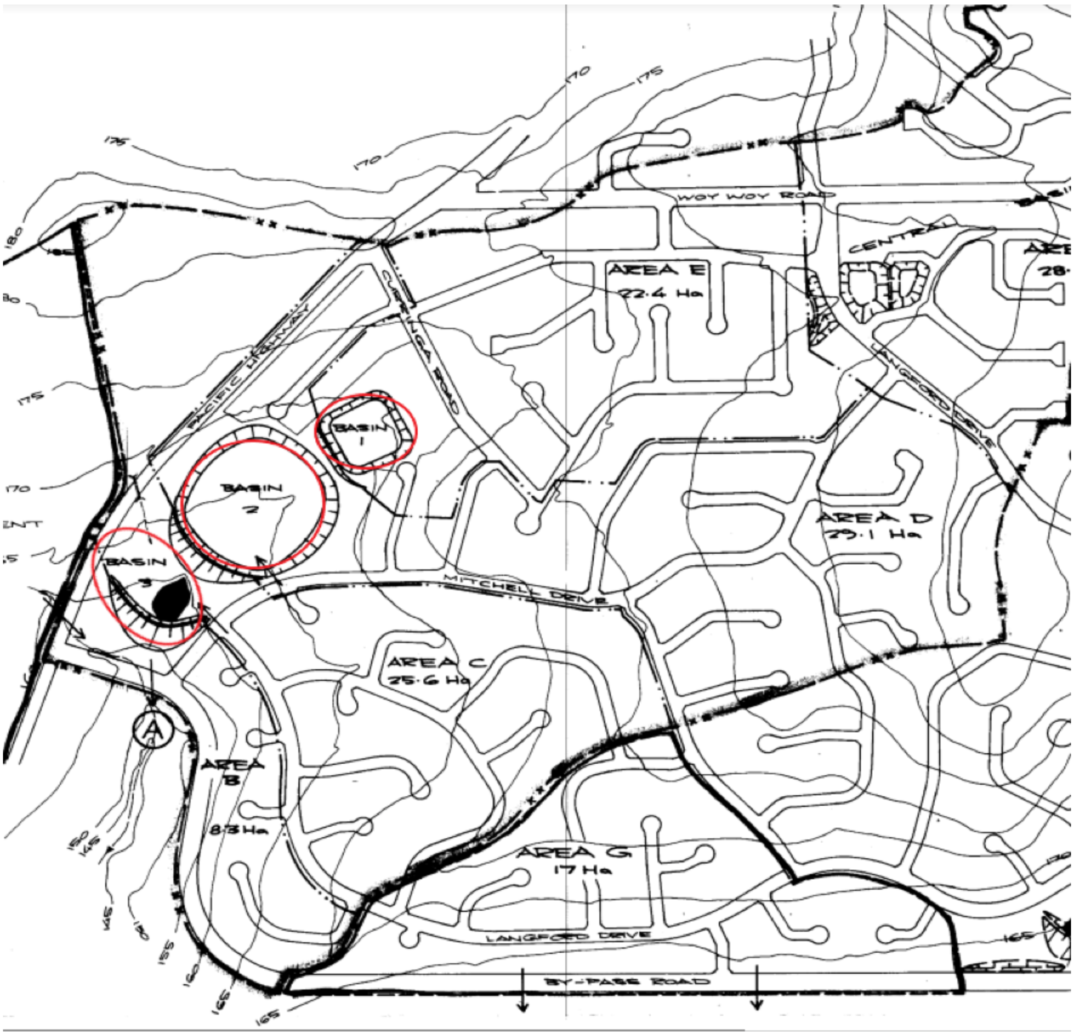


Figure 2-3: Location of the Northern Kariong Basin System - Extracted from Kariong Northern Basin System Report (Nichols, Watts and Associates Pty. Ltd., 1987) and Annotated in Red

2.1.4 Kariong Upper Catchment Drainage – Willing and Partners Consulting Engineers – May 1990

Following the previous three investigations, WPCE was engaged by the Department of Housing to update the previous hydrology to comply with the updated Australian Rainfall and Runoff (ARR) guidelines (Institution of Engineers, Australia, 1987). The purpose of this was to ensure the appropriate flood mitigation measures were being adopted.

The review found no change to the mitigation works recommended in the latest Kariong Trunk Drainage Upgrading study (Willing and Partners Consulting Engineers, 1989).

2.1.5 South Somersby Trunk Drainage Study – Kinhill Engineers Pty Ltd – July 1990

Kinhill Engineers Pty Ltd (Kinhill) was engaged by the Department of Planning, Housing and Lands, and Gosford City Council (GCC), to propose an upgraded trunk drainage system that would accommodate additional flows from urbanisation in the study area while minimising impact to the surrounding areas. For the purposes of this study, the trunk drainage system consisted of detention basins, and the existing natural watercourses. Local stormwater drainage was not considered in the study.

Flow from the study area was assessed with two RORB hydrological models for existing and post-development scenarios. Post-development flows were simulated to be higher than the existing scenario. Detention basins were proposed that reduced the post-development scenario flows to existing flows.

The study proposed three detention basins on Piles Creek upstream of Somersby Falls Rd, as well as six others in the Narara Creek catchment to the East. **Figure 2-4** shows a map of the locations of the proposed detention basins. Proposed basins 1, 2 and 3 fall within the Somersby industrial precinct, and are within the study area for this study. The basins have not been subsequently constructed.

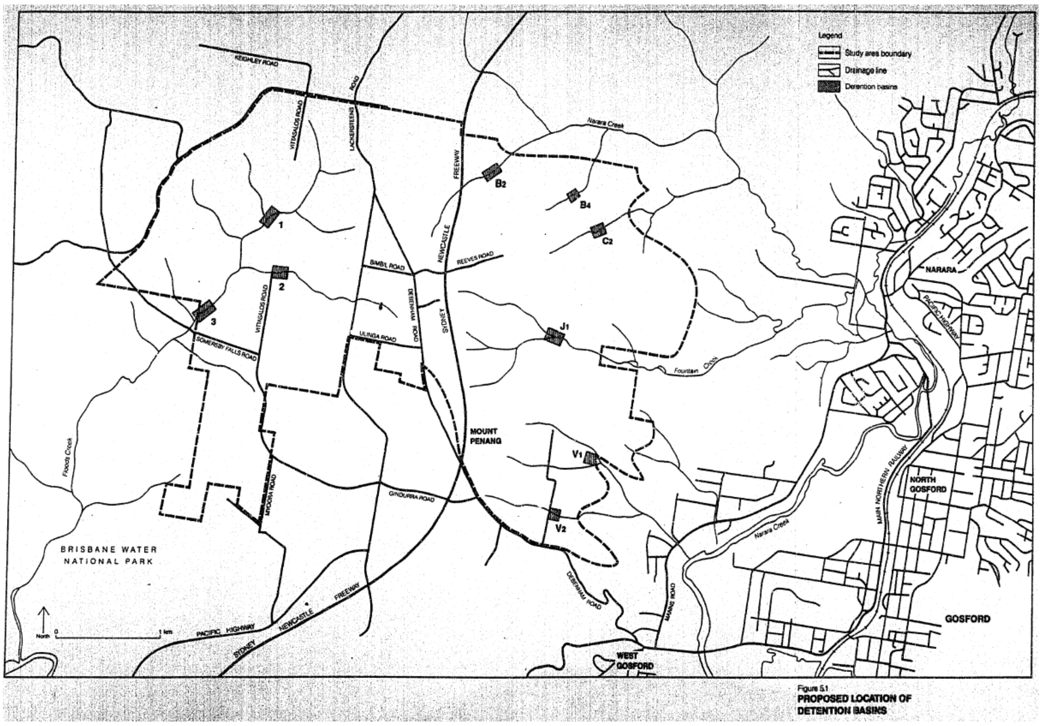


Figure 2-4: Map of the Proposed Detention Basin Locations - Extracted from the South Somersby Trunk Drainage Study Report (Kinhill Engineers Pty Ltd, 1990)

2.1.6 Somersby Drainage Study – Gutteridge Haskins & Davey – November 1994

Gutteridge Haskins & Davey (GHD) was engaged by GCC to undertake the following for the trunk drainage system in the Somersby Industrial Estate:

- Determine the size of drainage reserves required to contain the 100-year ARI flood extent in the Estate.
- Design sediment control measures for stormwater leaving the Estate.
- Detailed design of road stormwater drainage to convey flow to major drainage channels.

To determine flood extents at cross sections along the length of the water courses throughout the Estate, a RAFTS hydrologic model was used to simulate rainfall runoff and provide inflows to a HEC-2 hydraulic model.

This study found that flood extents ranged between 5 m to 135 m along major drainage channels in the Estate. It also found that where these channels were crossed by road hydraulic controls, the 100-year ARI flows generally exceed the existing hydraulic structure capacity and overtop the road.

2.1.7 Kariong Area Drainage Study – AWT Engineering – January 2003

AWT Engineering was engaged by GCC to identify causes and mitigation measures for existing stormwater drainage issues in the Kariong catchment area.

A DRAINS model was used to estimate design peak flows to the existing drainage system, and the flow capacity of the existing drainage system. Additionally, drainage asset inspections were undertaken to determine the extent of structural defects. This informed the recommended mitigation works and associated costing to address existing stormwater flooding issues.

The study found that the existing drainage system generally met GCC's pipe drainage standards. However, in the lower reaches of the catchment, excess overland flow that cannot be conveyed by the existing drainage system generally has an unsafe velocity depth product.

A range of mitigation works were considered, including:

- Increasing size or number of culverts
- Extending drainage lines
- Increasing the number of stormwater pits
- Constructing new drainage lines.

Following a phase of community consultation, the cost of constructing the mitigation measures was estimated to cost approximately $1.2M. Nine upgrades were undertaken by CCC, including maintenance and repair of the current stormwater infrastructure, increasing the capacity of the existing stormwater network and the construction of a retarding basin in Jarrah Park.

2.1.8 Updated Narara Creek Flood Study – Golder – July 2018

Golder was engaged by CCC to undertake a review and update of existing Narara Creek flood studies. The update involved building a new flood model of the entire Narara Creek catchment, which previously had each of the major subcatchments modelled separately. It also involved calibrating the new model to the February 1990, February 1992 and June 2007 storm events.

The adopted modelling methodology was to use the RAFTS hydrologic modelling package to provide lumped hydrologic inflows to a TUFLOW hydraulic model.

The upper catchment terrain at the interface of this Updated Narara Creek Flood Study with the Somersby study area is characterised by heavily vegetated bushland with well-defined ridgelines and steep valleys. The study found that in this area, the flowpaths are steep with flood extents confined to the channel.

2.1.9 Brisbane Water Estuary Catchments Overland Flood Study – Cardno – May 2021

Cardno was engaged by CCC to undertake an overland flood study of the portion of the Brisbane Water estuary catchment that is within the CCC LGA. This catchment sits immediately adjacent to the Kariong study area (to the east), and conveys overland flow away from the study area towards the east.

The study utilised the XP-RAFTS modelling package to simulate lumped hydrologic inflows. These inflows were injected into a TUFLOW hydraulic model, which routed the runoff through the catchment to simulate flood behaviour. This model was calibrated to the March 2002, March 2014, April 2015 and March 2016 storm events.

The upper catchment terrain at the interface of the Brisbane Water Estuary Catchments Overland Flood Study with the Kariong study area is a well-defined ridgeline, with steep valleys. The study found that in this area, the flowpaths are steep with flood extents confined to the channel.

2.2 TOPOGRAPHIC DATA

Two high-resolution 1 m LiDAR datasets were available for the study area. The datasets including key attributes are summarised in **Table 2-1**. The 1 m 2020 ELVIS LiDAR was publicly available on the ELVIS data portal by Geoscience Australia and partially covers the mid to southern portion of the catchment where the majority of residential and industrial development is located. The 1 m LiDAR dataset provided by Central Coast Council (CCC) covers the entire study area.

Table 2-1 - Summary of the LiDAR Provided by CCC and 1 m LiDAR Available on ELVIS

LiDAR Dataset	Resolution	Year Captured	Vertical Accuracy	Horizontal Accuracy	Coverage
CCC LiDAR	1 m	2022	+-0.1 m	+-0.3 m	Entire study area
ELVIS LiDAR	1 m	2020	+-0.3 m	+-0.8 m	Partial study Area

KBR has undertaken a review of both topographic datasets. Three (3) profiles along key flowpaths are shown in **Figure 2-6** to **Figure 2-8.**

A comparison of elevations was also undertaken on a cell-by-cell basis where the two LiDAR datasets overlapped. The differences were calculated by subtracting the ELVIS LiDAR from the CCC LiDAR.

The following was observed in reviewing the profiles and difference mapping:

- Vegetated channels have generally been captured at lower elevations in the CCC LiDAR dataset when compared to the ELVIS LiDAR dataset. This difference is likely due to a difference in LiDAR accuracy, tinning and filtering approaches on the raw LiDAR data.
- Throughout the catchment, the LiDAR datasets generally align within 20 mm at key hydraulic controls such as storage basin spillways and road embankment crests. The ELVIS LiDAR typically represents the higher elevation.
- Filtering of flow obstructions such as bridges is a source of differences between the two datasets. For example, Piles Creek at Old Pacific Highway, the ELVIS LiDAR dataset represents the channel under the bridge structure whereas the CCC LiDAR dataset represents the bridge deck surface (refer to **Figure 2-6**).
- Similarly, the treatment of buildings in the filtering process is a source of differences between the datasets with larger differences in elevations around the building footprints.

Both topographic datasets were compared against 234 Permanent Survey Marks (PSMs) with ground surface elevations located throughout the catchment. Ground levels from the PSMs were found to be similar in elevation to both topographic datasets, with the variance between both datasets and the PSMs largely within ± 0.1 m. The CCC LiDAR and PSMs displayed a mean difference of 0.119 m and standard deviation of 0.69, whereas a mean difference of 0.045 m and standard deviation of 0.52 was found between ELVIS LiDAR and PSMs. The variance between both topographic datasets and the PSMs is shown in **Figure 2-5**.

The CCC LiDAR was adopted as the basis of the TUFLOW model for the following reasons:

- The CCC LiDAR dataset covers the entire study area for consistent representation.
- The CCC LiDAR dataset was the most recently sampled dataset.
- The CCC LiDAR has a superior reported vertical and horizontal accuracy.
- The CCC LiDAR has lower elevations in vegetated areas which is more likely representative of the ground level in these locations.

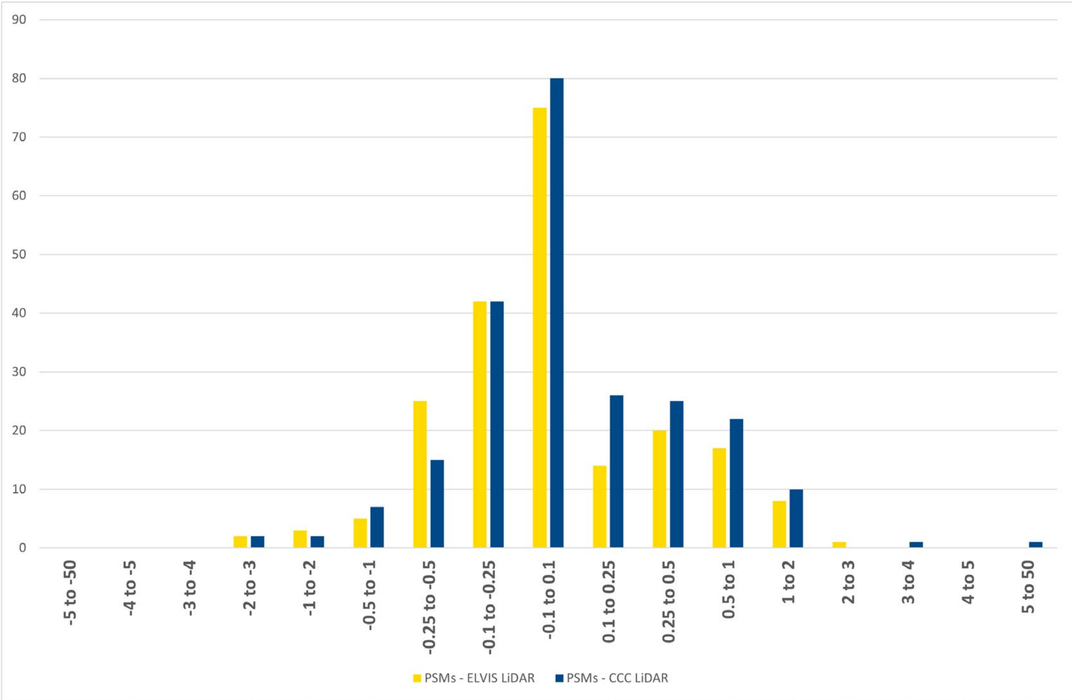
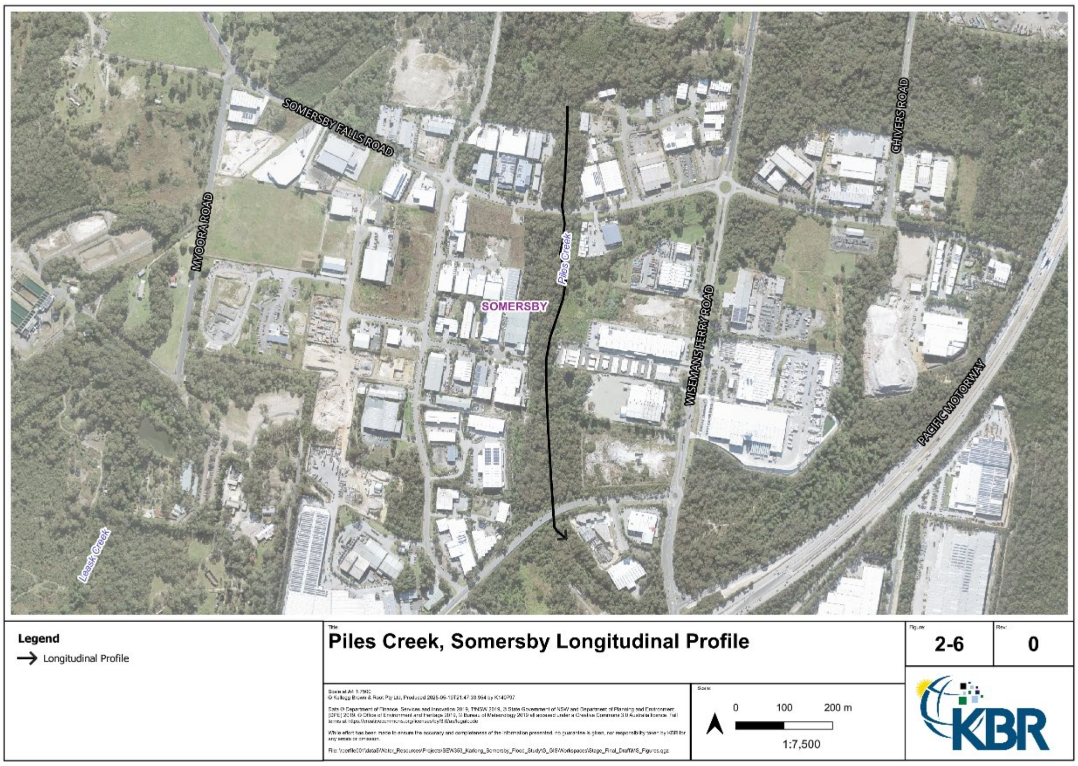


Figure 2-5: Variance Between PSMs and Topographic Datasets



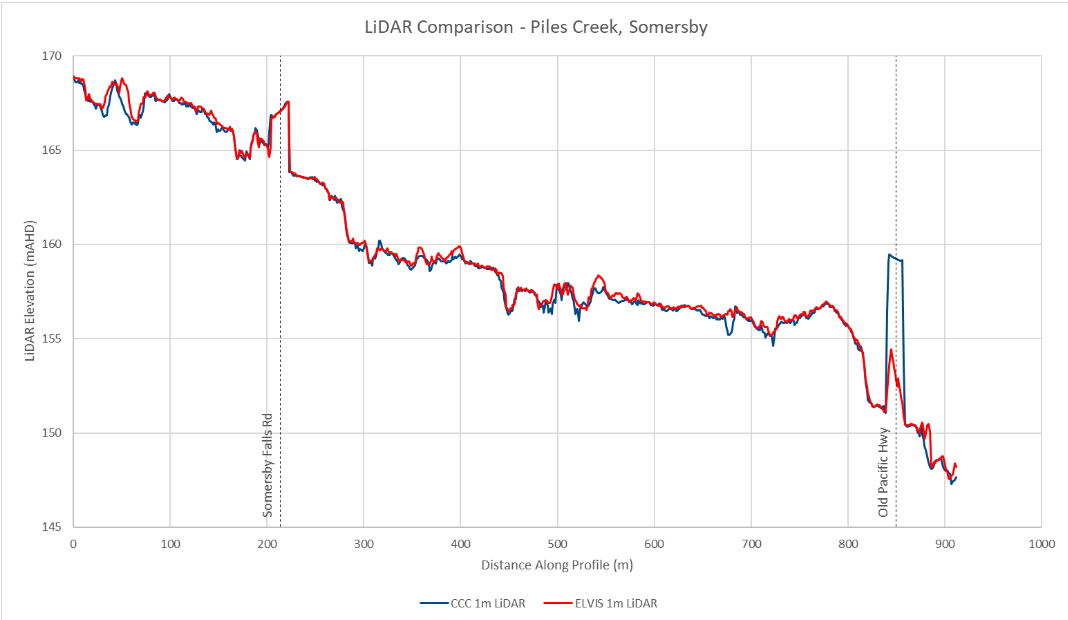
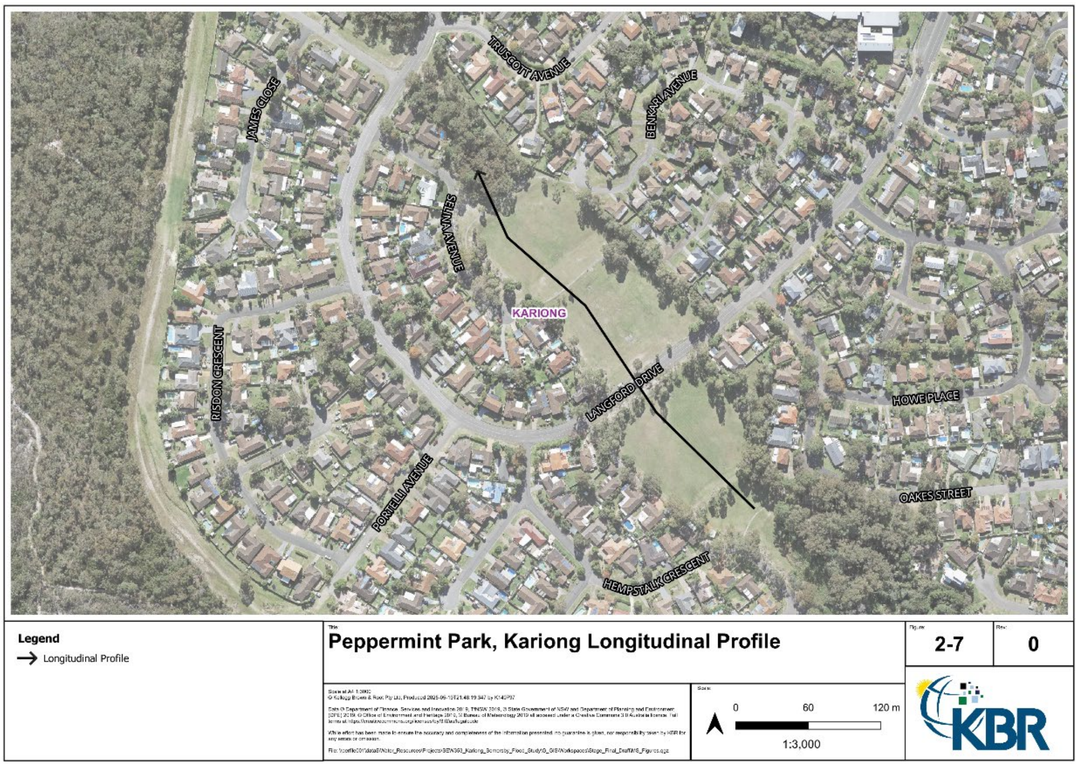


Figure 2-6: Longitudinal Section of CCC LiDAR and ELVIS LiDAR at Piles Creek, Somersby



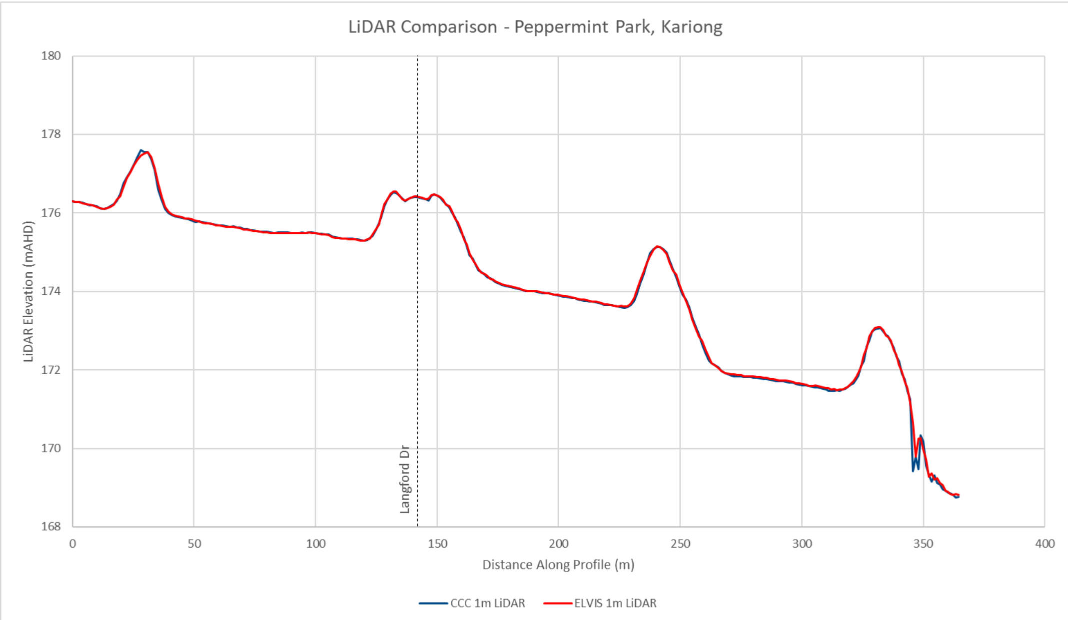
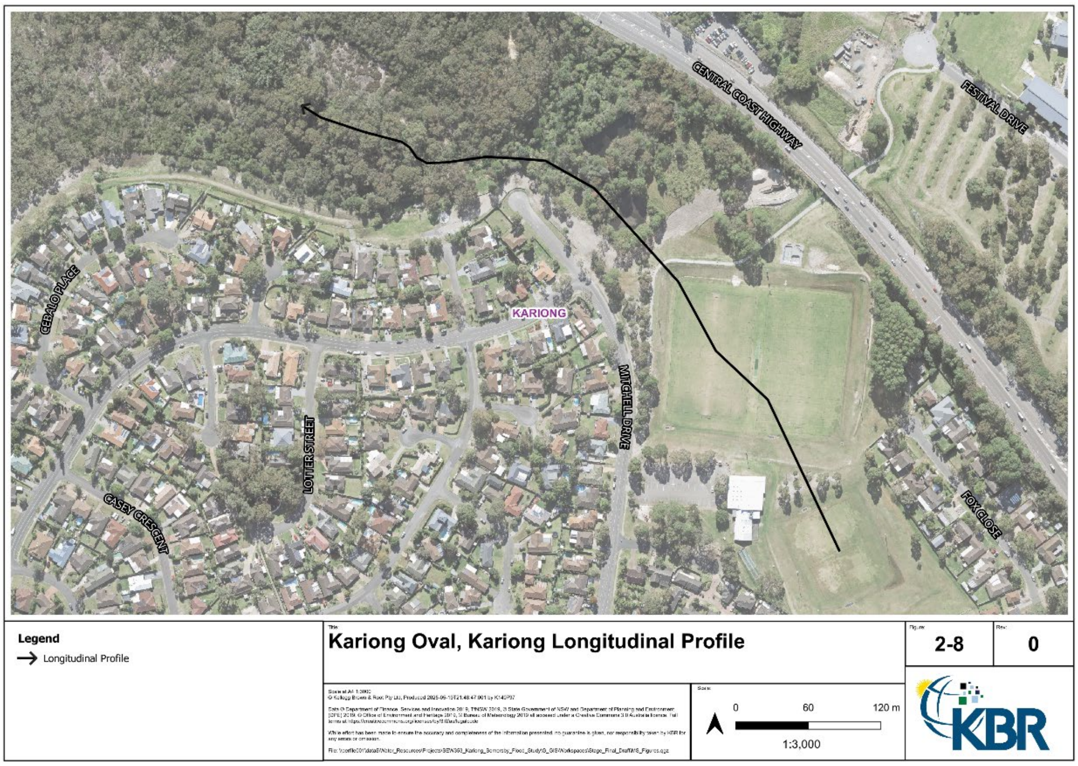


Figure 2-7: Longitudinal Section of CCC LiDAR and ELVIS LiDAR at Peppermint Park, Kariong



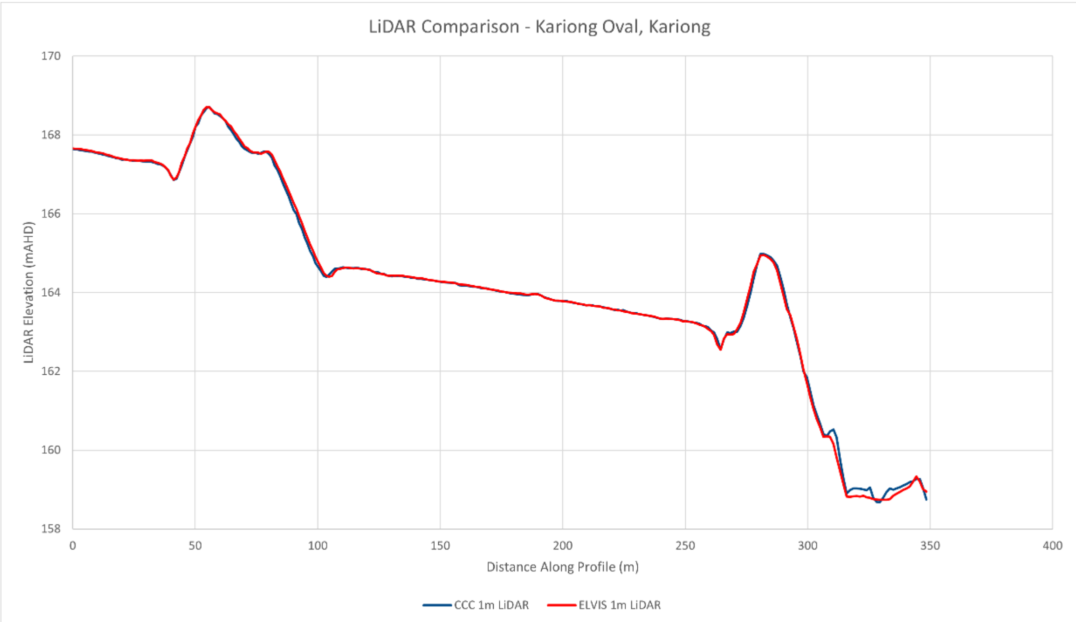


Figure 2-8: Longitudinal Section of CCC LiDAR and ELVIS LiDAR at Kariong Oval, Kariong

2.3 GIS DATA

The GIS data provided by CCC and obtained from other sources is detailed in **Table 2-2**, including a description and application to the study.

Table 2-2: Summary of Available GIS Data and its Intended Application

Dataset	Source	Contents	Application
Esri_DEM_Binning_IDW_NatNeigh_1m_Clipped.tif	CCC	2022 1 m LiDAR Survey	Formed the basis of topography for the hydraulic modelling. **Section 2.2** details the review and comparison of this dataset with other topographic information available.
Gosford 2020 1 m LiDAR	Geoscience Australia (ELVIS)	2020 1 m LiDAR Survey	Used to validate against CCC's LiDAR dataset. **Section 2.2** details the review and comparison of this dataset with other topographic information available.
Somersby and Kariong Survey Mark Export	NSW Government Spatial Services (SCIMS)	Coordinates and elevations of Permanent Survey Marks (PSMs) in the developed sections of the Somersby and Kariong study area.	Reviewing the elevation differences between LiDAR datasets and PSMs.
2022_LEP_Land_Zoning.shp	CCC	2022 LEP Land Zoning	Inform the hydraulic modelling.
Building_Footprints.shp	CCC	Building Footprints	Inform the hydraulic modelling.
Cadastre_Public_Use.shp	CCC	Cadastral Boundaries	Assist in spatially mapping and analysing community consultation responses.
Catchments.shp	CCC	Catchment Boundaries for major watercourses relevant to the study area	Assist with catchment delineation.
Study_Area.shp	CCC	Study Area Extent	Understand CCC's area of interest.
Regionally_Significant_Growth_Area.shp	CCC	Significant areas for growth and development	Inform the hydraulic modelling.
Drainage	CCC	Drainage and Storage Basin Assets	Inform the hydraulic modelling.

2.4 STORMWATER DRAINAGE NETWORK AND HYDRAULIC (CROSS-DRAINAGE) STRUCTURES

The drainage infrastructure in the study area is characterised by underground drainage networks and detention basins in developed areas as well as hydraulic (cross-drainage) structures at key road locations.

The infrastructure primarily consists of stormwater pits and pipes for the storm drainage network, as well as several culverts and channels for the hydraulic structures. A summary of the stormwater asset and hydraulic structure data provided by CCC is summarised in **Table 2-3**. Noting in several circumstances, assets were identified within the datasets however did not have accompanying information.

Table 2-3: Summary of Drainage Structure Data Provided. Percentage (%) of the total number of assets in the dataset that have complete asset information is shown.

Drainage Structure	Data Provided	Number of Asset	Percentage with Data Provided
Pit Register (Excel Spreadsheet)	ID, Length, Width, Depth, Material, Type (buried, junction, kerb inlet, node, letterbox, surface grate)	1467	62%
Pit (Shapefile)	Location, Material, Type (buried, junction, kerb inlet, node, letterbox, surface grate)	1697	100%
Pipe	Location, ID, Length, Pipe Size, Average Depth, Material	2087	78%
Headwall (Circular Culvert)	Location, ID, Pipe Size	871	98%
Box Culvert	Location, ID, Length, Width, Height	7	100%
Gross Pollutant Trap	Location, ID	7	100%
Channel	Location, ID, Channel Average, Length, Width, Type (Dish Drain, Open)	42	100%
Basin	Location, ID, Embankment Top Width, Base Width, Basin Height	18	78%

Where structure details are not available in the provided dataset, structure dimensions were estimated through visual and desktop assessment (e.g. Google Street View) and necessary dimensions and elevations extracted from the DEM with assumed cover and grades. In instances where these methods were not suitable, asset information was inferred/interpolated from known data.

2.5 BUILDING FOOTPRINTS

CCC provided a GIS dataset of the building footprints across the study area. A desktop assessment was completed by comparing the GIS dataset against the latest available aerial imagery. The GIS dataset was found to align well with aerial imagery and was integrated into the hydraulic model to account for obstructions caused by buildings throughout the study area.

2.6 AERIAL IMAGERY

CCC provided a set of aerial images of the study area that were captured between 2005 and 2019, as shown in **Table 2-2**. These were used to identify major developments in the catchment that could alter flood behaviour.

No notable developments were observed in the Kariong residential precinct during this time.

Table 2-4 summarises the rest of the changes to the catchment observed in the provided aerial imagery.

Table 2-4: Summary of Observed Changes to the Catchment from Aerial Imagery Provided by CCC

Time Period between Capture of Aerial Imageries (Year)	Development Observed from Aerial Imagery
2005 to 2007	Some land clearing to allow for the construction of additional large commercial buildings in the Somersby industrial precinct. Some minor developments of buildings on a small number of properties in the primary production precinct. Minor expansion of Hanson Cement plant, Somersby Sands supply plant and Grants Road Sand quarry.
2007 to 2010	Some land clearing to allow for the construction of additional large commercial buildings in the Somersby industrial precinct. Minor expansion of Gosford Quarries, Hanson Cement plant and Grant Road Sand quarry.
2010 to 2012	Some land clearing to allow for the construction of additional large commercial buildings in the Somersby industrial precinct. Minor expansion of Gosford Quarries and Hanson Cement plant.
2012 to 2014	Some land clearing to allow for the construction of additional large commercial buildings in the Somersby industrial precinct. Minor expansion of Hanson Cement plant.
2014 to 2016	Some land clearing to allow for the construction of additional large commercial buildings in the Somersby industrial precinct. Minor expansion of Gosford Quarries, Hanson Cement plant and Grant Road Sand quarry.
2016 to 2018	Extension of Pile Road to intersect Wisemans Ferry Rd. Some land clearing to allow for the construction of additional large commercial buildings in the Somersby industrial precinct. Minor expansion of Gosford Quarries and Somersby Sands supply plant.
2018 to 2019	Some land clearing to allow for the construction of additional large commercial buildings in the Somersby industrial precinct. Minor expansion of Gosford Quarries.

2.7 RAINFALL DATA

Rainfall data is a critical dataset that plays an important role in the calibration and validation process. It is primarily used to define temporal patterns and rainfall depth of historical rainfall events.

Two types of rainfall gauge will be utilised in this study:

- Daily rainfall gauges, which provides the total amount of rainfall recorded over a 24-hour period.
- Pluvio rainfall gauge, which reports rainfall depth at finer time increments such as every 15-minutes, or hourly.

The Bureau of Meteorology (the Bureau), Manly Hydraulics Laboratory (MHL) and Water NSW (WNSW) own and operate an extensive network of rainfall gauges across Australia. CCC provided a dataset of gauges owned and maintained by these providers. Among those rainfall gauges provided, there are thirty six (36) daily rainfall gauges within a 26km radius of the study area that are available for use. Out of these thirty six (36), fourteen (14) of the daily rainfall gauges are currently in operation.

In addition, there are six (6) pluvio rainfall gauges within proximity of the study area which are currently in operation. The identified daily and pluvio rainfall gauges, including station ID, station name, record period, availability of data during historic calibration events and distance from the study area, are summarised in **Table 2-5** and **Table 2-6**. The spatial distribution of these gauges is shown in **Figure 2-9**.

Table 2-5: Summary of Daily Rainfall Gauges within a 15 km Radius of the Study Area

Station Number	Station Name	Record Period	Status	Distance from Centroid of Study Area (km)	Availability of Data during Historic Event			
					June 2007	November 2011	March 2021	March 2022
61108	Gosford State Nursery	1901-1946	Closed	2.4	-	-	-	-
WTP_S.1	WTP-S.Rainfall_mm	1992-2023	Open	2.7	Yes	Yes	Yes	Yes
DAM-MOONEY.1	DAM-MOONEY.1	2014-2023	Open	2.8	-	-	Yes	Yes
61087	Gosford (Narara Research Station) Aws	1917-2013	Closed	5.1	Yes	Yes	-	-
61218	Somersby (Silvesters Road)	1962-1968	Closed	5.1	-	-	-	-
61093	Ourimbah (Dog Trap Road)	1953-2023	Open	5.9	Yes	Yes	Yes	-
61355	Greenway Close	1986-1997	Closed	6.0	-	-	-	-
67049	Arnold Grove	1889-1918	Closed	7.2	-	-	-	-
61023	Gertrude Place	1877-1993	Closed	7.4	-	-	-	-
61319	Gosford North (Glennie St)	1971-2015	Closed	7.9	Yes	Yes	-	-
61351	Peats Ridge (Waratah Road)	1981-2015	Closed	9.4	Yes	Yes	-	-
61425	Gosford Aws	2013-2023	Open	9.5	-	-	Yes	Yes

Station Number	Station Name	Record Period	Status	Distance from Centroid of Study Area (km)	Availability of Data during Historic Event			
					June 2007	November 2011	March 2021	March 2022
61432	Palm Grove (Lyrebird Lane)	2018-2023	Open	10.7	-	-	Yes	Yes
61216	Lower Mangrove (Popran Rd)	1998-2023	Open	11.1	Yes	Yes	Yes	Yes
61381	Mount Elliot	2000-2022	Open	11.2	-	Yes	Yes	Yes
61384	Kangy Angy (Ourimbah Creek)	2000-2017	Closed	12.1	Yes	Yes	-	-
61318	Woy Woy (Everglades Country Club)	1964-2010	Closed	12.6	Yes	-	-	-
61375	Mangrove Mountain Aws	1994-2023	Open	12.7	Yes	Yes	Yes	Yes
61036	Mangrove Mountain Post Office	1946-1979	Closed	12.7	-	-	-	-
61341	Woy Woy Rd	1977-1979	Closed	12.7	-	-	-	-
61253	Wattle Tree Road	1968-1971	Closed	13.1	-	-	-	-
61354	Marlows Creek (Spencer)	1986-2004	Closed	13.5	-	-	-	-
61248	Kincumber	1967-1975	Closed	14.2	-	-	-	-
61294	Avoca Beach Bowling Club	1970-2023	Open	15.4	Yes	Yes	Yes	Yes
61369	Terrigal Memorial Country Club	1990-2015	Closed	15.8	Yes	-	-	-
61383	Gears (Wyong River)	2000-2023	Open	15.8	Yes	Yes	-	Yes
61220	Yarramalong (Lewensbrook)	1966-2023	Open	17.2	Yes	Yes	Yes	Yes
61083	Wyong (Wyong Golf Club)	1985-2010	Closed	17.8	-	-	-	-

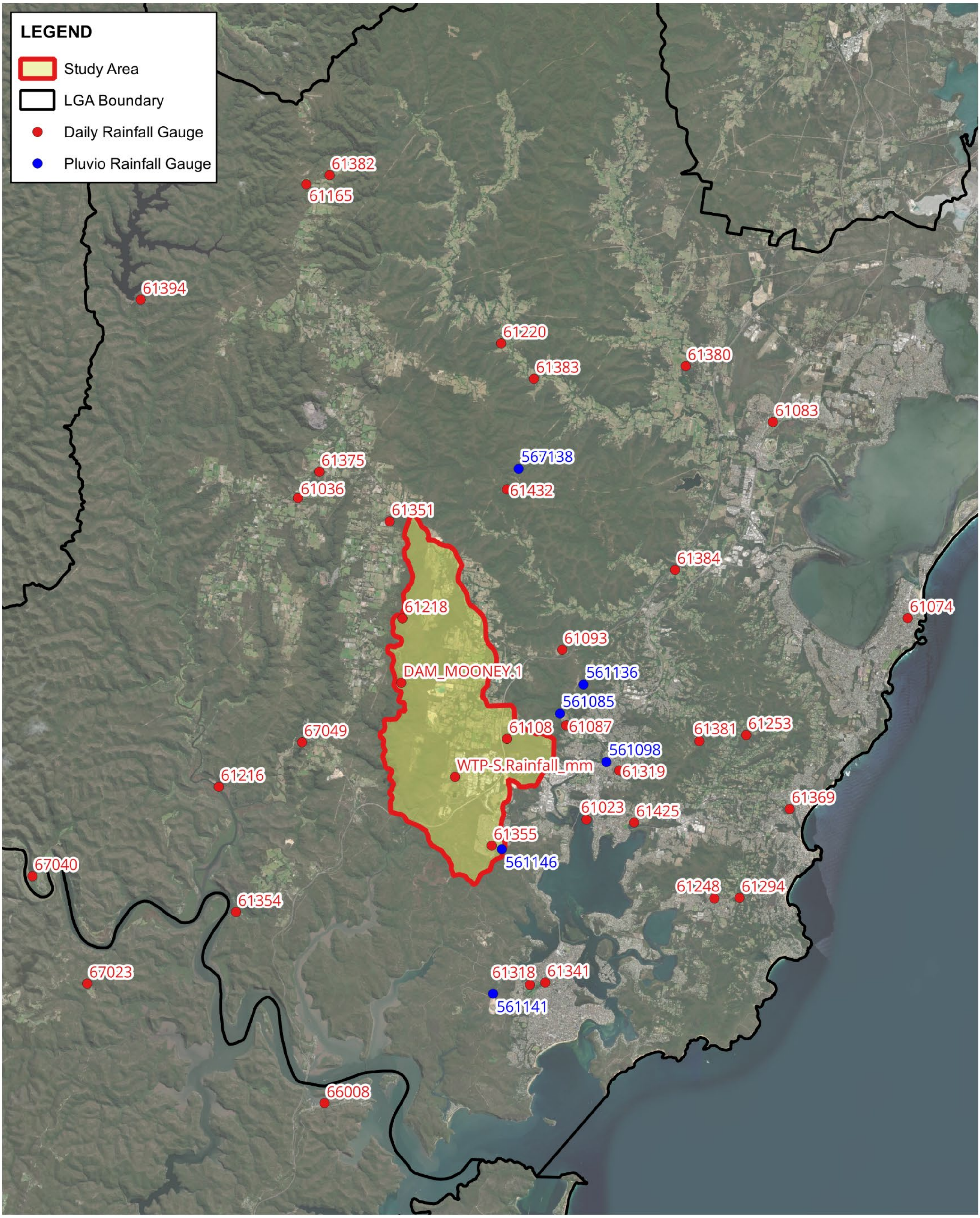
Station Number	Station Name	Record Period	Status	Distance from Centroid of Study Area (km)	Availability of Data during Historic Event			
					June 2007	November 2011	March 2021	March 2022
66008	Brooklyn (Sandbrook Inlet)	1913-2011	Closed	18.4	Yes	-	-	-
61380	Jilliby (Jilliby Creek)	2000-2021	Closed	19.2	Yes	Yes	-	-
67040	Gunderman (Wisemans Ferry Rd)	1962-2014	Closed	20.4	Yes	Yes	-	-
67023	Canoelands (Canoelands)	2000-2023	Open	20.5	-	-	Yes	Yes
61074	The Entrance (Eloora Street)	1943-2015	Closed	21.1	Yes	Yes	-	-
61165	Kulnura North (Wilcher)	1959-2012	Closed	23	-	-	-	-
61394	Mangrove Creek Dam	1982-2023	Open	23.7	Yes	Yes	-	Yes
61382	Kulnura (Jeavons)	2000-2023	Open	25.3	Yes	Yes	Yes	Yes

Table 2-6: Summary of Pluvio Rainfall Gauges

Station Number	Station Name	Record Period	Minimal Rainfall Record interval	Distance from Centroid of Study Area (km)	Availability of Data during Historic Event			
					June 2007	November 2011	March 2021	March 2022
561085	Narara	1989-2023	15-Minutes	4.9	Yes	Yes	Yes	Yes
561136	Strickland	1987-2023	15-Minutes	6.1	Yes	Yes	Yes	Yes
561146	Kariong Reservoir Rain	2005-2023	Hourly	6.3	Yes	Yes	Yes	Yes
561098	Wyoming	1988-2023	Hourly	7.2	Yes	Yes	Yes	Yes
567138	Sterland	1997-2023	Hourly	11.7	Yes	Yes	Yes	-
561141	Woy Woy	2005-2023	Hourly	12.6	Yes	Yes	Yes	Yes

2.8 STREAM GAUGE DATA

There are no stream gauges in the study area to inform model calibration or validation. All local stream gauges incorporate significantly larger catchments which are not a part of this study.



Title:

Spatial Distribution of Rainfall Gauges

Figure: **2-9**

Rev: **0**

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Scale:

0 1 2 3 4 5 km

1:220,000

KBR

2.9 SITE INSPECTION

An initial site visit was conducted on July 14, 2023, which focused on key local hydraulic features which influence the nature of flooding and require detailed consideration in the modelling. In preparation, KBR conducted a desktop assessment using aerial imagery, LiDAR and Google Streetview to inform key locations to attend during the site visit. Some of the key findings included:

- A general understanding of the topography of the area, including any elevation changes or slopes, vegetation types, landforms and flowpaths.
- Understanding of the major trunk drainage systems, including sub-surface drainage and detention basins. Inspection revealed that there are two major overland flowpaths that traverse through the residential area that have multiple formal/informal detention basins. It was generally found that the low points of the basins were large, raised, grated inlets that transferred flow into the sub-surface stormwater network (refer to **Figure 2-10** and **Figure 2-11** for examples). The locations of spillways were also identified.
- The sizes of the pit inlets vary substantially across the study area.
- General understanding of the existing development distribution including residential and industrial across the catchment.
- Confirmation of structure geometries by comparing measured sizes versus CCC data.

Examples of photos taken during the site visit to inform model development are shown in **Figure 2-10** to **Figure 2-12**.

Figure 2-10: Example of Raised Grated Letter Box Pit Inlet at Detention Basin on Langford Drive near Arunta Avenue

Figure 2-11: Grated Inlet at Detention Basin on Langford Drive near Arunta Avenue

Figure 2-12: Cross-Drainage Structure along Somersby Fall Road at Piles Creek

3 Community Consultation

3.1 THE COMMUNITY CONSULTATION PROCESS

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

The key elements of the consultation process in undertaking the flood study have been:

- Issue of a media release to inform the community of the purpose and objectives of the study.
- Issue of a cover letter, information sheet and questionnaire to inform the community of the study and obtain historical flood data and community perspective on flooding issues.
- A study webpage via CCC's online community engagement portal. www.yourvoiceourcoast.com/somersbykariongfloodstudy
- Issue of a letter to all property owners located within the defined Flood Planning Area (FPA) informing them of the outcome of the study.
- Public exhibition of the Draft Flood Study Report (To be completed).
- A community drop-in information session held during the public exhibition period (To be completed).

These elements are discussed in detail in the following report sections.

3.2 COMMUNITY QUESTIONNAIRE

A cover letter, information sheet and a questionnaire were distributed to all landowners, residents and businesses located within the study area in August 2023. Copies of the cover letter, information sheet and questionnaire are provided in **Appendix A**.

The information sheet provided an overview of the flood study, while 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 catchment. The questionnaire was accessible through CCC's online community engagement portal at this web address: www.yourvoiceourcoast.com/somersbykariongfloodstudy

A total of 133 completed questionnaires were received out of the 2275 delivered, representing a response rate of 5.8%. Return rates of between 5% and 10% are typical for initial consultation on a flood study.

The responses have been compiled into a GIS database which has been utilised to analyse the results and to provide a graphical representation of the data. **Figure 3-3** shows the geographical distribution of the responses. The map indicates a denser coverage of responses across the Kariong residential area and Somersby industrial precinct. Responses in the primary production precinct in the northern extent of the study area were well distributed across the study area. One respondent did not provide their name or address and is therefore not shown in **Figure 3-3**.

The majority of the respondents have resided at their property for over 20 years, which improves the likelihood of the residents observing flooding on or near their property. A summary of the length of time residents have been at their property is shown in **Table 3-1**.

Table 3-1: Residence Length Count

Residence Length	Count
Less than 1 year	6
1 to 5 years	8
5 to 10 years	23
10 to 20 years	37
Greater than 20 years	60
Not Stated	1

Comments relating to flood behaviour contained within the responses were extracted to allow for comparison against simulated historical flood events. Responses that provided information pertaining to a specific storm can be used for the purposes of calibrating the model in the absence of more accurate or reliable information. **Table 3-2** summarises the number of responses that provided information for specific storm events and shows that the March 2022 event had the largest number of responses appropriate for this purpose.

Table 3-2: Number of Responses that Provided Suitable Information for the Purposes of Model Result Calibration for Specific Events

Storm Event	Count
June 2007	91
November 2011	95
March 2021	120
March 2022	122
Other	11

Limited historical flood marks were identified during this community consultation. Only one (1) respondent reported having a flood mark, which was left by the debris on the respondent's fence. Six (6) respondents provided photo or video evidence of historical flood events with their responses. Five (5) of these responses related to the March 2022 event and one (1) related to the November 2011 event. These photos and videos provided generally depicted shallow ponding or local drainage issues, as seen in **Figure 3-1**.

Figure 3-1: Examples of Photographic Evidence of Flooding Provided by Residents

Multiple respondents referred to frequent flooding due to either ponding within their property, overflow from blocked drains or overflow from neighbouring properties. These typically reported shallow flood depths of less than 30 cm.

Approximately 48 respondents indicated they had experienced flooding either within or near their property. Where flooding was identified as an issue, the community were asked to separately report on the type of flooding observed. The nature of flooding experienced for the 48 respondents is summarised in **Figure 3-2** and shown spatially in **Figure 3-4**. Of particular note, 26 respondents indicated that overflow from blocked drains was a source of flooding, making it the most common reported source of flooding. Ponding of water within a property and water originating from local roads were the next most common sources of flooding indicated.

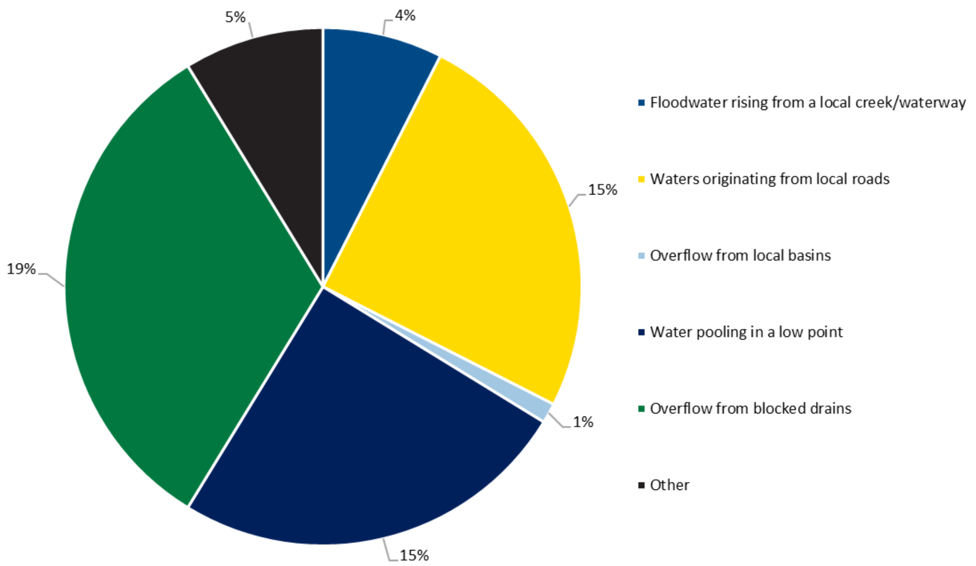


Figure 3-2: Summary of Types of Flooding Experienced

The responses also included comments for the purpose of the Flood Study. A number of respondents provided suggestions for alleviating the flood risk in the Somersby and Kariong catchments. These suggestions included:

- Clearing vegetation and debris from natural watercourses.
- Increased maintenance of the drainage system, for example ensuring pits, stormwater drains and waterways are kept clear of debris.
- Stabilising the banks of some natural watercourses to avoid the channel bank collapsing and becoming a blockage.

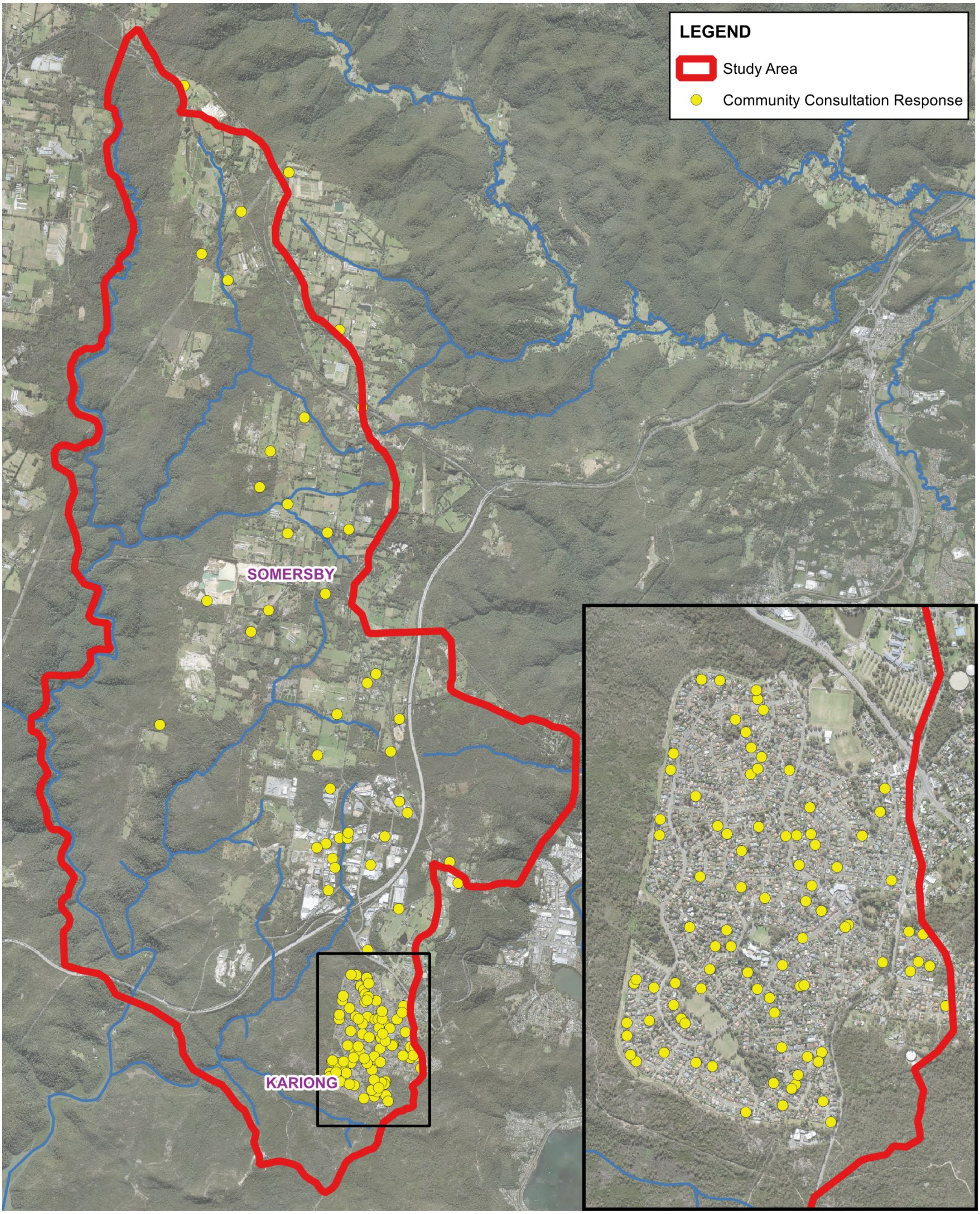
A number of respondents also expressed similar concerns over specific flooding issues. These included:

- Flooding of Peppermint Park.
- Erosion of private retaining walls or nearby natural watercourse banks due to flooding.

3.3 PUBLIC EXHIBITION OF DRAFT FLOOD STUDY AND COMMUNITY RESPONSE

Upon finalising the Draft Flood Study Report, the document will be made available for Public Exhibition. During this period, the report will be accessible to the public, enabling the community to review its contents and provide valuable feedback regarding the study and its conclusions. All input received will be reviewed and considered.

Where necessary, the Study will be revised to address outcomes from the public exhibition. This process ensures that the Study reflects a broad range of perspectives and that any critical issues are appropriately addressed before finalising the report.



Title:

Spatial Distribution of Community Consultation Responses Across the Study Area

Figure: 3-3

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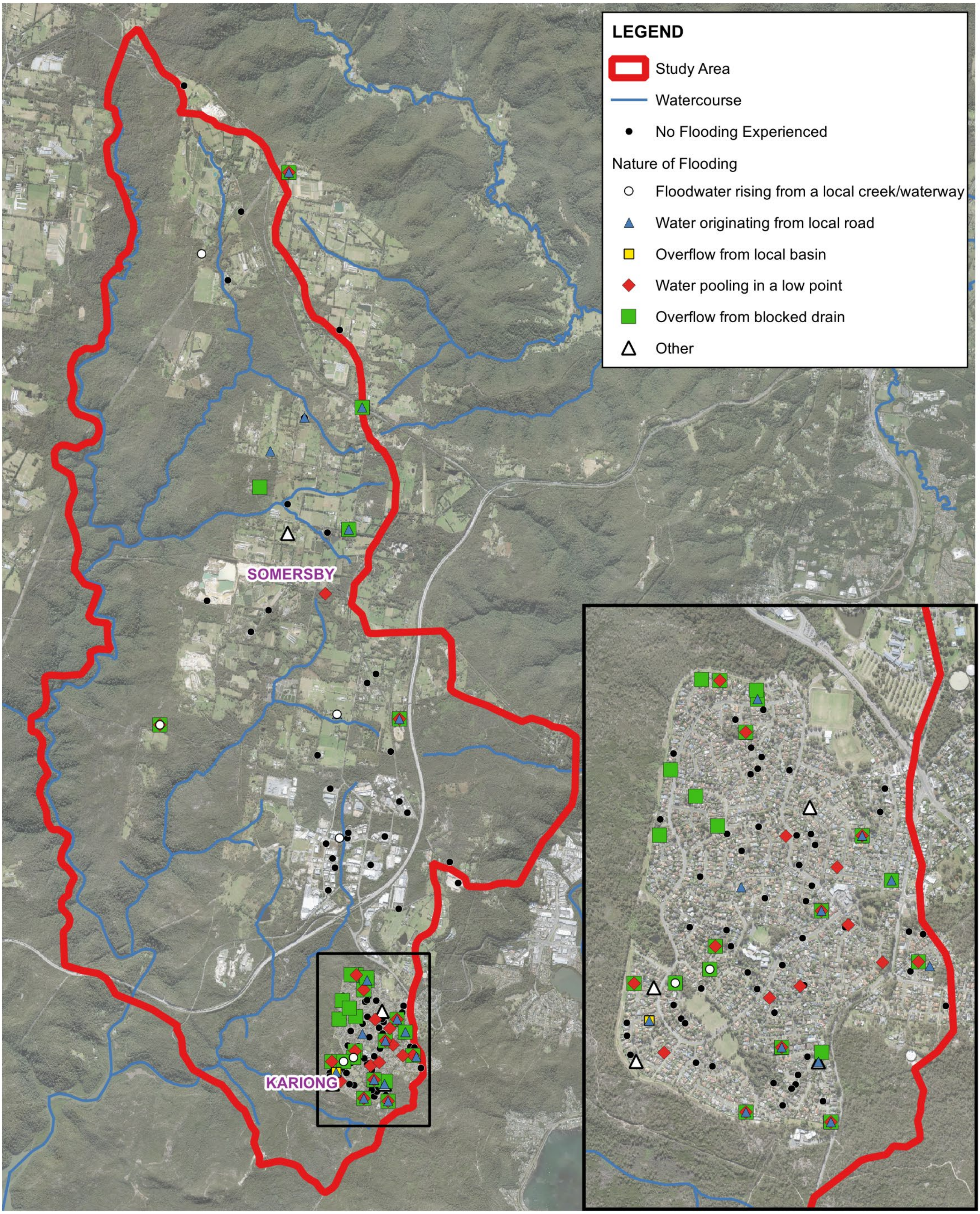

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Questionnaire Responses - Spatial Distribution of Nature of Flooding Experienced

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4 Model Development

4.1 MODELLING METHODOLOGY

The modelling undertaken to assess a catchments flood behaviour is typically considered in two key components:

- The hydrologic model simulates the catchment rainfall-runoff processes, producing inflows to the hydraulic model,
- The hydraulic model simulates the flow behaviour of the overland flowpaths, creeks and waterways producing flood inundation extents, depths and velocities. Hydraulic modelling allows for a detailed understanding of the flood behaviour/hazard across the catchment.

The hydrologic modelling component can either be undertaken using a standalone hydrologic model (e.g. RORB) or included within the hydraulic model when adopting a Direct Rainfall or Rain-on-Grid (RoG) approach. A RoG approach spatially distributes rainfall across the hydraulic model domain.

Once the model has been developed, it may then be used for:

- Establishing design flood conditions (within the scope of this Flood Study),
- Identification and assessment of flood mitigation options (typically undertaken as part of the subsequent Flood Risk Management Study); and
- Impact assessments for future development applications.

For the purpose of this study, a TUFLOW Rainfall-on-Grid (RoG) combined hydrologic and hydraulic model has been developed utilising the Heavily Parallelised Computing (HPC) engine (Release 2023-03-AC-iSP-w64). The RoG functionality eliminates the need for a separate hydrologic model and simulates the rainfall-runoff and routing process within TUFLOW by applying the rainfall directly to the model cells. The RoG approach was selected due to the following advantages over a standalone hydrologic method:

- the ability to capture cross-catchment flows as rainfall is applied across the entire model domain,
- The representation of all flow paths are captured in the topography, hence flows are routing by hydraulic principles and sub-catchment delineation is not required.

Outcomes from the hydraulic model includes spatial representation of peak flood levels, depths, velocity and flood hazard within the catchment.

Critical hydrologic inputs to the model included:

- Data from historical daily and pluviograph rainfall gauges were used to define the spatial and temporal rainfall distributions for the adopted calibration events,
- Intensity Frequency Duration (IFD) curves from the ARR Data Hub for the design events,
- Soil type and associated properties to estimate runoff losses.

Critical hydraulic inputs to the model included:

- LiDAR data to represent the study area topography,
- Hydraulic roughness retarding flow through the catchment,
- Downstream boundaries to represent the flow out of the model,

- Hydraulic structures including stormwater networks, cross-drainage structures and bridges.

Underlying all the inputs into the model was consideration given to:

- Required accuracy and resolution of the model,
- Computational limitations for efficient simulation.

4.2 MODEL DOMAIN

The catchment is represented using the TUFLOW HPC engine in the 2023-03-AC release. A model grid cell resolution of 4 m is adopted across the model domain with an increase in resolution to 2 m within the future development region using TUFLOW Quadtree facility. This results in a sampling distance of 2 m and 1 m respectively for the underlying topography. The adopted cell size optimised the model resolution while maintaining manageable model run times.

4.3 TOPOGRAPHY

Model base topography was sampled from the latest 2022 LiDAR dataset provided by CCC. Additional LiDAR data downloaded from Geoscience Australia from 2020 was used to validate and supplement the 2022 LiDAR where required. The model topography is displayed in **Figure 1-4.**

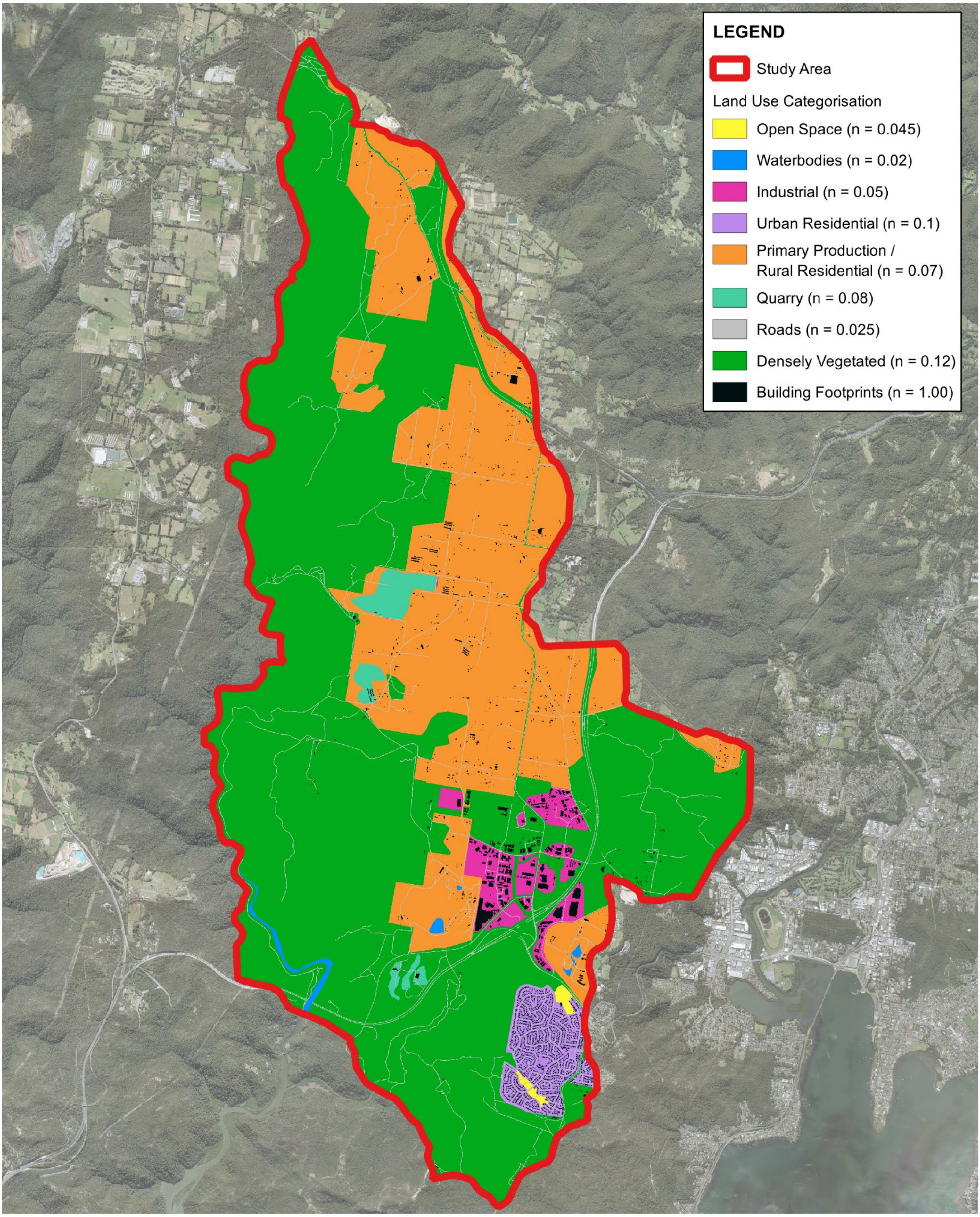
4.4 HYDRAULIC ROUGHNESS

To represent different surface types in the study area, a hydraulic roughness (Manning's 'n') value was assigned to each land use type/material. These were identified using aerial photography and cadastral data and represent variations in flow resistance across natural and developed surfaces, such as hardstand areas, buildings, cleared land and remnant vegetation.

Cadastral information and the Central Coast Council 2022 zoning policy was used to generate land use surface types and roughness zones in the catchment area, with some supplementation provided by aerial imagery. The adopted material distribution is displayed in **Figure 4-1**. The adopted Manning's 'n' values are presented in **Table 4-1**. It was assumed that the urban residential land use category would have a higher hydraulic roughness value due to the incorporation of fences through roughness rather than layered flow constrictions.

Table 4-1: Land Use Categorisation

Land Use Category	Manning's 'n' Value
Waterbodies	0.02
Roads	0.025
Open Space	0.045
Industrial	0.05
Primary Production, Rural Residential	0.07
Quarry	0.08
Urban Residential	0.1
Densely Vegetated	0.12
Building Footprints	1



Title:

Land Use Categorisation

Figure: **4-1**

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4.5 RAINFALL DATA

Rainfall data is the primary input to the TUFLOW RoG model which simulates the catchments response to rainfall. The applied rainfall is defined by:

- Rainfall depth – the depth of rainfall across the catchment over a defined time period.
- Temporal pattern – the distribution of the rainfall depth at selected time intervals over the duration of the rainfall event.
- Spatial distribution – the spread of rainfall depth and temporal patterns across the catchment.

For a TUFLOW RoG model, the rainfall is applied directly to all active 2D cells.

The rainfall inputs for the calibration and design event modelling are presented in **Section 5** and **Section 6** respectively.

4.6 RAINFALL SUBCATCHMENTS

Rainfall subcatchments were developed for the catchment based on the model topography. The primary aim of the process was to split the catchment up at junctions to enable the implementation of areal reduction factors to inflows if required, as well as to assign multiple temporal patterns to the catchment (based off the nearest pluviography) for historical calibration events.

The study area was divided into 61 subcatchments, as seen in **Figure 4-2**, with an average subcatchment area of one square kilometre.

4.7 INITIAL AND CONTINUING INFILTRATION MODEL PARAMETERS

Losses within the model were accounted for through the “soils” infiltration functionality of TUFLOW. The initial and continuing loss model was adopted. To incorporate this approach into a flood model, an initial loss value and continuing loss value were assigned to each soil class which corresponded to an adopted land use category/material type.

Varying perviousness percentages across the catchment have been accounted for by scaling down the initial losses between the fully pervious and impervious material types. The applied impervious ratios per land use category are presented in **Table 4-2**.

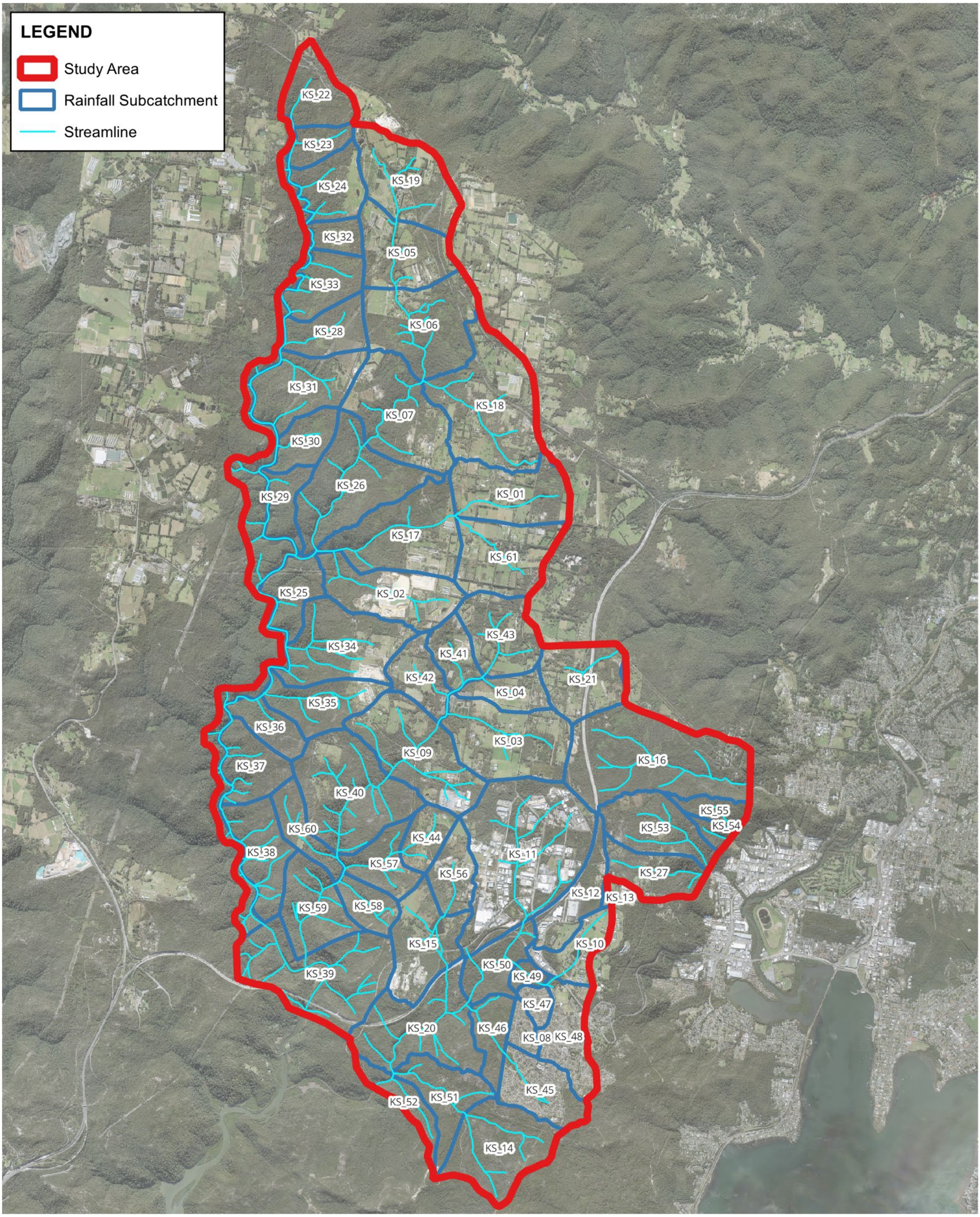
Continuing loss was applied to all pervious and semipervious areas within the model. The continuing loss was similarly scaled based on imperviousness. However, unlike impervious ratios as a percentage applied to initial loss, the continuing loss was scaled to fixed values based on the calibration process.

The adopted loss values for calibration are presented in **Section 5.3.4**. The adopted losses for design event modelling are discussed within **Section 6.1.3**. The spatial distribution of soil classes corresponded to the material distribution presented in **Figure 4-1**.

Table 4-2: Applied Impervious Ratios per Land Use Category

Land Use Category	Initial Loss Impervious Ratio (%)
Waterbodies	100
Roads	100
Open Space	5
Industrial	100
Primary Production, Rural Residential	15
Quarry	5
Urban Residential	75

Land Use Category	Initial Loss Impervious Ratio (%)
Densely Vegetated	5
Building Footprints	75



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Rainfall Subcatchments

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4.8 REPRESENTATION OF FENCES AND BUILDINGS

Buildings were represented within the model by applying the following procedure:

- Building footprints were contracted by 1 m on all sides to better facilitate flow paths between buildings. The contraction was necessary to remove the impact of eaves captured within the building footprint. A contraction distance of 1 m was also necessary to facilitate the TUFLOW cell size (2 m) to materially impact computations.
- The reduced footprint was then raised to the highest sampled elevation level within the reduced footprint, plus 0.3 m. The raising of the footprint accounts for the obstruction to flow caused by the building structure itself. The 0.3 m represents an indicative concrete slab level above ground.
- A depth-varying Manning's 'n' was applied over the contracted and raised building footprint. A low roughness values is applied for shallow depths to simulate runoff from roofs, and a higher roughness is applied at deeper depths to account for the slow-moving storage of flood waters that occurs within buildings.

An alternative approach of adopting a complete blockage of buildings within the model was not adopted since it does not allow for potential flood storage within the building footprints and can prevent flow between buildings when such spacing is small relative to the adopted model grid cell resolution.

Residential fences are effectively accounted for in the Manning's 'n' value adopted for the residential areas as they typically reduce flow velocities in smaller events and typically fail during major flood events.

4.9 REPRESENTATION OF BRIDGES

Bridges are represented within the model 2D domain through the application of layered flow constrictions. There was a total of nine (9) bridges represented throughout the model. A layered flow constriction applies depth averaged form loss and blockage to the transfer of flow between cells. There are three layers in the case of a bridge representing the below bridge deck structure, the bridge deck, and overflow.

Bridge decks were simulated as fully blocked with form loss coefficients of 1.56. A below deck blockage of 10% and form loss coefficient of 0.1 were adopted to represent flow obstruction and energy losses associated with bridge piers. Above deck parameters varied depending on barrier type, with blockage varying between 40-100% and form loss coefficients between 0.2 and 1.56 for full metal barriers with significant openings to fully blocked concrete barriers.

4.10 STORMWATER DRAINAGE NETWORK

CCC's cross-drainage structures and pit and pipe network were included within the model domain for pipes of diameter 375 mm or larger. CCC's stormwater network which was included in the model consisted of 1382 pipes and 1365 pits/manholes, with a further 150 cross-drainage structures (culverts) being represented. Pit inlet curves were implemented to appropriately determine the flow rate into varying types of pits including a combination of on-grade and sag pit inlet curves for kerb inlets, letterbox pits, raised grated pits and surface grated pits.

Using aerial imagery and existing elevation data, assumptions were made on the dimensions and invert levels where data was incomplete.

The modelled stormwater network is shown in **Figure 4-3**.

4.11 STRUCTURE BLOCKAGE

Blockage has been applied in accordance with ARR 2019 Book 6 Chapter 6 for cross-drainage structures with a 1 in 100 AEP debris potential of medium classification (MMM) as seen in **Table 4-5** to **Table 4-7**. The debris availability, mobility and transportability were all classified as medium for the 1 in 100 AEP. Adjustment from medium to low or high debris potential is conducted for varying AEP events in design modelling as presented in **Table 4-3**. For the calibration events, a medium debris potential was adopted. The blockage values for the varying debris potentials and associated control dimensions of the cross-drainage structures are presented in **Table 4-4**. These values can be seen to vary based on opening width of the structure (W) and the average length of the longest 10% of the debris that could arrive at the site (L_{10}). An L_{10} value of 2 m was selected.

Table 4-3: Adjustment of a Medium Debris Potential Classification for AEP

Event AEP	AEP >5%	AEP 5%-0.5%	AEP < 0.5%
Adjusted Debris Potential Classification	Low	Medium	High

Table 4-4: Blockage Associated with Cross-Drainage Structure Debris Potential Classification and Control Dimension

Control Dimension Inlet Clear Width (m)	AEP Adjusted Debris Potential at Structure		
	High	Medium	Low
$W < L_{10}$	100	50	25
$L_{10} < W < 3^* L_{10}$	20	10	0
$W > 3^* L_{10}$	10	0	0

Table 4-5: ARR 2019 Book 6 - Table 6.6.1. Debris Availability - in Source Area of a Particular Type/Size of Debris

Classification	Typical Source Area Characteristics (1% AEP Event)
High	Natural forested areas with thick vegetation and extensive canopy cover, 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 steep 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 where 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.
Low	Well maintained rural lands and paddocks with minimal outbuildings or stored materials in the source area. Streams with moderate to flat slopes and stable bed and banks. Arid areas where vegetation is deep rooted, and soils are resistant to scour. Urban areas that are well maintained with limited debris present in the source area.

Table 4-6: ARR 2019 Book 6 - Table 6.6.2. Debris Mobility - Ability of a Particular Type/Size of Debris to be Moved into Streams

Classification	Typical Source Area Characteristics (1% AEP Event)
High	Steep source areas 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 mobility categories.
Low	Low rainfall intensities and large, flat source areas. Receiving streams infrequently overtops their banks. Main debris source areas well away from streams.

Table 4-7: ARR 2019 Book 6 - Table 6.6.3. Debris Transportability - Ability of a Stream to Transport Debris Down to the Structure

Classification	Typical Source Area Characteristics (1% AEP Event)
High	Steep bed slopes (> 3%) and/or high stream velocity (V > 2.5 m/s) Deep stream relative to vertical debris dimension ($D > 0.5L_{10}$) Wide stream relative to horizontal debris dimension. ($W > L_{10}$) Stream relatively straight and free of major constrictions or snag points. High temporal variability in maximum stream flows.
Medium	Stream generally falling between High and Low categories
Low	Flat bed slopes (< 1%) and/or low stream velocity (V < 1 m/s). Shallow depth relative to vertical debris dimension ($D < 0.5L_{10}$). Narrow stream relative to horizontal debris dimension ($W < L_{10}$). Stream meanders with frequent constrictions/snag points. Low temporal variability in maximum stream flows.

Industry standard values were used for the blockage in stormwater drainage inlet pits, outlined in **Table 4-8**.

Table 4-8: Stormwater Drainage Inlet Pit Blockage

Inlet Types	Blockage Applied (%)
Sag Pits	50
On Grade	20

4.12 UPSTREAM BOUNDARY

The model covers the entire contributing catchment area and therefore has no upstream boundary condition.

4.13 DOWNSTREAM BOUNDARY

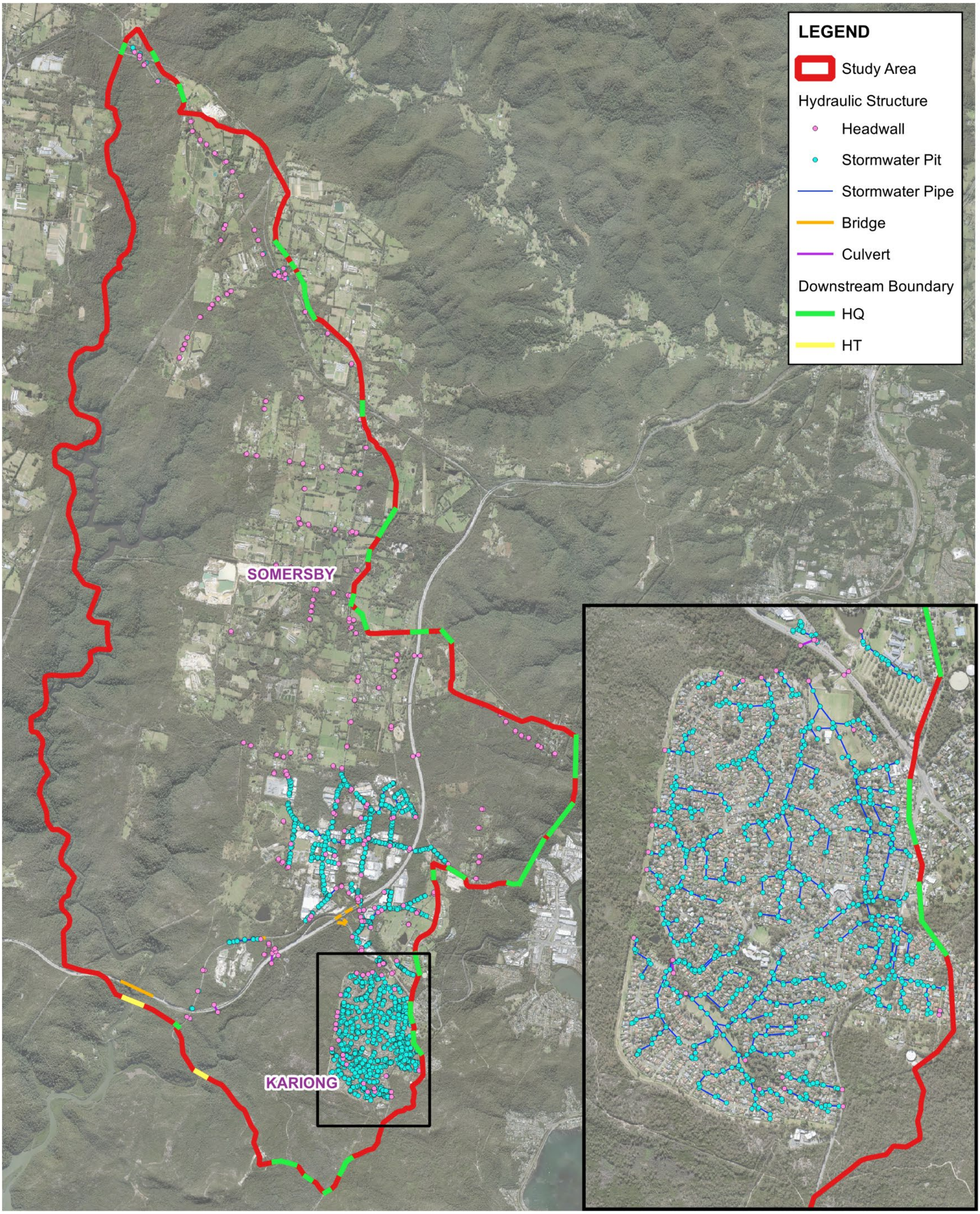
There were two types of downstream boundaries applied in the model;

- An automatically generated head-flow (HQ) boundary based on the input of slope for non-estuary flow channels; and
- A head-time (HT) boundary for the two boundaries on the primary catchment outlets.

For the head-flow boundaries the average bed slope local to each of the boundaries was calculated and input to the model.

The two head-time boundaries are located on Mooney Mooney Creek and Piles Creek at the downstream end of the study area. A constant water level was adopted across all modelled scenarios for each of the boundaries as they are at considerably lower elevations (approximately 1 m AHD) than the focus of the study (generally above 60 m AHD) and are not expected to influence model results.

The location of all downstream boundaries is presented in **Figure 4-3**.



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Hydraulic Model Schematisation

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5 Model Calibration and Validation

5.1 SELECTION OF CALIBRATION AND VALIDATION EVENTS

The Somersby and Kariong catchments have experienced several historical flooding events in recent decades. Based on the availability of suitable rainfall and historical flood level data, and noting the absence of a stream gauge within the catchment, four historical events were selected for calibration and validation as presented in **Table 5-1**. The four historical events were selected in conjunction with a review of available rainfall gauges in the catchment at the time of each event as outlined in **Section 5.3.1**.

The June 2007 and November 2011 events were selected for the purposes of model calibration as they represented the smallest and largest volumes of rainfall respectively, thus allowing for refinement of infiltration and roughness parameters. The March 2021 and March 2022 events were selected for model validation as the recorded rainfall volume is between that of the 2007 and 2011 events allowing for confirmation of the calibrated parameters. The range of historic events allows for parameters appropriate for different levels of stormwater network capacity.

Table 5-1: Calibration Events

Calibration/ Validation Events	Start Time	End Time	Duration (hours)	Total Event Rainfall (average value of operating gauges) (mm)
June 2007	7/06/2007 0:00	10/06/2007 0:00	72	314
November 2011	24/11/2011 0:00	27/11/2011 0:00	72	76
March 2021	19/03/2021 0:00	22/03/2021 0:00	72	279
March 2022	1/03/2022 0:00	4/03/2022 9:00	72	202

5.2 HISTORICAL RAINFALL AND CALIBRATION/VALIDATION PROCEDURE

The development of the calibration event rainfall required the collation of historical rainfall data from gauges described by rainfall depth and temporal pattern. For the historical events, derivation of rainfall depth was conducted by determining the rainfall totals from daily and continuous gauges, while the temporal patterns were determined by extracting the hyetographs at the continuous gauges.

The analysis ensured that the hydraulic model accurately reflected the observed data throughout the model by calibration to observed peak flood level estimates and residents' observations provided as part of the community consultation process. Where required, an iterative process of adjusting model roughness and loss values within reasonable bounds was undertaken until the model results provided a reasonable match to the historical data.

5.3 RAINFALL DATA

5.3.1 Spatial Distribution

The spatial distribution of calibration event rainfall was determined by reviewing gauges within the vicinity of the catchment, of which there were 32 daily gauges and 6 sub-daily gauges. The number of available gauges per event was determined by reviewing outliers and removing gauges where deemed appropriate. For each historical event, total rainfall depths for the event duration were summed across the daily and sub-daily rainfall gauges. A natural neighbour spatial distribution was applied to the calculated depths to produce a continuous total rainfall depth surface across the entire study area. Average rainfall depths for each subcatchment were subsequently extracted using the generated surface.

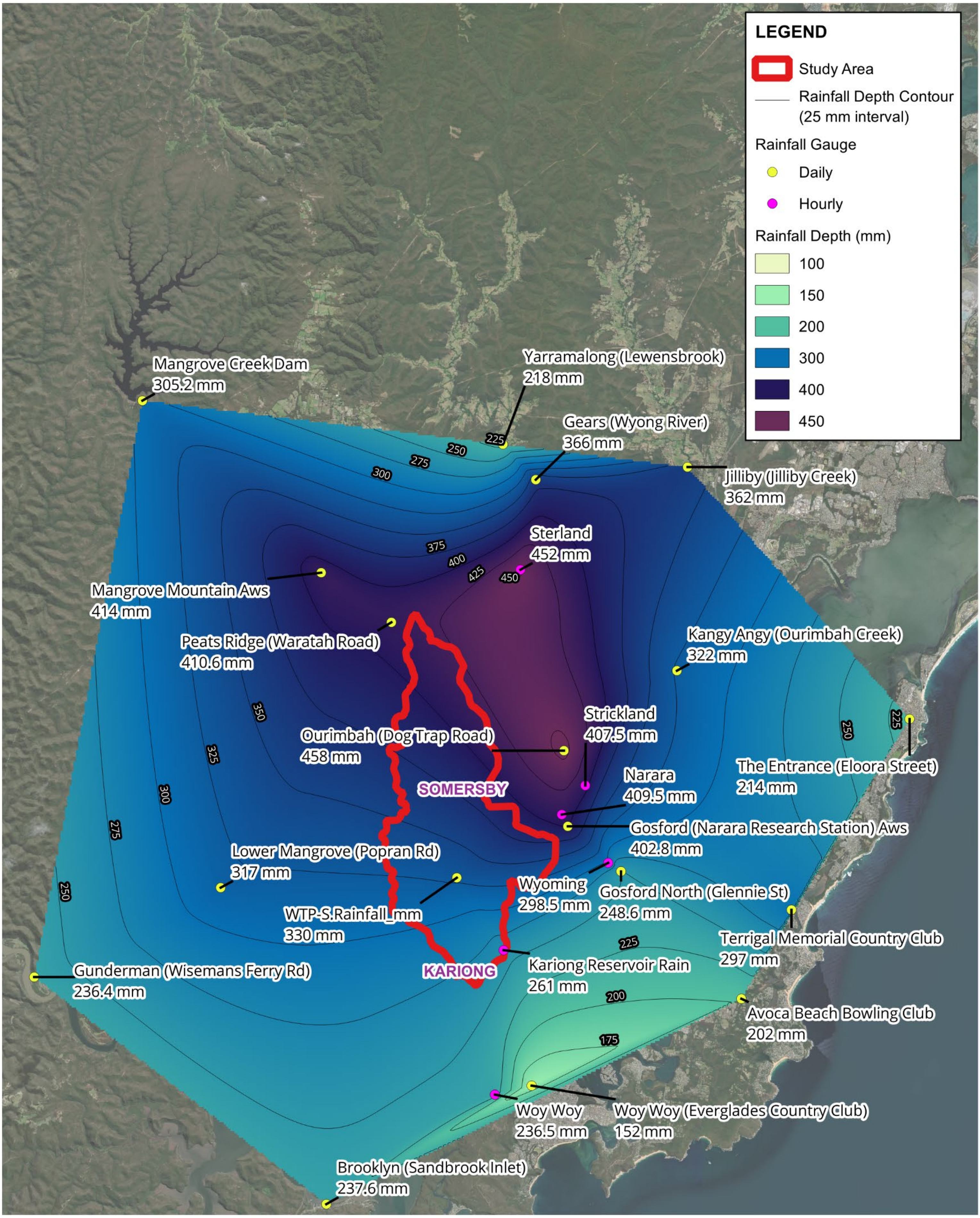
June 2007 Model Calibration

The June 2007 flood event resulted from widespread rainfall across the catchment with higher rainfall depths observed to the northeast. There were 25 active rainfall gauges with available data in the vicinity of the catchment for this event. Six of these gauges were hourly or sub-hourly gauges (Kariong Reservoir Rain, Narara, Sterland, Strickland, Woy Woy, Wyoming). The event spanned three days with rainfall depths assessed between 7/06/2007 0:00 - 10/06/2007 0:00 (daily gauge readings to 12am).

The event total rainfall depths have been summarised in **Table 5-2**, with the highest 3-day total rainfall recorded at Ourimbah (Dog Trap Road) gauge (458 mm). The total rainfall depth surface is presented in **Figure 5-1**.

Table 5-2: Event Total Rainfall - 7/06/2007 0:00 - 10/06/2007 0:00

Gauge Name	Rainfall Depth (mm)	Gauge Name	Rainfall Depth (mm)
Ourimbah (Dog Trap Road) (Daily)	458	Wyoming (Pluvio)	298.5
Sterland (Pluvio)	452	Terrigal Memorial Country Club (Daily)	297
Mangrove Mountain Aws (Daily)	414	Kulnura (Jeavons) (Daily)	286
Peats Ridge (Waratah Road) (Daily)	410.6	Kariong Reservoir Rain (Pluvio)	261
Narara (Pluvio)	409.5	Gosford North (Glennie St) (Daily)	248.6
Strickland (Pluvio)	407.5	Brooklyn (Sandbrook Inlet) (Daily)	237.6
Gosford (Narara Research Station) Aws (Daily)	402.8	Woy Woy (Pluvio)	236.5
Gears (Wyong River) (Daily)	366	Gunderman (Wisemans Ferry Rd) (Daily)	236.4
Jilliby (Jilliby Creek) (Daily)	362	Yarramalong (Lewensbrook) (Daily)	218
WTP-S.Rainfall_mm (Daily)	330	The Entrance (Eloora Street) (Daily)	214
Kangy Angy (Ourimbah Creek) (Daily)	322	Avoca Beach Bowling Club (Daily)	202
Lower Mangrove (Popran Rd) (Daily)	317	Woy Woy (Everglades Country Club) (Daily)	152
Mangrove Creek Dam (Daily)	305.2		



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Spatial Distribution of Total Event Rainfall Depths – June 2007

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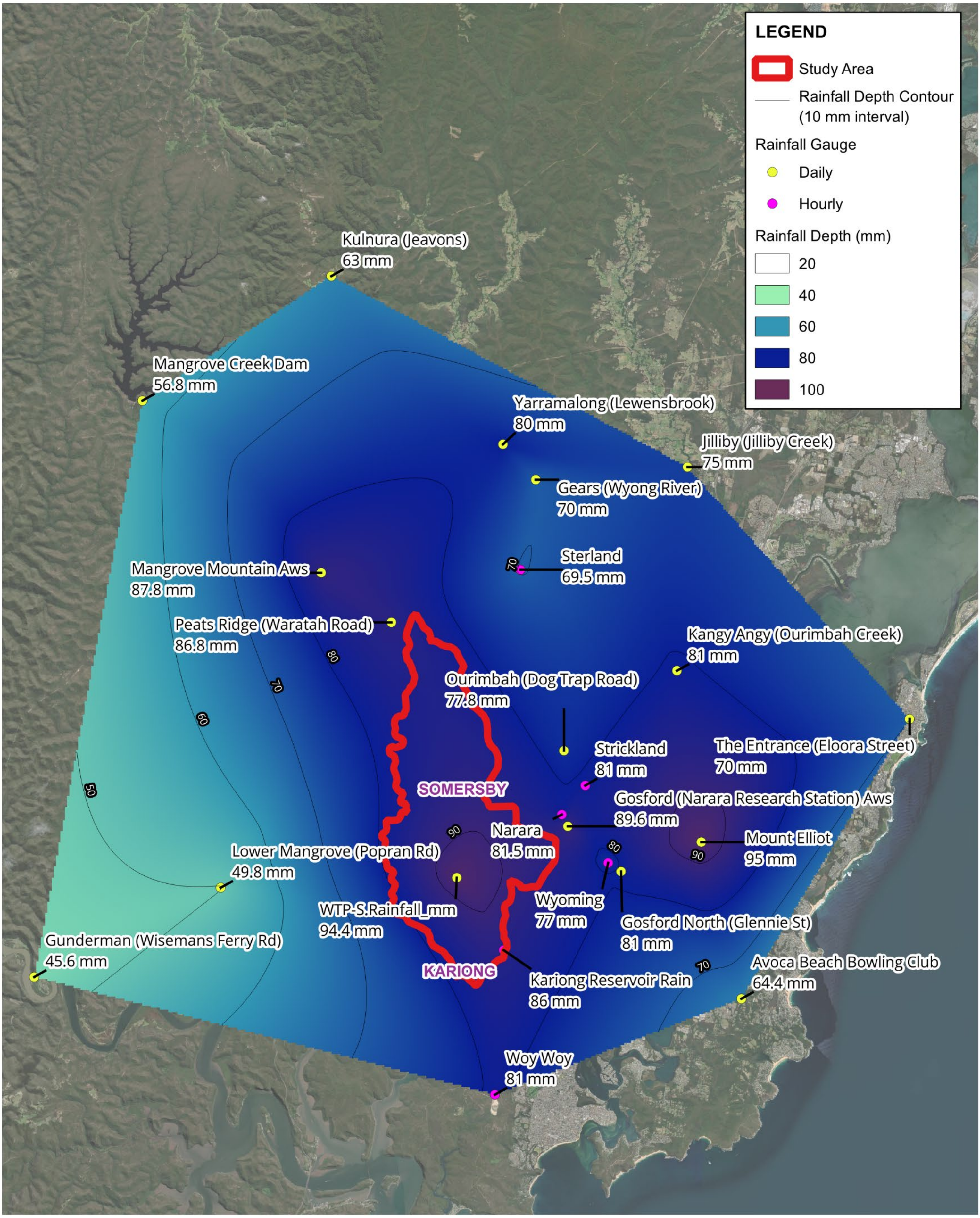
November 2011 Model Calibration

The November 2011 flood event resulted from widespread rainfall across the catchment with higher rainfall depths observed to the centre and to the east. There were 23 active rainfall gauges with available data in the vicinity of the catchment for the November 2011 event. Six of these gauges were hourly or sub-hourly gauges (Kariong Reservoir Rain, Narara, Sterland, Strickland, Woy Woy, Wyoming). The event spanned three days with rainfall depths assessed between 24/11/2011 0:00 – 27/11/2011 0:00 (daily readings to 12am).

The event total rainfall depths have been summarised in **Table 5-3** for all 23 gauges, with the highest 3-day total rainfall within the study area at Mount Elliot gauge (95 mm). The total rainfall depth surface is presented in **Figure 5-2**.

Table 5-3: Event Total Rainfall – 24/11/2011 0:00 – 27/11/2011 0:00

Gauge Name	Rainfall Depth (mm)	Gauge Name	Rainfall Depth (mm)
Mount Elliot (Daily)	95	Ourimbah (Dog Trap Road) (Daily)	77.8
WTP-S.Rainfall_mm (Daily)	94.4	Wyoming (Pluvio)	77
Gosford (Narara Research Station) Aws (Daily)	89.6	Jilliby (Jilliby Creek) (Daily)	75
Mangrove Mountain Aws (Daily)	87.8	Gears (Wyong River) (Daily)	70
Peats Ridge (Waratah Road) (Daily)	86.8	The Entrance (Eloora Street) (Daily)	70
Kariong Reservoir Rain (Pluvio)	86	Sterland (Pluvio)	69.5
Narara (Pluvio)	81.5	Avoca Beach Bowling Club (Daily)	64.4
Gosford North (Glennie St) (Daily)	81	Kulnura (Jeavons) (Daily)	63
Kangy Angy (Ourimbah Creek) (Daily)	81	Mangrove Creek Dam (Daily)	56.8
Strickland (Pluvio)	81	Lower Mangrove (Popran Rd) (Daily)	49.8
Woy Woy (Pluvio)	81	Gunderman (Wisemans Ferry Rd) (Daily)	45.6
Yarramalong (Lewensbrook) (Daily)	80		



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Spatial Distribution of Total Event Rainfall Depths – November 2011

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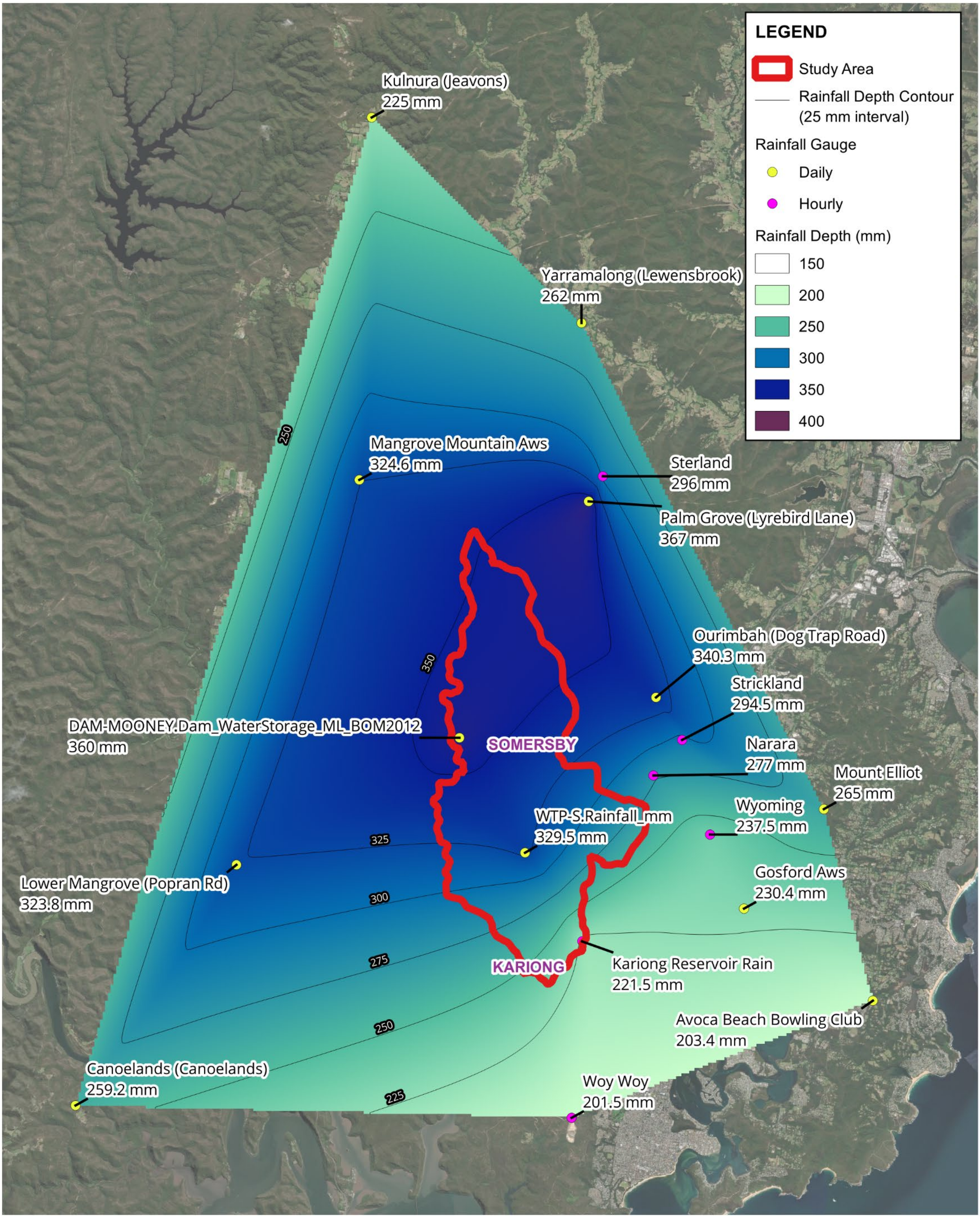
March 2021 Model Validation

The March 2021 flood event resulted from widespread rainfall across the catchment with higher rainfall depths observed to the north. There were 18 active rainfall gauges with available data in the vicinity of the catchment for the March 2021 event. Six of these gauges were hourly or sub-hourly gauges (Kariong Reservoir Rain, Narara, Sterland, Strickland, Woy Woy. The event spanned three days with rainfall depths assessed between 19/03/2021 0:00 – 22/03/2021 0:00 (daily readings to 12am).

The event total rainfall depths have been summarised in **Table 5-4** for all 18 gauges. The total rainfall depth surface is presented in **Figure 5-3**.

Table 5-4: Event Total Rainfall – 19/03/2021 0:00 – 22/03/2021 0:00

Gauge Name	Rainfall Depth (mm)	Gauge Name	Rainfall Depth (mm)
Palm Grove (Lyrebird Lane) (Daily)	367	Mount Elliot (Daily)	265
DAM-MOONEY.Dam_WaterStorage_ML_BOM2012 (Daily)	360	Yarramalong (Lewensbrook) (Daily)	262
Ourimbah (Dog Trap Road) (Daily)	340.3	Canoelands (Canoelands) (Daily)	259.2
WTP-S.Rainfall_mm (Daily)	329.5	Wyoming (Pluvio)	237.5
Mangrove Mountain Aws (Daily)	324.6	Gosford Aws (Daily)	230.4
Lower Mangrove (Popran Rd) (Daily)	323.8	Kulnura (Jeavons) (Daily)	225
Sterland (Pluvio)	296	Kariong Reservoir Rain (Pluvio)	221.5
Strickland (Pluvio)	294.5	Avoca Beach Bowling Club (Daily)	203.4
Narara (Pluvio)	277	Woy Woy (Pluvio)	201.5



Title:

Spatial Distribution of Total Event Rainfall Depths – March 2021

Figure: 5-3

Rev: 0

Scale at A4 1:180000

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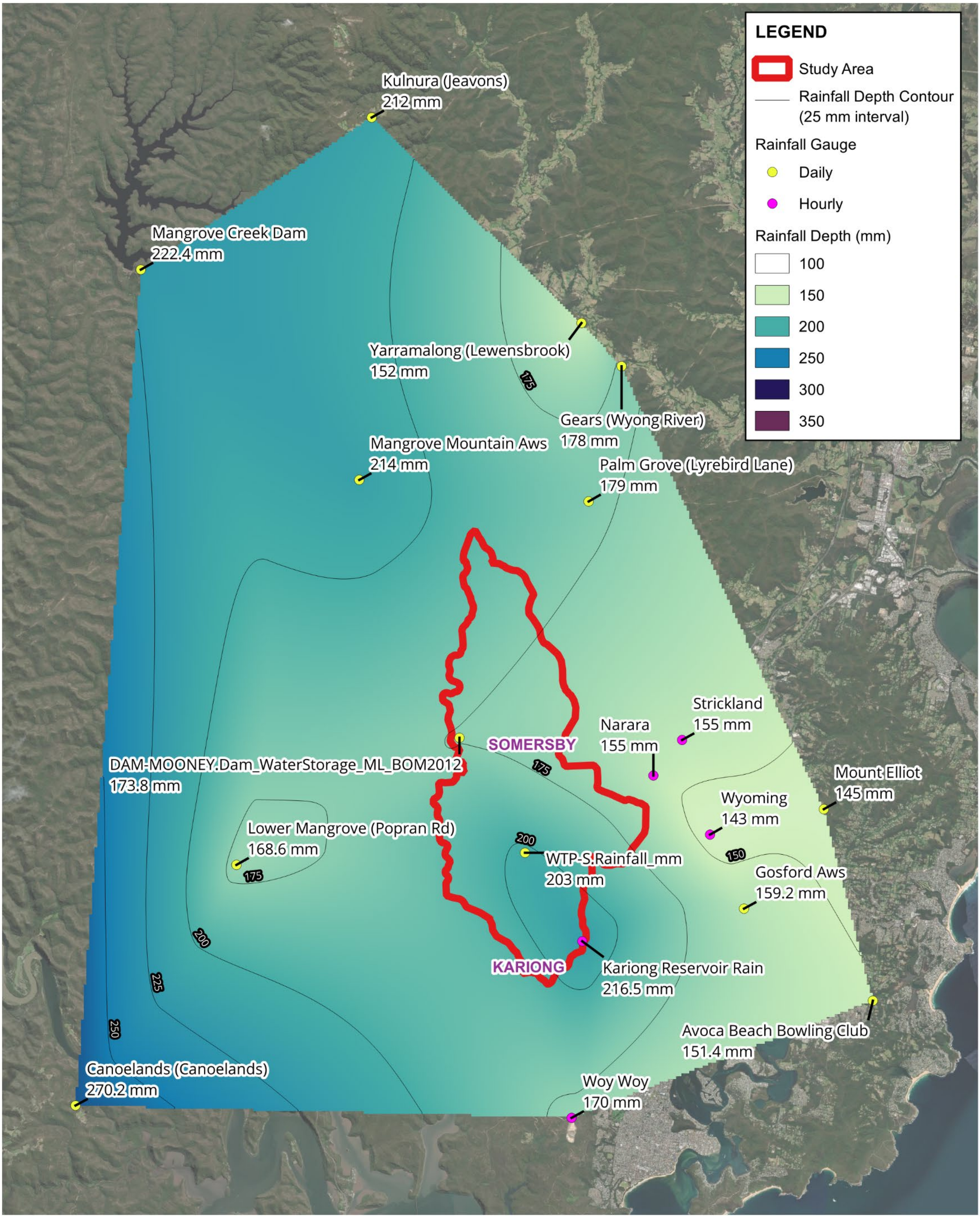
March 2022 Model Validation

The March 2022 flood event resulted from widespread rainfall across the catchment with higher rainfall depths to the west. There were 18 active rainfall gauges with available data in the vicinity of the catchment for the March 2022 event. Five of these gauges were hourly or sub-hourly gauges (Kariong Reservoir Rain, Narara, Strickland, Woy Woy, Wyoming). The event spanned three days with rainfall depths assessed between 1/03/2022 0:00 – 4/03/2022 0:00 (daily readings to 12am).

The event total rainfall depths have been summarised in **Table 5-5** for all 18 gauges, with the highest total rainfall at Canoelands gauge (270.2 mm) within the study area. The total rainfall depth surface across the whole catchment displayed in **Figure 5-4**.

Table 5-5: Event Total Rainfall 1/03/2022 0:00 – 4/03/2022 0:00

Gauge Name	Rainfall Depth (mm)	Gauge Name	Rainfall Depth (mm)
Canoelands (Canoelands) (Daily)	270.2	Woy Woy (Pluvio)	170
WTP-S.Rainfall_mm (Daily)	203	Lower Mangrove (Popran Rd) (Daily)	168.6
Mangrove Mountain Aws (Daily)	214	Gosford Aws (Daily)	159.2
Kariong Reservoir Rain (Pluvio)	216.5	Avoca Beach Bowling Club (Daily)	151.4
Mangrove Creek Dam (Daily)	222.4	Yarramalong (Lewensbrook) (Daily)	152
Kulnura (Jeavons) (Daily)	212	Narara (Pluvio)	155
Palm Grove (Lyrebird Lane) (Daily)	179	Strickland (Pluvio)	155
DAM-MOONEY.Dam_WaterStorage_ML_BOM2012 (Daily)	173.8	Mount Elliot (Daily)	145
Gears (Wyong River) (Daily)	178	Wyoming (Pluvio)	143



Title:

Spatial Distribution of Total Event Rainfall Depths – March 2022

Figure: 5-4

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Scale at A4 1:180000

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Scale:

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5.3.2 Temporal Patterns

For each historical event, temporal patterns were derived by selecting the nearest pluviograph operational during the event per subcatchment. The pluviograph data was provided in hourly and 15-minute intervals depending on the gauge. The hourly gauge values were segmented into 15-minute interval values to facilitate implementation into the hydraulic model. The distribution of temporal patterns and the hourly rainfall graphs for applied pluviographs have been presented below.

Temporal Pattern Distribution

Of the pluviographs operational during the selected historical events, the three nearest gauges to the catchment were selected for further analysis – Kariong Reservoir Rain, Narara and Sterland. Subcatchments were allocated to each of these three gauges for the June 2007, November 2011 and March 2021 events. During the March 2022 event, the Sterland gauge was not operational, as such the Strickland gauge temporal pattern was implemented instead for this event.

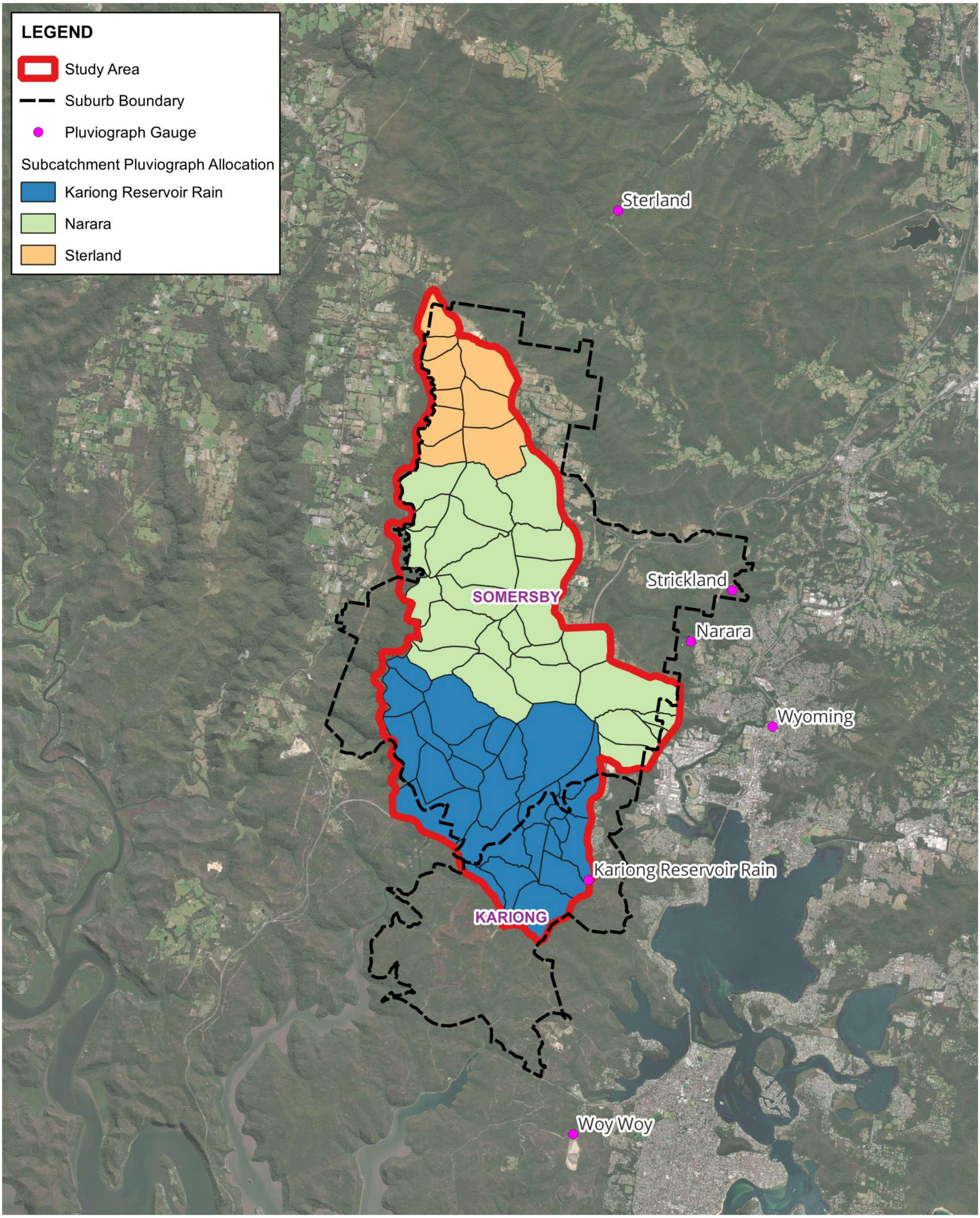
The subcatchment allocation and number of subcatchments per pluviograph for all four events is provided in **Table 5-6**, **Table 5-7**, **Figure 5-5** and **Figure 5-6**.

Table 5-6: Number of Subcatchments Designated to Pluviograph Generated Temporal Pattern – June 2007, November 2011 and March 2021

Pluviograph	Number of Subcatchments
Kariong Reservoir Rain	27
Narara	25
Sterland	9

Table 5-7: Number of Subcatchments Designated to Pluviograph Generated Temporal Pattern – March 2022

Pluviograph	Number of Subcatchments
Kariong Reservoir Rain	27
Narara	29
Strickland	5



Title:

Temporal Pattern Allocation of Pluviograph to Subcatchments – June 2007, November 2011, March 2021

Figure: 5-5

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Scale at A4 1:125000

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Scale:

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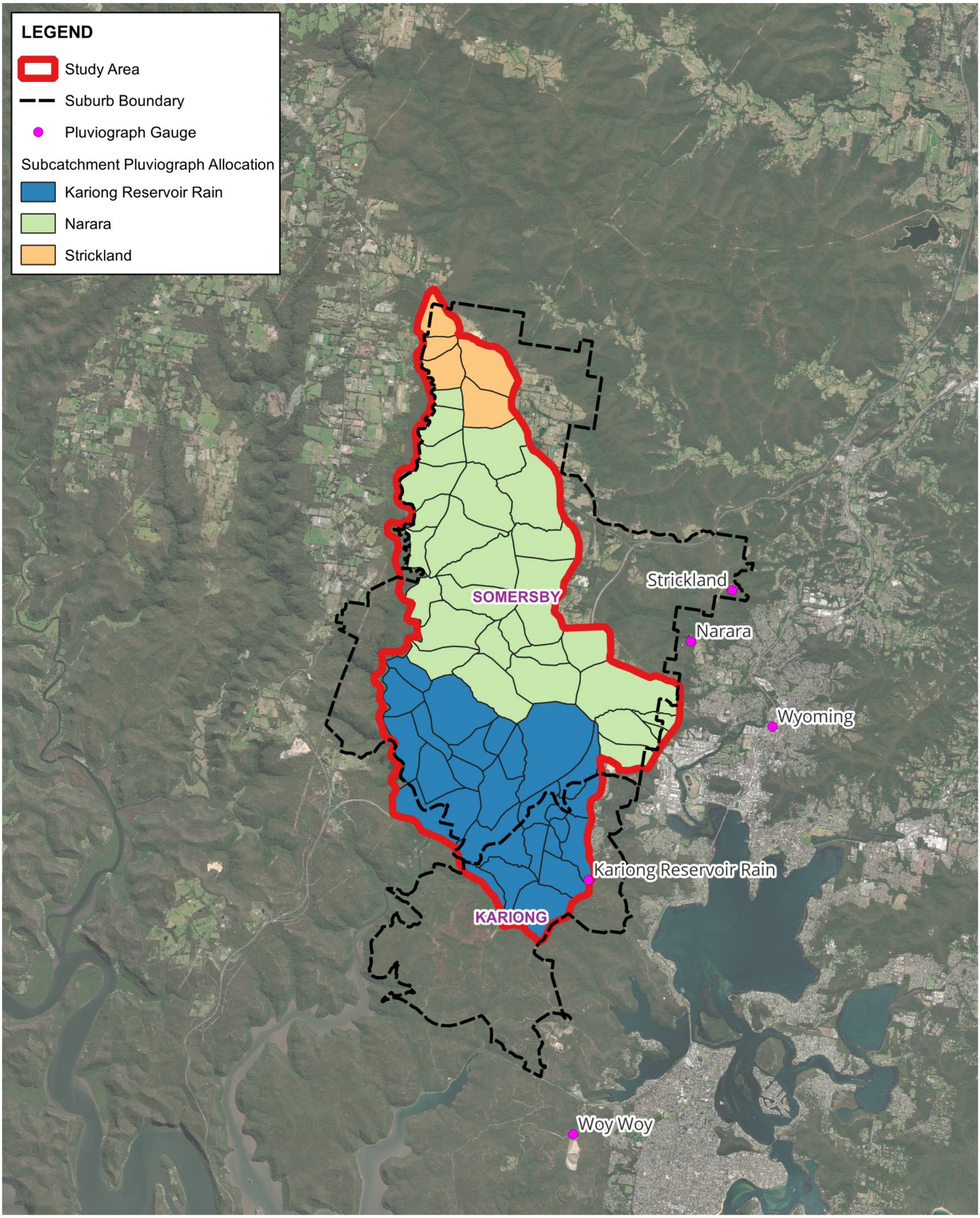

Title:

Temporal Pattern Allocation of Pluviograph to Subcatchments – March 2022

Figure: 5-6

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Scale at A4 1:125000

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Temporal Pattern Hourly Rainfall Data

The sub-hourly rainfall depth temporal patterns for the implemented pluviographs per event are displayed in **Figure 5-7** to **Figure 5-10** below. The temporal patterns start time was selected as 12 am to maintain consistency between the selected pluviographs and accompanying daily gauges at the same locations.

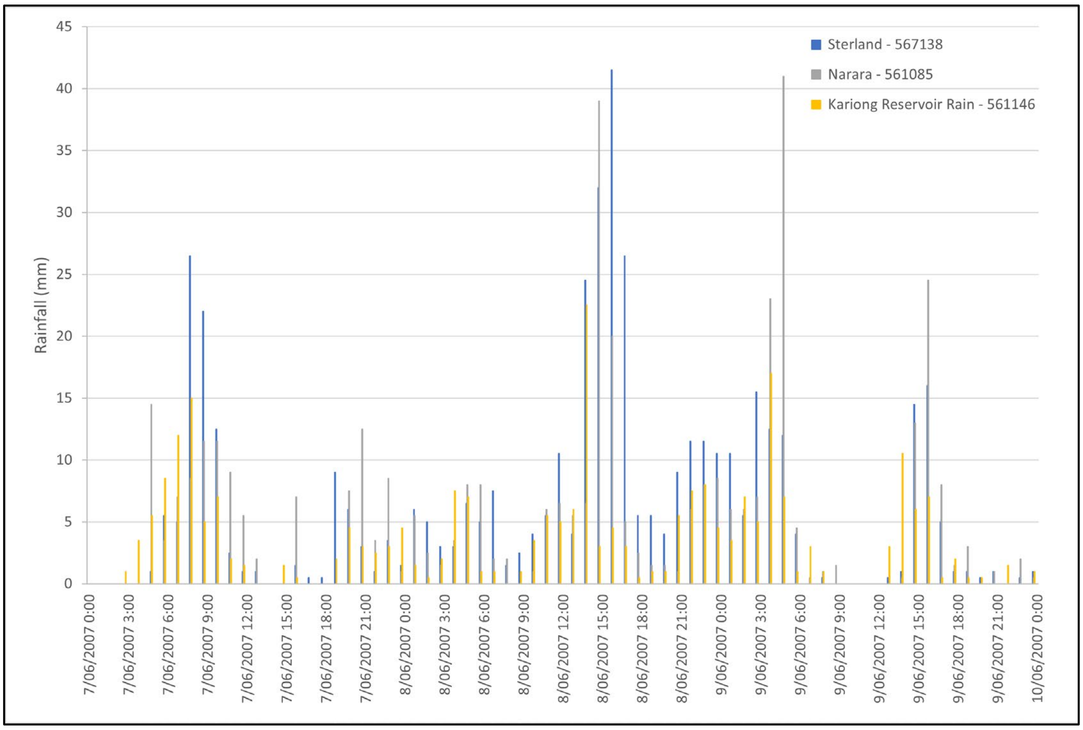


Figure 5-7: Recorded June 2007 – Sub-Hourly Rainfall Data

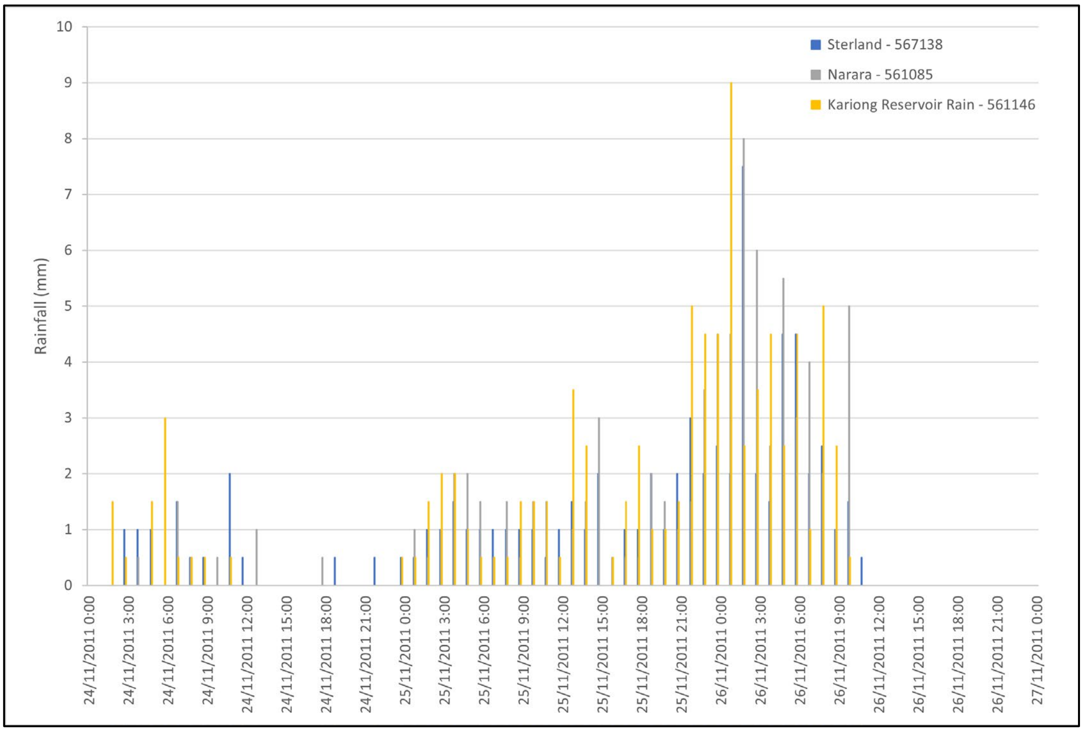


Figure 5-8: Recorded November 2011 – Sub-Hourly Rainfall Data

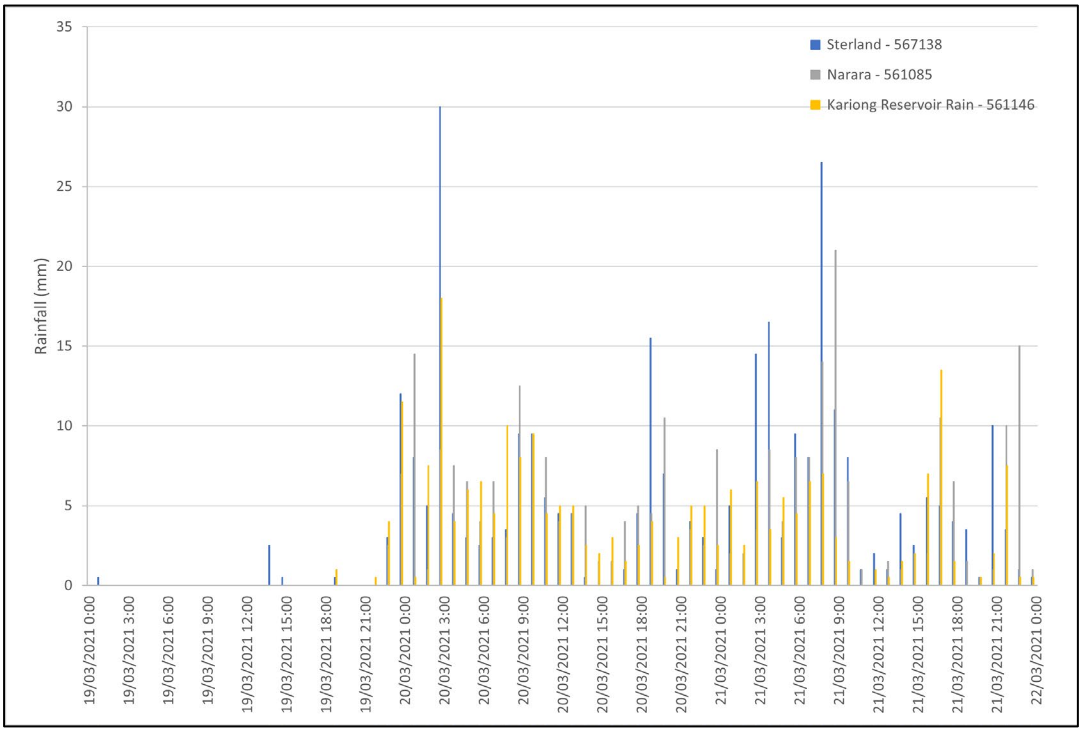


Figure 5-9: Recorded March 2021 – Sub-Hourly Rainfall Data

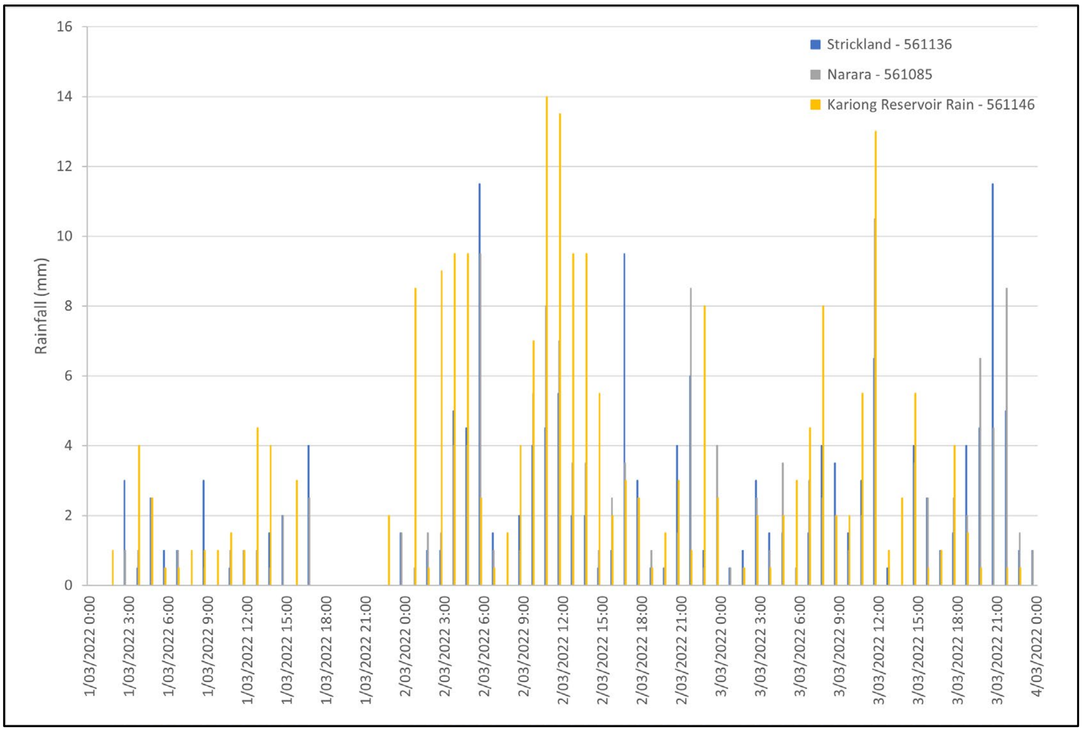


Figure 5-10: Recorded March 2022 – Sub-Hourly Rainfall Data

5.3.3 Intensity-Frequency-Duration Comparison to Historic Event Rainfall

To determine the approximate Annual Exceedance Probability (AEP) of the historic event rainfall, design rainfall depths were extracted from the Bureau of Meteorology 2016 Rainfall IFD Data System for the catchment centroid (-33.39107, 151.27347). The Intensity-Frequency-Duration (IFD) design rainfall depths were then converted into rainfall depth curves by plotting the rainfall depth against duration for each AEP event. The historical pluviographs used for each historic event were then plotted to determine approximate AEP and duration of the event.

It can be seen across the four events that higher rainfall in the catchment correlated with higher variability between the three pluviographs. The June 2007 event was the largest and most variable, with the Sterland Gauge recording an event comparable to a 60-hour design storm between a 2% and 1% AEP, while the Kariong Reservoir gauge recorded an event comparable to a 60-hour design storm between a 20% and 10% AEP. Comparison of the historic events against design rainfall depths and durations can be seen in **Table 5-8** and **Figure 5-11** to **Figure 5-14**.

Table 5-8: Historic Event Comparison to Design Rainfall Depth and Duration

Pluviographs	Historic Event Comparison to Design Rainfall Depth and Duration*			
	June 2007	November 2011	March 2021	March 2022
Kariong Reservoir	20% - 10% AEP 60 Hours	4 EY - 2 EY 30 - 36 Hours	20% AEP 48 Hours	50% - 20% AEP 60 - 66 Hours
Narara	2% AEP 60 Hours	4 EY - 2 EY 30 - 36 Hours	10% AEP 48 Hours	63.2% AEP 60 - 66 Hours
Sterland	2% - 1% AEP 60 Hours	4 EY 30 - 36 Hours	10% - 5% AEP 48 Hours	-
Strickland	-	-	-	63.2% AEP 60 - 66 Hours

**EY - Average number of exceedances per year, % AEP - Annual exceedance probability*

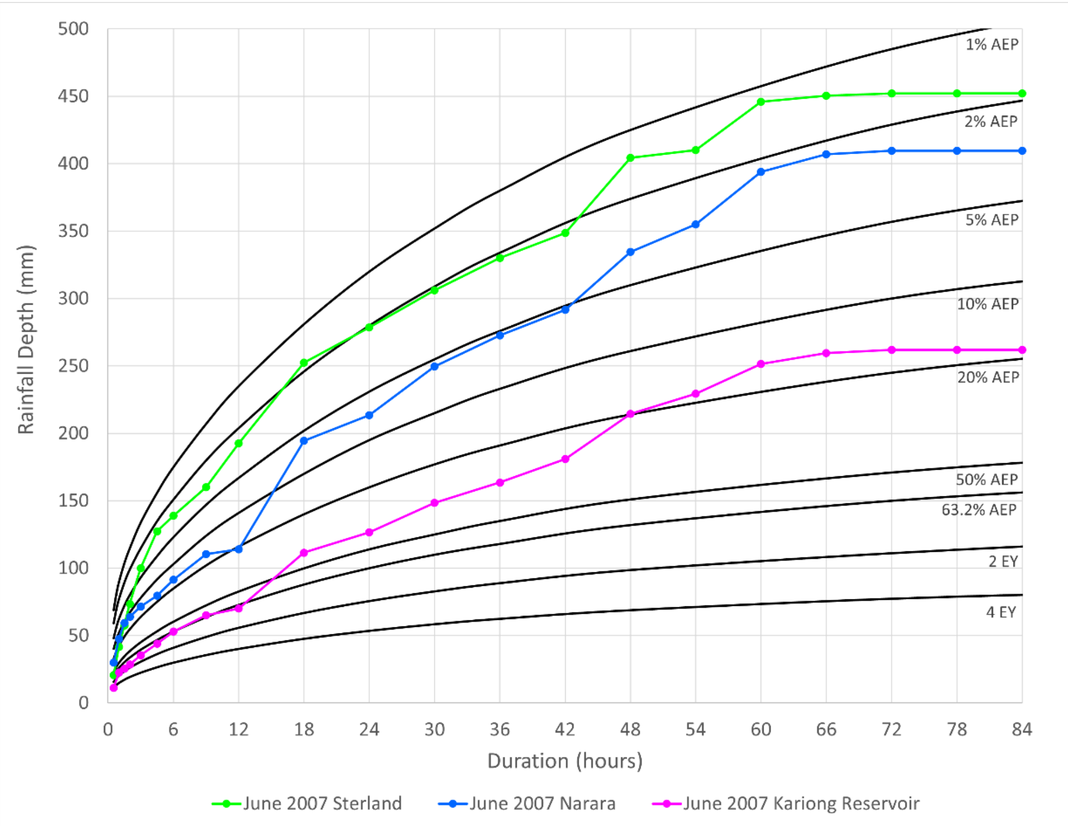


Figure 5-11: IFD Chart June 2007

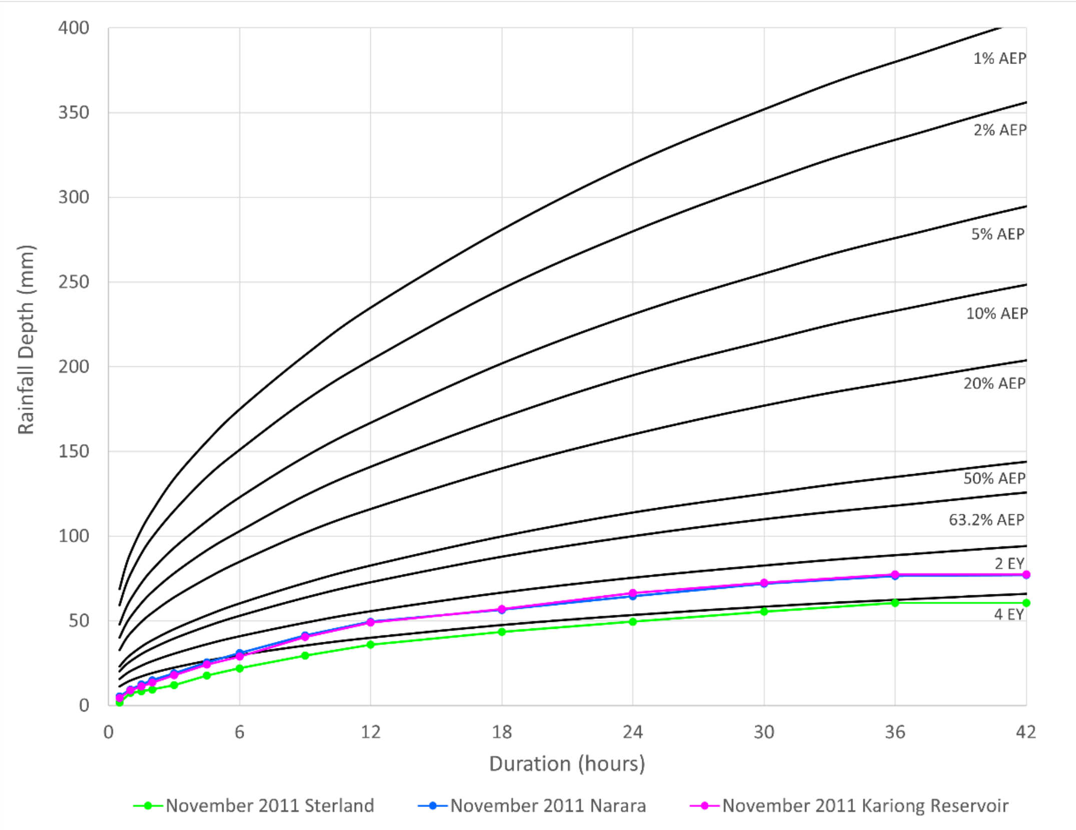


Figure 5-12: IFD Chart November 2011

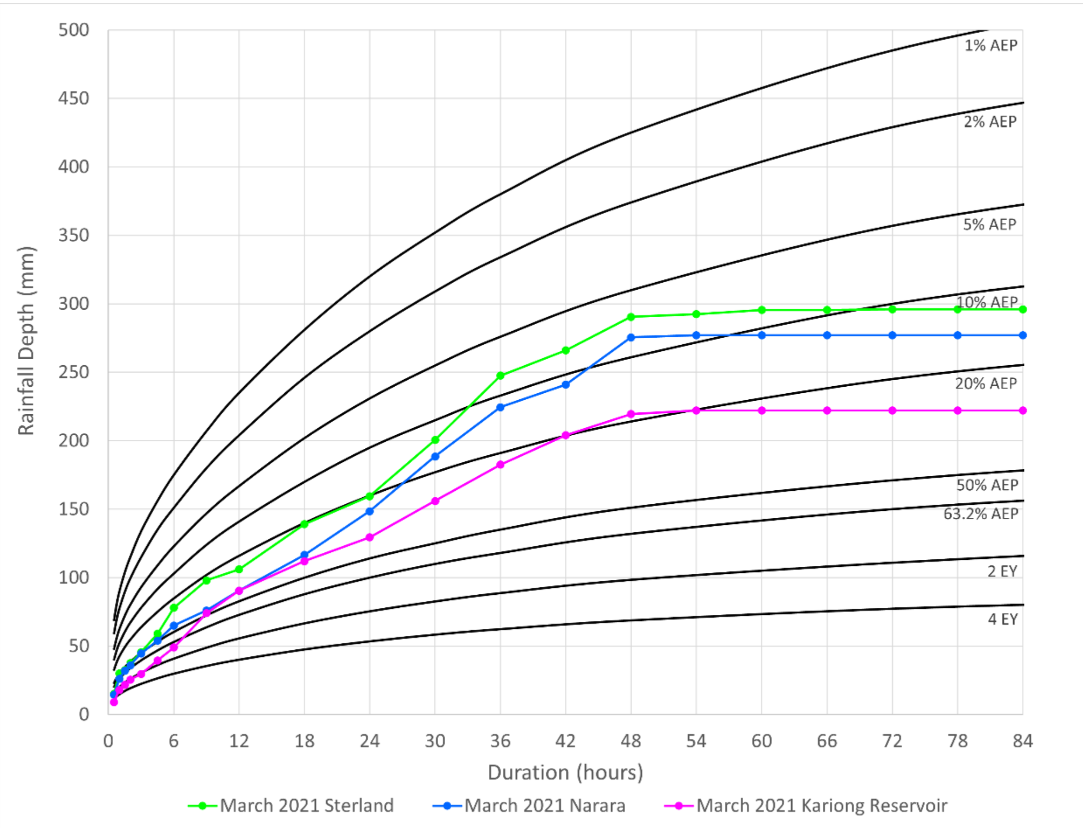


Figure 5-13: IFD Chart March 2021

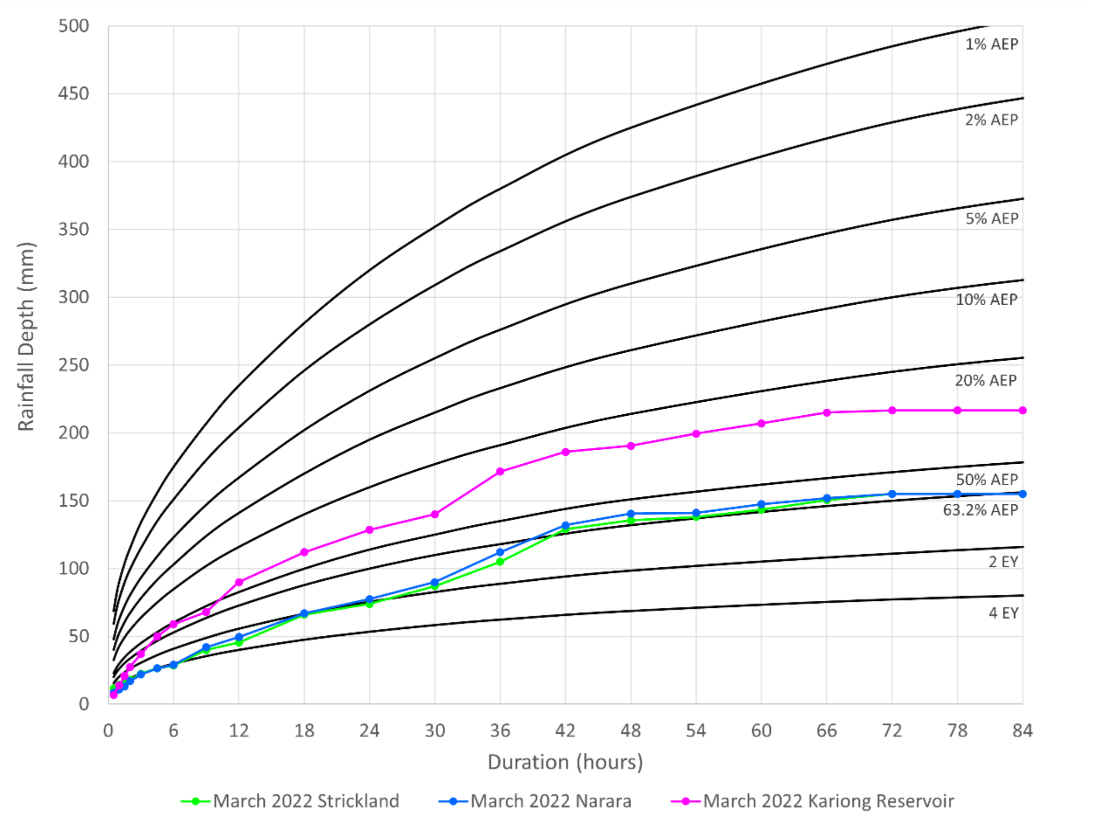


Figure 5-14: IFD Chart March 2022

5.3.4 Rainfall Losses

During the calibration process, initial and continuing loss values were iteratively adjusted until the simulated model results provided a reasonable match to the observations from community consultation responses.

The calibration process identified the catchment response was insensitive to initial loss. Initial losses adopting either the Probability Neutral Burst Initial Loss or fixed values such as 10 or 20 mm did not change the outcomes of the calibration. Hence, a fixed initial loss of 10 mm was adopted and scaled between the fully pervious and impervious material types as per **Table 4-2.**

For continuing losses applied to pervious material types, NSW state specific advice recommends the factoring of the ARR Data Hub continuing loss by a factor of 0.4, then rounding up. As such, the ARR Data Hub continuing loss of 3.2 mm/hr was adjusted to a value of 1.28 mm/hr. This continuing loss was then scaled to fixed values based off imperviousness of each of the categories as opposed to a direct percentage scaling as adopted for the initial loss.

Through the iterative process it was identified a single set of adopted losses fitted all four calibration events. As such a single set was maintained for all calibration events. However, the calibration events were also identified to be very long duration relative to the catchment size. As such, it was not considered appropriate to carry this set of calibrated losses through to design event modelling. The adopted losses for design event modelling are discussed within **Section 6.1.3**.

The initial and continuing losses adopted for each land use category during calibration are presented in **Table 5-9.**

Table 5-9: Adopted Loss Values for Each Land Use Category

Soil Classification / Material Type	Initial Loss (mm)	Continuing Loss (mm/hr)
Waterbodies	1	0.0
Roads	1	0.0
Open Space	9.5	1.28
Industrial	1	0.0
Primary Production, Rural Residential	8.5	0.5
Quarry	9.5	1.28
Urban Residential	2.5	0.3
Densely Vegetated	9.5	1.28
Building Footprints	2.5	0.5

5.4 CALIBRATION/VALIDATION DATA

As previously outlined, the model calibration and validation process relied upon observed peak flood level estimates and flood free property observations provided as part of the community consultation questionnaire responses. In the absence of surveyed flood levels or suitable stream gauge within the catchment, they represent the best available information upon which to base the model calibration and validation.

Responses from community consultation often required interpretation due to the nature of the responses. Flood level estimates are often constructed from the memories of residents, estimated from photographs taken following a flood event or from debris marks observed after a flood event. These approximate flood depths were then converted to levels by adding LiDAR data surface levels (m AHD) at the given location.

It is to be noted that due to the some of the responses relating to anecdotal evidence, such as stating the depths were “thereabouts” or “approximately”, that the location and reported depths may be inherently inaccurate or unreliable.

As such, a level of certainty was placed on each of the responses to help inform the weighting of responses through the calibration process. Three categories were adopted; high, medium and low, the basis of each category is presented in **Table 5-10**.

Of the responses collected in the community consultation, the number implemented into calibration and the confidence in the observed levels have been outlined in **Table 5-11** and **Table 5-12**.

Additionally, pictures of the flood levels during the March 2022 flood event were provided as part of the community consultation, they have been reviewed as a component of the calibration as outlined in **Section 5.5.4**.

Table 5-10: Community Response Certainty Definitions

Certainty	Definition
High	Responses were considered High Certainty when explicit detail was provided. This included responses with exact measurements, definitive language such as “certain,” “definitely,” or “most likely,” and cases where residents clearly stated their properties were not affected by flooding.

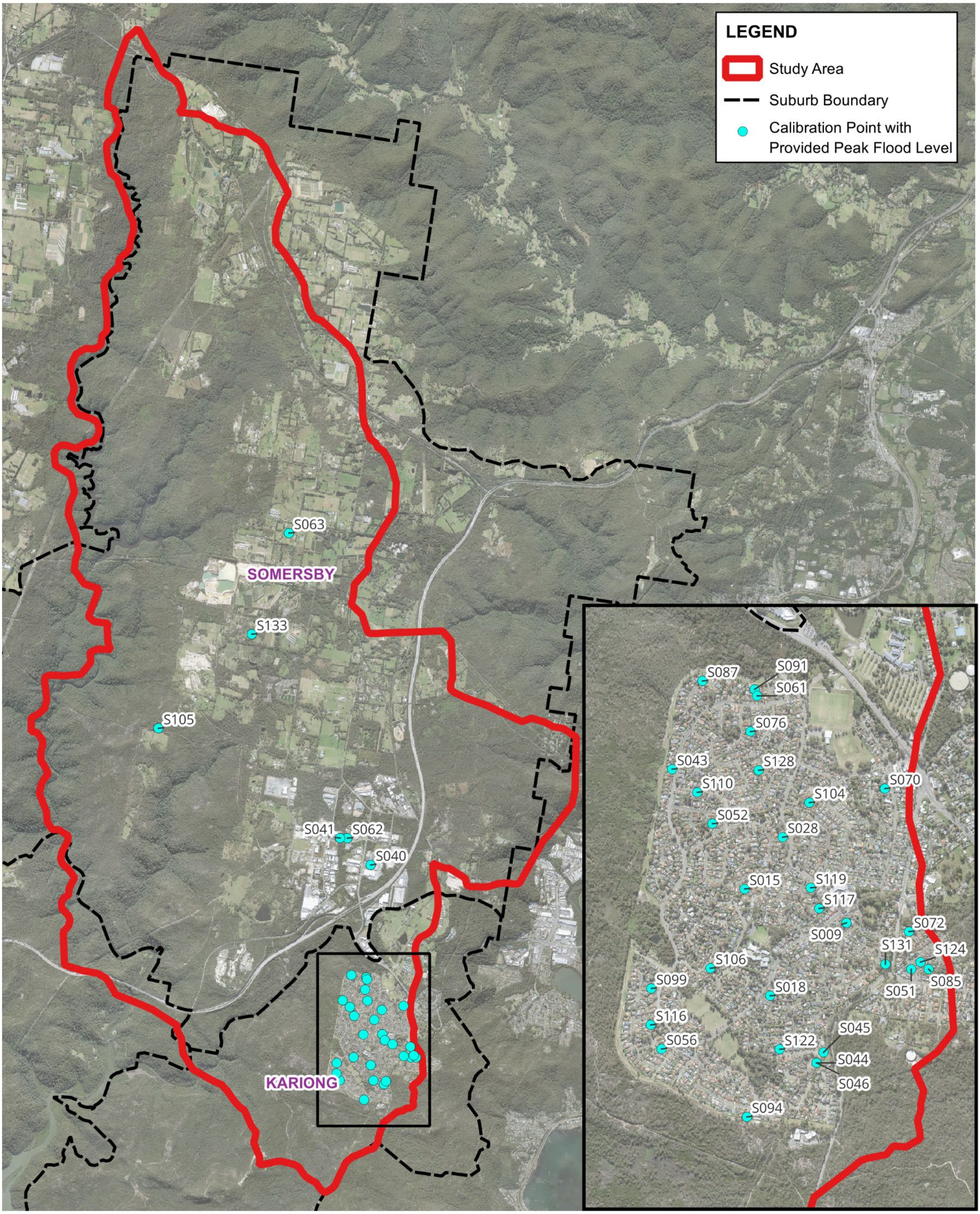
Certainty	Definition
Medium	Responses were considered Medium Certainty when approximate or generalised information was provided. This included language such as “thereabouts”, “roughly” or “approximately” and descriptions using generic terms like “up to the back shed” or “the backyard.”
Low	Responses were considered Low Certainty when uncertainty was explicitly stated or a lack of precise detail. These included statements using terms such as “uncertain” or instances where respondents indicated they “couldn’t say exactly.”

Table 5-11: Number of Community Consultation Responses Implemented in Calibration/Validation

Storm Event	Total Number of Responses Related to Event	Number of Responses with no Flooding Recorded at the Property	Number of Responses providing Peak Flood Levels for Calibration/ Validation
June 2007	92	74	18
November 2011	93	73	20
March 2021	122	103	19
March 2022	122	101	21

Table 5-12: The Confidence in Observed Peak Flood Level of the Community Consultation Responses Implemented in Calibration/Validation

Storm Event	Number of Responses providing Peak Flood Levels for Calibration/ Validation	Confidence in Observed Peak Flood Level		
		High	Medium	Low
June 2007	18	10	7	1
November 2011	20	11	9	0
March 2021	17	7	10	2
March 2022	22	10	11	1



Title:

Calibration Points with Provided Peak Flood Levels

Figure: 5-15

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5.5 CALIBRATION/VALIDATION RESULTS

5.5.1 June 2007 Model Calibration

The 18 observed/recorded peak flood levels and 74 flood free properties provided in the community consultation were used to inform the model calibration through comparison against simulated model results. No photos of flooding from the June 2007 event were provided as part of the community consultation process. The difference and location between these community consultation responses and the simulated levels is presented in **Table 5-13** and **Figure 5-16** respectively.

Table 5-14 provides a classification of the alignment between the simulated and observed peak flood levels and flood free properties.

The distribution of the observed flood level to simulated flood level difference is considered reasonable for calibration, with 17 of the 18 points simulated flood levels within 0.3 m of the observed levels and 16 of the 18 simulated flood levels within 0.1 m of the observed levels. Of the 74-flood free observed properties, 71 were simulated as flood free.

Of the community consultation responses received for the June 2007 event, a single respondent reported a depth at least 0.3 m higher than the simulated depth at the same location (ID S106). This calibration point was found to be within the vicinity of other points that indicated a reasonable alignment between simulated and observed levels and was hence considered likely to have issues with the uncertainty of location or flood level. The response indicated that flooding occurred within the house and yard of the property. While the property was not simulated to be located within a clearly defined flowpath, some localised ponding of waters was simulated.

Interrogation of the location through Google StreetView and aerial imagery highlighted several fences, kerbs and gutters that are beyond the resolution of the modelling. Presence of these key hydraulic controls may result in greater pooling than that simulated within the model. The limitations of the underlying topographic data should also be considered, with the potential for many of these key hydraulic controls to have been removed during LiDAR post-processing. Additionally, the mobilisation of debris could have blocked stormwater assets, exacerbating flood depths. Flood waters could have also backed up behind large debris, further increasing the flood depths observed.

Considering the known limitations of the topographic data used, and the difficulty of accurately recording flood levels during poor weather conditions, the overall level of agreement between the observed and simulated flood levels during the June 2007 calibration event was concluded as being satisfactory.

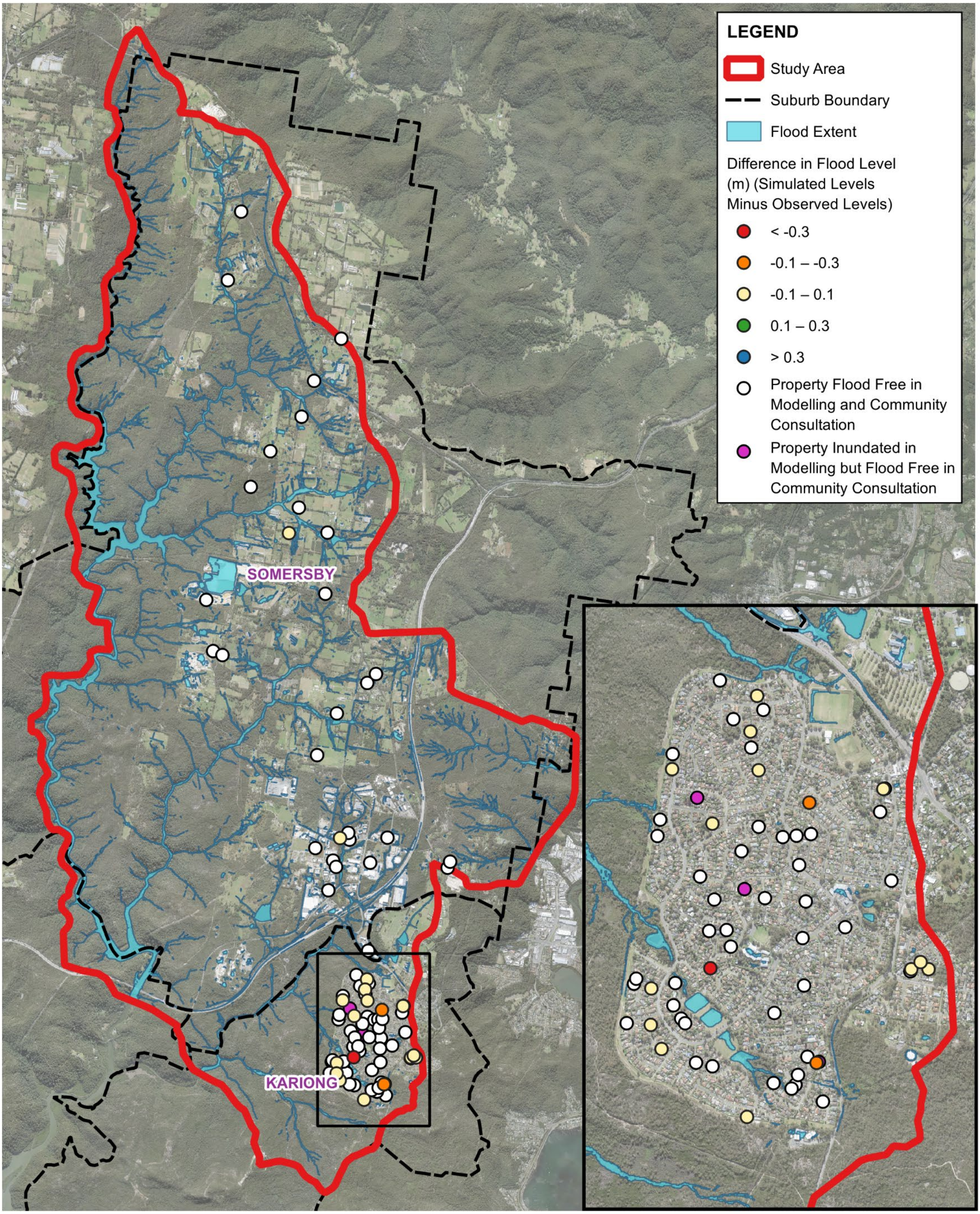
Table 5-13: June 2007 Calibration Event Peak Flood Level Comparison

Calibration Point ID	Observed Peak Flood Level (m AHD)	Observed Peak Flood Level Confidence	Simulated Peak Flood Level (m AHD)	Difference in Peak Flood Level (Simulated – observed) (m)
S061	158.22	Medium	158.27	0.05
S051	197.26	Medium	197.29	0.03
S085	199.60	High	199.63	0.03
S043	165.51	Medium	165.52	0.01
S041	168.85	Medium	168.86	0.00
S070	177.14	Medium	177.14	0.00

Calibration Point ID	Observed Peak Flood Level (m AHD)	Observed Peak Flood Level Confidence	Simulated Peak Flood Level (m AHD)	Difference in Peak Flood Level (Simulated – observed) (m)
S076	166.68	High	166.68	0.00
S128	171.48	Low	171.44	-0.03
S116	176.96	High	176.90	-0.05
S099	172.91	High	172.84	-0.07
S094	187.65	Medium	187.58	-0.07
S063	237.66	Medium	237.59	-0.07
S056	180.66	High	180.57	-0.09
S052	177.93	High	177.84	-0.10
S124	197.63	High	197.53	-0.10
S104	179.26	High	179.16	-0.11
S044	190.25	High	190.11	-0.14
S106	178.40	High	177.04	-1.36

Table 5-14: June 2007 Calibration Event Comparison of Community Consultation Observed Peak Flood Levels with Simulated Levels

	Properties with provided Observed Peak Flood Level and Comparison to the Simulated Levels (Simulated – Observed) (m)					Properties Indicated to be Flood Free in Community Consultation (0.05m Depth Cutoff Filter Applied for Classification)	
	< -0.3	-0.1 – -0.3	-0.1 – 0.1	0.1 - 0.3	> 0.3	Properties Flood Free in Simulated Results	Properties Impacted in Simulated Results
Number of Community Consultation Responses	1	2	15	0	0	71	3



Title:

Calibration Event – June 2007
Simulated Levels Minus Observed Levels

Figure: 5-16

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5.5.2 November 2011 Model Calibration

The 20 observed/recorded levels and 73 flood free properties provided in the community consultation were used to inform the model calibration through comparison against simulated model results. One photo of flooding from the November 2011 event was provided as part of the community consultation process. The difference and location between these community consultation responses and the simulated levels is presented in **Table 5-15** and **Figure 5-17** respectively. **Table 5-16** provides a classification of the alignment between the simulated and observed peak flood levels and flood free properties.

The distribution of the observed flood level to simulated flood level difference is reasonable for calibration, with 19 of the 20 points simulated flood levels within 0.3 m of the observed levels and 14 of the 20 simulated flood levels within 0.1 m of the observed levels. The single simulated level outside of -0.3 m of the observed level is within the vicinity of other points that provide a good alignment to observed levels and as such was determined to have issues with the uncertainty of location or flood level. Of the 73-flood free observed properties, 72 were simulated as flood free. As such a combination of simulated levels within 0.1 m of observed levels and flood free properties being flood free indicates an acceptable calibration to the November 2011 event.

Of the community consultation responses received for the November 2011 event, a single respondent reported a depth at least 0.3 m higher than the simulated depth at the same location (ID S106). This discrepancy has been reported upon in **Section 5.5.1**. The discrepancy at this location is consistent between all four simulated calibration events.

Table 5-15: November 2011 Calibration Event Peak Flood Level Comparison

Calibration Point ID	Observed Peak Flood Level (m AHD)	Observed Peak Flood Level Confidence	Simulated Peak Flood Level (m AHD)	Difference in Peak Flood Level (Simulated – observed) (m)
S099	172.78	High	172.82	0.05
S061	158.22	High	158.27	0.05
S087	161.70	High	161.73	0.03
S085	199.60	High	199.61	0.01
S128	171.43	High	171.43	0.01
S041	168.85	Medium	168.85	0.00
S043	165.51	Medium	165.51	0.00
S076	166.68	Medium	166.66	-0.02
S094	187.60	High	187.57	-0.03
S119	190.59	Medium	190.53	-0.05
S116	176.96	Medium	176.89	-0.06
S056	180.66	Medium	180.57	-0.09
S122	183.86	High	183.77	-0.09
S028	184.20	Medium	184.11	-0.09
S110	173.75	Medium	173.65	-0.10
S104	179.26	High	179.14	-0.12
S124	197.63	Medium	197.51	-0.12
S044	190.25	High	190.11	-0.14

Calibration Point ID	Observed Peak Flood Level (m AHD)	Observed Peak Flood Level Confidence	Simulated Peak Flood Level (m AHD)	Difference in Peak Flood Level (Simulated – observed) (m)
S046	190.25	High	190.11	-0.14
S106	178.40	High	177.01	-1.39

Table 5-16: November 2011 Calibration Event Comparison of Community Consultation Observed Peak Flood Levels with Simulated Levels

<table>
<tr><th rowspan="2"></th><th colspan="5">Properties with provided Observed Peak Flood Level and Comparison to the Simulated Levels
(Simulated – Observed) (m)</th><th colspan="2">Properties Indicated to be Flood Free in Community Consultation
(0.05m Depth Cutoff Filter Applied for Classification)</th></tr>
<tr><th>< -0.3</th><th>-0.1 – -0.3</th><th>-0.1 – 0.1</th><th>0.1 - 0.3</th><th>> 0.3</th><th>Properties Flood Free in Simulated Results</th><th>Properties Impacted in Simulated Results</th></tr>
<tr><td>Number of Community Consultation Responses</td><td>1</td><td>5</td><td>14</td><td>0</td><td>0</td><td>72</td><td>1</td></tr>
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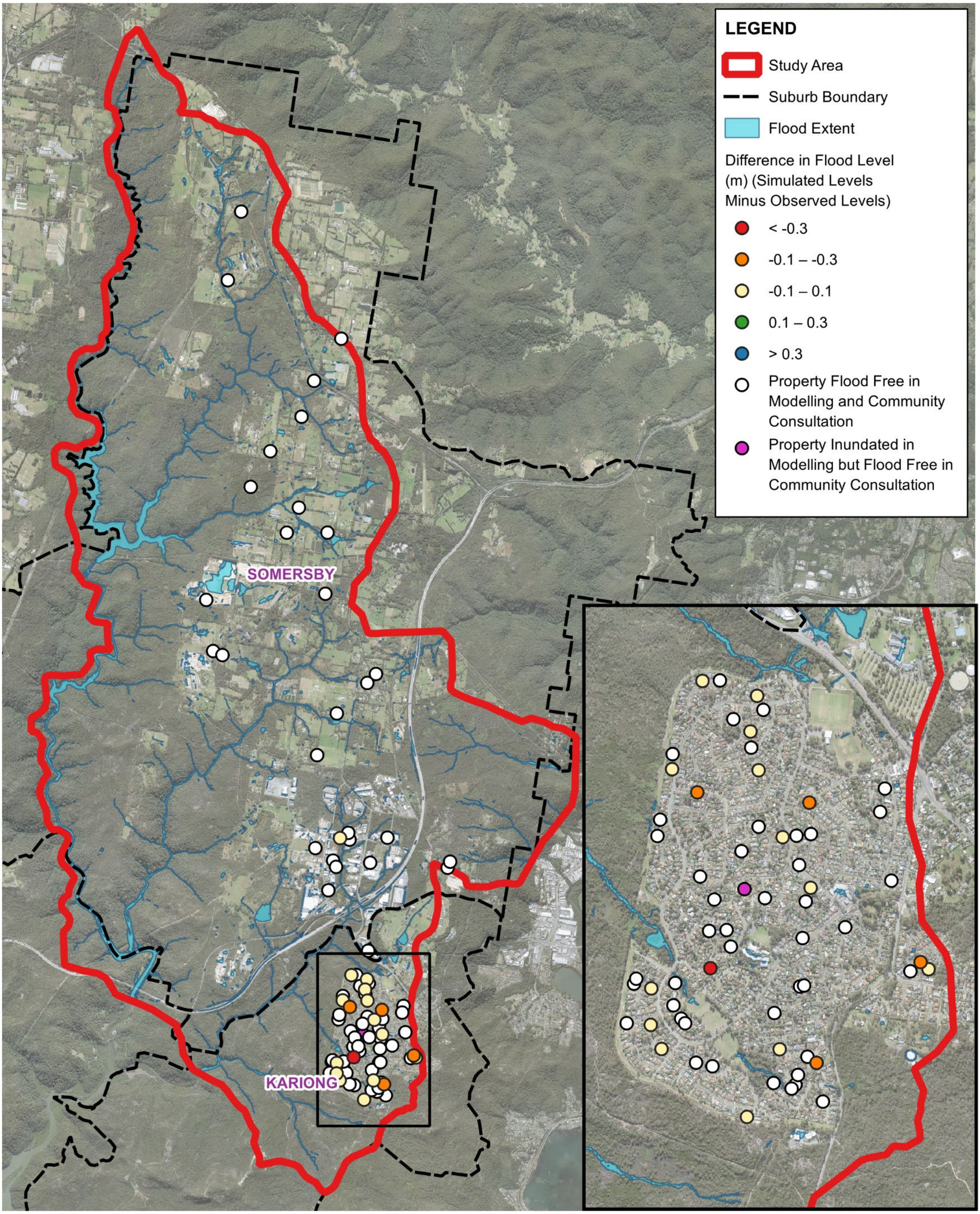

Title:

Calibration Event – November 2011 Simulated Levels Minus Observed Levels

Figure: 5-17

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5.5.3 March 2021 Model Validation

The 19 observed/recorded levels and 103 flood free provided in the community consultation were used to inform the model calibration through comparison against simulated model results. No photos of flooding from the March 2021 event were provided as part of the community consultation process. The difference and location between these community consultation responses and the simulated levels can be seen in **Table 5-17** and **Figure 5-18** respectively. **Table 5-18** provides a classification of the alignment between the simulated and observed peak flood levels and flood free properties.

The distribution of the observed flood level to simulated flood level difference is reasonable for validation, with 18 of the 19 points simulated flood levels within 0.3 m of the observed levels and 16 of the 17 simulated flood levels within 0.1 m of the observed levels. The simulated level that provides a difference of over -0.3 m is the same observed level from the previous two events and has other points that provide an alignment within 0.1 m of the observed levels near the same stormwater drainage system at Rees Street Reserve. As such it was determined that the point had issues with either uncertainty of location or flood level. Of the 103-flood free observed properties, 97 were simulated as flood free. As such a combination of simulated levels within 0.1 m of observed levels and flood free properties being flood free indicates an acceptable calibration to the March 2021 event.

Of the community consultation responses received for the March 2021 event, a single respondent reported a depth at least 0.3 m higher than the simulated depth at the given location (ID S106). This discrepancy was mentioned earlier in **Section 5.5.1**and is consistent for all four simulated calibration events.

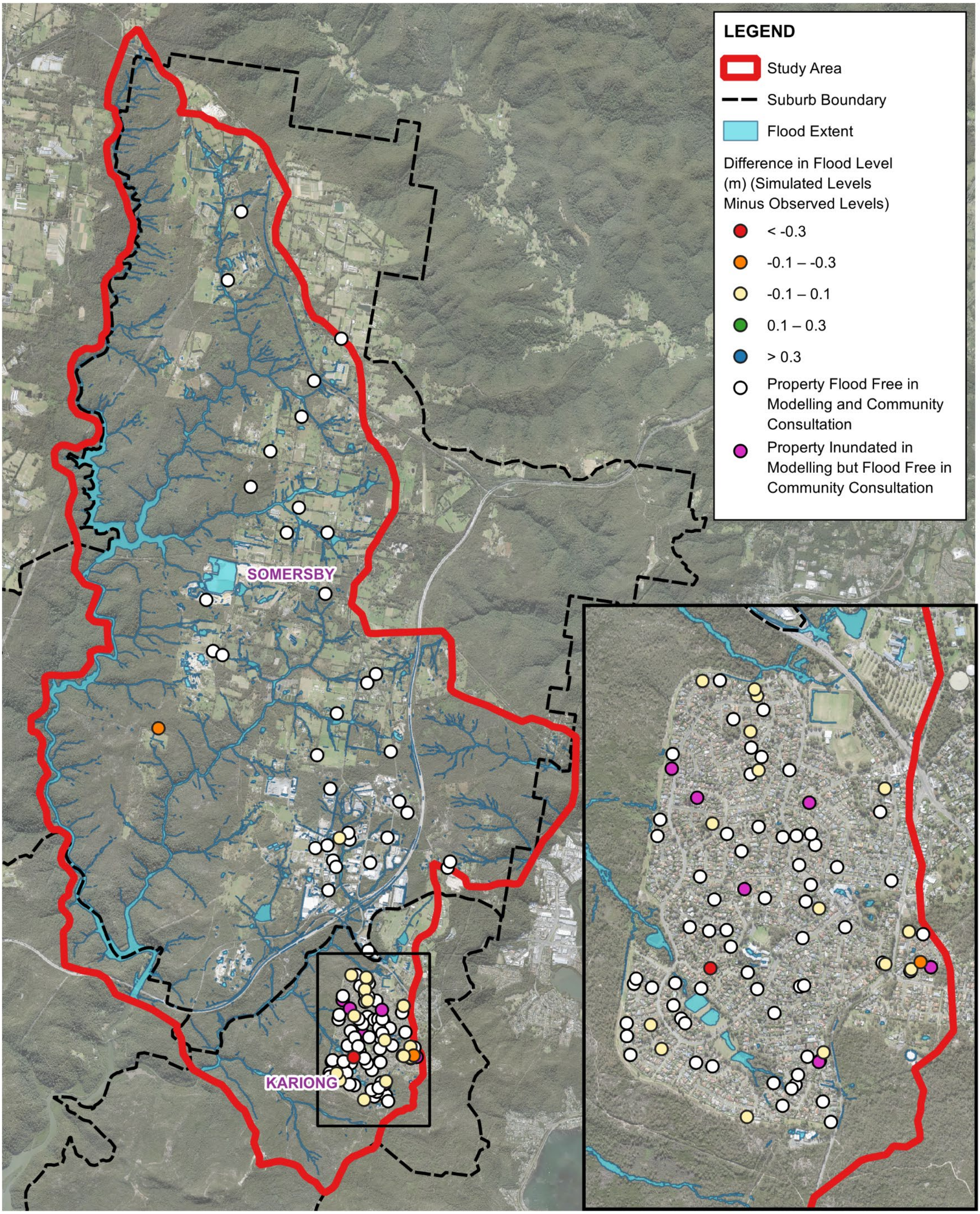
Table 5-17: March 2021 Validation Event Peak Flood Level Comparison

Calibration Point ID	Observed Peak Flood Level (m AHD)	Observed Peak Flood Level Confidence	Simulated Peak Flood Level (m AHD)	Difference in Peak Flood Level (Simulated – observed) (m)
S051	197.26	Medium	197.29	0.03
S087	161.70	High	161.73	0.03
S061	158.25	High	158.27	0.02
S128	171.43	Medium	171.44	0.01
S045	192.35	Medium	192.35	0.01
S041	168.85	Medium	168.86	0
S070	177.14	Medium	177.14	0
S072	193.94	Medium	193.94	0
S076	166.68	High	166.67	-0.01
S094	187.60	High	187.58	-0.02
S091	154.93	Low	154.89	-0.04
S116	176.96	Medium	176.90	-0.06
S131	194.41	Low	194.35	-0.07
S117	192.95	High	192.87	-0.08
S056	180.66	Medium	180.57	-0.09
S052	177.93	High	177.84	-0.1

Calibration Point ID	Observed Peak Flood Level (m AHD)	Observed Peak Flood Level Confidence	Simulated Peak Flood Level (m AHD)	Difference in Peak Flood Level (Simulated – observed) (m)
S124	197.63	Medium	197.53	-0.11
S105	197.10	Medium	196.96	-0.15
S106	178.40	High	177.03	-1.37

Table 5-18: March 2021 Validation Event Comparison of Community Consultation Observed Peak Flood Levels with Simulated Levels

	Properties with provided Observed Peak Flood Level and Comparison to the Simulated Levels (Simulated – Observed) (m)					Properties Indicated to be Flood Free in Community Consultation (0.05m Depth Cutoff Filter Applied for Classification)	
	< -0.3	-0.1 – -0.3	-0.1 – 0.1	0.1 - 0.3	> 0.3	Properties Flood Free in Simulated Results	Properties Impacted in Simulated Results
Number of Community Consultation Responses	1	2	16	0	0	97	6



Title:

Calibration Event – March 2021
Simulated Levels Minus Observed Levels

Figure: **5-18**

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Scale at A4 1:70000

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5.5.4 March 2022 Model Validation

The 22 observed/recorded levels and 101 flood free properties were used to inform the model calibration through comparison against simulated model results. One photo and two videos taken at Peppermint Park were provided from the March 2022 event as part of the community consultation and have been implemented into the validation process. Of note, the blockage factor applied to the sag inlet pit DPIT-21161 within the upstream Peppermint Park basin was increased from 50% to 75% in order to achieve alignment of the simulated flood extent against the provided photo and videos. This assumption is considered appropriate given the debris availability and transportability local to the basin.

The difference and location between these community consultation responses and the simulated levels can be seen in **Table 5-19** and **Figure 5-19** respectively. **Table 5-20** provides a classification of the alignment between the simulated and observed peak flood levels and flood free properties.

The distribution of the observed flood level to simulated flood level difference is reasonable for calibration, with 21 of the 22 points simulated flood levels within 0.3 m of the observed levels and 17 of the 21 simulated flood levels within 0.1 m of the observed levels. The simulated level outside of -0.3 m of the observed level is within the vicinity of other points that provide a good alignment to the observed data and as such was determined to have issues with either uncertainty of location or flood level. Of the 101 flood free observed properties, 95 were simulated as flood free. As such a combination of simulated levels within 0.1 m of observed levels and flood free properties being flood free indicates an acceptable calibration to the March 2022 event.

Of the community consultation responses received for the March 2022 event, a single respondent reported a depth at least 0.3 m higher than the simulated depth at the same location (ID S106). This discrepancy has been reported upon in **Section 5.5.1**. The discrepancy at this location is consistent between all four simulated calibration events.

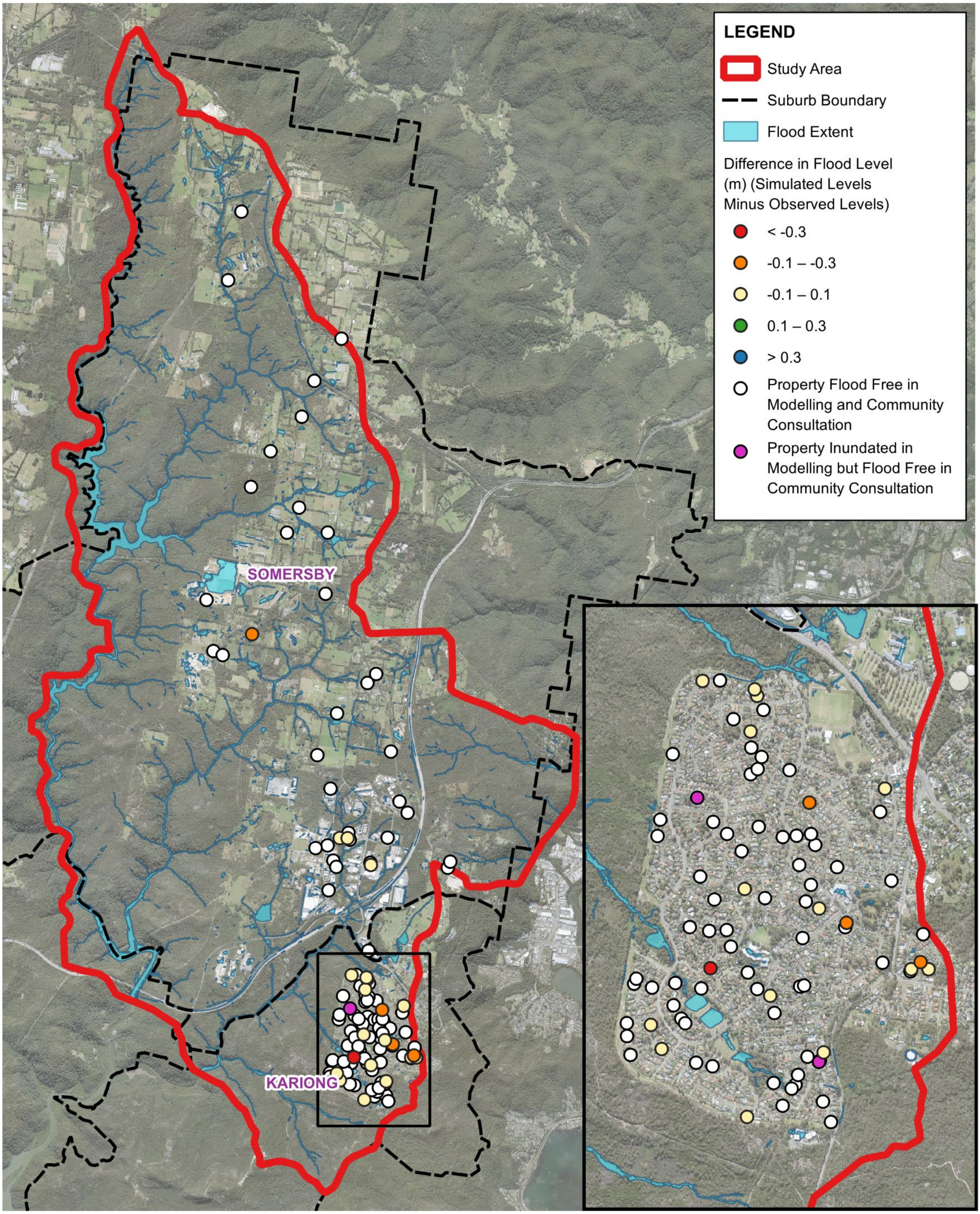
Table 5-19: March 2022 Validation Event Peak Flood Level Comparison

Calibration Point ID	Observed Peak Flood Level (m AHD)	Observed Peak Flood Level Confidence	Simulated Peak Flood Level (m AHD)	Difference in Peak Flood Level (Simulated – observed) (m)
S061	158.19	High	158.27	0.08
S087	161.70	High	161.73	0.03
S051	197.26	Medium	197.29	0.03
S040	178.61	Medium	178.62	0.01
S015	187.76	High	187.76	0.00
S062	170.31	Medium	170.31	0.00
S041	168.85	Medium	168.86	0.00
S070	177.14	Medium	177.14	0.00
S045	192.35	Medium	192.35	0.00
S018	186.24	Medium	186.23	-0.01
S076	166.68	High	166.67	-0.01
S091	154.93	Low	154.89	-0.04
S085	199.67	High	199.62	-0.05
S094	186.18	High	186.12	-0.06
S116	176.96	Medium	176.89	-0.06

Calibration Point ID	Observed Peak Flood Level (m AHD)	Observed Peak Flood Level Confidence	Simulated Peak Flood Level (m AHD)	Difference in Peak Flood Level (Simulated – observed) (m)
S117	192.95	Medium	192.87	-0.08
S056	180.66	High	180.57	-0.09
S009	191.87	Medium	191.76	-0.11
S124	197.63	Medium	197.52	-0.12
S104	179.26	High	179.15	-0.12
S133	248.21	High	248.09	-0.12
S106	178.41	High	177.03	-1.38

Table 5-20: March 2022 Validation Event Comparison of Community Consultation Observed Peak Flood Levels with Simulated Levels

	Properties with provided Observed Peak Flood Level and Comparison to the Simulated Levels (Simulated – Observed) (m)					Properties Indicated to be Flood Free in Community Consultation (0.05m Depth Cutoff Filter Applied for Classification)	
	< -0.3	-0.1 – -0.3	-0.1 – 0.1	0.1 - 0.3	> 0.3	Properties Flood Free in Simulated Results	Properties Impacted in Simulated Results
Number of Community Consultation Responses	1	4	17	0	0	99	2



Title:

Calibration Event – March 2022 Simulated Levels Minus Observed Levels

Figure: 5-19

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A comparison of flood extents to the photos and videos provided by community members during community consultation was conducted at Peppermint Park for the March 2022 event. The only photo of the event has been presented in **Figure 5-20** and a still extracted from a video taken of the event has been presented in **Figure 5-21**. The figures have been annotated with location markers 1-7 which correlate to marker locations presented in **Figure 5-22** which displays the simulated peak flood depth for the March 2022 event. A suitable alignment is achieved between the simulated peak flood extent and the marker locations.

It is noted however that the time of capture of the photo and video is unknown, hence they do not necessarily coincide with the flood peak and the simulated and observed flood extents are not directly comparable.

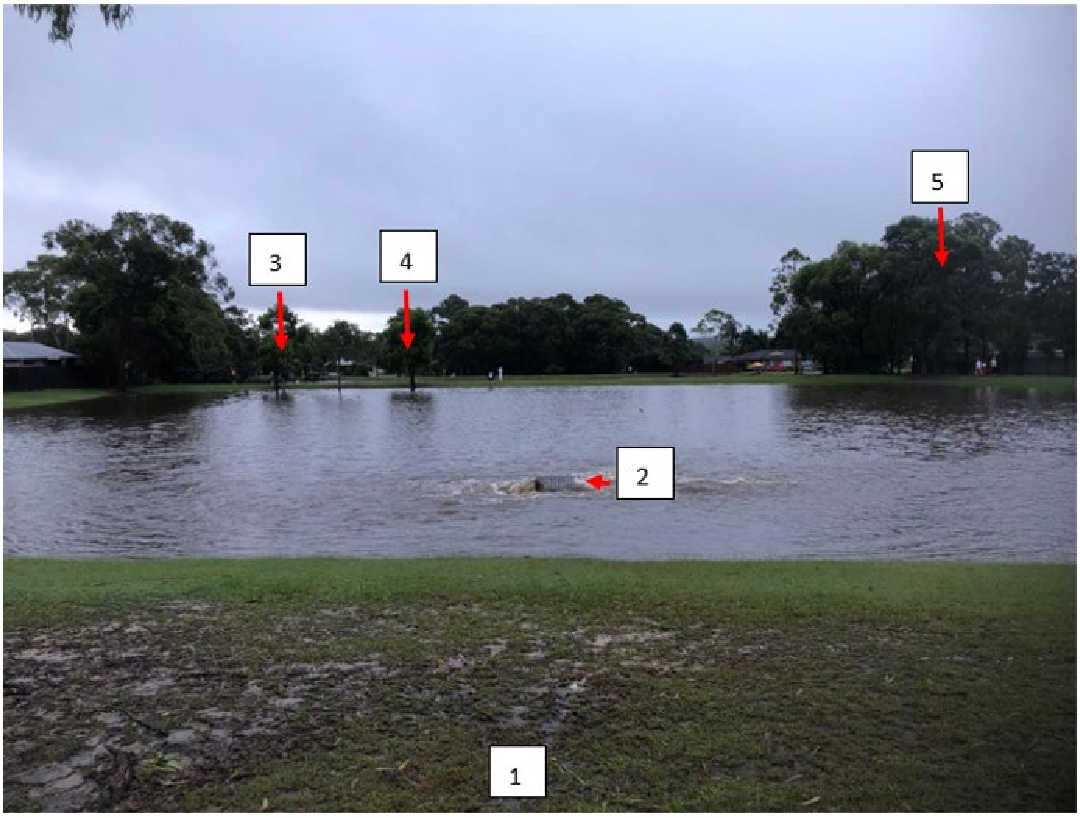
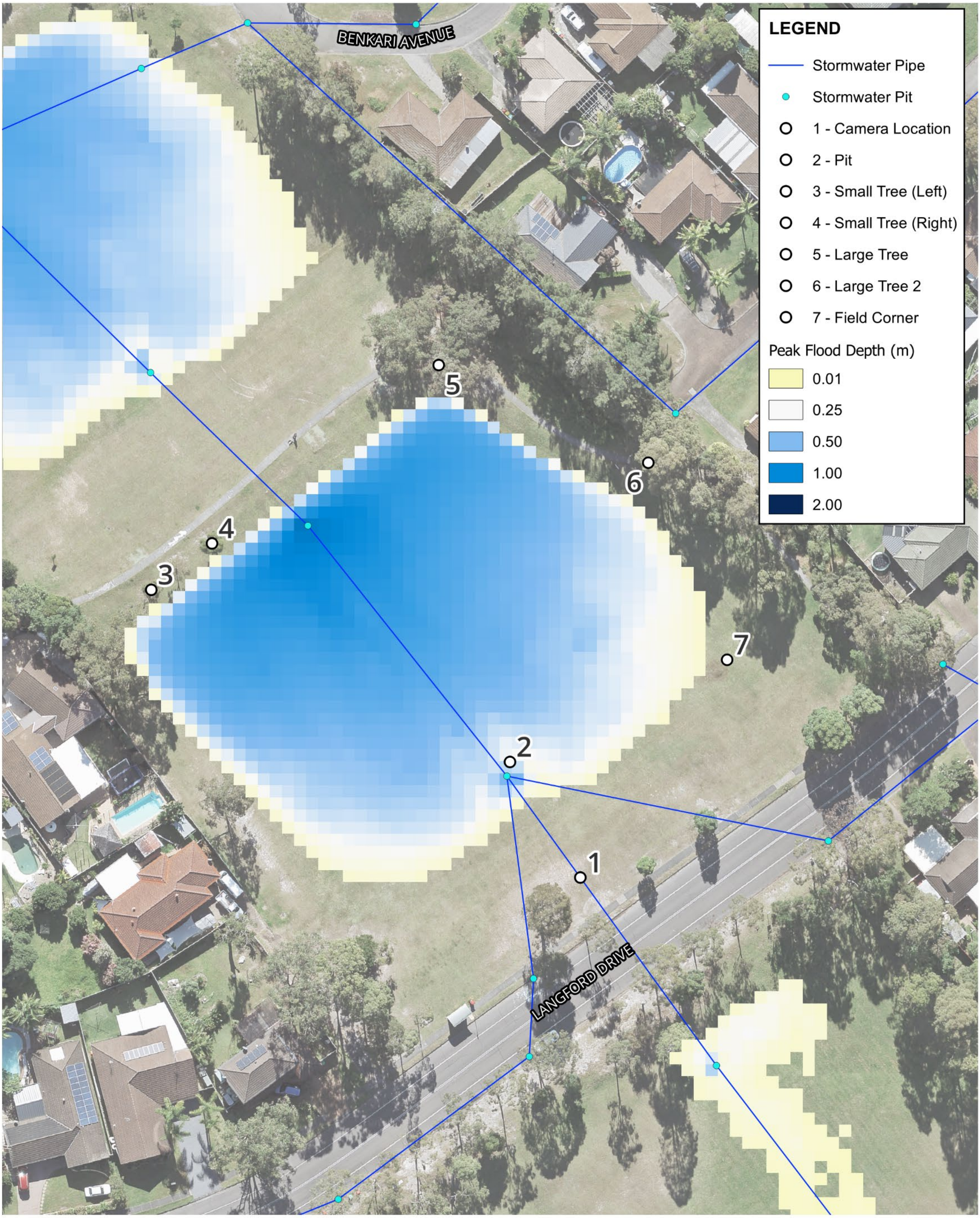


Figure 5-20: Peppermint Park – March 2022 – Photo Provided by Marcelo Rossignolli During the Community Consultation Stage

Figure 5-21: Peppermint Park – March 2022 – Video Still Provided by Marcelo Rossignolli During the Community Consultation Stage



Title:

Peppermint Park Flood Extent – March 2022

Figure: 5-22

Rev: 0

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5.6 CALIBRATION SUMMARY

A suitable alignment was achieved between the simulated and observed flood levels for the four historical events using standard ARR 2019 loss values. As such, the calibration/validation process was limited to localised changes to adopted Manning's n distribution to align with observed data.

The difference between the observed peak flood levels from community consultation responses and the simulated peak flood levels have been summarised in **Figure 5-23** and **Table 5-21**. The figure displays that across the historical events, a majority of the simulated flood levels (78.5%) were within ± 0.1 m.

With regard to properties indicated as flood free in the community consultation, **Figure 5-24** shows the 351 observed flood free community consultation recordings across the historical events and indicates that 96.6% of simulated results were flood free (with 0.05 m depth cutoff filter applied).

When taking into account the total of 430 observations, there is a 93% confidence of simulating the events within 0.1 m of the observed level or appropriately designating a flood free property in the simulation. Further note that 4% of properties were simulated lower than 0.1 m when compared to observed levels and 3% of properties were simulated as inundated when they were designated as flood free in the community consultation. It is therefore seen that the analysis has achieved suitable level of accuracy without a particular bias towards overestimation or underestimation of results.

As discussed in **Section 5.3.4**, calibrated losses were not maintained for design event modelling. This is due to the calibrated losses being reflective of a long duration event as well as the calibration showing an insensitive response to losses. This is further supported in the sensitivity testing within **Section 8.3**. Refer to **Section 6.1.3** for discussion on adopted design event modelling parameters.

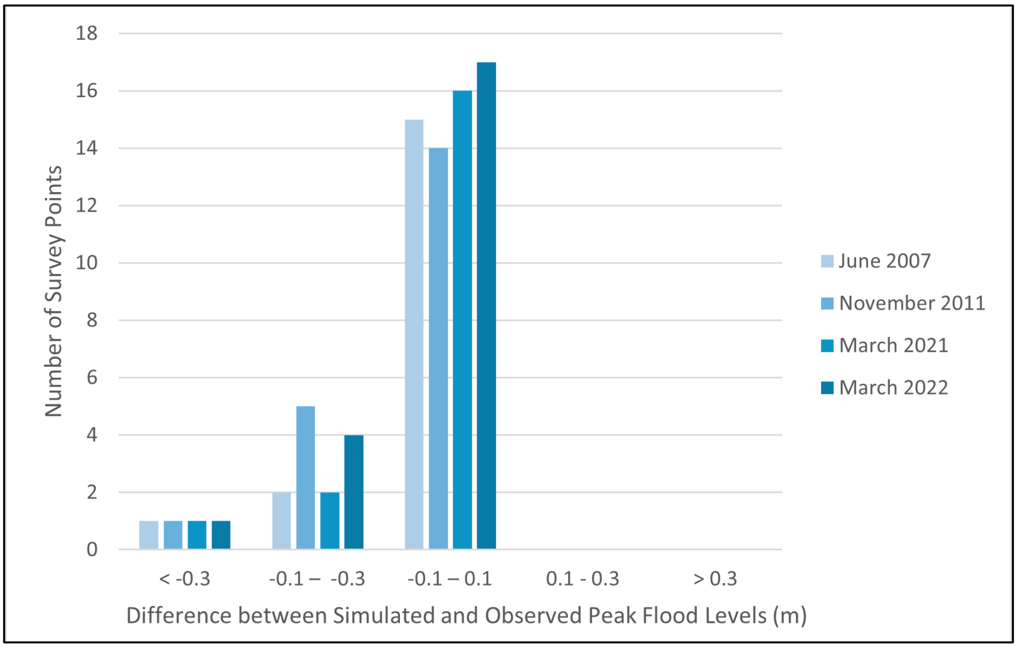


Figure 5-23: Difference between Observed and Simulated Peak Flood Levels for the Calibration and Validation Events

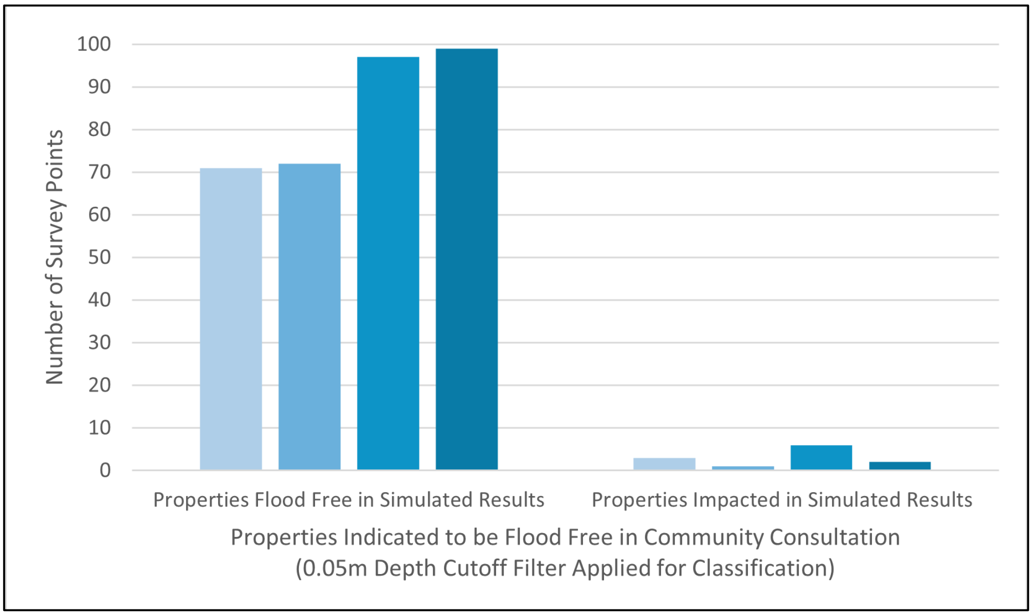


Figure 5-24: Properties Indicated to be Flood Free in Community Consultation for the Calibration and Validation Events

Table 5-21: Comparison of Community Consultation Observed Peak Flood Levels with Simulated Levels for the Calibration and Validation Events

	Properties with provided Observed Peak Flood Level and Comparison to the Simulated Levels (Simulated – Observed) (m)					Properties Indicated to be Flood Free in Community Consultation (0.05m Depth Cutoff Filter Applied for Classification)	
	< -0.3	-0.1 – -0.3	-0.1 – 0.1	0.1 - 0.3	> 0.3	Properties Flood Free in Simulated Results	Properties Impacted in Simulated Results
June 2007	1	2	15	0	0	71	3
November 2011	1	5	14	0	0	72	1
March 2021	1	2	16	0	0	97	6
March 2022	1	4	17	0	0	99	2
Total Number of Readings	4	13	62	0	0	339	12

6 Design Modelling Approach

A design event in flood modelling refers to a hypothetical flood event that is used to estimate the impacts of potential flooding under specific conditions. Design flood event modelling has been undertaken for the 20%, 10%, 5%, 2% AEP events, 1 in 100 AEP, 1 in 200 AEP, 1 in 500 AEP events, as well as the PMF event in accordance with the ARR 2019 guidelines (noting that ARR Version 4.2 was released after completion of the design event modelling and was therefore not adopted for this study). The design flood conditions form the basis for floodplain management in the catchment, including the development of flood planning levels for future development controls.

The design modelling approach is detailed in this section of the report covering design event model parameters, critical duration assessment, probable maximum flooding conditions and consideration of climate change.

6.1 ADOPTED DESIGN EVENT MODELLING PARAMETERS

6.1.1 Aerial Reduction Factors

Where flood estimates are required for catchments of significant size, there is a need to account for the areal reduction of design rainfall intensity. ARR 2019 includes the definition of Areal Reduction Factors (ARFs), which represent the ratio between the design values of areal average rainfall and point rainfall for the same duration and AEP. ARFs were not applied in this study as the key area of interest being Kariong township had small catchment sizes in the order of 1 to 3 km^2 which results in negligible ARFs being applied.

6.1.2 Temporal Patterns

ARR 2019 recommends an ensemble approach of 10 temporal patterns for each duration and exceedance probability in order to best simulate the variability of real storms. The temporal pattern just above the mean (or median) peak flow of the 10 patterns is then adopted as the representative temporal pattern for the duration of interest.

6.1.3 Rainfall Losses

In NSW, rainfall losses are derived based on a hierarchical approach in accordance with ARR. Where calibrated losses and FFA-reconciled losses are not available or may not be suitable for design event modelling, ARR Datahub provides initial and continuing losses for design event modelling. As mentioned in **Section 5.3.4** and **Section 5.6**, calibrated losses were not deemed to be appropriate for design event modelling in this catchment. This is due to the calibration events being long duration, low intensity events whereas the critical duration assessment demonstrates short duration, high intensity events drive critical flood behaviour in the catchment. As such, the losses for long duration events were not considered for the short duration events.

ARR Data Hub includes the NSW-specific Probability Neutral Burst Initial Loss (PNBIL), which accounts for pre-burst and storm initial loss in one value. The PNBIL was adopted in lieu of the calibrated losses as PNBIL provides recommended losses for short durations across all AEPs. This is the same applied continuing loss from the calibration process.

KBR adopted the PNBIL and a continuing loss of 1.28 mm/hr. The adopted PNBILs across the range of simulated design events are recorded in **Table 6-1**.

Table 6-1: Adopted PNBIL

Time (min)	20% AEP	10% AEP	5% AEP	2% AEP	1 in 100 AEP
60	16.9	16.5	17.6	18.6	17.7
90	19.8	19.3	20.3	19.5	14.5
120	18.9	18.2	19.8	19.5	16.6
180	21.5	19.1	18.8	18.1	13
270	21.1	19.1	17.8	17.0	12.2
360	20.8	19.2	16.8	15.8	11.3

6.1.4 Design Rainfall Depth

Design rainfall depths, or more commonly rainfall depth rates/intensities, are estimated through the generation of Intensity-Frequency-Duration (IFD) curves, which through a frequency analysis have established relationships between rainfall intensity, return period (or probability of exceedance) and storm duration. Design rainfall depths (mm) have been extracted from the Bureau of Meteorology 2016 Rainfall IFD Data System for the catchment centroid (-33.39107, 151.27347) and are presented in **Table 6-2**.

Table 6-2: Adopted Design Rainfall Depths (mm)

Duration	20% AEP	10% AEP	5% AEP	2% AEP	1 in 100 AEP	1 in 200 AEP	1 in 500 AEP
15 min	23.8	29.1	34.7	42.9	49.7	54.3	62.1
20 min	27.4	33.5	40	49.5	57.4	62.7	71.8
25 min	30.3	37.1	44.3	54.8	63.6	69.6	79.7
30 min	32.7	40.1	47.9	59.2	68.8	75.4	86.4
45 min	38.4	47	56.2	69.6	80.9	88.8	102
1 hour	42.7	52.3	62.6	77.5	90.1	99	113
1.5 hour	49.4	60.5	72.4	89.7	104	114	131
2 hour	54.8	67.2	80.3	99.4	115	126	145
3 hour	63.9	78.1	93.2	115	134	146	167
4.5 hour	75.1	91.7	109	135	156	170	194
6 hour	84.9	103	123	151	175	190	217
9 hour	102	124	147	180	207	225	256
12 hour	116	141	167	204	235	255	291
18 hour	140	170	202	246	281	306	350
24 hour	160	195	231	280	320	349	400
30 hour	177	215	255	309	352	400	465
36 hour	191	233	276	334	380	438	512

6.2 PROBABLE MAXIMUM FLOOD

Within Australia, there are several methodologies to modelling a Probable Maximum Flood (PMF) event, representing the theoretical largest flood that could conceivably occur at a particular location. Due to the location and relatively small size of the study area and noting the rapid response time of the catchments, only the Generalised Short Duration Method (GSDM) was applicable for the derivation of the Probable Maximum Precipitation (PMP) rainfall depths.

PMP rainfall depths were derived for the study area for a range of storm durations between 15 minutes and 6 hours, in accordance with the Bureau of Meteorology's GSDM guidelines (BoM, 2003). Spatial variance using more than one PMP ellipse was not necessary to be considered in this instance due to the relatively small size of Kariong Township and of individual catchments comprising the study area. The factors used in the estimation of the PMP are summarised in **Table 6-4.**

Raw initial rainfall point depth estimates were extracted using the Depth-Duration-Area curves for short duration rainfall for the catchment area of 66.5 km^2. These values were used in conjunction with the factors listed in **Table 6-3** to produce PMP estimates, to which the GSDM temporal pattern distribution was applied.

Table 6-3: Adopted GSDM Parameters

Parameter	Adopted Value
Area	66.5 km^2
Roughness Factor	1
Elevation Adjustment Factor	1
Moisture Adjustment Factor	0.70

Table 6-4: Adopted GSDM Rainfall Intensities

Duration (hours)	Rainfall Intensity (mm/hr)
0.25	480
0.5	360
0.75	307
1	280
1.5	240
2	205
2.5	184
3	167
4	143
5	124
6	110

6.3 CRITICAL DURATION ASSESSMENT

A critical duration assessment refers to the selection of the duration which results in the highest peak discharge in the study catchment for a specified design flood event. Within the study area, flooding is largely driven by overland flow, characterised by multiple overland flow paths through residential and rural environments. Overland flooding in the study area is generally a result of intense, short-duration rainfall events.

Due to the nature of the combined hydrologic and hydraulic modelling approach, a critical duration assessment was undertaken on the peak flood level outputs from TUFLOW. The 90-minute storm and Temporal Pattern 6 combination was selected for assessment. Note that the selected Temporal Pattern 6 refers to a different temporal pattern across each of the three temporal pattern bins.

Sensitivity testing of the selected combination was conducted by simulating all 10 temporal patterns for the 90-minute storm, as well as for the 60-minute and 120-minute storms (the next duration shorter and next duration longer). A median peak water level grid was produced from the 10 simulated temporal patterns for each duration. A maximum peak water level grid was then produced from each of the median peak water level grids per duration. Results demonstrated there were negligible differences greater than 0.05 m between the 'max-median' water level grid and peak flood levels simulated from the single duration and temporal pattern combination within the township of Kariong, outside of storage basins. Sensitivity testing was undertaken on the 1 in 100 AEP, 5%, and 20% AEP events for their respective temporal pattern bins. Should further detail be required of the rural overland flowpaths or the storage basins, a site-specific critical duration assessment should be undertaken.

A critical duration assessment was also undertaken for the PMF event. It is important to note that PMF methodologies only simulate a single temporal pattern per duration. Therefore, the critical duration was selected as the duration that produced the largest peak flow. The selected critical duration for the PMF was determined to be 60 minutes, reflecting the peak conditions identified through this process. Adopted critical durations are as presented in **Table 6-5**.

Table 6-5: Adopted Critical Durations

Temporal Pattern Bin	Critical Duration
Frequent	90min TP06 (ARR ID: 4606)
Intermediate	90min TP06 (ARR ID: 4593)
Rare	90min TP06 (ARR ID: 4562)
PMF	60 min

6.4 CLIMATE CHANGE ASSESSMENT

As outlined in **Section 6.1.4,** the Bureau of Meteorology 2016 Intensity-Frequency-Duration (IFD) data was utilised to simulate the present-day conditions. The BoM 2016 IFDs were developed using data from historical gauged records up to 2012. While the 2016 IFDs are reflective of the best information readily available, it does not consider the changing climate and its implications between the time period of the datasets used to derive the IFDs and to the present day.

The modelling of a future climate scenario provides insight into the sensitivity of the catchment and consequences to the community in relation to the changing climate. Climate change is increasingly demonstrated to be a key planning requirement due to the potential long-term impacts posed to the community.

During the undertaking of this Study, Geoscience Australia released an update of the climate change considerations chapter of ARR. An updated revision of ARR, Version 4.2 was published in late 2024 incorporating the new guidance as well as several other minor changes. The updated guidance recommends and provides a framework for scaling design rainfall including the PMF as well as hydrologic losses.

The ARR Version 4.2 recommended scaling factors are based on the latest Intergovernmental Panel on Climate Change (IPCC) modelling based on Shared Socioeconomic Pathways (SSPs) that cover a broad range of potential future case scenarios often referred to as very low (SSP1-1.9), low (SSP1-2.6), medium (SSP2-4.5), high (SSP3-7.0) and very high (SSP5-8.5) emissions pathways. The SSP's effectively replace the previous Representative Concentration Pathway (RCP) terminology referred to in previous ARR versions.

The ARR Version 4.2 scaling factors for rainfall and losses for a given location can be obtained from the ARR Data Hub. Scaling factors are provided for all four SSPs for horizons up to and including the year 2100. Provided rainfall scaling factors are both event and duration dependent, whereas hydrologic loss scaling factors are constant across events and durations. For the Kariong township, adopting the identified critical duration of 90-minutes, the recommended ARR Data Hub rainfall scaling factors are presented in **Table 6-6.**

Table 6-6: Climate Change Rainfall Scaling Factors for 90-minute Critical Duration

Year	SSP1-2.6	SSP2-4.5	SSP3-7	SSP5-8.5
2030	1.17	1.17	1.17	1.18
2050	1.2	1.24	1.26	1.31
2100	1.2	1.37	1.59	1.77

Whilst it is acknowledged that ARR Version 4.2 was published during the completion of this Study, the climate change analysis for this Study was completed in accordance *Understanding and managing flood risk – Flood risk management guideline FB01* (Department of Planning and Environment (DPE), 2023). The guideline specifies that the 1 in 200 AEP and 1 in 500 AEP events are in the order of 15% and 30% more rainfall then the current 1 in 100 AEP event and as such are considered to provide reasonable proxies for the scale of change to the 1 in 100 AEP event under RCP 4.5 and RCP8.5 at 2090 respectively. Increases in rainfall intensity under each event are presented in **Table 6-7**.

Table 6-7: Climate Change Scenario Rainfall Increases

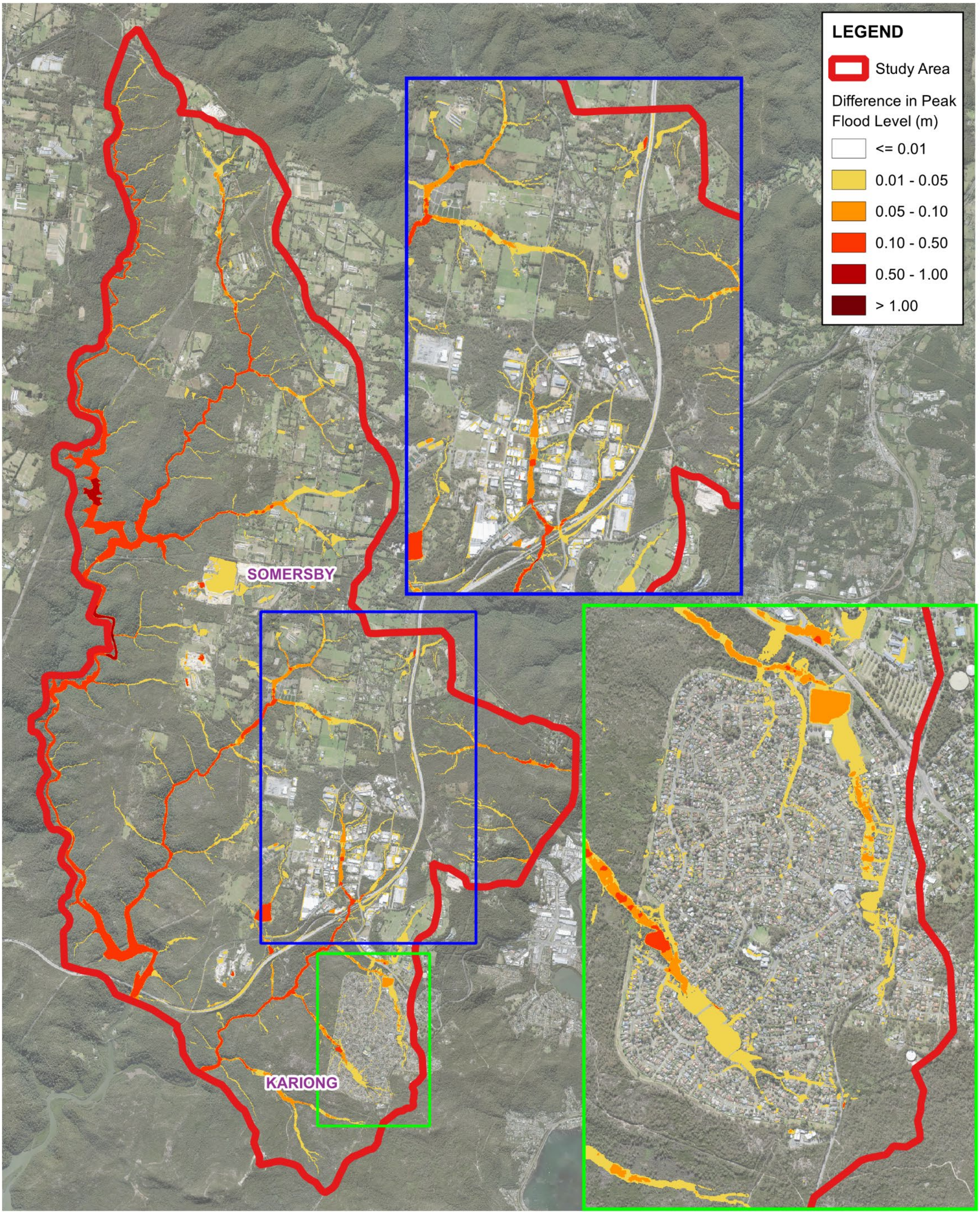
Duration	1 in 100 AEP Rainfall (mm)	1 in 200 AEP Rainfall (mm)	1 in 200 AEP Increase	1 in 500 AEP Rainfall (mm)	1 in 500 AEP Increase
90 minutes	104	114	10mm (+9.6% compared to 1 in 100 AEP)	131	27mm (+26.0% compared to 1 in 100 AEP)

No specific year has been designated for these projections for this study area specifically, as they are intended to reflect a generic increase in rainfall rather than a precise future date. This approach allows for a broad assessment of potential climate change impacts on flood behaviour. Comparing the percentage increase in rainfall for the 1 in 500 AEP event to the ARR Data Hub climate change rainfall scaling factors indicates that the in 500 AEP exceeds the 1 in 100 AEP event scaled to SSP1-2.6 in 2100 and is equivalent to a 1 in 100 AEP scaled to SSP3-7 in 2050.

No consideration was given to sea level rise scenarios due to the majority of the study area being above the influence of sea level rise.

Peak flood level difference mapping between the simulated climate change scenarios and the baseline conditions has been undertaken on the 1 in 100 AEP event and presented in **Figure 6-1** and **Figure 6-2. Figure 6-3** presents a comparison of peak flood extents between the 1 in 100 AEP event and simulated climate change scenarios.

The increase in rainfall applied to the hydraulic model has led to a broadscale increase in peak flood levels across the study area in comparison to the 1 in 100 AEP event. Increases in peak flood level in the 1 in 200 AEP event are generally between 0.01 m and 0.05 m in the upper reaches of the catchment with larger increases of up to 1 m simulated within the major waterway in the lower reaches of the catchment. In the 1 in 500 AEP event, increases in the upper reaches of the catchment are generally between 0.01 m and 0.1 m with increases of up to 1.3 m simulated in the lower reaches of the catchment. Of note however, given the undulating nature of the catchment, the increased peak flood levels do not result in significant increases in peak flood extent.



Title:

Difference in Peak Flood Level
1 in 200 AEP Design Event Minus 1 in 100 AEP Design Event

Figure: **6-1**

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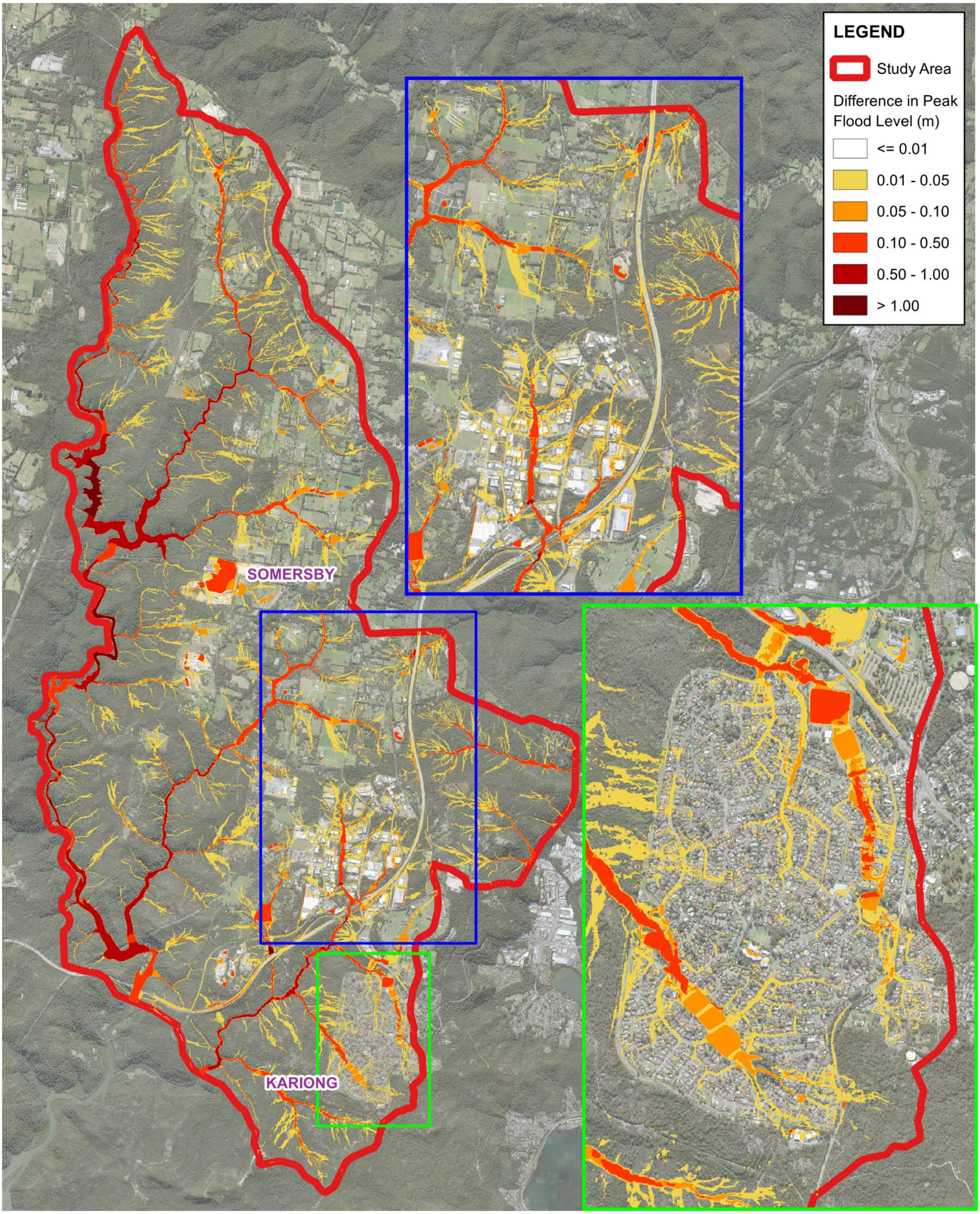

Title:

Difference in Peak Flood Level
1 in 500 AEP Design Event Minus 1 in 100 AEP Design Event

Figure: **6-2**

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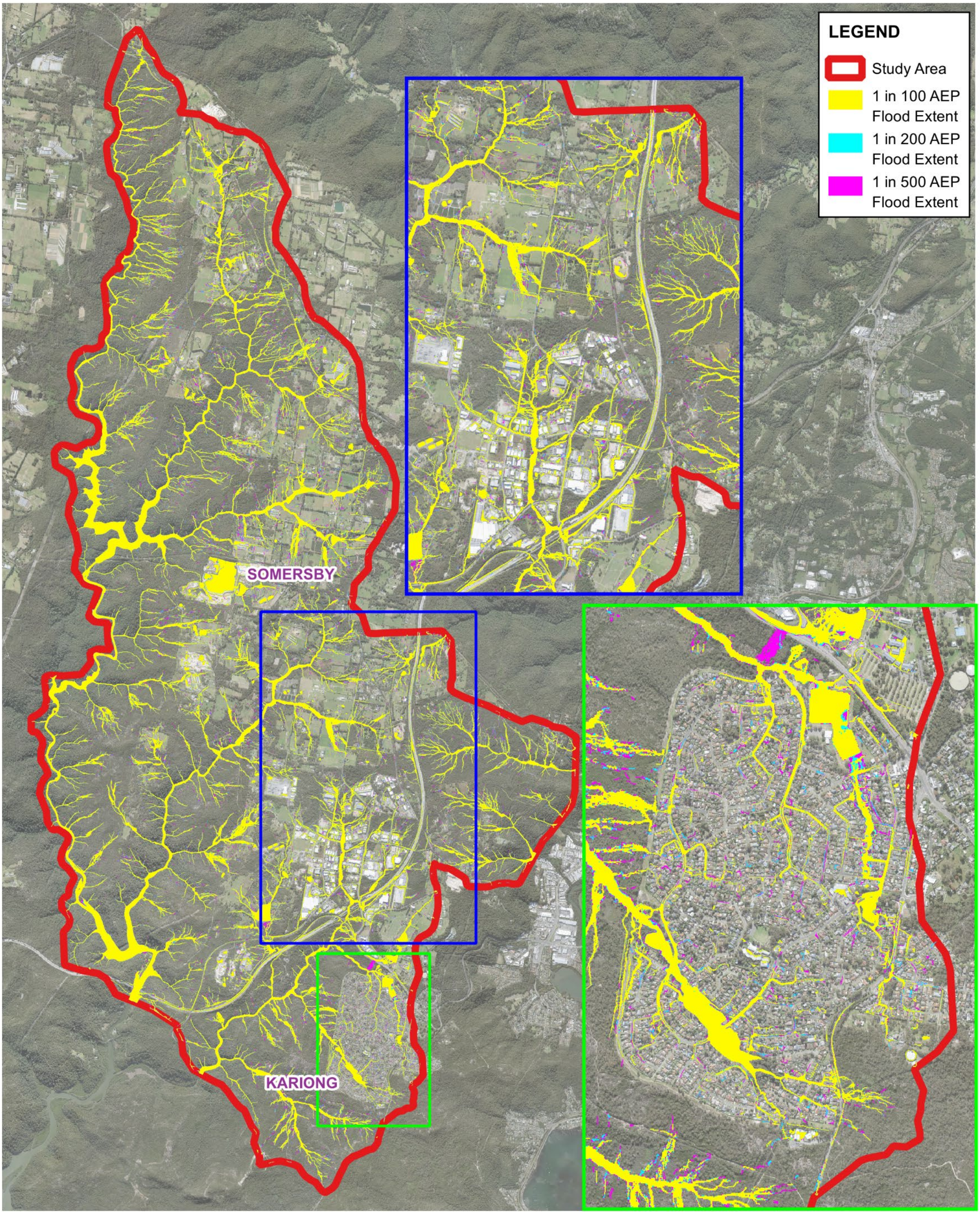

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1 in 100 AEP, 1 in 200 AEP and 1 in 500 AEP Flood Extent Comparison

Figure: 6-3

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7 Design Modelling Results

This section details the outcomes of the design event modelling across the simulated design storm events in terms of peak flood conditions, flood mapping, flood function, flood hazard, and flood emergency response classifications for communities.

7.1 PEAK FLOOD CONDITIONS

In the northern and western areas of the catchment, key flowpaths include Robinsons Creek, Floods Creek, and Mooney Mooney Creek. These watercourses form major conduits for floodwaters, shaping the hydraulic dynamics in the region with floodwaters generally contained within defined flowpaths.

In the Kariong Township, several critical flowpaths and hydraulic controls influence flood behaviour. Key flowpaths in the township grade into or feed directly into Piles Creek. In the southeastern end of Kariong, a prominent flowpath originates upstream Woy Woy Road, directing floodwaters into Peppermint Park. The park functions as a system of basins or water storages, with Langford Drive acting as a crucial hydraulic control. Langford Drive cuts through the park, containing floodwaters within both Peppermint Park and Rees Street Reserve to the north. Ultimately, this flowpath continues downstream, discharging into Piles Creek.

A significant flowpath originates near Milyerra Road in the eastern section of Kariong. Floodwaters from this area flow north, crossing Woy Woy Road into a series of low-lying green spaces bounded by Langford Drive to the north, Gilford Street to the west, and Woy Woy Road to the east. The flowpath continues northward, with Curringa Road acting as a key hydraulic control. Once overtopped, water is contained within the basins at Kariong Oval. Here, the flowpath integrates with minor flowpaths from Mitchell Road and Casey Crescent before ultimately discharging into Piles Creek. These flowpaths, along with the hydraulic controls formed by roads, basins, and natural topography, play a critical role in managing floodwaters and mitigating downstream impacts.

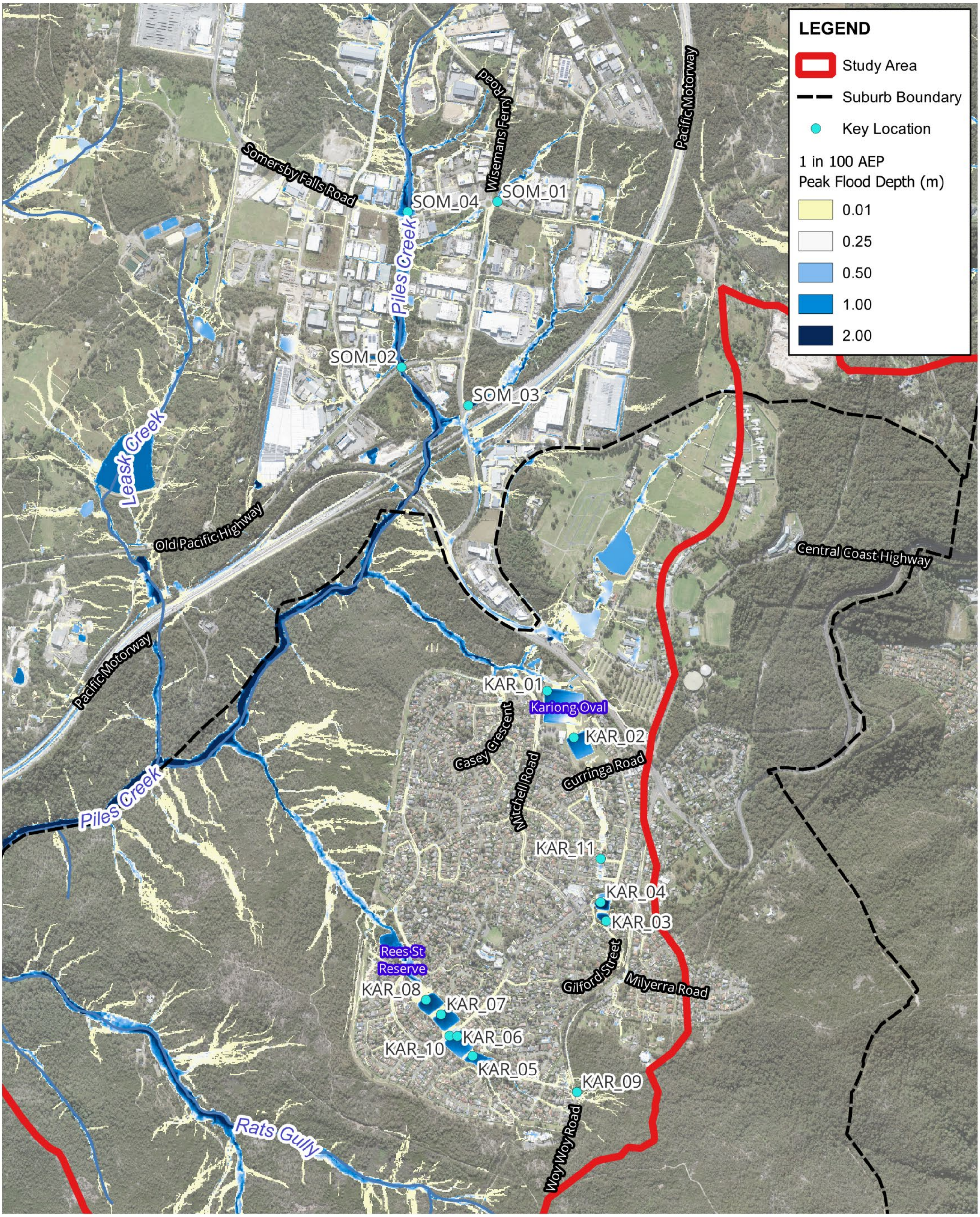
Piles Creek travels through the Somersby Industrial Area from north to south, with flows generally confined to the creek channel during a 1 in 100 AEP event. The creek passes beneath the Pacific Motorway and continues west within the catchment. The Old Pacific Highway and Somersby Falls Road both act as hydraulic controls in a 1 in 100 AEP event. A secondary flowpath originates south of Gindurra Road, flowing southwest through dense vegetation towards Wisemans Ferry Road. This flowpath passes beneath the road before discharging into Piles Creek. While overland flowpaths form along several roadways across the Somersby industrial area, the majority of floodwaters remain confined within the Piles Creek or defined tributary flowpaths.

Peak flood depths simulated across the range of design events at several key locations across the catchment are recorded in **Table 7-1**. These locations are presented in **Figure 7-1**.

Table 7-1: Peak Flood Depths at Key Locations

ID	Key Location	20% AEP Depth (m)	10% AEP Depth (m)	5% AEP Depth (m)	2% AEP Depth (m)	1 in 100 AEP Depth (m)	1 in 200 AEP Depth (m)	1 in 500 AEP Depth (m)	PMF Depth (m)
KAR_01	Kariong Oval DS Basin Outlet	1.13	1.33	1.51	1.69	1.86	1.91	1.97	2.25
KAR_02	Kariong Oval US	0.63	0.93	1.2	1.72	1.78	1.81	1.86	2.09

ID	Key Location	20% AEP Depth (m)	10% AEP Depth (m)	5% AEP Depth (m)	2% AEP Depth (m)	1 in 100 AEP Depth (m)	1 in 200 AEP Depth (m)	1 in 500 AEP Depth (m)	PMF Depth (m)
	Basin Outlet								
KAR_03	Gilford Street US Basin Outlet	1.56	1.85	1.92	1.97	1.99	2.01	2.04	2.20
KAR_04	Gilford Street DS Basin Outlet	0.56	0.98	1.67	2.29	2.34	2.37	2.42	2.73
KAR_05	Peppermint Park Basin 1 Outlet	1.61	1.67	1.71	1.79	1.82	1.84	1.87	2.08
KAR_06	Peppermint Park Basin 2 Outlet	0.96	1.45	1.8	1.96	2.02	2.05	2.1	2.33
KAR_07	Peppermint Park Basin 3 Outlet	1.29	1.52	1.84	1.99	2.05	2.07	2.11	2.3
KAR_08	Peppermint Park Basin 4 Outlet	0.96	1.07	1.37	1.92	2.00	2.04	2.09	2.34
KAR_09	Peppermint Park Basin 2 Outlet	0.65	0.76	0.82	1.00	1.08	1.13	1.18	1.33
KAR_10	Langford Drive	0.00	0.00	0.35	0.52	0.58	0.61	0.65	0.85
KAR_11	Rafferty Close, Kariong Town	0.00	0.00	0.00	0.45	0.65	0.72	0.8	1.18
SOM_01	US Somersby Falls Road	1.45	1.73	1.85	2.02	2.1	2.14	2.21	2.71
SOM_02	Piles Creek @ Holt Bragg Bridge	1.97	2.31	2.52	3.12	3.47	3.68	4.00	5.92
SOM_03	US Wisemans Ferry Road	1.12	1.34	1.61	2.39	2.96	3.08	3.23	4.31
SOM_04	Piles Creek US Somersby Falls Road, Somersby Industrial Area	1.36	2.15	2.77	3.25	3.35	3.41	3.49	4.06



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Key Locations

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7.2 FLOOD MAPPING

One of the significant benefits and outcomes of 2D (i.e. TUFLOW) modelling is the ability to visualise the spatial distribution of model outputs, such as peak flood level, depth, and velocity, as a high-definition flood map with the outputs overlaid on aerial photography. This visualisation is a critical component in developing an understanding and appreciation of flooding conditions, especially for community members and the end users of the data (e.g., CCC planners and planning engineers).

KBR has provided mapping in **Appendix C** for the following outputs based on the enveloped design event results, 20%, 10%, 5%, 2% AEP events, 1 in 100 AEP, 1 in 200 AEP, 1 in 500 AEP events, and the PMF event:

- Peak Water Level (m AHD)
- Peak Flood Depth (m)
- Peak Velocity (m/s)
- Flood Hazard Categorisation (H1-H6)

7.2.1 Result Filtering

The following filtering criteria was applied to the simulated model outputs as agreed with CCC:

- Depth > 0.10 m; OR
- Depth > 0.05 m AND Velocity Depth Product (VxD) > 0.025 m^2/s; OR
- Velocity > 2 m/s,

Additionally, isolated flood areas less than 100 m^2 were removed.

7.2.2 Flood Hazard

Flood hazard is typically derived from a combination of peak flood depth and velocity. The visualization of flood hazard provides for a better understanding of the potential flood risk within the study area. Handbook 7 – Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia (2017) provides a hazard classification as depicted in **Figure 7-2**. These categories indicate the restrictions on people, buildings, and vehicles:

- H1 – Generally safe for vehicles, people and buildings,
- H2 – Unsafe for small vehicles,
- H3 – Unsafe for vehicles, children, and the elderly,
- H4 – Unsafe for vehicles and people,
- H5 – Unsafe for vehicles and people. All building types vulnerable to structural damage. Some less robust building types vulnerable to failure,
- H6 – Unsafe for vehicles and people. All building types considered vulnerable to failure.

Flood hazard mapping for the 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1 in 100 AEP, Climate Change (1 in 200 AEP Proxy), Climate Change (1 in 500 AEP Proxy) and PMF events are provided in **Appendix C**.

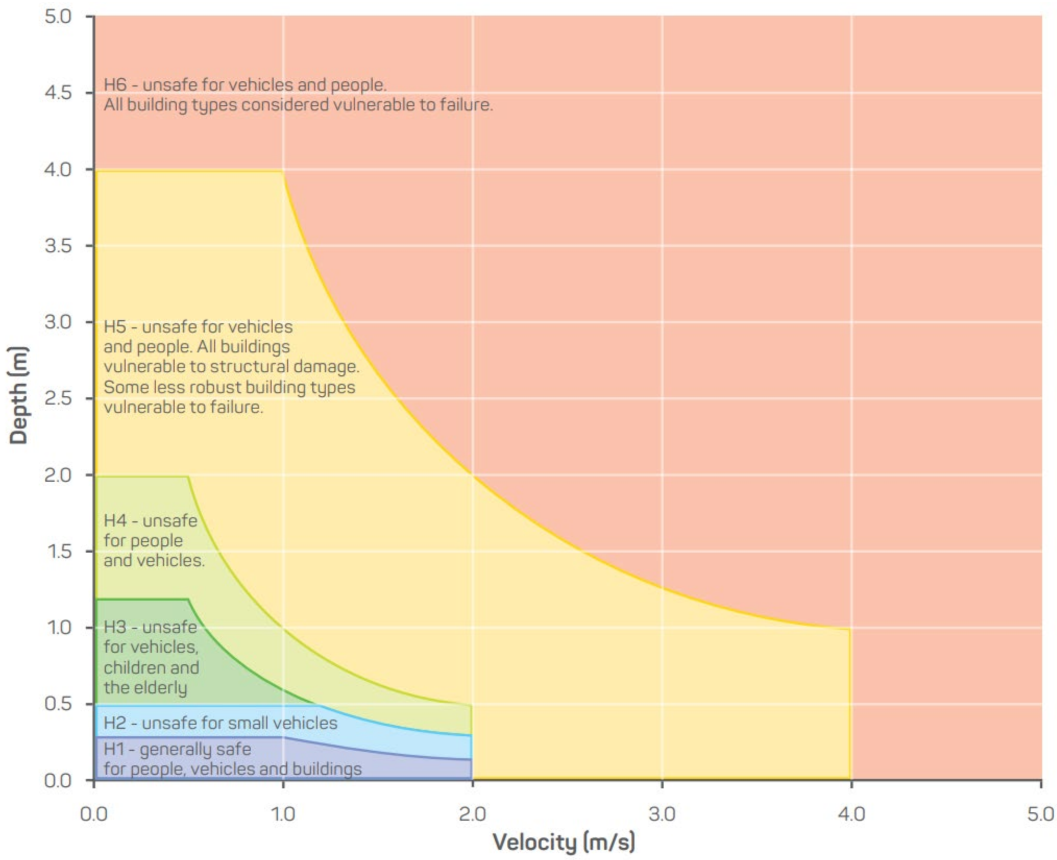


Figure 7-2: General Flood Hazard Vulnerability Curves (ADR, 2017)

7.2.3 Flood Function

Flood function categories are defined within the Flood Risk Management Guideline FB02: Flood Function (NSW Government, 2023) and the predeceasing framework Floodplain Development Manual (NSW Government, 2005). These definitions are essentially qualitative in nature.

The method of flood behaviour and associated impacts are likely to vary from one floodplain to another depending on the catchment characteristics and associated nature of flooding within the catchment. The hydraulic categories as per the Flood Risk Management Guideline FB02: Flood Function (NSW Government, 2023) are defined as follows:

- Floodways – 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 floodwaters 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%, and
- Flood Fringe – Remaining area of flood prone land, after Floodways 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.

While there are several common methodologies to defining the flood function, the indicator method has been adopted for this study by selecting a velocity depth product that exceeds a specific threshold. Adopted parameters are presented in **Table 7-2**. Sensitivity analysis was conducted on these parameters with velocity depth product ranging from 0.1 to 0.3 m^2/s, velocity ranging from

0.05 to 0.5 m/s and depths defining flood storage ranging from 0.1 to 0.5 m. The sensitivities allowed for the selection of suitable parameters to define the floodways, storages and flood fringe across the catchment. Floodways were defined by ensuring flow connectivity through major overland flowpaths. Flood storages were defined to capture stored floodwaters in areas such as Peppermint Park and other trapped low points.

Flood function mapping for the 5% AEP, 1 in 100 AEP, Climate Change (1 in 200 AEP Proxy) and PMF events are provided in **Appendix C**.

Table 7-2: Flood Function Definition Parameters

Category	Adopted Parameter Thresholds
Floodway	VxD > 0.25 m^2/s and V > 0.25 m/s
Flood Storage	Areas outside floodway where D > 0.30 m
Flood Fringe	All remaining areas

7.2.4 Flood Emergency Response Classification of Communities

KBR has completed the flood emergency response classification of communities in accordance with the Australian Disaster Resilience Handbook – Flood Emergency Response Classification of the Floodplain (AIDR, 2017).

The 2017 Australian Institute for Disaster Resilience (AIDR) Flood Emergency Response Classification (FERC) system offers a structured method to classify and manage flood risks across Australia. This framework aims to enhance flood risk understanding and management by categorising areas based on their flooding characteristics, thereby aiding emergency services, planners, and communities in developing targeted strategies to mitigate and respond to flood events effectively.

The FERC system uses three levels of classification: primary, secondary, and tertiary, each providing increasing detail about the flood risk and response requirements. **Figure 7-3** presents the AIDR flow chart detailing the FERC definition process. The classifications are defined in **Table 7-3**.

Table 7-3: Flood Emergency Response Classifications

<table>
<tr><th>Primary Classification</th><th>Secondary Classification</th><th>Tertiary Classification</th></tr>
<tr><td rowspan="4">Flooded (F): The area is flooded in the Probable Maximum Flood (PMF).</td><td rowspan="2">Isolated (I) – Areas isolated from community evacuation facilities by floodwater and/or impossible terrain. Likely to lose electricity, gas, water, sewerage, and telecommunications during a flood.</td><td>Submerged (FIS): Where all the land in the isolated area is fully submerged in a PMF.</td></tr>
<tr><td>Elevated (FIE): Where there is substantial elevated land in the isolated area above the PMF.</td></tr>
<tr><td rowspan="2">Exit Route (E): Areas not isolated in the PMF with an exit route to community evacuation facilities.</td><td>Overland Escape (FEO): Evacuation relies on escape routes that rise out of the floodplain.</td></tr>
<tr><td>Rising Road (FER): Evacuation follows roads that rise out of the floodplain.</td></tr>
<tr><td colspan="2">Not Flooded (N): The area is not flooded in the PMF.</td><td>Indirect Consequence (NIC): Areas not flooded but may lose services like electricity, gas, water, sewerage, telecommunications, and transport due to flooding elsewhere.</td></tr>
</table>

Primary Classification	Secondary Classification	Tertiary Classification
		Flood Free: Areas not affected by flooding or its indirect consequences.

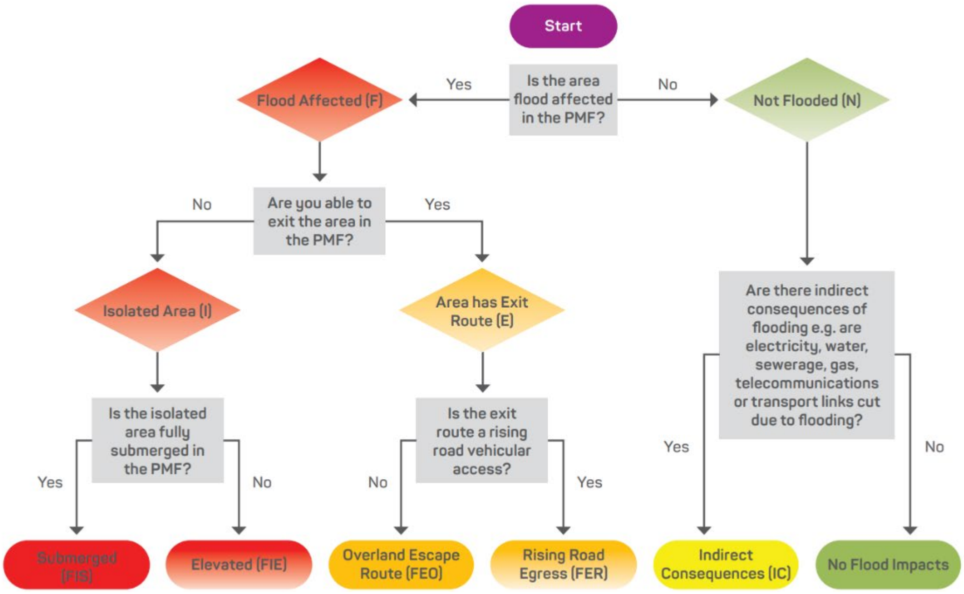


Figure 7-3: Flow Chart for Determining Flood Emergency Response Classifications

The classification exercise was completed on a catchment wide basis however due to the flooding characteristic of the catchment, flash flooding and overland flow, a tailored catchment approach has been implemented. The flooded and isolated areas designated of localised lots were not implemented due to the short nature of the critical storms in the catchment, subsiding in less than 2 hours across waterways in the catchment. Due to these shorter durations, the ability to implement the NSW Shelter-in-Place Guidelines for Flash Flooding for these sections of the catchment can become a emergency management policy in consultation with the guidelines on a region-by-region assessment. The determination of overland escape (FEO) and rising road (FER) classification was undertaken for localised regions with specific evacuation routes.

The FERC of communities was undertaken for the 5%, 1 in 100 AEP, and PMF events, with mapping presented in **Appendix E**. For the 5% and 1 in 100 AEP events, where the flow chart in **Figure 7-3** states PMF, the respective event was adopted. The FERC incorporates the FER and FIE region-based classifications while displaying the specific events road access and egress routes based on a road hazard classification. Further information on road hazard and road cutoff analysis is provided in **Section 10.4**.

For the purposes of defining FERC, it was assumed that the M1 is trafficable during a PMF storm event. If residents are able to access the M1 without hazardous roads due to flood behaviour, it is assumed that an FER classification can be made. That is the flood extent would be within the community; however evacuation is possible via roads. Additional, classification of FER was allocated to regions able to access routes out of the catchment or to emergency facilities located above the PMF, including the NSW Rural Fire Service located in Kariong and the Fire and Rescue NSW Kariong Fire Station.

After interrogating the results, it is clear that the majority of the catchment and communities are classified as FER for more frequent events including the 5% AEP. In the 1 in 100 AEP event however, this is reduced to regions around Kariong (which have access to emergency facilities and the M1) and elevated regions in Somersby (which have access to Peats Ridge Road via Wisemans Ferry Road).

In the PMF event, the whole region is designated as FIE, that is, the flood extent is within the community and no evacuation is possible, however refuge is possible on elevated ground. Emergency evacuation and access assessments on a region basis were conducted in conjunction with the road hazard assessment in **Section 10.4.4**.

8 Model Sensitivity Assessment

Sensitivity analyses are undertaken to assess the relative influence and uncertainty associated with certain model parameters on both the magnitude and extent of the simulated flood events. A sensitivity analysis is completed by adjusting model parameters (e.g. increasing and decreasing parameter values) within reasonable bounds and assessing their impact on simulated peak flows, levels, and velocities.

The following model parameter sensitivity assessments were undertaken:

- Blockage of hydraulic structures,
- Increase/decrease hydraulic roughness by 20%, and
- Rainfall losses

Peak flood level difference mapping between each sensitivity scenario and the baseline design event conditions has been undertaken on the 1 in 100 AEP events and presented in **Appendix D**.

8.1 BLOCKAGE OF HYDRAULIC STRUCTURES

As outlined in **Section 4.11**, structure blockage values were assigned to hydraulic structures within the model in accordance with ARR 2019 Chapter 6 Book 6. Two sensitivity scenarios were simulated to assess the sensitivity of the assigned structure blockage to model outputs:

- An unblocked scenario, setting all blockage to zero.
- An increase to the next highest ARR blockage matrix category as well as raising the blockage applied to all pits to 100% and 50% for sag and on grade pits respectively.

Within the unblocked scenario, flood levels decrease by up to 0.11 m in Kariong Township. In the industrial area of Somersby, there is a reduction of up to 0.25 m upstream of hydraulic structures. Conversely, a slight increase in flood levels of up to 0.03 m is simulated at Kariong Oval, which is located is downstream of hydraulic structures in the lower reaches of the catchment.

Increasing the blockage of hydraulic structures to the next blockage category results in a notable rise in flood levels. In the industrial area, flood levels increase by up to 0.47 m, while Kariong experiences an increase of up to 0.3m. This scenario highlights the significant impact that increased blockage can have on flood levels, particularly in industrial and urban areas, where water flow is more likely to be impeded by structure blockages given the increased debris potential of such areas.

8.2 HYDRAULIC ROUGHNESS

Manning's roughness coefficients, governing flow resistance in channels and over floodplains, were systematically adjusted by +/- 20% from baseline values across the study area. This adjustment aimed to understand how variations in surface conditions influence flood behaviour, affecting flood velocities, water depths, and inundation patterns.

When hydraulic roughness was increased by 20% under 1 in 100 AEP conditions, increases in peak flood levels are largely within the major waterways catchment-wide. The differences become exaggerated where the increased roughness slowing down the flood wave has caused flood waters to back up causing larger depths. There are increases of up to 0.01 m within the flow path passing through Peppermint Park, with a decrease of up to 0.02 m in properties on Curringa Road which is located in the lower reaches of the catchment.

When hydraulic roughness was decreased by 20%, peak flood level decreases of up to 0.39 m were simulated, with decreases in flood extent particular along the main waterways catchment-wide.

Across both sensitivity scenarios, the township of Kariong remains mostly unimpacted due to the changes in flood levels being contained within the waterways.

8.3 INITIAL AND CONTINUING LOSSES THROUGH SOILS LAYER

Initial loss and continuing losses, which govern the infiltration and runoff processes within the catchment, were systematically adjusted by +/- 20% from baseline values across the study area.

A 20% reduction in initial loss resulted in an increase in peak flood level by up to 0.38 m throughout Mooney Mooney Creek. Minor increases of up to 0.01 m were also simulated at the quarry in the northern catchment, Piles Creek, and within the flowpath downstream of Peppermint Park. Conversely, a 20% increase in initial loss resulted in a reduction in peak flood level of up to 0.47 m within Mooney Mooney Creek. Minor decreases of up to 0.02 m were simulated at the quarry, Piles Creek, and flowpaths downstream of Peppermint Park and Kariong Oval.

A 20% decrease in continuing loss resulted in relatively little impact across the study area. An increase in peak flood level of up to 0.02 m was simulated within Mooney Mooney Creek. Conversely, increasing the continuing loss by 20% resulted in a decrease in peak flood level of up to 0.02 m in the same location. The increase and decrease in both initial and continuing losses were found to result in no change in flood levels beyond 10 mm across the remainder of the study area.

This sensitivity assessment indicates that the model is largely insensitive to minor changes in initial and continuing losses with the most noticeable changes observed within major waterways and flowpaths and upstream of major hydraulic structures.

8.4 SENSITIVITY ASSESSMENT SUMMARY

Changes in peak flood level between each sensitivity scenario and the 1 in 100 AEP design event at key locations across the catchment are summarised in **Table 8-1** and the locations are presented in **Figure 7-1**. The assessment demonstrated that the study area is most sensitive to stormwater infrastructure blockages, followed by hydraulic roughness to a lesser extent. The study area demonstrates a largely insensitive response to changes in initial and continuing losses.

Table 8-1: Change in Peak Flood Level at Key Locations

ID	Key Location	Change in Peak Flood Level (m)							
		Unblocked Scenario	High Blockage Scenario	+20% Mannings Scenario	-20% Mannings Scenario	+20% IL Scenario	-20% IL Scenario	+20% CL Scenario	-20% CL Scenario
KAR_01	Kariong Oval DS Basin Outlet	0.02	-0.01	-0.01	0.01	-0.01	0.01	0.00	0.00
KAR_02	Kariong Oval US Basin Outlet	0.01	0.04	0.00	0.01	0.00	0.00	0.00	0.00
KAR_03	Gilford Street US Basin Outlet	0.01	-0.01	0.01	-0.01	0.00	0.00	0.00	0.00
KAR_04	Gilford Street DS Basin Outlet	-0.03	0.03	0.01	-0.01	0.00	0.00	0.00	0.00
KAR_05	Peppermint Park Basin 1 Outlet	-0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
KAR_06	Peppermint Park Basin 2 Outlet	-0.03	0.03	0.02	-0.02	0.00	0.00	0.00	0.00
KAR_07	Peppermint Park Basin 3 Outlet	-0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00
KAR_08	Peppermint Park Basin 4 Outlet	-0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00
KAR_09	Peppermint Park Basin 2 Outlet	0.00	0.00	-0.02	0.02	0.00	0.00	0.00	0.00
KAR_10	Langford Drive	-0.03	0.03	0.01	-0.01	0.00	0.00	0.00	0.00
KAR_11	Rafferty Close, Kariong Town	-0.09	0.17	-0.01	-0.01	-0.01	0.00	0.00	0.00
SOM_01	US Somersby Falls Road	-0.12	0.26	0.00	0.00	0.00	0.00	0.00	0.00
SOM_02	Piles Creek @ Holt Bragg Bridge	-0.02	0.01	0.05	-0.09	0.00	0.00	0.00	0.00
SOM_03	US Wisemans Ferry Road	-0.91	0.65	-0.07	0.06	0.00	0.00	0.00	0.00
SOM_04	Piles Creek US Somersby Falls Road, Somersby Industrial Area	-0.23	0.21	0.01	-0.01	0.00	0.00	0.00	0.00

9 Model Verification

As an additional model validation exercise, KBR developed a RORB hydrologic model covering the study area. RORB is a commonly used hydrologic modelling platform that simulates the catchment rainfall-runoff processes, producing inflows to the hydraulic model. The 5% AEP and 1 in 100 AEP rainfall events were run in the RORB model, with flow hydrographs from representative subcatchments extracted and compared to the results of the TUFLOW model in order to validate and verify the application of Rain-on-Grid hydraulic modelling.

9.1 RORB MODEL CONFIGURATION

The RORB model subcatchments were initially built based on the hydraulic model subcatchments. These subcatchments were then modified to better fit a hydrological model which favours uniformly sized subcatchments. Subcatchment routing was then conducted by generating nodes at subcatchment centroid and outlet and by assigning downstream reaches.

The selection of RORB runoff routing parameters K_c and m were based on recommended equations from RORB V6 User Manual and ARR 2019 Book 7 Chapter 6. These equations are highly dependent on the subcatchment characteristics. Thus, six (6) different subcatchments, representing different subcatchment sizes and types; urban residential, industrial/ farmlands, and vegetated watershed, were selected. K_c was calculated for each of these subcatchments, as recorded in **Table 9-1**. Across the six subcatchments, an average K_c of 3.3 was calculated and adopted alongside the recommended value of m = 0.8. Initial loss and continuing loss values of 9.5 mm/hr and 1.28 mm/hr were adopted to align with the calibrated catchment losses. Urbanisation was represented by the imperviousness fraction for each subcatchment.

Six (6) outlets that represent different types and sizes of catchments were selected for analysis. DSKS_40 and DSKS_46 are outlets of vegetated watersheds with relatively high total catchment areas of 15 km^2 and 11 km^2, respectively. DSKS_41 and DSKS_04 are outlets of industrial and farmland subcatchments, with total catchment areas of 1.3 km^2 and 3.0 km^2. DSKS_18 and DSKS_20 are outlets of urban residential subcatchments with relatively small total catchment areas of 0.9 km^2 and 1.1 km^2.

The RORB model GIS representation and the locations of the selected outlets is presented in **Figure 9-1**. It is important to note that the RORB model is uncalibrated and fit for the purpose of this validation exercise only.

Table 9-1: Subcatchment K_c Calculation

Subcatchment	Area (km^2)	K_c RORB Manual Equation	K_c ARR 2019 Equation
DSKS_40	15	8.5	4.1
DSKS_46	11	7.3	3.6
DSKS_18	0.9	2.1	1.1
DSKS_20	1.1	2.3	1.2
DSKS_41	1.3	2.5	1.3
DSKS_04	3	3.8	2.0
	Average	3.3	

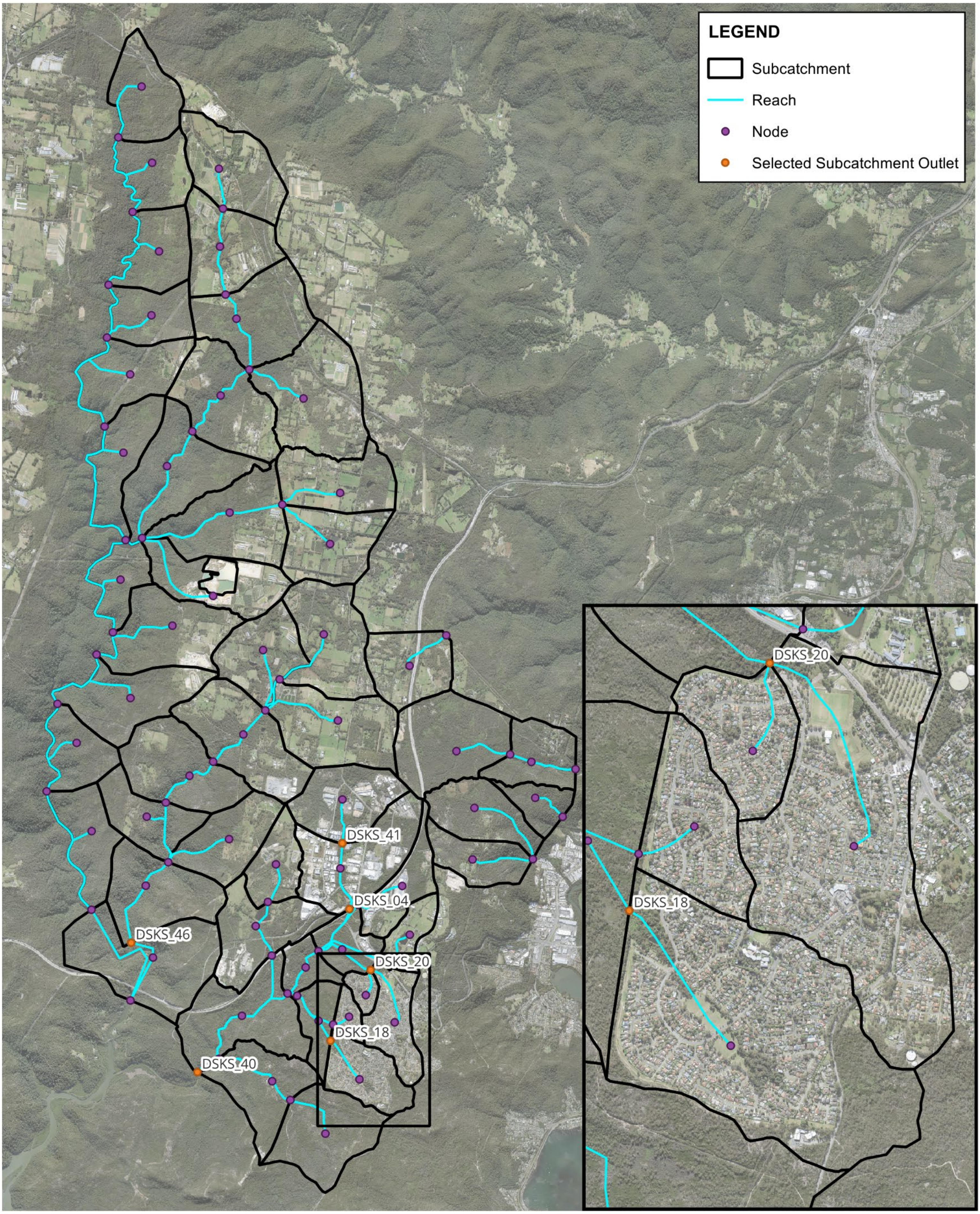
9.2 RESULT COMPARISON

Figure 9-2 to **Figure 9-7** below show the comparison between TUFLOW and RORB flow hydrographs for the 5% AEP and 1 in 100 AEP events at selected outlets. Comparison of 1 in 100 AEP flow hydrographs for DSKS_40 and DSKS_41 shows a relatively close match in terms of peak flow and time of peak flow. This indicates that the averaged K_c of 3.3 is a good match for these catchments. DSKS_20 and DSKS_18 are located in smaller, urbanised residential catchments. DSKS_20 still shows a close match in time of peak flow, although a noticeable difference in peak flow is observed. As for DSKS_18, there is a significant difference in peak flow and time of peak flow. This difference can be attributed to RORB having a quicker response rate due to the simplified nature of the catchments with no hydraulic structures, hydraulic controls or local storages. In contrast, subcatchment DSKS_41, which had a similar area to DSKS_20 and DSKS_18, performed quite well.

Comparison of 5% AEP flow hydrographs show a close match in terms of peak flow and time of peak flow for DSKS_40. While time of peak flow has been comparable for all the outlets, the magnitude of peak flows has notable differences. This can again be attributed to a combination of RORB not accounting for local hydraulic controls and storages as well as the influence of the stormwater drainage network in the 5% AEP event. This is a benefit of using a ROG model as the flows will be more representative of the flood behaviour within the more complex, urbanised catchments.

These results demonstrate that RORB can be a suitable tool for subcatchments in the study area however significant variance in K_c would be required to meet the significant differences in subcatchment types. Where K_c aligned with rural catchments which typically do not have major hydraulic controls the RORB results aligned with the TUFLOW.

A summary of the resulting peak flows and corresponding peak times is presented in **Table 9-2**.



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RORB Model GIS Representation

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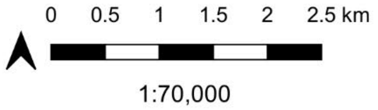


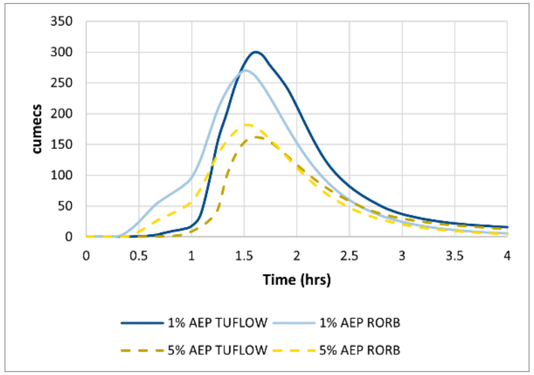


Figure 9-2: TUFLOW and RORB Flow Hydrograph at DSKS_40

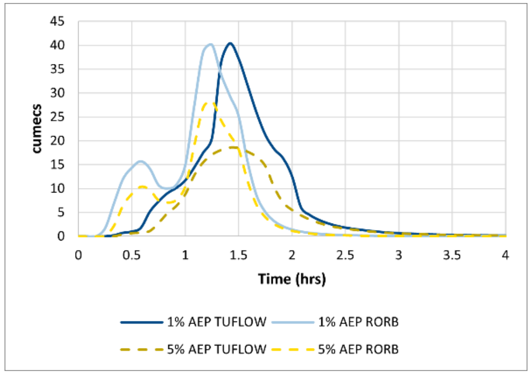


Figure 9-3: TUFLOW and RORB Flow Hydrograph at DSKS_41

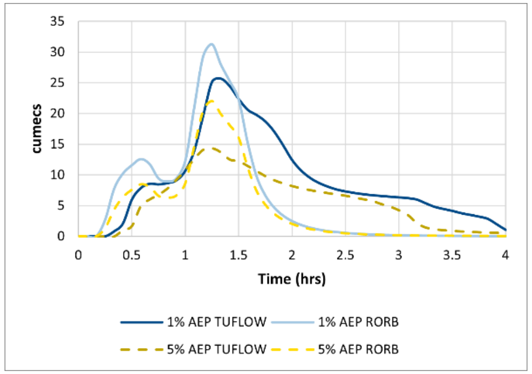


Figure 9-4: TUFLOW and RORB Flow Hydrograph at DSKS_20

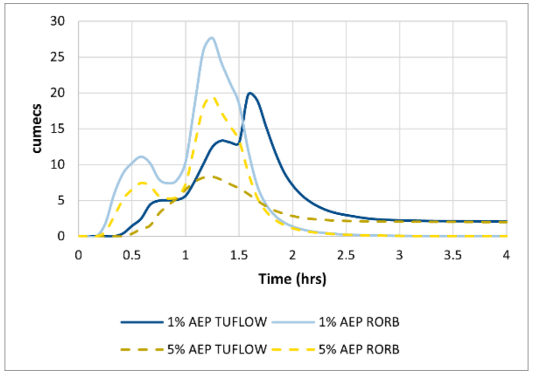


Figure 9-5: TUFLOW and RORB Flow Hydrograph at DSKS_18

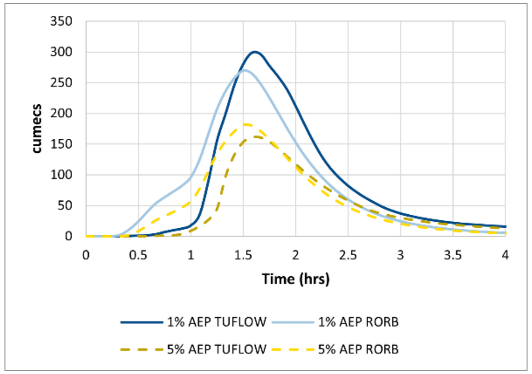


Figure 9-6: TUFLOW and RORB Flow Hydrograph at DSKS_46

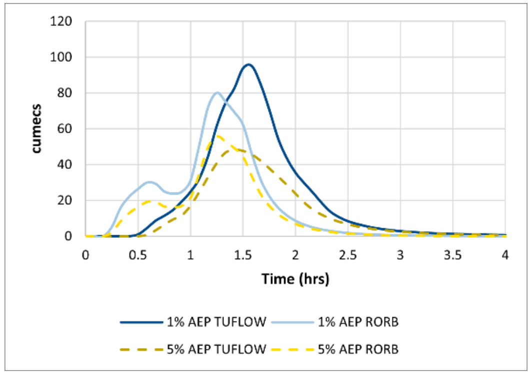


Figure 9-7: TUFLOW and RORB Flow Hydrograph at DSKS_04

Table 9-2: 1 in 100 AEP TUFLOW and RORB Peak Flow and Time of Peak

Subcatch-ment	Area (km²)	1 in 100 AEP TUFLOW Peak Flow (m³/s)	1 in 100 AEP TUFLOW Time of Peak (hr)	1 in 100 AEP RORB Peak Flow (m³/s)	1 in 100 AEP RORB Time of Peak (hr)	Difference in Time of Peak Flow (hr)	Difference in Peak Flow (%)
DSKS_40	15.0	299.1	1.67	269.8	1.50	0.17	10
DSKS_46	11.0	263.2	1.75	199.6	1.50	0.25	24
DSKS_18	0.9	19.7	1.58	27.7	1.25	0.33	-40
DSKS_20	1.1	25.7	1.33	31.3	1.25	0.08	-21
DSKS_41	1.3	40.4	1.42	40.1	1.25	0.17	1
DSKS_04	3.0	95.0	1.58	80.1	1.25	0.28	16

Table 9-3: 5% AEP TUFLOW and RORB Peak Flow and Time of Peak

Subcatch-ment	Area (km²)	5% AEP TUFLOW Peak Flow (m³/s)	5% AEP TUFLOW Time of Peak (hr)	5% AEP RORB Peak Flow (m³/s)	5% AEP RORB Time of Peak (hr)	Difference in Time of Peak Flow (hr)	Difference in Peak Flow (%)
DSKS_40	15.0	161.3	1.58	181.2	1.50	0.08	-13
DSKS_46	11.0	127.8	1.83	133.8	1.58	0.25	-5
DSKS_18	0.9	8.3	1.25	19.5	1.25	0	-135
DSKS_20	1.1	14.4	1.25	22.0	1.25	0	-53
DSKS_41	1.3	18.6	1.42	28.3	1.25	0.17	-52
DSKS_04	3.0	48.2	1.42	55.7	1.25	0.17	-16

10 Floodplain Management Planning

The floodplain management and planning elements of the study included the derivation of a flood planning area, identification of potential emergency management issues and provision of flood intelligence to the NSW SES, and an assessment of the cumulative impacts of development across the catchment. These items are detailed in the following sections.

10.1 FLOOD PLANNING AREA

The development of an appropriate Flood Planning Level (FPL) and resulting Flood Planning Area (FPA) is a critical component of CCC's future flood planning and flood risk management in the catchment. Prior to the Study, no FPA was available covering the Study Area. The FPA typically determines the extent in which land use planning controls may be applied to existing and future development across the floodplain in accordance with CCC's planning policies.

The objective of establishing an FPA is not to remove all flood risk to the community but instead to limit the frequency of exposure to and the consequences of flooding without unnecessarily sterilising land for future development or redevelopment. As there was no existing FPA for the Study Area, careful consideration was given to the derivation of the FPA to ensure the appropriate balance of managing current and future flood risk without sterilising land for development/redevelopment.

The FPL is based on a Defined Flood Event (DFE) which sets a standard to limit the exposure and growth of flood risk associated with new development and redevelopment. Freeboard is added to the simulated DFE peak flood levels to determine the FPL. Freeboard is added to provide a reasonable certainty of achieving the desired level of service expected from the selected DFE.

Freeboard takes into account elements such as uncertainties associated with the simulated flood levels (i.e. uncertainties and simplifications in the models used to estimate the flows); local factors influencing peak flood levels such as obstructions to flow at a lot level that are not able to be represented within the catchment wide model; and wave action. However, freeboard should not be relied upon to provide flood risk protection beyond the DFE to which it is applied.

For this Study, the 1 in 100 AEP event was selected as the DFE which is the commonly adopted DFE for derivation of FPLs for residential and industrial land uses in NSW. Taking in to account the model parameter sensitivity analysis and the study area containing both overland and major flow paths, a 0.5 m freeboard was applied to the 1 in 100 AEP DFE flood levels to determine the FPL. The adopted 0.5 m freeboard is the typical freeboard used for mainstream flooding in NSW.

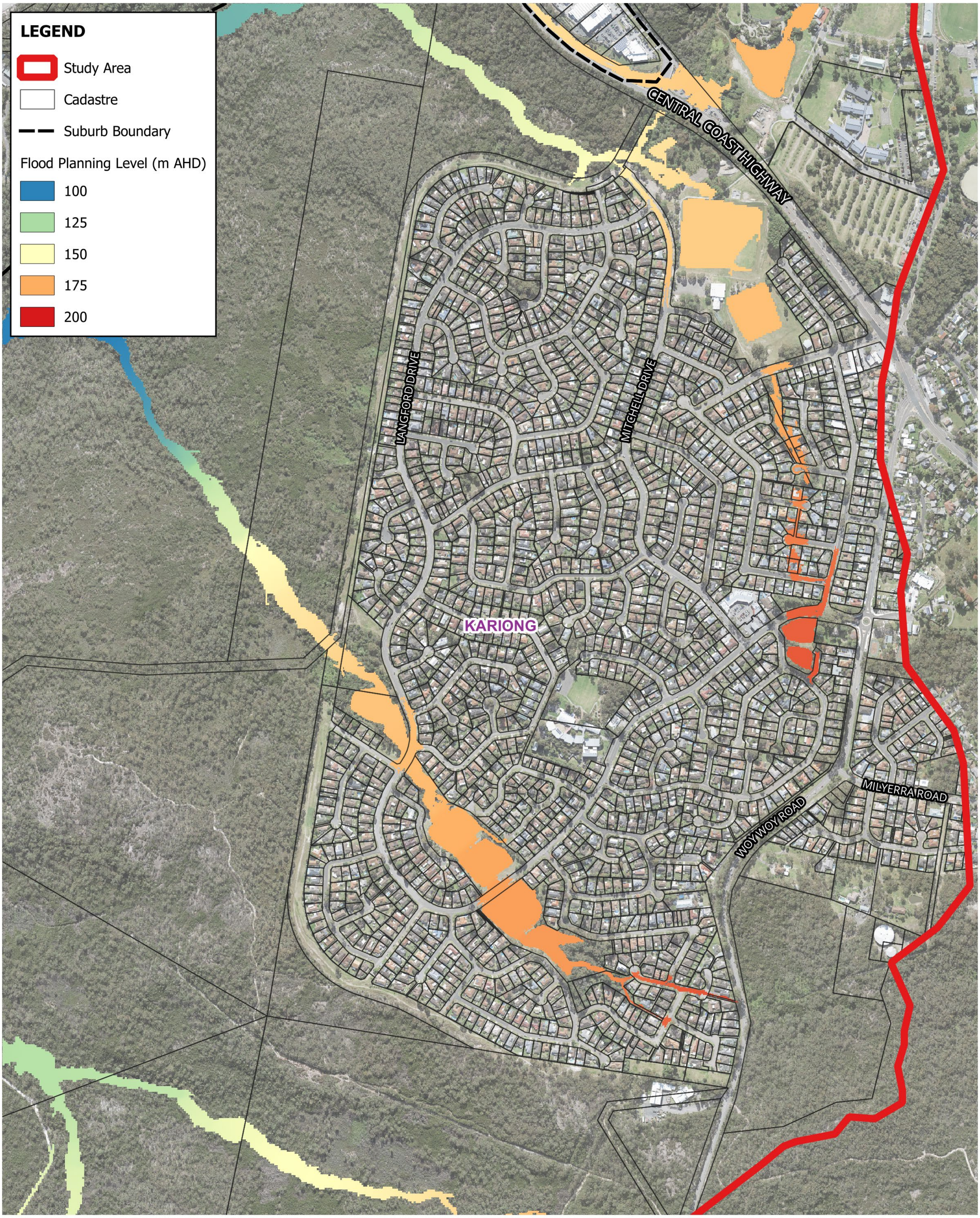
It is noted that different FPLs, based on varying DFEs and freeboard allowances can be adopted across a catchment due to varying flood behaviour and to apply to different types of development. However, a single DFE, freeboard and resulting FPL was considered appropriate and adopted for this Study.

The establishment of the FPA from the derived FPL is not a simple exercise, with different techniques adopted for different catchments and modelling methodologies. The FPA for the Study Area was developed to incorporate both mainstream and major overland flow components. As previously mentioned, careful consideration was given to the derivation of the FPA to ensure the appropriate balance of managing current and future flood risk without sterilising land for development/redevelopment. Through an iterative and collaborative process with CCC, the following methodology was applied to develop the final FPA:

- 1 in 100 AEP rainfall inputs were increased by a factor of 30% and simulated to provide a flood extent.

- The 1 in 100 AEP (not including 30% increased rainfall) peak flood level grid was raised by 0.5 m and extended laterally to intersect the surrounding topography.
- The laterally extended grid was then trimmed to the 1 in 100 AEP plus 30% rainfall extent.
- The trimmed extent was then filtered to remove all areas that were simulated as H1 within the 1 in 100 AEP hazard grid.
- The hazard filtered grid was then further filtered to remove flood islands less than 500 m^2.
- The filtered grid was further processed to remove any inundation areas that are 90% or more contained within the road reserve.
- The resulting FPA underwent a further review and refinement by CCC based on their local experience and engineering judgment, including removal of select farm dams from the FPA.

The extent and level of the flood planning area are presented in **Figure 10-1** to **Figure 10-3**.



Title:

Flood Planning Level
Kariong Town

Figure: **10-1**

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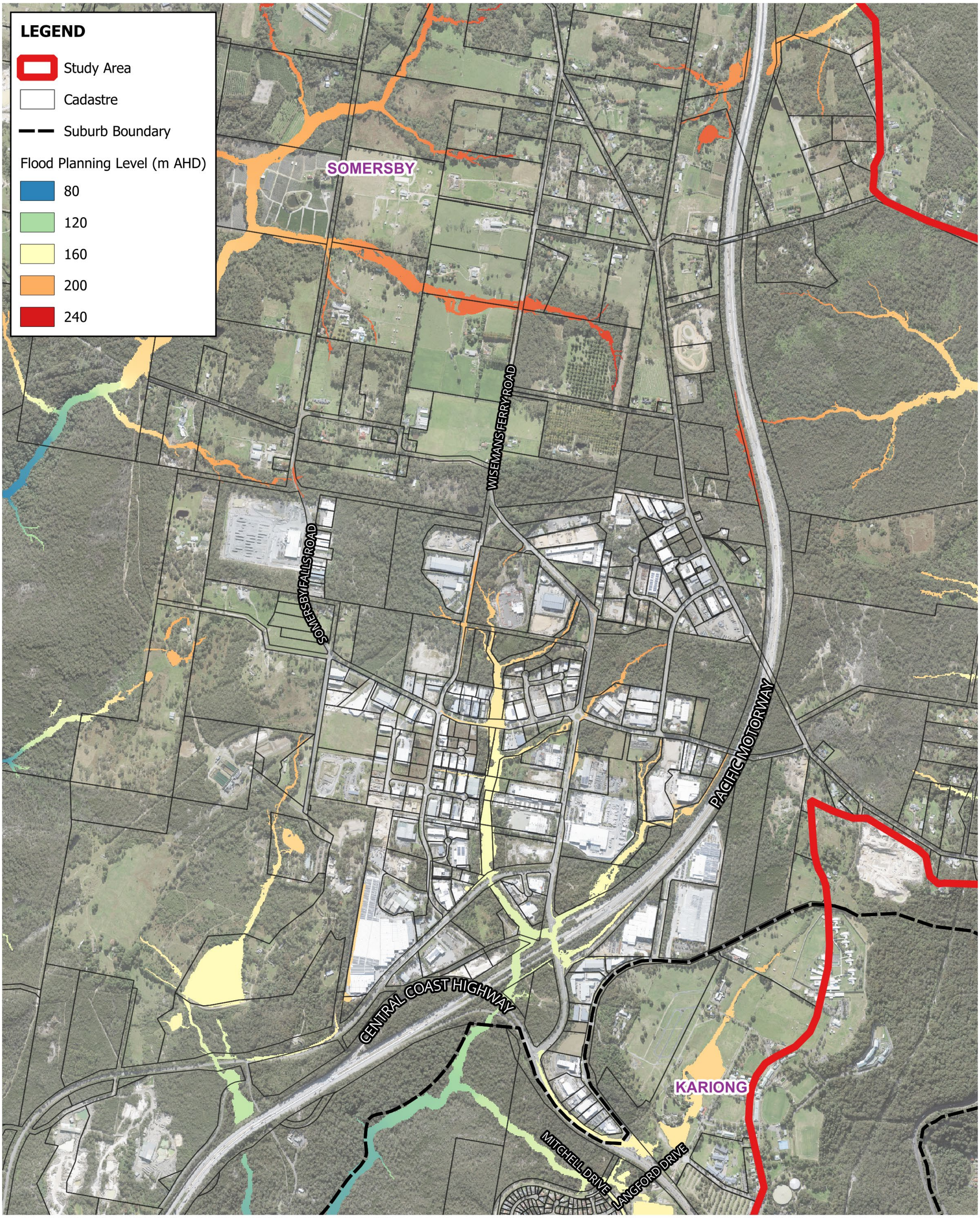

Title:

Flood Planning Level
Somersby Industrial Area

Figure: **10-2**

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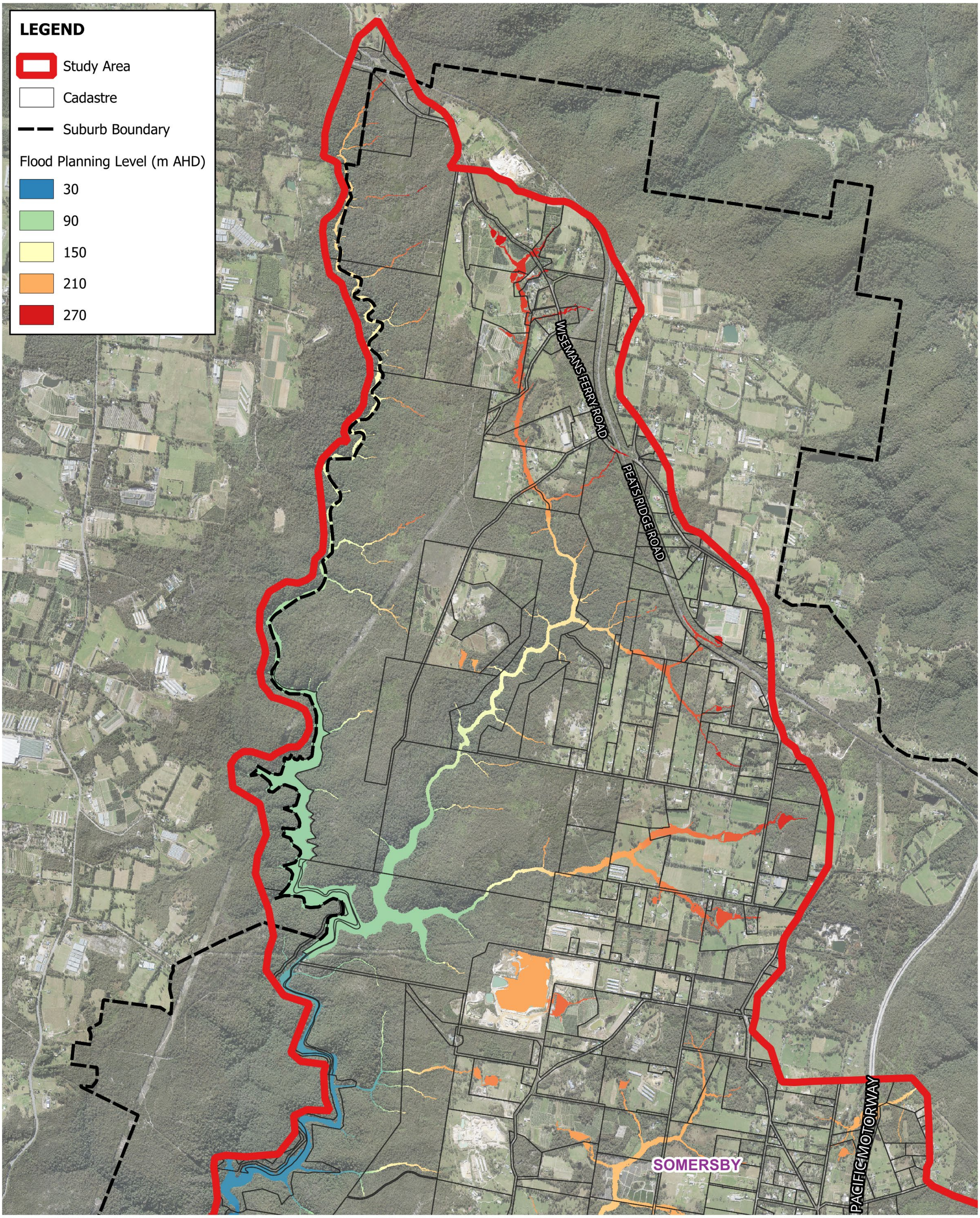

Title:

Flood Planning Level Northern Catchment

Figure: 10-3

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10.2 EMERGENCY MANAGEMENT ACTIVITIES

The descriptions of the physical flood behaviour to inform emergency management are detailed for both historical and design flood events within **Section 4** and **Section 6** respectively.

Hazard analysis indicates that roads throughout the catchment are generally overtopped by floodwaters with a hazard rating exceeding H2, making them unsafe for small and larger vehicles. The downstream sections of Casey Crescent and Mitchell Road, which discharge into Piles Creek, are also unsafe for vehicles. Despite these hazards, evacuation routes are available, with the M1 expected to remain trafficable as outlined in **Section 7.2** and further detailed in mapping of the FERCs included in **Appendix E**.

The flood affectation of several essential community facilities within Somersby and Kariong has been noted in **Table 10-1**.

Table 10-1: Flood Affectation of Essential Community Facilities

Facility Type	Essential Community Facility	Flood Affectation
Emergency Services Facility	Rural Fire Service Station	While partial flooding occurs along the driveway, the station remains accessible with a clear evacuation route towards Woy Woy Road
	Fire and Rescue NSW Kariong Fire Station	While partial flooding occurs at the back of the property, the station remains accessible with a clear evacuation route towards the Central Coast Highway.
Public Facility	Kariong Scout Hall	The scout hall is unaffected by flooding and has clear road access to the Central Coast Highway.
	Parklands Community Preschool	This facility is unaffected by flooding and has a clear evacuation path to the M1.
	Endeavour Early Education	The eastern side of the building has flood hazard ratings reaching H3, making parts of the site unsafe for people and vehicles. Clear road access unaffected by flooding allows safe evacuation for small vehicles.
	Kariong Child Care Centre	Minor H1 flood hazards are present, but the site can be evacuated, with clear road access available for emergency use.
	Little Angels Learning Centre	Milyerra Road has an H1 hazard along the road, but the building itself remains unaffected, allowing evacuation by small vehicles if necessary.
	Kariong Public School	Some areas are subject to flood hazards unsafe for children. However, the school oval, designated as an emergency muster point, is flood-free. Evacuation routes to the M1 are safe.
	Central Coast Sports College	This facility is unaffected by flooding and free of flood hazards
	Kariong Mountains High School	While some flood extents affect the buildings, emergency muster points such as the school oval remain flood-free, and safe evacuation routes to the M1 are available.
	Kariong Dental Care	Minor flooding is contained along Mitchell Drive in front of the practice, but the hazard level is low enough to allow safe vehicular access.

Facility Type	Essential Community Facility	Flood Affectation
	Kariong Medical Centre	The parking lot presents hazards unsafe for small vehicles; however, a flood-free evacuation route is available via the centre's back exit.
	Kariong Correctional Centre	This facility is unaffected by flooding.
	Great Beginnings Kariong	This facility is unaffected by flooding.

These considerations ensure that emergency management strategies are well-aligned with the observed flood behaviour, enabling safe evacuation and reducing risks to the community. These locations are presented in **Figure 10-4.**

The flood emergency response classification of communities is provided in **Section 7.2** with **Appendix E** showing the classifications across the 5% AEP, 1 in 100 AEP and PMF events.

Maps to inform emergency management are provided in **Appendix C**. Mapping includes flood function for selected events as well as peak flood levels, extents and velocities for critical design events.

A review of the 2021 Census by the Australian Bureau of Statistics provides insight on the demographics of Somersby and Kariong. This outlined the proportion of the community with increased vulnerability in comparison to the NSW average. The Census data is provided in **Table 10-2** and depicts:

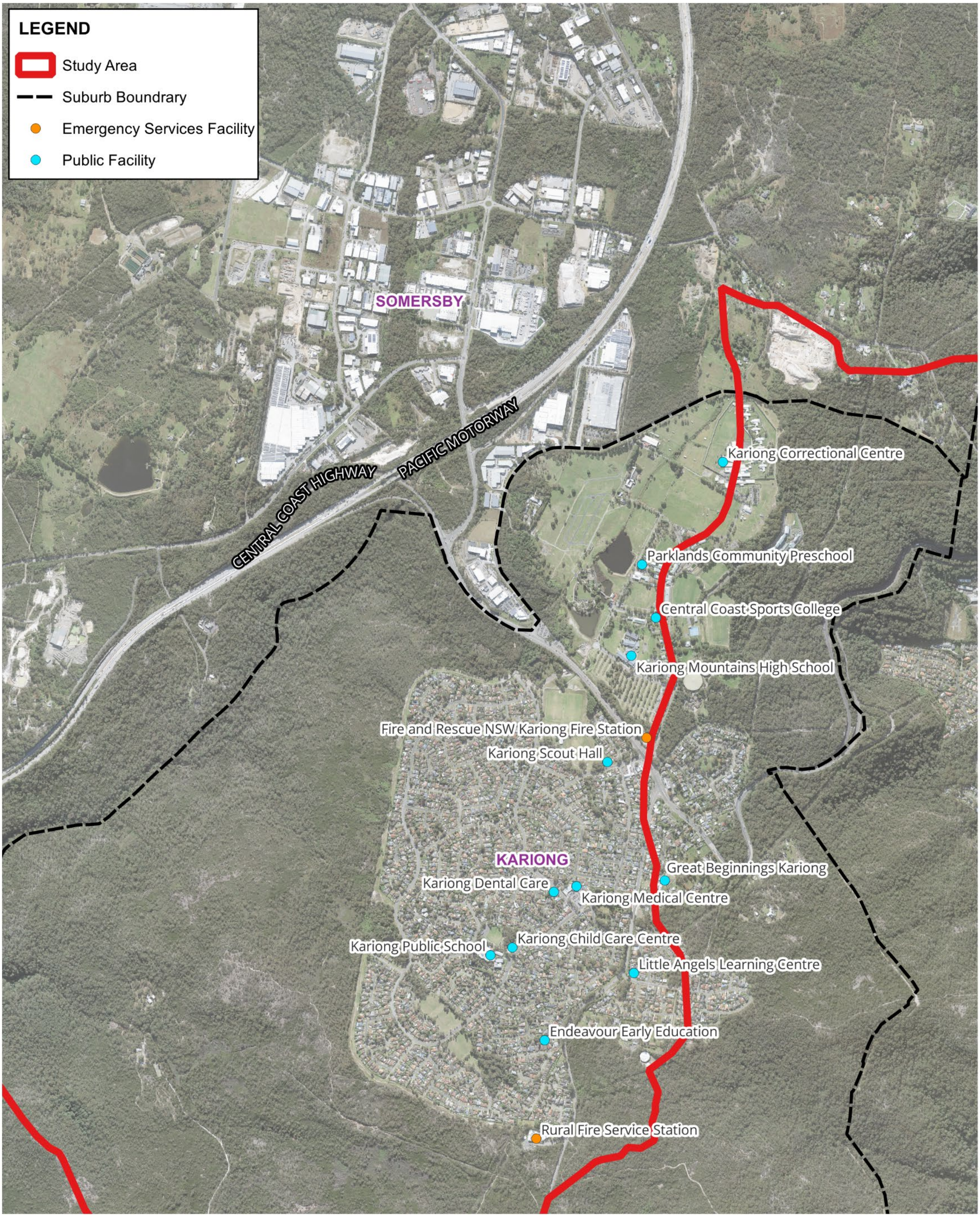
- Vulnerable age groups (less than 5 years and over 75 years),
- One parent families,
- Households where a non-English language is used,
- Rented properties, and
- The population with long term health conditions.

These categories were selected as they depict population with potentially increased evacuation and shelter risk as well as potential lack of local flood awareness or communication difficulties. Kariong and Somersby localities composition had lower vulnerability in comparison to the NSW average for older age groups, households where a non-English language is used and the proportion of renters in the localities. However increased vulnerability due to community composition was seen in the form of long-term health conditions and further note that in the Kariong Locality, the number of children less than 5 years and the number of one parent families was above the NSW average.

Table 10-2: 2021 Census Data Correlated to Vulnerability in Communities

Category		Kariong Locality		Somersby Locality		New South Wales
		Number	%	Number	%	%
Vulnerable age groups	Less than 5 years	414	6.4	45	4.1	5.8
	Greater than 75 years	266	4.1	87	7.5	7.9
Family composition	One parent families	293	16.4	20	10.1	15.8

Category		Kariong Locality		Somersby Locality		New South Wales
		Number	%	Number	%	%
Language used at home	Households where a non-English language is used	308	14.7	40	11.8	29.5
Tenure Type	Rented	469	22.4	85	25	32.6
Long-term health conditions	One or more conditions	1864	28.9	334	30.7	27



Title:

Essential Community Facility Locations

Figure: 10-4

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10.3 ASSESSMENT OF CUMULATIVE IMPACTS OF DEVELOPMENT

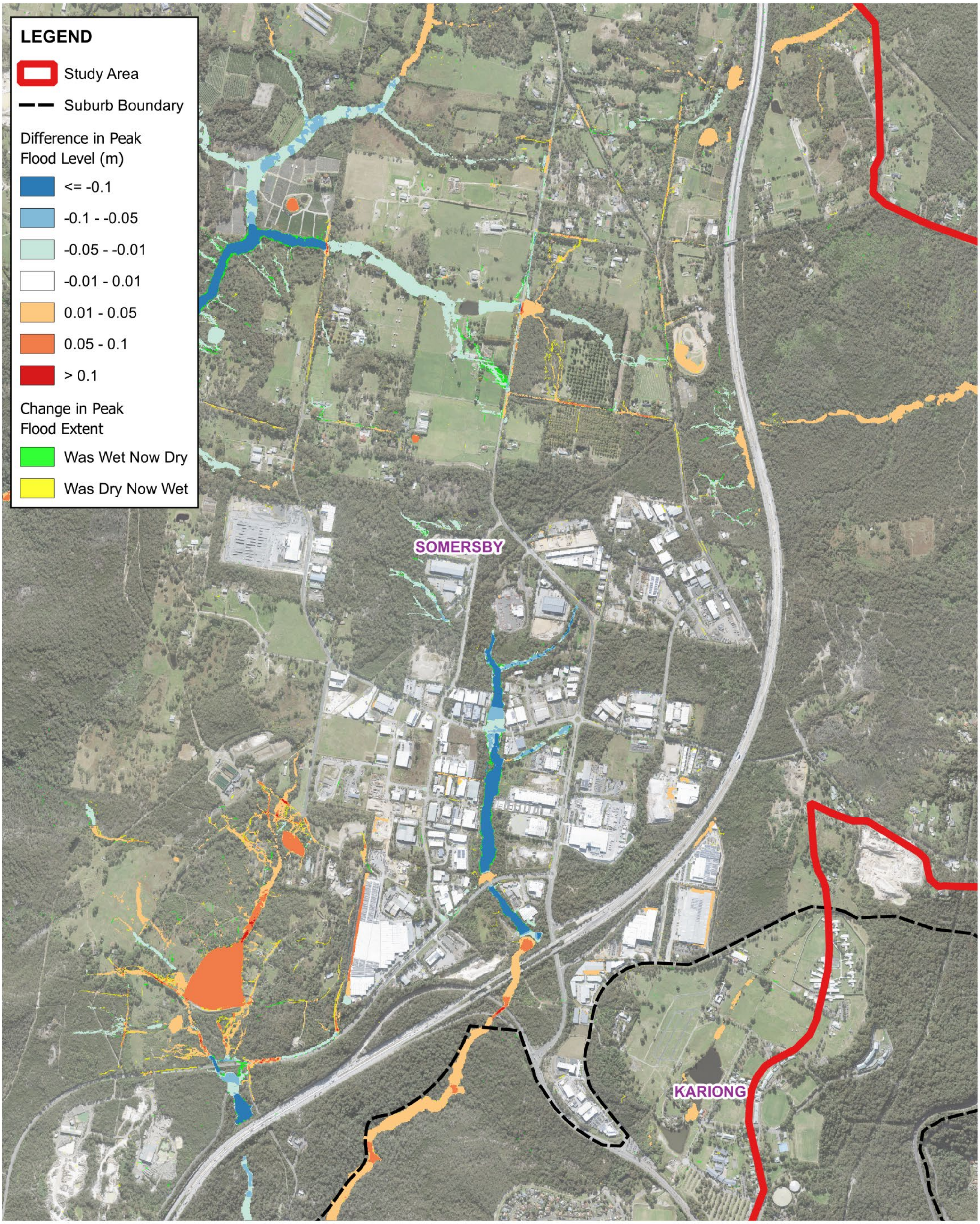
To assess the impact of cumulative development in the study area, land currently zoned as Urban Land, Commercial, Infrastructure, Tourism, Employment, and Character Areas had a fraction impervious increase of 5% applied in the TUFLOW RoG model. This adjustment accounts for potential knock-down rebuilds, extensions, and the subdivision of lots, reflecting a conservative approach to the anticipated changes in land use intensity over a 20 year period. Additionally, any land rezoned under Central Coast Regional Plan 2041 (CCRP 2041) was updated to reflect its proposed land use type.

The Watalgan District's future planning initiatives emphasise the protection of agricultural land and primary production, while containing rural residential development within defined village growth boundaries. As such, no increase in fraction impervious was used for areas zoned as Agricultural and Rural. This approach ensures that the district's rural and agricultural uses are preserved.

Given that the district strategy takes an overall approach to future development scenarios, it is recommended to maintain the proposed zoning as outlined, with one key exception. Specifically, the tourism area was used in place of the CCRP 2041 holistic catchment zone.

The regional plan newly rezoned areas were scaled such that 50% of the development has been completed. Additionally, the proposed rezoning of the tourist area was adopted, however current residential planning proposals were not implemented.

The 1 in 200 AEP event was selected to reflect a 1 in 100 AEP future scenario. The difference between the future development scenario and existing scenario demonstrates reductions throughout the industrial area with slight increases in flood depth through the main channel leading towards the residential area of Kariong. This is presented in **Figure 10-5** and **Figure 10-6**.



Title:

Difference in Peak Flood Level - Somersby Industrial Area Future Development Minus Design 1 in 200 AEP

Figure: 10-5

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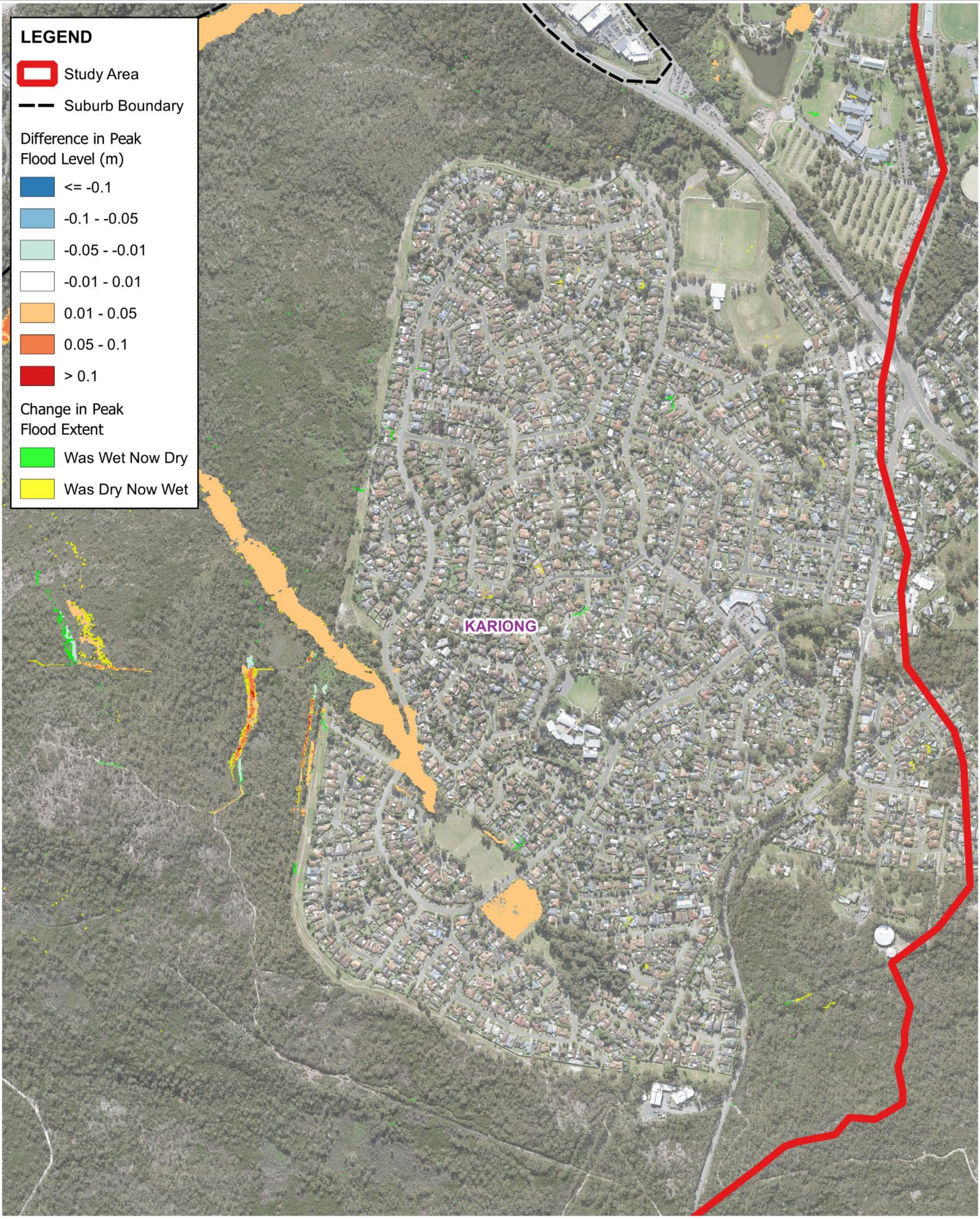

Title:

Difference in Peak Flood Level - Kariong Town Future Development Minus Design 1 in 200 AEP

Figure: 10-6

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10.4 ROAD INUNDATION ANALYSIS

A detailed analysis of the impact of flood waters to vehicles and roads has been undertaken across the range of design events simulated. Each road within the study area has been segmented at each intersection with a different road, resulting in a total of 412 road segments totalling 163 unique roads. Across each road segment, the maximum post-processed flood hazard and depth outputs were sampled and interrogated. Inspection was undertaken at bridges to confirm impact to roadways or if all depths and hazards were located in the waterway or flow path below deck level.

10.4.1 Road Hazard Analysis

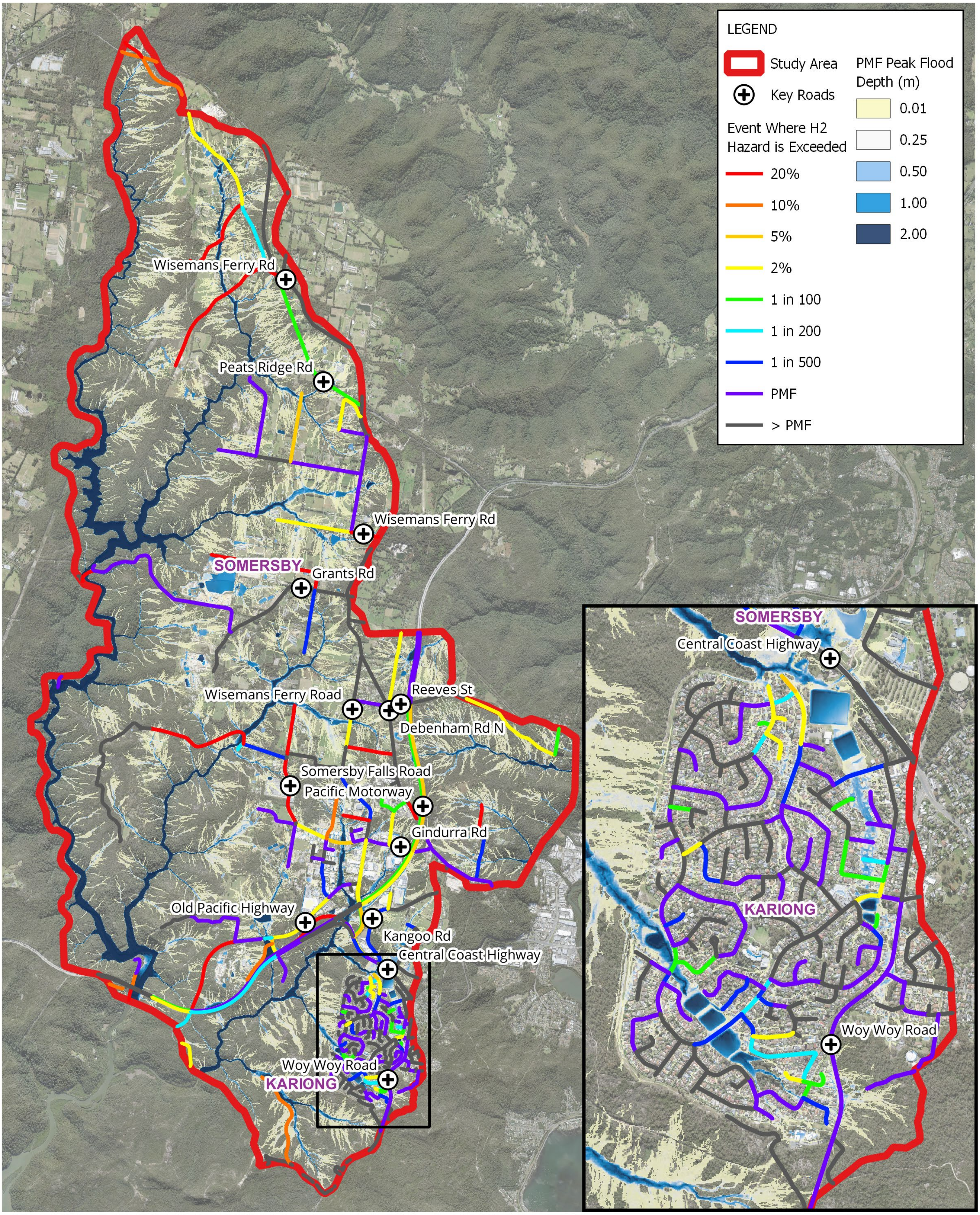
In accordance with the Flood Risk Management Manual (DPE, 2023), a H2 hazard category is identified as being unsafe for small vehicles. As such, all road segments with a hazard category above H2 have been flagged and presented in **Figure 10-7**. The road hazard categorisation has been implemented as the primary assessment of road access and evacuation due to the combined depth and velocity factors incorporated, rather than solely assessing the road due to a water depth. The road hazard analysis was incorporated into the FERC of communities in **Section 7.2.4**.

10.4.2 Road Cutoff Analysis

To provide additional information to the road hazard mapping, a road cutoff analysis based solely on depth was undertaken. This was conducted by designating roads with maximum depths greater than 150 mm as being cutoff. While no prescriptive depth criteria are stated within the Flood Risk Management Manual, research has indicated that 150 mm depth of water is sufficient to float small vehicles (G P Smith, B D Modra, T A Tucker, and R J Cox, 2017). This also corresponds with the common kerb height and has been selected as the criteria for which a roadway has been completely inundated and therefore cut off (refer to **Figure 10-8**).

10.4.3 Duration of Inundation Analysis

Duration of inundation assessments of the roads has not been conducted throughout the catchment due to the primary flooding mechanisms in the catchment being flash flooding and overland flow. These dominant mechanisms have resulted in critical storm durations ranging between 60 – 90 minutes, with critical peak flows and levels throughout the catchment receding generally within 2 hours. The impacts of isolation are therefore reduced and the ability to implement the NSW Shelter-in-Place guideline for flash flooding for these sections of the catchment can become an emergency management policy in consultation with the guideline on a region-by-region basis.



Title:

Road Hazard Analysis

Figure: 10-7

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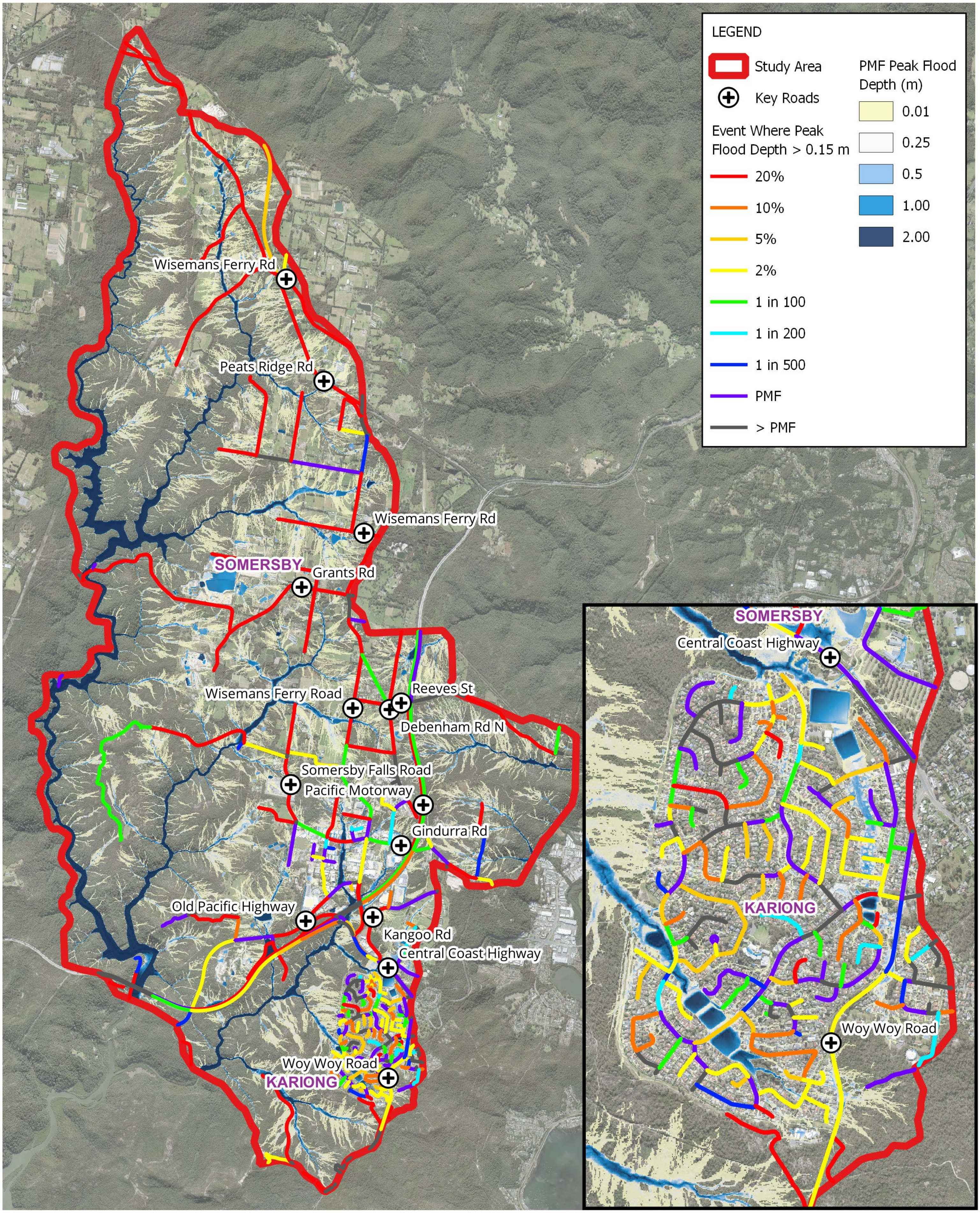

Title:

Road Cutoff Analysis

Figure: **10-8**

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10.4.4 Road Hazard and Flood Emergency Response Classification Summary Analysis

A combined approach of assessing the FERC classified regions with the road hazard classifications was undertaken to provide potential localised emergency actions and emergency evacuation and access routes. The assessment is provided below in **Table 10-3** and **Figure 10-9**.

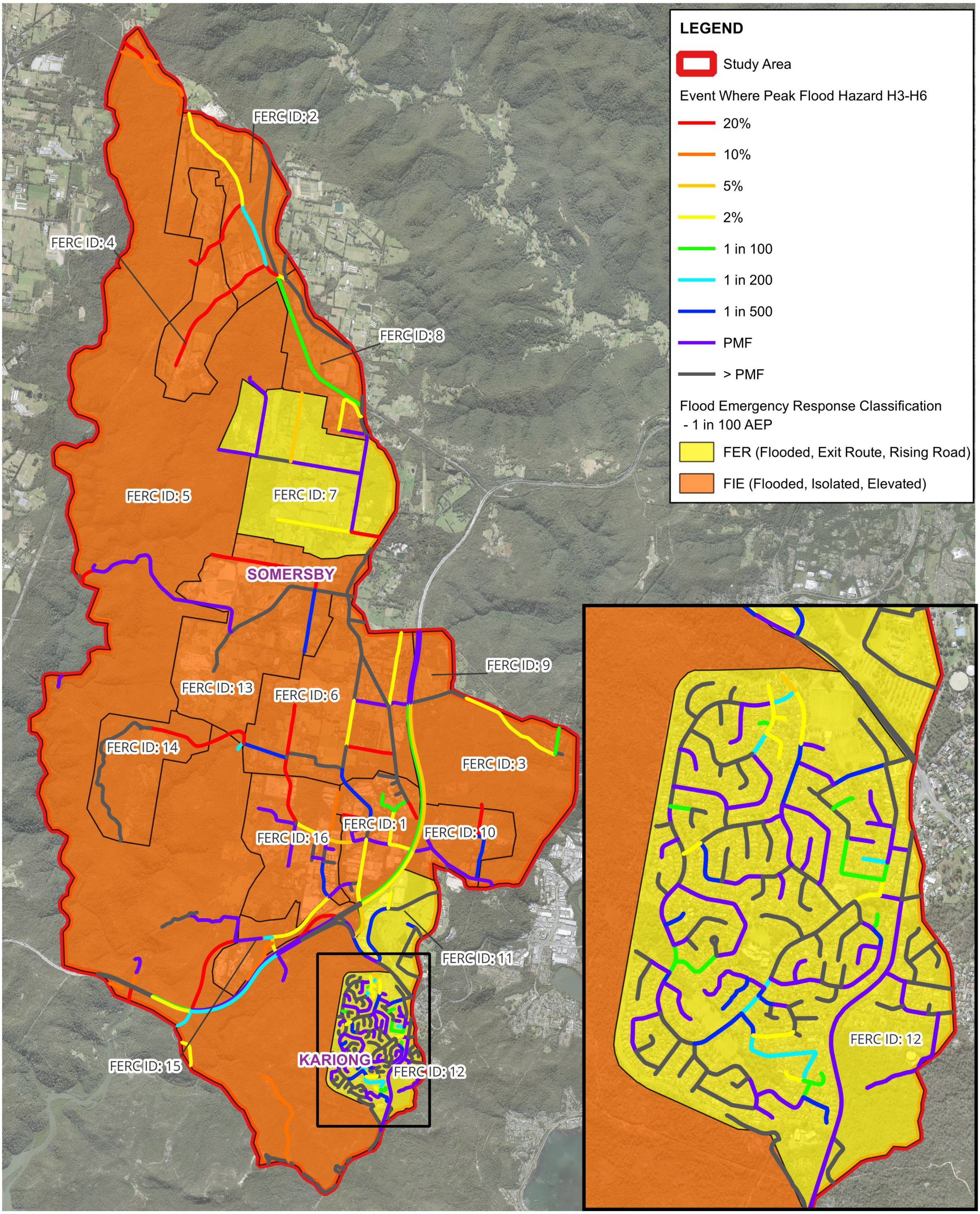
Table 10-3: FERC Regions and their Critical Access and Evacuation Summary

FERC Area ID	FERC Area	Critical Access and Evacuation Roads	Closure Location	Event Inundated above Hazard: H2 (AEP Tipping Point)	Impact on Access and Egress
1	Somersby industrial Area – East of Piles Creek	Wisemans Ferry Rd – M1	Wisemans Ferry Rd underpass below Pacific Motorway	5%	Kariong and Somersby are Cut-off. Requirement for Emergency Services to use the M1 Northbound On ramp to access Somersby from Kariong.
		Wisemans Ferry Rd – Kariong	Wisemans Ferry Rd M1 On Ramp Northbound	PMF	Access to the M1 from Somersby and vice versa is available up until the PMF.
2	Residential Areas with Access to Wisemans Ferry Road without crossing Little Mooney Mooney Creek	Wisemans Ferry Road	Wisemans Ferry Rd – Underpass of Peats Ridge Rd	20%	Wisemans Ferry Road may be cut off from evacuation and emergency access from the south and as such localised community awareness should be considered.
3	National Parks and Vegetated Land	-	-	-	-
4	Residential Areas west of Little Mooney Mooney Creek	Little Mooney Creek Rd / Konda Rd	Little Mooney Mooney Creek	20%	Localised roads may be cutoff and as such localised community awareness

FERC Area ID	FERC Area	Critical Access and Evacuation Roads	Closure Location	Event Inundated above Hazard: H2 (AEP Tipping Point)	Impact on Access and Egress
					should be considered.
5	National Parks and Vegetated Land	-	-	-	-
6	Somersby Residential Area – East of Floods Creek and West of the M1	Wisemans Ferry Rd and Debenham Rd N	Major road resilient above the PMF	-	Localised roads may be cutoff and as such localised community awareness should be considered.
7	Somersby Residential Area – Surrounding Robinsons Creek	Wisemans Ferry Rd	Wisemans Ferry Rd – northbound	PMF	Access Northbound is available up till the PMF event.
			Wisemans Ferry Rd – southbound	20%	Impacts at Wisemans Ferry Rd / Elwins Rd provide potential evacuation and access impacts.
8	Somersby residential area – Surrounding Peats Ridge Rd	Peats Ridge Rd / Wisemans Ferry Rd	Peats Ridge Rd	1 in 100	It is recommended to use Wisemans Ferry Rd instead of Peats Ridge Rd in large events, as Peats Ridge Rd is inundated in the 1 in 100 AEP event.
9	Somersby Residential Area - East of the M1 access via Reeves St	Reeves St	Elevated access, closure located in FERC area ID 1	PMF	Access via Reeves Rd and Debenham Rd N are resilient up to the PMF.
10	Somersby Residential Area - East of the M1 access	Gindurra Rd	Gindurra Rd - M1 Underpass	2%	Access Via Kangaroo Rd from Kariong is recommended before
		Kangoo Rd	Kangoo Rd Junction with	1 in 500	

FERC Area ID	FERC Area	Critical Access and Evacuation Roads	Closure Location	Event Inundated above Hazard: H2 (AEP Tipping Point)	Impact on Access and Egress
	via Gindurra Rd		Central Coast Hwy		accessing via Somersby on Gindurra Rd.
11	Kariong/Somersby – East of M1 and North of Central Coast Hwy	Kangoo Rd	Kangoo Rd Junction with Central Coast Hwy	1 in 500	Access Via Kangaroo Rd from Kariong. Additional roads resilient above the PMF leading out of the modelled area at Festival Dr and McCabe Rd.
12	Kariong Town Centre	Woy Woy Rd / Central Coast Hwy	Access to M1 Along Central Coast Hwy	PMF	Due to the number of residential roads, immunity up to the PMF of Woy Woy Rd and Central Coast Hwy and the location of two emergency service facilities Kariong is resilient up to the PMF.
13	Somersby West of Floods Creek with access via Grants Rd	Grants Rd	Grants Rd is resilient above the PMF	-	-
14	Properties Located on the Hawkesbury Track (West of Somersby Falls)	Hawkesbury Track	Floods Creek / Somersby Falls	20%	Properties are isolated in frequent events including the 20% AEP event. Localised community awareness should be considered.
15	Gosford Quarries and access to Girrakool	Old Pacific Hwy	Old Pacific Hwy / Pile St	2%	Gosford Quarries isolated in the 2% AEP event.

FERC Area ID	FERC Area	Critical Access and Evacuation Roads	Closure Location	Event Inundated above Hazard: H2 (AEP Tipping Point)	Impact on Access and Egress
	Office – NSW National Parks				Localised community awareness should be considered.
		Quarry Rd	Quarry Rd/ Girrakool Rd	5%	Girrakool Office is isolated in the 5% AEP event. Localised community awareness should considered.
16	Somersby industrial Area – West of Piles Creek	Somersby Falls Rd	Somersby Falls Rd over Piles Creek	5%	Access Via Old Pacific Hwy is recommended instead of using Somersby Falls Rd northbound or southbound.
			Somersby Falls Rd Northbound	10%	
		Old Pacific Hwy	Old Pacific Hwy Near Piles Creek	PMF	



Title:

FERC Regions and Critical Access / Evacuation

Figure: **10-9**

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11 Assumptions and Limitations

Hydrologic and hydraulic model inputs were subject to certain assumptions and limitations that may impact on model results. These are summarised in **Table 11-1** below.

Table 11-1: Model Limitations

Limitation	Description	Impact on Results
Missing drainage structure information	Missing geometric details such as invert levels and dimensions were estimated through visual and desktop assessment, and interpolation from known data.	Minor underestimation or overestimation of flows in the stormwater network may occur. As the stormwater network is typically designed to convey overland flows up to the 20% AEP event, the risk to rarer events is minimal.
Ungauged catchment	There are no stream gauges in the study area to inform model calibration or validation.	There is degree of uncertainty in runoff estimates and streamflow predictions for the catchment. Note however that there is greater uncertainty associated with model calibration to anecdotal data (i.e. derived from community consultation) than to using stream gauge data.
Reliance on community-sourced observations	The hydraulic model was calibrated against peak flood level estimates provided from residents' observations.	Community sourced-based observations may be limited by potential issues such as data inaccuracy, faulty memory and subjective biases. This may lead to poor calibration and greater uncertainty in model accuracy and predictive performance.
Quality of underlying topographic data	The 2022 LiDAR (1 m resolution) was adopted across the entire catchment area.	There is a risk that the elevations across the study area are not completely representative of the actual surface topography, particularly at key hydraulic structures. A detailed review of topographic data at critical locations was been undertaken, and this risk is considered minimal.

12 Conclusions

The primary objective of this study has been to develop a series of hydrologic and hydraulic models to inform the catchment-wide risk associated with flooding across past, existing, and future catchment conditions. Outcomes of this assessment can inform decision-making processes within CCC as well as to form the basis of later more detailed studies.

At the onset of the study, KBR undertook a review of available information and derived a methodology appropriate to the scope of the study. An initial community consultation process was established to inform the community of the Study and to ensure the adopted methodology is suitable to the community’s needs. A key outcome of the initial community consultation process was to collate historical event information to inform the model calibration and validation stage of the study.

A combined hydrologic and hydraulic Rain-on-Grid TUFLOW model of the Somersby and Kariong catchment was developed and calibrated to the June 2007 and November 2011 historic events. The calibrated model was subsequently validated to the March 2021 and the March 2022 historic events with suitable correlation to reported data points achieved across the four events. Design event modelling was subsequently completed in accordance with ARR Version 4.1 guidelines.

A series of model parameter sensitivity analyses was undertaken as well as a future climate change assessment. Floodplain management planning exercises were completed, inclusive of the derivation of a Flood Planning Area and a road inundation analysis.

The study identified flooding associated with overland flow to be the dominant flooding mechanism within the study area. The relatively short critical duration coupled with the rapid response times of the catchments suggest that the study area is at most risk to short duration, high intensity rainfall events. Overall, Somersby and Kariong is a relatively low risk catchment, with flooding generally confined to flood storage basins and waterways. However, outcomes of the study have demonstrated that the study area is sensitive to stormwater infrastructure blockages. These impacts are further exacerbated with the increased rainfall intensities associated with the future climate change.

KBR recommends the installation of stream gauges to assist in the capture of recorded water levels should further calibration and validation to future storms be undertaken. The gauges should be installed near the outlet of each watercourse in a strategic location that is free from interferences or locations prone to blockages.

The outputs from this study can be used to inform a subsequent Flood Risk Management Study. The subsequent study should include a review of CCC’s planning and stormwater management policies; and CCC's land use planning policies with respect to development with the floodplain..

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