WOLLONGONG CITY COUNCIL

HEWITTS CREEK FLOOD STUDY

DECEMBER 2019

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HEWITTS CREEK FLOODPLAIN RISK MANAGEMENT STUDY AND PLAN

ADDENDUM TO REVIEW OF HEWITTS CREEK FLOOD STUDY (2015)

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HEWITTS CREEK FLOODPLAIN RISK MANAGEMENT STUDY AND PLAN

ADDENDUM TO REVIEW OF HEWITTS CREEK FLOOD STUDY (2015)

FINAL

JANUARY 2020

Project Hewitts Creek Floodplain Risk Management Study and Plan	**Project Number** 117028
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4	Final Flood Study Addendum	WCC	DEC 19
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HEWITTS CREEK FLOODPLAIN RISK MANAGEMENT STUDY AND PLAN

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LIST OF ACRONYMS

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

EXECUTIVE SUMMARY

Introduction

The study area is located within the Wollongong City Council Local Government Area (LGA) and incorporates Slacky, Tramway, Woodlands, Hewitts and Thomas Gibson Creeks. The combined catchment is approximately 7.5km^2 and incorporates the northern Wollongong suburbs of Bulli and Thirroul. The catchment extends from the Illawarra Escarpment in the west, discharging into the Thirroul and Sandon Point Beaches in the east.

The flood behaviour in the catchment is influenced by catchment runoff, in addition to the interaction with ocean conditions, particularly in the lower catchment. Significant flooding was experienced in August 1998 when vast areas of the Illawarra region were impacted. Within the Hewitts Creek catchment both public and private property were damaged in that event. Anecdotal and surveyed flood levels exist for the 1998 event in addition to the 1988, 1991 and 2013 events.

In order to understand and allow for the management of flooding in the Hewitts Creek catchment, Wollongong City Council prepared the Hewitts Creek (incorporating Slacky, Tramway, Woodlands, Hewitts and Thomas Gibson Creeks) Flood Study and Floodplain Risk Management Study and Plan in 2002. More recently, preparing the Review of Hewitts Creek Flood Study in 2015, which provided updated flood information for the catchment.

Following the completion of the 2015 Flood Study Review, Council developed a revised Conduit Blockage Policy in 2016. The 2015 Flood Study Review was based on Council's previous Conduit Blockage Policy (2002) as documented in Council's 2009 Development Control Plan.

This report provides an addendum to the 2015 Flood Study Review and outlines the revised design flood behaviour considering Council's Revised blockage policy, in addition to catchment changes since 2015 and recommendations coming out of review of the models.

This document was placed on Public Exhibition for a period of four weeks (9 September to 8 October 2019). During the consultation period Council sent letters to 1,900 residents and property owners in the catchment area inviting them to learn more about the study. An information session was held for community members to discuss the study and ask questions. Copies of the draft report, a Frequently Asked Questions sheet and Feedback form were available at Thirroul Library and on the project webpage. Submissions could be made during the information session, via the Feedback form, via Council's website and through the Customer Service Centre. A total of 15 submissions were received. These submissions have been considered in the finalisation of this report.

Flood Models

The Review of Hewitts Creek Flood Study (2015) aimed to determine design flood behaviour in the study area. To achieve this, a Watershed Bounded Network Model (WBNM) hydrologic model and a 1D/2D TUFLOW hydraulic model were established. The models have been reviewed as part of the current study to ensure they have been developed using best practice approaches and to determine the suitability for use in the Floodplain Risk Management Study.

Both the WBNM hydrologic model and TUFLOW hydraulic model established as part of the Flood Study Review (2015) were generally considered appropriate. Some minor updates were required to ensure the models produce an improved representation of design flood behaviour. These updates included updating the terrain information to a more recent dataset, refinement of the models in the new development areas, improved representation at a number of hydraulic structures, and inclusion of the drainage network. These updated models formed the basis for assessment of a range of scenarios including Council's Revised Conduit Blockage Policy (2016).

Modelled Scenarios and Results

The primary objective of this Flood Study Addendum was to update the design flood behaviour to existing floodplain conditions, considering recent developments and floodplain changes, and to take into account Council's Revised Blockage Policy. In order to understand the relevant changes to flood behaviour as a result of each of these updates a series of scenarios have been assessed and compared where relevant. The scenarios are outlined in Table ES1 below.

Table ES1 – Modelled Scenarios

Scenario ID	Aim	Blockage Policy	Catchment Conditions	Topographic Dataset
0	Re-establish the conditions presented in the Flood Study Review (2015) considering the model review (Section 3).	2002	2015	2013 LiDAR and field survey
1	Understand the influence of the 2016 Revised Blockage Policy (Section 2.6.2).	2016	2015	2013 LiDAR and field survey
2	Understand the influence of catchment changes since 2015.	2016	2018	2013 LiDAR, field survey and recent catchment changes/developments

The 2015 Flood Study Review was undertaken in accordance with the methodologies outlined in Australian Rainfall and Runoff 1987 (ARR 1987), which were applicable at the time of the study. In late 2016, a first release of a revised Australian Rainfall and Runoff guideline became available, a later revision was subsequently released in mid 2019. The design flood behaviour produced as part of this Flood Study Addendum has been developed using the methodologies described in ARR 1987. The revised guidelines will be considered as part of the Floodplain Risk Management Study stage.

The updated hydrologic and hydraulic models were used to simulate flood behaviour under each scenario for a range of design events and relevant flood mapping produced.

Scenario ID 2 reflects 2018 catchment conditions and Council's Revised Conduit Blockage Policy and therefore represents the current revised design flood behaviour for the Hewitts Creek catchment. Flood mapping (peak flood level, depth, velocity and hydraulic hazard (1% AEP only)) for Scenario ID 2 for the 5 year ARI, 1% AEP and probable maximum flood (PMF) events is reproduced in Figures ES1 to ES7. Mapping presented in Figures ES1 to ES7 has adopted the "risk management" blockage scenario.

Comparison was made between the scenarios to understand the influence of the various factors on design flood behaviour. The following provides a brief summary.

- Scenario ID 0 (Re-established Base Case) – This scenario was compared to the results from the Flood Study Review (2015). Across a large proportion of the study area the flood level results in the 1% AEP remain within +/- 0.1m of those presented in the Flood Study Review (2015). The inclusion of the drainage network through the catchment has reduced flooding and, in some cases, completely removed shallow overland flow. Other localised variation in flood levels occur as a result of the changes to the model terrain (LiDAR) and hydraulic structures. The magnitude of these changes is generally between 0.1m and 0.5m. Additional flood information is available in the upper sections of Hewitts Creek due to the extension of the hydraulic model.
- Scenario ID 1 (Revised Conduit Blockage Policy) – This scenario was compared to Scenario ID 0. The changes in flood behaviour as a result of the Revised Conduit Blockage Policy are generally limited to upstream of some structures where flood levels are reduced by between 0.1m and 1.0m, with a maximum reduction of 1.9m. The flood level reduction generally extends between 300m and 600m upstream. There are also small patches of associated reduction in flood extent. There is limited change in flood levels downstream of structures.
- Scenario ID 2 (Current Catchment Conditions) - This scenario was compared to Scenario ID 1. Changes to flood behaviour as a result of developments within the catchment are minor, localised and generally contained within the development site. There are no impacts on the broader flood behaviour.
- Scenario ID 2 (Current Catchment Conditions) - This scenario was also compared to the results from the Flood Study Review (2015). Across a large proportion of the study area the flood level results in the 1% AEP are reduced from those presented in the Flood Study Review (2015). The inclusion of the drainage network through the catchment has reduced flooding and, in some cases, completely removed shallow overland flow. In addition, the application of the Revised Conduit Blockage Policy has reduced flood levels upstream of some structures (up to 1.9m). Other localised variation in flood levels occur as a result of the changes to the model terrain and hydraulic structures. Additional flood information is available in the upper sections of Hewitts Creek due to the extension of the hydraulic model.

Updated design flood behaviour for current Hewitts Creek catchment conditions has been defined for the 5 year ARI, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP and PMF events.

Hydraulic hazard for the 1% AEP event is shown on Figure ES7. Hazard classifications H5 and H6, those areas considered unsafe for buildings, are generally contained to the creek lines and immediately adjacent riparian areas, in addition to localised areas where street flow may become hazardous. Some areas of the catchment are subject to hazard classification H4 which is considered unsafe for people and vehicles. The hydraulic hazard across most developed areas of the catchment is category H3 or less. While category H3 has the potential to be unsafe for children and the elderly and pose a potential mobilisation hazard for vehicles, the flood behaviour across most of the remaining study area is unlikely to pose a significant threat to people.

Climate Change

Climate change is expected to have adverse impacts upon sea levels and rainfall intensities into the future and as such a range of scenarios have been assessed in order to understand the sensitivity of the catchments' flood behaviour to these influences. Potential increases to rainfall intensity and sea level due to climate change and a combination of both have been considered as part of the current Flood Study Addendum for the 1% AEP event. All climate change scenarios were based on Scenario ID 2. Rainfall increases of 20% and sea level rise increases of 0.4m and 0.9m were assessed.

Increases in rainfall intensity have been shown to increase flood levels along waterways by between 0.1m and 0.3m. Larger increases of between 0.5m and 1.0m are shown to occur upstream of hydraulic structures. Increases in sea level are shown to result in increased flood levels however are limited to the downstream areas of the Hewitts Creek catchment.

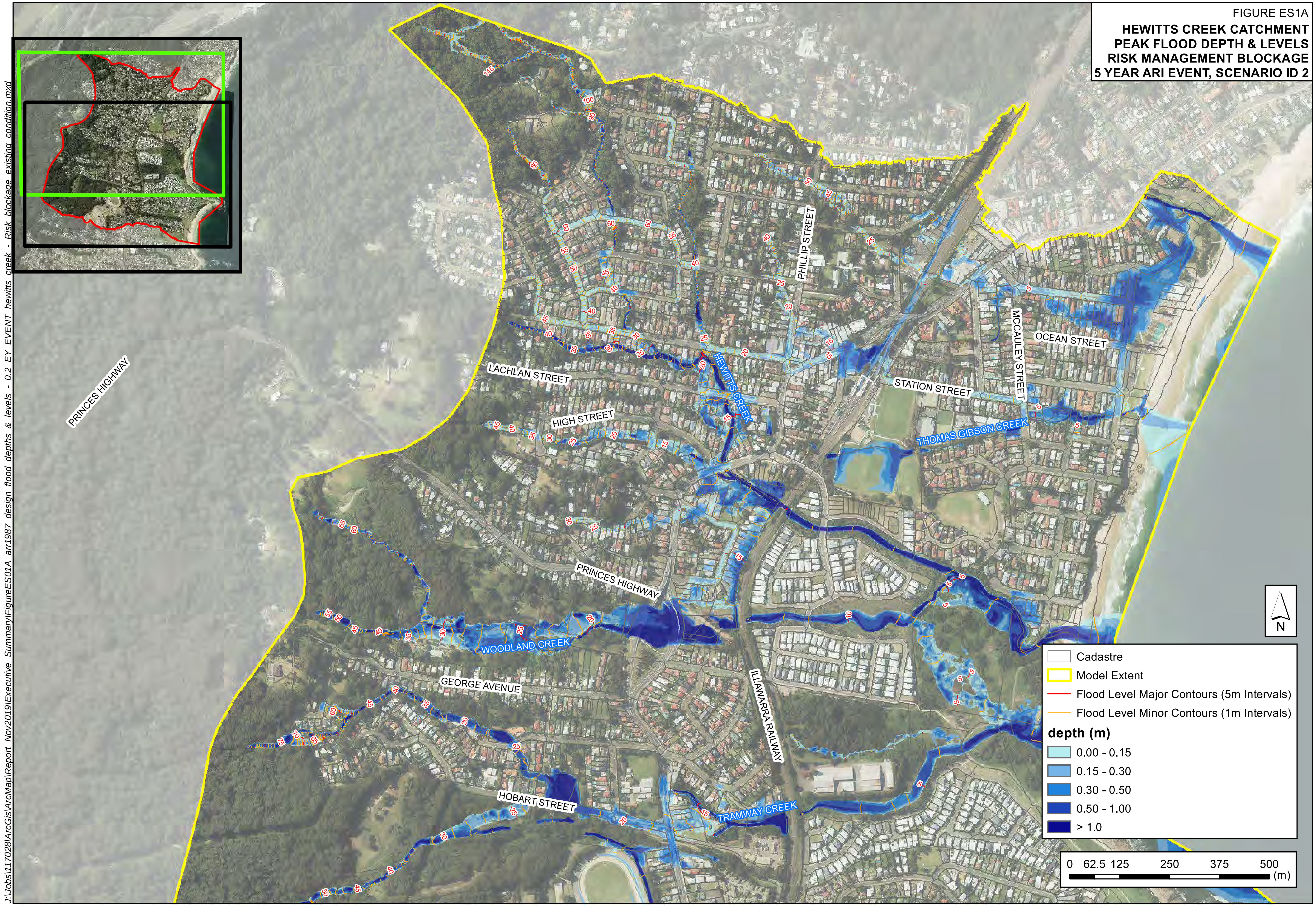
FIGURE ES1A
HEWITTS CREEK CATCHMENT
PEAK FLOOD DEPTH & LEVELS
RISK MANAGEMENT BLOCKAGE
5 YEAR ARI EVENT, SCENARIO ID 2
PRINCES HIGHWAY
LACHLAN STREET
HIGH STREET
HEWITTS CREEK
PHILLIP STREET
STATION STREET
MCCAULEY STREET
OCEAN STREET
THOMAS GIBSON CREEK
WOODLAND CREEK
GEORGE AVENUE
ILLAWARRA RAILWAY
HOBART STREET
TRAMWAY CREEK
N
Cadastre
Model Extent
Flood Level Major Contours (5m Intervals)
Flood Level Minor Contours (1m Intervals)
depth (m)
0.00 - 0.15
0.15 - 0.30
0.30 - 0.50
0.50 - 1.00
> 1.0
0 62.5 125 250 375 500
(m)
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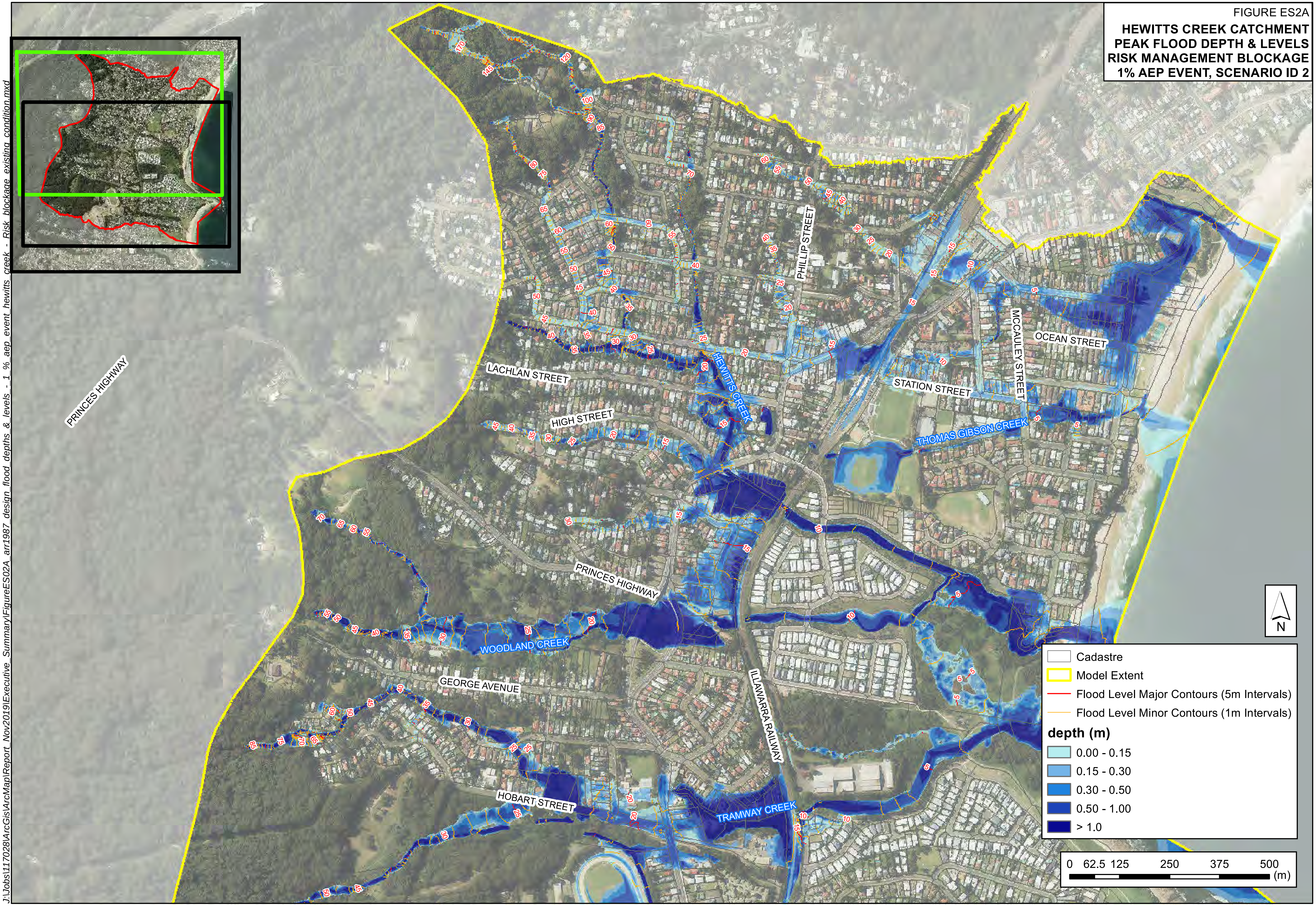

FIGURE ES2A
HEWITTS CREEK CATCHMENT
PEAK FLOOD DEPTH & LEVELS
RISK MANAGEMENT BLOCKAGE
1% AEP EVENT, SCENARIO ID 2

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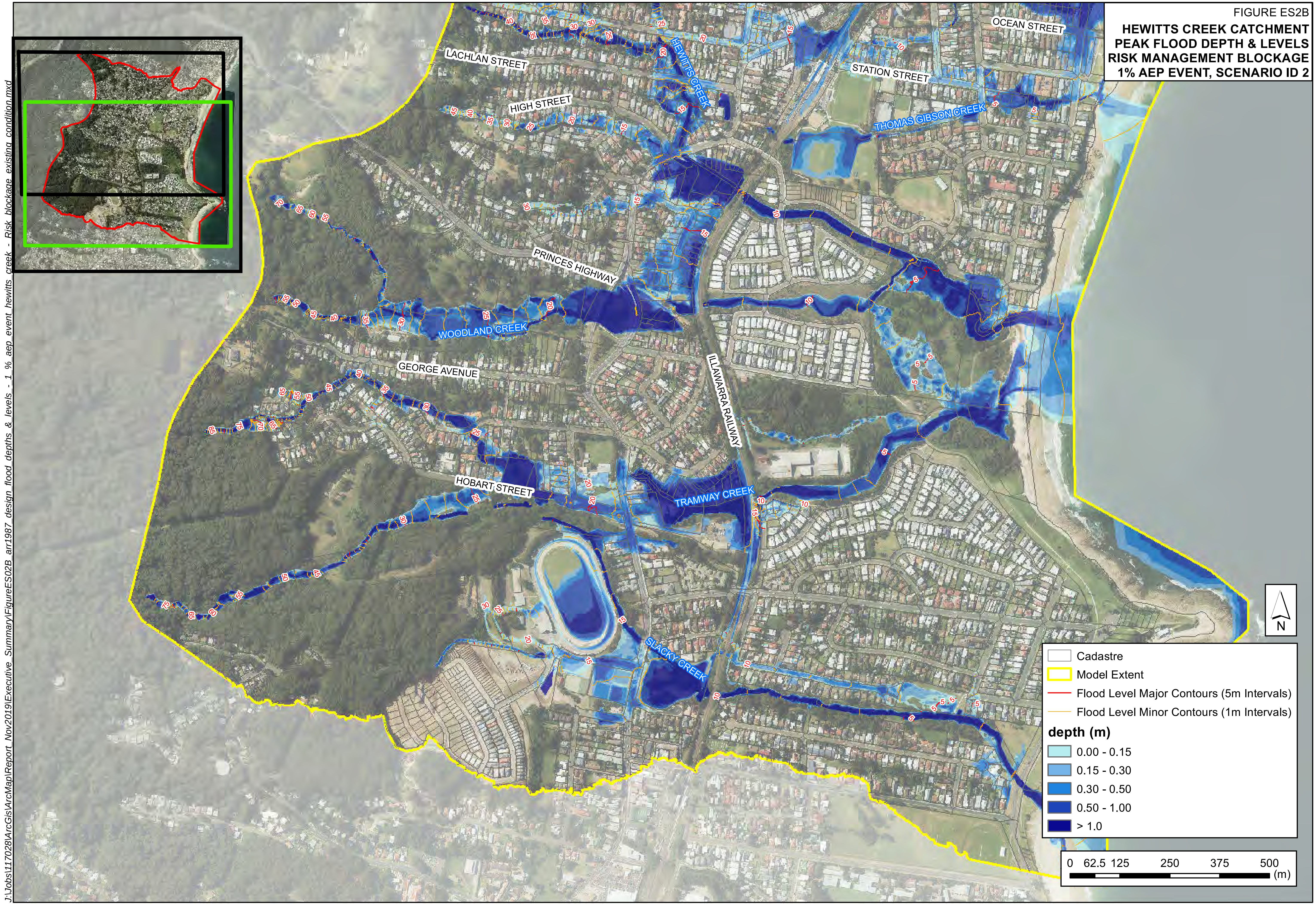

FIGURE ES2B
HEWITTS CREEK CATCHMENT
PEAK FLOOD DEPTH & LEVELS
RISK MANAGEMENT BLOCKAGE
1% AEP EVENT, SCENARIO ID 2
OCEAN STREET
LACHLAN STREET
STATION STREET
HEWITTS CREEK
HIGH STREET
THOMAS GIBSON CREEK
PRINCES HIGHWAY
WOODLAND CREEK
GEORGE AVENUE
ILLAWARRA RAILWAY
HOBART STREET
TRAMWAY CREEK
SLACKY CREEK
N
Cadastre
Model Extent
Flood Level Major Contours (5m Intervals)
Flood Level Minor Contours (1m Intervals)
depth (m)
0.00 - 0.15
0.15 - 0.30
0.30 - 0.50
0.50 - 1.00
> 1.0
0 62.5 125 250 375 500
(m)
J:\Jobs\117028\ArcGis\ArcMap\Report_Nov2019\Executive_Summary\FigureES02B_arr1987_design_flood_depths_&_levels - 1 % aep event_hewitts_creek - Risk_blockage_existing_condition.mxd

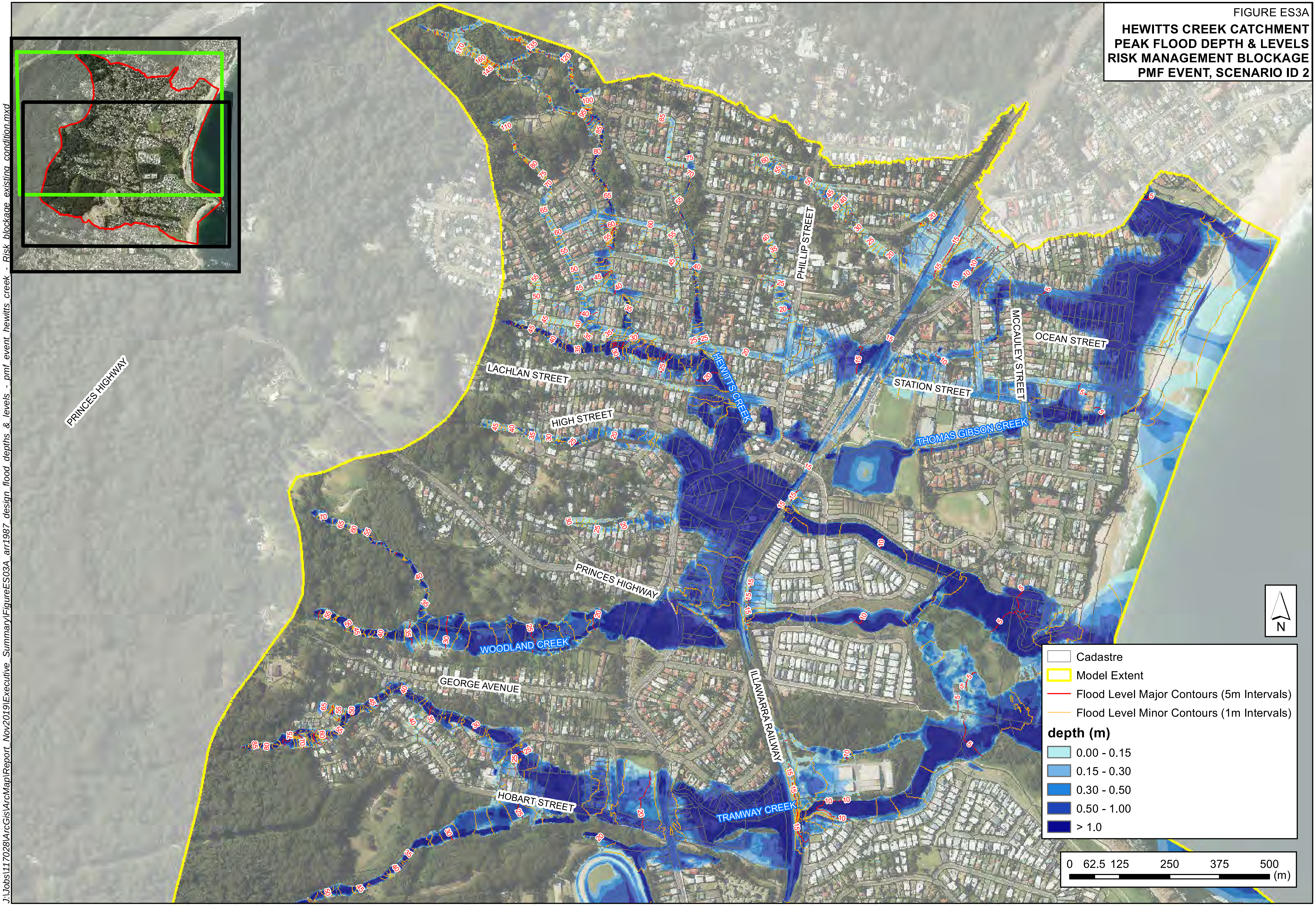

FIGURE ES3A
HEWITTS CREEK CATCHMENT
PEAK FLOOD DEPTH & LEVELS
RISK MANAGEMENT BLOCKAGE
PMF EVENT, SCENARIO ID 2

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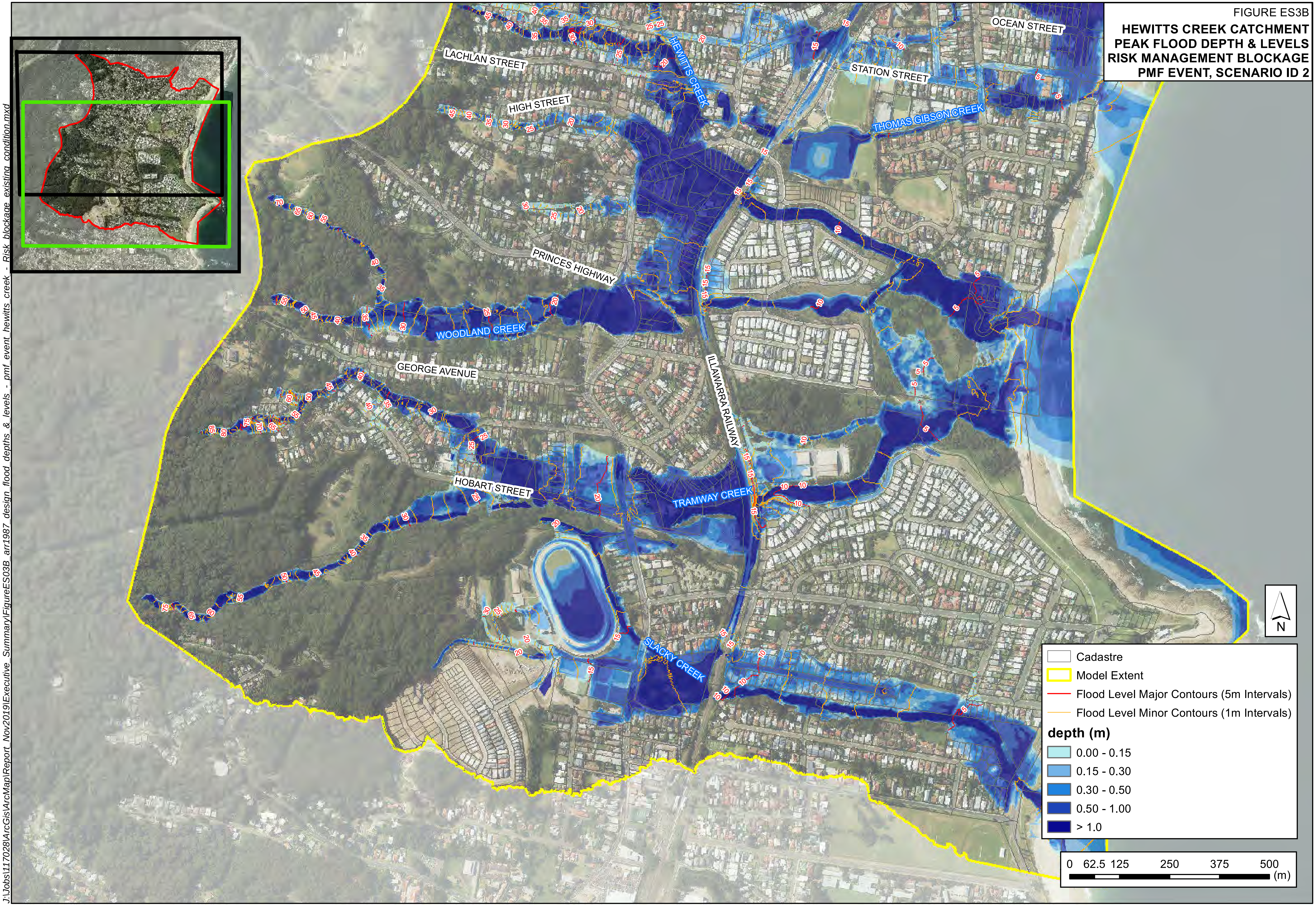

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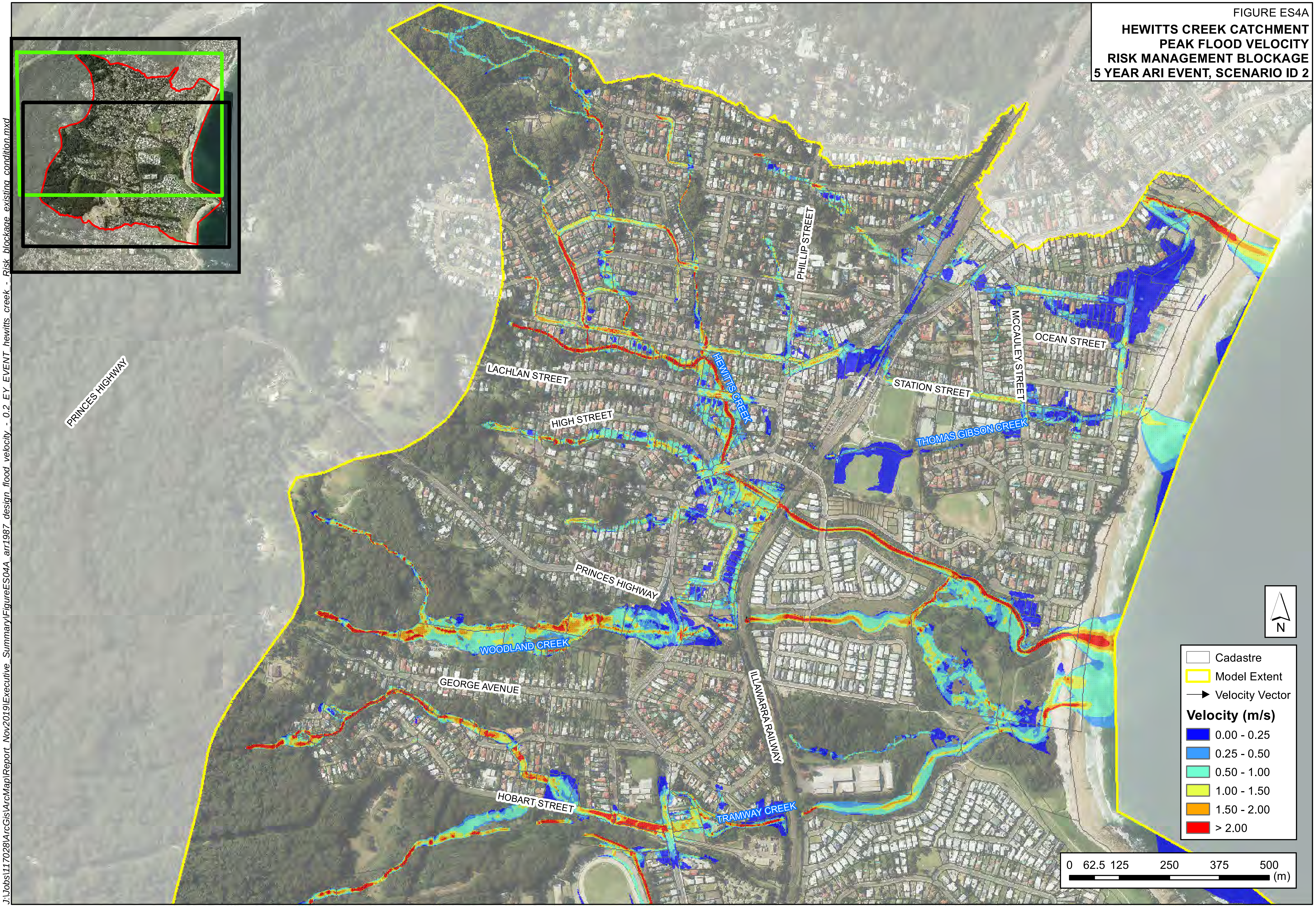

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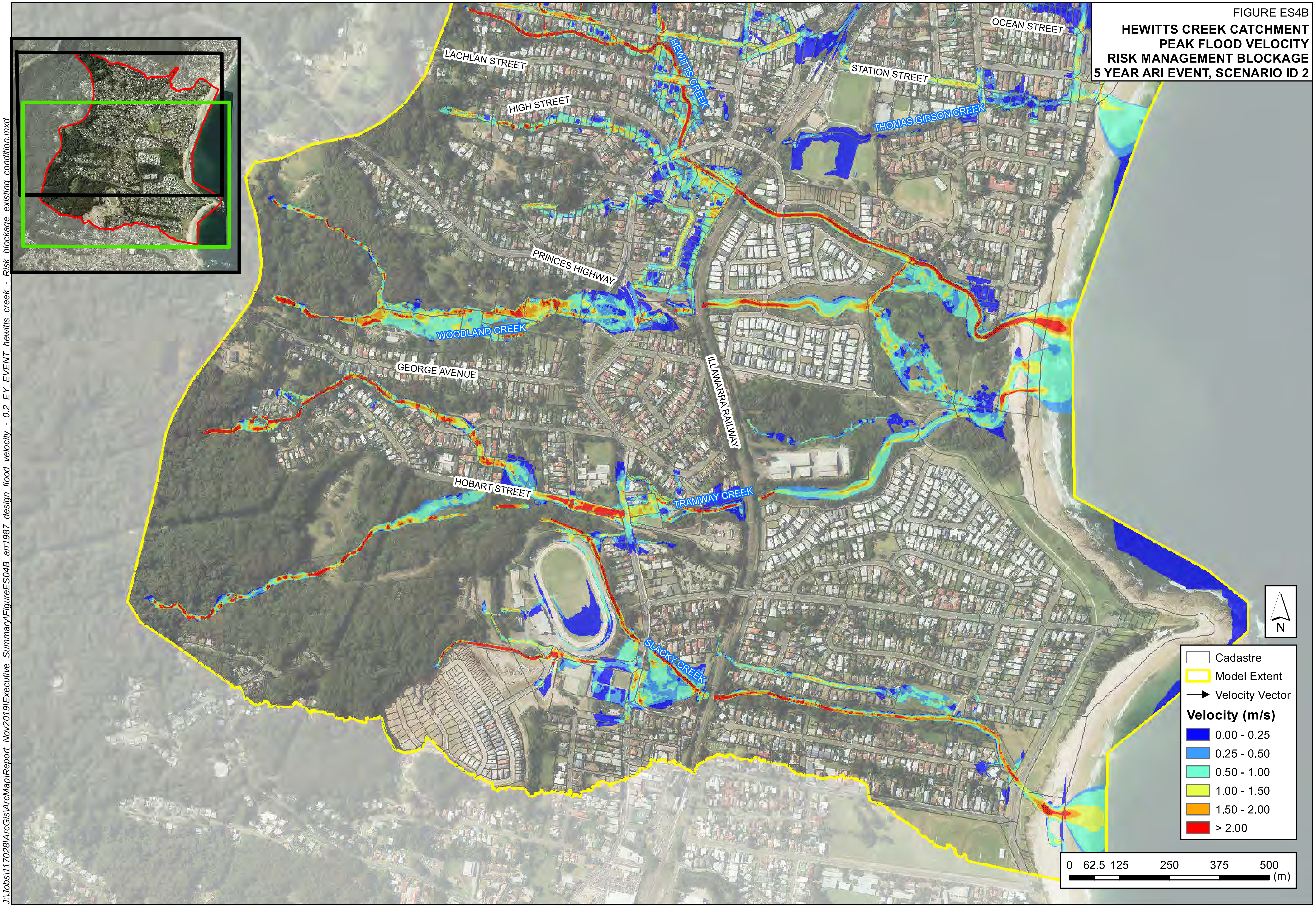
FIGURE ES4B

HEWITTS CREEK CATCHMENT
PEAK FLOOD VELOCITY
RISK MANAGEMENT BLOCKAGE
5 YEAR ARI EVENT, SCENARIO ID 2



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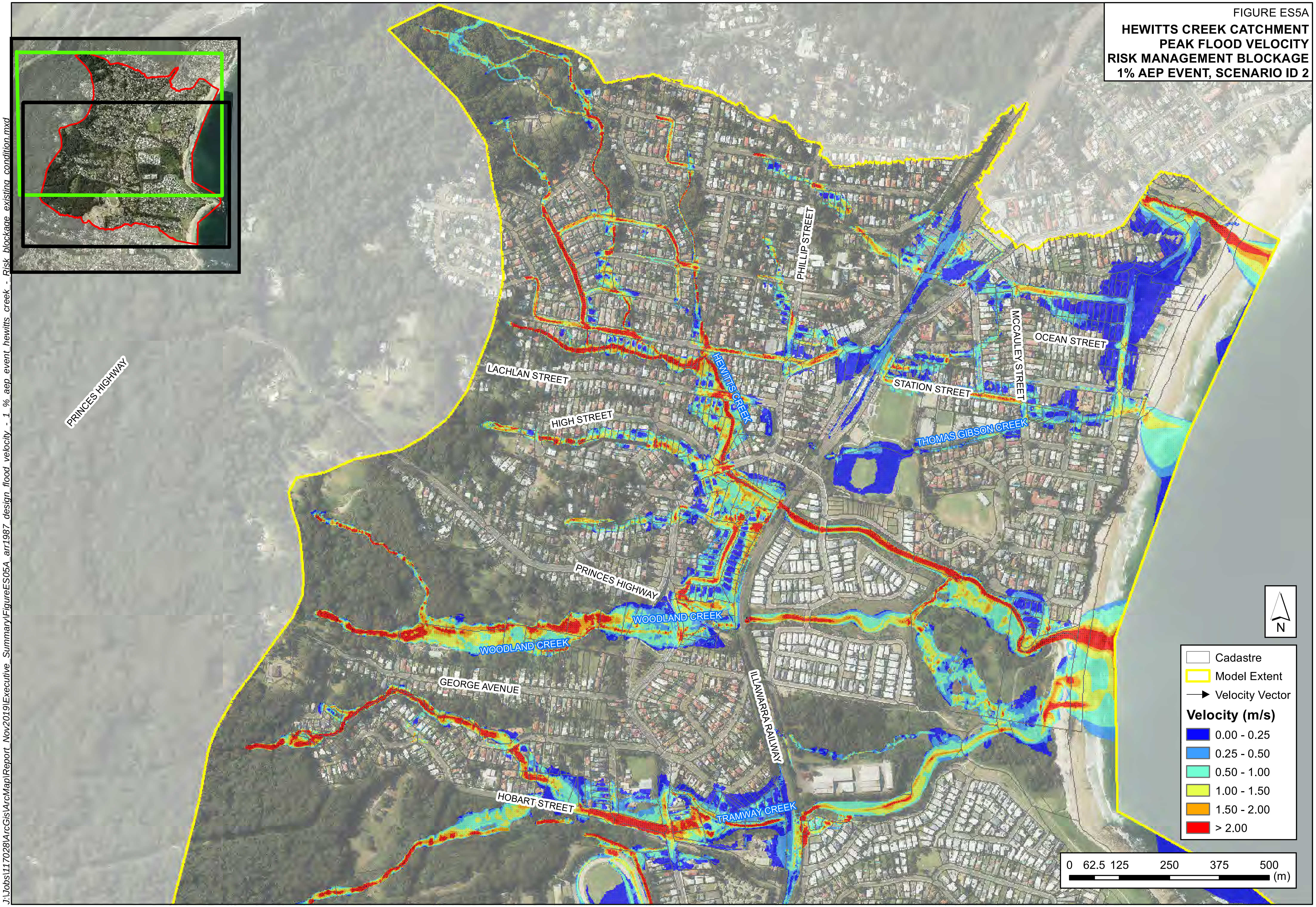

FIGURE ES5A
HEWITTS CREEK CATCHMENT
PEAK FLOOD VELOCITY
RISK MANAGEMENT BLOCKAGE
1% AEP EVENT, SCENARIO ID 2

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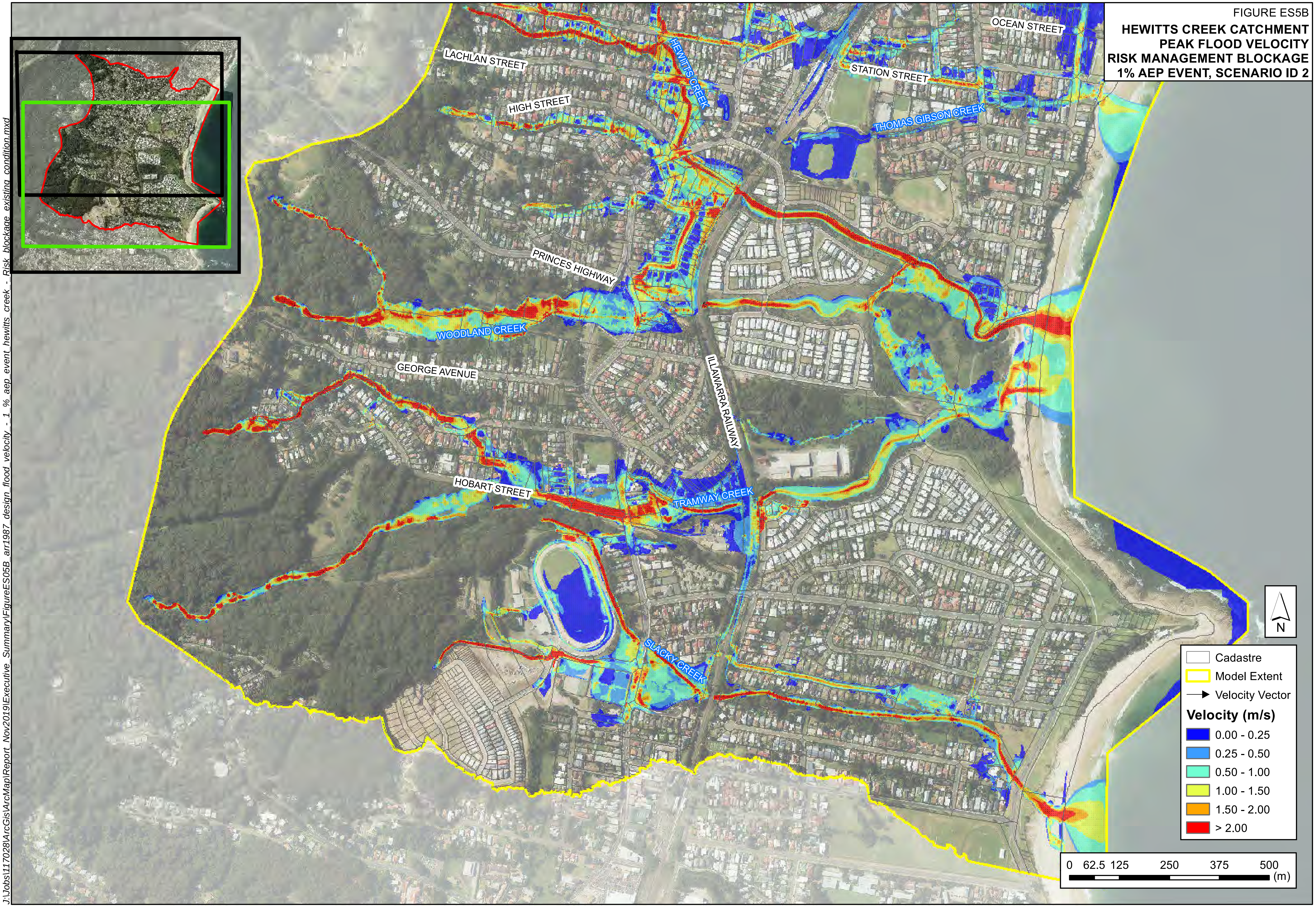

FIGURE ES5B
HEWITTS CREEK CATCHMENT
PEAK FLOOD VELOCITY
RISK MANAGEMENT BLOCKAGE
1% AEP EVENT, SCENARIO ID 2

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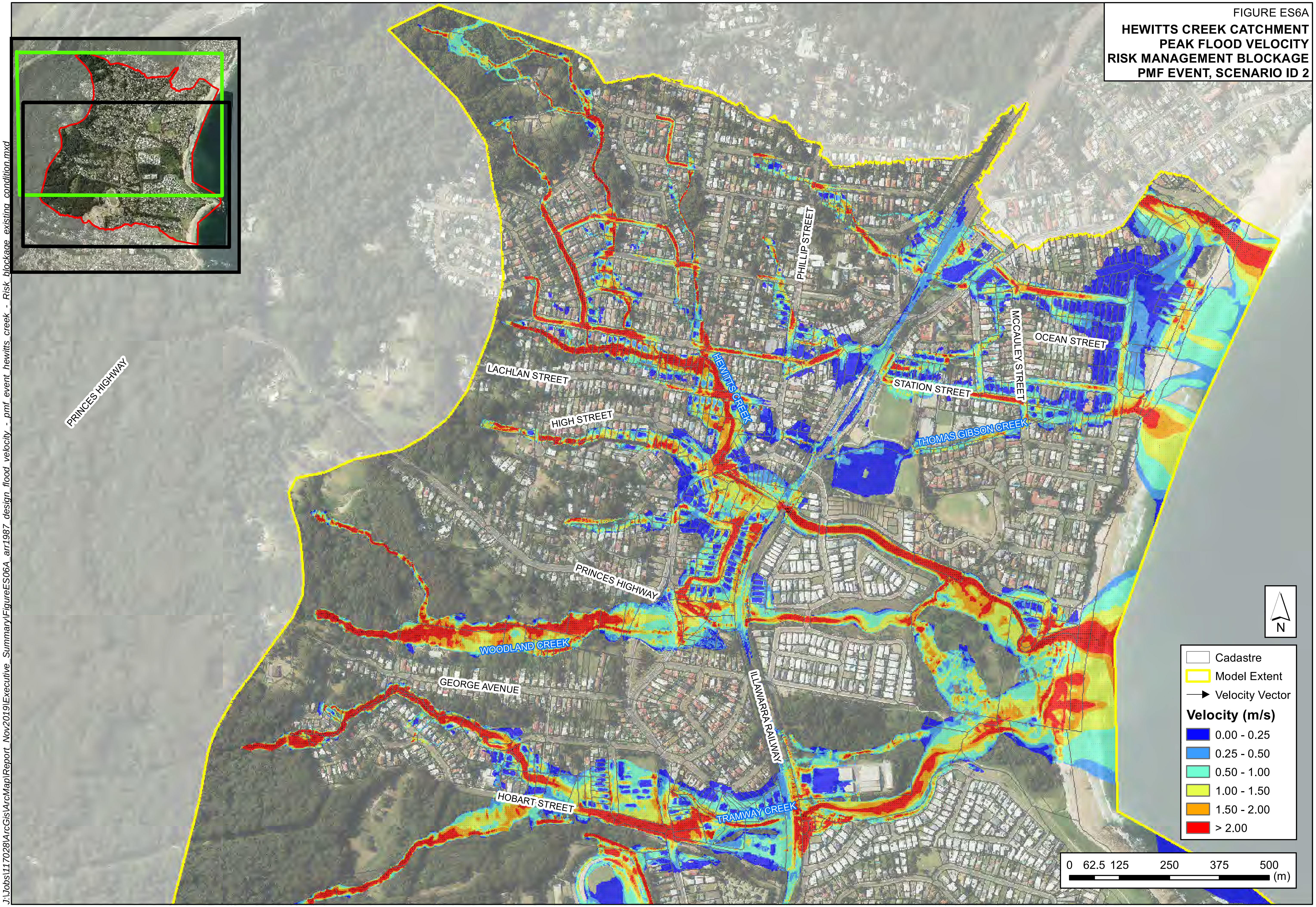

FIGURE ES6A
HEWITTS CREEK CATCHMENT
PEAK FLOOD VELOCITY
RISK MANAGEMENT BLOCKAGE
PMF EVENT, SCENARIO ID 2
PRINCES HIGHWAY
PHILLIP STREET
MCCAULEY STREET
OCEAN STREET
LACHLAN STREET
HEWITTS CREEK
STATION STREET
HIGH STREET
THOMAS GIBSON CREEK
PRINCES HIGHWAY
WOODLAND CREEK
GEORGE AVENUE
ILLAWARRA RAILWAY
HOBART STREET
TRAMWAY CREEK
N
Cadastre
Model Extent
Velocity Vector
Velocity (m/s)
0.00 - 0.25
0.25 - 0.50
0.50 - 1.00
1.00 - 1.50
1.50 - 2.00
> 2.00
0 62.5 125 250 375 500 (m)
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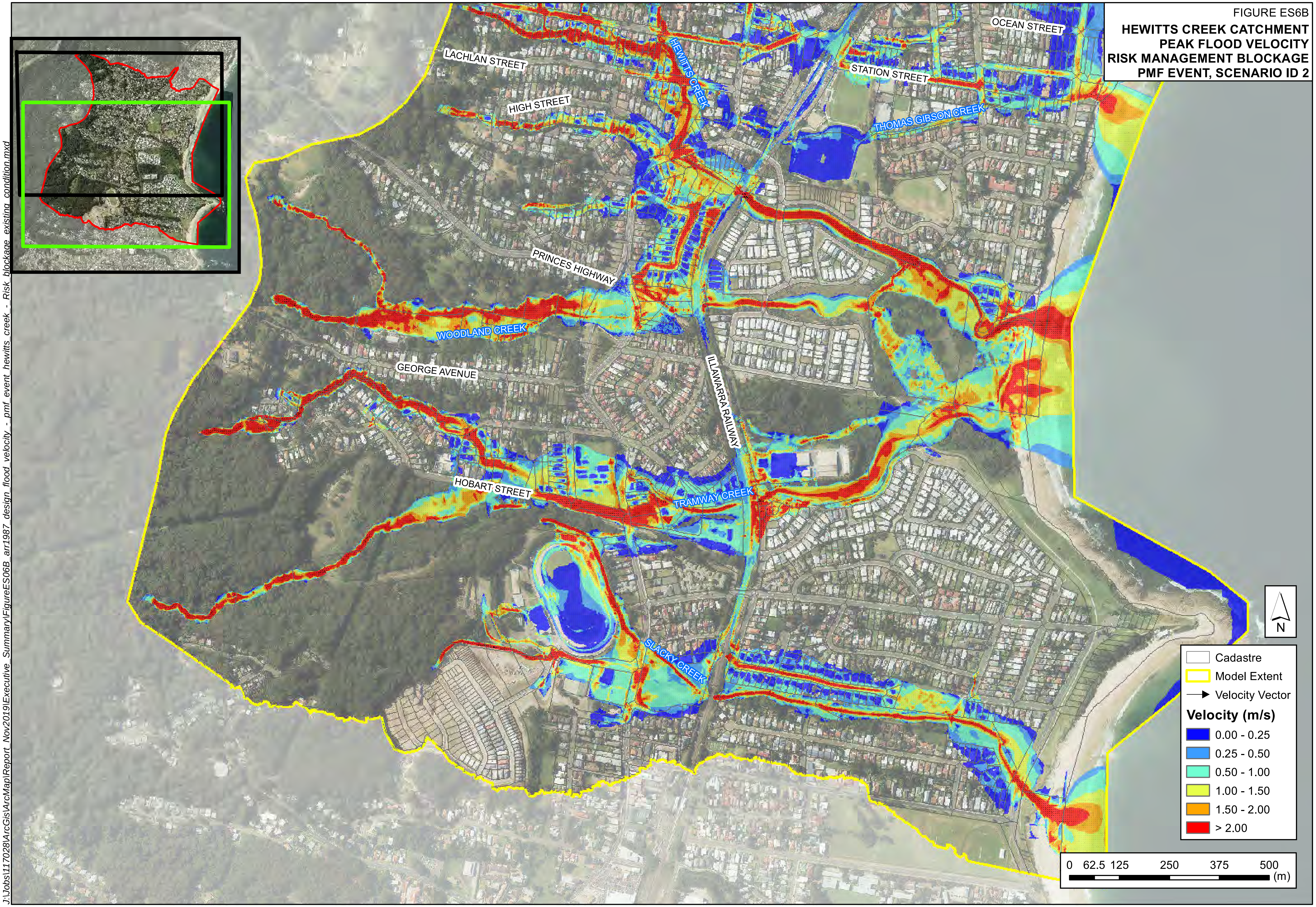

FIGURE ES6B
HEWITTS CREEK CATCHMENT
PEAK FLOOD VELOCITY
RISK MANAGEMENT BLOCKAGE
PMF EVENT, SCENARIO ID 2

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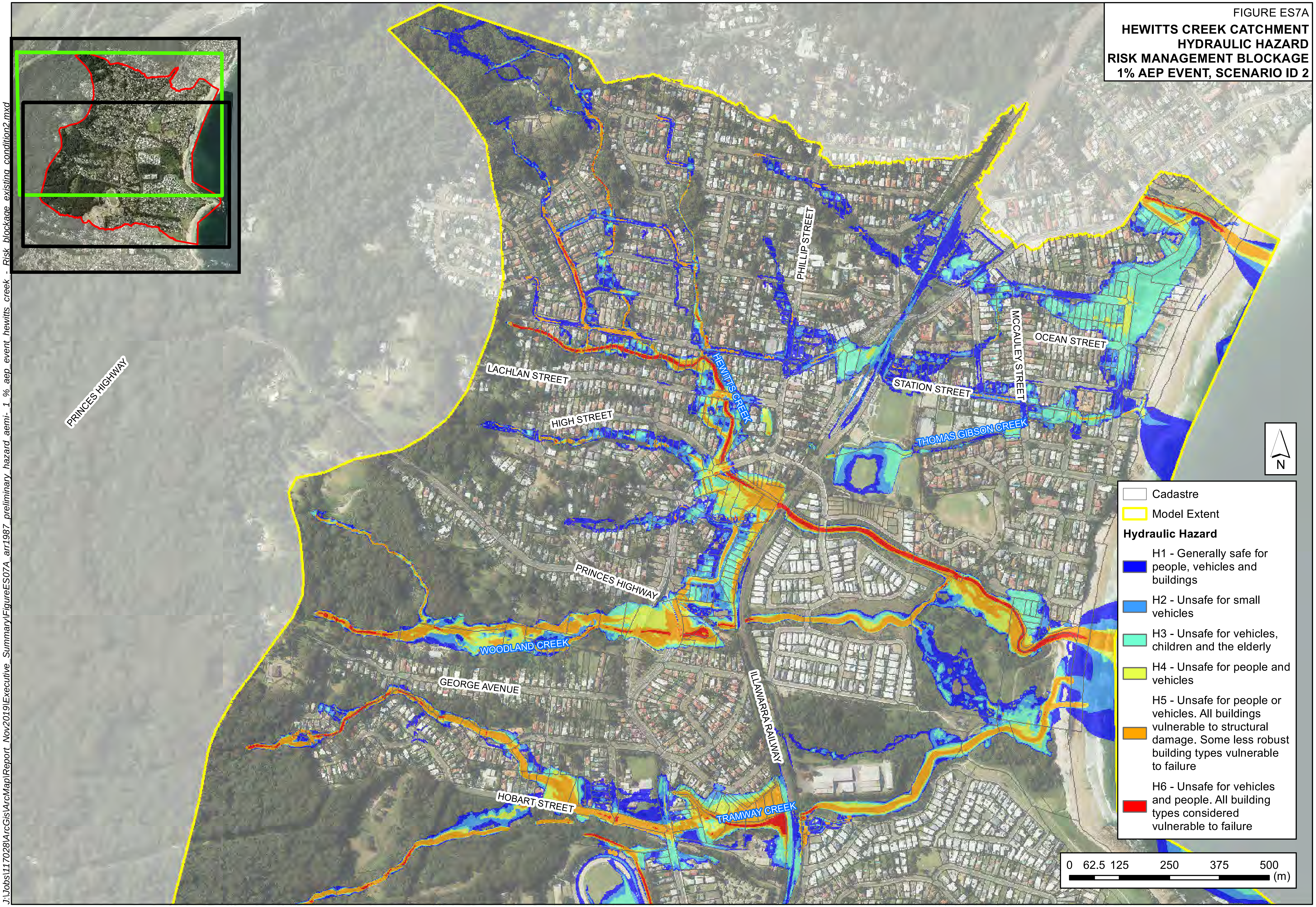
FIGURE ES7A
HEWITTS CREEK CATCHMENT
HYDRAULIC HAZARD
RISK MANAGEMENT BLOCKAGE
1% AEP EVENT, SCENARIO ID 2
PRINCES HIGHWAY
LACHLAN STREET
HIGH STREET
HEWITTS CREEK
PHILLIP STREET
MCCAULEY STREET
OCEAN STREET
STATION STREET
THOMAS GIBSON CREEK
PRINCES HIGHWAY
WOODLAND CREEK
GEORGE AVENUE
ILLAWARRA RAILWAY
HOBART STREET
TRAMWAY CREEK
N
Cadastre
Model Extent
Hydraulic Hazard
H1 - Generally safe for people, vehicles and buildings
H2 - Unsafe for small vehicles
H3 - Unsafe for vehicles, children and the elderly
H4 - Unsafe for people and vehicles
H5 - Unsafe for people or vehicles. All buildings 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
0 62.5 125 250 375 500 (m)
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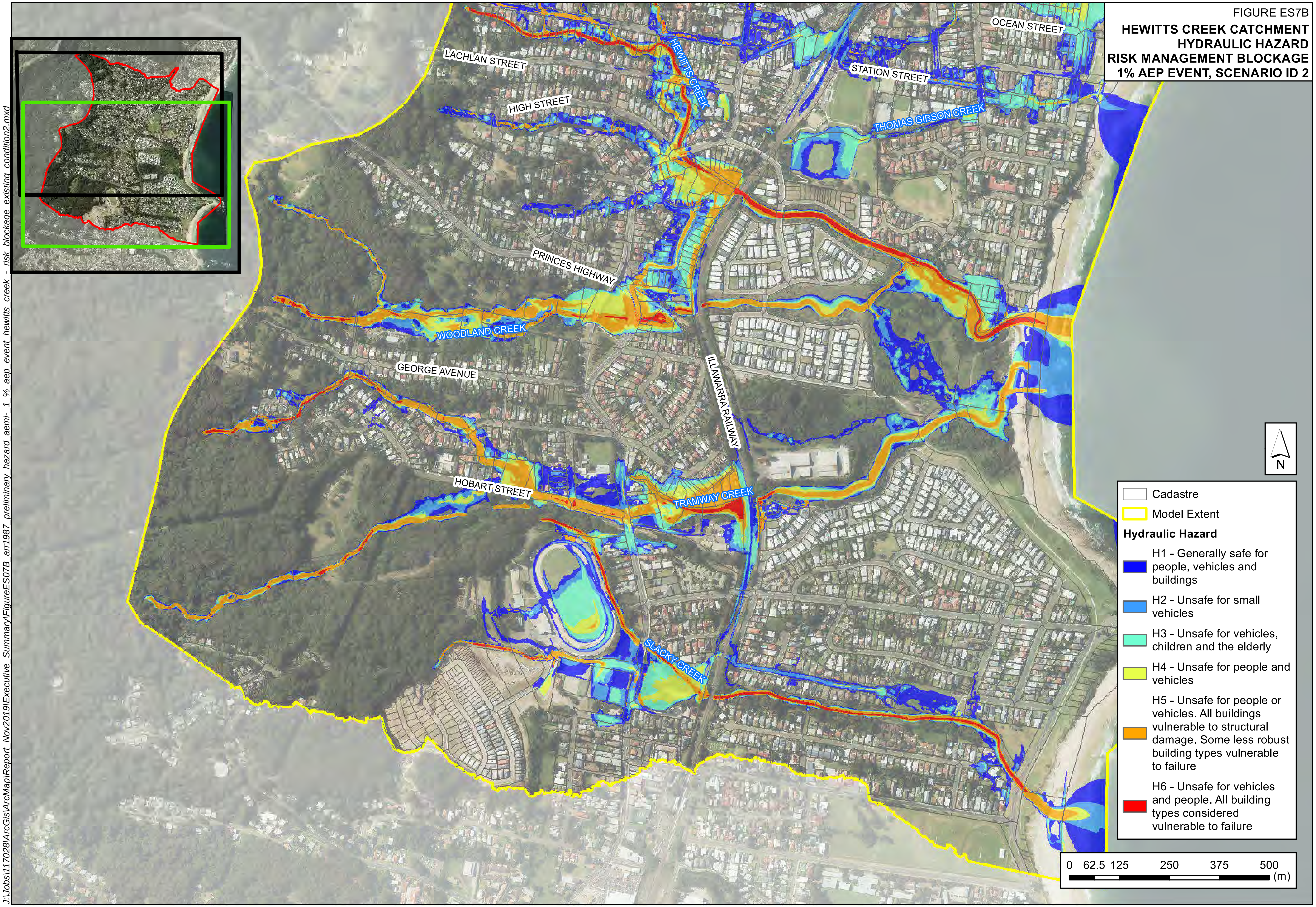

FIGURE ES7B

HEWITTS CREEK CATCHMENT HYDRAULIC HAZARD RISK MANAGEMENT BLOCKAGE 1% AEP EVENT, SCENARIO ID 2

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FOREWORD

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

Under the Policy, the management of flood liable land remains the responsibility of local government. The State Government subsidises flood mitigation works to alleviate existing problems and provides specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities.

The Policy provides for technical and financial support by the Government through four sequential stages:

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

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

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

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

This report is an addendum to the 2015 Review of Hewitts Creek Flood Study. It provides revised design flood levels considering model updates and applicable Council policies. For complete details of the models developed as part of the 2015 Review of Hewitts Creek Flood Study, readers should refer to that report.

1. INTRODUCTION

1.1. Overview

A Floodplain Risk Management Study and Plan for the Hewitts Creek catchment is being undertaken by Wollongong City Council (Council). This current study aims to provide an update to the previous Floodplain Risk Management Study and Plan completed in 2002 and builds on the updated flood modelling developed as part of the Review of Hewitts Creek Flood Study, completed in 2015.

The overall objective of this study is to review Council's current Floodplain Risk Management Study and Plan and develop an updated Floodplain Risk Management Plan for the Hewitts Creek catchment to be based on the Review of Hewitts Creek Flood Study (2015) and this Flood Study Addendum. The updated plan will develop flood risk mitigation strategies that address existing, future and continuing flood risks in the Hewitts Creek catchment.

In 2016, Council developed a Revised Conduit Blockage Policy. The 2015 Flood Study Review was based on Council's previous Conduit Blockage Policy (2002) as documented in Council's 2009 Development Control Plan, as such the current study will also provide an addendum to the 2015 Flood Study Review updating design flood behaviour considering Council's revised blockage policy, in addition to catchment changes since 2015 and recommendations coming out of review of the models including the inclusion of the pit and pipe network.

The 2015 Flood Study Review was undertaken in accordance with the methodologies outlined in Australian Rainfall and Runoff 1987 (ARR 1987), which were applicable at the time of the study. In late 2016, a first release of a revised Australian Rainfall and Runoff guideline became available, a later revision was subsequently released in mid 2019. The design flood behaviour produced as part of this Flood Study Addendum has been developed using the methodologies described in ARR 1987. The revised guidelines will be considered as part of the Floodplain Risk Management Study stage.

This document, the Flood Study Addendum Report, outlines the revised flood behaviour as a result of the changes described above. The Flood Study Addendum will then form the technical basis for assessment in the Floodplain Risk Management Plan for the Hewitts Creek catchment.

1.2. Study Area

The study area is located within the Wollongong City Council Local Government Area (LGA) and incorporates Slacky, Tramway, Woodlands, Hewitts and Thomas Gibson Creeks. The combined catchment is approximately 7.5km^2 and incorporates the northern Wollongong suburbs of Bulli and Thirroul (Volume 2 Map Set A – Figure 1). The catchment extends from the Illawarra Escarpment in the west, discharging into the Thirroul and Sandon Point Beaches in the east.

The upper half of the catchment, forming a section of the Illawarra Escarpment, is heavily vegetated, falling steeply from 500m to 250m AHD. The lower half of the catchment is generally flatter with a mixture of land uses including, residential, commercial, industrial and open space. The catchment land use is shown on Volume 2 Map Set A – Figure 2.

The flood behaviour in the catchment is influenced by catchment runoff, in addition to the interaction with ocean conditions, particularly in the lower catchment. Significant flooding was experienced in August 1998 when vast areas of the Illawarra region were impacted. Within the Hewitts Creek catchment both public and private property were damaged in that event. Anecdotal and surveyed flood levels exist for the 1998 event in addition to the 1988, 1991 and 2013 events. These events were used for calibration in the 2015 Flood Study Review.

Locations with known or reported flooding problems were identified as part of the Flood Study Review (2015), including:

- Coal haulage embankment in the Slacky Creek catchment,
- Flow diversions on Hewitts Creek associated with the Lachlan Street culvert under capacity,
- Flow diversions on Thomas Gibson Creek associated with the Cliff Parade culvert under capacity,
- Flow diversions on Tramway Creek associated with the Illawarra Railway culvert under capacity.

These locations will help to inform the Floodplain Risk Management Study and Plan by identifying locations to potentially target flood mitigation strategies.

1.3. Existing Flood Mitigation

Following the completion of the previous Floodplain Risk Management Study and Plan in 2002 a number of recommendations have been implemented across the catchment. In addition, other works have been undertaken which are likely to have improved the existing flood risk. Table 1 provides a summary.

Table 1 – Floodplain Risk Management Measures Implemented

Location	Measure
Black Diamond Place, Bulli	Modifications to detention basin adjacent to Slacky Creek
Old Bulli Mine Dam, Bulli	Embankment upgrade works and creek rehabilitation on a tributary of Slacky Creek
Princes Highway and Lawrence Hargrave Drive, Thirroul	Construction of a bridge and associated road works on/adjacent to Woodlands Creek
Princes Highway, Bulli	Voluntary purchase of two properties adjacent to Tramway Creek
51 George Street, Thirroul	New footbridge over Hewitts Creek
Lachlan Street, Thirroul	Improvements to existing culvert on Hewitts Creek
The Esplanade, Thirroul	New overland flow path adjacent to Flanagan's Creek
Blackhall Street, Bulli	New footbridge at Blackhall Street on Slacky Creek
Hewitts Creek Catchment	Planning Matrix

2. DATA COLLECTION AND REVIEW

2.1. Overview

A range of data exists for the Hewitts Creek catchment including topographic information, previous reports and previously established hydrologic and hydraulic models. The following section provides an overview of the data available to the current study.

2.2. Topographic Information

2.2.1. LiDAR

Light Detection and Ranging (LiDAR) survey is aerial survey data that provides a detailed topographic representation of the ground with a survey mark approximately every square metre. LiDAR provides the primary source of terrain information for the modelling tools. LiDAR capture methods often provide less survey marks in heavily vegetated or inundated areas, for this reason the model terrain information is often supplemented with field survey in these areas.

LiDAR captured in May 2005 by AAM Hatch was utilised over the study area in the Flood Study Review (2015). The accuracy of the ground information obtained from LiDAR survey can be adversely affected by the nature and density of vegetation, the presence of steeply varying terrain, the vicinity of buildings and/or the presence of water. The 2005 LiDAR has a stated vertical accuracy of +/-0.15m @ 68% confidence and horizontal accuracy of +/-0.55m @ 68% confidence.

The Flood Study Review (2015) states that the filtered ground data was used to produce a regular 1 m resolution digital elevation model (DEM) of the study area.

An updated LiDAR survey of the study area and its immediate surroundings was undertaken in 2013 and provided by LPI. The 2013 LiDAR was not utilised in the Flood Study Review (2015), as it is understood that the study had commenced prior to the LiDAR being available.

The Flood Study Addendum will take the opportunity to include the more recent LiDAR in the TUFLOW model.

2.2.2. 2005 and 2013 LiDAR Comparison

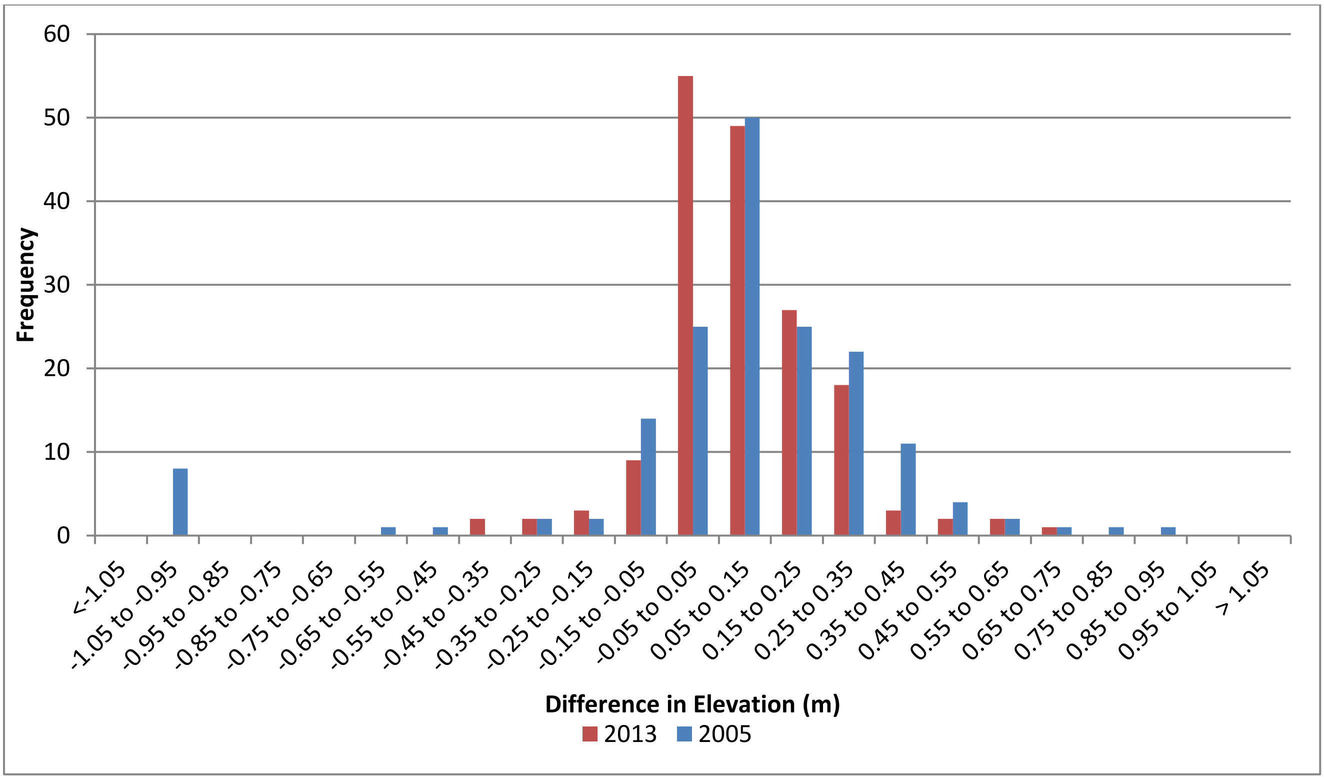
A comparison has been undertaken between the two LiDAR sets (2005 and 2013) to determine which set most appropriately represents the study area. The LiDAR data sets were compared to ground survey and cross sections captured in April/May 2013 by K F Williams and Associates and Survey Control Information Management System (SCIMS) survey marks.

Both datasets have an expected vertical accuracy of 0.3m for 95% of the points. This level of accuracy is confirmed by the SCIMS marks comparison, with the 2013 LIDAR performing slightly better than 2005, which is marginally skewed to over approximation of actual levels (Diagram 1).

There has been general improvement in the methods to capture LiDAR, particularly post 2010 and therefore it is not unexpected that the more recent set provides a better representation.

Both datasets compare reasonably well to the ground survey and cross sections captured in 2013. The 2013 LIDAR matches the "ground profiles" better than the 2005 LIDAR does, however, appear to be located in newly developed areas where the ground level had changed, and the 2005 LIDAR was known to be out of date. This comparison however provides an additional confirmation that the 2013 LIDAR is a good match to detail survey levels in open ground areas.

Diagram 1 – 2005 and 2013 LiDAR Dataset Accuracy Comparison



While both LiDAR sets are comparable, overall the 2013 data is a better reflection of current ground conditions, mainly due to it capturing changes to the catchment in the years after the 2005 data capture.

Within the creeks, both datasets exhibit inaccuracies due to the limitations of LiDAR in heavily vegetated areas. Reasonable effort was made during the model development in the Flood Study Review (2015) to provide a more representative in-bank, including the use of field survey from 2013 and the Flood Study (2002). It is therefore proposed as part of the current Flood Study Addendum to update the TUFLOW model terrain using the more recent 2013 LiDAR but maintain the in-bank representation derived in the Flood Study Review (2015).

2.2.3. Other Survey

Field survey can be used to supplement the LiDAR in defining the model terrain, particularly in areas that are heavily vegetated or have substantially changed since the LiDAR was captured. A comprehensive survey of the creek channels and structures was captured by NSW Public Works as part of the Flood Study (2002). The Flood Study Review (2015) obtained survey for 8 cross sections throughout Hewitts and Slacky Creeks and undertook a comparison between the two datasets. This comparison confirmed that the survey captured in the Flood Study (2002) still provided an appropriate representation of the creek channels through the catchment and was therefore adopted for use in the TUFLOW model developed in the Flood Study Review (2015). These cross sections represent the best available representation of the creek channels and as discussed above in Section 2.2.2, the in-bank representation will be adopted for the current modelling as part of the Flood Study Addendum.

The location of cross sections obtained in the Flood Study (2002) and the Flood Study Review (2015) is shown on Volume 2 Map Set A – Figure 3.

2.2.4. Recent Catchment Changes

Since the completion of the Flood Study Review (2015), a number of significant developments have occurred or are being undertaken in the catchment, namely:

- Bulli Brickworks subdivision – Stages 1 and 2 are complete with Stage 3 currently under construction.
- Armagh Parade subdivision, Thirroul.

The locations of these developments are shown on Volume 2 Map Set A – Figure 1.

These catchment changes are not included in the existing TUFLOW model and would not be shown in the 2013 LiDAR (Section 2.2.1). Plans including site contour information were provided by Council for inclusion in the updated modelling as part of the Flood Study Addendum.

2.2.5. Hydraulic Structures

Details of key hydraulic structures within the Study Area, are required within the hydraulic model to appropriately represent flood behaviour. The Flood Study Review (2015) captured the details via survey at thirteen structures including culverts and bridges. This information has also been supplemented where needed by information provided by Council, in the form of structure drawings, the Flood Study (2002) and field inspections undertaken by WMAwater.

The location of hydraulic structures within the TUFLOW model domain are shown on Volume 2 Map Set A – Figure 3.

2.2.6. Pit and Pipe Database

The TUFLOW model established as part of the Flood Study Review (2015) contained only major hydraulic structures located along the main creek lines, the smaller trunk drainage system was not included. The trunk drainage system captures runoff and can reduce inundation in smaller flood events. This is particularly important in the model representation through more urbanised catchments where these systems tend to replace the former creek lines. The inclusion of this information also allows for potential mitigation strategies on these systems to be identified.

A revised database was provided by Council in January 2018. This revised database has been supplemented where needed, including additional details that were gathered via visual inspection or assumed based on location, surrounding pipes, available LiDAR data and reasonable pipe cover depths. Pit inverts were assumed to be 1-1.5 m below the ground level (from LiDAR), and were manually adjusted where needed to ensure no negative grades were assigned to pipes. In addition, pit inlets were assumed to be 2.5m by 0.15m, this is a representative pit that combines the typical dimension of a lintel and grate inlet. The sensitivity of design flood behaviour to this pit size assumption was tested and the impact found to be insignificant. The results of the sensitivity test are discussed in Section 3.3.

The pit and pipe network included in the TUFLOW model as part of the Flood Study Addendum is shown on Volume Map Set A – Figure 3.

2.3. Geographic Information System (GIS) Data

GIS layers assist in providing context to the study inputs and outcomes. Council has provided a range of GIS layers to assist with the study, which include:

- Aerial imagery,
- Cadastral boundaries and DP numbers,
- Roadways,
- Contours,
- LEP zoning,
- Council owned land,
- Watercourses,
- Stormwater details (pits, pipes, basins, etc),
- Flood risk precincts, and
- Historical flood levels.

2.4. Site Visit

A site visit was undertaken by the WMAwater project team and staff from Council on 17th March 2017. The aim of this visit was for the project team to familiarise themselves with the study area and for Council to highlight key areas of interest.

A subsequent visit was undertaken by the WMAwater project team on the 30th November 2017 to confirm the sizing of a number of structures in the study area. A number of photos from the site visit are included below.

Photo 1 – Woodland Creek Princes Highway looking East

Photo 2 – Woodland Creek Princes Highway looking North

Photo 3 – Woodland Creek Princes Highway looking South

Photo 4 – Woodland Creek Princes Highway looking East

2.5. Previous Studies

2.5.1. Hewitts Creek (incorporating Slacky, Tramway, Woodlands and Thomas Gibson Creeks) Flood Study, 2002

This report investigated and quantified existing flood behaviour in the Slacky, Tramway, Woodlands, Hewitts and Thomas Gibson Creek catchments for the 5%, 2%, 1% AEP and PMF events. The study undertook comprehensive data collection and drew on information about the significant flood event in August 1998 to improve the performance of the modelling tools. Information from the April 1988 and June 1991 flood events was also considered.

A suite of modelling tools were developed to describe flood behaviour in the catchment including WBNM and PSxRM hydrologic models and a HEC-RAS hydraulic model.

The study used a range of data to build the modelling tools, including mapping, photography, creek survey, rainfall and tide information.

The study concluded that catchment flood behaviour can be adversely impacted by many culverts and bridges, in addition to development in the area upstream of the Illawarra Railway.

Data from the Flood Study (2002), particularly the creek survey was used in the development of the TUFLOW model as part of the Flood Study Review (2015). The TUFLOW model has subsequently formed the basis for the current Flood Study Addendum.

2.5.2. Hewitts Creek Floodplain Risk Management Study and Plan, 2002

Following the Hewitts Creek Flood Study completed in 2002, a Floodplain Risk Management Study and Plan was prepared for the catchment and completed in 2002. The broad aim of the study and plan was to investigate and make recommendations to assist in minimising the effects of flooding in the catchment. A range of options were considered and the most promising assessed for their benefits to flood behaviour in addition to costs/benefits. The Plan recommended a range of different elements for each major sub-catchment including 15 combined schemes, including:

- Land use planning,
- Development controls,
- Formalised overland flow diversions,
- Drainage and culvert upgrades,
- Small levee,
- Voluntary purchase,
- Debris control structures,
- Riparian Management Study,
- Further development of the SES Local Flood Plan,
- Flood awareness.

A number of these recommendations have been implemented by Council since the completion of the study (Table 1).

Data from the Flood Study (2002) was used in the development of the TUFLOW model as part of the Flood Study Review (2015). The TUFLOW model has subsequently formed the basis for the current Flood Study Addendum. The recommendations made will be reviewed as part of the Floodplain Risk Management Study considering current design flood behaviour and will assist in identifying other potential mitigation strategies for investigation.

2.5.3. Review of Hewitts Creek Flood Study, 2015

The Review of Hewitts Creek Flood Study was completed in August 2015 and undertaken in accordance with NSW Government's Flood Prone Land Policy. The study provided an update to the assessment undertaken in the Flood Study (2002), updating the modelling tools. The Flood Study aimed to determine design flood behaviour in the study area. To achieve this, a WBNM hydrologic model and a 1D/2D TUFLOW hydraulic model were established.

To ensure the established models were able to reproduce historical flood behaviour the models were calibrated and validated to storm events of August 1998, January 2013 and April 1988.

The study determined design flood behaviour for the 5 year ARI and 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP and PMF events and considered the sensitivity of design flood behaviour to model parameter selection and climate change. The study also developed mapping of a range of metrics which aim to identify flood risk in the catchment including, provisional flood hazard, hydraulic categories, flood emergency response classification and preliminary flood planning levels.

The project undertook a community consultation program which gathered useful information about flood behaviour within the catchment. This information was used in the model build process and will be very useful when identifying appropriate mitigation strategies.

The modelling tools and outputs developed in this study form the basis of the assessment undertaken in the current study. The modelling tools have been reviewed to determine any updates required to represent current catchment conditions or policies. The findings of the review are described in Section 3.

2.6. Council Policies

2.6.1. 2002 Conduit Blockage Policy

Blockage of bridges, culverts and other stormwater conduits is a key consideration for Council in fulfilling its floodplain management responsibilities. Flood levels can be significantly influenced by the degree of blockage at a particular culvert or bridge. The policy was initially established in 2002, primarily in response to major flooding that occurred in the LGA in August 1998 and October 1999 and until its revision in 2016, sat within Council's Development Control Plan 2009.

The catchments in Wollongong exhibit a range of conditions which contribute to a higher likelihood of debris blockage, including:

- Orographic influenced extreme rainfall due to the Illawarra escarpment,
- Multiple parallel catchments running from the escarpment to the coast,
- Development in the flatter lower parts of the catchment on flood prone land,
- Most of the upper catchment areas are forested, so there is a relatively high availability of debris, and
- Several major arterial roads and railway lines along the coast, with structures and embankments aligned perpendicular to the flow direction in the majority of catchments.

The policy was implemented as part of Council's Development Control Plan 2009 (DCP). The policy required that flood modelling assume bridges and culverts with a diagonal opening span less than 6 m should be completely blocked, and the bottom 25% of the area of larger openings should be assumed blocked. Although there was significant uncertainty about the amount of blockage to apply, and whether this blockage would always occur to the same degree in subsequent floods, the policy as it was implemented was effective in identifying and planning for flood risks at locations potentially sensitive to blockage.

The 2002 Conduit Blockage Policy was applied in the Review of Hewitts Creek Flood Study (2015).

2.6.2. 2016 Revised Conduit Blockage Policy

Since the implementation of the 2002 Conduit Blockage Policy there has been advancements in a number of technical areas. This meant that a review of the 2002 Conduit Blockage Policy was appropriate to ensure that the policy meets the current and future requirements of Council and the community in a fair and reasonable way and is based on sound technical fundamentals. These advancements included:

- data techniques and modelling tools used for flood estimation and floodplain management, particularly in modelling flow behaviour in and around culverts and bridges.
- Wollongong faces significant development pressures for both "greenfield" urban release areas and infill development of existing urban areas. The policy must facilitate best practice flood risk management both for existing flood affected communities and future development areas.
- Guidelines for blockage have been released as part of the Project 11 work for the Australian Rainfall & Runoff revision.
- Council has accrued years of experience with the operation of the existing policy, and additional insight has been gathered from this experience.

While the previous 2002 policy had been effective in identifying and managing flood risks at locations potentially sensitive to blockage, it used a relatively broad-brush approach. The revised 2016 policy is based on the detailed probabilistic analysis of blockage data and provides the following:

- Clarification of policy wording to clarify the intent and improve consistency with current modelling and design practice.
- Refinement of culvert and bridge size categories.
- Revised blockage factors based on the data analysis and modelling undertaken.
- A differentiation between blockage factors for “Design” and “Risk Management” purposes.

The refined culvert and bridge sizing classes are outline in Table 2 below.

Table 2 – Culvert and Bridge Sizing Classes

	Class 1	Class 2	Class 3	Class 4
Pipes	<1.2m diameter	>1.2m diameter	N/A	N/A
Box Culverts/ Bridges	<1.5m diagonal or <0.9m width or height	>1.5m and <3.0m diagonal or >0.9m width or height	>3.0m and <6.0m diagonal or >1.2m width or height	>6.0m diagonal or >2.5m width or height

“Design” blockage factors are applied for all design flood modelling purposes, excluding those listed for risk management purposes. These applications include:

- Estimation of design flood levels, velocities, and depths for flood studies,
- Flood hazard and hydraulic categories, including delineation of the High Flood Risk Precinct,
- Infrastructure design,
- Structural design of proposed development,
- Impact assessment of proposed development,
- Assessing the benefit of proposed flood mitigation works,
- Estimating flood damages,
- Assessment of risk to life and evacuation considerations, and
- All other design flood estimation tasks except those listed for risk management purposes below.

“Risk Management” blockage factors are applied for the following applications:

- Setting Flood Planning Levels (FPLs), such as floor levels for new development;
- Delineating the Medium and Low Flood Risk Precincts.

Table 3 and Table 4 below provides a summary of the Revised Conduit Blockage Policy.

Table 3 - “Design” Blockage Factors - Revised Conduit Blockage Policy

Design AEP	Bridge / Culvert Classification				Debris Blockage of Overtopping Flows
	Class 1	**Class 2**	**Class 3**	**Class 4**	
20% AEP or more frequent (e.g. 50% AEP, 20% AEP)	35%	25%	15%	0%	Must include appropriate representation of obstructions to flow, such as bridge decks, fences, handrails, buildings, crash/noise barriers, etc. Modelling of pervious structures such as fences and railings above the structure should assume a 50% debris blockage of the unblocked flow area through the obstruction, plus associated hydraulic energy losses.
Rarer than 20% AEP and more frequent than 2% AEP (e.g. 10% AEP, 5% AEP)	50%	40%	30%	5%	
2% AEP or greater (e.g. 2% AEP, 1% AEP, PMF)	70%	50%	40%	10%	

Table 4 - “Risk Mangement” Blockage Factors - Revised Conduit Blockage Policy

Bridge / Culvert Classification			Debris Blockage of Overtopping Flows
Class 1 and Class 2	**Class 3**	**Class 4**	
Additional 25% blockage above “design” factors **(e.g. for 1% AEP event, 95% blockage for Class 1 75% blockage for Class 2)**	Additional 20% blockage above “design” factors (e.g. 60% blockage for 1% AEP event)	Additional 5% blockage above “design” factors (e.g. 15% blockage for 1% AEP event)	Additional 25% blockage above “design” factors (75% debris blockage of unblocked flow area)

The 2016 Revised Conduit Blockage Policy will be applied as part of this Flood Study Addendum.

3. MODEL REVIEW AND UPDATE

3.1. Overview

The Review of Hewitts Creek Flood Study was completed in August 2015 and was undertaken in accordance with NSW Government's Flood Prone Land Policy. The Flood Study aimed to determine design flood behaviour in the study area, to achieve this a WBNM hydrologic model and a 1D/2D TUFLOW hydraulic model were established. The models have been reviewed to determine the suitability for use in the Floodplain Risk Management Study. The following sections describe the outcomes of the review and any updates required. The updates have been undertaken and the changes to design flood behaviour are documented as part of this Flood Study Addendum report.

3.2. WBNM Hydrologic Model

A WBNM hydrologic model was established as part of the 2002 Floodplain Risk Management Study. This WBNM hydrologic model formed the basis for development of the WBNM hydrologic model as part of the 2015 Flood Study Review.

As there is no streamflow gauge within the study area it is difficult to make a definitive statement about the model results, rather a statement can be made about the appropriateness of the model build and parameters selected to develop the current WBNM hydrologic model.

In refining the WBNM hydrologic model as part of the Flood Study Review (2015), the sub-catchment delineation was refined based on the stream network, observed flow behaviour, available topographic information and to define appropriate inflow locations to the 1D/2D TUFLOW hydraulic model. The refined sub-catchments appear to be reasonable with appropriate boundaries at major hydraulic controls such as Princes Highway and the Illawarra Railway Line. It is noted that the WBNM hydrologic model contains 144 sub areas, this is considered to be on the high side, with WBNM guidance recommending a maximum of 35 for a catchment of less than 10km^2, but the guidance also notes that, generally the appropriate catchment wide lag can be maintained with a greater number of subareas. The number of subareas is also dependent on the scale of the features being modelled in the catchment. In this case, some urban features are being assessed and therefore a smaller sub-catchment size is appropriate. The majority of the sub-catchment delineation developed as part of the Flood Study Review (2015) is considered appropriate for use as part of the current Flood Study Addendum. The updates required are discussed in the following paragraph.

Since the completion of the 2015 Flood Study Review new development has occurred in Bulli at the Brickworks site and at the western extent of the urban area in Thirroul (Armagh Parade) (Volume 2 Map Set A – Figure 1). In addition, during recent storm events flows from the Flanagans Creek catchment have been shown to overflow into the adjacent catchment. The sub-catchments through these areas required further refinement in order to derive appropriate inflows for the TUFLOW model as part of the current Flood Study Addendum. The number of sub-catchments has been increased to 161. The sub-catchment layout is shown on Volume 2 Map Set A - Figure 5.

A key factor contributing to determination of catchment lag is the shape of the subareas, for example an overly elongated catchment can result in a lag that is not representative. The sub-catchments developed as part of the Flood Study Review (2015) appear to be reasonably shaped and no adjustments have been made.

Percentage impervious applied as part of the Flood Study Review (2015) appear reasonable and appropriate given current catchment conditions. The upper catchment areas contain no impervious areas, which is appropriate for the undeveloped areas of the catchment and the lower developed catchment areas vary on average from 10 – 50% impervious. The percentage impervious was adjusted as part of the Flood Study Addendum through the sub-catchments that had been refined as a result of development changes within the catchment. Consistency was maintained with those typical values applied in the Flood Study Review (2015).

A catchment lag parameter “C” of 1.29 and a stream lag of 1.0 has been applied across the catchment as part of the Flood Study Review (2015). This “C” value is at the lower end of the recommended values but considering the steepness of the upper catchment and values adopted in surrounding catchments, appears reasonable. A stream lag of 1.0 is recommended for natural catchments and streams and its application is appropriate. The Flood Study Review (2015) tested the sensitivity of the peak flow estimates to alternative “C” values. A comparison of adopting “C” values of 1.3 and 1.7 was shown to have a minor impact on peak flood levels for the 1% AEP event. At the majority of locations flood levels changed by less than 0.1m. Five locations were found to be more sensitive, Kelton Lane at Thirroul where flood levels reduced by 0.6m, Illawarra Railway at Thirroul, William Street at Bulli, Hobart Street at Bulli and Bulli Showground at Bulli, where flood levels reduced by between 0.1m - 0.2m.

The Flood Study Review (2015) notes that the WBNM hydrologic model provides routed inflows to the upstream boundaries of the TUFLOW model and provides local flow inputs within the TUFLOW hydraulic model. These local flow inputs are routed within the TUFLOW model and not internally routed through the WBNM hydrologic model. This is a reasonable approach for a hydrologic and hydraulic modelling suite. As part of the current Flood Study Addendum a refined WBNM hydrologic model has been developed which includes a representation of significant catchment storages to allow the hydrologic model to be more representative at any point in the catchment.

Design rainfall inputs were derived from the methodologies defined in Australian Rainfall and Runoff 1987 for six locations and automatically varied across the catchment by WBNM. Derived rainfall depths were consistent with those recommended for use by Wollongong City Council. Zone 1 temporal patterns were applied. This approach is considered appropriate considering the application of Australian Rainfall and Runoff 1987. A range of durations from 15 minute to 11 hours were simulated and the critical storm duration identified. The critical storm duration produces peak flood conditions at the location of interest. The 2 hour and 9 hour durations were found to be critical for the catchment.

An initial loss value of 0mm was applied to both pervious and impervious surfaces and a recommended continuing loss rate of 2.5mm/hr and 0mm/hr for pervious and impervious surfaces, respectively. An initial loss value of 0mm is at the lower end of recommended values, however The Flood Study Review (2015) argues that the likelihood of flood producing short duration rainfall events occurring in isolation is limited. The use of an initial loss of 0mm is therefore reasonable.

The Probable Maximum Precipitation was derived using the Generalised Short Duration Method and is considered appropriate for event durations up to 6 hours.

The Flood Study Review (2015) compared the peak flood levels for 0.5% AEP and 0.2% AEP events to the 1% AEP event, in order to gain an understanding of the sensitivity of flood behaviour to potential rainfall increases as a result of climate change. This comparison represented an average rainfall increase of 15% and 30%. The comparison showed relatively small increases along Thomas Gibson Creek and the eastern and western tributaries of Hewitts Creek, where levels generally changes by less than 0.1m. Flood levels were more sensitive along Hewitts Creek, Woodlands Creek, Tramway Creek and Slacky Creek with an average increase of 0.1m and 0.2m for the 0.5% AEP and 0.2% AEP events, respectively. The most sensitive location was at the Illawarra Railway at Hewitts Creek, where flood levels increased up to 0.4m and 0.9m in the 0.5% AEP and 0.2% AEP events, respectively. The current Flood Study Addendum will consider the sensitivity of catchment flood behaviour to potential increases in rainfall as a result of climate change in accordance with current industry guidance.

Since the completion of the Flood Study Review (2015), Australian Rainfall and Runoff has been updated providing new methodologies to determine a range of design inputs, including rainfall depths, temporal patterns, and losses. These aspects will be considered later in the Floodplain Risk Management Study.

The WBNM hydrologic model established as part of the Flood Study Review (2015) is considered appropriate and has been adopted for use in this Flood Study Addendum.

3.3. TUFLOW Hydraulic Model

A HEC-RAS hydraulic model was established as part of the 2002 Floodplain Risk Management Study. For the study the one dimensional formulation was used and was considered best practice at the time. Significant development in the available modelling software has meant that two dimensional modelling is now considered best practice.

A two-dimensional TUFLOW hydraulic model was developed of the Hewitts Creek and surrounding catchments as part of the Flood Study Review (2015). TUFLOW is an industry standard software package the is widely used in Australia as well as internationally. The TUFLOW model covered a floodplain area of approximately 5.3km^2, encompassing the residential and commercial development areas of the catchment. A 2 m model grid resolution was adopted. This is a reasonable resolution balancing hydraulic features in the catchment (including floodplain features, waterway size and obstructions through the urban area) and computational limits of TUFLOW including model run times.

The Flood Study Review (2015) TUFLOW run files indicate Version 2013-12-AA-iDP-w64 was used. Version 2016-03-AE-w64 has been used as part of this review and in the modelling undertaken as part of the current Flood Study Addendum. The existing model was run in Version 2013-12-AE-w32 and compared to results from Version 2016-03-AE-w64 to establish if any differences occur as a result of the TUFLOW version used. Peak flood levels from the two versions are generally within +/-0.01m and up to a maximum of +/-0.05m at some isolated locations.

The Digital Elevation Model used to define the ground surface in TUFLOW was derived from a number of sources, including:

- 1 m DEM developed from LiDAR survey captured in 2005,
- Additional topographic ground survey (from Flood Study (2002) and Flood Study Review (2015)), and
- Design and “works-as-executed” drawings.

A more recent LiDAR data set captured in 2013 is available. This data was not used in the Flood Study Review (2015) as it is understood the study commenced prior to the LiDAR being available. A comparison of the two LiDAR datasets has been undertaken as part of the current study (Section 2.2.2). While both datasets provide a reasonable representation of the ground terrain, overall it was determined that the 2013 data better reflects current ground conditions, including recent development. The floodplain terrain representation within the TUFLOW model has been updated using the 2013 LiDAR data as part of the current Flood Study Addendum. A comparison of the model DTMs is provided in Volume 2 Map Set A – Figure 7. As part of this update, the data has been further supplemented with additional detail of catchment changes between 2013 and current conditions, provided by Council (Section 2.2.4). The model grid resolution of 2m has been maintained.

Additional topographic survey was previously captured to define channel geometry and hydraulic structures. Survey was captured as part of the 2002 study and during April 2013. The April 2013 survey was used to determine if the 2003 data was still an appropriate representation of the creek channels. The analysis undertaken in the Flood Study Review (2015) confirmed that the 2003 survey was an appropriate representation of the creek channels and was used within the TUFLOW hydraulic model. This data is the best available information of the creek channels and this channel definition will be maintained as part of the current Flood Study Addendum.

The Flood Study Review (2015) tested the sensitivity of peak flood levels for the 1% AEP event to potential channel sedimentation. The results showed that the peak flood levels were relatively insensitive with peak flood levels generally changing by less than 0.02m. Kelton Lane in Thirroul was shown to be more sensitive to channel sedimentation with peak flood levels increasing by 0.2m.

Features such as buildings are not typically adequately represented within the model DEM due to the limitations of model grid cell size and a need to represent the ground terrain, as such individual building footprints were digitised and a higher Manning's 'n' (n=1.0) roughness value applied as part of the Flood Study Review (2015). This is a reasonable approach, the impediment to flow is represented and flow is allowed to enter buildings utilising the storage that is available. This representation of buildings will be maintained as part of the current Flood Study Addendum.

A berm exists at the outlet of each creek system. Flanagans, Slacky and Hewitts Creeks are defined as Intermittently Closed or Open Lake or Lagoon (ICOLL). The entrances have been shown to naturally open during a flood event. The entrances are modelled as open in the TUFLOW model under the assumption that the entrances would have naturally breached. The geometry was based on calibration and validation events. The Flood Study Review (2015) did not document the sensitivity of flood levels in the catchment to this assumption. The sensitivity of flood levels to model assumptions is a key factor considered in determining the appropriate freeboard for flood planning levels in the catchment. It would therefore be appropriate to assess this sensitivity as part of the later Floodplain Risk Management Study to inform the assessment of freeboard.

Hydraulic structures have been included in the TUFLOW model as either a 1D structure or 2D layered flow constriction. A 1D structure is typically used when the structure is much smaller than the 2D grid resolution. It is preferred to use 2D structures as a 1D structure requires an approximation of energy losses, which are more reasonably simulated in the 2D scheme. In addition to major road structures AIDR Handbook 7 (2017) identified a number of private footbridges. In total 39 structures were included with dimension details outlined in the Flood Study Review (2015). A review of the representation of the structures within the TUFLOW model identified a number of inconsistencies with structure survey information, and in-field inspections. In addition, a number of structures are currently represented in 1D and are considered too large to be appropriately represented in comparison to the 2D grid resolution. Table 5 outlines the updates made to the TUFLOW model as part of the current Flood Study Addendum. Those structures not included in Table 5 below remain unchanged.

Volume 2 Map Set A – Figure 3 shows all structures (including Structure ID) included in the current Flood Study Addendum TUFLOW model.

The Flood Study Review (2015) applied Council's 2002 Conduit Blockage Policy (Section 2.6.1); as part of the current Flood Study Addendum Council's Revised Conduit Blockage Policy (Section 2.6.2) will be applied. Section 4 details which policy was applied to each scenario. Blockage factors applied as part of the Revised Conduit Blockage Policy are detailed in APPENDIX C.

Table 5 – Updates to Hydraulic Structures

ID	Watercourse	Street or Landmark	Structure Type	Structure Details	Structure Dimensions (m) From 2015 Flood Study	Model Update
1	Slacky Creek	William Street, Bulli	Culvert	3 Rectangular Culverts	3 x 2.4m x 1.5m	2 x 2.4m x 1.5m openings and 1 x 2.4m x 1.67m opening
4	Slacky Creek, (western tributary)	Hobart Street, Bulli	Bridge	Single Span Opening	invert creek Obvert 27m deck 1.6m	1D structure revised to 2D Layered Flow Constriction (LFC) and fence added on top 1m
9	Slacky Creek	Park at Black Diamond Place, upstream of the Illawarra Railway, Bulli	Culvert	2 Rectangular Culverts	2 x 2.85m x 3m openings	1D structure revised to 2D LFC Based on survey dimension
11	Slacky Creek	South of Beach Street, Bulli	Foot Bridge	Single Span Opening	invert creek, obvert 4.3mAHD deck 0.7m	1D structure revised to 2D LFC and fence added on top 1m
12	Slacky Creek	Blackall Street, Bulli	Bridge	Single Span Opening	invert creek, obvert 3.03mAHD deck 0.65m fence 0.5m	1D structure revised to 2D LFC and fence change 1m
13	Slacky Creek	Blackall Street, Bulli	Foot Bridge	Single Span Opening	invert creek, obvert 3.17mAHD deck 0.5m fence 1m	1D structure revised to 2D LFC and fence change 1m
18	Woodlands Creek	Air Avenue, Bulli	Bridge	2 Span Bridge	invert creek, obvert 14.6mAHD deck 0.7m fence 1.2m	1D structure revised to 2D LFC
19	Hewitts Creek	George Street, Thirroul	Foot Bridge	Single Span Bridge	invert creek, obvert 29.32mAHD deck 0.8m	1D structure revised to 2D LFC and fence added on top 1m
20	Hewitts Creek	George Street, Thirroul	Foot Bridge	Two Span Bridge	invert creek, obvert 27.9mAHD deck 0.1m	1D structure revised to 2D LFC and fence added on top 1m
21	Hewitts Creek	Kelton Lane, Thirroul	Bridge	Single Span Bridge	invert creek, obvert 24.06mAHD deck 0.9m	1D structure revised to 2D LFC and fence added on top 1m
22	Hewitts Creek	Lachlan Street, Thirroul	Culvert	2 Rectangular Culverts	2 x 2 x 2.75m openings	2 x 2 x 2.27m openings
23	Hewitts Creek	Lawrence Hargrave Drive, Thirroul	Culvert	3 Rectangular Culverts	2 x 2.75m x 2.45m openings	3 x 2.75m x 2.45m openings
25	Hewitts Creek	High Street, Thirroul	Bridge	Single Span Bridge	invert 10.7, obvert 12.8m AHD deck 0.15m and fence 1.2m	Invert 11.72, obvert 13.07m AHD deck 0.15m and fence 1.25m
26	Hewitts Creek	Illawarra Railway, Thirroul	Bridge	Single Span Bridge	Irregular 1D culvert	1D structure revised to 2D LFC

ID	Watercourse	Street or Landmark	Structure Type	Structure Details	Structure Dimensions (m) From 2015 Flood Study	Model Update
27	Hewitts Creek	Brickworks Avenue, Thirroul	Bridge	3 Span Bridge	invert creek, obvert 12.7mAHD deck 0.7m fence 1.2m	1D structure revised to 2D LFC
28	Hewitts Creek	Hamilton Road, Thirroul	Foot Bridge	Twin Span Bridge	invert creek, obvert 2.94mAHD deck 0.75m fence 1m	1D structure revised to 2D LFC
29	Hewitts Creek (eastern tributary)	Palm Grove, Thirroul	Culvert	1 Circular Culvert	0.9m diameter	Schematisation refined for incorporating pits and SW
30	Hewitts Creek (eastern tributary)	Virginia Terrace, Thirroul	Culvert	1 Circular Culvert	1.2m diameter	Schematisation refined for incorporating pits and SW
31	Hewitts Creek (eastern tributary)	George Street Thirroul	Culvert	1 Circular Culvert	1.0m diameter	Schematisation refined for incorporating pits
32	Hewitts Creek (western tributary)	Deborah Avenue, Thirroul	Culvert	1 Circular Culvert	1.5m diameter	
33	Hewitts Creek (western tributary)	Virginia Terrace, Thirroul	Culvert	1 Circular Culvert	1.5m diameter	Schematisation refined for incorporating pits
34	Hewitts Creek (western tributary)	George Street (West), Thirroul	Culvert	1 Rectangular Culvert	2.12m x 1.5m opening	Connection to the box culvert improved upstream
35	Thomas Gibson Creek	Lawrence Hargrave Drive, Thirroul	Culvert	1 Circular Culvert	0.45m diameter	Schematisation refined for incorporating pits and SW
37	Thomas Gibson Creek	Thomas Gibson Park, Thirroul	Culvert	1 Circular Culvert	0.75m diameter	Invert changed and schematisation refined for incorporating pits and SW

The existing TUFLOW model generally does not include a representation of the stormwater drainage network, with only crossing structures linking open channel sections included, as detailed above. A key component of the flood behaviour in the catchment is a result of shallow overland flow. A number of areas have been identified where inclusion of the drainage network would likely alter the design flood results. The TUFLOW model was therefore updated as part of the current Flood Study Addendum to include pipes of diameter greater than 450mm shown in Council's stormwater GIS layer and pit and pipe database (Section 2.2.6). Pipes smaller than approximately 450mm tend to become blocked and do not contribute significantly to available capacity in flood events and have therefore not been included. Pit dimensions were not available as part of the pit and pipe database, an assumed typical pit was applied at all locations. This typical pit represents the combined dimensions of a lintel and grate pit inlet and was assumed to be 2.5m by 0.15m. In these types of urbanised catchments, it is often the capacity of the pipe network that controls the amount of flow that can enter the drainage system and not the inlet.

To test the sensitivity of design flood behaviour to this typical pit assumption, a scenario was tested where the pit size was halved. The results show that the design flood behaviour is not sensitive to the typical pit assumption, with changes in flood level less than 0.01m.

In addition, in accordance with Council's DCP – Chapter E14 (Stormwater Management) (2009), a blockage factor of 20% was also applied to pits for all scenarios (ID 0, 1 and 2). It was assumed that all pits were on-grade. The included drainage network is shown on Volume 2 Map Set A – Figure 3.

Manning's 'n' is applied to the model terrain to represent the resistance of the surface to flow. The Flood Study Review (2015) outlines the following values (Table 6) of Manning's 'n' applied to the existing TUFLOW model.

Table 6 – Manning's 'n' Values

Land Use	Manning's 'n' value
Grass (maintained)	0.03
Parkland	0.04
Dense vegetation	0.09
Riparian Corridor	0.09
Creek Channel	0.06 – 0.12
Tidal Inundation Zone	0.035
Roads, car parks, open concrete	0.02
Railway	0.08
Urban Block/Default	0.07

An artificially high Manning's 'n' value of 1.0 was applied to building footprints to represent the resistance to flow moving through these buildings.

Manning's 'n' values for applicable land use types are considered appropriate. The distribution of hydraulic roughness was therefore adopted from the Flood Study Review (2015) for use in the TUFLOW model as part of the current Flood Study Addendum. This distribution is shown on Volume 2 Map Set A – Figure 4.

The Flood Study Review (2015) considered the sensitivity of design flood levels to the selected Manning's 'n' values by adjusting the values up and down by 20%. Results generally changed by less than 0.1m, with the maximum variance of +0.11m at the footbridge near Beach Street, Bulli and Blackhall Street, Bulli.

Inflow boundaries are extracted from the WBNM hydrologic model, with routed hydrographs applied at the upstream TUFLOW model boundary to represent inflow from the upper catchment. Internally local inflow hydrographs are applied across the catchment. This boundary configuration has been maintained in the updated TUFLOW model as part of the current Flood Study Addendum.

A timeseries water level has been applied at the downstream model boundary to represent the tidal water level in the Tasman Sea. A combination of "Normal Tide" (0.63m AHD constant) and "Storm Tide" (2.3/2.6m AHD variable) were applied and results enveloped to determine the design flood behaviour. This methodology is in accordance with guidance from DPIE and ARR and will be maintained in the current Flood Study Addendum.

In conclusion, the TUFLOW model is generally fit for use in the current Flood Study Addendum and the later Floodplain Risk Management Study with the following updates:

- LiDAR updated to 2013 data, in-bank defined by cross sections as per the Flood Study Review (2015) (Volume 2 Map Set A – Figure 6),
- Changes to hydraulic structures (Table 5) (Volume 2 Map Set A – Figure 3),
- Inclusion of drainage network with diameter greater than 450mm (Volume 2 Map Set A – Figure 3).

A full summary of the updates is provided in APPENDIX D. Further information on model establishment is available in the Flood Study Review (2015).

3.4. Detention Basins

It was noted in the review of the WBNM hydrologic model established in the Flood Study Review (2015) that the sub-catchments providing local flow inputs within the TUFLOW hydraulic model were not internally routed within WBNM, nor does the WBNM hydrologic model contain a representation of formal and informal storages within the catchment. Formal and informal storages attenuate flows during storm events by temporarily storing catchment runoff. While this would be a reasonable approach for a hydrologic and hydraulic modelling suite, Council has identified that a useful output would be a hydrologic model that makes an approximation of the effects of these aspects, primarily for emergency management purposes. Inclusion of these aspects in the WBNM hydrologic model also provides an additional high level checkpoint for the hydraulic model.

A number of both formal and informal storages were identified across the catchment. Those storages included in the WBNM hydrologic model are shown on Volume 2 Map Set A - Figure 5. The available storage was defined by a stage-storage relationship determined from LiDAR or provided design plans. The outlet relationship was defined by the outlet structure.

Comparisons were made between the outputs from the WBNM hydrologic and TUFLOW hydraulic model at a number of locations across the catchment identified on Volume 2 Map Set A - Figure 5. Comparison of peak flow is provided below in Table 7 and a comparison of the hydrographs generated from WBNM and TUFLOW at the same locations are shown on Volume 2 Map Set A - Figure 7. Peak flows are typically reproduced on average within 8%, with greater attenuation generally occurring within the TUFLOW model. Reasonable agreement is also achieved between the two models in the representation of hydrograph shape as shown on Volume 2 Map Set A - Figure 7.

Table 7 – WBNM and TUFLOW Peak Flow Comparison

Location	WBNM without Storages	WBNM with Storages	TUFLOW	Difference WBNM with Storages Compared to TUFLOW (%)
WC15	35	35	30	-19%
TGC26	8	5	4	-15%
TGC22	11	8	7	-9%
TC5	31	29	30	4%
SC31	74	35	39	9%
SC19	24	32	32	0%
SC12	61	32	30	-5%
HC41	82	82	82	0%

4. MODELLING SCENARIOS

4.1. Overview

The primary objective of this Flood Study Addendum is to update the design flood behaviour to existing floodplain conditions, considering recent developments and floodplain changes, and to take into account Council's revised Blockage Policy (Section 2.6.2). In order to understand the relevant changes to flood behaviour as a result of each of these updates a series of scenarios have been assessed and compared where relevant.

The 2015 Flood Study Review was undertaken in accordance with the methodologies outlined in Australian Rainfall and Runoff 1987 (ARR 1987), which were applicable at the time of the study. In late 2016, a first release of a revised Australian Rainfall and Runoff guideline became available, a later revision was subsequently released in mid 2019. The design flood behaviour produced as part of this Flood Study Addendum has been developed using the methodologies described in ARR 1987. The revised guidelines will be considered as part of the Floodplain Risk Management Study stage.

The following table outlines each of the scenarios considered.

Table 8 – Overview of Modelling Scenarios

Scenario ID	Aim	Model Updates	Catchment Conditions	Topographic Dataset	Blockage Policy	Scenario for Difference Mapping	Map Set
0	Re-establish the conditions presented in the Flood Study Review (2015) considering the model review (Section 3).	Hydraulic Structures, Drainage Network	2015	2013 LiDAR and field survey	2002	Flood Study Review (2015)	D
1	Understand the influence of the 2016 Revised Blockage Policy (Section 2.6.2).	As above	2015	2013 LiDAR and field survey	2016	Scenario ID 0	D
2	Understand the influence of catchment changes since 2015.	As above	2018	2013 LiDAR, field survey and recent catchment changes/developments	2016	Scenario ID 1	B
3	To be considered as part of Floodplain Risk Management Study						
4	Assess the sensitivity of catchment flood behaviour to climate change.	As above	2018	2013 LiDAR, field survey and recent catchment changes/developments	2016	Scenario ID 2	C
5	To understand potential hazard exposure in the catchment.	As above	2018	2013 LiDAR, field survey and recent catchment changes/developments	2016	N/A	B

The updated TUFLOW model has been used to simulate a range of different catchment combinations. The results of each simulation have been combined into a peak design flood envelope. The presented flood mapping shows the results of the design flood envelope. The contributing combinations are described in the following sections.

Each scenario was assessed for a range of design flood events, which are hypothetical floods with different likelihoods of occurrence. Design flood events provide information to Council for planning and flood risk management purposes.

4.2. Scenario ID 0 – Review of Existing Models

4.2.1. Overview

Scenario ID 0 considers 2015 catchment conditions with refinements to the models as identified in Section 3. Council's 2002 Conduit Blockage Policy (Section 2.6.1) has been applied, where design mapping is derived from an envelope of:

- an unblocked scenario,
- a blocked scenario, (where blockage varies between 100% and 25%, in accordance with Council's 2002 Conduit Blockage Policy) and
- a partially blocked case where the culvert on Slacky Creek at the detention basin at Black Diamond Place, Bulli and through the Illawarra Railway are blocked in accordance with the 2002 Condit Blockage Policy.

The updated model was run for the 1% AEP and PMF events for critical storm durations, 2 hour and 9 hour and 90 minute, respectively, identified in the Flood Study Review (2015).

4.2.2. Results

Impact mapping is provided in Volume 2 Map Set D, these maps identify the changes in peak flood level, as a result of the model updates described in Section 3, in comparison to those presented in the Flood Study Review (2015).

Peak flood depth, level and velocity are tabulated at reporting locations across the catchment in APPENDIX B - Table B1. Reporting locations are shown on Volume 2 Map Set A – Figure 1.

Across a large proportion of the study area the flood level results in the 1% AEP remain within +/- 0.1m of those presented in the Flood Study Review (2015). Other more significant changes are described in the following paragraphs. The most significant variation in flood level are associated with changes to the model as a result of the review discussed in Section 3.

The inclusion of the drainage network through the catchment has reduced flooding and, in some cases, completely removed shallow overland flow. This can be seen at:

- Beacon Avenue on the downstream reach of Slacky Creek,
- In the vicinity of Hobart and William Streets on the upper reaches of Slacky Creek,
- Spray Street,
- In the vicinity of Station Street and Raymond Road,
- In the vicinity of George Street and Virginia Terrace associated with flooding from Hewitts Creek,
- Mount Gilead Road, and
- Nardoo Cres.

Refinements to the sub-catchments in the vicinity of the Bulli Brickworks site have resulted in a change to the flood behaviour and extent, locally. In addition, the extension of the model to include new residential development in Armagh Parade, Thirroul has provided flood information through an area where previously none was available.

Along the main creek lines and vegetated areas, the current LiDAR is generally lower than that used in the Flood Study Review (2015). There has been general improvement in LiDAR capture methods and the lower levels are considered to be a better representation of the terrain. These changes have resulted in a broadening of the flood extent along Slacky Creek and Tramway Creek downstream of the Illawarra Railway, the upper reaches of Slacky and Woodlands Creeks

Upstream of William Street on Slacky Creek, there is a mixture of increases (up to 0.3m) and decreases (up to 0.3m) in flood levels. This is due to a combination of model changes in this area including, changes to a structure (ID 1), the inclusion of the drainage system and changes in the current LiDAR.

A reduction in flood level of up to 0.5m is observed along Hewitts Creek to the west of Corbett Avenue. This is a result of the current LiDAR showing lower ground levels in this area.

A mixture of increases and decreases in flood levels is observed in the vicinity of Kanangra Drive and George Street. A number of structures through this area were adjusted (Structure ID 19, ID 20, ID 21, ID 22, ID 30, ID 31, ID 32, ID 33 and ID 35), as part of the Scenario ID 0 (Section 4.2) and these changes have contributed to the change in flood behaviour in this area. In addition, sections of the drainage system have also been included through this area.

On Slacky Creek in the vicinity of Beacon Avenue, the changes to LiDAR result in less flow overflowing to Structure ID 10.

The drainage system has been included in the unnamed drainage line travelling from Phillip Street through to its outlet near Cliff Parade. This change has reduced flood levels by up to 0.5m.

It is considered that the updated design flood results are an appropriate representation of catchment conditions in 2015 considering the Council policies that applied at the time.

4.3. Scenario ID 1 – 2016 Revised Blockage Policy

4.3.1. Overview

Scenario ID 1 considers 2015 catchment conditions with refinements to the models as identified in Section 3. Council's 2016 Revised Conduit Blockage Policy (Section 2.6.2) has been applied, where design mapping is derived from an envelope of:

- an unblocked scenario,
- a blocked scenario, (where blockage varies between 95% and 0%, in accordance with Council's 2016 Revised Conduit Blockage Policy).

Separate mapping is developed for design and risk management purposes, where different factors are applied based on the 2016 Revised Conduit Blockage Policy.

The updated model was run for the 1% AEP and PMF events for critical storm durations, 2 hour and 90 minute, respectively. It was found that the changes to the blockage applied across the catchment resulted in only the 2 hour event remaining as the critical storm duration for the catchment.

4.3.2. Results

Impact mapping is provided in Volume 2 Map Set D, these maps identify the changes in peak flood level, as a result of the 2016 Revised Conduit Blockage Policy, in comparison to those presented as part of the Review of the Existing Models Scenario ID 0 (Section 4.2).

Peak flood depth, level, velocity and flow are tabulated at reporting locations across the catchment in APPENDIX B - Table B2, Table B4, Table B6 and Table B8. Reporting locations are shown on Volume 2 Map Set A – Figure 1.

Under "design" and "risk management" blockage conditions changes in flood behaviour, compared to Scenario ID 0, are limited to upstream of key structures across the catchment, such as Illawarra Railway and Princes Highway. The 2016 Revised Conduit Blockage Policy applies variable blockage between 0% and 95% to the structures in the Hewitts Creek catchment, whereas Council's previous Conduit Blockage Policy (2002) applied 100% for the majority of structures across the catchment. Generally, there is a reduction in flood levels and the key changes are described in the following paragraphs.

Under the "design" scenario, flood levels are shown to reduce between 0.1m and 0.3m over a broad area upstream of the majority of key structures. There are also small patches of associated reduction in flood extent.

The most significant change occurs at Illawarra Railway line on Hewitts Creek where flood levels are reduced by up to 1.9 m. This extends upstream on Hewitts Creek for 250m and across to Woodlands Creek where levels are reduced by up to 0.25m adjacent to the railway line. Under Council's previous Conduit Blockage Policy (2002) the structures at Illawarra Railway were modelled as 100% blocked. Under the 2016 Revised Conduit Blockage Policy the structure on Hewitts Creek is modelled as 10% blocked. This represents a substantial reduction in the assumed blockage and therefore obstruction presented.

Additionally, there is a significant reduction at the Illawarra Railway on Tramway Creek, where flood levels are reduced by up to 0.6m and an area in the vicinity of Bowman Close, is no longer considered flooded in the 1% AEP. The flood level reductions on Tramway Creek extend up to 600m upstream of the railway line. The applied blockage at this location reduces from 100% to 50% with the application of the 2016 Revised Conduit Blockage Policy.

Similar changes occur under the risk management scenario, with reductions limited to up to 0.2m upstream of the Illawarra Railway on Tramway Creek. On Hewitts Creek upstream of the Illawarra Railway flood levels are reduced by 1.7m, for 200m upstream of the railway line. There is no change to flood levels on the overflow to Woodlands Creek under the risk management scenario. This is a result of the increased blockage applied in the risk management scenario but noting that it is reduced from that applied in the 2002 Conduit Blockage Policy.

4.4. Scenario ID 2 – Current Catchment Conditions (2018)

4.4.1. Overview

Scenario ID 2 considers 2018 catchment conditions with refinements to the models as identified in Section 3. Council's 2016 Revised Conduit Blockage Policy (Section 2.6.2) has been applied, where design mapping is derived from an envelope of:

- an unblocked scenario,
- a blocked scenario, (where blockage varies between 95% and 0%, in accordance with Council's 2016 Revised Conduit Blockage Policy).

The model terrain has been modified to include developments that have occurred in the catchment since the completion of the Flood Study Review (2015). These developments include:

- Bulli Brickworks subdivision – Stages 1 and 2 are complete with Stage 3 under construction at the time this study commenced.
- Armagh Parade subdivision, Thirroul.

The location of these developments is shown on Volume 2 Map Set A - Figure 1.

Separate mapping is developed for design and risk management purposes, where different factors are applied based on the 2016 Revised Conduit Blockage Policy.

The updated model was run for the 1% AEP and PMF events for critical storm durations, 2 hour and 90 minutes, respectively. A full range of storm durations were assessed, and it was found that the changes to the blockage applied across the catchment resulted in only the 2 hour event remaining as the critical storm duration for the catchment.

4.4.2. Results

Impact mapping is provided in Volume 2 – Map Det D, these maps identify the changes in peak flood level, as a result of catchment changes since 2015, in comparison to those presented as part of the 2016 Revised Blockage Policy Scenario ID 1 (Section 4.3).

Peak flood depth, level, velocity and flow are tabulated at reporting locations across the catchment in APPENDIX B - Table B3, Table B5, Table B7 and Table B9. Reporting locations are shown on Volume 2 Map Set A – Figure 1.

Changes to the floodplain were identified at the Brickworks at Bulli and Armagh Parade, Thirroul (Section 2.2.4). These developments result in very minor and localised changes to flood behaviour with a slight change in the flood extent. The minor impacts are generally contained within the development sites.

It is considered that the updated design flood results are an appropriate representation of current catchment conditions and considering the Council policies that currently apply. This information represents the most up to date design flood information for the Hewitts Creek catchment. A more detailed discussion of the updated design flood results in provided in Section 5.

5. UPDATED DESIGN FLOOD RESULTS

5.1. Overview

The Review of Hewitts Creek Flood Study was completed in August 2015, a WBNM hydrologic model and a 1D/2D TUFLOW hydraulic model were established to determine design flood behaviour across the Hewitts Creek catchment. The models have been reviewed (Section 3 and 4.2), and updated considering the review, Council's Revised Blockage Policy (Section 2.6.2 and 4.3) and catchment changes since 2015 (Section 2.2.4 and 4.4).

The models as developed for Scenario ID 2 (Section 2.2.4 and 4.4) are considered suitable for use in the Floodplain Risk Management Study.

5.2. Design Flood Mapping

Design flood mapping, based on Scenario ID 2, of peak depth, level and velocity for the 5 year ARI, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP and PMF events are provided in Volume 2 Map Set B.

Design envelope flood results have been filtered for mapping purposes to exclude areas of very shallow inundation or runoff, that would typically not be considered flooding. The following criteria have been applied to the mapping:

- Peak flood depths less than 0.15m were excluded, removing very shallow inundation and catchment runoff,
- Velocity x Depth greater than 0.025m^2/s were reinstated, including shallow areas where greater velocity and therefore hazard exists. These areas are typically part of overland flowpaths or located in the steep sections of the upper catchment. This criteria ensures continuity of mapping along these paths,
- Areas of inundation less than 100m^2 were excluded, removing isolated puddles formed as a result of shallow depressions in the ground terrain representation within the hydraulic model.

5.3. Summary of Results

During events as frequent as the 5 year ARI flow is not contained to the main creek lines and shallow overland flow travels through developed areas, particularly roadways. Road inundation occurs in relatively frequent events (5 year ARI) at the following locations:

- Princes Highway, at Woodlands Creek and Slacky Creek,
- Beacon Avenue,
- Hobart Street,
- Cliff Parade,
- Bath Street,
- Station Street,
- Lawrence Hargrave Drive at the Thirroul Community Centre,

- Lachlan Street,
- Phillip Street,
- Deborah Avenue,
- Kanangra Drive and
- George Street.

Property inundation also occurs in relatively frequent events (5 year ARI). The most significantly affected location is the Bath Street and Cliff Parade area. At this location depths increase to up to 0.5m in the 1% AEP event. Similarly, properties are impacted on the eastern side of Hewitts Avenue, where depths are up to 0.5m in the 1% AEP event. Property inundation is also shown to occurs with shallow depths of up to 0.3m in the 1% AEP event, on Corbett Avenue and the western side of Pass Avenue.

As larger events occur inundation tends to spread from these areas becoming deeper, with large developed areas being inundated to substantial depths in the 1% AEP event. Overflow occurs between Hewitts and Woodlands Creeks in the larger events.

5.4. Comparison of Council's Revised Blockage Policy – Risk Management and Design Blockage Factors

Council's Revised Blockage Policy sets out two sets of blockage factors to be applied for different uses. For example, "Design" blockage factors are to be applied for all design flood modelling purposes including impact assessments and design. "Risk Management" blockage factors on the other hand are to be applied for setting flood planning levels and delineating medium and low flood risk precincts.

In general, the "Risk Management" blockage factors result in slightly higher flood levels relative to those with the "Design" blockage factors applied. The increase in flood levels as a result of the "Risk Management" blockage factor is generally +0.05m with higher increases (up to 0.3m) localised upstream of structures. The extent of inundation remains similar between the results for both sets of blockage factors, with the exception of upstream and downstream of the Illawarra Railway Line on Tramway Creek. At this location flood levels increase by up to 0.5m upstream resulting in a broader inundation extent and overflow of the rail line under the "Risk Management" blockage scenario.

5.5. Comparison to Results from Flood Study Review (2015)

Comparing the flood behaviour derived as part of this current Flood Study Addendum to those produced in the Flood Study Review (2015), the most significant changes occur as a result of the inclusion of the drainage network, changes to the terrain and the application of the 2016 Revised Conduit Blockage Policy. The comparison of these changes is described in Section 4 and shown on Volume 2 Map Set D, however are mainly contained to areas adjacent to structures and through creek areas.

The most significant change is the removal of shallow overland flow through some residential areas. Flood levels are typically reduced in comparison to Flood Study Review (2015). The inclusion of the drainage network through the catchment has reduced flooding and, in some cases, completely removed shallow overland flow. This can be seen at:

- Beacon Avenue on the downstream reach of Slacky Creek,
- In the vicinity of Hobart and William Streets on the upper reaches of Slacky Creek,
- Spray Street,
- In the vicinity of Station Street and Raymond Road,
- In the vicinity of George Street and Virginia Terrace associated with flooding from Hewitts Creek,
- Mount Gilead Road, and
- Nardoo Cres.

The inclusion of Council's 2016 Revised Blockage Policy results in a reduction in flood levels, which are limited to upstream of key structures across the catchment, such as Illawarra Railway and Princes Highway.

Refinements to the sub-catchments in the vicinity of the Bulli Brickworks site have resulted in a change to the flood behaviour and extent, locally. In addition, the extension of the model to include new residential development in Armagh Parade, Thirroul has provided flood information through an area where previously none was available. This area is shown as newly flooded on the mapping provided in Volume 2 Map Set D.

There are some locations where flood levels increase, most notably in the vicinity of The Esplanade. These changes are due to a combination of model changes in this area including, changes to structures, the inclusion of the drainage system, the addition of an inflow from the Flanagans Creek upper catchment and changes in the 2013 LiDAR.

5.6. Hydraulic Hazard

Floods can be hazardous to people, property and infrastructure. However, this flood risk only exists when the community and the built environment interact with hazardous flood behaviour. Floodplain management aims to support management of flood risk by supporting land use planning, emergency management and flood risk management. Understanding flood risk and how it can impact on development and people is essential to the management of flood risk.

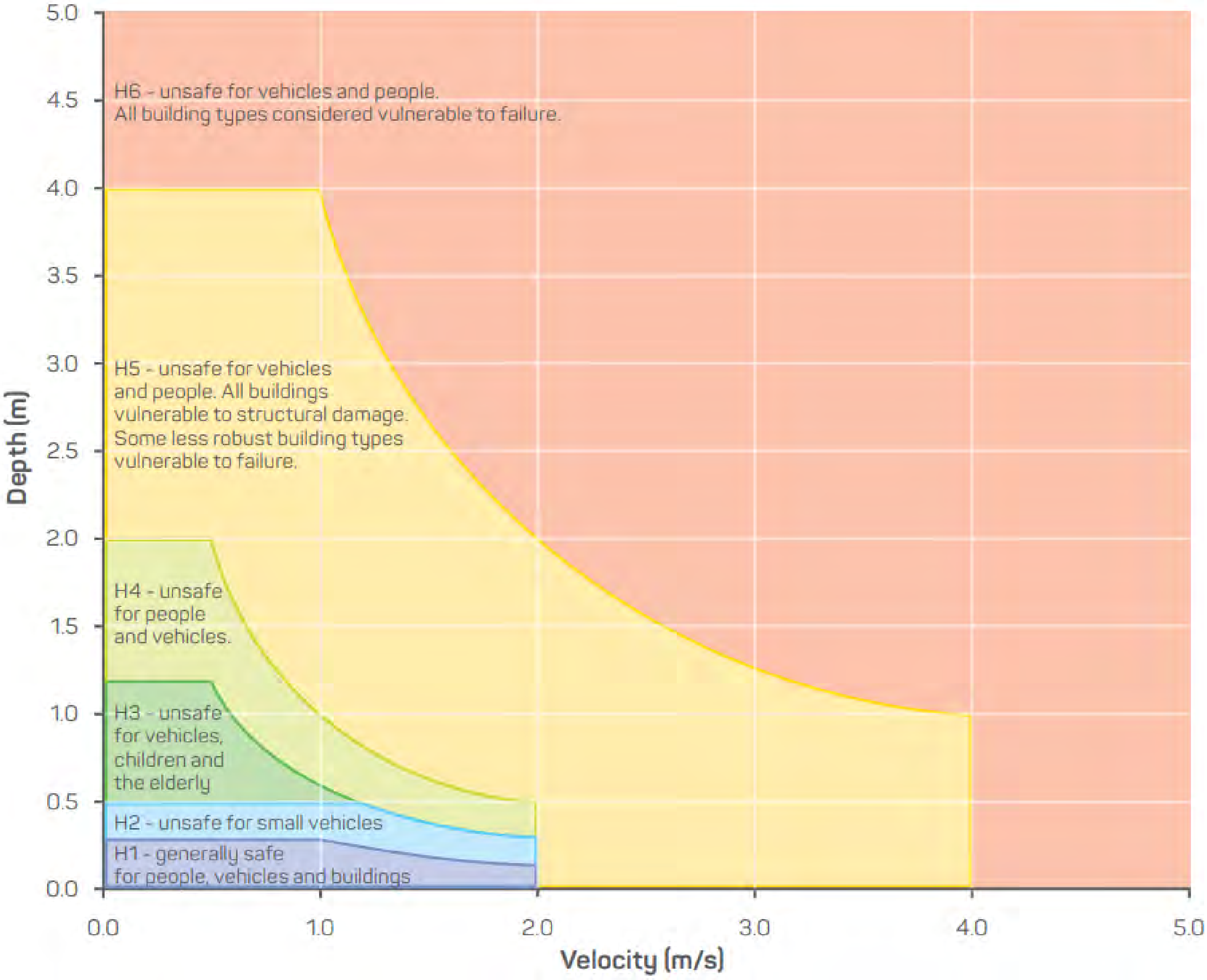
Hydraulic hazard is a measure of potential risk to life and property damage from flood. Hydraulic hazard is typically determined by considering the depth and velocity of floodwaters. Hazard was mapped as part of the Flood Study Review (2015) using the appropriate guideline the Floodplain Development Manual. The Floodplain Development Manual produces an essentially binary measure of hazard – either Low or High Hazard. In recent years, there have been several developments in the classification of hazards. Research has been undertaken to assess the hazard to people, vehicles and buildings based on flood depth, velocity and velocity depth product.

Mapping of hydraulic hazard has been prepared across the floodplain based on the methodology outlined in AIDR Handbook 7 (2017) and documented in ARR (2016). The classification is divided into 6 categories (H1-H6), listed in Table 9, which indicate constraints and vulnerabilities of hazard on people, buildings and vehicles within each zone. The criteria and threshold values (vulnerability curves) for each of the hazard categories are reproduced in Diagram 2.

Table 9 – Hazard Categories

Category	Constraint to people/vehicles	Building Constraints
H1	Generally safe for people, vehicles and buildings	*No constraints*
H2	Unsafe for small vehicles	*No constraints*
H3	Unsafe for vehicles, children and the elderly	*No constraints*
H4	Unsafe for vehicles and people	*No constraints*
H5	Unsafe for vehicles and people	All buildings 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

Diagram 2: Hydraulic Hazard Vulnerability Curves



Hydraulic hazard mapping for the 1% AEP, and PMF based on Scenario ID 2 is provided in Volume 2 Map Set B. Scenario ID 2 represents the current design flood behaviour across the catchment considering current development and Council's Revised Conduit Blockage Policy.

The mapping of hydraulic hazard for the 1% AEP events shows classifications H5 and H6, those areas considered unsafe for buildings, are generally contained to the creek lines and immediately adjacent riparian areas. However, the following roads are also affected by classifications H5 and H6:

- Kanangra Drive,
- George Street,
- Hewitts Avenue, Princes Highway at Woodlands Creek and
- Hobart Street.

Some areas of the catchment are subject to hazard classification H4 which is considered unsafe for people and vehicles, including south side of Lachlan Street, backyards of properties on High Street, Lawrence Hargrave Drive near Hewitts Avenue, Allenby Parade, Corbett Avenue and the intersection of Cliff Parade and Bath Street.

The hydraulic hazard across most developed areas of the catchment is category H3 or less. While category H3 has the potential to be unsafe for children and the elderly and pose a potential mobilisation hazard for vehicles, the flood behaviour across most of the remaining study area is unlikely to pose a significant threat to people.

Hazard classification H3 is considered unsafe for vehicles, and more vulnerable people. This classification occurs in similar areas to classification H4 with the addition of the Princes Highway near the Point Road intersection.

The remaining inundated areas are generally classified as H1 "generally safe for people, vehicles and buildings" and H2 "unsafe for small vehicles".

This classification will be an important consideration when developing floodplain risk management options for the Hewitts Creek catchment.

6. CLIMATE CHANGE ASSESSMENT

Climate change is expected to have adverse impacts upon sea levels and rainfall intensities into the future. Intensive scientific investigation is ongoing to estimate the effects that increasing amounts of greenhouse gases (water vapour, carbon dioxide, methane, nitrous oxide, ozone) may be having on the average earth surface temperature. Changes to surface and atmospheric temperatures may affect climate and sea levels. The extent of any permanent climatic or sea level change can only be established through scientific observations over several decades.

Both increases in sea levels and rainfall intensities have the potential to impact on flood behaviour. Considering and understanding the sensitivity of the current catchment flood behaviour to these influences is crucial in the management of future flood risk. While the primary factor influencing future changes to flood behaviour in coastal areas is changes to sea levels, potential increases in rainfall intensity could potentially influence flood behaviour in the catchment. As such both increases to rainfall intensity and sea level due to climate change, and a combination of both, have been considered as part of the current Flood Study Addendum for the 1% AEP event.

The impacts of climate change were considered as part of the Flood Study Review (2015), however given the updates made to the modelling tools and Council's Revised Blockage Policy, reassessment of the impacts of climate change was warranted.

6.1. Sea Level Rise

The former policy statement of the NSW Government set out a series of state-wide sea level rise planning benchmarks, including an increase of 0.4m by 2050 and 0.9m by 2100. In 2012, the NSW Government released the first stage of the Coastal Management Reforms which no longer recommended state-wide sea level rise benchmarks for use by local councils. Council's now have the flexibility to consider local conditions when determining future hazards.

In setting their adopted sea level rise projections in 2013, Council have considered a range of scientific research including the NSW Chief Scientist and Engineer's Report (2012). The report considers the science behind the previous NSW Government state-wide planning benchmarks. Council's adopted sea level rise policy sets projections of 0.4m for 2050 and 0.9m for 2100.

In order to understand the impacts increases in sea level rise will have on flood behaviour within the catchment, increases of 0.4m and 0.9m have been assessed for the 1% AEP event.

6.2. Rainfall Intensity

Any change in design flood rainfall intensities will increase the frequency, depth and extent of inundation across the catchment. It has also been suggested that the cyclone belt may move further southwards. Projected increases to evaporation are also an important consideration because increased evaporation would lead to generally dryer catchment conditions, resulting in lower runoff from rainfall. The combination of uncertainty about projected changes in rainfall and evaporation makes it extremely difficult to predict with confidence the likely changes to peak flows for large flood events within the catchments under warmer climate scenarios.

In light of this uncertainty, the NSW Government released *Practical Consideration of Climate Change* in 2007 which recommends sensitivity analysis on flood modelling should be undertaken to develop an understanding of the effect of various levels of change in the hydrologic regime. Specifically, it has suggested that a range of percentage increases to rainfall intensity be analysed.

ARR (2016) considered a range of research sources to develop a best practice methodology for considering the impact of climate change on rainfall as part of design flood estimation. The methodology includes the application of IFD curve adjustment factors derived from the temperature predictions available from the Australian Climate Futures web tool. The Australian Climate Futures web tool provides temperature predictions under a range of Representative Concentration Pathways (RCP), predicted future greenhouse gas concentration scenarios. ARR (2016) recommends the consideration of RCP 4.5 (low) and RCP 8.5 (high). IFD curve adjustment factors for both RCP 4.5 and RCP 8.5, as a percentage increase, for the study catchment are available from the Australian Rainfall and Runoff Data Hub. The percentage increases in rainfall intensity expected by 2090 are 7.6% and 16.3% for RCP 4.5 and RCP 8.5, respectively. Current research suggests that greenhouse gas concentrations are tracking closer to RCP 8.5.

The effect of increasing the design rainfalls by 20% has been evaluated for the 1% AEP event. A 20% increase in rainfall aligns with the IFD curve adjustment factor (16.3%) for RCP 8.5.

6.3. Modelled Scenarios

Considering the range of guidance available the following scenarios have been considered in order to determine the sensitivity of design flood behaviour to the potential impacts of climate change. All scenarios are based on Scenario ID 2 (Section 4.4), where the ocean boundary condition and catchment inflows (where relevant) have been adjusted for each scenario.

Table 10 – Climate Change Scenarios

Scenario	Design Rainfall	Ocean Boundary Condition
1% AEP SLR 0.4m	1% AEP	5% AEP + 0.4m
	5% AEP	1% AEP + 0.4m
1% AEP SLR 0.9m	1% AEP	5% AEP + 0.9m
	5% AEP	1% AEP + 0.9m
1% AEP +20% Rainfall SLR 0.9m	1% AEP + 20%	Neap Tide
	1% AEP + 20%	5% AEP + 0.9m
	5% AEP + 20%	1% AEP + 0.9m

6.4. Climate Change Impacts

The impacts of increases in sea level are shown to be limited to the very downstream areas of the Hewitts, Slacky, Tramway and Thomas Gibson Creek catchments and specifically within 200m of the ocean entrance. There is a minor increase in flood extent that is limited to the coastal foreshore area. Under the 2050 (0.4m increase) scenario increases in the 1% AEP flood levels are up to 0.2m. A similar extent of impact is shown to occur under the 2100 (0.9m increase) scenario, with flood levels increasing in the 1% AEP event by up to 0.3m.

There are some notable exceptions across the broader catchment where flood levels are more highly sensitive to rainfall increases, particularly between Lawrence Hargrave Drive and the Illawarra Railway, where flood levels are shown to increase by up to 0.6m. This flows through to increases of up to 0.4m on Hewitts Creek, downstream of the railway. The area upstream of the Illawarra Railway on Tramway Creek experiences increases of up to 0.3m. Increases of up to 0.2m were shown to occur along Slacky Creek and the downstream areas of Thomas Gibson Creek (Cliff Parade, The Esplanade and Bath Street). Smaller impacts were shown to occur on Slacky Creek, upstream of the Princes Highway, upstream of Lawrence Hargrave Drive and in the vicinity of Hewitts Avenue on Hewitts and Woodlands Creeks and in the upper reaches of Hewitts Creek where increases were shown to be between 0.1 – 0.15m.

Modelled impacts of the various climate change scenarios at key reporting locations are shown in Table 11 below.

Mapping of the impacts of the various climate change scenarios are provided in Volume 2 Map Set C. Mapping was prepared by comparing the peak water level from the various climate change scenarios with the results of Scenario ID 2. This was done for both “Design” and “Risk Management” blockage cases.

Table 11 – Climate Change Results

Location (refer to Volume 2 Map Set A – Figure 1)	Watercourse	Change in Peak Flood Level (mAHD)							
		1% AEP Scenario ID2		1% AEP SLR 0.4m		1% AEP SLR 0.9m		1% AEP +20% Rainfall SLR 0.9m	
		Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage
32:US Deborah Avenue	Hewitts Creek	63.19	63.27	0.00	0.00	0.00	0.00	0.08	0.08
33:US Virginia Terrace	Hewitts Creek	50.54	50.60	0.00	0.00	0.00	0.00	0.09	0.08
34:US George Street	Hewitts Creek	32.15	32.24	0.00	0.00	0.00	0.00	0.12	0.10
21:US Kelton Lane	Hewitts Creek	24.69	24.69	0.00	0.00	0.00	0.00	0.25	0.27
29:US Palm Grove	Hewitts Creek	74.97	75.01	0.00	0.00	0.00	0.00	0.04	0.04
30:US Virginia Terrace	Hewitts Creek	41.06	41.11	0.00	0.00	0.00	0.00	0.06	0.05
31:US George Street	Hewitts Creek	25.35	25.37	0.00	0.00	0.00	0.00	0.02	0.02
22:US Lachlan Street	Hewitts Creek	18.77	18.92	0.00	0.00	0.00	0.00	0.15	0.14
23:US Lawrence Hargrave Drive	Hewitts Creek	13.48	13.69	0.00	0.00	0.00	0.00	0.14	0.16
26:US Illawarra Railway	Hewitts Creek	12.17	12.31	0.00	0.00	0.00	0.00	0.56	0.68
27:US Brickworks Avenue	Hewitts Creek	9.90	10.12	0.00	0.00	0.00	0.00	0.46	0.36
28:US Hamilton Road	Hewitts Creek	1.86	1.98	0.40	0.40	0.90	0.90	0.90	0.90
36:US Illawarra Railway	Thomas Gibson Creek	11.81	12.00	0.00	0.00	0.00	0.00	0.07	0.14
38:US McCauley Street	Thomas Gibson Creek	7.12	7.14	0.00	0.00	0.00	0.00	0.04	0.04
39:US Cliff Parade	Thomas Gibson Creek	4.65	4.66	0.00	0.00	0.00	0.00	0.09	0.09
15:US Princes Highway	Woodlands Creek	18.82	18.94	0.00	0.00	0.00	0.00	0.15	0.12
17:US Illawarra Railway	Woodlands Creek	16.54	16.54	0.00	0.00	0.00	0.00	0.11	0.16
18:US Air Avenue	Woodlands Creek	11.21	11.21	0.00	0.00	0.00	0.00	0.01	0.01
14:US Illawarra Railway	Tramway Creek	16.65	17.04	0.00	0.00	0.00	0.00	0.34	0.12
1:US William Street	Slacky Creek	27.01	27.19	0.00	0.00	0.00	0.00	0.13	0.11
2:US Hobart Street	Slacky Creek	22.49	22.60	0.00	0.00	0.00	0.00	0.19	0.17
5:US disused railway line	Slacky Creek	21.53	21.53	0.00	0.00	0.00	0.00	0.26	0.26
7:US Access bridge at Bulli showground	Slacky Creek	18.22	18.22	0.00	0.00	0.00	0.00	0.09	0.09
8:US Princes Highway	Slacky Creek	14.55	14.63	0.00	0.00	0.00	0.00	0.03	0.03
9:Park at Black Diamond Place	Slacky Creek	12.73	12.73	0.00	0.00	0.00	0.00	0.16	0.16
9:US Illawarra Railway	Slacky Creek	12.59	12.59	0.00	0.00	0.00	0.00	0.20	0.20
10:US Illawarra Railway (Beacon Avenue)	Slacky Creek	11.79	11.77	0.00	0.00	0.00	0.00	0.38	0.40
11:US of timber footbridge (Beach Street)	Slacky Creek	4.47	4.47	0.00	0.00	0.02	0.02	0.22	0.22
12:US Blackhall Street	Slacky Creek	2.80	2.80	0.17	0.17	0.66	0.66	0.66	0.66

7. COMMUNITY CONSULTATION

7.1. Northern Floodplain Risk Management Committee

The Floodplain Risk Management Study and current Flood Study Addendum are being overseen by Council's Northern Floodplain Risk Management Committee. The committee includes representatives from a number of stakeholders, including:

- Wollongong City Council,
- Department of Planning, Industry and Environment (formerly Office of Environment and Heritage),
- State Emergency Service,
- Transport for NSW,
- Sydney Water,
- Roads and Maritime Services,
- Councillors and
- Community.

The committee has received project updates throughout the project. At the Northern Floodplain Risk Management Committee meeting on 28 May 2019, the draft Hewitts Creek Flood Study Addendum was presented and unanimously supported for Public Exhibition.

7.2. Public Exhibition

The draft Flood Study Addendum was placed on Public Exhibition for the period 9 September to 8 October 2019, to allow the community and other stakeholders to review and comment on the report prior to finalisation and adoption by Council. A copy of Council's Engagement Report for the Public Exhibition period is provided in Appendix E.

Council sent letters to more than 1,900 residents and property owners in the catchment area inviting them to learn more about the Study. Emails with this information were sent to community, education, Register of Interest (flood), business, government and emergency services' stakeholders. The information was also provided to Council's Customer Service Centre. Copies of the draft report, a Frequently Asked Questions sheet and Feedback form were available at Thirroul Library and on the project webpage. A copy of the available Frequently Asked Questions sheet is provided in Appendix E. A notice of the Public Exhibition was published in the Advertiser on 18 September 2019.

An information session was held at Bulli Senior Citizens Centre on the 18 September 2019. The information session was attended by 27 community members.

Details of the number of participants for each engagement activity are presented in Table 12.

Table 12 – Engagement Participation Results

Engagement Activity	Participation
Northern Floodplain Risk Management Committee Meeting	6
Drop-in Community Information Session at Bulli Senior Citizens Centre	27
Online Participation • Aware – Total number of users who viewed the project page • Informed – Total number of users who clicked a hyperlink, e.g. to download a document • Engaged – Total number of users who actively contributed to the project, e.g. submitted feedback via the online form	 89 70 2

Feedback on the study was gathered during the information session, via the Feedback form, Council's website and through the Customer Service Centre during the exhibition period. A total of 15 submissions were received. The key themes of the feedback included:

- Australian Rainfall and Runoff: Appropriateness of using the methodologies and data described in Australian Rainfall and Runoff 1987.
- Flood Modelling: Concerns that the flood modelling results were overly conservative particularly in the more frequent events.
- Blockage: Appropriateness of Council's Blockage Policy (2016) and its application to catchment wide studies.
- Mapping: Clarification of the hazard mapping was requested.
- Rainfall Intensity: Concern that the applied percentage increase in rainfall intensity used to test the sensitivity of flood behaviour to climate change was overly conservative, particularly when applied to the data derived in Australian Rainfall and Runoff 1987.
- Report Presentation: Suggestions to improve report clarity were made.
- Overland Flooding: Consideration of the impacts of new developments, such as recent land clearing and vegetation removal as part of the development at Armagh Parade and the impact of these changes further downstream at Turnbull Gully and Deborah Ave culvert.
- Flood Mitigation: A number of submissions included suggestions to reduce flooding and items to investigate as part of the Floodplain Risk Management Study. Endeavour Energy's focus was on the future Floodplain Risk Management Study and mitigating risks to the electricity distribution network.
- Floodplain Risk Management Process: Frustration over the ongoing floodplain risk management process and perceived lack of action.
- Perceived Causes of Flooding: The contribution of, new developments and a seeming lack of culvert maintenance, to increased flood risk.
- Maintenance: More regular clearing of vegetation and debris from various creek, culverts and pipes due to current and ongoing build-up, or overgrown weeds was identified.
- Impact on Individual Properties: A request was made for property level information.
- Insurance: The impact of Council flood information on how insurers set their premiums.

Council provided responses to all submissions received. The outcomes of the Public Exhibition and how they will be considered as part of the study will be reported to the Northern Floodplain Risk Management Committee and Council prior to adoption of the study.

8. CONCLUSIONS AND RECOMMENDATIONS

This report provides an addendum to the 2015 Flood Study Review and outlines the revised design flood behaviour considering Council's Revised Conduit Blockage Policy, in addition to catchment changes since 2015 and recommendations coming out of review of the models.

Both the WBNM hydrologic model and TUFLOW hydraulic model established as part of the Flood Study Review (2015) were generally considered appropriate for use in the addendum. Some minor updates were required to ensure the models produce an improved representation of design flood behaviour. These updates included updating the terrain information to a more recent dataset, refinement of the models in new development areas, improved representation at a number of hydraulic structures and inclusion of the drainage network.

These updated models formed the basis for assessment of a range of scenarios including Council's Revised Conduit Blockage Policy (2016). In order to understand the relevant changes to flood behaviour as a result of each of these updates a series of scenarios have been assessed and compared where relevant. The following provides a brief summary.

- Scenario ID 0 (Re-established Base Case) – This scenario was compared to the results from the Flood Study Review (2015). Across a large proportion of the study area the flood level results in the 1% AEP remain within +/- 0.1m of those presented in the Flood Study Review (2015). The inclusion of the drainage network through the catchment has reduced flooding and, in some cases, completely removed shallow overland flow. Other localised variation in flood levels occur as a result of the changes to the model terrain and hydraulic structures. The magnitude of these changes is generally between 0.1m and 0.5m.
- Scenario ID 1 (Revised Conduit Blockage Policy) – This scenario was compared to Scenario ID 0. The changes in flood behaviour as a result of the Revised Conduit Blockage Policy are generally limited to upstream of some structures where flood levels are reduced by between 0.1m and 1.0m, with a maximum reduction of 1.9m. The flood level reduction generally extends between 300m and 600m upstream. There are also small patches of associated reduction in flood extent. There is limited change in flood levels downstream of structures.
- Scenario ID 2 (Current Catchment Conditions) - This scenario was compared to Scenario ID 1. Changes to flood behaviour as a result of developments within the catchment are minor, localised and generally contained within the development site. There are no impacts on the broader flood behaviour.

Updated design flood behaviour for current Hewitts Creek catchment conditions has been defined for the 5 year ARI, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP and PMF events. The outcomes of this mapping will be used to inform the flood risk management assessment undertaken as part of the Floodplain Risk Management Study stage.

Council's Revised Blockage Policy sets out two sets of blockage factors to be applied for different uses, "Design" and "Risk management". Mapping is provided for both sets of blockage factors. In general, the "Risk Management" blockage factors result in slightly higher flood levels relative to those with the "Design" blockage factors applied. The increase in flood levels as a result of the "Risk Management" blockage factor is generally +0.05m with higher increases (up to 0.3m) localised upstream of some structures. A larger increase (+0.5m) occurs upstream of the Illawarra Highway on Tramway Creek.

The potential impacts of climate change on catchment flood behaviour have also been assessed. Increases in rainfall intensity have been shown to increase flood levels along waterways generally between 0.1m and 0.3m. Larger increases of between 0.5m and 1.0m are shown to occur upstream of hydraulic structures. Increases in sea level are shown to result in increased flood levels however are limited to the downstream areas of the Hewitts Creek catchment.

The design flood behaviour produced as part of this Flood Study Addendum has been developed using the methodologies described in ARR 1987. The revised guidelines (ARR (2016)) will be considered as part of the Floodplain Risk Management Study stage.

9. REFERENCES

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Appendix A

APPENDIX A. GLOSSARY

Taken from the Floodplain Development Manual (April 2005 edition)

acid sulfate soils	Are sediments which contain sulfidic mineral pyrite which may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual published by Acid Sulfate Soil Management Advisory Committee.
Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Annual Damage (AAD)	Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
Average Recurrence Interval (ARI)	The long term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
caravan and moveable home parks	Caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the LG Act.
catchment	The land area draining through the mainstream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
consent authority	The Council, government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the Council, however legislation or an EPI may specify a Minister or public authority (other than a Council), or the Director General of DIPNR, as having the function to determine an application.
development	Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act). **infill development:** refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development. **new development:** refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power.

redevelopment: refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services.

disaster plan (DISPLAN)	A step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.
discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
ecologically sustainable development (ESD)	Using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act 1993. The use of sustainability and sustainable in this manual relate to ESD.
effective warning time	The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.
emergency management	A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.
flash flooding	Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
flood awareness	Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.
flood education	Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves and their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.
flood fringe areas	The remaining area of flood prone land after floodway and flood storage areas have been defined.
flood liable land	Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).
flood mitigation standard	The average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.

floodplain Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.

floodplain risk management options The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.

floodplain risk management plan A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammetic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.

flood plan (local) A sub-plan of a disaster plan that deals specifically with flooding. They can exist at State, Division and local levels. Local flood plans are prepared under the leadership of the State Emergency Service.

flood planning area The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the Aflood liable land@ concept in the 1986 Manual.

Flood Planning Levels (FPLs) FPL=s are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the Astandard flood event@ in the 1986 manual.

flood proofing A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.

flood prone land Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.

flood readiness Flood readiness is an ability to react within the effective warning time.

flood risk Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below.

existing flood risk: the risk a community is exposed to as a result of its location on the floodplain.

future flood risk: the risk a community may be exposed to as a result of new development on the floodplain.

continuing flood risk: the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.

flood storage areas Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.

floodway areas Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.

freeboard Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.

habitable room **in a residential situation:** a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom.

in an industrial or commercial situation: an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.

hazard A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Manual.

hydraulics Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.

hydrograph A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.

hydrology Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.

local overland flooding Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.

local drainage Are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.

mainstream flooding Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.

major drainage Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purpose of this manual major drainage involves:

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

mathematical/computer models	The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
merit approach	The merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well being of the State=s rivers and floodplains. The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into Council plans, policy and EPIs. At a site specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local floodplain risk management policy and EPIs.
minor, moderate and major flooding	Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood: **minor flooding:** causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded. **moderate flooding:** low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered. **major flooding:** appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.
modification measures	Measures that modify either the flood, the property or the response to flooding. Examples are indicated in Table 2.1 with further discussion in the Manual.
peak discharge	The maximum discharge occurring during a flood event.
Probable Maximum Flood (PMF)	The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.
Probable Maximum Precipitation (PMP)	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
probability	A statistical measure of the expected chance of flooding (see AEP).
risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.

runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	Equivalent to Awater level@. Both are measured with reference to a specified datum.
stage hydrograph	A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
survey plan	A plan prepared by a registered surveyor.
water surface profile	A graph showing the flood stage at any given location along a watercourse at a particular time.
wind fetch	The horizontal distance in the direction of wind over which wind waves are generated.

Appendix B

APPENDIX B. MODELLING RESULTS

Table B1 – Design Flood Flow and Level Comparison – Scenario ID 0 and Flood Study Review (2015)

Location (refer to Volume 2 Map Set A - Figure 1)	Watercourse	2015 Flood Study Review[1]				Scenario ID 0			
		Peak Flood Flow (m^3/s)		Peak Flood Level (mAHD)		Peak Flood Flow (m^3/s)		Peak Flood Level (mAHD)	
		1% AEP	**PMF**	**1% AEP**	**PMF**	**1% AEP**	**PMF**	**1% AEP**	**PMF**
32:US Deborah Avenue	Hewitts Creek	9.4	22.6	63.25	63.54	13.1	28.6	63.32	63.68
33:US Virginia Terrace	Hewitts Creek	9.7	18.9	50.16	50.59	11.1	21.1	50.61	50.99
34:US George Street	Hewitts Creek	11.5	22.7	29.48	29.88	12.5	24.2	32.30	32.65
21:US Kelton Lane	Hewitts Creek	61.5	152.3	25.35	26.61	62.1	136.7	24.80	25.96
29:US Palm Grove	Hewitts Creek	1.3	3.0	75.14	75.32	0.7	1.2	75.01	75.15
30:US Virginia Terrace	Hewitts Creek	4.9	10.0	40.99	41.23	4.2	7.5	41.11	41.27
31:US George Street	Hewitts Creek	9.1	18.3	32.38	32.70	10.1	17.2	25.37	25.44
22:US Lachlan Street	Hewitts Creek	68.6	167.3	19.19	19.81	68.6	151.6	19.02	19.58
23:US Lawrence Hargrave Drive	Hewitts Creek	70.2	165.1	14.57	16.21	78.4	151.5	14.12	16.24
26:US Illawarra Railway	Hewitts Creek	93.9	243.1	14.06	16.17	89.8	219.0	14.09	16.21
27:US Brickworks Avenue	Hewitts Creek	94.3	291.2	11.58	13.24	98.2	325.9	11.64	12.79
28:US Hamilton Road	Hewitts Creek	102.0	301.0	2.60	4.00	107.7	263.8	2.54	3.66
36:US Illawarra Railway	Thomas Gibson Creek	1.4	5.0	14.46	14.95	1.3	6.7	14.30	15.07
38:US McCauley Street	Thomas Gibson Creek	4.4	20.6	7.17	7.52	4.2	18.8	7.14	7.50
39:US Cliff Parade	Thomas Gibson Creek	11.8	30.5	4.75	5.15	9.8	27.1	4.66	5.07
15:US Princes Highway	Woodlands Creek	57.1	144.8	19.15	19.68	50.9	131.5	19.04	19.45
17:US Illawarra Railway	Woodlands Creek	32.9	47.2	16.59	17.22	32.1	54.1	16.59	17.12
18:US Air Avenue	Woodlands Creek	24.8	37.3	11.19	12.65	24.7	42.5	11.83	12.81
14:US Illawarra Railway	Tramway Creek	49.1	164.9	17.29	17.69	50.1	157.3	17.22	17.59
1:US William Street	Slacky Creek	38.8	104.5	27.57	28.11	38.4	96.4	27.31	27.79
2:US Hobart Street	Slacky Creek	39.2	68.2	22.72	23.42	38.6	56.5	22.75	23.42
5:US disused railway line	Slacky Creek	24.8	37.2	22.95	23.43	25.2	38.7	22.01	23.40
7:US Access bridge at Bulli showground	Slacky Creek	30.5	41.8	18.32	18.55	29.8	38.5	18.22	18.46
8:US Princes Highway	Slacky Creek	39.6	79.3	14.65	14.85	35.4	74.9	14.59	14.80

Location (refer to Volume 2 Map Set A - Figure 1)	Watercourse	2015 Flood Study Review[1]				Scenario ID 0			
		Peak Flood Flow (m^3/s)		Peak Flood Level (mAHD)		Peak Flood Flow (m^3/s)		Peak Flood Level (mAHD)	
		1% AEP	**PMF**	**1% AEP**	**PMF**	**1% AEP**	**PMF**	**1% AEP**	**PMF**
9:Park at Black Diamond Place	Slacky Creek	24.6	67.7	13.22	14.68	35.6	53.8	12.82	14.17
9:US Illawarra Railway	Slacky Creek	35.9	68.9	13.12	14.63	37.9	62.9	12.68	14.27
10:US Illawarra Railway (Beacon Avenue)	Slacky Creek	17.9	45.1	12.90	14.55	3.4	32.2	12.84	14.14
11:US of timber footbridge (Beach Street)	Slacky Creek	48.1	123.9	4.75	5.58	50.0	113.6	4.42	5.44
12:US Blackhall Street	Slacky Creek	51.4	125.0	2.98	4.36	46.0	108.8	2.78	4.07

(1) Values reproduced from the Flood Study Review (2015) Reference 7

Table B2 – Design Flood Levels – Scenario ID 1

Location (refer to Volume 2 Map Set A - Figure 1)	Watercourse	Scenario ID 1 - Design Peak Flood level (mAHD)															
		5 year ARI		10% AEP		5% AEP		2% AEP		1% AEP		0.5% AEP		0.2% AEP		PMF	
		Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage
32:US Deborah Avenue	Hewitts Creek	62.83	62.98	62.92	63.04	63.01	63.11	63.12	63.20	63.19	63.26	63.23	63.30	63.30	63.36	63.57	63.64
33:US Virginia Terrace	Hewitts Creek	50.32	50.25	50.37	50.35	50.41	50.46	50.48	50.53	50.53	50.58	50.58	50.64	50.65	50.70	50.90	50.96
34:US George Street	Hewitts Creek	31.85	31.91	31.90	31.97	31.97	32.04	32.07	32.14	32.13	32.22	32.21	32.29	32.29	32.36	32.51	32.58
21:US Kelton Lane	Hewitts Creek	23.94	23.94	24.11	24.11	24.33	24.33	24.55	24.54	24.69	24.69	24.85	24.86	25.07	25.09	25.90	25.97
29:US Palm Grove	Hewitts Creek	74.60	74.86	74.80	74.89	74.85	74.93	74.94	74.98	74.97	75.01	74.99	75.03	75.03	75.07	75.10	75.14
30:US Virginia Terrace	Hewitts Creek	40.77	40.90	40.83	40.94	40.92	40.99	41.02	41.07	41.05	41.11	41.09	41.14	41.14	41.18	41.23	41.26
31:US George Street	Hewitts Creek	25.27	25.29	25.28	25.31	25.30	25.33	25.34	25.36	25.35	25.37	25.37	25.38	25.39	25.40	25.43	25.44
22:US Lachlan Street	Hewitts Creek	18.29	18.46	18.39	18.56	18.52	18.67	18.67	18.82	18.77	18.92	18.86	19.01	18.98	19.13	19.41	19.57
23:US Lawrence Hargrave Drive	Hewitts Creek	12.96	13.14	13.07	13.28	13.20	13.40	13.39	13.58	13.48	13.69	13.57	13.79	13.68	13.93	15.38	15.49
26:US Illawarra Railway	Hewitts Creek	10.75	10.75	10.99	10.99	11.26	11.26	11.68	11.92	12.17	12.31	12.48	12.71	13.03	13.27	15.29	15.41
27:US Brickworks Avenue	Hewitts Creek	8.89	8.89	9.07	9.09	9.30	9.32	9.58	9.81	9.90	10.12	10.18	10.36	10.49	10.63	11.68	11.79
28:US Hamilton Road	Hewitts Creek	1.51	1.51	1.57	1.57	1.65	1.65	1.73	1.80	1.86	1.98	2.03	2.12	2.23	2.33	3.06	3.14
36:US Illawarra Railway	Thomas Gibson Creek	11.70	11.71	11.72	11.76	11.74	11.80	11.78	11.93	11.81	12.00	11.86	12.09	11.92	12.21	13.40	14.68
38:US McCauley Street	Thomas Gibson Creek	7.01	7.03	7.03	7.05	7.06	7.08	7.10	7.11	7.12	7.14	7.15	7.16	7.17	7.18	7.32	7.32
39:US Cliff Parade	Thomas Gibson Creek	4.45	4.46	4.49	4.50	4.54	4.55	4.60	4.61	4.65	4.66	4.70	4.71	4.77	4.78	5.05	5.05
15:US Princes Highway	Woodlands Creek	17.80	18.29	18.10	18.49	18.40	18.68	18.71	18.86	18.82	18.94	18.91	19.02	19.02	19.12	19.35	19.40
17:US Illawarra Railway	Woodlands Creek	16.19	16.26	16.32	16.30	16.40	16.35	16.47	16.47	16.54	16.54	16.60	16.63	16.72	16.77	17.09	17.10
18:US Air Avenue	Woodlands Creek	11.14	11.14	11.17	11.17	11.20	11.20	11.21	11.21	11.21	11.21	11.22	11.22	11.23	11.23	11.55	11.55
14:US Illawarra Railway	Tramway Creek	11.65	14.48	13.16	15.20	14.48	16.01	16.03	16.95	16.65	17.04	16.91	17.12	17.06	17.20	17.45	17.50
1:US William Street	Slacky Creek	26.19	26.73	26.53	26.84	26.71	26.95	26.92	27.11	27.01	27.19	27.10	27.26	27.20	27.35	27.60	27.72
2:US Hobart Street	Slacky Creek	21.71	21.81	21.86	21.97	22.04	22.17	22.31	22.46	22.49	22.60	22.62	22.70	22.75	22.82	23.23	23.28
5:US disused railway line	Slacky Creek	20.36	20.46	20.59	20.67	20.82	20.80	21.43	21.36	21.53	21.53	21.71	21.71	21.89	21.89	22.47	22.71
7:US Access bridge at Bulli showground	Slacky Creek	17.89	17.89	17.98	17.98	18.07	18.07	18.11	18.11	18.22	18.22	18.29	18.29	18.33	18.33	18.46	18.46

Location (refer to Volume 2 Map Set A - Figure 1)	Watercourse	Scenario ID 1 - Design Peak Flood level (mAHD)															
		5 year ARI		**10% AEP**		**5% AEP**		**2% AEP**		**1% AEP**		**0.5% AEP**		**0.2% AEP**		**PMF**	
		Design Blockage	**Risk Blockage**	**Design Blockage**	**Risk Blockage**	**Design Blockage**	**Risk Blockage**	**Design Blockage**	**Risk Blockage**	**Design Blockage**	**Risk Blockage**	**Design Blockage**	**Risk Blockage**	**Design Blockage**	**Risk Blockage**	**Design Blockage**	**Risk Blockage**
8:US Princes Highway	Slacky Creek	14.36	14.46	14.39	14.51	14.43	14.54	14.49	14.61	14.53	14.63	14.55	14.65	14.57	14.67	14.81	14.87
9:Park at Black Diamond Place	Slacky Creek	11.94	11.94	12.13	12.13	12.34	12.34	12.52	12.52	12.68	12.67	12.80	12.80	12.96	12.96	13.97	13.97
9:US Illawarra Railway	Slacky Creek	11.85	11.85	12.04	12.04	12.25	12.25	12.42	12.42	12.52	12.52	12.69	12.69	12.87	12.87	13.89	13.89
10:US Illawarra Railway (Beacon Avenue)	Slacky Creek	11.41	11.41	11.43	11.43	11.47	11.47	11.55	11.55	11.69	11.69	11.90	11.90	12.31	12.31	13.82	13.82
11:US of timber footbridge (Beach Street)	Slacky Creek	3.88	3.88	4.01	4.01	4.13	4.13	4.33	4.33	4.42	4.42	4.58	4.58	4.74	4.74	5.44	5.44
12:US Blackhall Street	Slacky Creek	2.50	2.50	2.57	2.57	2.63	2.63	2.67	2.67	2.78	2.78	2.82	2.82	2.88	2.88	4.07	4.07

Table B3 – Design Flood Levels – Scenario ID 2

Location (refer to Volume 2 Map Set A - Figure 1)	Watercourse	Scenario ID 2 - Design Peak Flood level (mAHD)															
		5 year ARI		10% AEP		5% AEP		2% AEP		1% AEP		0.5% AEP		0.2% AEP		PMF	
		Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage
32:US Deborah Avenue	Hewitts Creek	62.85	62.99	62.94	63.05	63.03	63.12	63.15	63.22	63.19	63.27	63.25	63.31	63.32	63.38	63.59	63.65
33:US Virginia Terrace	Hewitts Creek	50.33	50.26	50.37	50.37	50.42	50.47	50.49	50.54	50.54	50.60	50.60	50.65	50.67	50.71	50.92	50.97
34:US George Street	Hewitts Creek	31.85	31.92	31.91	31.98	31.98	32.06	32.08	32.15	32.15	32.24	32.22	32.30	32.30	32.37	32.52	32.59
21:US Kelton Lane	Hewitts Creek	23.94	23.94	24.11	24.11	24.33	24.33	24.55	24.54	24.69	24.69	24.85	24.86	25.07	25.09	25.90	25.98
29:US Palm Grove	Hewitts Creek	74.60	74.86	74.80	74.89	74.85	74.93	74.94	74.98	74.97	75.01	74.99	75.03	75.03	75.07	75.10	75.14
30:US Virginia Terrace	Hewitts Creek	40.77	40.90	40.83	40.94	40.92	40.99	41.02	41.07	41.06	41.11	41.09	41.14	41.14	41.18	41.23	41.26
31:US George Street	Hewitts Creek	25.27	25.29	25.28	25.31	25.30	25.33	25.34	25.36	25.35	25.37	25.37	25.38	25.39	25.40	25.43	25.44
22:US Lachlan Street	Hewitts Creek	18.29	18.47	18.39	18.56	18.52	18.67	18.68	18.82	18.77	18.92	18.86	19.01	18.98	19.13	19.41	19.57
23:US Lawrence Hargrave Drive	Hewitts Creek	12.95	13.14	13.07	13.28	13.21	13.40	13.39	13.59	13.48	13.69	13.57	13.79	13.68	13.93	15.38	15.49
26:US Illawarra Railway	Hewitts Creek	10.75	10.75	10.99	10.99	11.26	11.26	11.68	11.92	12.17	12.31	12.48	12.71	13.03	13.27	15.29	15.41
27:US Brickworks Avenue	Hewitts Creek	8.88	8.89	9.07	9.09	9.30	9.32	9.58	9.81	9.90	10.12	10.18	10.36	10.49	10.64	11.68	11.79
28:US Hamilton Road	Hewitts Creek	1.51	1.51	1.57	1.57	1.65	1.65	1.73	1.80	1.86	1.98	2.03	2.12	2.23	2.33	3.06	3.14
36:US Illawarra Railway	Thomas Gibson Creek	11.70	11.71	11.72	11.76	11.74	11.80	11.78	11.93	11.81	12.00	11.86	12.09	11.92	12.21	13.40	14.68
38:US McCauley Street	Thomas Gibson Creek	7.01	7.03	7.03	7.05	7.06	7.08	7.10	7.11	7.12	7.14	7.15	7.16	7.17	7.18	7.32	7.32
39:US Cliff Parade	Thomas Gibson Creek	4.45	4.46	4.49	4.50	4.54	4.55	4.60	4.61	4.65	4.66	4.70	4.71	4.77	4.78	5.05	5.05
15:US Princes Highway	Woodlands Creek	17.80	18.29	18.10	18.49	18.40	18.68	18.71	18.86	18.82	18.94	18.91	19.02	19.02	19.12	19.35	19.40
17:US Illawarra Railway	Woodlands Creek	16.19	16.26	16.32	16.30	16.40	16.35	16.47	16.47	16.54	16.54	16.60	16.63	16.72	16.77	17.09	17.10
18:US Air Avenue	Woodlands Creek	11.14	11.14	11.17	11.17	11.20	11.20	11.21	11.21	11.21	11.21	11.22	11.22	11.23	11.23	11.55	11.55
14:US Illawarra Railway	Tramway Creek	11.65	14.48	13.16	15.20	14.48	16.01	16.03	16.95	16.65	17.04	16.91	17.12	17.06	17.20	17.45	17.50
1:US William Street	Slacky Creek	26.19	26.73	26.53	26.84	26.71	26.95	26.92	27.11	27.01	27.19	27.10	27.26	27.20	27.35	27.60	27.72
2:US Hobart Street	Slacky Creek	21.71	21.81	21.86	21.97	22.04	22.17	22.31	22.46	22.49	22.60	22.62	22.70	22.75	22.82	23.23	23.28
5:US disused railway line	Slacky Creek	20.36	20.46	20.59	20.67	20.82	20.80	21.43	21.36	21.53	21.53	21.71	21.71	21.89	21.89	22.47	22.71
7:US Access bridge at Bulli showground	Slacky Creek	17.89	17.89	17.98	17.98	18.07	18.07	18.11	18.11	18.22	18.22	18.29	18.29	18.33	18.33	18.46	18.46

Location (refer to Volume 2 Map Set A - Figure 1)	Watercourse	Scenario ID 2 - Design Peak Flood level (mAHD)															
		5 year ARI		**10% AEP**		**5% AEP**		**2% AEP**		**1% AEP**		**0.5% AEP**		**0.2% AEP**		**PMF**	
		Design Blockage	**Risk Blockage**	**Design Blockage**	**Risk Blockage**	**Design Blockage**	**Risk Blockage**	**Design Blockage**	**Risk Blockage**	**Design Blockage**	**Risk Blockage**	**Design Blockage**	**Risk Blockage**	**Design Blockage**	**Risk Blockage**	**Design Blockage**	**Risk Blockage**
8:US Princes Highway	Slacky Creek	14.41	14.48	14.42	14.52	14.49	14.55	14.51	14.61	14.55	14.63	14.56	14.65	14.59	14.67	14.82	14.86
9:Park at Black Diamond Place	Slacky Creek	12.00	11.98	12.20	12.20	12.40	12.40	12.59	12.59	12.73	12.73	12.81	12.81	12.97	12.97	13.99	13.99
9:US Illawarra Railway	Slacky Creek	11.89	11.89	12.11	12.11	12.31	12.31	12.47	12.47	12.59	12.59	12.71	12.71	12.88	12.88	13.91	13.91
10:US Illawarra Railway (Beacon Avenue)	Slacky Creek	11.41	11.41	11.43	11.43	11.50	11.50	11.59	11.59	11.79	11.77	11.98	11.94	12.33	12.33	13.84	13.84
11:US of timber footbridge (Beach Street)	Slacky Creek	3.91	3.91	4.04	4.04	4.16	4.16	4.36	4.36	4.47	4.47	4.62	4.62	4.77	4.77	5.45	5.45
12:US Blackhall Street	Slacky Creek	2.51	2.51	2.60	2.60	2.64	2.64	2.69	2.69	2.80	2.80	2.83	2.83	2.89	2.89	4.09	4.09

Table B4 – Design Flood Depths – Scenario ID 1

Location (refer to Volume 2 Map Set A - Figure 1)	Watercourse	Scenario ID 1 - Design Peak Flood Depth (m)															
		5 year ARI		10% AEP		5% AEP		2% AEP		1% AEP		0.5% AEP		0.2% AEP		PMF	
		Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage
32:US Deborah Avenue	Hewitts Creek	3.59	3.74	3.68	3.80	3.77	3.87	3.88	3.95	3.95	4.02	3.99	4.06	4.06	4.12	4.33	4.39
33:US Virginia Terrace	Hewitts Creek	1.96	1.89	2.01	1.99	2.05	2.10	2.12	2.17	2.17	2.22	2.22	2.28	2.29	2.34	2.54	2.59
34:US George Street	Hewitts Creek	1.44	1.50	1.49	1.55	1.55	1.63	1.65	1.73	1.72	1.81	1.80	1.87	1.87	1.94	2.10	2.16
21:US Kelton Lane	Hewitts Creek	2.15	2.15	2.32	2.32	2.54	2.54	2.76	2.75	2.90	2.91	3.06	3.08	3.28	3.31	4.11	4.19
29:US Palm Grove	Hewitts Creek	2.48	2.75	2.68	2.77	2.73	2.81	2.82	2.87	2.85	2.89	2.88	2.92	2.91	2.95	2.99	3.02
30:US Virginia Terrace	Hewitts Creek	2.80	2.93	2.86	2.97	2.94	3.02	3.04	3.10	3.08	3.13	3.12	3.16	3.17	3.21	3.26	3.29
31:US George Street	Hewitts Creek	0.02	0.04	0.03	0.06	0.05	0.08	0.09	0.10	0.10	0.12	0.12	0.13	0.14	0.15	0.18	0.19
22:US Lachlan Street	Hewitts Creek	3.14	3.32	3.24	3.41	3.37	3.53	3.53	3.67	3.62	3.77	3.72	3.86	3.84	3.98	4.26	4.42
23:US Lawrence Hargrave Drive	Hewitts Creek	2.24	2.43	2.36	2.57	2.49	2.69	2.68	2.87	2.77	2.98	2.86	3.08	2.97	3.22	4.67	4.78
26:US Illawarra Railway	Hewitts Creek	1.86	1.86	2.11	2.11	2.38	2.38	2.80	3.03	3.28	3.43	3.60	3.83	4.15	4.38	6.41	6.53
27:US Brickworks Avenue	Hewitts Creek	1.62	1.62	1.81	1.82	2.04	2.06	2.31	2.55	2.63	2.86	2.92	3.10	3.22	3.37	4.41	4.52
28:US Hamilton Road	Hewitts Creek	1.77	1.77	1.83	1.83	1.92	1.92	2.00	2.06	2.13	2.25	2.29	2.39	2.49	2.59	3.33	3.41
36:US Illawarra Railway	Thomas Gibson Creek	0.51	0.53	0.54	0.58	0.56	0.62	0.60	0.75	0.63	0.82	0.67	0.91	0.73	1.03	2.22	3.49
38:US McCauley Street	Thomas Gibson Creek	1.34	1.36	1.37	1.38	1.40	1.41	1.44	1.45	1.46	1.47	1.48	1.49	1.51	1.52	1.65	1.66
39:US Cliff Parade	Thomas Gibson Creek	1.97	1.98	2.01	2.02	2.07	2.07	2.12	2.13	2.17	2.18	2.22	2.23	2.29	2.30	2.57	2.57
15:US Princes Highway	Woodlands Creek	3.49	3.98	3.79	4.18	4.09	4.37	4.40	4.55	4.50	4.63	4.60	4.71	4.71	4.81	5.04	5.09
17:US Illawarra Railway	Woodlands Creek	4.58	4.65	4.71	4.69	4.79	4.74	4.85	4.85	4.93	4.93	4.98	5.02	5.11	5.16	5.47	5.49
18:US Air Avenue	Woodlands Creek	0.52	0.52	0.55	0.55	0.57	0.57	0.59	0.59	0.59	0.59	0.60	0.60	0.60	0.60	0.93	0.93
14:US Illawarra Railway	Tramway Creek	3.59	6.42	5.10	7.14	6.41	7.95	7.97	8.89	8.59	8.98	8.85	9.06	9.00	9.14	9.39	9.44
1:US William Street	Slacky Creek	1.71	2.26	2.05	2.36	2.24	2.47	2.45	2.64	2.54	2.72	2.63	2.79	2.73	2.87	3.13	3.25
2:US Hobart Street	Slacky Creek	2.95	3.04	3.09	3.20	3.28	3.41	3.55	3.70	3.73	3.83	3.85	3.94	3.98	4.06	4.46	4.51
5:US disused railway line	Slacky Creek	2.38	2.48	2.61	2.68	2.84	2.82	3.44	3.38	3.55	3.55	3.73	3.73	3.91	3.91	4.49	4.73
7:US Access bridge at Bulli showground	Slacky Creek	1.70	1.70	1.79	1.79	1.88	1.88	1.92	1.92	2.03	2.03	2.09	2.09	2.13	2.13	2.26	2.26

Location (refer to Volume 2 Map Set A - Figure 1)	Watercourse	Scenario ID 1 - Design Peak Flood Depth (m)															
		5 year ARI		10% AEP		5% AEP		2% AEP		1% AEP		0.5% AEP		0.2% AEP		PMF	
		Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage
8:US Princes Highway	Slacky Creek	2.06	2.17	2.09	2.21	2.13	2.24	2.19	2.31	2.23	2.33	2.25	2.35	2.27	2.37	2.51	2.57
9:Park at Black Diamond Place	Slacky Creek	2.38	2.38	2.58	2.58	2.79	2.79	2.97	2.97	3.13	3.12	3.25	3.25	3.41	3.41	4.42	4.42
9:US Illawarra Railway	Slacky Creek	2.67	2.67	2.86	2.86	3.07	3.07	3.24	3.24	3.35	3.35	3.51	3.51	3.70	3.70	4.71	4.71
10:US Illawarra Railway (Beacon Avenue)	Slacky Creek	0.14	0.14	0.16	0.16	0.20	0.20	0.28	0.28	0.42	0.42	0.63	0.63	1.04	1.04	2.55	2.55
11:US of timber footbridge (Beach Street)	Slacky Creek	2.34	2.34	2.47	2.47	2.59	2.59	2.79	2.79	2.88	2.88	3.04	3.04	3.20	3.20	3.90	3.90
12:US Blackhall Street	Slacky Creek	1.95	1.95	2.01	2.01	2.07	2.07	2.12	2.12	2.23	2.23	2.26	2.26	2.33	2.33	3.51	3.51

Table B5 – Design Flood Depths – Scenario ID 2

Location (refer to Volume 2 Map Set A - Figure 1)	Watercourse	Scenario ID 2 - Design Peak Flood Depth (m)															
		5 year ARI		10% AEP		5% AEP		2% AEP		1% AEP		0.5% AEP		0.2% AEP		PMF	
		Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage
32:US Deborah Avenue	Hewitts Creek	3.61	3.75	3.70	3.81	3.79	3.88	3.91	3.98	3.95	4.03	4.01	4.07	4.08	4.14	4.35	4.41
33:US Virginia Terrace	Hewitts Creek	1.97	1.90	2.01	2.01	2.06	2.11	2.13	2.18	2.18	2.24	2.24	2.29	2.31	2.35	2.56	2.61
34:US George Street	Hewitts Creek	1.44	1.50	1.50	1.56	1.56	1.64	1.67	1.74	1.73	1.82	1.81	1.88	1.88	1.95	2.11	2.17
21:US Kelton Lane	Hewitts Creek	2.15	2.15	2.33	2.33	2.54	2.54	2.76	2.76	2.90	2.91	3.06	3.08	3.28	3.31	4.11	4.19
29:US Palm Grove	Hewitts Creek	2.48	2.75	2.68	2.77	2.73	2.81	2.82	2.87	2.85	2.89	2.88	2.92	2.91	2.95	2.99	3.02
30:US Virginia Terrace	Hewitts Creek	2.80	2.93	2.86	2.97	2.94	3.02	3.05	3.10	3.08	3.13	3.12	3.16	3.17	3.21	3.26	3.29
31:US George Street	Hewitts Creek	0.02	0.04	0.03	0.06	0.05	0.08	0.09	0.10	0.10	0.12	0.12	0.13	0.14	0.15	0.18	0.19
22:US Lachlan Street	Hewitts Creek	3.14	3.32	3.24	3.41	3.37	3.53	3.53	3.67	3.62	3.78	3.72	3.86	3.84	3.98	4.26	4.42
23:US Lawrence Hargrave Drive	Hewitts Creek	2.24	2.43	2.36	2.57	2.50	2.69	2.68	2.88	2.77	2.98	2.86	3.08	2.97	3.22	4.67	4.78
26:US Illawarra Railway	Hewitts Creek	1.86	1.86	2.11	2.11	2.38	2.38	2.80	3.03	3.28	3.43	3.60	3.83	4.15	4.38	6.41	6.53
27:US Brickworks Avenue	Hewitts Creek	1.62	1.62	1.81	1.83	2.04	2.06	2.31	2.55	2.64	2.86	2.92	3.10	3.22	3.37	4.41	4.52
28:US Hamilton Road	Hewitts Creek	1.77	1.77	1.83	1.83	1.92	1.92	2.00	2.06	2.13	2.25	2.29	2.39	2.49	2.59	3.33	3.41
36:US Illawarra Railway	Thomas Gibson Creek	0.51	0.53	0.54	0.58	0.56	0.62	0.60	0.75	0.63	0.82	0.67	0.91	0.73	1.03	2.22	3.50
38:US McCauley Street	Thomas Gibson Creek	1.34	1.36	1.37	1.38	1.40	1.41	1.44	1.45	1.46	1.47	1.48	1.49	1.51	1.52	1.65	1.66
39:US Cliff Parade	Thomas Gibson Creek	1.97	1.98	2.01	2.02	2.07	2.07	2.12	2.13	2.17	2.18	2.22	2.23	2.29	2.30	2.57	2.57
15:US Princes Highway	Woodlands Creek	3.49	3.98	3.79	4.18	4.09	4.37	4.40	4.55	4.50	4.63	4.60	4.71	4.71	4.81	5.04	5.09
17:US Illawarra Railway	Woodlands Creek	4.58	4.65	4.71	4.69	4.79	4.74	4.85	4.85	4.93	4.93	4.98	5.02	5.11	5.16	5.47	5.49
18:US Air Avenue	Woodlands Creek	0.52	0.52	0.55	0.55	0.57	0.57	0.59	0.59	0.59	0.59	0.60	0.60	0.60	0.60	0.93	0.93
14:US Illawarra Railway	Tramway Creek	3.59	6.42	5.10	7.14	6.42	7.95	7.97	8.89	8.59	8.98	8.85	9.06	9.00	9.14	9.39	9.44
1:US William Street	Slacky Creek	1.71	2.26	2.05	2.36	2.24	2.47	2.45	2.64	2.54	2.72	2.63	2.79	2.73	2.87	3.13	3.25
2:US Hobart Street	Slacky Creek	2.95	3.04	3.09	3.20	3.28	3.41	3.55	3.70	3.73	3.83	3.85	3.94	3.98	4.06	4.46	4.51
5:US disused railway line	Slacky Creek	2.38	2.48	2.61	2.68	2.84	2.82	3.44	3.38	3.55	3.55	3.73	3.73	3.91	3.91	4.49	4.73
7:US Access bridge at Bulli showground	Slacky Creek	1.70	1.70	1.79	1.79	1.88	1.88	1.92	1.92	2.03	2.03	2.09	2.09	2.13	2.13	2.26	2.26

Location (refer to Volume 2 Map Set A - Figure 1)	Watercourse	Scenario ID 2 - Design Peak Flood Depth (m)															
		5 year ARI		**10% AEP**		**5% AEP**		**2% AEP**		**1% AEP**		**0.5% AEP**		**0.2% AEP**		**PMF**	
		Design Blockage	**Risk Blockage**	**Design Blockage**	**Risk Blockage**	**Design Blockage**	**Risk Blockage**	**Design Blockage**	**Risk Blockage**	**Design Blockage**	**Risk Blockage**	**Design Blockage**	**Risk Blockage**	**Design Blockage**	**Risk Blockage**	**Design Blockage**	**Risk Blockage**
8:US Princes Highway	Slacky Creek	2.11	2.18	2.12	2.23	2.19	2.26	2.22	2.32	2.25	2.34	2.27	2.35	2.29	2.37	2.52	2.57
9:Park at Black Diamond Place	Slacky Creek	2.44	2.43	2.65	2.65	2.85	2.85	3.04	3.04	3.18	3.18	3.26	3.26	3.42	3.42	4.44	4.44
9:US Illawarra Railway	Slacky Creek	2.72	2.72	2.94	2.94	3.13	3.13	3.30	3.30	3.41	3.41	3.53	3.53	3.70	3.70	4.73	4.73
10:US Illawarra Railway (Beacon Avenue)	Slacky Creek	0.14	0.14	0.16	0.16	0.22	0.22	0.31	0.31	0.52	0.50	0.71	0.67	1.06	1.06	2.57	2.57
11:US of timber footbridge (Beach Street)	Slacky Creek	2.37	2.37	2.50	2.50	2.62	2.62	2.82	2.82	2.93	2.93	3.08	3.08	3.23	3.23	3.91	3.91
12:US Blackhall Street	Slacky Creek	1.96	1.96	2.04	2.04	2.08	2.08	2.13	2.13	2.24	2.24	2.28	2.28	2.34	2.34	3.53	3.53

Table B6 – Design Flood Velocities – Scenario ID 1

Location (refer to Volume 2 Map Set A - Figure 1)	Watercourse	Scenario ID 1 - Design Peak Flood Velocity (m^3/s)															
		5 year ARI		10% AEP		5% AEP		2% AEP		1% AEP		0.5% AEP		0.2% AEP		PMF	
		Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage
32:US Deborah Avenue	Hewitts Creek	1.43	1.43	1.66	1.44	2.18	2.18	2.12	2.12	2.10	2.10	2.14	2.14	2.06	2.06	2.10	2.10
33:US Virginia Terrace	Hewitts Creek	2.02	2.02	1.99	1.99	1.98	1.98	2.02	2.02	1.99	1.99	1.98	1.98	1.98	1.98	2.42	2.42
34:US George Street	Hewitts Creek	1.47	1.47	1.48	1.48	1.59	1.59	1.59	1.59	1.63	1.63	1.71	1.71	1.76	1.76	2.10	2.10
21:US Kelton Lane	Hewitts Creek	1.88	2.00	2.00	2.10	2.22	2.30	2.37	2.45	2.53	2.59	2.70	2.75	2.72	2.75	2.89	2.89
29:US Palm Grove	Hewitts Creek	0.39	0.39	0.38	0.38	0.39	0.39	0.39	0.39	0.40	0.40	0.40	0.40	0.40	0.40	0.41	0.41
30:US Virginia Terrace	Hewitts Creek	0.74	0.74	0.74	0.74	0.80	0.82	0.89	0.89	0.89	0.89	0.91	0.91	1.08	1.08	1.07	1.07
31:US George Street	Hewitts Creek	0.03	0.16	0.08	0.26	0.21	0.39	0.45	0.54	0.52	0.69	0.68	0.83	0.87	0.96	1.16	1.24
22:US Lachlan Street	Hewitts Creek	0.96	0.96	0.98	0.98	0.97	0.97	1.01	1.01	1.04	1.04	1.10	1.10	1.19	1.19	1.58	1.58
23:US Lawrence Hargrave Drive	Hewitts Creek	2.30	2.30	2.48	2.48	2.78	2.78	3.04	3.04	3.23	3.23	3.41	3.41	3.63	3.63	4.11	4.11
26:US Illawarra Railway	Hewitts Creek	1.01	1.01	0.99	0.99	0.99	0.99	1.00	1.00	1.00	1.00	0.99	0.99	1.00	1.00	1.30	1.29
27:US Brickworks Avenue	Hewitts Creek	1.76	1.76	1.88	1.88	2.00	2.00	2.08	2.08	2.17	2.17	2.30	2.29	2.48	2.48	2.93	2.93
28:US Hamilton Road	Hewitts Creek	3.28	3.28	3.65	3.65	4.00	4.00	4.24	4.24	4.48	4.48	4.67	4.67	4.81	4.81	5.10	5.10
36:US Illawarra Railway	Thomas Gibson Creek	0.29	0.29	0.31	0.31	0.34	0.34	0.29	0.29	0.37	0.37	0.38	0.38	0.40	0.40	0.45	0.45
38:US McCauley Street	Thomas Gibson Creek	0.41	0.41	0.43	0.43	0.41	0.41	0.44	0.44	0.40	0.40	0.43	0.43	0.45	0.45	0.61	0.61
39:US Cliff Parade	Thomas Gibson Creek	0.58	0.58	0.62	0.62	0.69	0.69	0.75	0.75	0.81	0.81	0.88	0.88	0.96	0.96	1.28	1.28
15:US Princes Highway	Woodlands Creek	1.56	1.56	1.59	1.59	1.66	1.66	1.66	1.66	1.67	1.67	1.65	1.65	1.65	1.65	1.74	1.74
17:US Illawarra Railway	Woodlands Creek	1.14	1.14	1.12	1.12	1.13	1.13	1.12	1.12	1.11	1.11	1.14	1.14	1.11	1.11	1.15	1.15
18:US Air Avenue	Woodlands Creek	1.76	1.76	1.84	1.84	1.91	1.91	1.95	1.95	1.98	1.98	1.99	1.99	2.01	2.01	2.18	2.18
14:US Illawarra Railway	Tramway Creek	2.35	2.35	2.31	2.31	2.36	2.36	2.36	2.36	2.39	2.39	2.37	2.37	2.39	2.39	1.74	1.74
1:US William Street	Slacky Creek	1.12	1.12	1.15	1.15	1.16	1.16	1.13	1.13	1.13	1.13	1.17	1.17	1.20	1.20	1.61	1.61
2:US Hobart Street	Slacky Creek	0.71	0.71	0.69	0.69	0.65	0.65	0.63	0.63	0.63	0.63	0.62	0.62	0.63	0.63	0.54	0.54
5:US disused railway line	Slacky Creek	0.99	0.99	0.98	0.98	0.90	0.90	0.98	0.98	0.96	0.96	0.96	0.96	0.91	0.91	0.91	0.91
7:US Access bridge at Bulli showground	Slacky Creek	1.70	1.70	1.83	1.83	1.90	1.90	1.92	1.92	1.94	1.94	1.96	1.96	1.97	1.97	2.10	2.10

Location (refer to Volume 2 Map Set A - Figure 1)	Watercourse	Scenario ID 1 - Design Peak Flood Velocity (m^3/s)															
		5 year ARI		**10% AEP**		**5% AEP**		**2% AEP**		**1% AEP**		**0.5% AEP**		**0.2% AEP**		**PMF**	
		Design Blockage	**Risk Blockage**	**Design Blockage**	**Risk Blockage**	**Design Blockage**	**Risk Blockage**	**Design Blockage**	**Risk Blockage**	**Design Blockage**	**Risk Blockage**	**Design Blockage**	**Risk Blockage**	**Design Blockage**	**Risk Blockage**	**Design Blockage**	**Risk Blockage**
8:US Princes Highway	Slacky Creek	1.83	1.83	1.83	1.83	1.88	1.88	1.86	1.86	1.84	1.84	1.87	1.87	1.95	1.95	2.08	2.08
9:Park at Black Diamond Place	Slacky Creek	2.37	2.37	2.17	2.17	2.15	2.15	1.91	1.91	1.92	1.92	1.96	1.96	1.87	1.87	1.35	1.35
9:US Illawarra Railway	Slacky Creek	1.32	1.32	1.32	1.32	1.33	1.33	1.37	1.37	1.35	1.35	1.37	1.37	1.30	1.30	1.28	1.28
10:US Illawarra Railway (Beacon Avenue)	Slacky Creek	0.91	0.91	0.98	0.98	1.12	1.12	1.28	1.28	1.44	1.44	1.49	1.49	1.54	1.54	1.64	1.64
11:US of timber footbridge (Beach Street)	Slacky Creek	1.90	1.90	1.93	1.93	2.01	2.01	2.04	2.04	2.03	2.03	2.03	2.03	2.08	2.08	2.10	2.10
12:US Blackhall Street	Slacky Creek	2.03	2.03	2.18	2.18	2.38	2.38	2.61	2.61	2.84	2.84	2.85	2.85	3.14	3.14	4.05	4.05

Table B7 – Design Flood Velocities – Scenario ID 2

Location (refer to Volume 2 Map Set A - Figure 1)	Watercourse	Scenario ID 2 - Design Peak Flood Velocity (m^3/s)															
		5 year ARI		10% AEP		5% AEP		2% AEP		1% AEP		0.5% AEP		0.2% AEP		PMF	
		Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage
32:US Deborah Avenue	Hewitts Creek	1.52	1.44	1.92	1.92	2.26	2.26	2.11	2.11	2.07	2.07	2.13	2.13	2.22	2.22	2.15	2.15
33:US Virginia Terrace	Hewitts Creek	2.02	2.02	1.99	1.99	2.02	2.02	2.02	2.02	1.99	1.99	1.98	1.98	1.98	1.98	2.39	2.39
34:US George Street	Hewitts Creek	1.47	1.47	1.50	1.50	1.56	1.56	1.61	1.61	1.64	1.64	1.80	1.80	1.63	1.63	2.06	2.06
21:US Kelton Lane	Hewitts Creek	1.87	2.00	2.00	2.10	2.21	2.30	2.38	2.45	2.53	2.59	2.70	2.75	2.72	2.75	2.89	2.89
29:US Palm Grove	Hewitts Creek	0.39	0.39	0.38	0.38	0.39	0.39	0.39	0.39	0.40	0.40	0.40	0.40	0.40	0.40	0.41	0.41
30:US Virginia Terrace	Hewitts Creek	0.74	0.74	0.74	0.74	0.80	0.82	0.89	0.89	0.88	0.88	0.91	0.91	1.08	1.08	1.08	1.08
31:US George Street	Hewitts Creek	0.03	0.16	0.08	0.27	0.22	0.39	0.46	0.55	0.53	0.70	0.69	0.84	0.87	0.96	1.17	1.24
22:US Lachlan Street	Hewitts Creek	0.97	0.97	0.98	0.98	0.97	0.97	1.02	1.02	1.04	1.04	1.10	1.10	1.19	1.19	1.59	1.59
23:US Lawrence Hargrave Drive	Hewitts Creek	2.30	2.30	2.49	2.49	2.78	2.78	3.04	3.04	3.24	3.24	3.41	3.41	3.63	3.63	4.12	4.12
26:US Illawarra Railway	Hewitts Creek	1.01	1.01	0.99	0.99	0.99	0.99	1.00	1.00	1.00	1.00	0.99	0.99	1.00	1.00	1.30	1.30
27:US Brickworks Avenue	Hewitts Creek	1.76	1.76	1.88	1.88	2.00	2.00	2.08	2.08	2.18	2.18	2.30	2.29	2.47	2.47	2.93	2.93
28:US Hamilton Road	Hewitts Creek	3.28	3.28	3.65	3.65	4.00	4.00	4.24	4.24	4.49	4.49	4.67	4.67	4.78	4.78	5.10	5.10
36:US Illawarra Railway	Thomas Gibson Creek	0.29	0.29	0.31	0.31	0.34	0.34	0.29	0.29	0.37	0.37	0.38	0.38	0.40	0.40	0.45	0.45
38:US McCauley Street	Thomas Gibson Creek	0.41	0.41	0.43	0.43	0.43	0.43	0.44	0.44	0.40	0.40	0.43	0.43	0.45	0.45	0.61	0.61
39:US Cliff Parade	Thomas Gibson Creek	0.58	0.58	0.62	0.62	0.69	0.69	0.75	0.75	0.81	0.81	0.88	0.88	0.96	0.96	1.28	1.28
15:US Princes Highway	Woodlands Creek	1.56	1.56	1.59	1.59	1.66	1.66	1.66	1.66	1.67	1.67	1.65	1.65	1.65	1.65	1.74	1.74
17:US Illawarra Railway	Woodlands Creek	1.13	1.13	1.12	1.12	1.13	1.13	1.12	1.12	1.11	1.11	1.14	1.14	1.11	1.11	1.15	1.15
18:US Air Avenue	Woodlands Creek	1.76	1.76	1.84	1.84	1.91	1.91	1.95	1.95	1.98	1.98	1.99	1.99	2.01	2.01	2.18	2.18
14:US Illawarra Railway	Tramway Creek	2.30	2.30	2.31	2.31	2.37	2.37	2.36	2.36	2.39	2.39	2.39	2.39	2.35	2.35	1.74	1.74
1:US William Street	Slacky Creek	1.12	1.12	1.15	1.15	1.16	1.16	1.13	1.13	1.13	1.13	1.17	1.17	1.20	1.20	1.61	1.61
2:US Hobart Street	Slacky Creek	0.71	0.71	0.69	0.69	0.65	0.65	0.63	0.63	0.63	0.63	0.62	0.62	0.63	0.63	0.54	0.54
5:US disused railway line	Slacky Creek	0.91	0.91	0.95	0.95	0.93	0.93	0.91	0.91	0.96	0.96	0.95	0.95	0.90	0.90	0.91	0.91
7:US Access bridge at Bulli showground	Slacky Creek	1.70	1.70	1.83	1.83	1.90	1.90	1.93	1.93	1.94	1.94	1.96	1.96	1.97	1.97	2.09	2.09

Location (refer to Volume 2 Map Set A - Figure 1)	Watercourse	Scenario ID 2 - Design Peak Flood Velocity (m^3/s)															
		5 year ARI		10% AEP		5% AEP		2% AEP		1% AEP		0.5% AEP		0.2% AEP		PMF	
		Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage
8:US Princes Highway	Slacky Creek	2.02	2.02	2.00	2.00	2.04	2.04	1.90	1.90	1.98	1.98	1.95	1.95	2.06	2.06	2.18	2.18
9:Park at Black Diamond Place	Slacky Creek	2.45	2.45	2.37	2.37	2.28	2.28	2.22	2.22	2.20	2.20	2.15	2.15	2.20	2.20	1.82	1.82
9:US Illawarra Railway	Slacky Creek	1.33	1.33	1.41	1.41	1.38	1.38	1.32	1.32	1.36	1.36	1.40	1.40	1.33	1.33	1.31	1.31
10:US Illawarra Railway (Beacon Avenue)	Slacky Creek	0.91	0.91	0.98	0.98	1.18	1.18	1.34	1.34	1.47	1.47	1.49	1.49	1.54	1.54	1.64	1.64
11:US of timber footbridge (Beach Street)	Slacky Creek	1.91	1.91	1.96	1.96	2.02	2.02	2.03	2.03	2.03	2.03	2.03	2.03	2.08	2.08	2.10	2.10
12:US Blackhall Street	Slacky Creek	2.04	2.04	2.24	2.24	2.43	2.43	2.65	2.65	2.85	2.85	2.91	2.91	3.19	3.19	4.05	4.05

Table B8 – Design Flood Flows – Scenario ID 1

Location (refer to Volume 2 Map Set A - Figure 1)	Watercourse	Scenario ID 1 - Design Peak Flood Flows (m^3/s)															
		5 year ARI		10% AEP		5% AEP		2% AEP		1% AEP		0.5% AEP		0.2% AEP		PMF	
		Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage
32:US Deborah Avenue	Hewitts Creek	6.64	6.67	7.95	7.90	9.77	9.81	11.39	11.38	13.24	13.15	14.97	15.06	17.29	17.44	31.08	31.08
33:US Virginia Terrace	Hewitts Creek	6.86	6.86	8.18	8.18	9.67	9.67	10.33	10.33	11.10	11.10	12.09	12.09	13.64	13.64	21.07	21.07
34:US George Street	Hewitts Creek	7.53	7.53	8.72	8.72	10.43	10.43	11.30	11.30	12.51	12.51	14.02	14.02	15.65	15.65	24.11	24.11
21:US Kelton Lane	Hewitts Creek	31.46	31.46	37.45	37.45	45.62	45.62	53.19	53.19	62.12	62.12	71.01	71.01	83.28	83.28	136.65	136.65
29:US Palm Grove	Hewitts Creek	0.38	0.40	0.48	0.48	0.50	0.52	0.59	0.59	0.67	0.67	0.76	0.76	0.86	0.86	1.23	1.23
30:US Virginia Terrace	Hewitts Creek	2.10	2.10	2.43	2.58	2.91	3.17	3.75	3.85	4.29	4.16	4.76	4.96	5.39	5.60	7.47	7.51
31:US George Street	Hewitts Creek	4.31	4.38	5.23	5.24	5.92	7.06	7.95	8.55	9.39	9.74	10.69	10.95	12.30	12.64	16.82	17.00
22:US Lachlan Street	Hewitts Creek	34.95	34.95	41.56	41.56	50.40	50.40	59.23	59.23	68.67	68.67	79.22	79.22	93.11	93.11	151.36	151.36
23:US Lawrence Hargrave Drive	Hewitts Creek	6.01	13.14	11.33	21.06	19.36	29.86	33.90	44.89	43.20	54.55	53.38	65.10	67.48	79.34	153.15	153.15
26:US Illawarra Railway	Hewitts Creek	42.96	42.96	50.60	50.60	60.65	60.65	72.52	81.92	90.68	100.85	108.43	116.51	129.75	136.99	237.66	239.65
27:US Brickworks Avenue	Hewitts Creek	43.29	43.29	50.97	50.97	61.14	61.14	72.69	82.17	90.18	101.33	109.09	117.33	130.06	137.52	244.05	249.67
28:US Hamilton Road	Hewitts Creek	59.07	59.07	69.25	69.25	81.71	81.71	94.31	94.31	107.21	112.20	125.84	128.78	147.89	148.99	254.75	255.83
36:US Illawarra Railway	Thomas Gibson Creek	0.83	0.83	0.96	0.96	1.12	1.12	1.26	1.26	1.39	1.39	1.54	1.54	1.74	1.74	3.96	3.17
38:US McCauley Street	Thomas Gibson Creek	2.41	2.41	2.82	2.82	3.30	3.30	3.73	3.73	4.18	4.18	4.64	4.64	5.56	5.56	9.96	9.70
39:US Cliff Parade	Thomas Gibson Creek	4.97	4.97	5.87	5.87	7.08	7.08	8.29	8.29	9.84	9.84	11.49	11.49	13.73	13.73	25.70	25.70
15:US Princes Highway	Woodlands Creek	25.71	25.71	30.26	30.26	35.83	35.83	42.64	42.64	48.39	49.36	57.42	57.17	68.82	71.05	130.77	130.71
17:US Illawarra Railway	Woodlands Creek	23.75	23.75	28.11	28.11	32.73	32.73	36.82	36.82	39.46	39.46	41.42	41.42	44.07	44.07	60.21	60.21
18:US Air Avenue	Woodlands Creek	23.77	23.77	25.36	25.36	26.58	26.58	27.24	27.24	27.62	27.62	27.87	27.87	28.22	28.22	43.70	43.70
14:US Illawarra Railway	Tramway Creek	13.44	12.94	16.59	15.47	20.17	20.17	26.85	26.85	31.23	31.23	33.40	39.91	41.30	53.19	126.23	134.70
1:US William Street	Slacky Creek	18.61	18.72	22.58	22.62	27.66	27.67	32.99	33.01	38.34	38.39	44.01	44.05	51.44	51.47	96.33	96.35
2:US Hobart Street	Slacky Creek	18.97	18.97	22.87	22.87	27.95	28.06	33.49	33.40	38.61	38.61	43.92	43.92	48.44	48.44	56.48	56.48
5:US disused railway line	Slacky Creek	16.66	16.66	18.94	18.94	21.80	21.80	24.03	24.03	25.16	25.16	27.35	27.35	29.90	29.90	38.67	38.67
7:US Access bridge at Bulli showground	Slacky Creek	22.30	22.30	24.82	24.82	27.08	27.08	29.24	29.24	29.81	29.81	31.58	31.58	33.23	33.23	38.54	38.54

Location (refer to Volume 2 Map Set A - Figure 1)	Watercourse	Scenario ID 1 - Design Peak Flood Flows (m^3/s)															
		5 year ARI		10% AEP		5% AEP		2% AEP		1% AEP		0.5% AEP		0.2% AEP		PMF	
		Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage
8:US Princes Highway	Slacky Creek	24.95	24.95	28.00	28.00	30.91	30.91	32.90	32.90	35.44	35.44	38.23	38.23	44.42	44.42	74.77	74.77
9:Park at Black Diamond Place	Slacky Creek	24.96	24.96	27.81	27.81	31.11	31.11	33.76	33.76	35.48	35.48	38.51	38.51	41.11	41.11	53.75	53.75
9:US Illawarra Railway	Slacky Creek	27.35	27.35	30.18	30.18	33.50	33.50	36.28	36.28	37.87	37.87	40.61	40.61	43.88	43.88	62.89	62.89
10:US Illawarra Railway (Beacon Avenue)	Slacky Creek	0.57	0.57	0.71	0.71	1.09	1.09	1.86	1.86	3.43	3.43	5.55	5.55	10.63	10.63	32.23	32.23
11:US of timber footbridge (Beach Street)	Slacky Creek	32.65	32.65	36.36	36.36	41.22	41.22	46.20	46.20	49.93	49.93	54.95	54.95	63.16	63.16	113.57	113.57
12:US Blackhall Street	Slacky Creek	30.44	30.44	33.85	33.85	38.19	38.19	42.59	42.59	46.01	46.01	50.89	50.89	59.23	59.23	108.77	108.77

Table B9 – Design Flood Flows – Scenario ID 2

Location (refer to Volume 2 Map Set A - Figure 1)	Watercourse	Scenario ID 2 - Design Peak Flood Flows (m3/s)															
		5 year ARI		10% AEP		5% AEP		2% AEP		1% AEP		0.5% AEP		0.2% AEP		PMF	
		Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage
32:US Deborah Avenue	Hewitts Creek	6.90	6.90	8.32	8.35	10.10	10.10	11.90	11.90	13.50	13.72	15.55	15.55	18.05	18.05	30.76	32.79
33:US Virginia Terrace	Hewitts Creek	7.10	7.10	8.52	8.52	9.74	9.74	10.47	10.47	11.39	11.39	12.50	12.50	14.15	14.15	21.88	21.88
34:US George Street	Hewitts Creek	7.63	7.63	8.97	8.97	10.61	10.61	11.50	11.50	12.71	12.71	14.04	14.04	15.99	15.99	24.77	24.77
21:US Kelton Lane	Hewitts Creek	31.44	31.44	37.39	37.39	45.57	45.57	53.29	53.29	62.14	62.14	71.00	71.00	83.24	83.24	136.72	136.72
29:US Palm Grove	Hewitts Creek	0.38	0.40	0.48	0.48	0.50	0.52	0.59	0.59	0.67	0.67	0.76	0.76	0.86	0.86	1.23	1.23
30:US Virginia Terrace	Hewitts Creek	2.10	2.10	2.43	2.50	2.91	3.15	3.69	3.81	4.25	4.46	4.57	4.78	5.59	5.46	7.48	7.51
31:US George Street	Hewitts Creek	4.31	4.31	5.23	5.42	5.92	7.12	8.03	8.58	9.44	9.76	10.65	10.93	12.24	12.65	16.88	17.06
22:US Lachlan Street	Hewitts Creek	34.98	34.98	41.57	41.57	50.46	50.46	59.09	59.09	68.77	68.77	79.27	79.27	93.29	93.29	151.37	151.37
23:US Lawrence Hargrave Drive	Hewitts Creek	5.97	13.18	11.32	21.10	19.46	29.82	33.99	44.97	43.26	54.62	53.44	65.19	67.54	79.39	153.32	153.32
26:US Illawarra Railway	Hewitts Creek	42.97	42.97	50.61	50.61	60.64	60.64	72.48	81.91	88.89	100.88	108.45	116.50	129.80	137.08	235.93	240.13
27:US Brickworks Avenue	Hewitts Creek	43.28	43.28	51.00	51.00	61.12	61.12	72.65	82.12	90.08	101.37	109.11	117.36	130.14	137.57	244.12	249.91
28:US Hamilton Road	Hewitts Creek	59.13	59.13	69.30	69.30	81.72	81.72	94.35	94.35	107.28	112.25	125.86	128.79	147.93	149.00	254.70	255.82
36:US Illawarra Railway	Thomas Gibson Creek	0.83	0.83	0.96	0.96	1.12	1.12	1.26	1.26	1.39	1.39	1.54	1.54	1.74	1.74	3.98	3.18
38:US McCauley Street	Thomas Gibson Creek	2.41	2.41	2.82	2.82	3.30	3.30	3.73	3.73	4.18	4.18	4.64	4.64	5.56	5.56	9.97	9.70
39:US Cliff Parade	Thomas Gibson Creek	4.97	4.97	5.87	5.87	7.08	7.08	8.29	8.29	9.84	9.84	11.49	11.49	13.73	13.73	25.70	25.70
15:US Princes Highway	Woodlands Creek	25.71	25.71	30.26	30.26	35.83	35.83	42.64	42.64	48.39	49.36	57.42	57.17	68.82	71.05	130.77	130.71
17:US Illawarra Railway	Woodlands Creek	23.75	23.75	28.11	28.11	32.73	32.73	36.82	36.82	39.46	39.46	41.42	41.42	44.07	44.07	60.21	60.21
18:US Air Avenue	Woodlands Creek	23.77	23.77	25.36	25.36	26.58	26.58	27.24	27.24	27.62	27.62	27.87	27.87	28.22	28.22	43.70	43.70
14:US Illawarra Railway	Tramway Creek	13.34	12.96	16.61	15.47	20.51	20.51	26.78	26.78	31.21	31.21	33.41	39.91	41.30	53.19	126.21	134.69
1:US William Street	Slacky Creek	18.61	18.72	22.58	22.62	27.66	27.67	32.99	33.01	38.34	38.39	44.01	44.05	51.43	51.47	96.31	96.35
2:US Hobart Street	Slacky Creek	18.97	18.97	22.87	22.87	27.95	28.06	33.49	33.42	38.62	38.62	43.92	43.92	48.43	48.43	56.36	56.36
5:US disused railway line	Slacky Creek	16.67	16.67	18.94	18.94	21.80	21.80	24.04	24.04	25.16	25.16	27.35	27.35	29.90	29.90	38.67	38.67
7:US Access bridge at Bulli showground	Slacky Creek	22.30	22.30	24.82	24.82	27.09	27.09	29.25	29.25	29.81	29.81	31.58	31.58	33.30	33.30	38.46	38.46

Location (refer to Volume 2 Map Set A - Figure 1)	Watercourse	Scenario ID 2 - Design Peak Flood Flows (m3/s)															
		5 year ARI		10% AEP		5% AEP		2% AEP		1% AEP		0.5% AEP		0.2% AEP		PMF	
		Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage	Design Blockage	Risk Blockage
8:US Princes Highway	Slacky Creek	27.42	27.42	30.98	30.98	35.48	35.48	37.61	37.61	39.72	39.72	42.34	42.34	49.41	49.41	79.03	79.03
9:Park at Black Diamond Place	Slacky Creek	25.67	25.67	29.10	29.10	32.07	32.07	34.67	34.67	36.50	36.50	38.87	38.87	41.51	41.51	53.80	53.80
9:US Illawarra Railway	Slacky Creek	28.04	28.04	31.37	31.37	34.44	34.44	37.15	37.15	39.02	39.02	41.13	41.13	44.10	44.10	63.28	63.28
10:US Illawarra Railway (Beacon Avenue)	Slacky Creek	0.57	0.57	0.71	0.71	1.30	1.30	2.24	2.24	4.27	4.27	5.97	5.97	10.76	10.76	32.57	32.57
11:US of timber footbridge (Beach Street)	Slacky Creek	33.13	33.13	37.78	37.78	42.29	42.29	47.38	47.38	51.66	51.66	56.96	56.96	64.47	64.47	114.70	114.70
12:US Blackhall Street	Slacky Creek	31.01	31.01	35.05	35.05	39.28	39.28	43.67	43.67	47.99	47.99	52.64	52.64	60.36	60.36	110.05	110.05

Appendix C

APPENDIX C. APPLIED BLOCKAGE FACTORS

As applied in Scenario ID 1 and Scenario ID 2

Structure ID (1)	Class	Type	Pipe Diameter/ Culvert Width (m)	Culvert Height (m)	Design Blockage Factors			Risk Management Blockage Factors		
					<20% AEP	20% - 2% AEP	>2% AEP	<20% AEP	20% - 2% AEP	>2% AEP
1	2	Culvert	2.4	1.67	25	40	50	50	65	75
2	1	Pipe	1.12		35	50	70	60	75	95
3	3	Culvert	3.5	1.2	15	30	40	35	50	60
4	4	Bridge			0	5	10	5	10	15
5	2	Pipe	1.8		25	40	50	50	65	75
6	3	Culvert	2.75	1.7	15	30	40	35	50	60
7	1	Pipe	0.45		35	50	70	60	75	95
8	2	Culvert	2.45	1.7	25	40	50	50	65	75
9	3	Culvert	2.85	3.0	15	30	40	35	50	60
10	4	Culvert	4.8	5.9	0	5	10	5	10	15
11	4	Bridge			0	5	10	5	10	15
12	4	Bridge			0	5	10	5	10	15
13	4	Bridge			0	5	10	5	10	15
14	2	Pipe	2.4		25	40	50	50	65	75
15	2	Culvert	2.4	1.2	25	40	50	50	65	75
16	2	Pipe	1.8		25	40	50	50	65	75
17	2	Pipe	2.5		25	40	50	50	65	75
18	4	Bridge			0	5	10	5	10	15
19	4	Bridge			0	5	10	5	10	15
20	3	Bridge			15	30	40	35	50	60
21	4	Bridge			0	5	10	5	10	15
22	3	Culvert	2.27	2	15	30	40	35	50	60
23	3	Culvert	2.45	2.75	15	30	40	35	50	60
24	1	Pipe	1.2		35	50	70	60	75	95
25	3	Bridge			15	30	40	35	50	60
26	4	Bridge			0	5	10	5	10	15
27	4	Bridge			0	5	10	5	10	15
28	4	Bridge			0	5	10	5	10	15
29	1	Pipe	0.9		35	50	70	60	75	95
30	1	Pipe	1.2		35	50	70	60	75	95
31	1	Pipe	1.05		35	50	70	60	75	95
32	2	Pipe	1.5		25	40	50	50	65	75
33	2	Pipe	1.5		25	40	50	50	65	75
34	2	Culvert	2.12	1.5	25	40	50	50	65	75
35	1	Pipe	0.45		35	50	70	60	75	95
36	2	Pipe	2		25	40	50	50	65	75
37	1	Pipe	0.75		35	50	70	60	75	95
38	1	Pipe	0.95		35	50	70	60	75	95
39	1	Pipe	0.95		35	50	70	60	75	95

Note (1) – At some structure locations multiple culverts of different dimensions exist. Applicable blockage factors are assigned to each individual culvert.

Appendix D

APPENDIX D. SUMMARY OF MODEL BUILD

Table D1 – Hydrologic Model Details and Universal Parameters

Model	WBNM
Sub-catchments	Shown on Volume 2 Map Set A – Figure 6 and Hydrological Subareas_HC_2017_region.shp Sub-catchment delineation refined as part of this Flood Study Addendum in the Bulli Brickworks Site and Armagh Parade Thirroul area.
Design Rainfall IFD (Gauge)	Automatically assigned by WBNM
Temporal Patterns	Zone 1
Lag "C"	1.29
Impervious Lag	0.1
Stream Lag	1.0
Initial Loss (Pervious and Impervious) (mm)	0
Continuing Loss Rate (Impervious) (mm/hr)	0
Continuing Loss Rate (Pervious) (mm/hr)	2.5

Table D2 – Hydrologic Model Parameters

Sub-catchment	Area (ha)	Percentage Impervious (%)
SC_13	6.832	0
SC_14	21.209	0.1
SC_15	11.964	0.4
SC_16	12.937	6.9
SC_17	8.795	2
SC_18	10.194	0.9
SC_19	7.322	5
SC_20	2.157	23.1
SC_4	21.402	0
SC_5	11.317	0
SC_1	23.917	0
SC_2	16.093	0
SC_3	11.742	0
SC_7	4.746	16.2
SC_6	5.828	10.7
SC_8	2.601	25.7
SC_10	2.48	46.4
SC_9	6.753	33.6
SC_11	2.827	28.3
SC_27	3.085	8.1
SC_12	1.27	17.9
SC_25	3.953	6.6
SC_26	7.041	38.7
SC_28	5.049	43
SC_21	9.076	10
SC_22	9.382	28.3
SC_23	6.141	36.4
SC_24	2.947	28.6
SC_30	5.409	28.2
SC_31	4.818	38.7
SC_29	2.29	46.5
SC_32	9.882	46.3
SC_34	6.429	37.6
SC_33	4.534	38.4
SC_35	2.689	49.9
SC_36	5.874	38.5
SC_37	6.902	36.2
SC_38	4.78	28.4
TC_1	4.701	42.7
TC_2	3.202	41.4
TC_3	2.136	48.4
TC_4	6.604	46.7
TC_5	12.45	39.5

Sub-catchment	Area (ha)	Percentage Impervious (%)
TC_6	1.715	44.5
TC_7	8.765	17.7
TC_8	6.746	2
TC_9	9.173	30.5
WC_7	11.879	3.3
WC_8	8.196	2.3
WC_9	11.08	3.3
WC_10	16.596	0.8
WC_1	20.209	3.7
WC_6	12.353	2.5
WC_11	6.826	2.2
WC_12	7.648	3.7
WC_2	8.171	1.8
WC_3	6.009	2
WC_4	9.625	5.7
WC_5	4.687	25.5
WC_13	17.611	18.4
WC_14	4.804	35.1
WC_15	9.508	37.6
HC_50	6.303	42.4
HC_24	7.421	1.8
HC_25	5.699	2.7
HC_26	10.731	10.7
HC_27	5.716	8.9
HC_28	8.243	7
HC_19	8.013	6.8
HC_20	3.507	0
HC_21	9.019	1.4
HC_22	5.027	0.2
HC_16	4.289	6.3
HC_17	7.318	5.5
HC_23	4.087	4.3
HC_29	5.712	16.1
HC_32	0.818	47.4
HC_33	1.384	15.5
HC_34	1.244	24.6
HC_30	3.411	46.4
HC_31	2.494	47.7
HC_18	3.051	32.2
HC_4	5.15508	0
HC_5_1	2.26744	0
HC_5_4	0.492656	0
HC_5_5	0.351338	0
HC_5_3	0.666137	0

Sub-catchment	Area (ha)	Percentage Impervious (%)
HC_5_7	0.103532	0
HC_5_2	2.27631	0
HC_5_6	0.0532114	0
HC_6	2.792	12.7
HC_7	2.14	50.4
HC_1	10.383	0
HC_2	8.308	1.9
HC_3	2.044	23.7
HC_8	1.112	44
HC_9	1.615	44.2
HC_10	1.934	44.1
HC_35	1.665	39.3
HC_36	0.314	47.7
HC_37	0.948	36.5
HC_11	2.748	24.5
HC_12	2.561	46.6
HC_13	4.035	38.4
HC_14	2.036	48.3
HC_15	2.368	43.4
HC_38	0.888	41.6
HC_39	0.507	50.9
HC_40	2.756	41.7
HC_42	4.93	9
HC_43	8.53	14.2
HC_44	7.27	35.9
HC_45	4.263	40.2
HC_46	3.494	32.2
HC_47	4.281	37.1
HC_48	1.458	54.3
HC_49	5.697	37.6
HC_41	1.701	19.5
HC_51	5.664	35.3
HC_52	9.024	27.6
TGC_23	0.518	57.7
TGC_24	1.865	53.2
TGC_25	4.496	7.2
TGC_26	7.826	34.8
TGC_21	4.567	36.9
TGC_22	2.781	48.7
TGC_28	2.03	50
TGC_27	2.494	40.7
TGC_12	1.84	45.2
TGC_13	3.097	47.8
TGC_14	2.034	47.6

Sub-catchment	Area (ha)	Percentage Impervious (%)
TGC_15	1.073	46.1
TGC_16	2.215	49.9
TGC_17	3.909	51.7
TGC_18	2.62	51.5
TGC_19	1.725	60.9
TGC_20	3.871	51.2
TGC_1	1.938	44.9
TGC_2	3.672	47
TGC_3	4.564	29.1
TGC_4	2.876	46.2
TGC_5	3.023	54.4
TGC_6	1.297	67.5
TGC_7	3.827	61.1
TGC_29	3.7	45.5
TGC_8	3.446	49.1
TGC_9	4.606	51.3
TGC_10	1.678	29.5
TGC_11	1.927	40.6
FL1B	26.9038	0
FL1A	36.0443	0
FL1E	24.7698	0
FL1D	23.5285	0
FL1C	18.8005	0
FL1F	20.5626	0
FL1G	11.8618	0
FL1I	5.33071	0
FL1H	6.85331	0
FL3	1.12055	0
FL2	1.297	20
OCEAN	0	0

Table D3 – Design Rainfall Intensity – Frequency – Duration – Gauge Hewitts #1

Year (y ARI/% AEP) Min	5y	10%	5%	2%	1%	0.50%	0.20%
5	179.3	201.3	230.6	268.6	297.4	326.5	365.6
10	141.1	159.7	184.2	216.3	240.8	265.6	299.1
15	119.9	136.5	158.2	186.8	208.7	230.9	261.1
20	105.8	121.1	140.8	166.9	187.0	207.5	235.3
30	87.7	101.0	118.1	140.9	158.5	176.5	201.1
45	71.8	83.3	98.0	117.7	132.9	148.7	170.2
60	62.0	72.2	85.4	103.0	116.7	130.9	150.4
90	49.7	58.0	68.6	82.9	94.0	105.5	121.3
120	42.3	49.5	58.5	70.8	80.3	90.2	103.8
180	33.7	39.4	46.7	56.6	64.2	72.2	83.1
270	26.8	31.4	37.2	45.1	51.3	57.7	66.5
360	22.8	26.7	31.7	38.4	43.7	49.2	56.7
540	18.1	21.3	25.3	30.7	35.0	39.4	45.5
720	15.4	18.1	21.6	26.2	29.8	33.6	38.8
1080	12.4	14.6	17.3	20.9	23.8	26.7	30.8
1440	10.7	12.5	14.7	17.8	20.2	22.7	26.1

Table D4 – Design Rainfall Intensity – Frequency – Duration – Gauge Hewitts #2

Year (y ARI/% AEP) Min	5y	10%	5%	2%	1%	0.50%	0.20%
5	180.0	200.9	229.1	265.6	293.1	320.8	357.8
10	141.5	159.2	182.8	213.5	236.8	260.3	292.0
15	120.2	136.0	156.8	184.1	204.9	226.0	254.4
20	106.1	120.6	139.5	164.4	183.4	202.8	228.9
30	87.9	100.5	116.9	138.6	155.2	172.2	195.2
45	71.9	82.8	96.9	115.5	129.9	144.7	164.8
60	62.0	71.8	84.3	101.0	113.9	127.3	145.4
90	49.8	57.7	67.9	81.6	92.2	103.1	118.1
120	42.4	49.3	58.1	69.9	79.1	88.6	101.5
180	33.8	39.4	46.5	56.1	63.6	71.3	81.9
270	26.9	31.4	37.2	45.0	51.0	57.3	66.0
360	22.9	26.8	31.7	38.4	43.7	49.1	56.6
540	18.2	21.4	25.4	30.8	35.1	39.5	45.6
720	15.5	18.2	21.7	26.4	30.1	33.9	39.2
1080	12.5	14.6	17.3	21.0	23.9	26.8	30.9
1440	10.7	12.5	14.8	17.8	20.2	22.7	26.1

Table D5 – Design Rainfall Intensity – Frequency – Duration – Gauge Hewitts #3

Year (y ARI/% AEP) Min	5y	10%	5%	2%	1%	0.50%	0.20%
5	181.6	203.8	233.3	271.6	300.7	330.0	369.2
10	143.0	161.9	186.7	219.1	243.9	269.0	302.9
15	121.6	138.5	160.5	189.5	211.6	234.2	264.8
20	107.4	122.9	143.0	169.5	189.9	210.7	238.9
30	89.1	102.6	120.1	143.3	161.2	179.6	204.6
45	73.0	84.7	99.7	119.8	135.4	151.5	173.5
60	63.0	73.5	87.0	105.0	119.1	133.6	153.6
90	50.4	58.8	69.6	84.1	95.3	107.0	123.1
120	42.8	50.0	59.2	71.6	81.2	91.2	104.9
180	34.0	39.7	47.0	56.9	64.6	72.5	83.5
270	26.9	31.5	37.3	45.2	51.3	57.6	66.3
360	22.8	26.7	31.7	38.3	43.5	48.9	56.3
540	18.1	21.2	25.2	30.5	34.6	38.9	44.8
720	15.4	18.0	21.4	25.9	29.4	33.1	38.2
1080	12.5	14.5	17.2	20.7	23.5	26.4	30.3
1440	10.7	12.5	14.7	17.7	20.0	22.4	25.7

Table D6 – Design Rainfall Intensity – Frequency – Duration – Gauge Hewitts #4

Year (y ARI/% AEP) Min	5y	10%	5%	2%	1%	0.50%	0.20%
5	179.1	199.7	227.5	263.3	290.4	317.5	353.8
10	140.7	158.1	181.3	211.4	234.2	257.2	288.1
15	119.5	135.0	155.4	182.1	202.4	223.0	250.7
20	105.4	119.6	138.1	162.5	181.0	199.9	225.4
30	87.3	99.6	115.6	136.8	153.0	169.5	191.9
45	71.4	82.0	95.7	113.9	127.9	142.2	161.7
60	61.6	71.0	83.2	99.5	112.1	125.0	142.6
90	49.2	56.9	66.8	80.0	90.2	100.7	115.1
120	41.8	48.4	56.9	68.3	77.1	86.2	98.5
180	33.2	38.5	45.4	54.5	61.6	69.0	79.0
270	26.3	30.6	36.1	43.5	49.2	55.1	63.3
360	22.3	26.0	30.7	37.0	42.0	47.0	54.0
540	17.7	20.7	24.5	29.6	33.5	37.7	43.3
720	15.0	17.6	20.8	25.2	28.6	32.2	37.1
1080	11.9	13.9	16.4	19.8	22.4	25.2	29.0
1440	10.0	11.7	13.8	16.7	18.9	21.2	24.3

Table D7 – Design Rainfall Intensity – Frequency – Duration – Gauge Hewitts #5

Year (y ARI/% AEP) Min	5y	10%	5%	2%	1%	0.50%	0.20%
5	181.3	203.3	232.6	270.7	299.6	328.7	367.7
10	142.7	161.4	186.0	218.3	242.9	267.8	301.4
15	121.3	138.1	159.9	188.7	210.7	233.1	263.3
20	107.2	122.5	142.4	168.7	188.9	209.6	237.5
30	88.9	102.3	119.6	142.6	160.3	178.5	203.3
45	72.8	84.4	99.3	119.2	134.6	150.5	172.3
60	62.8	73.2	86.5	104.4	118.3	132.7	152.4
90	50.3	58.7	69.5	83.9	95.2	106.9	122.9
120	42.8	50.0	59.3	71.7	81.4	91.4	105.2
180	34.0	39.8	47.2	57.2	65.0	73.1	84.2
270	27.0	31.7	37.6	45.6	51.9	58.4	67.4
360	22.9	26.9	32.0	38.9	44.2	49.8	57.5
540	18.2	21.4	25.5	31.0	35.4	39.8	46.1
720	15.5	18.2	21.7	26.5	30.2	34.0	39.4
1080	12.5	14.7	17.4	21.1	24.0	27.1	31.2
1440	10.7	12.5	14.9	18.0	20.4	23.0	26.4

Table D8 – Design Rainfall Intensity – Frequency – Duration – Gauge Hewitts #6

Year (y ARI/% AEP) Min	5y	10%	5%	2%	1%	0.50%	0.20%
5	180.3	202.3	231.6	269.6	298.4	327.4	366.4
10	141.9	160.5	185.1	217.2	241.7	266.5	300.0
15	120.6	137.3	159.0	187.7	209.6	231.8	262.0
20	106.5	121.8	141.6	167.8	187.9	208.4	236.2
30	88.3	101.6	118.8	141.7	159.3	177.4	202.0
45	72.3	83.8	98.6	118.4	133.7	149.5	171.0
60	62.4	72.7	85.9	103.6	117.4	131.7	151.3
90	49.9	58.2	68.9	83.2	94.4	106.0	121.9
120	42.4	49.6	58.7	71.0	80.6	90.6	104.2
180	33.7	39.4	46.8	56.6	64.4	72.4	83.4
270	26.7	31.3	37.2	45.1	51.3	57.8	66.6
360	22.7	26.6	31.6	38.4	43.7	49.2	56.8
540	18.0	21.1	25.2	30.6	34.9	39.3	45.5
720	15.3	18.0	21.4	26.1	29.8	33.6	38.8
1080	12.3	14.4	17.1	20.8	23.6	26.6	30.7
1440	10.5	12.3	14.6	17.6	20.0	22.5	26.0

Table D9 – Hydraulic Model Details and Universal Parameters

Model	TUFLOW 1D/2D
Version	2016-03-AE-w64
Extent	Shown on Volume 2 Map Set A – Figure 3 and 2d_code_Study_Area_region.shp Extended as part of this Flood Study Addendum to include Armagh Parade Thirroul.
Terrain	2m DEM derived from 2013 LiDAR, additional topographic ground survey from Flood Study (2002), Flood Study Review (2015) (Shown on Volume 2 Map Set A – Figure 3), and plans for: • Bulli Brickworks subdivision – Stages 1 and 2 are complete with Stage 3 currently under construction. • Armagh Parade subdivision, Thirroul.
Pit and pipe Database	Provided by Council, pipes greater than 450mm diameter included. Shown on Volume 2 Map Set A – Figure 3.
Pit size (assumed)	2.5m x 0.15m (combined lintel and grate pit), 20% blockage
Entrance condition	Open, geometry based on calibration events
Manning's 'n'	Values in Table G7 below and application shown on Volume 2 Map Set A – Figure 4 and 2d_mat_Hewits_01_region.shp
Inflow Boundary	From WBNM
Downstream Boundary	Neap (0.63mAHD) and Storm Tide (2.3/2.6mAHD)

Table D10 – Manning's 'n' Values

Land Use	Manning's 'n' value
Grass (maintained)	0.03
Parkland	0.04
Dense vegetation	0.09
Riparian Corridor	0.09
Creek Channel	0.06 – 0.12
Tidal Inundation Zone	0.035
Roads, car parks, open concrete	0.02
Railway	0.08
Urban Block/Default	0.07
Buildings	1.0

Table D11 – Hydraulic Structures

ID	Watercourse	Street or Landmark	Structure Type	Structure Details	Adopted Size	Source of Change
1	Slacky Creek	William Street, Bulli	Culvert	3 Rectangular Culverts	2 x 2.4m x 1.5m openings and 1 x 2.4m x 1.67m opening	Flood Study Review (2015) Report
2	Slacky Creek	Hobart Street, Bulli	Culvert	3 Circular Pipes	3 x 1.12m diameter	N/A
3	Slacky Creek, (western tributary)	Hobart Street, Bulli	Culvert	2 Rectangular Culverts	2 x 3.5m x 1.2m openings	N/A
4	Slacky Creek, (western tributary)	Hobart Street, Bulli	Bridge	Single Span Opening	invert creek Obvert 27m deck 1.6m	1D structure revised to 2D LFC and fence changed 1m high
5	Slacky Creek	Hobart Street, Bulli	Culvert	2 Circular Culverts	2 x 1.8m diameter	N/A
6	Slacky Creek	Hobart Street (Coal haulage embankment),Bulli	Culvert	3 Rectangular Culverts	3 x 2.75m x 1.7m openings	N/A
7	Slacky Creek	Adjacent to Bulli Showground and Racing Complex, Bulli	Culvert	4 Circular Culverts	4 x 0.45m diameter	N/A
8	Slacky Creek	Princes Highway, Bulli	Culvert	4 Rectangular Culverts	4 x 2.45m x 1.7m openings	N/A
9	Slacky Creek	Park at Black Diamond Place, upstream of the Illawarra Railway, Bulli	Culvert	2 Rectangular Culverts	2 x 2.85m x 3m openings	Survey
10	Slacky Creek	Illawarra Railway and Beacon Avenue underpass, Bulli	Culvert	2 Rectangular Culverts	1 x 4.8m x 5.9m opening and 1 x 4.8m x 4.05m opening	N/A
11	Slacky Creek	South of Beach Street, Bulli	Foot Bridge	Single Span Opening	invert creek, obvert 4.3mAHD deck 0.7m	1D structure revised to 2D LFC and fence changed 1m high
12	Slacky Creek	Blackall Street, Bulli	Bridge	Single Span Opening	invert creek, obvert 3.03mAHD deck 0.65m fence 0.5m	1D structure revised to 2D LFC and fence changed 1m high
13	Slacky Creek	Blackall Street, Bulli	Foot Bridge	Single Span Opening	invert creek, obvert 3.17mAHD deck 0.5m fence 1m	1D structure revised to 2D LFC and fence changed 1m high
14	Tramway Creek	Illawarra Railway, Bulli	Culvert	1 Circular Culvert	2.4m diameter	N/A
15	Woodlands Creek	Princes Highway, Bulli	Culvert	3 Rectangular Culverts	3 x 2.4m x 1.2m openings	N/A
16	Woodlands Creek	Disused heavy vehicle safety ramp at Princes Highway, Bulli	Culvert	4 Circular Culvers	4 x 1.8m diameter	Pipe size change to 1.8 based on survey
17	Woodlands Creek	Illawarra Railway, Bulli	Culvert	1 Circular Culvert	2.57m diameter	N/A
18	Woodlands Creek	Air Avenue, Bulli	Bridge	2 Span Bridge	invert creek, obvert 14.6mAHD deck 0.7m fence 1.2m	1D structure revised to 2D LFC and fence changed 1m high

ID	Watercourse	Street or Landmark	Structure Type	Structure Details	Adopted Size	Source of Change
19	Hewitts Creek	George Street, Thirroul	Foot Bridge	Single Span Bridge	invert creek, obvert 29.32mAHD deck 0.8m	1D structure revised to 2D LFC and fence changed 1m high
20	Hewitts Creek	George Street, Thirroul	Foot Bridge	Two Span Bridge	invert creek, obvert 27.9mAHD deck 0.1m	1D structure revised to 2D LFC and fence changed 1m high
21	Hewitts Creek	Kelton Lane, Thirroul	Bridge	Single Span Bridge	invert creek, obvert 24.06mAHD deck 0.9m	1D structure revised to 2D LFC and fence changed 1m high
22	Hewitts Creek	Lachlan Street, Thirroul	Culvert	2 Rectangular Culverts	2X 2 x 2.27m openings	Survey
23	Hewitts Creek	Lawrence Hargrave Drive , Thirroul	Culvert	3 Rectangular Culverts	3 x 2.75m x 2.45m openings	Flood Study Review (2015) Report and confirmed by survey
24	Hewitts Creek	Lawrence Hargrave Drive , Thirroul	Culvert	2 Circular Culverts	2 x 1.2m diameter	N/A
25	Hewitts Creek	High Street, Thirroul	Bridge	Single Span Bridge	invert 11.72, obvert 13.07m AHD deck 0.15m and fence 1.25m	1D structure revised to 2D LFC and fence changed 1m high confirmed by survey
26	Hewitts Creek	Illawarra Railway, Thirroul	Bridge	Single Span Bridge	1D Cross section	1D structure revised to 2D LFC and fence changed 1m high
27	Hewitts Creek	Brickworks Avenue, Thirroul	Bridge	3 Span Bridge	invert creek, obvert 12.7mAHD deck 0.7m fence 1.2m	1D structure revised to 2D LFC and fence changed 1m high
28	Hewitts Creek	Hamilton Road, Thirroul	Foot Bridge	Twin Span Bridge	invert creek, obvert 2.94mAHD deck 0.75m fence 1m	1D structure revised to 2D LFC and fence changed 1m high
29	Hewitts Creek (eastern tributary)	Palm Grove , Thirroul	Culvert	1 Circular Culvert	0.9m diameter	Revised schematisation pits connected to pipe - Model Correction
30	Hewitts Creek (eastern tributary)	Virginia Terrace, Thirroul	Culvert	1 Circular Culvert	1.2m diameter	Revised schematisation pits connected to pipe - Model Correction
31	Hewitts Creek (eastern tributary)	George Street Thirroul	Culvert	1 Circular Culvert	1.0m diameter	Revised schematisation pits connected to pipe - Model Correction
32	Hewitts Creek (western tributary)	Deborah Avenue, Thirroul	Culvert	1 Circular Culvert	1.5m diameter	N/A
33	Hewitts Creek (western tributary)	Virginia Terrace, Thirroul	Culvert	1 Circular Culvert	1.5m diameter	Revised schematisation pits connected to pipe - Model Correction
34	Hewitts Creek	George Street (West), Thirroul	Culvert	1 Rectangular Culvert	2.12m x 1.5m opening	Connection to the box culvert improved upstream - Model correction

ID	Watercourse	Street or Landmark	Structure Type	Structure Details	Adopted Size	Source of Change
	(western tributary)					
35	Thomas Gibson Creek	Lawrence Hargrave Drive, Thirroul	Culvert	1 Circular Culvert	0.45m diameter	Revised schematisation pits connected to pipe - Model Correction
36	Thomas Gibson Creek	Illawarra Railway, Thirroul	Culvert	1 Circular Culvert	1.52m diameter	N/A
37	Thomas Gibson Creek	Thomas Gibson Park, Thirroul	Culvert	1 Circular Culvert	0.75m diameter	Revised schematisation pits connected to pipe, invert adjusted - Model Correction based on survey
38	Thomas Gibson Creek	McCauley Street , Thirroul	Culvert	Single Circular Pipe	0.95m diameter	N/A
39	Thomas Gibson Creek	Cliff Parade, Thirroul	Culvert	Single Circular Pipe	0.95m diameter	N/A