PORT MACQUARIE-HASTINGS COUNCIL

Coast, Estuary & Floodplain Advisory Sub-Committee

Business Paper

date of meeting:	**Thursday 28 March 2019**
location:	**Committee Room** **Port Macquarie-Hastings Council** **17 Burrawan Street** **Port Macquarie**
time:	**2:00pm**

Coast, Estuary & Floodplain Advisory Sub-Committee

CHARTER

Adopted: OC 18/11/15

1. Advise Council on conditions and management issues for the coast, estuaries and floodplains of the Port Macquarie-Hastings local government area.

2. Advise Council on the development of coastal zone, estuary and floodplain risk management plans for the Port Macquarie-Hastings local government area.

3. Advise Council on the implementation of adopted coastal zone, estuary and floodplain risk management plans.

4. Act as a committee for the purpose of relevant NSW guidelines as they relate to estuary, coastline and floodplain management.

Coast, Estuary & Floodplain Advisory Sub-Committee

ATTENDANCE REGISTER

Member	29/09/15	09/02/16	24/11/16	30/03/17	31/07/18
Councillor Mike Cusato (Chair)	✓	✓	A	✓	✓
Councillor Rob Turner (Deputy Chair)	-	-	-	-	X
Adrian Button (Waterways User Rep.)	A	✓	A	✓	X
Alan MacIntyre (Community Rep.)	✓	✓	✓	✓	A
Bob Jolly (Community Rep. - Lake Cathie)	✓	✓	✓	✓	✓
Kingsley Searle (Oyster Industry & Community Rep. – North Shore)	✓	✓	✓	✓	✓
Laurie Lardner (Community Rep.)	A	✓	✓	A	✓
Patrick McEntee (Community Rep.)	✓	✓	A	X	X
Paul Hyde (Hastings River Fisherman's Co-op)	X	✓	X	X	X
Tony Troup (Oyster Industry)	✓	✓	✓	A	✓
Staff					
Melissa Watkins (PMHC)	-	-	-	-	✓
Maria Doherty (PMHC)	-	-	-	-	✓
Gordon Cameron (PMHC)	✓	✓	✓	✓	✓
Blayne West (PMHC)	-	-	-	-	✓
Jesse Dick (PMHC)	✓	✓	✓	A	✓
Agencies					
Tina Clemens Jaimee Vlastuin (Lands Department)	A ✓	✓	✓	A	✓
Scott Anderson Michael Northam (alternate) (DPI - Fisheries)	 ✓	 ✓	 ✓	 ✓	✓ ✓
Steve Atkins Eric Claussen Shane Robinson (National Parks Wildlife Service)	A ✓	A	✓	✓	 -
John Schmidt Nic Denshire Toong Chin (Office of Environment & Heritage)	A	✓ ✓ A	✓	✓ ✓	✓ ✓
Matt Dawson Andre Uljee (Maritime Division - RMS)	✓	 ✓	A A	✓	 ✓
Anthony Day Ray Richards Maria Fraser Paul Burg (SES Rep)	A ✓	 ✓	 ✓ ✓	 ✓	 ✓

Key: ✓ = Present
A = Absent With Apology
X = Absent Without Apology

Coast, Estuary & Floodplain Advisory Sub-Committee Meeting
Thursday 28 March 2019

Items of Business

Item: 01

Subject: ACKNOWLEDGEMENT OF COUNTRY

"I acknowledge that we are gathered on Birpai Land. I pay respect to the Birpai Elders both past and present. I also extend that respect to all other Aboriginal and Torres Strait Islander people present."

Item: 02

Subject: APOLOGIES

RECOMMENDATION

That the apologies received be accepted.

Item: 03

Subject: CONFIRMATION OF PREVIOUS MINUTES

RECOMMENDATION

That the Minutes of the Coast, Estuary & Floodplain Advisory Sub-Committee Meeting held on 31 July 2018 be confirmed.

PRESENT

Members:

Councillor Mike Cusato (Chair)
Bob Jolly (Community Rep. - Lake Cathie)
Kingsley Searle (Oyster Industry & Community Rep. – North Shore)
Laurie Lardner (Community Rep.)
Tony Troup (Oyster Industry)

Staff:

Melissa Watkins (PMHC)
Maria Doherty (PMHC)
Gordon Cameron (PMHC)
Blayne West (PMHC)
Jesse Dick (PMHC)

Agencies:

Tina Clemens (DPI Lands)
Scott Anderson (DPI - Fisheries)
Michael Northam (DPI - Fisheries)
John Schmidt (Office of Environment & Heritage)
Nicholas Denshire (Office of Environment & Heritage)
Andre Uljee (Maritime Division - RMS)
Maria Frazer (State Emergency Services)
Paul Burg (State Emergency Services)

Other Attendees:

Dr Matthew Taylor (DPI Fisheries)
Kylie Russell (DPI Fisheries)
Monique Retallick (WMAwater)
Mikayla Ward (WMAwater)

The meeting opened at 1:00pm.

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01 ACKNOWLEDGEMENT OF COUNTRY

The Acknowledgement of Country was delivered.

02 APOLOGIES

CONSENSUS:

That the apologies from Alan MacIntyre (Community Rep.) and Shaun Kerrigan (National Parks Wildlife Service) be accepted.

03 CONFIRMATION OF MINUTES

CONSENSUS:

That the Minutes of the Coast, Estuary & Floodplain Advisory Sub-Committee Meeting held on 30 March 2017 be confirmed.

04 DISCLOSURES OF INTEREST

There were no disclosures of interest presented.

05 BUSINESS ARISING FROM PREVIOUS MINUTES

Camden Haven Prawn Study:

Dr Matt Taylor & Kylie Russell (DPI – Fisheries) provided the committee with a presentation to discuss preliminary results of the Camden Haven Prawn Study. The presentation was well received by the committee who thanked Matt & Kylie for their presentation. When available, the final report will be provided to PMHC for circulation to committee members.

Preliminary findings seem to indicate issues with pH and aluminium levels within the catchment and that there was a significant decline in the diversity and extent of seagrass in Queens Lake.

PMHC and DPI – Fisheries to discuss potential opportunities to install data loggers within the Camden Haven catchment, possibly as part of the next round of Ecohealth monitoring.

Seagrass Mapping:

Dr Matt Taylor confirmed that the Seagrass Mapping results are available and will form part of the final Camden Haven Prawn Study report.

06 WRIGHTS CREEK FLOOD STUDY UPDATE - DRAFT REPORT

Monique Retallick & Mikayla Ward (WMAwater) provided a detailed presentation on the report. The presentation was well received by the committee.

Gordon Cameron discussed the next stage of the project after the flood study (ie. The management study). Potential to create a special working group to discuss possible options to resolve issues within the catchment.

Councillor Mike Cusato encouraged committee members to make a submission on the Wrights Creek Flood Study Update.

CONSENSUS:

That it be a recommendation to Council that the draft Wrights Creek Flood Study Update (2018) be placed on public exhibition for six weeks.

07 IMPLEMENTATION UPDATE ON FLOODPLAIN RISK, ESTUARY AND COASTAL ZONE MANAGEMENT PLAN PROJECTS

There was general discussion on various actions listed in the report.

Maia Frazer (SES) advised that action item 11 from the Hastings River Floodplain Management Plan needed revision. PMHC staff to liaise with SES representatives to clarify the status of action item 11 prior to the next meeting.

CONSENSUS:

That the Committee note the report.

08 UPDATE OF BIODIVERSITY STRATEGY AND ECOHEALTH MONITORING

Blayne West provided an overview of the Biodiversity Strategy & Ecohealth Monitoring. The results of the Ecohealth Monitoring are available online and can be found on the PMHC website at:
http://www.pmhc.nsw.gov.au/Services/Environment/Waterways/Protecting-our-rivers/Looking-after-our-local-rivers-and-estuaries

Councillor Mike Cusato encouraged committee members to make a submission on the biodiversity strategy.

CONSENSUS:

That the Committee note the report.

09 ACTIVE COAST, ESTUARY & FLOODPLAIN PROJECTS STATUS UPDATE

Gordon Cameron provided an overview of the current active coast, estuary & floodplain projects.

CONSENSUS:

That the Committee note the status of the active Coast, Estuary and Floodplain projects.

10 RECENT LEGISLATION REFORMS

Jesse Dick provided an overview of the recent legislation changes that relate to the functions of the committee.

Tina Clemens (DPI Lands) provided additional information regarding the Crown Land Management Act changes.

John Schmidt (OEH) provided additional information regarding the works that Council can undertake without a certified Coastal Management Plan (CMP).

Councillor Mike Cusato noted the impact that these changes may have on Local Government.

CONSENSUS:

That the Committee note the report.

11 GENERAL BUSINESS

11.01 FLOOR LEVEL DATA

Maria Frazer (SES) questioned whether Council held any floor level data that was freely available for use by the SES.

PMHC staff confirmed that whilst some floor level data did indeed exist, it was spread across multiple flood studies, each of a differing age and was not readily obtainable without undertaking a data request from the consultants who undertook the original study.

The meeting closed at 3:10pm.

Item: 04

Subject: DISCLOSURES OF INTEREST

RECOMMENDATION

That Disclosures of Interest be presented

DISCLOSURE OF INTEREST DECLARATION

Name of Meeting: ……………………………………………………………………..

Meeting Date: ……………………………………………………………………..

Item Number: ……………………………………………………………………..

Subject: ……………………………………………………………………..
……………………………………………………….……………...…..

I, ... declare the following interest:

☐ **Pecuniary:**
Take no part in the consideration and voting and be out of sight of the meeting.

☐ **Non-Pecuniary - Significant Interest:**
Take no part in the consideration and voting and be out of sight of the meeting.

☐ **Non-Pecuniary - Less than Significant Interest:**
May participate in consideration and voting.

For the reason that: ....

...

Name: ……………………………………………………….

Signed: .... Date: ....

(Further explanation is provided on the next page)

Further Explanation
(Local Government Act and Code of Conduct)

A conflict of interest exists where a reasonable and informed person would perceive that a Council official could be influenced by a private interest when carrying out their public duty. Interests can be of two types: pecuniary or non-pecuniary.

All interests, whether pecuniary or non-pecuniary are required to be fully disclosed and in writing.

Pecuniary Interest

A pecuniary interest is an interest that a Council official has in a matter because of a reasonable likelihood or expectation of appreciable financial gain or loss to the Council official. (section 442)

A Council official will also be taken to have a pecuniary interest in a matter if that Council official's spouse or de facto partner or a relative of the Council official or a partner or employer of the Council official, or a company or other body of which the Council official, or a nominee, partner or employer of the Council official is a member, has a pecuniary interest in the matter. (section 443)

The Council official must not take part in the consideration or voting on the matter and leave and be out of sight of the meeting. The Council official must not be present at, or in sight of, the meeting of the Council at any time during which the matter is being considered or discussed, or at any time during which the council is voting on any question in relation to the matter. (section 451)

Non-Pecuniary

A non-pecuniary interest is an interest that is private or personal that the Council official has that does not amount to a pecuniary interest as defined in the Act.

Non-pecuniary interests commonly arise out of family, or personal relationships, or involvement in sporting, social or other cultural groups and associations and may include an interest of a financial nature.

The political views of a Councillor do not constitute a private interest.

The management of a non-pecuniary interest will depend on whether or not it is significant.

Non Pecuniary – Significant Interest
As a general rule, a non-pecuniary conflict of interest will be significant where a matter does not raise a pecuniary interest, but it involves:

(a) A relationship between a Council official and another person that is particularly close, for example, parent, grandparent, brother, sister, uncle, aunt, nephew, niece, lineal descendant or adopted child of the Council official or of the Council official's spouse, current or former spouse or partner, de facto or other person living in the same household.
(b) Other relationships that are particularly close, such as friendships and business relationships. Closeness is defined by the nature of the friendship or business relationship, the frequency of contact and the duration of the friendship or relationship.
(c) An affiliation between a Council official an organisation, sporting body, club, corporation or association that is particularly strong.

If a Council official declares a non-pecuniary significant interest it must be managed in one of two ways:

1. Remove the source of the conflict, by relinquishing or divesting the interest that creates the conflict, or reallocating the conflicting duties to another Council official.
2. Have no involvement in the matter, by taking no part in the consideration or voting on the matter and leave and be out of sight of the meeting, as if the provisions in section 451(2) apply.

Non Pecuniary – Less than Significant Interest
If a Council official has declared a non-pecuniary less than significant interest and it does not require further action, they must provide an explanation of why they consider that the conflict does not require further action in the circumstances.

SPECIAL DISCLOSURE OF PECUNIARY INTEREST DECLARATION

By *[insert full name of councillor]*	
In the matter of *[insert name of environmental planning instrument]*	
Which is to be considered at a meeting of the *[insert name of meeting]*	
Held on *[insert date of meeting]*	
PECUNIARY INTEREST	
Address of land in which councillor or an associated person, company or body has a proprietary interest (*the* ***identified land)*** [i]	
Relationship of identified land to councillor [*Tick or cross one box*.]	☐ Councillor has interest in the land (e.g. is owner or has other interest arising out of a mortgage, lease trust, option or contract, or otherwise). ☐ Associated person of councillor has interest in the land. ☐ Associated company or body of councillor has interest in the land.
MATTER GIVING RISE TO PECUNIARY INTEREST	
Nature of land that is subject to a change in zone/planning control by proposed LEP *(the* ***subject land*** [iii] [*Tick or cross one box*]	☐ The identified land. ☐ Land that adjoins or is adjacent to or is in proximity to the identified land.
Current zone/planning control [*Insert name of current planning instrument and identify relevant zone/planning control applying to the subject land*]	
Proposed change of zone/planning control [*Insert name of proposed LEP and identify proposed change of zone/planning control applying to the subject land*]	
Effect of proposed change of zone/planning control on councillor [*Tick or cross one box*]	☐ Appreciable financial gain. ☐ Appreciable financial loss.

Councillor's Name: ....

Councillor's Signature: ………………………………. Date: ………………..

PORT MACQUARIE HASTINGS COUNCIL

Important Information

This information is being collected for the purpose of making a special disclosure of pecuniary interests under sections 451 (4) and (5) of the *Local Government Act 1993.* You must not make a special disclosure that you know or ought reasonably to know is false or misleading in a material particular. Complaints made about contraventions of these requirements may be referred by the Director-General to the Local Government Pecuniary Interest and Disciplinary Tribunal.

This form must be completed by you before the commencement of the council or council committee meeting in respect of which the special disclosure is being made. The completed form must be tabled at the meeting. Everyone is entitled to inspect it. The special disclosure must be recorded in the minutes of the meeting.

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i. Section **443** (1) of the *Local Government Act 1993* provides that you may have a pecuniary interest in a matter because of the pecuniary interest of your spouse or your de facto partner or your relative[iv] or because your business partner or employer has a pecuniary interest. You may also have a pecuniary interest in a matter because you, your nominee, your business partner or your employer is a member of a company or other body that has a pecuniary interest in the matter.
ii. Section **442** of the *Local Government Act 1993* provides that a ***pecuniary interest*** is an interest that a person has in a matter because of a reasonable likelihood or expectation of appreciable financial gain or loss to the person. A person does not have a pecuniary interest in a matter if the interest is so remote or insignificant that it could not reasonably be regarded as likely to influence any decision the person might make in relation to the matter or if the interest is of a kind specified in section **448** of that Act (for example, an interest as an elector or as a ratepayer or person liable to pay a charge).
iii. A pecuniary interest may arise by way of a change of permissible use of land adjoining, adjacent to or in proximity to land in which a councillor or a person, company or body referred to in section **443** (1) (b) or (c) of the *Local Government Act 1993* has a proprietary interest..
iv. ***Relative*** is defined by the *Local Government Act 1993* as meaning your, your spouse's or your de facto partner's parent, grandparent, brother, sister, uncle, aunt, nephew, niece, lineal descendant or adopted child and the spouse or de facto partner of any of those persons.

Item: 05

Subject: **BUSINESS ARISING FROM PREVIOUS MINUTES**

Nil.

Item: 06

Subject: HIBBARD PRECINCT FLOOD STUDY - DRAFT REPORT

Presented by: Development and Environment, Melissa Watkins

RECOMMENDATION

That the Committee recommend to Council, that the draft *Hibbard Precinct Flood Study (2019)* be placed on public exhibition for not less than 28 days.

Background

In late 2016 Council engaged Advisian to prepare a Floodplain Management Plan for the Hibbard Precinct. Part of the Floodplain Management Plan is to determine the nature and extent of the flooding in this area, ie preparation of a Flood Study.

The primary goal of the *Hibbard Precinct Flood Study* is to define the extent of the floodway at a local scale, as well as to undertake a detailed investigation to assess options for maintaining the floodway into the future and for mitigating impacts associated with its adoption on affected landowners.

Accordingly, the existing two-dimensional RMA-2 hydraulic model (*last modified for the Hastings River Flood Study Update 2018*) was further refined to incorporate additional topographic detail and physical features across the Hibbard Precinct. The upgraded flood model was used to confirm the importance of the floodway and will be used to assess options for maintaining the flood function of this area of the floodplain when the stage 2 (options) assessment commences.

This report documents the findings from the stage 1 (Flood Study) investigations.

Discussion

The development of Floodplain Management Plans follow guidelines established in the NSW Government's *Floodplain Development Manual (2005)*. The manual outlines the steps involved in the process, and the activities required to develop a Floodplain Management Plan in flood affected areas. The Floodplain Risk Management process involves the following stages:

STAGE	DESCRIPTION
1. Flood Study	Determines the nature and extent of the flood problem.
2. Floodplain Risk Management Study	Evaluates management options for the floodplain in respect of both existing and proposed developments.
3. Floodplain Risk Management Plan	Involves formal adoption by Council of a plan of management for the floodplain.
4. Implementation of Plan	Results in construction of flood mitigation works to protect existing development and the

	application of environmental and planning controls to ensure that new development is compatible with the hazard.

Advisian have commenced Stage 1 (Flood Study) and have updated the previous flood modelling that was completed as part of the *Hastings River Flood Study (2006),* the *Hastings River Floodplain Risk Management Study (2012)* and the *Hastings River Flood Study (2018).*

The *Hastings River Floodplain Risk Management Study (2012)* and the *Hastings River Flood Study (2018)* defines flood behaviour and quantifies the flood characteristics within the Hibbard Precinct (along with the remainder of the Hastings River catchment). This information is presently used to assist development assessment and provides baseline flood data that is relied upon for development within the Hibbard precinct.

The *Hibbard Precinct Flood Study* updates the previous *Hastings River Floodplain Risk Management Study (2012)* and the *Hastings River Flood Study (2018)* and provides Council with a suitable platform for undertaking the next steps in the Floodplain Risk Management process.

Updated Model

The RMA-2 model developed for the Updated *Hastings River Flood Study (2018)* was used as the base model for the Hibbard Precinct investigations. As the model had been developed and used for regional scale investigations, it was refined for the local scale investigations. More detailed topographic data was collected to assist with the local scale definition of topography and key physical features. This included Light Detection and Ranging (LiDAR) survey, spot elevations of hydraulic controls such as road and fence (brick and concrete only) crest heights, creek cross-sections and details of bridge and culvert crossings. The refinements in the vicinity of the Hibbard Precinct led to an increase in the total number of nodes and elements in the model from 49,300 and 57,800 to 64,150 and 77,700, respectively. This represents an increase in the number of nodes and elements of more than 30%, all of which were incorporated only in the vicinity of Hibbard. Refer to **Figure 1** below.

Figure 1: Updated RMA-2 Model Mesh

Calibration to 2013 flood event

Calibration and verification of any hydraulic flood model is an important step in the model development process. If an acceptable calibration of the model to recorded events can be achieved, it ensures the reliability of the results of design flood simulations.

The 2013 flood was an event of significance to the local community and thus, data was gathered during the consultation process which included the location and height that floodwaters reached at the peak of the event. Following discussions with residents, a surveyor was commissioned to collect elevations for four flood marks identified as representative peak levels for the February 2013 at Hibbard.

Flood levels predicted by the updated RMA-2 model for the February 2013 event are considered to match reasonably well to the recorded data.

Previous Floodway Assessment

The floodway corridor determined as part of the *Hastings River FRMS (2012)* was delineated based on a review of predicted flood behaviour and then tested and further refined by encroachment modelling. Refer to **Figure 2** below. Because the 2012 modelling relied on the broad scale flood model developed as part of the lower *Hastings River Flood Study (2006)* there existed limitations in the amount of local scale detail that could be taken into consideration.

In recognition of this, a Development Moratorium was imposed which restricted fill and development west of Boundary Street until such time that the refined Hibbard Floodway Investigation had been completed.

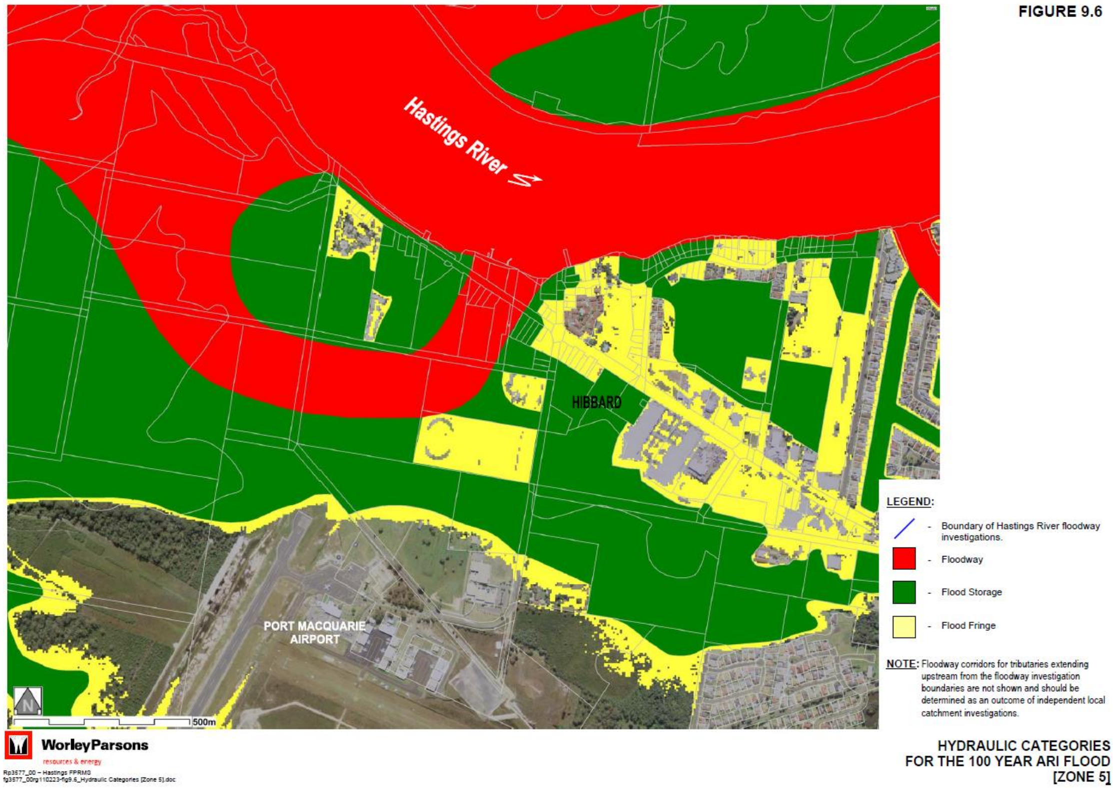


Figure 2: Currently Adopted Hydraulic Category Mapping (as per *Hastings River FRMS 2012*).

The following provisions are contained within Council's adopted *Flood Policy (2018)* with the controls stemming from the Council imposed Development Moratorium:

- *No filling of land is permitted west of Boundary Street until the Hibbard Precinct Floodway Refinement Study has been undertaken. Refer to Ordinary Council Meeting 17 February 2010, Item 06.1).*
- *Development (excluding filling) must be limited to areas outside the provisional Floodway area as shown on **Figure 2**; and*
- *All development within the Hibbard (West) Precinct must be accompanied by a Flood Risk Assessment and Flood Impact Assessment.*

Refined Floodway Assessment

As discussed above, the floodway corridor was identified using a broad scale flood model developed as part of the lower *Hastings River Flood Study (2006)* there existed limitations in the amount of local scale detail that could be taken into Consideration. However it is well recognised that this local detail is especially important in urbanised areas such as Hibbard where floodwaters can be obstructed and/or re-directed by hydraulic controls such as buildings, fences and road embankments. These localised features have now been incorporated into the Hibbard Precinct flood model with the refined model used to re-simulate design flood conditions.

With this new information available a reassessment of the floodway corridor was undertaken by applying a two stage analysis. Stage 1 involved a preliminary floodway analysis and stage 2 involved an encroachment/blockage testing analysis.

<u>Stage 1 analysis</u>

The Stage 1 analysis involved a detailed review of the flood modelling results that were generated using the Hibbard Precinct RMA-2 model.

The analysis involved identifying those parts of the floodplain across which velocities, depths and the velocity-depth product were 'locally' high and indicative of an area with high hydraulic importance and/or an area conveying a significant amount of the flow occurring 'locally'. The emphasis on 'locally' is included to reinforce that floodway runners can be formed away from and separate to the greater floodplain. This scenario of a flood runner is considered applicable to the Hibbard Precinct with floodwaters arriving overland from the west and not from flows leaving the Hastings River located immediately north of the Precinct.

Through the Stage 1 analysis a 'preliminary' floodway extent was determined through Hibbard. The Stage 1 floodway corridor includes a main floodway arm that crosses Tuffins Lane before turning towards the north to cross Hastings River Drive. Before crossing Hastings River Drive the floodway arm splits into two branches which flow to the east and west of the Riverside Resort and the brick fence that exists along its frontage.

A secondary floodway arm that starts immediately east and downstream of Tuffins Lane conveys floodwaters through the Ultiqa Village Resort and along the narrow canal and creek system. These floodway arms combine upstream of Hastings River Drive. Refer to **Figure 3** below.

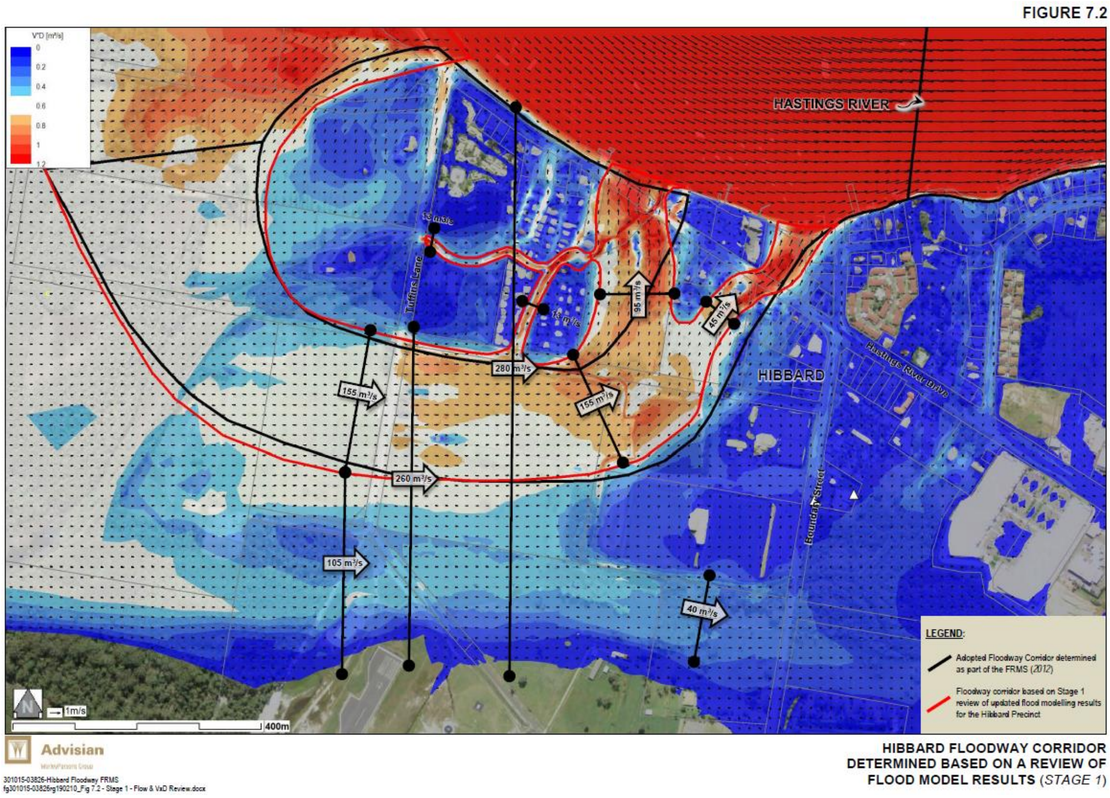


Figure 3: Stage 1 Floodway Analysis Results.

Stage 2 analysis

The Stage 2 analysis involved encroachment/blockage modelling of the Stage 1 floodway corridor to assess whether the corridor was sufficiently sized to ensure local flows could be conveyed without causing flood level increases of greater than 100mm. The threshold of 100mm is widely used in floodplain management and is referenced in OEHs guideline document, *Floodplain Risk Management Guideline – Floodway Definition* (2007).

Five encroachment scenarios were tested by gradually increasing the encroachment extent. This approach was adopted in lieu of simply running one scenario for the whole floodway extent and was use to better understand any impacts at the upstream limit of testing that may influence impacts downstream.

The Stage 2 blockage testing showed that the initial Stage 1 floodway corridor is likely to lead to flood level increases locally of up to 100mm. Blockage of the eastern floodway arm is predicted to cause flood levels to increase locally by up to 120mm which is above the threshold target and therefore indicates blockage of a floodway. Refer to **Figures 4 & 5** below.

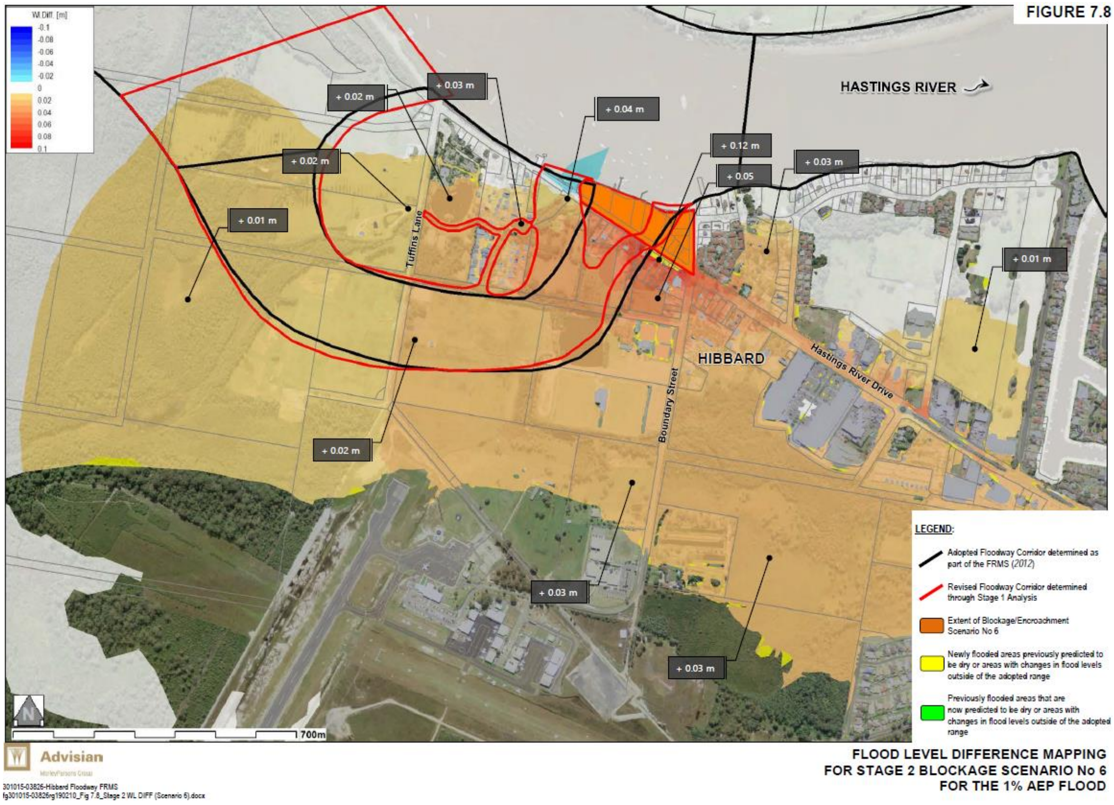


Figure 4: Stage 2 Floodway Blockage Analysis Results (Scenario 6 shown).

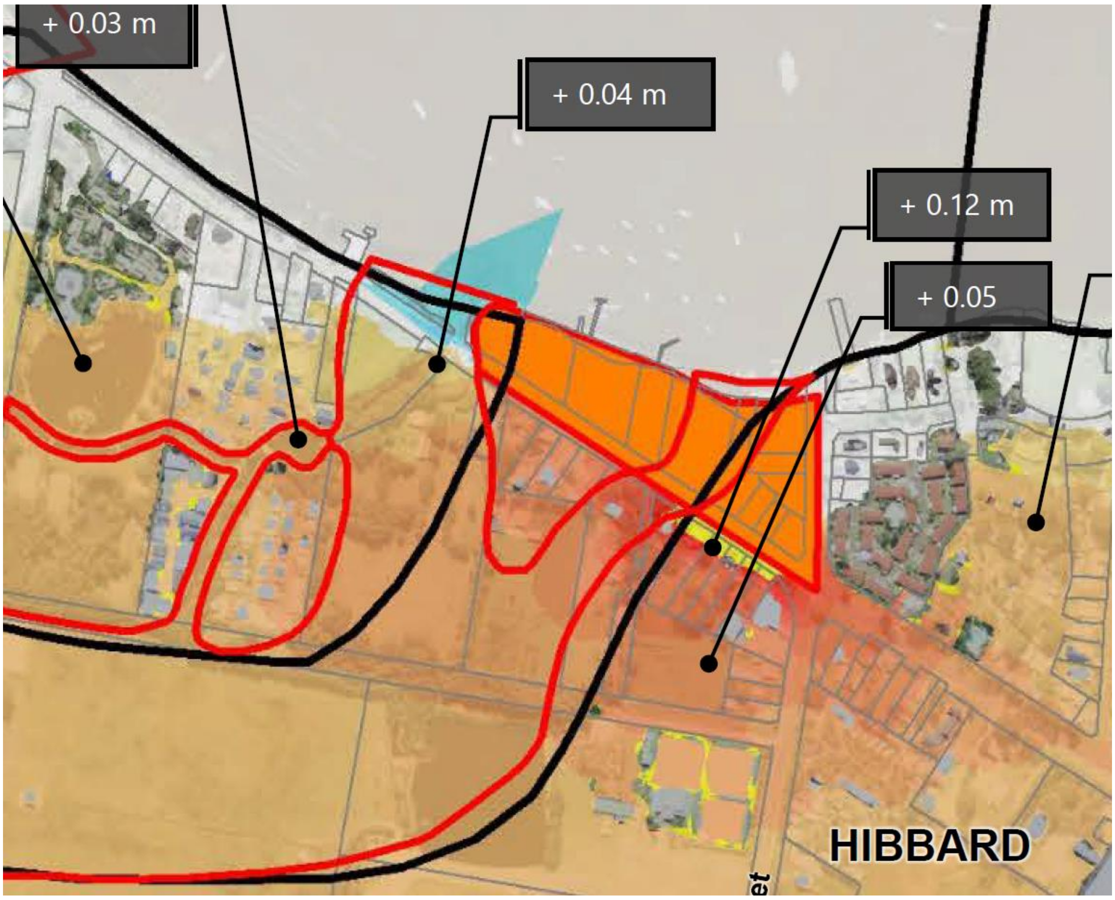


Figure 5: Close-up of Stage 2 Floodway Blockage Analysis Results (Scenario 6 shown).

Flood levels are predicted to reach up to 50mm further upstream of the two floodway arms, however this increase is limited by the large flood storage area to the south-west of Hibbard.

Based on the results of the Stage 2 encroachment modelling it is proposed that the floodway corridor delineated through the Stage 1 analysis be adopted for the Hibbard Precinct. Refer to **Figure 6** below.

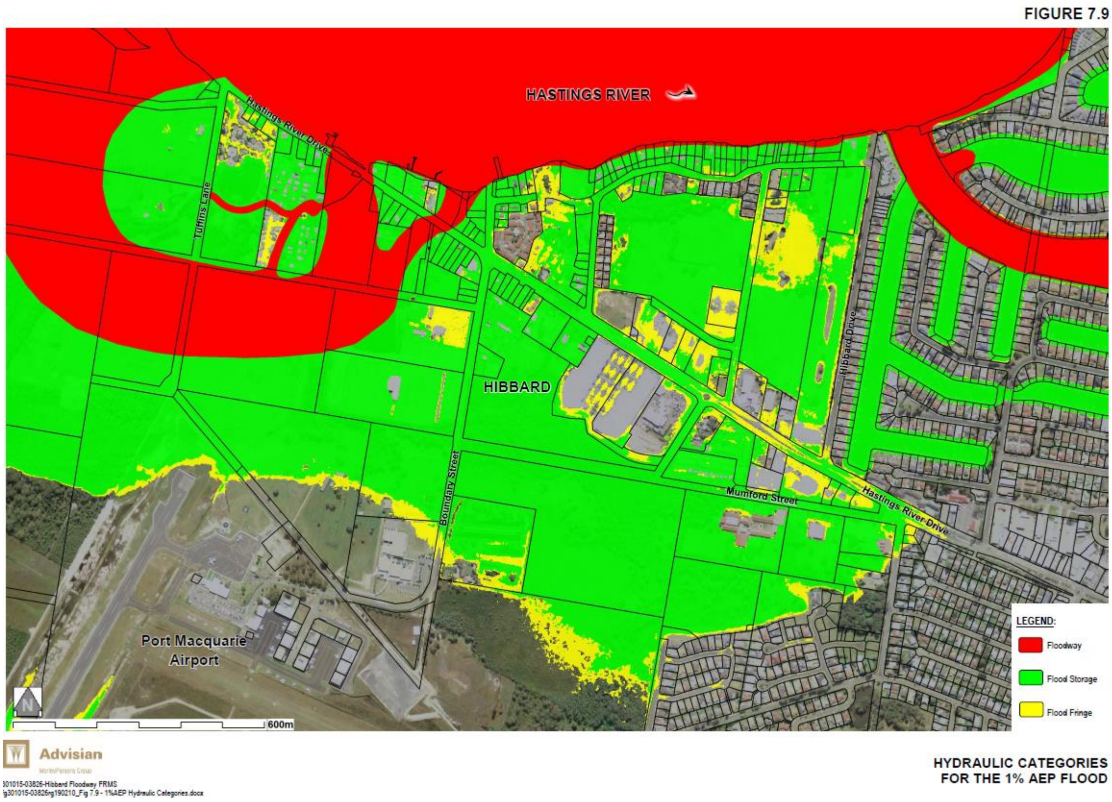


Figure 6: Proposed Hydraulic Category Mapping to be adopted.

Conclusion

This Flood Study refines the *Hastings River Flood Study Update (2018)* model with more detailed local data of the floodplain within the Hibbard Precinct.

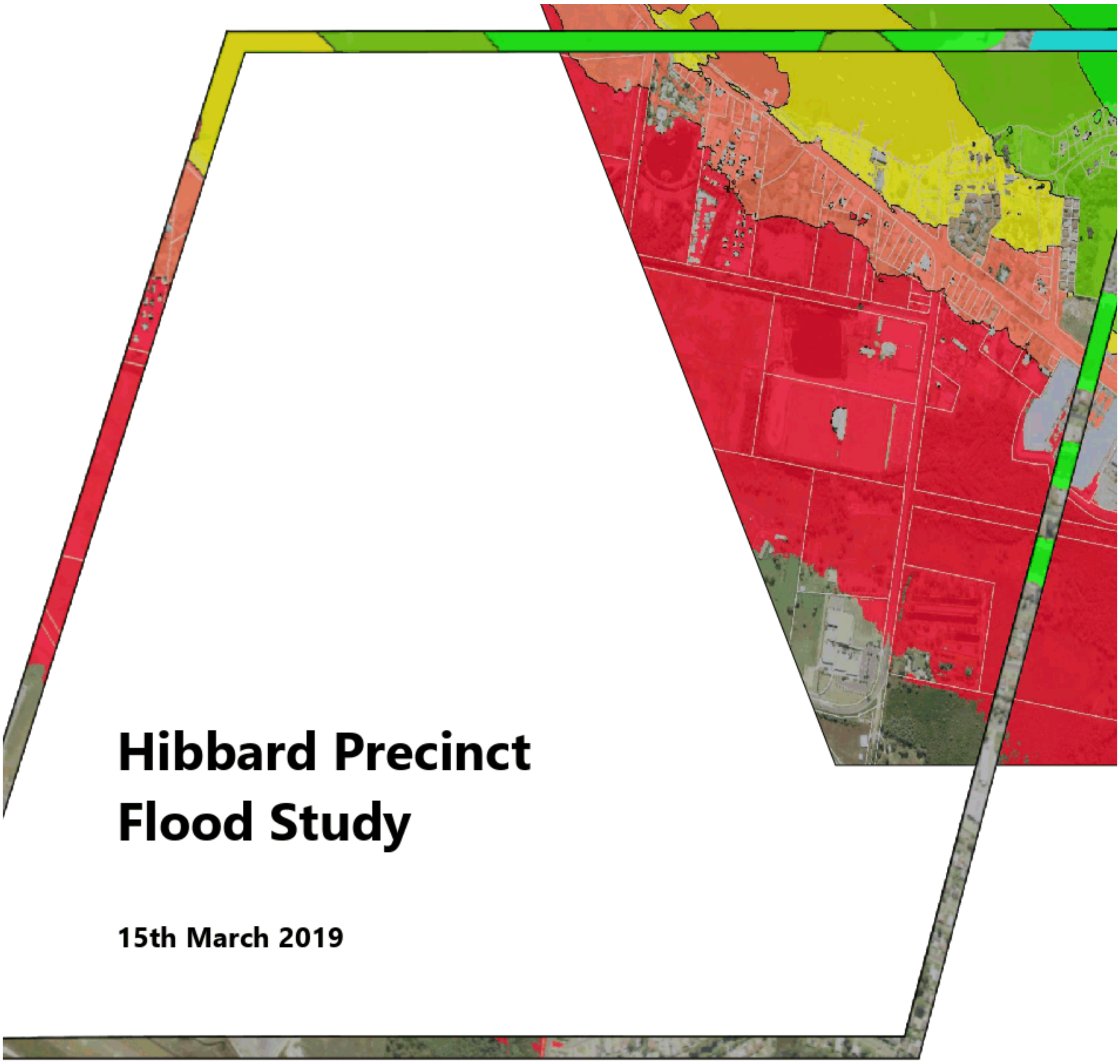
The updated hydraulic model has been calibrated to historical floods confirming its ability to reproduce historical flood behaviour on the catchment.

The updated flood study was used in a two stage approach to define the floodway corridor through the Hibbard precinct. The updated flood study also provides Council with a suitable platform for undertaking the subsequent stages of the Floodplain Management process, flood planning, and development of flood risk management strategies for the study area.

The *Hibbard Precinct Flood Study* (2019) is recommended to be placed on public exhibition.

Attachments

1View. Hibbard Precinct Flood Study - Final Draft (Rev B)



Hibbard Precinct Flood Study

15th March 2019

Level 17, 141 Walker St
North Sydney NSW 2060
Australia

rp301015-03826rg_crt190315-Hibbard Precinct FS (Rev B).docx

Revision B

www.advisian.com

Advisian
WorleyParsons Group

Disclaimer

Project: HIBBARD PRECINCT FLOOD STUDY

Rev	Description	Author	Reviewer	Advisian Approval	Date
A	Draft Report *(Issued for Client Review)*	RG	CRT	Chris Thomas	20/02/2019
B	Final Draft Report	CT	LT	Chris Thomas	15/03/2019

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Appendices

List of Figures

1 INTRODUCTION

The *Hastings River Flood Study* was published in 2006 and was based on flood modelling that was developed over the preceding 5 years. The study was developed from topographic and hydrographic survey data that was current at that time. The Flood Study (*2006*) included modelling results for the design 5%, 2%, 1% and 0.5% Annual Exceedance Probability (*AEP*) floods and for the Probable Maximum Flood (*PMF*), as well as mapping of provisional flood hazard and hydraulic categories.

The *Hastings Floodplain Risk Management Study* (*2012*) (*FRMS*) and the *Hastings Floodplain Risk Management Plan* (*2014*) (*FRMP*) examined a range of options for managing, mitigating and/or reducing the existing flood risk that the community of the lower Hastings Valley can be exposed to. This included consideration and modelling of structural measures such as levees, changes to planning controls and the preparation of emergency response community data sheets.

The FRMS (*2012*) also included a detailed review of the provisional floodway areas that were determined as part of the Flood Study (*2006*). This involved a detailed assessment of flooding patterns across floodplain areas to identify areas of significant flow followed by encroachment and blockage modelling to confirm and/or refine the extent of the floodway areas.

An updated flood study for the Lower Hastings River was published in September 2018. The *Hastings River Flood Study Update* (*2018*) presents updated flood characteristics for the region that have been derived from updated modelling that incorporates the physical changes to the floodplain that have occurred since 2006. The most notable of these changes include the upgrade to the Oxley Highway and construction of the new Pacific Highway between the Oxley Highway and Telegraph Point.

In addition to these topographic changes, the updated modelling included modifications to selected model parameters and an overall refinement of the RMA-2 model network to better utilise the processing and modelling capabilities of present-day computers and the RMA-2 modelling software.

The Updated Flood Study (*2018*) includes modelling results for the 1% AEP flood and a range of climate change scenarios. The climate change modelling considered various climate change scenarios which were identified in the 2012 and 2014 studies to provide Council with an understanding of the potential future changes to flood characteristics along the Hastings River downstream of the Bains Bridge crossing near Beechwood, as well as along the Wilson and Maria Rivers which drain the northern section of the valley.

The climate change scenario which has been relied upon for this study is based on a present day 1% AEP catchment flood event with a 900 mm provision for Sea Level Rise (*SLR*) and a 10% increase in rainfall intensity and volume due to predicted changes in emissions to the year 2100.

Following completion of the *Updated Hastings River Flood Study* (*2018*), Council commissioned Advisian to undertake detailed flood modelling and investigations for the Hibbard Precinct for the purpose of better defining the floodway between Fernbank Creek and the Hibbard Precinct.

The 2012 FRMS documented the provisional extent of this floodway and highlighted the need for it to be assessed at a local scale due to the existing development within or nearby to the floodway extent. The Implementation Plan included within the 2014 FRMP listed confirmation of the Hibbard Floodway extent as a priority item for Council's Floodplain Management Committee.

The primary goal of the Hibbard Precinct Flood Study is to define the extent of the floodway at a local scale, which will then be used to undertake a detailed investigation to assess options for maintaining the floodway into the future and for mitigating impacts associated with its adoption on affected landowners. The detailed investigation of the selected option(s) will form a future stage of this project.

Accordingly, the existing two-dimensional RMA-2 flood model (*last modified for the Hastings River Flood Study Update*) was further refined to incorporate additional topographic detail and physical features across the Hibbard Precinct. The upgraded flood model was used to confirm the importance of the floodway and to assess options for maintaining the flood function of this area of the floodplain. This report documents the findings from these investigations.

2 DESCRIPTION OF THE HIBBARD PRECINCT

2.1 Study Area

The Hibbard Precinct is situated along the southern floodplain of the Hastings River approximately four (4) kilometres west of the central business district (CBD) of Port Macquarie. As shown in **Figure 2.1**, Hibbard is located approximately 2.1 kilometres south-east of the Maria and Hastings River confluence and approximately 6.5 river kilometres west of the river entrance.

As shown in **Figure 2.2**, the Hibbard Precinct primarily consists of a mixture of residential and commercial properties the majority of which are located along Hastings River Drive, Boundary Street and Hibbard Drive. Many of the commercial properties are caravan parks or hotel/motel accommodation reflecting the strength of the local tourism market. The Precinct also includes several large areas of open space, sporting fields, creeks and wetlands. As shown in **Figure 2.2**, Port-Macquarie Regional Airport is located immediately south of the Precinct.

2.2 Topography

The topography across the Hibbard Precinct generally ranges between 1.0 and 4.0 mAHD. Between the Hastings River in the north and the Port Macquarie Airport in the south, the floodplain is generally flat with very little overall change in elevation. The topography does increase near the Port Macquarie Airport which is typically at or above 6.0 mAHD(*refer* **Figure 2.3**).

The lowest elevations throughout the Hibbard Precinct occur within the creek channels and waterbodies (*lake and wetlands*). The topographic mapping shown in **Figure 2.3** does not reliably represent the elevation in the vicinity of these waterbodies as the topographic data has been derived using Light Detection and Ranging (LiDAR) survey techniques. LiDAR techniques are not able to penetrate water surfaces. Accordingly, the elevations shown in **Figure 2.3** are likely to represent the water surface at the time of data capture.

Locations of higher terrain, such as areas with topographic elevation above 3.0 mAHD, are generally limited to areas of development across which a fill mound had been constructed. This includes the Ultiqa Village Resort and the Riverside Residential Village, both of which are located to the west of Hibbard, the Port Home Zone and commercial lots near the centre and the residences to the east (*refer* **Figure 2.3**).

3 REVIEW OF AVAILABLE DATA

3.1 Topographic Data

3.1.1 Aerial Laser Survey (ALS) and Light Detection and Ranging (LiDAR) Survey

The RMA-2 model that was originally developed as part of the *Hastings River Flood Study* (*2006*) and used extensively for flood investigations up to and including the *Updated Hastings River Flood Study* (*Exhibition Draft, 2018*) was developed based on Aerial Laser Survey (*ALS*) that covered the entire Port Macquarie-Hastings Local Government Area. The ALS data was obtained in September 2005 and comprises spot elevations across all terrestrial sections of the lower Hastings River floodplain at an average spacing of 1.4 metres. The data is understood to have been verified to a vertical and horizontal accuracy of 0.2 metres and 0.75 metres, respectively.

Further validation of the ALS data was undertaken by comparison against 1,970 test points gathered by traditional survey methods. The mean difference between ALS and field survey was found to be 0.03 metres with a standard deviation of 0.07 metres.

As part of the Hibbard Precinct Flood Study, Port Macquarie-Hastings Council provided Light Detection and Ranging (*LiDAR*) survey for the study area and it's surrounds. The metadata provided with the LiDAR survey indicates a collection date for the survey of May 2012 and vertical and horizontal accuracies of 0.3 metres and 0.8 metres, respectively.

The extent of 2012 LiDAR data made available for use in updating the RMA-2 flood model is shown in **Figure 3.1**.

A comparison of topographic elevations between the 2012 LiDAR and 2005 ALS survey is provided in **Appendix A** in **Figures A1** to **A4**. **Figures A1** and **A3** provide a comparison of topographic elevations based on an adopted low range of values of +/- 0.5 metres at intervals of 0.05 metres. **Figures A2** and **A4** provide a comparison of topographic elevations based on a high range of values of +/- 2 metres at intervals of 0.2 metres.

Figures A1 to **A4** generally indicate that changes to topographic elevations are sporadic between the two data-sets with neither clearly being higher or lower across the wider floodplain and across the Hibbard Precinct. Several locations of significant change in floodplain elevations align with known locations of development completed since 2002.

3.1.2 Hydraulic Controls

Survey data for hydraulic controls across the Hibbard Precinct was collected by Pacific Surveys at the commencement of the study. As shown in **Figure 3.2**, the survey involved collection of:

- Spot elevations along Tuffins Lane, Hastings River Drive, Boundary Street and Hibbard Drive (including road crests);
- Hydrographic survey of creek channels through and along the boundaries of the Ultiqa Village Resort to the east of Tuffins Lane;

- Survey of footbridges located within the Ultiqa Village Resort and the Hastings River crossing located to the west of the Aquatic Caravan Park; and,
- Elevations at the base and top of the impervious fence along the western boundary the Ultiqa Village Resort (*east of Tuffins Lane*) and the southern boundary of the Aquatic Caravan Park (*north of Hastings River Drive*).

Additional survey data collected by King & Campbell covering the road surface and shoulder areas of Boundary Street and parts of Hastings River Drive were also incorporated into the topographic survey data base. The extent of this survey data is also shown in **Figure 3.2**.

Cross-sections of all surveyed bridges are included within **Appendix B**.

3.2 Hydrographic Data

Hydrographic survey was also collected by Pacific Surveys at seventeen locations along the creek channels that pass through and around the Ultiqa Village Resort. The location and extent of the creek cross-sections collected are shown in **Figure 3.2**.

The cross-section data is also included within **Appendix B**.

No additional hydrographic survey was collected to define bed elevations along the Hastings River. Bathymetric data for the Hastings River was obtained as part of the *Hastings River Flood Study* (*2006*) and incorporated into the RMA-2 model. It is considered to still be representative of river bed conditions in the vicinity of Hibbard and sufficiently accurate for the modelling of flood conditions.

3.3 Previous Investigations

3.3.1 Lower Hastings River Flood Study (2006)

The *Lower Hastings River Flood Study* (*2006*) was prepared by Patterson Britton & Partners (*now Advisian*) for Port Macquarie-Hastings Council. The primary objective of the study was to quantify and define flood characteristics along the lower reaches of the Hastings, Wilson and Maria Rivers for existing topographic and development conditions. The report provides information relating to historic and design flood behaviour along both the Hastings and Wilson Rivers, including the flood immunity of the existing Pacific Highway crossing of both rivers.

The Flood Study indicates that the Hastings, Wilson and Maria Rivers have experienced significant flooding on a number of occasions in the past. The 1963 and 1968 floods are the largest floods to have occurred over the last 70 years and are considered to approximate the 1% Annual Exceedance Probability (*AEP*) (*also known referred to as the 100 year Average Recurrence Interval flood*) flood along the Hastings River (*Patterson Britton, 2006*).

A RAFTS-XP hydrologic model of the Hastings, Maria and Wilson River catchments was developed as part of the study and was used to establish discharge hydrographs for the design 20, 50, 100 and 200 year recurrence floods. The RAFTS model was calibrated using available daily read rainfall and pluviometer data, as well as streamflow data for a significant flood that occurred in 1978.

The model was also verified using available rainfall and streamflow data for a smaller flood that occurred in 1995.

Design flood characteristics for the Hastings, Maria and Wilson Rivers were defined using a fully two-dimensional hydrodynamic model that was developed using the RMA-2 software. The RMA-2 model was used to simulate flood behaviour during the design 20, 50, 100 and 200 year average recurrence floods.

The Probable Maximum Flood was also approximated using an equivalent extreme event. The extreme flood was approximated using a peak discharge equivalent to three (3) times the peak 100 year average recurrence flood discharge.

The RMA-2 model was calibrated and verified using historic flood mark information for floods that occurred in 1963, 1968, 1978 and 1995.

3.3.2 Hastings River Floodplain Risk Management Study (2012)

The *Hastings Floodplain Risk Management Study* (*2012*) (*FRMS*) expanded on the investigations carried out for the *Lower Hastings River Flood Study* (*2006*) by assessing a range of mitigation measures to reduce flood risk to the local community.

Several flood response (*or structural mitigation*) options were explored, including levees at Hibbard, Settlement Point and at two different locations at North Shore. These potential levee proposals were investigated in isolation and as part of various combinations of levees which were targeted toward protecting existing development from flooding while at the same time minimising the adverse impact of the levee on predicted peak flood levels elsewhere. A high flow bypass option was also considered for the purpose of alleviating the magnitude of flooding predicted at North Shore.

Each of the flood response options was modelled using modified versions of the existing case RMA-2 flood model. The modelling was undertaken to quantify the potential impact of each option on flood characteristics.

A triple-bottom line assessment was also undertaken to identify the flood response option that afforded the greatest benefit. The option involving construction of a levee system to protect North Shore and a concurrent levee system along Settlement Point was identified as having the best benefit relative to cost. This option was recommended in the Floodplain Risk Management Plan for further investigation with a view to developing a business case to support proceeding with implementation of the associated works.

The 2012 FRMS also addressed flood emergency management issues and provided recommendations for additions / changes to flood-related clauses within Council's existing Flood Policy. Response modification measures such as installation of extra stream flow gauges and road upgrades were proposed.

An interim assessment of climate change on flood levels was provided based on the modelling that had been completed at that time. However, it was recommended that a more detailed study be undertaken following the adoption of the Hastings Floodplain Risk Management Plan.

3.3.3 Hastings River Floodplain Risk Management Plan (2014)

The *Hastings River Floodplain Risk Management Plan (2014) (FRMP)* detailed the recommended flood, property and responses modification works first proposed in the 2012 FRMS. The FRMP prioritised the proposed works into low, medium and high priority tasks and provided an indicative cost estimate for each item of work.

Updates to planning controls and policies were given highest priority and included items such as adopting floodway and flood storage extents, changing relevant sections of the DCP and LEP as well as reviewing Section 149 Certificates for flood prone properties. High priority was also given for the raising of sections of Settlement Point Road, Shoreline Drive and North Shore Drive.

The FRMP also recommended that detailed flood modelling and investigations be undertaken for the Hibbard Precinct in order to better define the identified floodway between Fernbank Creek and the Hibbard Precinct. The confirmation of the Hibbard Floodway extent was prioritised by Council's Floodplain Management Committee. Advisian has prepared this Hibbard Precinct Flood Study in accordance with recommendations in the 2014 FRMP.

3.3.4 Updated Hastings River Flood Study (Exhibition Draft, 2018)

Council commissioned Advisian to undertake an update to the 2006 Hastings River Flood Study with the primary purpose of assessing the impacts of climate change on design flood characteristics (principally peak levels), in accordance with recommendations documented in the 2012 FRMS and 2014 FRMP. The update was also to incorporate any further physical changes to floodplain topography that could impact on flood characteristics.

The existing two-dimensional RMA-2 flood model was refined for this Updated Flood Study and was used to update flood maps for the 1% AEP flood event. A range of development that has occurred across the floodplain since 2006 was also incorporated into the updated flood model. This included road embankments, bridge and culvert structures associated with the Oxley Highway upgrade and the new section of the Pacific Highway between the Oxley Highway and Telegraph Point.

The climate change assessment considered five scenarios:

- Scenario 1- 100 year ARI catchment event with 900 mm Sea Level Rise (SLR) + 10% increase in rainfall intensity and volume
- Scenario 2 - 100 year ARI catchment event with 900 mm SLR
- Scenario 3 - 100 year ARI catchment event with 400mm SLR + 10% increase in rainfall intensity and volume
- Scenario 4 - 100 year ARI catchment event with 400 mm SLR
- Scenario 5 - PMF event with 900 mm SLR (*900 mm SLR applied to the adopted 100yr Tide 2.2 mAHD*)

Aside from the PMF scenario, it was found that Scenario 1 provided the most conservative estimate for flood level increases both across tidally influenced areas and in areas further upstream.

As Scenario 1 is consistent with previous NSW SLR Policy Statement benchmarks, Council's Coast, Estuary and Floodplain Advisory Sub-Committee recommended that it be adopted for future flood planning and floodplain management policies. Accordingly, this study proceeded on that basis, providing peak flood levels and mapping based on the application of Scenario 1 in the updated flood modelling.

However, at its December 2018 meeting, Council adopted Scenario 3 as the basis for defining Flood Planning Levels (FPLs). That is, it adopted the 400 mm sea level rise scenario as the basis for defining FPLs.

The timing of this policy decision coincided with completion of most of the modelling that was undertaken for this report, which was based on Scenario 1. In order to ensure that the project is not delayed, Council instructed that the Hibbard Precinct Flood Study be completed based on the existing modelling and that further modelling to generate flood levels and flooding mapping based on Scenario 3 be completed as part of management study (options) phase.

4 HIBBARD PRECINCT RMA-2 FLOOD MODEL

4.1 Background

The RMA-2 model adopted for the Hibbard Precinct investigations was first developed in the years preceding 2006 as part of the *Hastings River Flood Study* (*2006*). The model was later relied upon for a range of studies including the *Hastings River Floodplain Risk Management Study* (*2012*), various studies associated with the Pacific Highway Upgrade (*2007 onwards*) and the *Updated Hastings River Flood Study* (*2018*). The history of the development of the RMA-2 flood model is discussed in the following sections.

4.1.1 2006 Flood Study Model

Flood characteristics for the lower Hastings, Maria and Wilson Rivers were until recently defined by the results of flood modelling that was completed between 2004 and 2006 as part of the *Hastings River Flood Study* (*2006*). A two-dimensional (2D) hydrodynamic flood model was developed as part of the Flood Study using the RMA-2 software package. The model was calibrated against significant historical floods including the 1963 and 1968 events and was applied to simulate a range of design floods including the 1% Annual Exceedance Probability (AEP) flood.

The RMA-2 model was developed from available bathymetric data for the major tributaries and Aerial Laser Survey (ALS) data that was obtained for floodplain areas extending to the predicted extent of the Probable Maximum Flood (PMF). It covered the full extent of the Hastings River floodplain from the Bains Bridge crossing near Beechwood to the ocean entrance at Port Macquarie. The model also included the floodplains of the Wilson and Maria Rivers extending downstream from the Pacific Highway crossing of the Wilson River near Telegraph Point and south along the Maria River from its headwaters near the Port Macquarie-Hastings LGA and Kempsey Shire LGA boundary.

The extent of the 2006 RMA-2 flood model is shown in **Figure 4.1**.

The 2006 RMA-2 model was limited in size and level of detail by the processing limitations of both the modelling software and the computer hardware that was available at the time. It is important to recognise that although the Flood Study was formally adopted in 2006, the network generation and flood modelling was largely completed by December 2004. There have been many advancements in both the software and the processing capacity of computers since then.

The 2006 model was based on topographic elevations defined at 12,900 nodes and floodplain roughness' defined across 14,450 model elements. The 2006 RMA-2 model network is shown in **Figure 4.1**.

Between 2006 and 2015, the RMA-2 model was used as the basis for numerous flood related investigations. These included the following:

- Hydrology and Hydraulics investigations for the Pacific Highway Upgrade between the Oxley Highway and Kundabung.

This included investigations for the river crossings of the Hastings and Wilson Rivers and their associated floodplains for the Environmental Impact Statement, for the concept design and for the detail design and construction phases of the project.

- The *Hastings Floodplain Risk Management Study* (*2012*).

  This involved an assessment of a range of flood modification measures aimed at reducing potential flood damages that could be experienced in rural, commercial and residential areas.

In addition, the RMA-2 flood model has been used extensively as a tool to assess residential and commercial development applications proposed at a range of locations across the floodplain including, but not limited to, Wauchope, Sancrox, Hibbard, North Shore and the western areas of Port-Macquarie.

Each of the investigations completed post 2006 has involved varying degrees of updates to the 2006 RMA-2 flood model. The updates have in most cases been confined to localised network refinements completed to ensure the topography in the vicinity of the area of interest was reliably defined. In many cases, this has involved the inclusion of updated topographic data based on detailed site survey. An example of this is the work-as-executed survey obtained for the Pacific Highway Upgrade Project to define the post-development road surface and drainage infrastructure.

The updates to the RMA-2 flood model between 2006 and 2015 led to a significant increase in model size with the total number of nodes and elements increasing to 31,600 and 35,700, respectively. This represents a 250% increase in the number of model nodes and elements relative to 2006 and reflects the greater level of topographic detail that was incorporated into the model over this period. This greater level of floodplain delineation within the model network enables more reliable results to be produced.

4.1.2 2018 Updated Flood Study Model

The RMA-2 flood model that was developed as part of the *Hastings Flood Study* (*2006*), and refined as part of subsequent flood investigations in the years following, was then updated to formalise the network changes that have occurred since 2006 and to ensure the model could be reliably used to simulate a range of climate change scenarios.

The following major changes to the RMA-2 model were completed as part of the *Updated Hastings River Flood Study* (*2018*):

(i) Consolidation of all previous model updates to create the most up-to-date representation of the Hastings River floodplain

(ii) Inclusion of the recently constructed Oxley Highway between Port Macquarie and Thrumster

(iii) Model refinement along the peripheries of the floodplain in particular for areas between the 1% AEP and PMF flood extents

The changes outlined above led to an increase in the number of model nodes and elements from 12,900 and 14,450 to 49,300 and 57,800, respectively. In that regard, the present-day version of the RMA-2 model is based on four times the number of nodes and elements to define the topography and roughness compared to the 2006 version.

An overview of the 2018 RMA-2 updated model network is shown in **Figure 4.1**.

A comparison of the changes to the RMA-2 model network between 2006 and 2018 is provided in **Figures 4.2** to **4.5**. The comparison shows the extent to which additional detail has been incorporated into the RMA-2 model across the entire model domain, including the Hibbard Precinct.

4.2 Flood Model Updates

4.2.1 Model Network

The RMA-2 model that was developed for the *Updated Hastings River Flood Study* (*2018*) was used as the base model for the Hibbard Precinct investigations which are the subject of this report. As the model had been developed and used for regional scale investigations, it was considered beneficial to further refine the model network for the local scale investigations required to assess the provisional floodway delineation previously determined for the Hibbard Precinct.

More detailed topographic data was also collected as part of the study to assist with the local scale definition of topography and key physical features. As discussed in **Section 3.1**, this included Light Detection and Ranging (*LiDAR*) survey, spot elevations of hydraulic controls such as road and fence (*brick and concrete only*) crest heights, creek cross-sections and details of bridge and culvert crossings.

The refinements in the vicinity of the Hibbard Precinct led to an increase in the total number of nodes and elements from 49,300 and 57,800 to 64,150 and 77,700, respectively. This represents an increase in the number of nodes and elements of more than 30%, all of which were incorporated only in the vicinity of Hibbard.

The final RMA-2 model network across the Hibbard Precinct is shown in **Figure 4.6**. The upgraded network includes a much finer network spacing, particularly at hydraulic controls such as roads, impervious fences, buildings and channels. In that regard, where the topography is generally flat the network spacing can be larger without affecting the reliability of the flood model predictions.

4.2.2 Model Topography

Topographic elevations within the RMA-2 model are assigned to each node based on the most reliable data source available. In that regard, most nodes across the Hibbard Precinct have been assigned elevations based on the 2012 LiDAR survey. The exceptions to this are:

- Crest elevations along Tuffins Lane, Boundary Street, Hastings River Drive and Hibbard Drive have been assigned based on surveyed spot elevations.
- Elevations at the base and crest of brick fences (*such as those located along Tuffins Lane along the part of the western boundary of the Ultiqa Village Resort and at the Aquatic Caravan Park*) based on surveyed spot elevations, *refer* **Plates 4.1** *and* **4.2**.
- Bed elevations along creeks based on surveyed cross-sections, and
- Elevation and locations of bridge approach abutments, piers and culverts.

Plate 4.1 Brick Fence along Tuffins Lane and the western boundary of the Ultiqa Village Resort

Plate 4.2 Brick Fence along Hastings River Drive and the southern boundary of the Aquatic Caravan Park

The final elevations assigned to the RMA-2 model nodes are shown in **Figure 4.7** as thematic terrain mapping.

Elevations for nodes outside of the study area were not changed as part of these updates. That is, all areas outside of the study area have been unchanged from the model version developed as part of the *Updated Hastings River Flood Study* (*Exhibition Draft, 2018*) and as discussed in **Section 4.1.2**.

4.2.3 Model Roughness Values and Distribution

Roughness values for creek channels and overbank areas were estimated across the Hibbard Precinct from aerial photograph analysis and field observations. Element types were delineated to '*pick-up*' distinct variations in hydraulic roughness across the floodplain. In some instances, the RMA-2 model network was refined to allow greater delineation of element types where it was considered that a variation in roughness was warranted.

To allow for greater discretisation of roughness values throughout the study area a new set of material roughness types was created for specific use within the study area. This option was preferred as opposed to using the existing types and values that had been adopted for the remainder of the RMA-2 model domain due to the greater concentration of urban development.

The roughness types and values adopted for the Hibbard Precinct are listed in **Table 4.1**.

Table 4.1 ADOPTED RMA-2 MODEL ROUGHNESS PARAMETERS FOR THE HIBBARD PRECINCT

RMA-2 ELEMENT NUMBER^	DESCRIPTION	ROUGHNESS PARAMETER VALUE
1	Waterway Clear	0.030
2	Waterway Overgrown	0.080
3	Bridges & Culverts	0.100
4	Grassed Floodplain	0.035
5	Light Trees / Foliage	0.055
6	Moderate Trees / Foliage	0.075
7	Dense Trees / Foliage	0.095
8	Urban Area – Open and Unobstructed	0.040
9	Urban Area – Clutter and Fences	0.060
10	Buildings – Blocked to Flow	N/A
11	Roadways and Hardstand Areas	0.015
12	MDST Flow Control Element ^^	N/A

^ *The listed element numbers and roughness types are only applicable to the RMA-2 model network across the Hibbard Precinct study area. Accordingly, the element numbers and types does not include those adopted elsewhere across the remainder of the model domain.*

^^ *MDST Flow Control Elements are used at critical flow locations (such as weirs, fences and road embankments) to reduce the potential for sub-surface flows.*

The distribution of material types across the Hibbard Precinct based on the final model network is shown in **Figure 4.8**.

4.2.4 Boundary Conditions

The Hastings River RMA-2 model has three upstream boundary conditions and one downstream boundary. The three upstream boundaries are used to input flow hydrographs into the model and are located as follows:

(i) The Hastings River approximately 500 metres upstream of Bains Bridge (*approximately 5.5 river kilometres upstream of the Wauchope Railway Bridge*).

(ii) The Wilson River approximately 3.5 river kilometres upstream of the Pacific Highway Crossing at Telegraph Point, and

(iii) The Maria River approximately 1 kilometre north of the confluence with the Wilson River.

The only downstream boundary is located approximately 1 kilometre east of the Hastings River breakwater/river entrance and 6.5 kilometres east of Hibbard. For all simulations time-varying ocean levels are defined at the downstream boundary.

The locations and configuration of the boundary conditions adopted for the Hibbard Precinct RMA-2 model match those used for the *Updated Hastings River Flood Study* (*Exhibition Draft, 2018*) modelling.

4.3 Validation to the February 2013 Flood

Calibration and verification of any hydraulic flood model is an important step in the model development process. If an acceptable calibration of the model to recorded events can be achieved, it ensures the reliability of the results of design flood simulations such as the 1% Annual Exceedance Probability (*AEP*) flood.

As discussed in **Section 3.3**, the RMA-2 model was calibrated and verified as part of the *Hastings River Flood Study* (*2006*) using flood mark information recorded for floods that occurred in 1963, 1968, 1978 and 1995. Out of these four events, one flood mark was recorded in the vicinity of the Hibbard Precinct for the 1963, 1968 and 1995 events (*refer Section 6.3 of the 2006 Flood Study*).

The community consultation undertaken in the early stages of the study identified the February 2013 flood as an event of significance to the local community. Data gathered during the consultation process included the location and height that floodwaters reached at the peak of the event. Following discussions with residents, a surveyor was commissioned to collect elevations for four (4) flood marks that were identified as representative peak levels for the February 2013 at Hibbard. The location and surveyed elevation of each of the February 2013 flood marks is shown in **Figure 4.9**.

Rainfall and streamflow records were also obtained from data loggers for those gauges that were operational, and which fall within the Hastings River catchment. The locations of all streamflow gauges for which data was collected are shown in **Figure 4.10**.

4.3.1 February 2013 Event Overview

On the 18th February 2013, a low-pressure system formed off the east coast of Australia. Over the next few days the system tracked in a westerly direction, making landfall on the north coast of New South Wales on the 22nd February (*refer* **Plate 4.3**). This resulted in widespread, persistent and heavy rainfall across the Hastings River catchment.

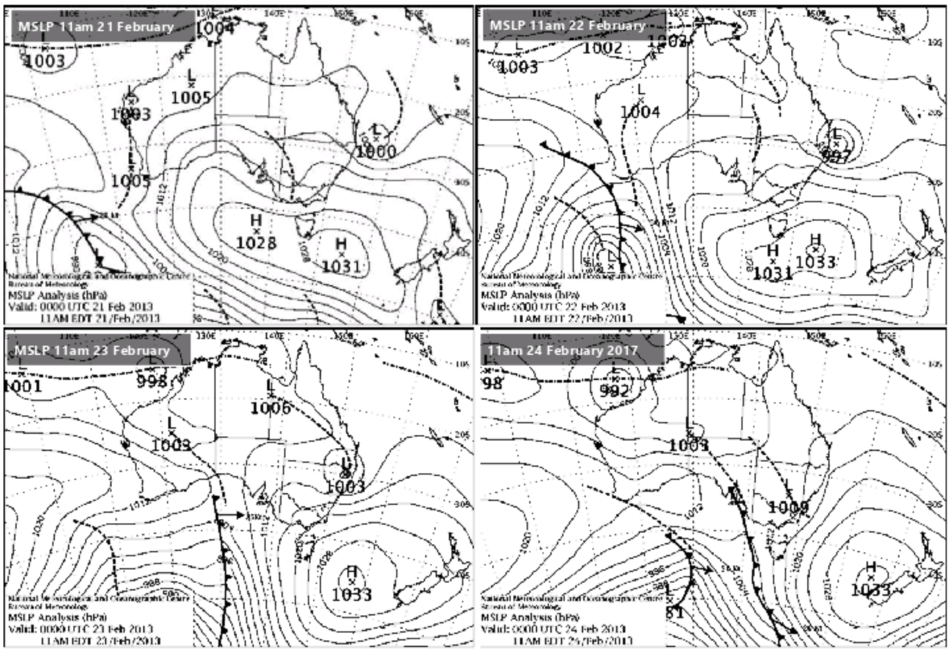

Plate 4.3 Mean Sea Level Pressure (MSLP) Plots for the February 2013 Event

Rainfall across the Hastings River catchment was well above average during February 2013 (*refer* **Plate 4.4**). Heaving rain and thunderstorms affected large parts of the New South Wales east coast between the 20th and 25th of February, with locally heavy rainfall breaking records at some locations.

Severe thunderstorms affected parts of the Hastings River catchment between the 22nd and 23rd February, with multiple rainfall gauges recording over 150 mm in a 24-hour period across the two days. The BOM rainfall gauge at Yarras recorded 415 mm in the period between 9am on the 22nd February and 9am on the 23rd February.

Cumulative rainfall totals for the month of February 2013 as recorded at various daily-read gauges and pluviographs throughout the catchment are presented in **Plate 4.5**. The data shows that significant rainfall was recorded throughout February, most notably between the 22nd and 24th.

An estimate of the Annual Exceedance Probability (*AEP*) can be determined by comparing the recorded rainfall totals to Intensity-Frequency-Duration for various durations. Due to large spatial extent of the Hastings River catchment this analysis was undertaken for rainfall data recorded across the upper, middle and lower parts of the catchment.

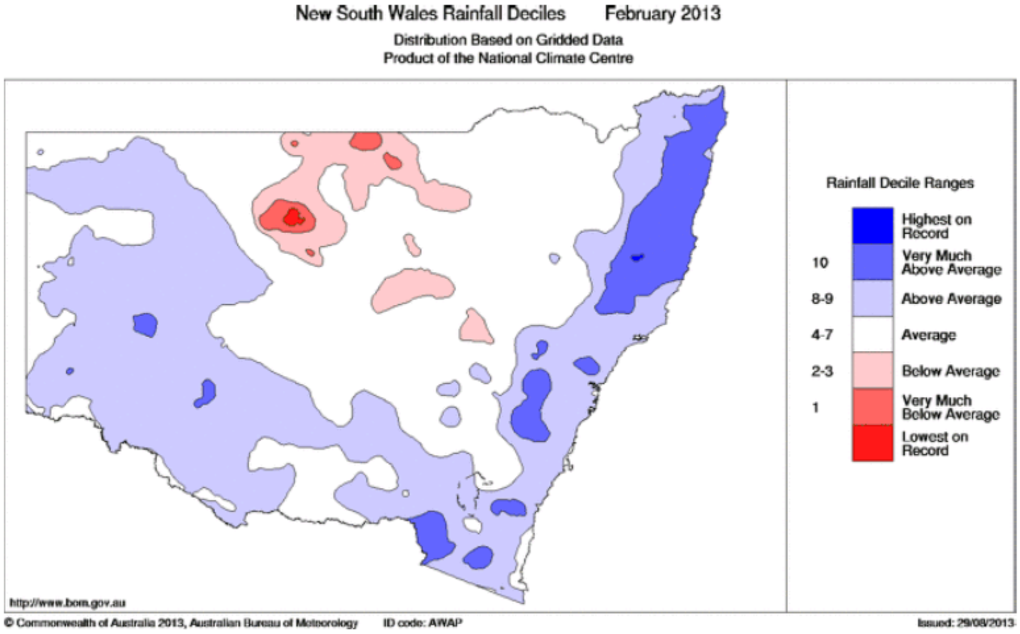

Plate 4.4 Monthly Rainfall Totals across New South Wales

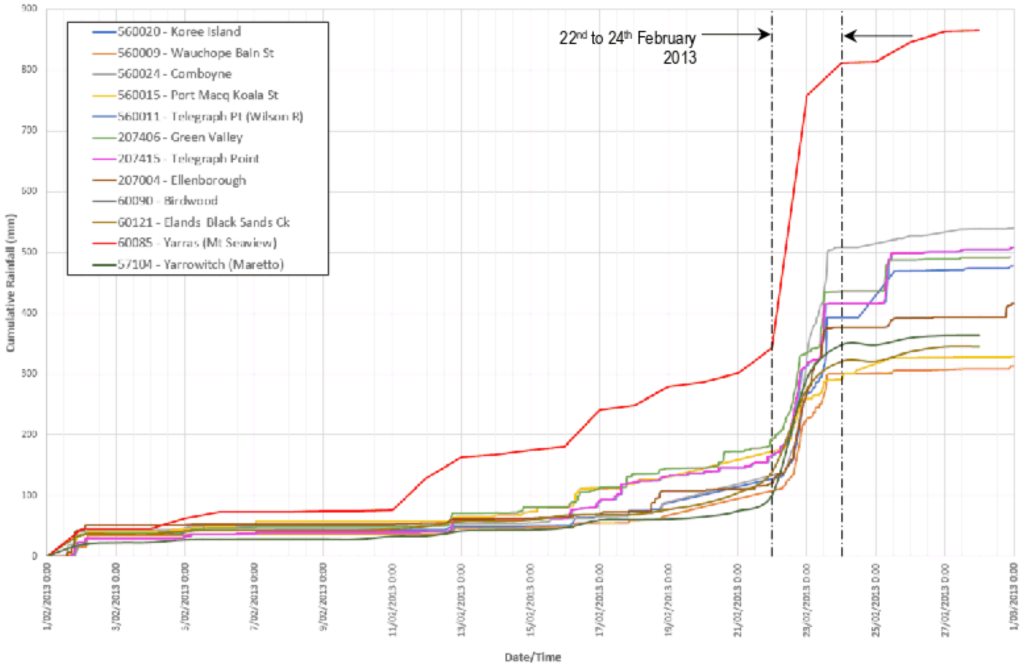

Plate 4.5 Cumulative Rainfall Totals across the Hastings River Catchment for February 2013

As shown in **Plate 4.6**, **Plate 4.7** and **Plate 4.8** for the upper, middle and lower catchments, respectively, a maximum AEP for all gauges and durations of between 2% and 1% AEP was recorded at the Yarras Gauge (*60085*) for a 24 hour duration.

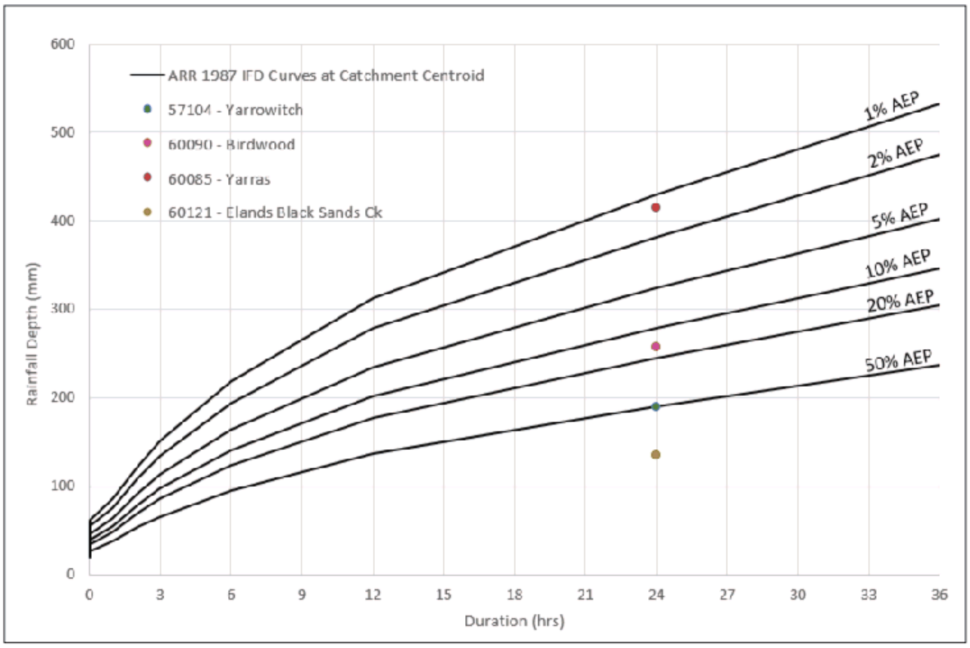

Plate 4.6 Annual Exceedance Probability (AEP) of Rainfall recorded for the February 2013 Event across the Upper Hastings River Catchment

Based on **Plate 4.6**, the rainfall recorded at the Yarras Gauge over a 24 hour period was in the order of a 1.2% AEP event; which is approximately equivalent to an average recurrence interval of 83 years.

It should be noted that each of the Yarras, Yarrowitch, Birdwood and Elands Black Sands Creek rainfall gauges referred to in **Plate 4.6** are daily read rainfall stations; that is, the depth of rainfall is measured once every 24 hours (typically at 9 am). All other gauges within the catchment are continuous recording stations which have the capacity to generate pluviographs. Therefore, for the gauges referred to in **Plate 4.6**, it is only possible to approximate AEPs for the 24-hour duration storm and hence the recorded rainfall is presented as a coloured "dot" corresponding to the different gauges.

The second largest rainfall total for the February 2013 event was recorded at the Comboyne Gauge (560024), which is located in the southern section of the Upper Hastings River Catchment. As shown in **Plate 4.7**, the Comboyne Gauge recorded 325 mm over a 24 hour period. This equates to a 5% AEP event for this duration; ie., equivalent to an average recurrence interval of once every 20 years.

All other gauges across the upper and middle areas of the catchment recorded rainfall that was approximately equivalent to the ARR 87 estimate for the 20% AEP event; ie., equivalent to an average recurrence interval of once every 5 years.

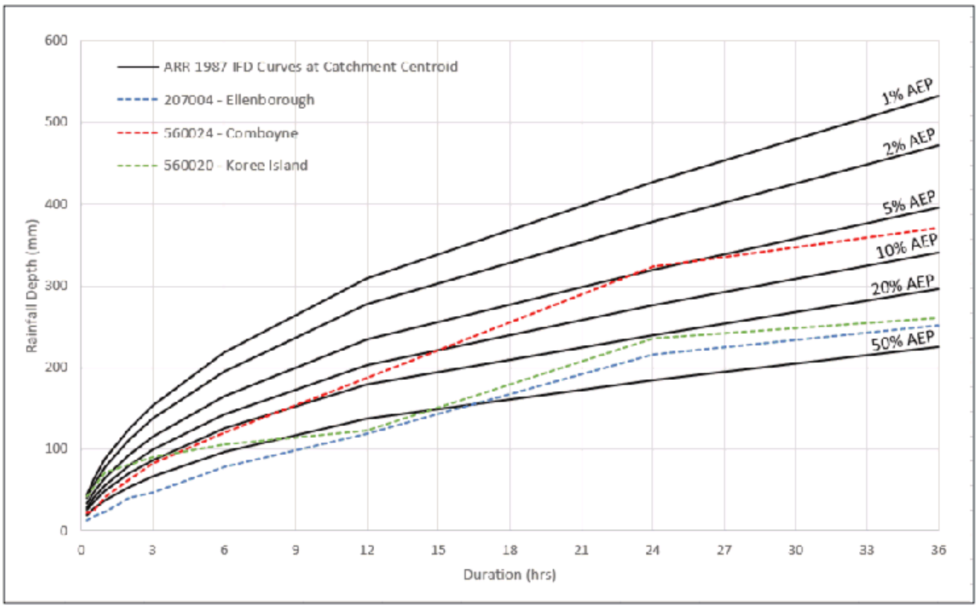

Plate 4.7 Annual Exceedance Probability (AEP) of Rainfall recorded for the February 2013 Event across the Middle Hastings River Catchment

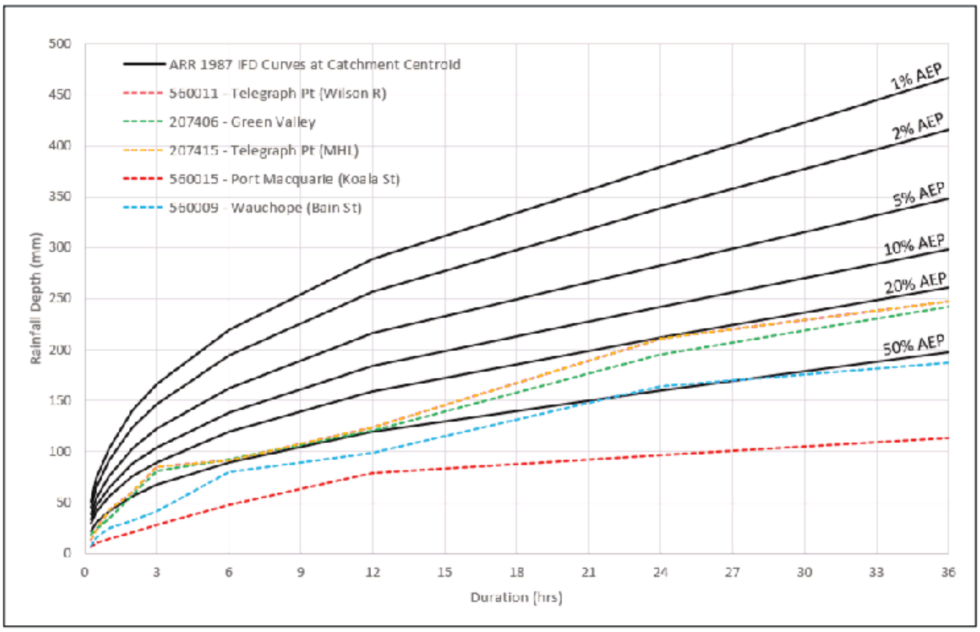

Plate 4.8 Annual Exceedance Probability (AEP) of Rainfall recorded for the February 2013 Event across the Lower Hastings River Catchment

4.3.2 Hydraulic Model Inflows – XP-RAFTS Modelling

The validation was completed using an updated version of the XP-RAFTS hydrologic model that was developed as part of the *Updated Hastings River Flood Study* (*Exhibition Draft, 2018*). This updated version of the model was adopted as it incorporates increased sub-catchment definition downstream of the boundary inflow locations to the RMA-2 hydraulic model which can be used to validate predicted flows against those recorded at available streamflow gauges.

An overview of the rainfall gauges relied upon and the spatial distribution adopted to simulate the February 2013 event in XP-RAFTS is shown in **Figure 4.11**. Rainfall data from a total of eleven (*11*) gauges was used to define the rainfall distribution across the catchment.

Due to the lack of pluviometers in the upper catchment, sub-catchments west of Ellenborough and Kindee Bridge relied on daily rainfall totals which were temporally distributed according to the temporal distribution recorded at Ellenborough (207004) and Comboyne (560024), respectively.

Figure 4.12 and **Figure 4.13** provide a comparison between discharge hydrographs simulated using XP-RAFTS and hydrographs derived from rating curves and data recorded at the Ellenborough gauge (*Hastings River*) and at Avenal Gauge (*Wilson River*), respectively.

As shown in **Figure 4.12**, the predicted flow hydrograph at Ellenborough matches well to the recorded data. It has a similar shape to the recorded hydrograph and generates a similar peak discharge (*3,567 m^3/s compared to 3,660 m^3/s*).

As shown in **Figure 4.13**, validation of the model to recorded data from the Avenal Gauge is less convincing. It was not possible to match both the recorded peak discharge and the double peak evident in the recorded hydrograph shape. The multiple simulated hydrographs presented in **Figure 4.13** show the extensive scenario testing that was undertaken to achieve better validation by using different combinations of recorded temporal distributions and daily rainfall totals.

Because a reasonable fit between predicted and recorded discharges could not be achieved at the Avenal Gauge (*Wilson River*) it was decided that the recorded flows would be adopted for input into the RMA-2 model. This was the case only for the Wilson River inflow with all other inflows (*boundary and element*) based on results derived from the "validated" XP-RAFTS model.

4.3.3 RMA-2 Model Validation

Validation of the Hibbard RMA-2 model was undertaken by adopting the inflow hydrographs extracted from the XP-RAFTS model at the Hastings River and Maria River inflow locations. For the reasons outlined above, the recorded hydrograph for the Wilson River was adopted as the upstream boundary condition at Telegraph Point. Flows generated from rainfall falling across sub-catchments within the RMA-2 model domain were input as local element inflows.

A comparison of predicted flood level hydrographs to recorded levels at gauges located within the RMA-2 model domain are shown on:

- **Figure 4.14** for the Hastings River at Wauchope Railway Bridge Gauge (*207401*)
- **Figure 4.15** for the Wilson River at Telegraph Point Gauge (*207415*)
- **Figure 4.16** for the Hastings River at Dennis Bridge Gauge (*207444*)
- **Figure 4.17** for the Hastings River at Settlement Point Gauge (*207418*), and,
- **Figure 4.18** for the Hastings River at Port Macquarie Gauge (*207420*).

Flood levels predicted by the RMA-2 model for the February 2013 event are considered to match reasonably well to the recorded data. In particular, the shape of the flood level hydrographs are well replicated and differences in peak levels were generally within 0.2 to 0.3 metres, or better. As the focus of this study is the Hibbard Precinct, the validation evident by the comparisons outlined above were considered to be adequate.

Accordingly, no modifications were made to the RMA-2 model network or adopted roughness parameters to try to improve the validation to recorded gauge data.

A comparison of peak February 2013 flood levels predicted using the Hibbard RMA-2 flood model against flood marks recorded in the vicinity of Hibbard is presented in **Figure 4.19**.

The RMA-2 flood model generates peak flood levels which are in good agreement with the two HWMs surveyed at a residential property located along Boundary Street. Predicted and recorded flood levels are within 0.01 and 0.04 metres at these locations. Predicted flood levels generated from the RMA-2 model are within 0.09 metres of the recorded HWM located along Hibbard Drive and along the river frontage.

A final HWM located on the banks of the '*Southern Cove*' is considered to be unreliable due to conflicting information provided by the landowner.

Overall the Hibbard RMA-2 flood model is considered to predict flood levels for the February 2013 event that are in good agreement to the three (3) reliable flood marks located within the study area. The good agreement to these flood marks, and the reasonable agreement to the available gauge records, indicates that the RMA-2 flood model that has been developed for the Hibbard Precinct is a reliable tool for use in predicting design flood characteristics across the precinct.

4.4 Sensitivity Analysis

An analysis was completed for the 1% AEP flood to assess the sensitivity of the results generated by the Hibbard RMA-2 flood model to variations in adopted parameters and to changes to model inputs. The following sensitivity scenarios were simulated.

- **Sensitivity Scenario 1** – Modelling of buildings within the precinct based on the allowing them to be "flooded" but applying a roughness of 0.15 as opposed to having the buildings completely "blocked out" such that no flow travels through them during a simulation.
- **Sensitivity Scenario 2** – 20% increase to the roughness value for all elements within the study area.

- **Sensitivity Scenario 3** – 20% decrease to the roughness value for all elements within the study area.
- **Sensitivity Scenario 4** – Reduced ocean tailwater levels from peaks of 2.2 mAHD to 0.5 mAHD; reduction by 1.7 metres.

Flood level difference mapping was prepared for each sensitivity scenario and is presented in **Figures 4.20** to **4.23**.

As shown in **Figure 4.20**, peak flood levels for the 1% AEP event were not sensitive to changes to the approach adopted for modelling buildings (*Sensitivity Scenario 1*). By allowing floodwaters to enter the building footprints, albeit with a high roughness value, peak 1% AEP flood levels reduced slightly (*by up to 0.02 metres*) across areas south of Hastings River Drive. The reduction in levels is attributed to a minor increase in available flood storage.

Sensitivity Scenarios 2 and 3 were found to cause the smallest change to peak 1% AEP flood levels across Hibbard. As shown in **Figure 4.21** and **4.22**, the changes to roughness values caused maximum changes to flood levels of +/- 0.01 metres.

It is worth noting again that the changes to roughness values were only applied to those parts of the network within the study area. Areas outside the Hibbard Precinct were not altered from the roughness values adopted in the modelling undertaken for the Updated Hastings River Flood Study (*Exhibition Draft, 2018*).

Sensitivity Scenario 4 generated the largest change in peak 1% AEP flood levels across Hibbard. As shown in **Figure 4.23**, 1% AEP catchment flood levels across Hibbard would be lowered by about 0.35 metres if the assumed peak ocean level is reduced from 2.2 to 0.5 mAHD. This indicates that the level that floodwater reach at Hibbard during large floods is particularly influenced by ocean entrance conditions and specifically ocean storm surge levels. The 1963 flood is considered to be the largest recorded flood in the lower Hastings Valley. It was characterised by elevated ocean levels which prevented floodwaters from the upper catchment discharging to the ocean. This led to elevated flood levels across the area downstream of Dennis Bridge, including Hibbard.

Notwithstanding, the results of Sensitivity Scenario 4 also show that it takes a substantial reduction in ocean level to result in a modest reduction in peak 1% AEP flood level at Hibbard – compare a 1.7 m reduction in ocean level to a resultant reduction in 1% AEP flood level at Hibbard of only 0.35 m. In reality, the meteorology that would generate major flooding in the Hastings Valley is unlikely to be independent of an elevated ocean condition. For example, an East Coast Low similar to that which made landfall at Newcastle in June 2007 is considered to be characteristic of the weather event that would cause major flooding in the Hastings. East Coast Lows typically generate ocean levels that exceed 1.8 mAHD.

Therefore, although the choice of ocean level for modelling is shown by Sensitivity Scenario 4 to have the potential to lower 1% AEP flood levels at Hibbard, the adoption of an ocean level for the generation of flood levels for planning purposes (*e.g., setting minimum floor levels for residential development*) would necessitate the adoption of an ocean level of 1.8 mAHD or higher, which in turn would result in very little reduction in the 1% AEP flood levels generated for this report.

5 DESIGN EVENT MODELLING

5.1 General

Design floods are hypothetical floods that are commonly used for planning and floodplain risk management investigations. Design floods are based on statistical analysis of rainfall and flood records and are defined by their probability of occurrence. For example, a 1% Annual Exceedance Probability (*AEP*) flood is the best estimate of a flood that will have a 1 chance in 100 of occurring in any given year.

Design floods can also be expressed by their expected interval of occurrence, for example the 1% AEP flood can also be expressed as the 100 year Average Recurrence Interval (*ARI*) flood. That is, it represents a flood that is likely to occur on average, once in every one hundred years.

It should be noted that there is no guarantee that the design 1% AEP flood will occur just once in a one hundred year period. It may occur more than once, or at no time at all in the one hundred year period. This is because the design floods are based upon a statistical '*average*'.

5.2 Hydrodynamic Modelling

5.2.1 Design Simulations

The Hibbard RMA-2 flood model that was developed for the project was used to simulate flooding of the Hastings River across the Hibbard Precinct and adjoining floodplain. The model was used to simulate the design 5% and 1% AEP flood events, and an adopted Extreme Flood.

The design simulations were based on a range of boundary condition data which is described in the following sections.

5.2.2 Inflow Hydrographs

Upstream boundary conditions were defined for each design flood based on the inflow hydrographs generated using the RAFTS hydrologic model developed as part of the *Lower Hastings River Flood Study* (*2006*). In that regard, the adopted inflow hydrographs are unchanged to those adopted for the 2006 Flood Study.

The peak flows for each design event at the three upstream inflow locations to the RMA-2 model are listed in **Table 5.1**. As shown in **Table 5.1**, the adopted Extreme flood event has been assumed to correspond to a flood that is three (3) times the magnitude of the peak flow for the 1% AEP flood. Inflow hydrographs for the 5% and 1% AEP floods and the adopted Extreme Flood are shown graphically in **Figures 5.1 to 5.3** for the Hastings, Wilson and Maria Rivers, resepctively.

5.2.3 Ocean Levels

Ocean boundary conditions for each design flood are defined based on the varying tide levels adopted as part of the *Lower Hastings River Flood Study* (*2006*). Accordingly, a varying tidal boundary condition with a peak level of 2.2 mAHD was adopted for all design flood simulations.

The adopted tidal boundary condition is shown graphically in **Figure 5.4**.

Table 5.1 Peak Flows for Design Events Extracted from the Flood Study (2006)

Inflow Location	Peak Flow (m^3/s)		
	5% AEP Event	1% AEP Event	Extreme Flood
Hastings River	4,565	**6,848**	20,550
Wilson River	1,740	**2,707**	8,115
Maria River	420	**711**	2,130

5.3 Design Flood Modelling Results

5.3.1 Peak Flood Levels and Extents

Peak flood level estimates were extracted from the modelling results and were used to generate flood extent and flood level plots for each design events. The plots show the variation in flood levels across the Hibbard Precinct at contour intervals of 0.1 metres. Mapping for the 5% and 1% AEP flood events are shown in **Figures 5.5** and **5.6**, respectively. Mapping for the adopted extreme event is presented in **Figure 5.7**.

The variations in peak flood levels between design events are listed in **Table 5.2** for six points scattered across the Hibbard Precinct. The locations of each point selected for this comparison are identified on **Figures 5.5** to **5.7**.

Table 5.2 Comparison of Peak Flood Levels Predicted for Each Design Event at Points Throughout the Hibbard Precinct

Flood Level Comparison Points ^	Predicted Flood Levels (*mAHD*)		
	5% AEP Flood	1% AEP Flood	Extreme Flood Event
A	2.53	3.24	7.57
B	2.53	3.23	7.51
C	2.53	3.23	7.38
D	2.50	3.12	7.35
E	2.51	3.16	7.40
F	2.40	2.95	7.26
G	2.39	2.96	7.12
H	2.35	2.88	7.00

^ Point locations are identified on **Figures 5.5** to **5.7**

5.3.2 Peak Flood Depths

Peak flood depth estimates were extracted from the flood modelling results and were used to generate depth mapping for each of the design events. The plots show the variation in flood depths across Hibbard at the peak of each event.

Peak depths for the 5% AEP flood event are shown in **Figure 5.8**. The variations in flood depths are shown at intervals of 0.3 metres and for depths up to 3.0 metres. As shown in **Figure 5.8**, flood depths are predicted to exceed 3.0 metres only within watercourses such as creek and river channels (*refer yellow shading*).

Similar mapping of peak flood depths for the 1% AEP flood event is presented in **Figure 5.9**. Depths for the 1% AEP event are shown at 0.5 metres and to a maximum depth of 5.0 metres. Flood depths are only predicted to exceed 5 metres within the Hastings River channel and in parts of the canal subdivision located downstream of Hibbard.

Flood depth mapping for the adopted extreme flood event are shown in **Figure 5.10**. Depth mapping is presented at intervals of 1.0 metre to a maximum depth of 8.0 metres.

As shown in **Figure 5.10**, most of Hibbard is predicted to be inundated to flood depths of between 4.5 to 7.0 metres at the peak of the extreme event.

5.3.3 Peak Flow Velocities

Mapping showing the variation in peak flow velocities predicted across Hibbard for the 5% and 1% AEP floods and the adopted Extreme event are shown in **Figures 5.11** to **5.13**, respectively.

The mapping indicates that flow velocities for the 5% AEP event will generally range between 0.0 and 0.4 m/s across Hibbard (*refer* **Figure 5.11**). Flow velocities are predicted to increase slightly for the 1% AEP flood with typical velocities of between 0.1 and 0.5 m/s across Hibbard (*refer* **Figure 5.12**). Localised flow paths with higher velocities are shown to form in between buildings and at locations where road embankments are overtopped.

For the extreme flood event, peak flow velocities are predicted to range between 0.3 and 1.2 m/s across Hibbard (*refer* **Figure 5.13**).

5.3.4 Comparison to Previous Studies

Flood level difference maps have been prepared to compare the Hibbard Precinct RMA-2 results to those generated as part of previous studies (*refer* **Section 3.3**). The comparison plots have been prepared to cover the entire model domain with an inset included focusing on the Hibbard Precinct.

Table 5.3 lists the design events simulated as part of the Hibbard Precinct study along with any previous simulations from previous studies for which a comparison plot has been prepared.

Table 5.3 Comparison of Hibbard Design Flood Modelling Results to Results Determined from Previous Studies

Design Flood Event	Previous Studies	
	Lower Hastings River Flood Study *(2006)*	Updated Hastings River Flood Study (*Exhibition Draft, 2018*)
5% AEP	Refer **Figure C1** in **Appendix C**	/
1% AEP	Refer **Figure C2** in **Appendix C**	Refer **Figure C3** in **Appendix C**
1% AEP Climate Change Scenario	/	Refer **Figure C5** in **Appendix C**
Extreme Flood	Refer **Figure C4** in **Appendix C**	/

6 IMPACT OF CLIMATE CHANGE ON FLOOD CHARACTERISTICS

6.1 Background

A detailed assessment of the potential impact of climate change on peak flood levels in the Hastings River was recently completed and documented in the *Updated Hastings River Flood Study* (*Exhibition Draft, 2018*). The updated flood study included assessment and modelling of five climate change scenarios with different magnitudes of sea level rise and/or increases in rainfall intensities.

The five climate change scenarios considered were:

- Scenario 1 - 1% AEP catchment event with 900 mm Sea Level Rise (*SLR*) + 10% increase in rainfall intensity and volume
- Scenario 2 - 1% AEP catchment event with 900 mm SLR
- Scenario 3 - 1% AEP catchment event with 400mm SLR + 10% increase in rainfall intensity and volume
- Scenario 4 - 1% AEP catchment event with 400 mm SLR
- Scenario 5 - Extreme event with 900 mm SLR
  (*900mm SLR applied to the adopted 100yr Tide_2.2 mAHD*)

The report recommended that Climate Change Scenario 1 be adopted for the purpose of flood planning and floodplain management (*i.e., a 1% AEP event with 900 mm Sea Level Rise and 10% increase in rainfall intensity*).

Scenario 1 is also consistent with the NSW Sea Level Rise Policy Statement benchmarks, existing planning directions of Port-Macquarie Hastings Council, and reflects the certainties of sea level rise while acknowledging the limitations of the predicted rainfall increases. Although the NSW Sea Level Rise Policy is no longer in effect, the guideline documents are still considered to represent a reliable guide to the potential changes to sea levels and rainfall intensities due to climate change.

6.2 Modelling of Climate Change Impacts

6.2.1 Boundary Conditions

The boundary conditions adopted in the modelling undertaken for the *Updated Hastings River Flood Study* (*Exhibition Draft, 2018*) were also assumed to assess the potential impact of climate change on peak flood levels for the Hibbard Precinct. That is, Climate Change Scenario 1 was applied using the Hibbard Precinct RMA-2 flood model.

The magnitude of flows entering the RMA-2 flood model at the peak of the 1% AEP event with and without climate change are listed in **Table 6.1**. As shown in **Table 6.1**, a 10% increase in rainfall intensities during the design 1% AEP rainfall event is predicted to increase peak flows entering the study area by between 15.3% and 19.3%.

Table 6.1 Comparison between Existing and Predicted Year 2100 Flood Flows

Inflow Location	Peak Flow (m^3/s)		Difference (%)
	1% AEP Event	1% AEP Event with 10% Rainfall Increase	
Hastings River	6,848	7,896	+15
Wilson River	2,707	3,122	+15
Maria River	711	848	+19

The ocean boundary conditions used for modelling of the 1% AEP event was modified by increasing the tidal elevation at each timestep in the simulation by 900mm. This resulted in a peak tidal elevation for Climate Change Scenario 1 of 3.1 mAHD; i.e., 2.2 mAHD plus 0.9 metres SLR.

6.2.2 Results

Predicted flood levels and extents at the peak of the adopted 1% AEP climate change scenario are shown in **Figure 6.1**. Variations in flood depths and flow velocities are shown in **Figures 6.2** and **6.3**.

A comparison of flood levels across the Hibbard Precinct for the 1% AEP flood with and without climate change are listed in **Table 6.2**. The location of each comparison point is identified on **Figure 6.1**.

Table 6.2 Comparison of Peak Flood Levels Predicted for Each Design Event at Points Throughout the Hibbard Precinct

Flood Level Comparison Points ^	Predicted Flood Levels (*mAHD*)		
	1% AEP Flood	1% AEP Flood with Climate Change	Difference
A	3.24	3.92	+ 0.68 m
B	3.23	3.87	+ 0.64 m
C	3.23	3.85	+ 0.62 m
D	3.12	3.82	+ 0.70 m
E	3.16	3.82	+ 0.66 m
F	2.95	3.72	+ 0.77 m
G	2.96	3.69	+ 0.73 m
H	2.88	3.63	+ 0.75 m

Difference mapping comparing peak flood levels predicted for the 1% AEP flood with climate change based on modelling undertaken using the Hibbard RMA-2 hydrodynamic model to the results documented in the *Updated Hastings River Flood Study* (*Exhibition Draft, 2018*) are shown in **Figure C5** of **Appendix C**.

7 PROVISIONAL HAZARD MAPPING

7.1 Adopted Criteria

The personal danger and physical property damage caused by a flood varies both in time and place across the floodplain. Accordingly, the variability of flood patterns across the floodplain over the full range of floods, needs to be understood by flood prone landholders and by floodplain risk managers.

Representation of the variability of flood hazard across the floodplain provides floodplain risk managers with a tool to assess the existing flood risk and to determine the suitability of land use and future development. The hazard associated with a flood is represented by the static and dynamic energy of the flow, which is in essence, the depth and velocity of the floodwaters. Therefore, the flood hazard at a particular location within the floodplain, is a function of the velocity and depth of the floodwaters at that location.

The NSW Government's '*Floodplain Development Manual*' (*2005*), characterises hazards associated with flooding into a combination of three hydraulic categories and two hazard categories. Hazard categories are broken down into high and low hazard for each hydraulic category as follows:

- Low Hazard – Flood Fringe
- Low Hazard – Flood Storage
- Low Hazard – Floodway
- High Hazard – Flood Fringe
- High Hazard – Flood Storage
- High Hazard - Floodway

As a result, the manual effectively divides hazard into two categories, namely, high and low. An interpretation of the hazard at a particular site can be established from **Figures L1** and **L2** on the following page, which have been taken directly from the manual.

As shown in the **Figures L1** and **L2**, flood hazard is a measure of the degree of difficulty that pedestrians, cars and other vehicles will have in egressing flooded areas, and the likely damage to property and infrastructure. At low hazard, passenger cars and pedestrians (adults) are able to move out of a flooded area. At high hazard, wading becomes unsafe, cars are immobilised and damage to light timber-framed houses would occur.

Figure L1 and **L2** show that the flood hazard throughout the floodplain is categorised according to a combination of the flow velocity and the depth of floodwaters. The hazard categories are defined by lower and upper bound values for the product of flow velocity and floodwater depth.

The *'Hastings River Flood Study'* (*2006*) found that by adopting the Low and High criteria for hazards defined in the '*Floodplain Development Manual*' (*2005*) the majority of land within the lower Hastings Valley would be classified as high hazard for large events such as the 1% AEP flood. For the purposes of better understanding the variability of hazard throughout the floodplain the high hazard category was further subdivided into High Hazard, Very High Hazard and Extreme Hazard. Similarly, the low hazard category defined in the manual was subdivided to create Low Hazard and Medium Hazard categories.

This greater discretisation of hazards was adopted as it allows for a greater understanding of the flood hazard affecting existing development and areas of potential future development, the low and high hazard categories were further subdivided. A summary of the criteria adopted for each hazard category is listed in **Table 7.1** and shown in **Plate 7.1**.

TABLE 7.1 ADOPTED HAZARD CRITERIA

HAZARD CATEGORY	CRITERIA	PRACTICAL APPLICATION
Low	• Depth (*d*) < 0.4m & Velocity (*v*) < 0.5m/s	• Suitable for cars
Medium	• exceeding Low criteria, and *d* ≤ 0.8m, *v* ≤ 2.0m/s, and *vxd* ≤ 0.5	• Suitable for heavy vehicles and wading by able bodied adults
High	• exceeding Medium criteria, and *d* ≤ 1.8m, *v* ≤ 2.0m/s, and *vxd* ≤ 1.5	• Suitable for light construction, timber frame, brick veneer etc
Very High	• exceeding High criteria, and 0.5m/s < velocity < 4m/s and *vxd* ≤ 2.5	• Suitable for heavy construction, steel frame, concrete etc
Extreme	• exceeding Very High criteria and v > 5m/s	• Unsuitable for development - indicates significant conveyance of flow or floodway

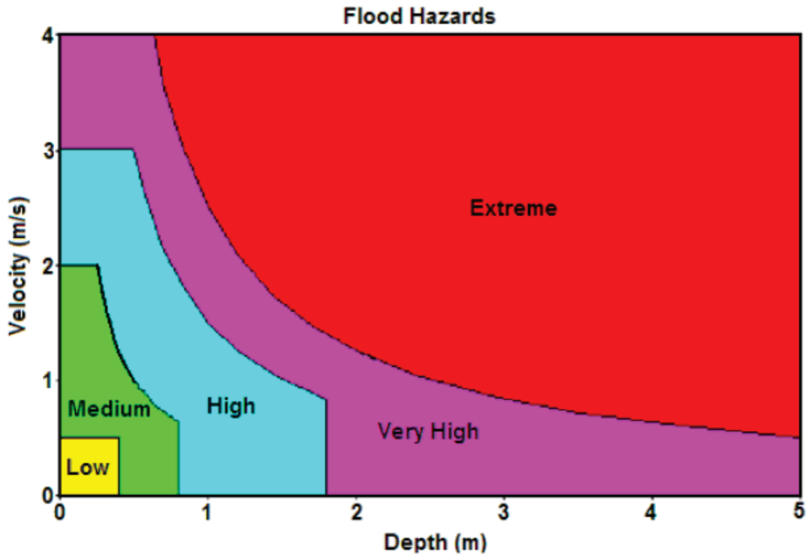

PLATE 7.1 CHART OF ADOPTED HAZARD CRITERIA

7.2 Updated Provisional Flood Hazards

The modelling results described in **Section 5** for design flood events and **Section 6** for the adopted climate change scenario we used to prepare provisional flood hazard mapping for the Hibbard Precinct. Accordingly, the model results were analysed to determine those parts of the floodplain that fall within each of the Low, Medium, High, Very High and Extreme Hazard categories that are listed in **Table 7.1**.

Provisional flood hazard mapping for the 5% and 1% AEP floods and the adopted climate change scenario (*refer* **Section 6**) are presented in **Figures 7.1** to **7.3**, respectively.

8 UPDATED HYDRAULIC CATEGORIES

8.1 General

A major component of the Hibbard Precinct Flood Study is the re-assessment of hydraulic categories in the vicinity of Hibbard. This has involved a review of the existing floodway corridor, which when defined as part of the *Hastings River Floodplain Risk Management Study* (*2012*), was based on modelling that was broad scale and which reflected the regional focus of that study.

As discussed in **Section 4.2**, the regional Hastings River flood model has been updated to incorporate additional detail in the Hibbard area. The updates include network refinement to incorporate building footprints, hydraulic controls such as impervious fences, culverts, bridges and road crests, as well as general refinements to better reflect the floodplain topography. These updates have resulted in a flood model that has greater capacity to simulate the pattern of flooding through Hibbard which in turn, can be used to better define the hydraulic function of areas within the precinct.

8.2 Definitions

The NSW Floodplain Development Manual (2005) defines three hydraulic categories of flood prone land; viz., floodway, flood storage and flood fringe. Each of these hydraulic categories are combined with flood hazard to define the variation in risk across flood-prone areas. The combination of hydraulic categories and food hazard can be used to assess the risk to existing development and to identify appropriate types of development for different areas of the floodplain.

Floodways are those areas of a floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels and are areas that if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood level. By definition, floodways are areas of high flow conveyance and can often be identified by areas of high flow velocity (*NSW Office of Environment & Heritage, 2013*).

The blocking of floodways typically results in significant impacts on flood characteristics such as increases in predicted peak flood level and changes in flow velocities. Therefore, it is important to define floodways in floodplain risk management so that areas where development is undesirable can be identified.

8.3 Previous Investigations

Hydraulic category mapping for the lower Hastings River floodplain is documented in Section 9 of the *Hastings River Floodplain Risk Management Study* (*2012*).

In order to delineate the floodway corridor a three-stage approach was adopted based on a methodology outlined by Thomas et at (*2012*). Stage 1 of this approach involved delineation of a '*preliminary*' floodway extent that was based on a detailed review of existing flood modelling results that considered the following:

- the location of flood storages readily identifiable from aerial photography;

- available ALS / LiDAR terrain data;
- the location and potential impacts of hydraulic controls;
- mapping of contours of 'velocity-depth' product (*V x D*);
- mapping of the variation in flood depths and peak flow velocities; and,
- the distribution of floodwater flow, including the area required to carry 80% of the peak flow in the 1% AEP flood.

The 'preliminary' floodway corridor determined from this Stage 1 analysis was then tested and verified as part of the second stage of the process which involved selective encroachment analysis.

The Stage 2 analysis involved flood modelling to test whether the "*blockage*" of areas outside of the preliminary floodway corridor would result in significant increases in local flood levels; i.e., increases of more than 100 mm. Where encroachment modelling results in flood level increases that are greater than 100 mm it follows that the preliminary floodway corridor is too narrow requiring it to be widened and re-tested. This iterative approach led to the development of the Stage 2 floodway corridor.

The final and third stage involved a joint review of the Stage 2 floodway corridor by representatives from Council, the Office of Environment and Heritage (OEH) and Advisian (*WorleyParsons at the time*). The review relied upon flood engineering judgement and experience and a practical "common sense" check of the floodway line against cadastral and property constraints to "fine tune" the floodway extent mapping

Once the floodway extent was defined, investigations were undertaken to determine the flood storage and flood fringe. In order to determine the boundary between flood storage and fringe, the variation in peak flood depths in areas outside of the floodway extent were mapped. A depth of 0.3 metres was selected as the transitionary point between flood storage and fringe; i.e., an area is designated as flood fringe if the flood depths are 0.3 metres or less.

8.4 Re-Assessment of the Hibbard Floodway Corridor

As discussed in **Section 8.3**, the floodway corridor determined as part of the Hastings River FRMS (*2012*) was delineated based on a review of predicted flood behaviour and then tested and further refined by encroachment modelling. Because both of these stages of assessment relied on the broad scale flood model developed as part of the *Lower Hastings River Flood Study* (*2006*) there existed limitations in the amount of local scale detail that could be taken into consideration. Having the local scale detail is especially important in urbanised areas such as Hibbard where floodwaters can be obstructed and/or re-directed by hydraulic controls such as buildings, fences and road embankments.

These localised features have now been incorporated into the Lower Hastings River/Hibbard Precinct flood model and the refined model has been used to re-simulate design flood conditions. With this new information available a re-assessment of the floodway corridor was undertaken by applying the same methodology adopted for the *Lower Hastings Floodplain Risk Management Study* (*2012*). The method also considered the findings of additional research documented in Thomas et al (2018).

As the floodway re-assessment was focused only on a localised part of the lower Hastings River floodplain that covers less than 1% of the total floodplain assessed as part of the floodplain risk management study, it is possible that the previously adopted flood level increase criteria, that is the 100 mm increase, may not be entirely applicable.

This recognises that the encroachment/blockage testing will be applied only to the southern floodplain and the presence of a significant flood storage area upstream of Hibbard which would dampen the peak magnitude of any resulting increases in flood levels.

The applicability of the increase threshold value, and the findings of the Stage 1 and Stage 2 investigations are documented in the following sections.

8.4.1 Applicability of the Stage 2 Flood Level Increase Criteria

As discussed in **Section 8.3**, the Stage 2 analysis undertaken as part of the FRMS (*2012*) involved flood modelling to test whether the "*blockage*" of areas outside of the Stage 1 floodway corridor would result in flood level increases of more than 100 mm. Where the encroachment modelling indicated that flood level increases were greater than 100 mm, this indicated the floodway corridor was too narrow requiring it to be widened and re-tested.

Although this same approach can be applied to test floodway corridors at Hibbard the 100 mm increase criteria may only be applicable at a 'local' scale such as directly against a blockage point instead of across a widespread area. This is particularly the case for any flood level increases that extend upstream of Hibbard (*i.e., west of Tuffins Lane*) due to the large flood storage area located upstream and to the south-west which would act to dampen the peak magnitude of any increase in flood level due to a localised floodway encroachment.

A secondary reason the 100 mm increase criteria will not be possible to achieve over an extended area is due to the encroachment/blockage testing applying only to Hibbard and the southern floodplain.

In that regard, the encroachment/blockage scenarios will not apply to the full "width" of the floodplain which would typically be necessary to cause the widespread 100mm increase to occur. For example, the main Hastings River channel and the Kings Point floodway channel crossing were retained as "unblocked" flow paths during the analysis carried out to assess the extent of the Hibbard Precinct floodway.

Notwithstanding, the encroachment/blockage modelling can still be applied at Hibbard to test whether a proposed floodway extent has been sized sufficiently for the passage of local flood flows. Accordingly, the 100 mm criteria was adopted and used to assess the impact of encroachment scenarios on peak flood levels immediately upstream of Hibbard or adjacent to the floodway itself.

8.4.2 Stage 1 – Delineating the Floodway based on Existing Modelling Results

The Stage 1 analysis involved a detailed review of the flood modelling results documented in **Section 5.3**.

The analysis involved identifying those parts of the floodplain across which velocities, depths and the velocity-depth product were 'locally' high and indicative of an area with high hydraulic importance and/or an area conveying a significant amount of the flow occurring 'locally'. The emphasis on 'locally' is included to reinforce that floodway runners can be formed away from and separate to the greater floodplain. This scenario of a flood runner is considered applicable to the Hibbard Precinct with floodwaters arriving overland from the west and not from flows leaving the Hastings River which is located immediately north of the Precinct (*refer* **Figure 8.1**).

This separation of the flows that are conveyed through Hibbard from those to the north (*within the Hastings River and the northern floodplain*) is evident by comparing the magnitude of the velocity-depth product.

In that regard, the velocity-depth product for the 1% AEP event across Hibbard is predicted to reach up to 1.2 m^2/s compared to 2.6 m^2/s across the floodplain north of the Hastings River (*refer* **Figure 8.1**). The difference in flood characteristics is even more evident when comparing the magnitude of flows through the northern and southern (*Hibbard Precinct*) floodplains at the peak of the 1% AEP flood.

As shown in **Figure 8.1**, a peak flow magnitude of 900 m^3/s is predicted across the northern floodplain compared to 280 m^3/s through Hibbard.

Application of Stage 1 of the assessment procedure led to identification of a 'preliminary' floodway extent for the Hibbard Precinct. This is shown in **Figure 8.2**.

The Stage 1 floodway corridor includes a main floodway arm that crosses Tuffins Lane before turning towards the north to cross Hastings River Drive. Before crossing Hastings River Drive the floodway arm splits into two branches which flow to the east and west of the Riverside Resort and the brick fence that exists along its frontage (*refer* **Figure 8.2**).

A secondary floodway arm that starts immediately east and downstream of Tuffins Lane conveys floodwaters through the Ultiqa Village Resort and along the narrow canal and creek system. As shown in **Figure 8.2**, this floodway arm joins the western floodway branch upstream of Hastings River Drive.

In determining the Stage 1 floodway corridor, flow distributions were analysed relative to the predicted velocity-depth product. As shown in **Figure 8.2**, the Stage 1 floodway corridor aligns generally well with a velocity-depth value in the range of 0.7 m^2/s to 1.2 m^2/s.

Although there are several locations where flow paths exhibit velocity-depth values within or near this range these were not included as they either conveyed a relatively (*assessed based on local flow distributions*) low proportion of the local flow and/or were separated from the main floodway arm by a band of lesser hydraulic importance. For locations falling in the latter category inclusion of the area was only considered where it was required to maintain the conveyance capacity of the corridor.

Thomas et al (*2012 and 2018*) and the Hastings River FRMS (*2012*) determined that for most situations the area of the floodplain that conveys 80% of the peak 1% AEP flow is representative of the floodway extent. However, a strict application of this criterion to the Hibbard Precinct, when considered in isolation, is not considered appropriate. This is because if the full width of the Hastings floodplain at Hibbard is considered, those areas to the north of Hibbard that were identified in the 2102 FRMS already convey over 80% of the total flow.

Therefore, in applying a flow criterion to the Hibbard floodway arm a value of 60% of the total local flow was initially adopted.

8.4.3 Stage 2 – Encroachment/Blockage Modelling

Encroachment modelling was undertaken for the Stage 1 floodway corridor to assess whether the corridor was sufficiently sized to ensure all local flows could be conveyed without causing flood level increases of greater than 100 mm locally and adjacent to blockage locations.

Five encroachment scenarios were set-up and simulated by gradually increasing the encroachment extent. This approach was adopted in lieu of simulating a single scenario in which the whole floodway extent was blocked on the basis that any impacts at the upstream limit of testing could influence impacts for sections downstream. Therefore, this issue was avoided by simulating gradual increases in the encroachment extent.

The results of the five encroachment scenarios are presented as flood level difference mapping in **Figure 8.3** to **Figure 8.7**.

The flood level difference plots indicate that the maximum flood level increase caused by any of the modelled scenarios is predicted to be 100 mm. This maximum increase occurs for the second encroachment scenario. This scenario was the first to include blockages to areas outside of both floodway arms, including blockage of Boundary Street (*refer* **Figure 8.4**). This indicates that the width of both floodway arms is sufficient to ensure flood level increases locally do not exceed 100 mm.

For all other blockage/encroachment scenarios the maximum flood level increase is predicted to be 50 mm. Although this magnitude of increase is below the target criteria of 100 mm, the large spatial extent across which it occurs (*extending approximately 4.2 km upstream to Dennis Bridge and the Pacific Highway and 5.0 km to the south-west into the large flood storage area*) makes it an unreasonable target (*refer discussion under* **Section 8.4.1**).

In order to confirm the importance of maintaining the two floodway arms that cross Hastings River Drive to the west and east of the Riverside Resort, a final encroachment scenario was run that blocks the eastern floodway arm as far south as Hastings River Drive. As shown in **Figure 8.8**, blockage of the eastern floodway arm causes flood levels to increase locally by up to 120 mm, which is in excess of the 100 mm criterion.

As for other blockage scenarios, the extent of flood level increases are significant. They extend across all of Hibbard and include areas upstream and west of Tuffins Lane.

8.4.4 Final Floodway Extent

The Stage 2 encroachment modelling shows that the Stage 1 floodway corridor will lead to flood level increases locally of up to 100 mm (*refer* **Figure 8.4**). Blockage of the eastern floodway arm is predicted to cause flood levels to increase locally by up to 120 mm which is above the threshold target and therefore indicates blockage of a floodway (*refer* **Figure 8.8**).

Although flood level increases further upstream of the two floodway arms are only predicted to reach up to 50 mm, these increases are effectively "damped" by the extensive floodplain storage upstream and to the south-west of Hibbard. This floodplain storage feeds floodwaters into the Hibbard floodway during major flooding of the Hastings River. Although the predicted increases are less than the 100 mm criteria that is typically adopted, the extent of the floodplain over which they would occur indicates that the associated blockage of the Hibbard floodway arms would result in significant impacts (*refer* **Figure 8.4** to **Figure 8.7**).

Therefore, based on the discussion above and the results of the Stage 2 encroachment modelling, it is proposed that the floodway corridor delineated through the Stage 1 analysis be adopted for the Hibbard Precinct.

8.5 Flood Storage and Fringe

As discussed in **Section 8.2**, in the Hastings River FRMS (*2012*) the transition between areas categorised as flood storage and flood fringe was delineated based on mapping flood depths of up to 0.3 metres. Accordingly, flood storage and flood fringe were defined as:

- Flood Storage - those parts of the floodway outside of the floodway corridor and with depths of <u>over</u> 0.3 metres at the peak of the 1% AEP flood.
- Flood Fringe - those parts of the floodway outside of the floodway corridor and with depths of <u>up to</u> 0.3 metres at the peak of the 1% AEP flood.

It is proposed that these criteria for flood storage and fringe areas be retained for the mapping of hydraulic categories at Hibbard.

Notwithstanding, as design flood behaviour has changed as a function of the hydraulic model updates made as part of this study (*refer* **Section 4.2**) remapping of storage and fringe areas is recommended.

8.6 Hydraulic Category Mapping for the Hibbard Precinct

Mapping of hydraulic categories for the Hibbard Precinct are shown in **Figure 8.9** for the 1% AEP flood.

9 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

The Hibbard Precinct is an area to the west of Port Macquarie that has developed as "strip" development adjacent to Hastings River Drive which served historically as the major connection between the CBD and the Pacific Highway. Development occurred due to proximity to infrastructure, the river and Port Macquarie Regional Airport. This includes service industries to support the airport, tourism facilities including accommodation, and more recently, commercial and bulky goods development that could take advantage of the relatively flat land and good access afforded by the road network.

However, parts of Hibbard are very low lying and have historically served to convey floodwaters from the extensive flood storage area located to the south west of the airport back into the main channel of the Hastings River. The *Hastings River Floodplain Risk Management Study (2012)* identified the importance of the connection between this flood storage and the main channel of the Hastings River. Investigations completed for the FRMS identified a provisional floodway corridor through the Hibbard Precinct and sought to formally recognise the need for the free passage of floodwaters to be maintained into the future.

Notwithstanding, the FRMS recognised that floodway mapping prepared at that time was based on a broad scale assessment of flood characteristics commensurate with the valley wide scale of the study. The FRMS recommended that a more detailed investigation was required to confirm the existence of a floodway through the Hibbard Precinct, and if one existed, to more accurately define its extent and function.

Investigations completed for this study have confirmed that a floodway corridor does exist through the Hibbard Precinct. Flood modelling of blockage scenarios has established that if a floodway is not retained through the Hibbard Precinct then 1% AEP flood levels in areas upstream and particularly to the south-west can be expected increase. This could reduce the level of service currently afforded by important infrastructure, including the Port Macquarie Regional Airport.

Notwithstanding, the investigations have established that the extent of the floodway required is less than the extent that was provisionally determined as part of the 2012 FRMS. The recommended floodway is presented in **Figure 8.9.**

9.2 Recommendations

The follow recommendations are made:

(i) Revised 1% AEP flood levels for the Hibbard Precinct be adopted based on the peak flood levels presented in **Figure 5.6** and **Table 5.2**.

(ii) Revised 1% AEP Hazard Categories be adopted based on the mapping presented in **Figure 7.2**.

(iii) Revised Hydraulic Categories, including the "new" floodway, be adopted based on the mapping presented in **Figure 8.9.**

(iv) Revised Flood Planning Levels for the Hibbard Precinct be considered in the floodplain risk management study phase

10 REFERENCES

- Australian Institute for Disaster Resilience (2017), "*Australian Disaster Resilience Handbook 7 Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia*"; © Commonwealth of Australia 2017 third edition.
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- Department of Environment, Climate Change & Water (*2009*), '*Scientific Basis of the 2009 Sea Level Rise Benchmark – Draft Technical Note*'
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- NSW Government (*April 2005*), '*Floodplain Development Manual: the Management of Flood Liable Land*'; ISBN 0 7347 5476 0
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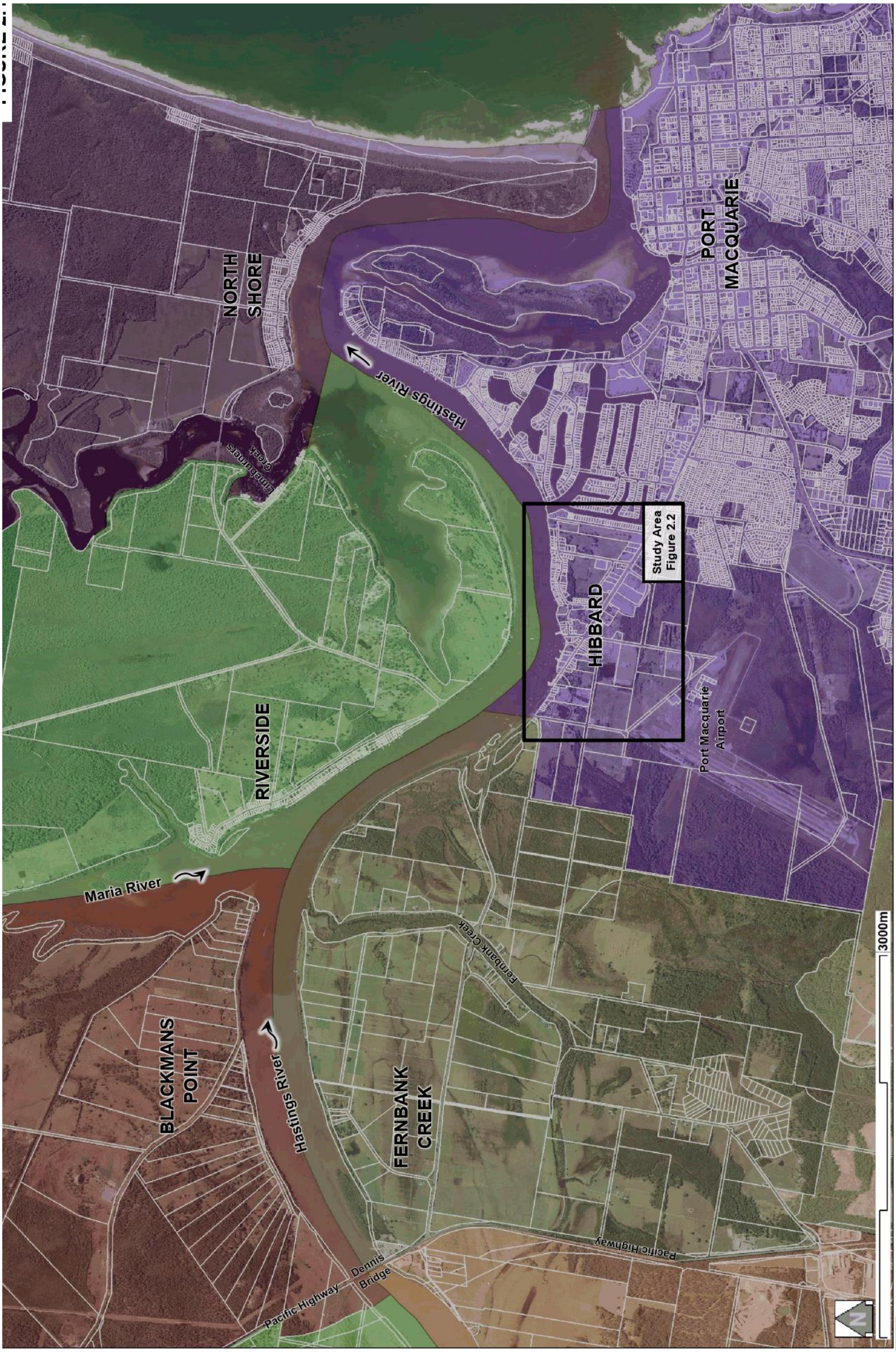
- Port Macquarie-Hastings Council (*2006*), '*Hastings River Flood Study*'; prepared by Patterson Britton & Partners (*now WorleyParsons*)
- Port-Macquarie Hastings Council (*2012*), '*Hastings River Floodplain Risk Management Study*', prepared by WorleyParsons
- Port-Macquarie-Hastings Council (*2018*), '*Hastings Flood Study Update (Exhibition Draft*', prepared by Advisian (*part of the WorleyParsons group)*
- Port Macquarie – Hastings Council (September, *2015*), '*Port Macquarie Hastings LGA Flood Policy*'
- Port Macquarie – Hastings Council, '*Port Macquarie-Hastings Council – Development Control Plan 2013*'
- Port Macquarie-Hastings Council (*2011*), '*Port Macquarie-Hastings Local Environmental Plan 2011*'
- Thomas C R & Golaszewski, R (2012), '*Refinement of Procedures for Floodway Definition*';. Proceedings of 52nd Annual Floodplain Management Authorities Conference, Narooma, February 2012
- Thomas C R, Golaszewski R & Cox R (2018), '*Methodology for Determining Floodway / Flow Conveyance Extent in Australian Floodplains*', Proceedings of Hydrology and Water Resources Symposium, Melbourne, December 2018

Figures



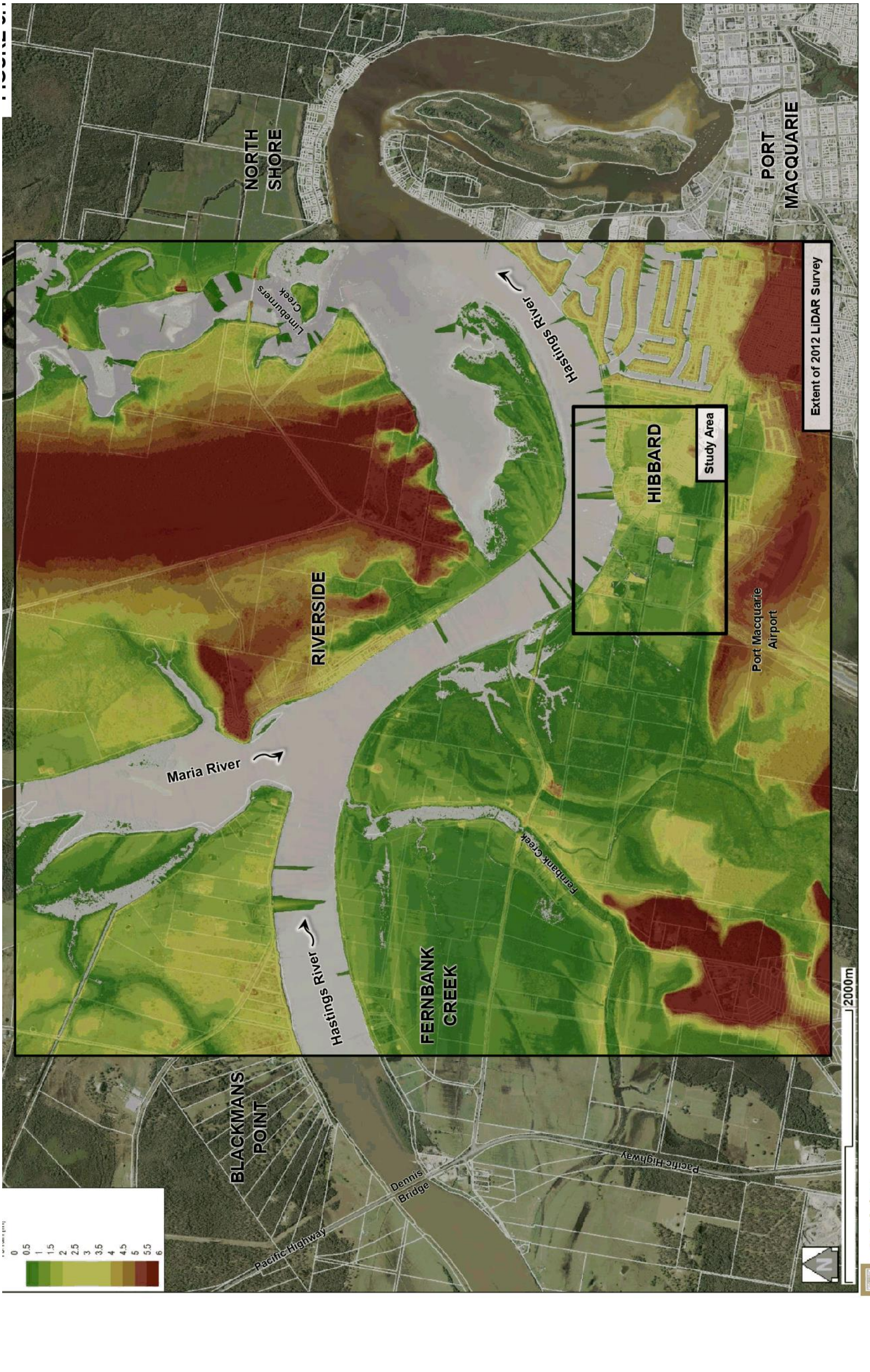
LOCATION OF THE HIBBARD PRECINCT STUDY AREA

301015-03826-Hibbard Floodway Investigation
fg301015-03826lt180904_Fig 2.1 Study Area.docx

THE HIBBARD PRECINCT

301015-03826-Hibbard Floodway Investigation
fg301015-03826rt180904_Fig 2.2 The Hibbard Precinct.docx

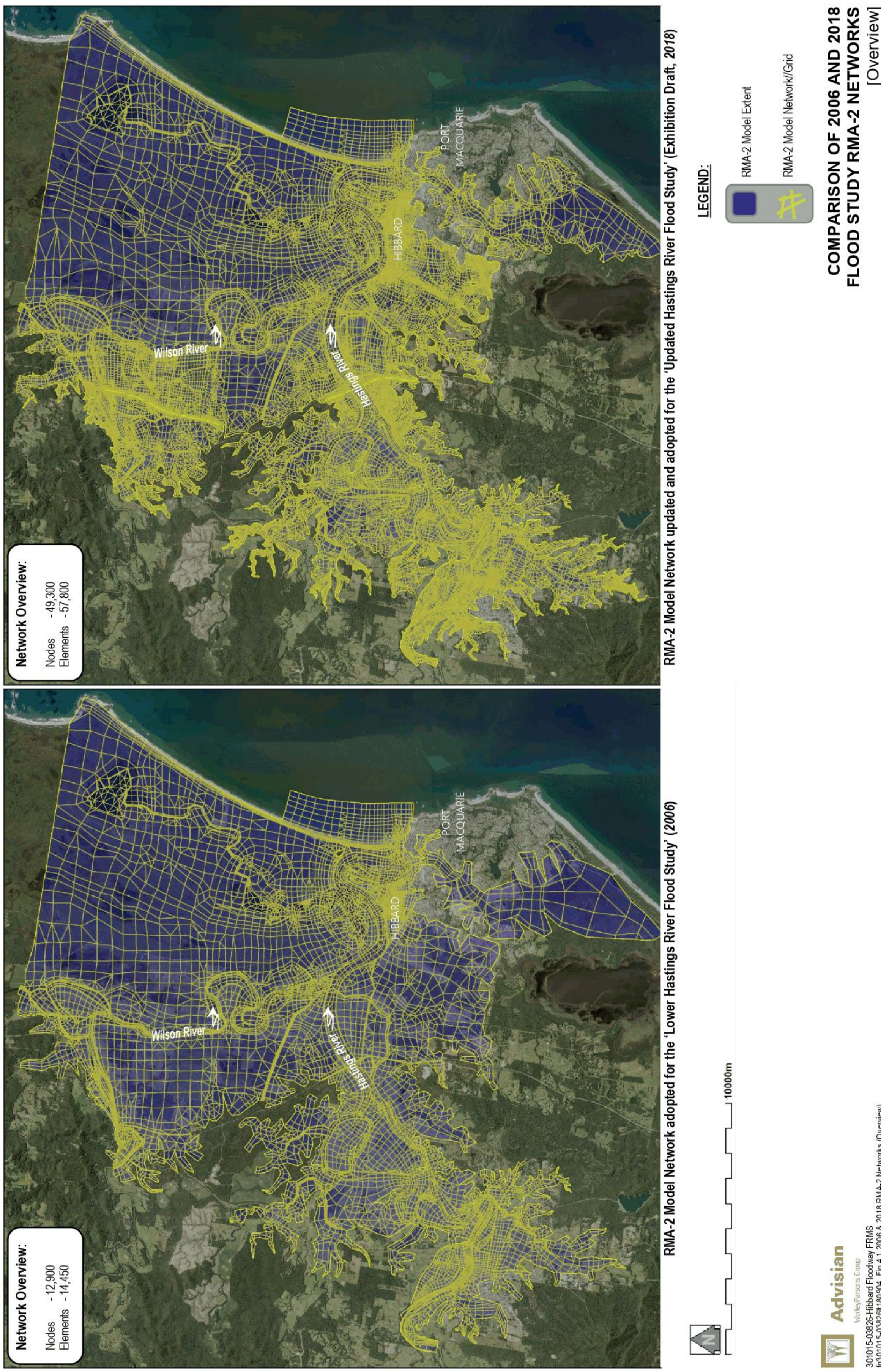
TOPOGRAPHY BASED ON 2012 LIDAR IN THE VICINITY OF THE HIBBARD PRECINCT



EXTENT OF AVAILABLE 2012 LiDAR SURVEY


LEGEND:
Survey collected by Pacific Surveys:
Surveyed spot elevations
Hydrographic survey
Location of surveyed bridges
Surveyed heights along impervious fences
Survey collected by King & Campbell:
Survey of Boundary Street and parts of Hastings River Drive
HASTINGS RIVER
Hibbard Drive
Woods Street
Mumford Street
Hastings River Drive
HIBBARD
Boundary Street
Aquatic Caravan Park and Aquatic Motel
Ultiqa Village Resort
Hydro Golf & Putt-Putt
Newman Senior Technical College
Port Macquarie Airport
Tuffins Lane
700m
Advisian
301015-03826-Hibbard Floodway Investigation
fg301015-03826lt180904_Fig 3.2 Collected Survey.docx
OVERVIEW OF AVAILABLE TOPOGRAPHIC

FIGURE 4.1


Network Overview:
Nodes - 49,300
Elements - 57,800
Wilson River
Hastings River
HIBBARD
PORT MACQUARIE
RMA-2 Model Network updated and adopted for the 'Updated Hastings River Flood Study' (Exhibition Draft, 2018)
Network Overview:
Nodes - 12,900
Elements - 14,450
RMA-2 Model Network adopted for the 'Lower Hastings River Flood Study' (2006)
10000m
LEGEND:
RMA-2 Model Extent
RMA-2 Model Network//Grid
COMPARISON OF 2006 AND 2018 FLOOD STUDY RMA-2 NETWORKS
[Overview]
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS

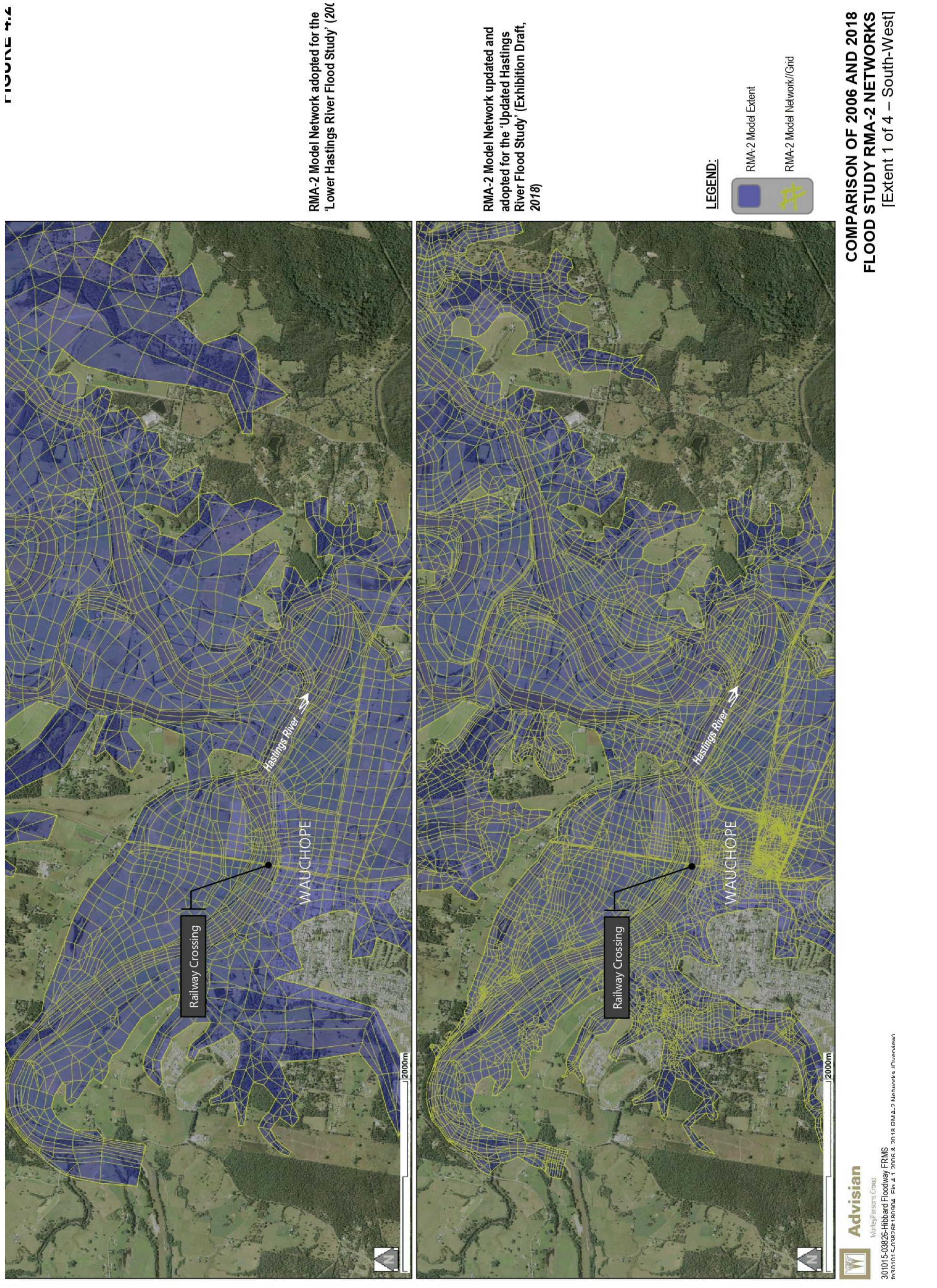


FIGURE 4.2
RMA-2 Model Network adopted for the 'Lower Hastings River Flood Study' (200
RMA-2 Model Network updated and adopted for the 'Updated Hastings River Flood Study' (Exhibition Draft, 2018)
LEGEND:
RMA-2 Model Extent
RMA-2 Model Network//Grid
COMPARISON OF 2006 AND 2018 FLOOD STUDY RMA-2 NETWORKS
[Extent 1 of 4 – South-West]
Hastings River
WAUCHOPE
Railway Crossing
2000m
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS

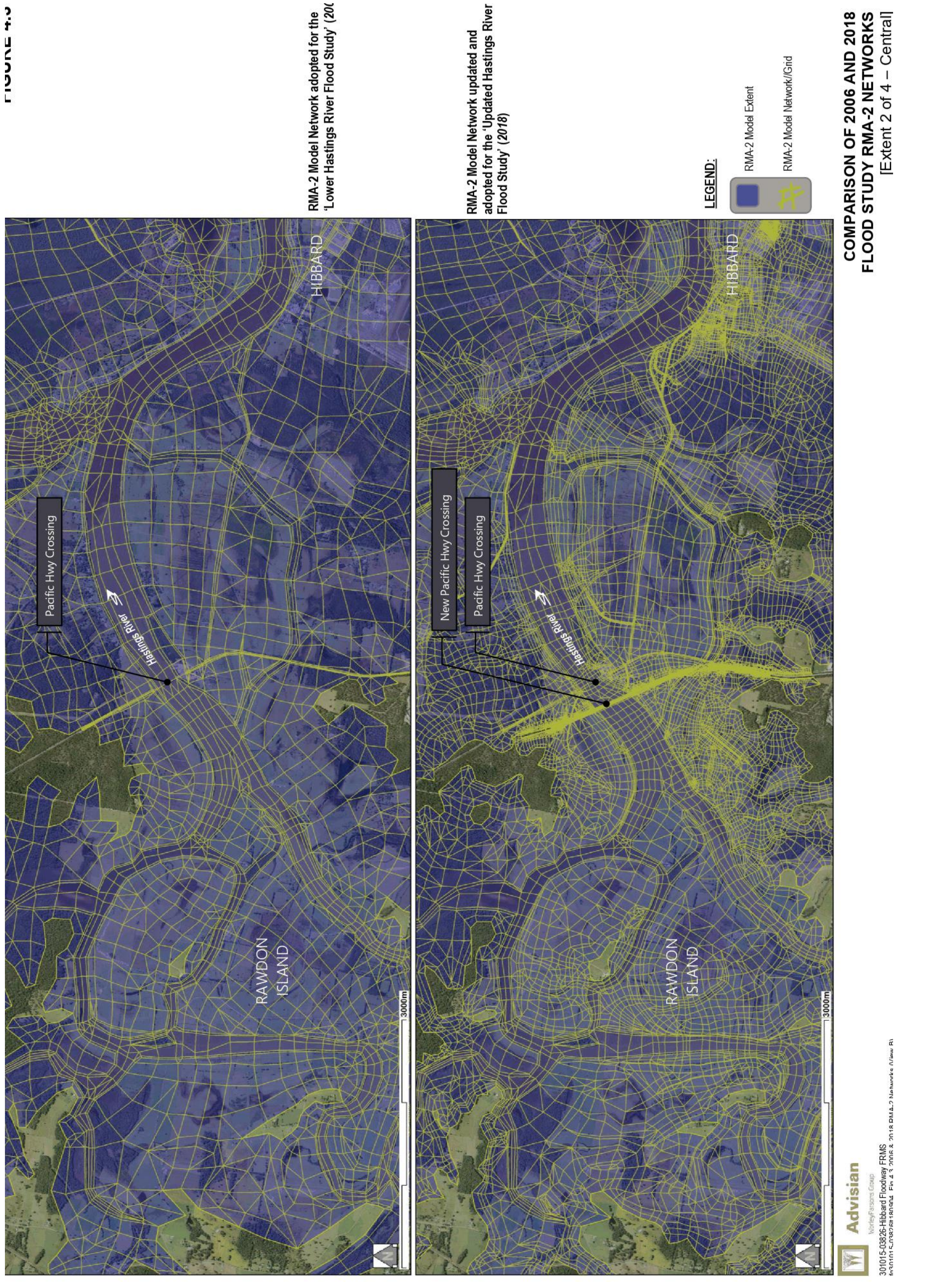
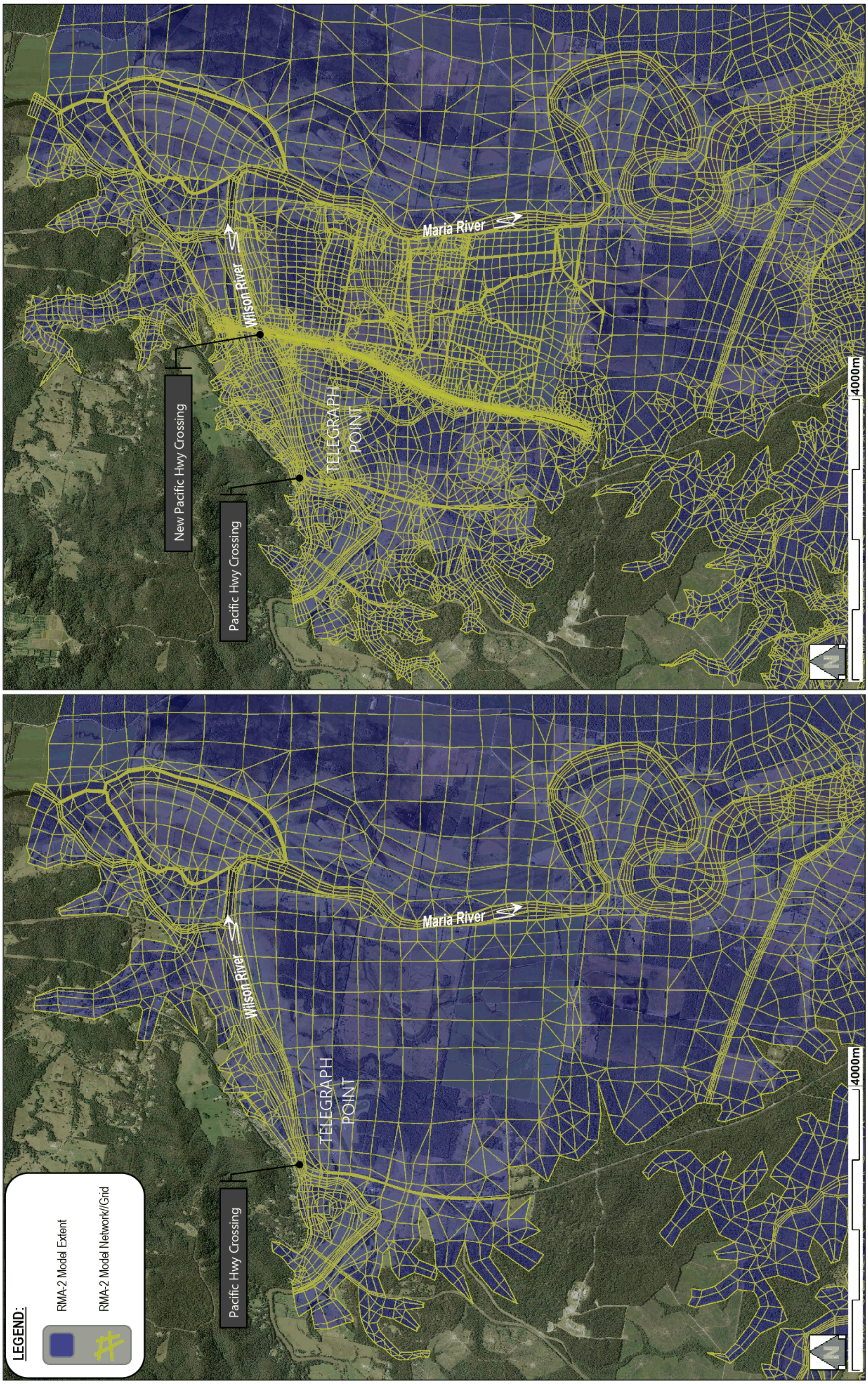

RMA-2 Model Network adopted for the 'Lower Hastings River Flood Study'
RMA-2 Model Network updated and adopted for the 'Updated Hastings River Flood Study' (2018)
LEGEND:
RMA-2 Model Extent
RMA-2 Model Network/Grid
COMPARISON OF 2006 AND 2018 FLOOD STUDY RMA-2 NETWORKS
[Extent 2 of 4 – Central]
Pacific Hwy Crossing
New Pacific Hwy Crossing
Hastings River
HIBBARD
RAWDON ISLAND
3000m
Advisian
301015-03826-Hibbard Floodway FRMS

FIGURE 4.4

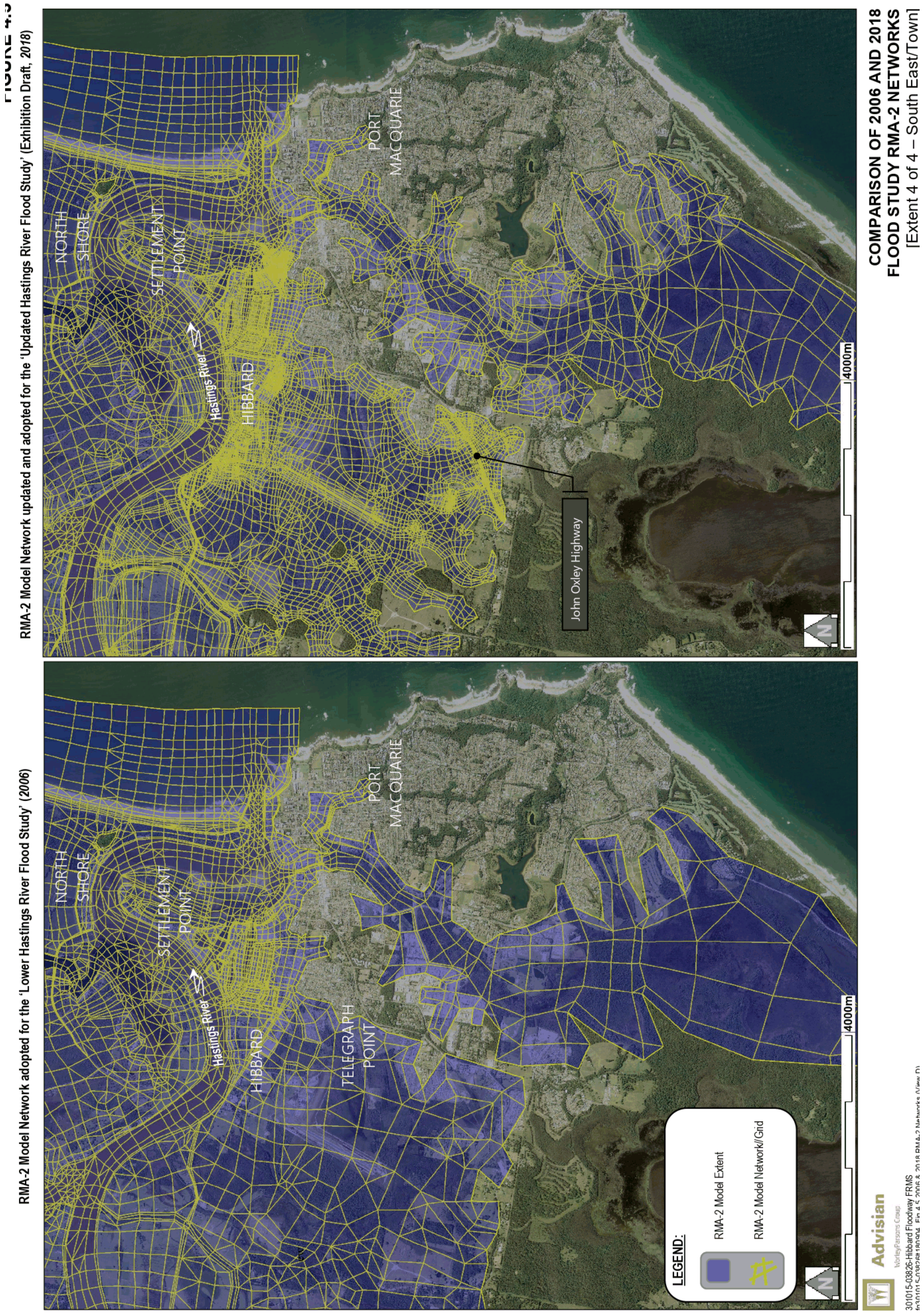
RMA-2 Model Network updated and adopted for the 'Updated Hastings River Flood Study' (Exhibition Draft, *2018*)

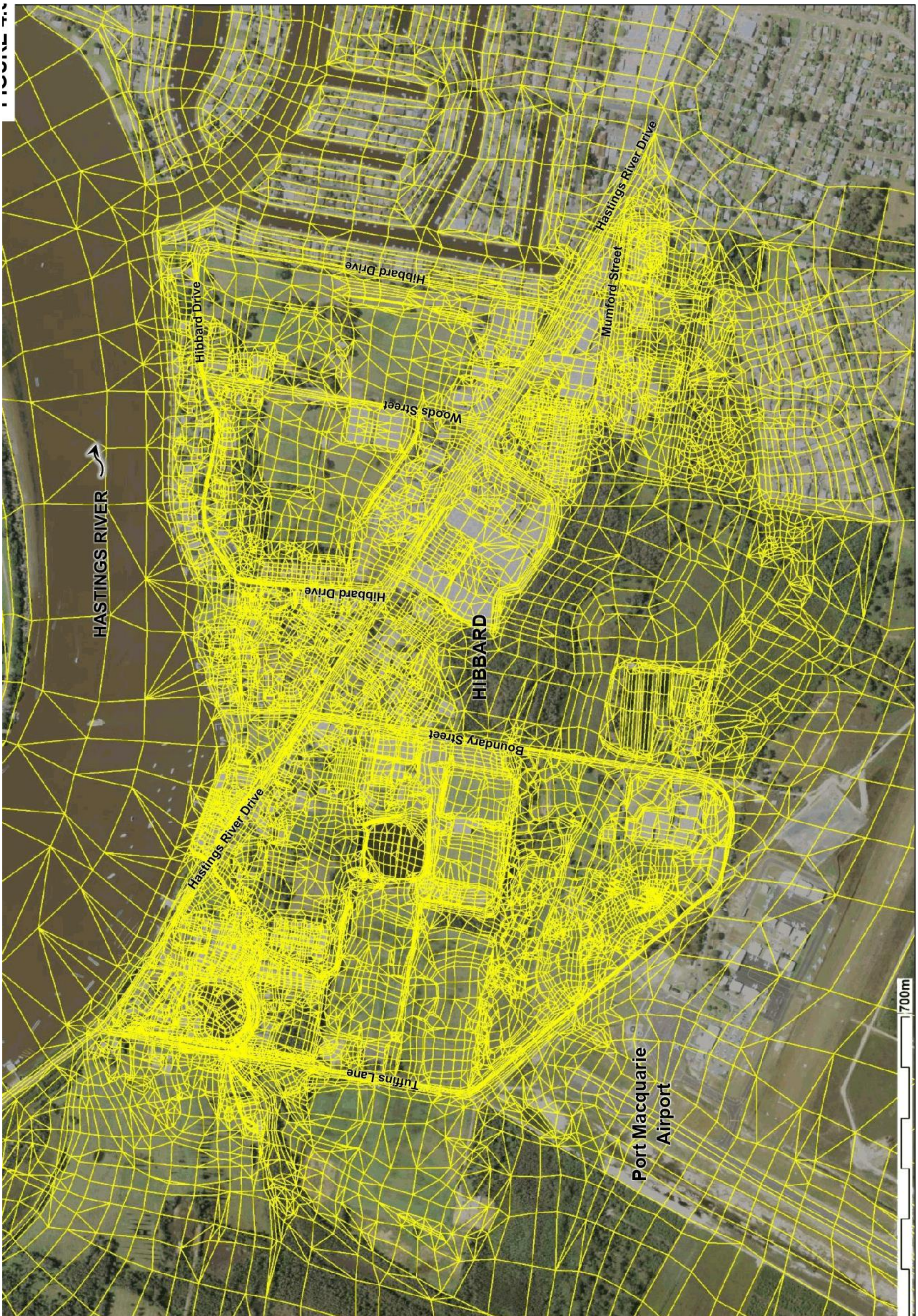
RMA-2 Model Network adopted for the 'Lower Hastings River Flood Study' (*2006*)



COMPARISON OF 2006 AND 2018 FLOOD STUDY RMA-2 NETWORKS
[Extent 3 of 4 – North]

Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS


RMA-2 Model Network updated and adopted for the 'Updated Hastings River Flood Study' (Exhibition Draft, 2018)
RMA-2 Model Network adopted for the 'Lower Hastings River Flood Study' (2006)
NORTH SHORE
SETTLEMENT POINT
PORT MACQUARIE
Hastings River
HIBBARD
TELEGRAPH POINT
John Oxley Highway
4000m
LEGEND:
RMA-2 Model Extent
RMA-2 Model Network/Grid
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS
COMPARISON OF 2006 AND 2018
FLOOD STUDY RMA-2 NETWORKS
[Extent 4 of 4 – South East/Town]



EXTENT OF RMA-2 MODEL REFINEMENTS COMPLETED AS PART OF THE HIBBARD PRECINCT FLOOD STUDY

Advisian
WorleyParsons Group

301015-03826-Hibbard Floodway Investigation
fg301015-03826rt180904_Fig 4.6 2019 Hibbard FS RMA-2 Network.docx

TOPOGRAPHY BASED ON ELEVATIONS ASSIGNED WITHIN THE UPDATED RMA-2 MODEL

Advisian
WorleyParsons Group

301015-03826-Hibbard Floodway Investigation
fg301015-03826lt180904_Fig 4.6 2019 Hibbard FS RMA-2 Network.docx

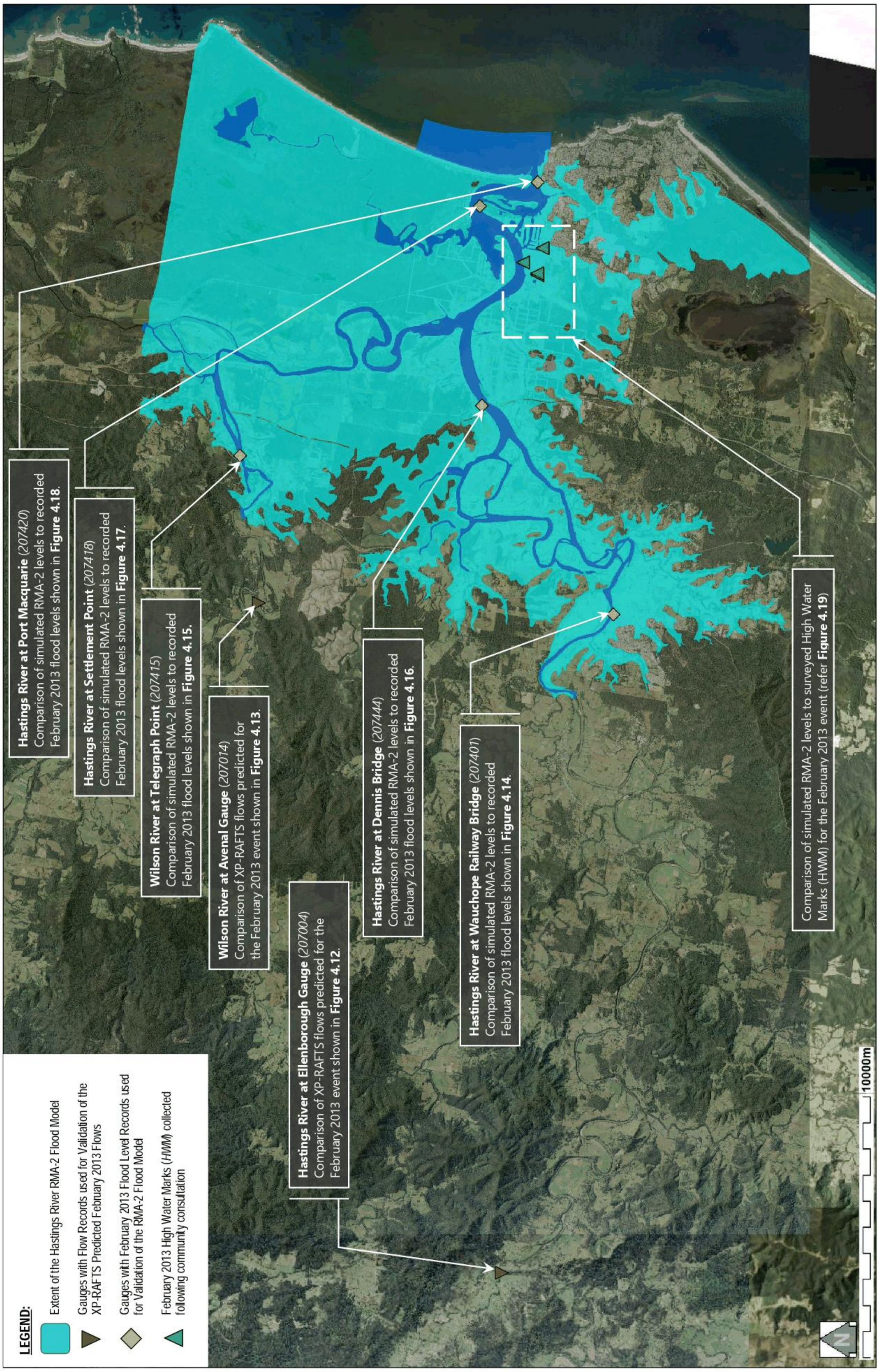
LEGEND:
Waterway - Clear (n= 0.030)
Waterway - Overgrown (n= 0.080)
Bridges / Culverts (n = 0.100)
Grassed Floodplain (n = 0.035)
Light Trees / Foliage (n = 0.055)
Moderate Trees / Foliage (n = 0.075)
Dense Trees / Foliage (n = 0.095)
Urban Area – Open / Unobstructed (n = 0.040)
Urban Area – Clutter / Fences (n = 0.060)
Buildings – No Flow (N/A)
Roadways / Hardstands (n = 0.015)
MDST Flow Control Element
HASTINGS RIVER
HIBBARD
Hastings River Drive
Boundary Street
Tuffins Lane
ADOPTED ELEMENTS TYPES AND
DISTRIBUTION FOR THE UPDATED
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway Investigation
fg301015-03826rt180904_Fig 4.8 Material Types.docx

FIGURE 4.9

LOCATION AND SURVEYED ELEVATION OF THE HIGH WATER MARKS COLLECTED FOR THE FEBRUARY 2013 EVENT

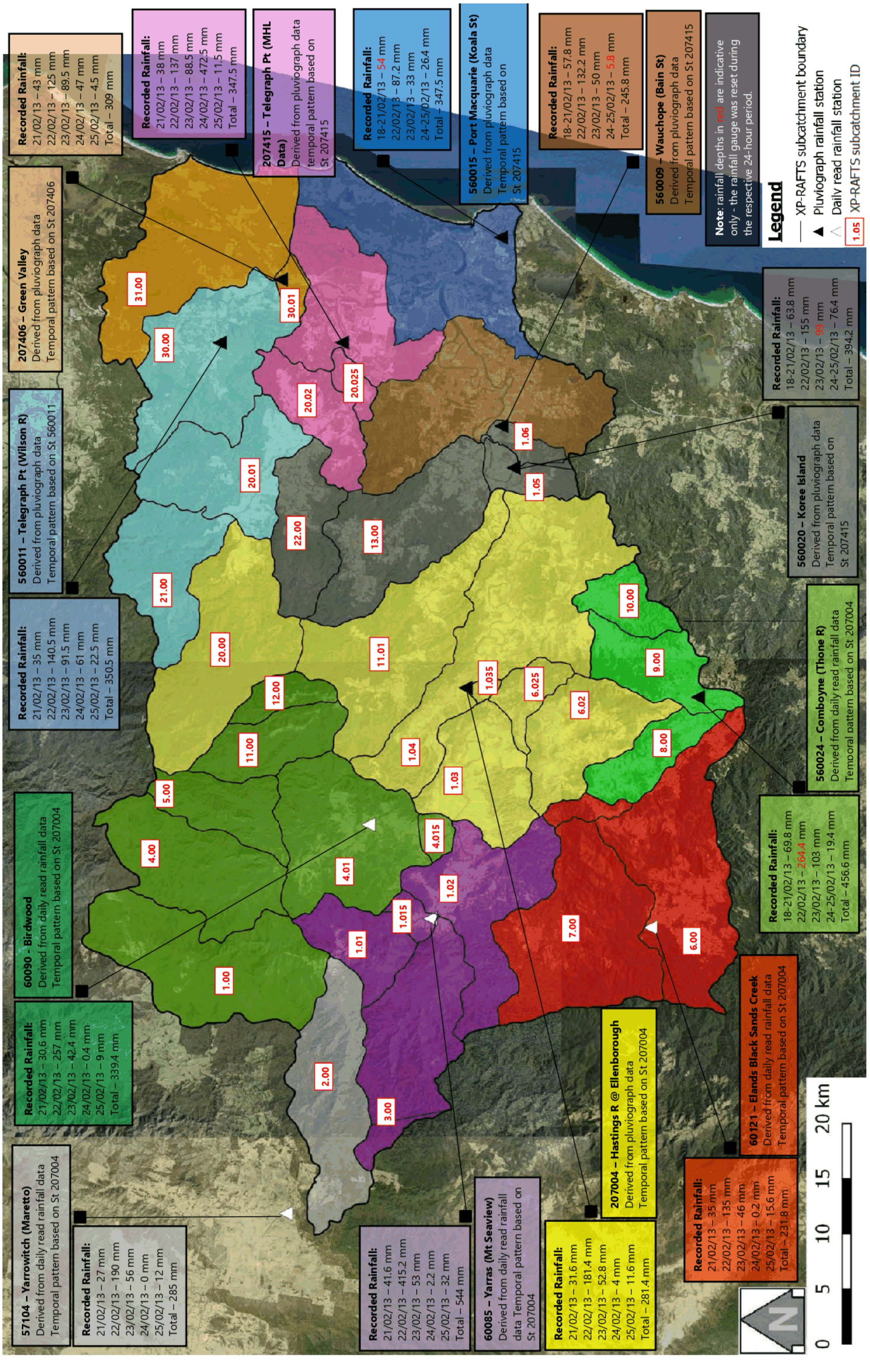
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS

FIGURE 4.10

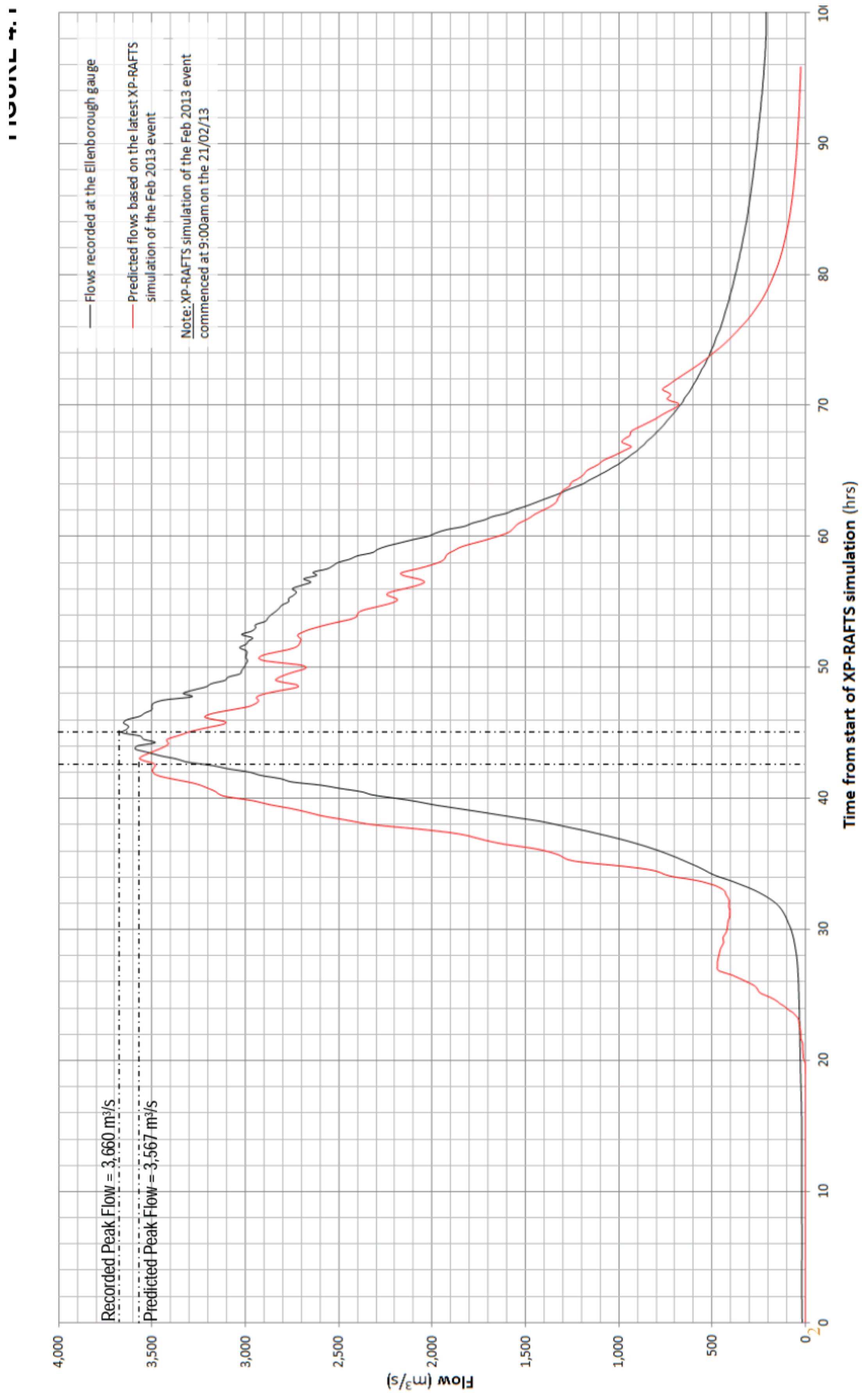


LOCATION OF ALL STREAMFLOW & FLOOD MARK DATA COLLECTED AND USED FOR VALIDATION TO THE FEBRUARY 2013 EVENT

Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS



ADOPTED SPATIAL DISTRIBUTION OF RAINFALL FOR MODELLING OF THE FEBRUARY 2013 STORM EVENT IN THE XP-RAFTS HYDROLOGIC MODEL



COMPARISON OF PREDICTED XP-RAFTS FLOWS TO RECORDED FLOWS AT THE ELLENBOROUGH GAUGE (207004

Advisian
WorleyParsons Group

301015-03826-Hibbard Floodway FRMS
fg301015-03826rg180718_Fig 4.12 - XP-RAFTS Validation to Ellenborough Gauge.docx

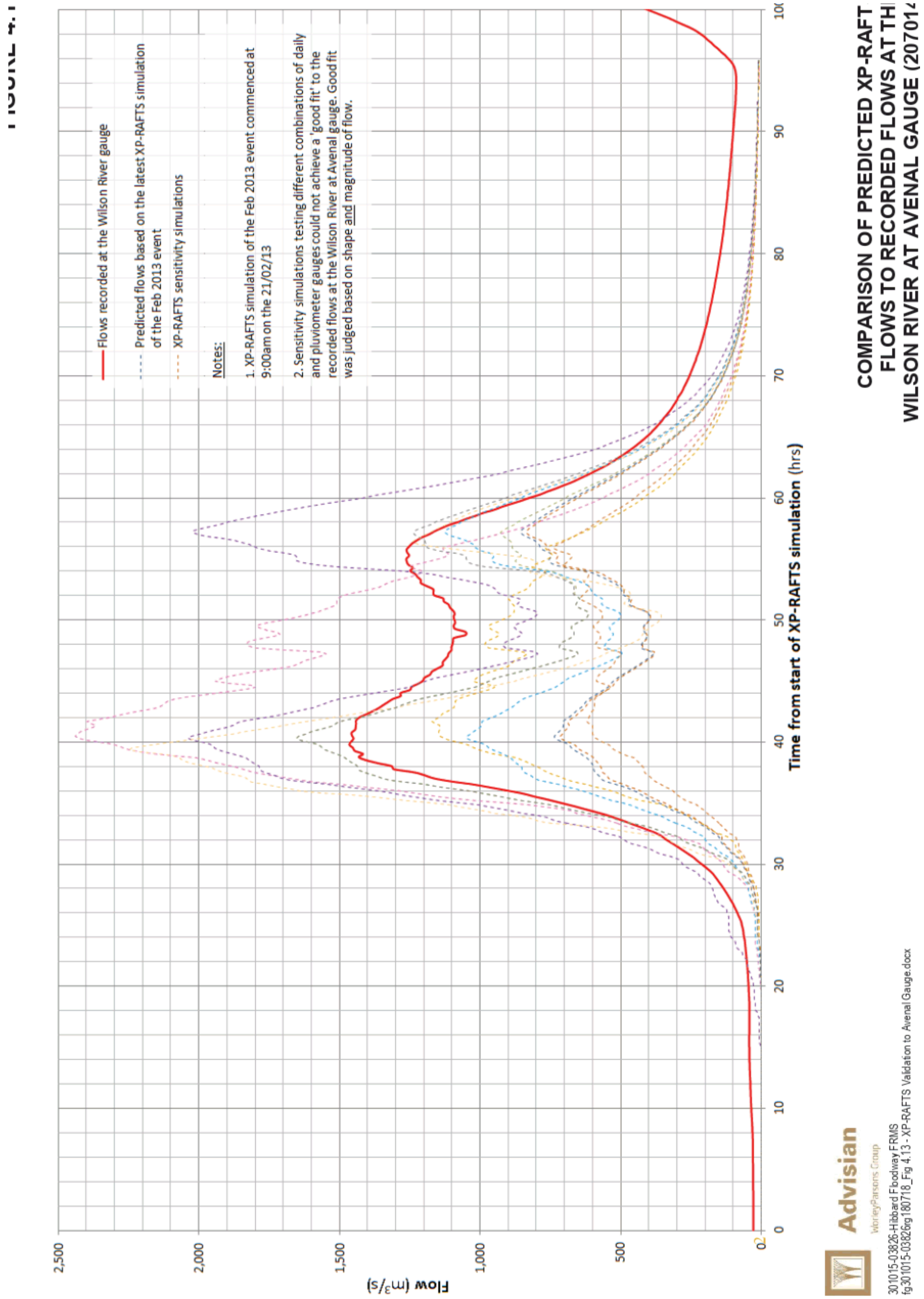
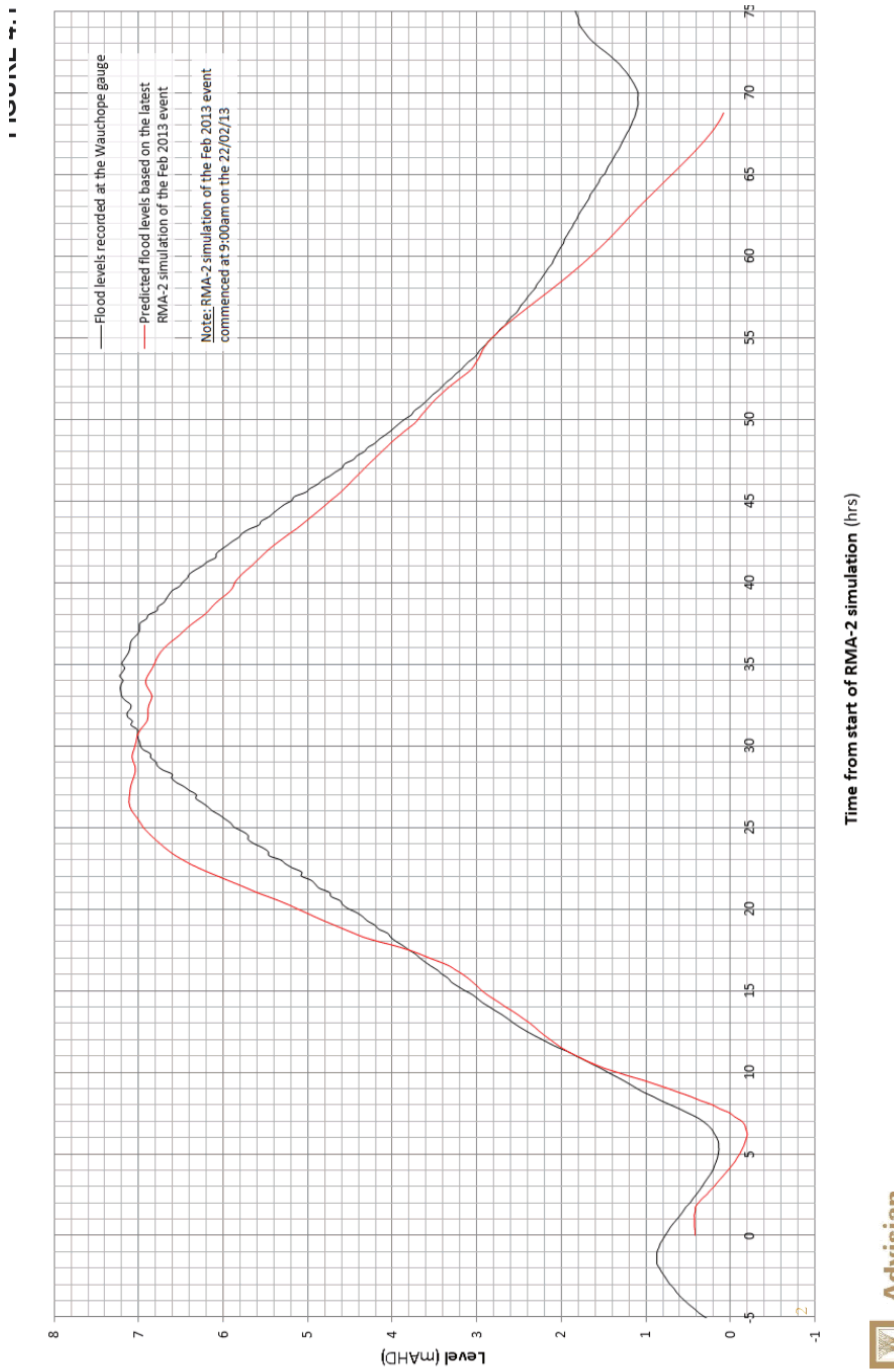
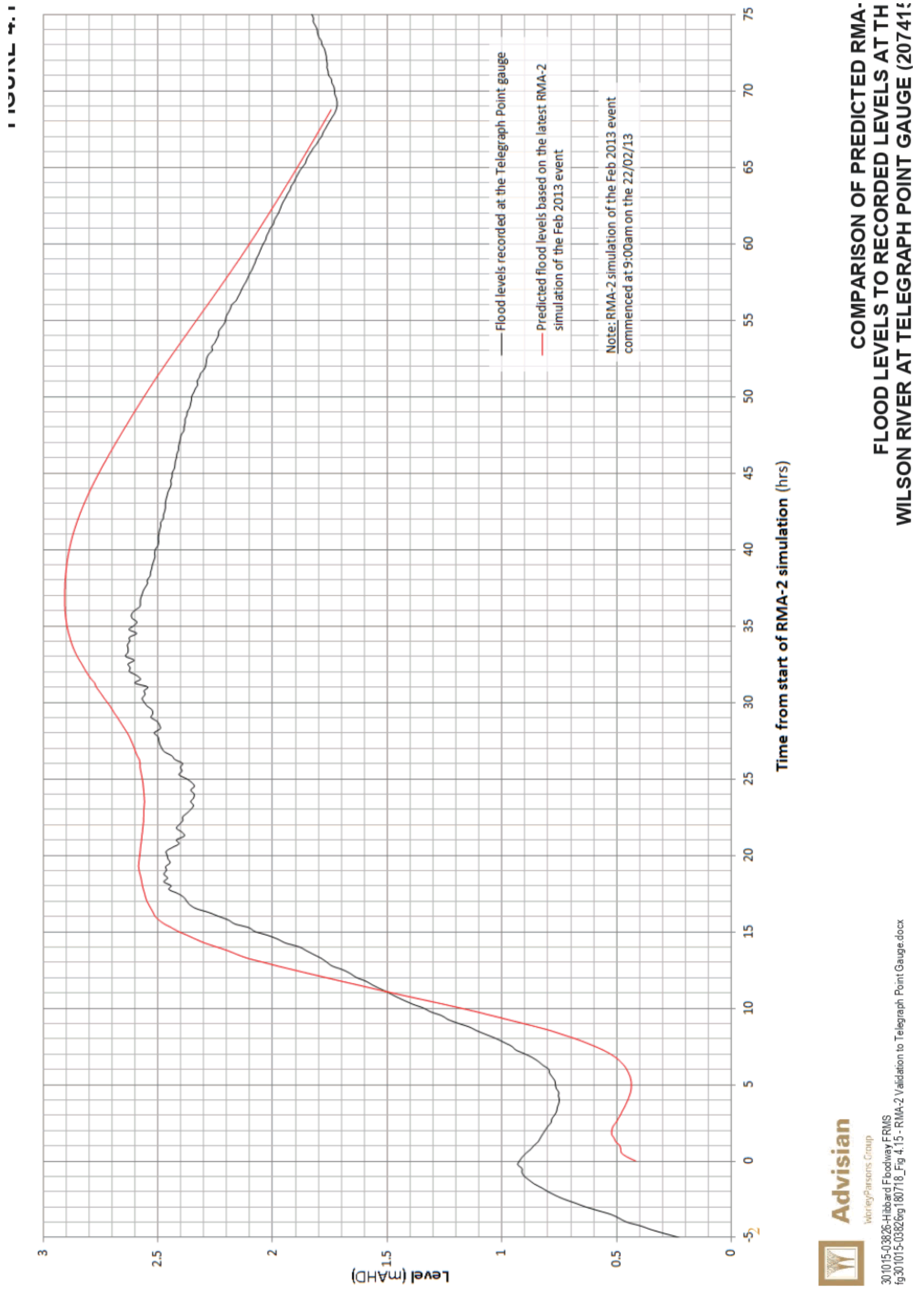


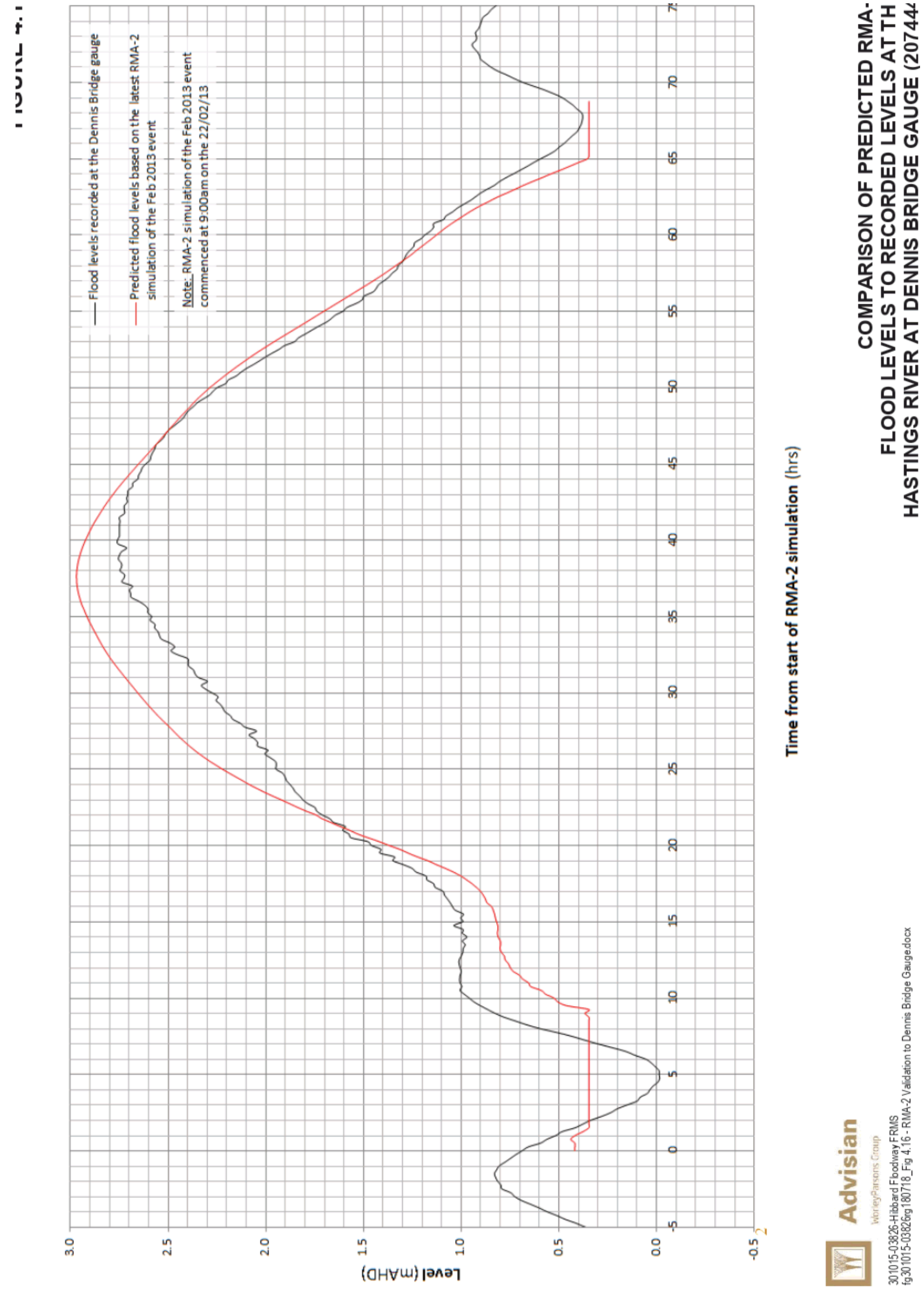
FIGURE 4.1
Flows recorded at the Wilson River gauge
Predicted flows based on the latest XP-RAFTS simulation of the Feb 2013 event
XP-RAFTS sensitivity simulations
Notes:
1. XP-RAFTS simulation of the Feb 2013 event commenced at 9:00am on the 21/02/13
2. Sensitivity simulations testing different combinations of daily and pluviometer gauges could not achieve a 'good fit' to the recorded flows at the Wilson River at Avenal gauge. Good fit was judged based on shape and magnitude of flow.
Flow (m³/s)
2,500
2,000
1,500
1,000
500
0
Time from start of XP-RAFTS simulation (hrs)
0
10
20
30
40
50
60
70
80
90
100
COMPARISON OF PREDICTED XP-RAFTS FLOWS TO RECORDED FLOWS AT THE WILSON RIVER AT AVENAL GAUGE (207014)
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS
fg301015-03826rg180718_Fig 4.13 - XP-RAFTS Validation to Avenal Gauge.docx

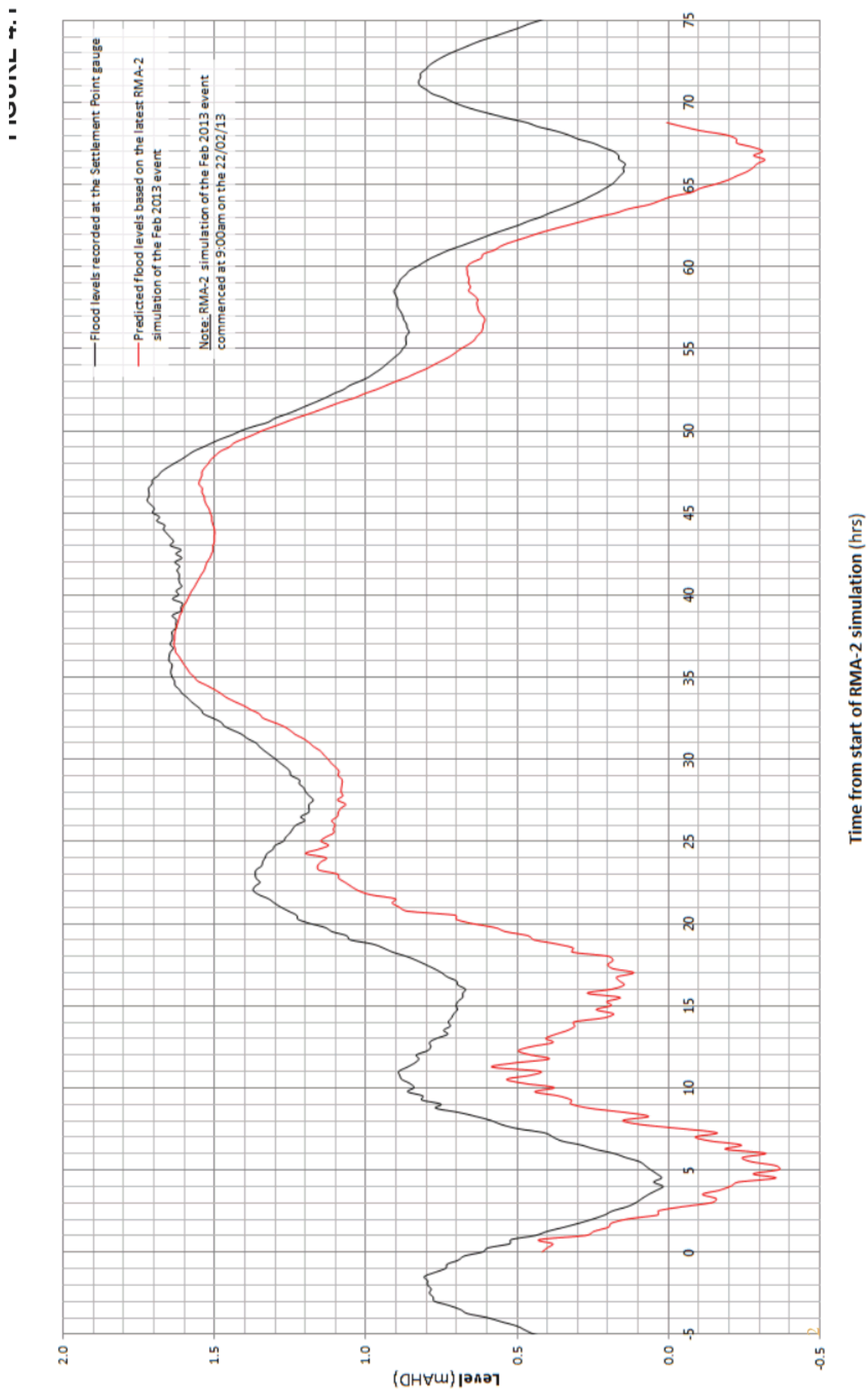


COMPARISON OF PREDICTED RMA-
FLOOD LEVELS TO RECORDED LEVELS AT THI
HASTINGS RIVER AT WAUCHOPE GAUGE (207401

Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS
fg301015-03826rg180718_Fig 4.14 - RMA-2 Validation to Wauchope Gauge.docx


COMPARISON OF PREDICTED RMA-
FLOOD LEVELS TO RECORDED LEVELS AT TH
WILSON RIVER AT TELEGRAPH POINT GAUGE (20741
Flood levels recorded at the Telegraph Point gauge
Predicted flood levels based on the latest RMA-2 simulation of the Feb 2013 event
Note: RMA-2 simulation of the Feb 2013 event commenced at 9:00am on the 22/02/13
Time from start of RMA-2 simulation (hrs)
Level (mAHD)
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS
fg301015-03826rg180718_Fig 4.15 - RMA-2 Validation to Telegraph Point Gauge.docx

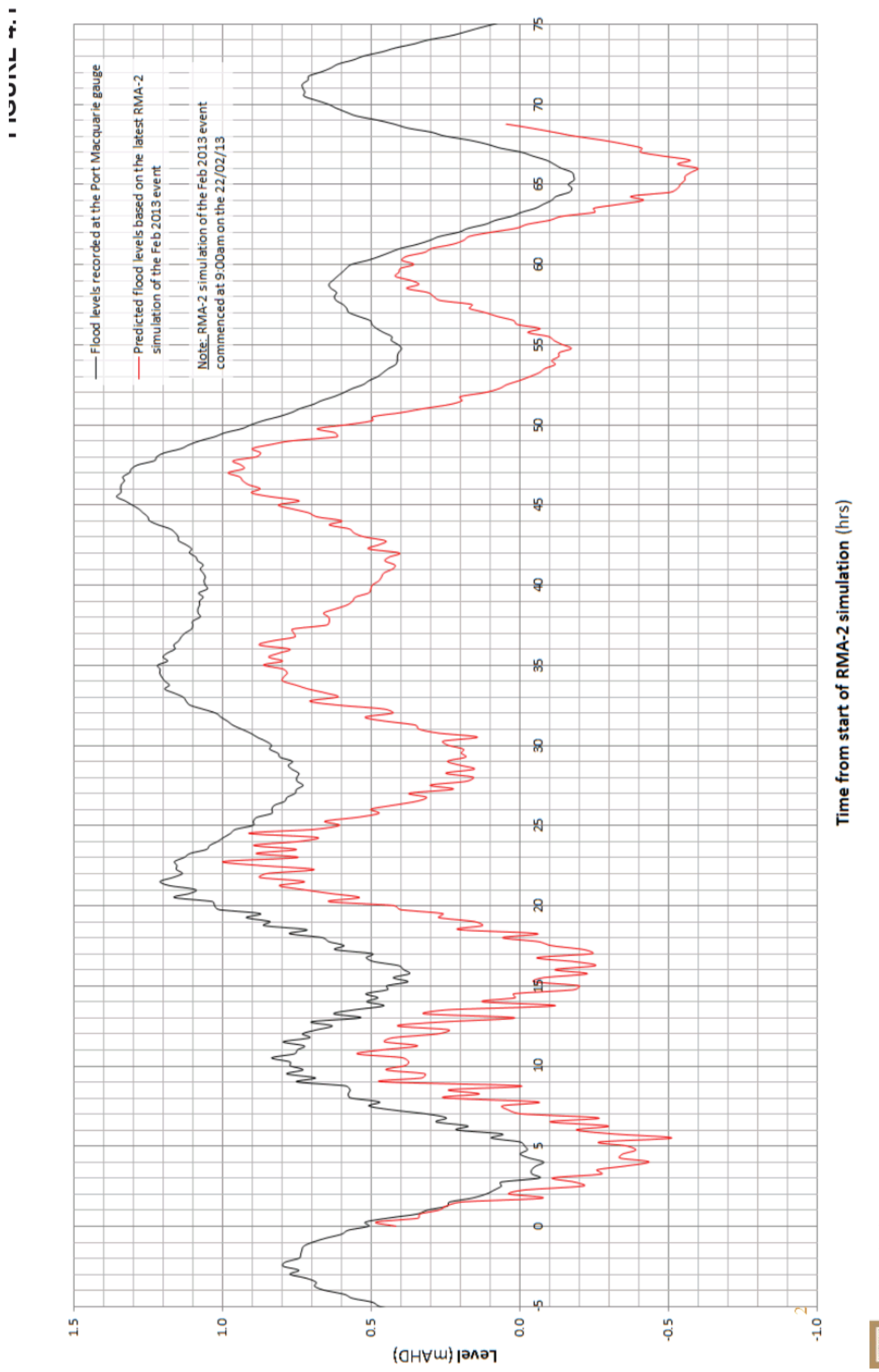

COMPARISON OF PREDICTED RMA-
FLOOD LEVELS TO RECORDED LEVELS AT TH
HASTINGS RIVER AT DENNIS BRIDGE GAUGE (207444
Flood levels recorded at the Dennis Bridge gauge
Predicted flood levels based on the latest RMA-2 simulation of the Feb 2013 event
Note: RMA-2 simulation of the Feb 2013 event commenced at 9:00am on the 22/02/13
Level (mAHD)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
Time from start of RMA-2 simulation (hrs)
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS
fg301015-03826rg180718_Fig 4.16 - RMA-2 Validation to Dennis Bridge Gauge.docx



COMPARISON OF PREDICTED RMA-
FLOOD LEVELS TO RECORDED LEVELS AT TH
HASTINGS RIVER AT SETTLEMENT POINT GAUGE (20741

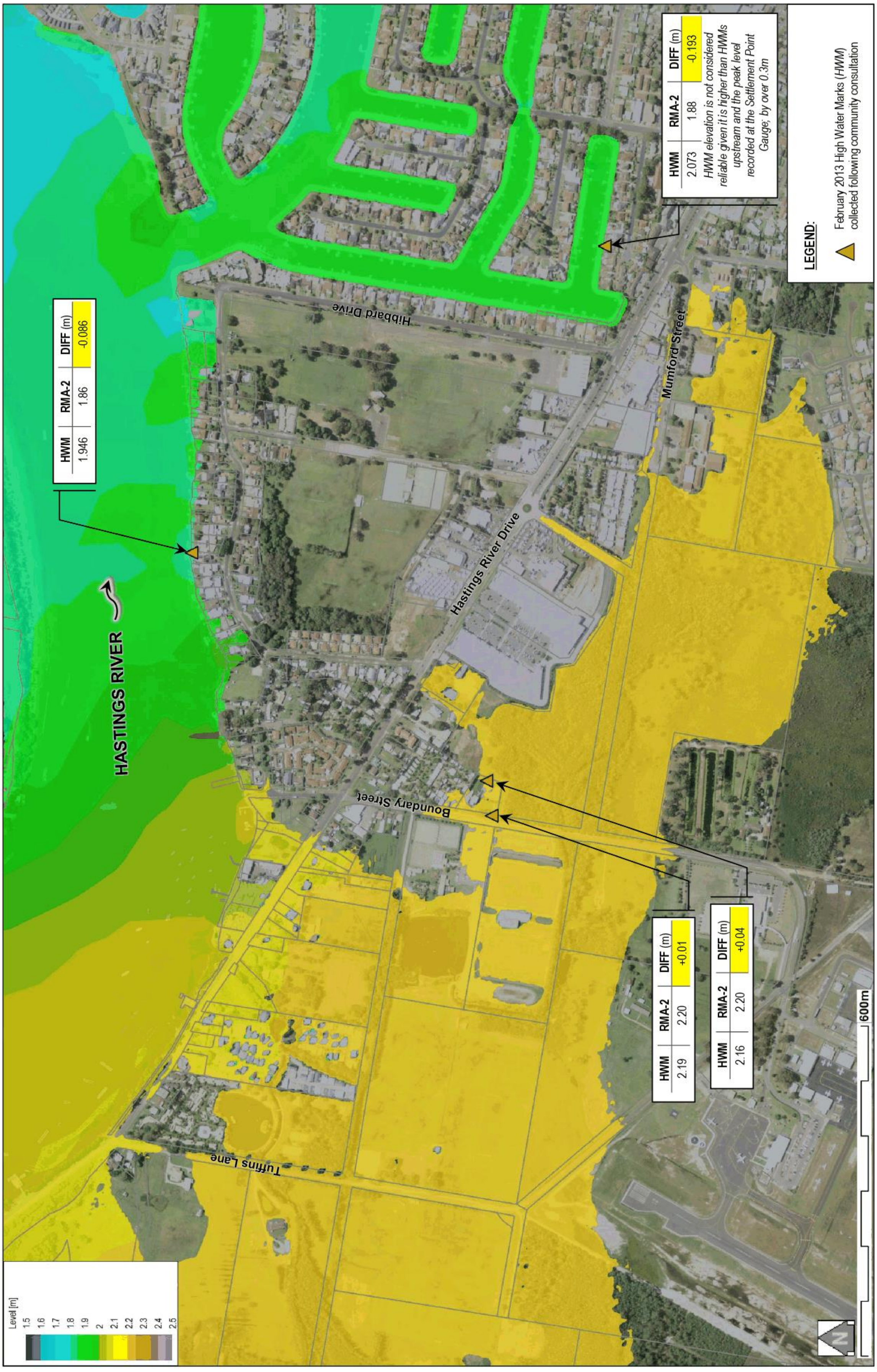
Advisian
WorleyParsons Group

301015-03826-Hibbard Floodway FRMS
fg301015-03826rg180718_Fig 4.17 - RMA-2 Validation to Settlement Point Gauge.docx



COMPARISON OF PREDICTED RMA-
FLOOD LEVELS TO RECORDED LEVELS AT TH
HASTINGS RIVER AT PORT MACQUARIE GAUGE (20745(

Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS
fg301015-03826rg180718_Fig 4.18 - RMA-2 Validation to Port Macquarie Gauge.docx



VALIDATION OF THE RMA-2 HIBBARD MODEL TO HIGH WATER MARKS COLLECTED FOR THE FEBRUARY 2013 EVENT

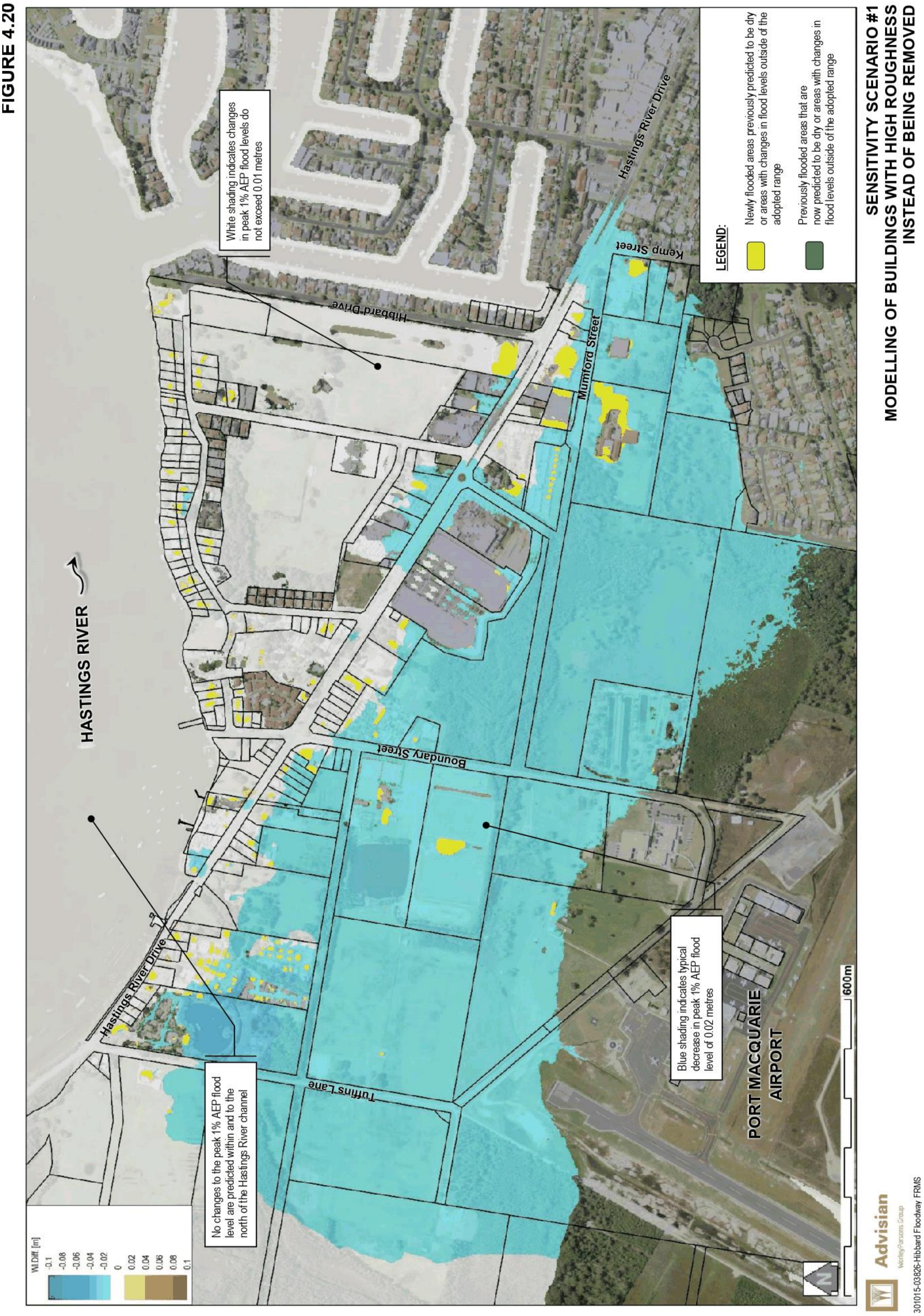
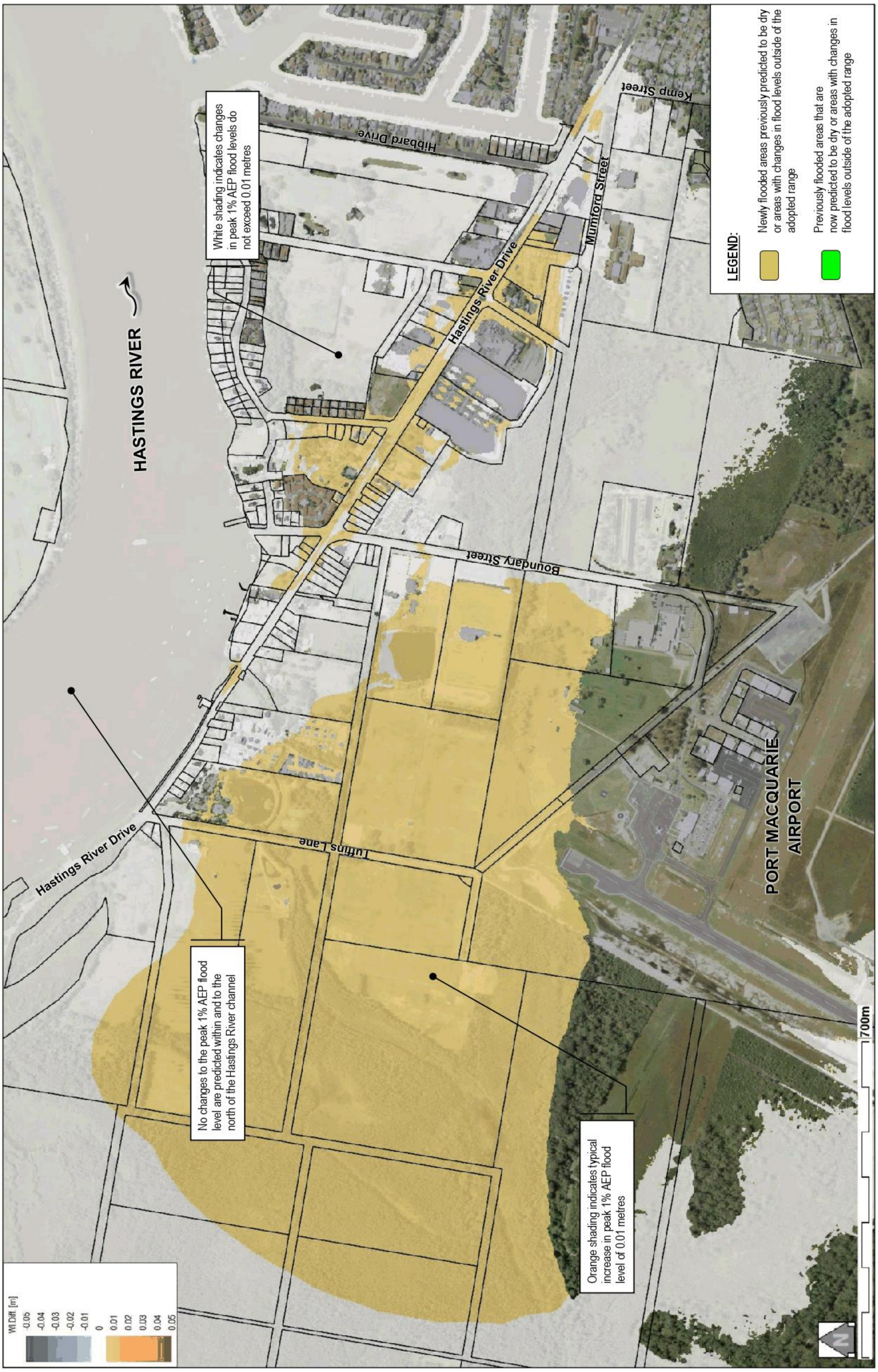


FIGURE 4.20
SENSITIVITY SCENARIO #1
MODELLING OF BUILDINGS WITH HIGH ROUGHNESS
INSTEAD OF BEING REMOVED
LEGEND:
Newly flooded areas previously predicted to be dry or areas with changes in flood levels outside of the adopted range
Previously flooded areas that are now predicted to be dry or areas with changes in flood levels outside of the adopted range
White shading indicates changes in peak 1% AEP flood levels do not exceed 0.01 metres
Blue shading indicates typical decrease in peak 1% AEP flood level of 0.02 metres
No changes to the peak 1% AEP flood level are predicted within and to the north of the Hastings River channel
HASTINGS RIVER
Hastings River Drive
Hibbard Drive
Kemp Street
Mumford Street
Boundary Street
Tuffins Lane
PORT MACQUARIE AIRPORT
600m
WL Diff. [m]
-0.1
-0.08
-0.06
-0.04
-0.02
0
0.02
0.04
0.06
0.08
0.1
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS

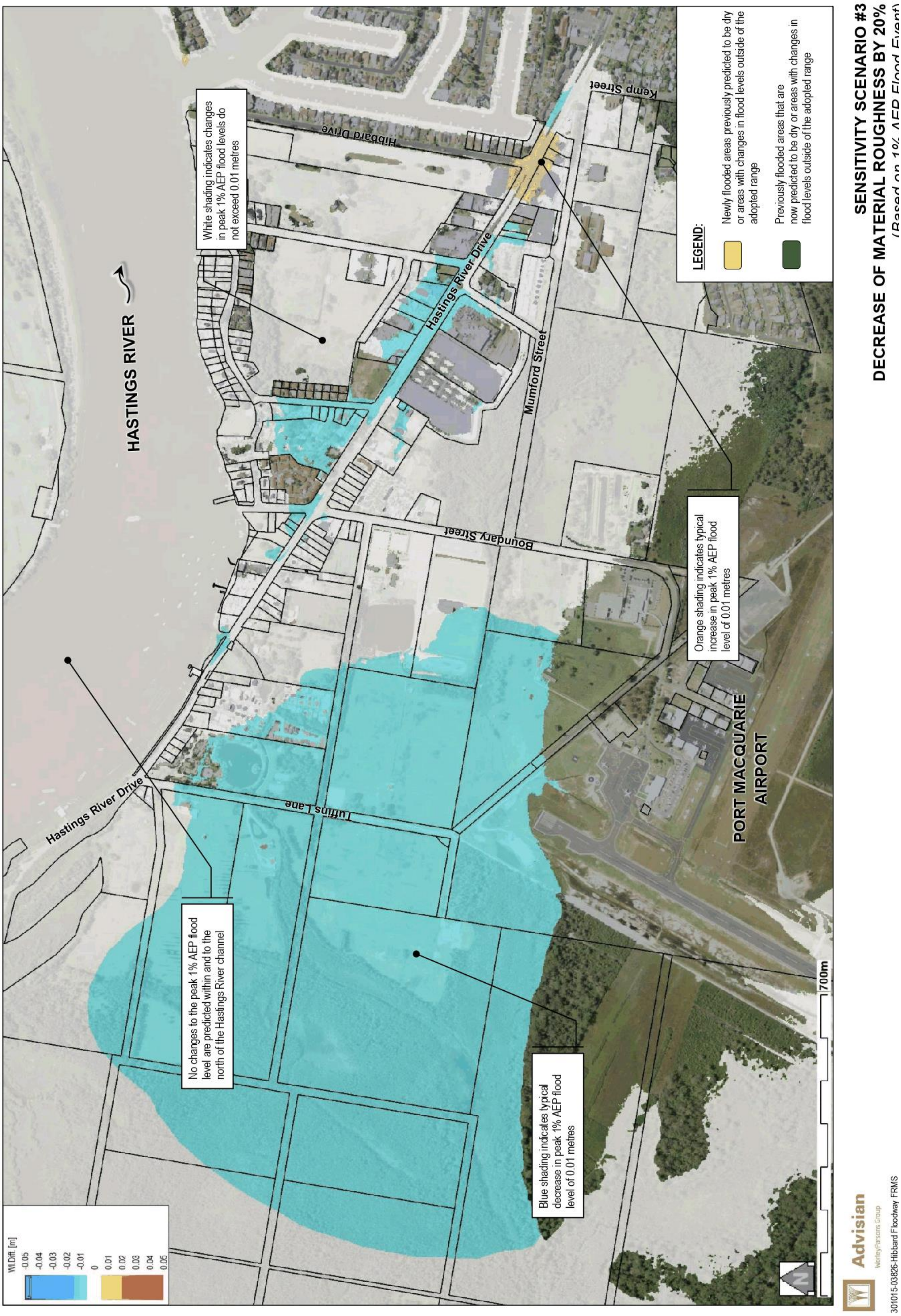
FIGURE 4.21



SENSITIVITY SCENARIO #2
INCREASE OF MATERIAL ROUGHNESS BY 20%
(Based on 1% AEP Flood Event)

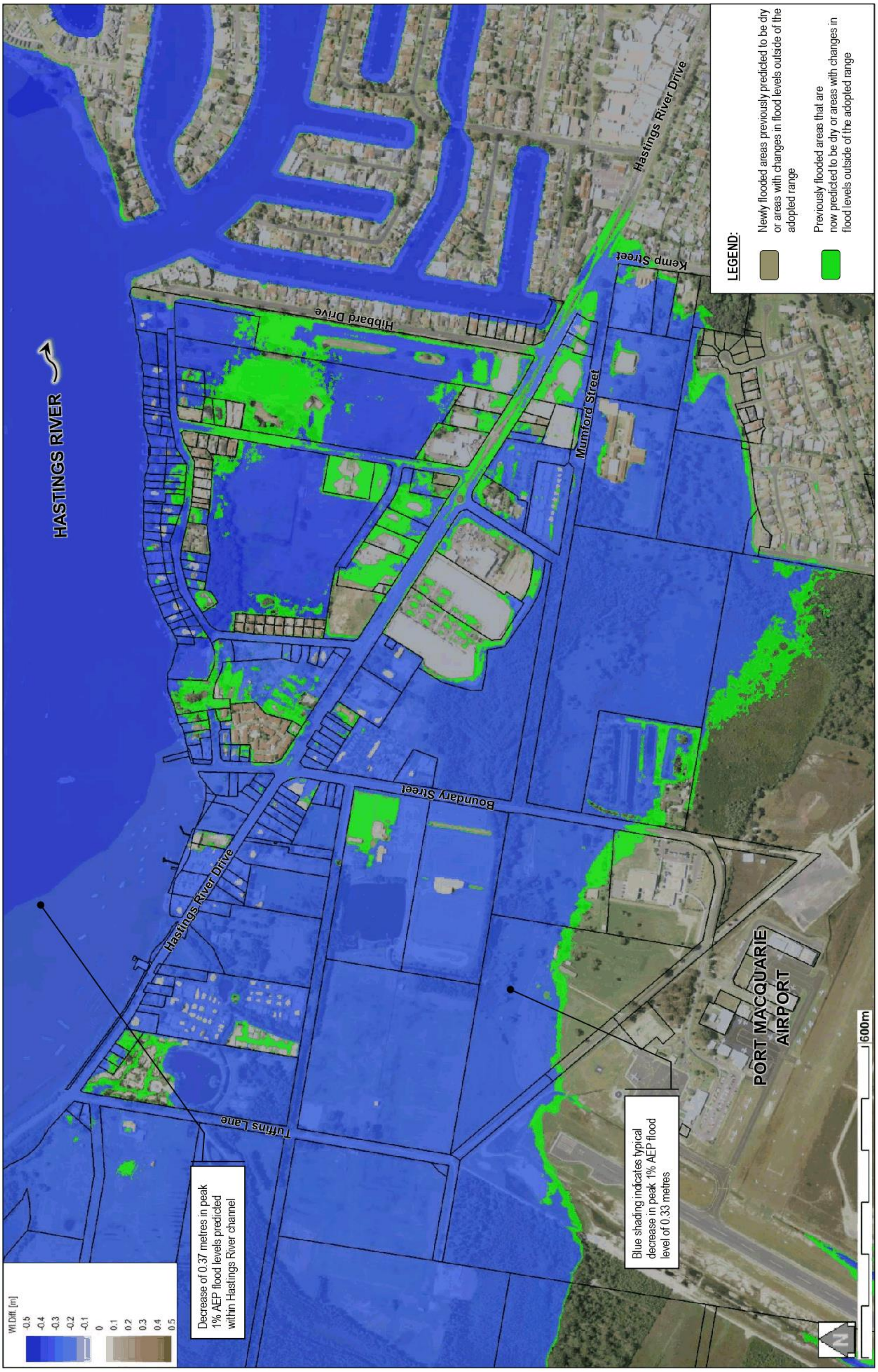
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS

FIGURE 4.22



SENSITIVITY SCENARIO #3
DECREASE OF MATERIAL ROUGHNESS BY 20%
(Based on 1% AEP Flood Event)

FIGURE 4.23



SENSITIVITY SCENARIO #4
ADOPTION OF LOCAL TAILWATER LEVELS
(Based on 1% AEP Flood Event)

Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS

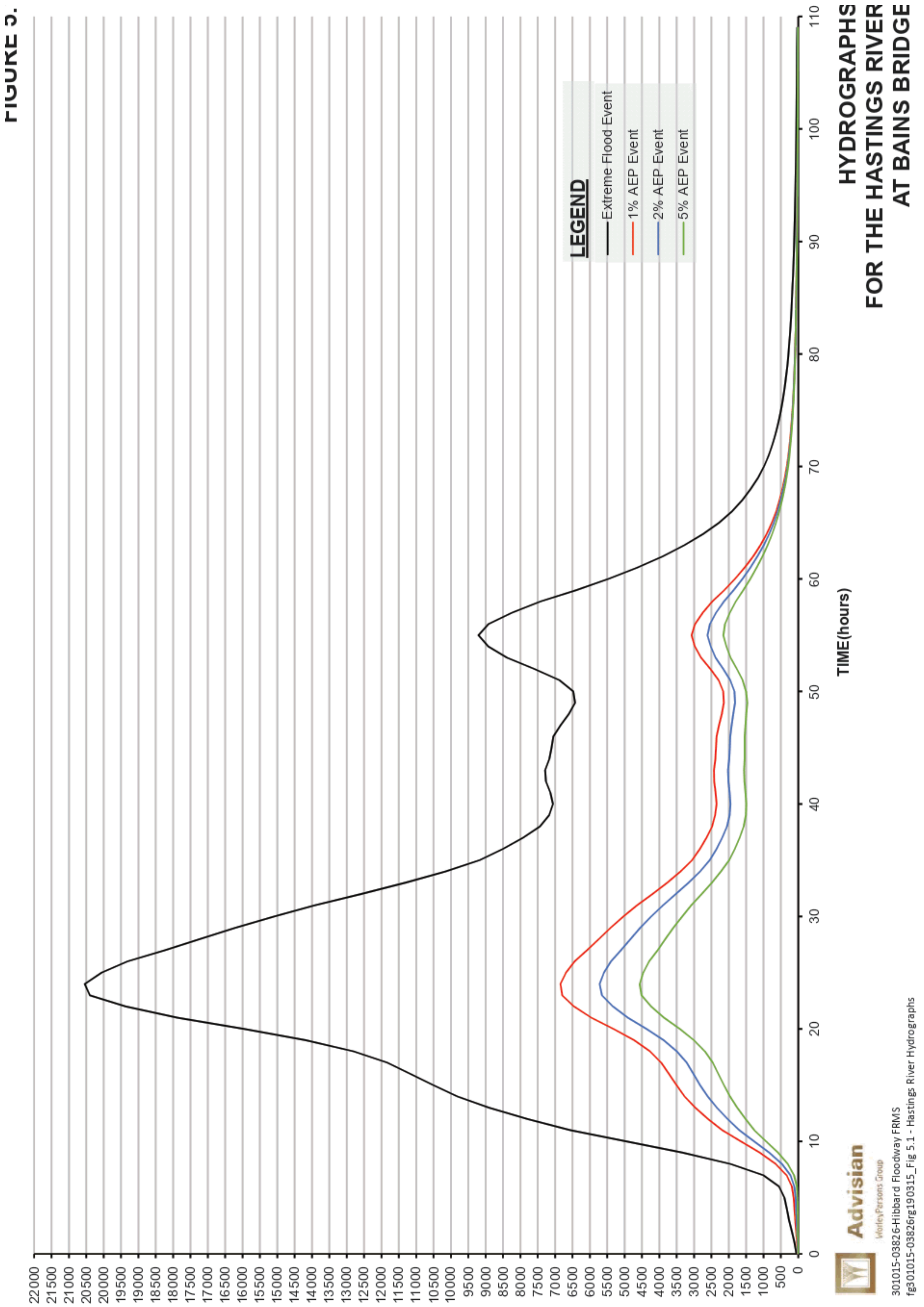
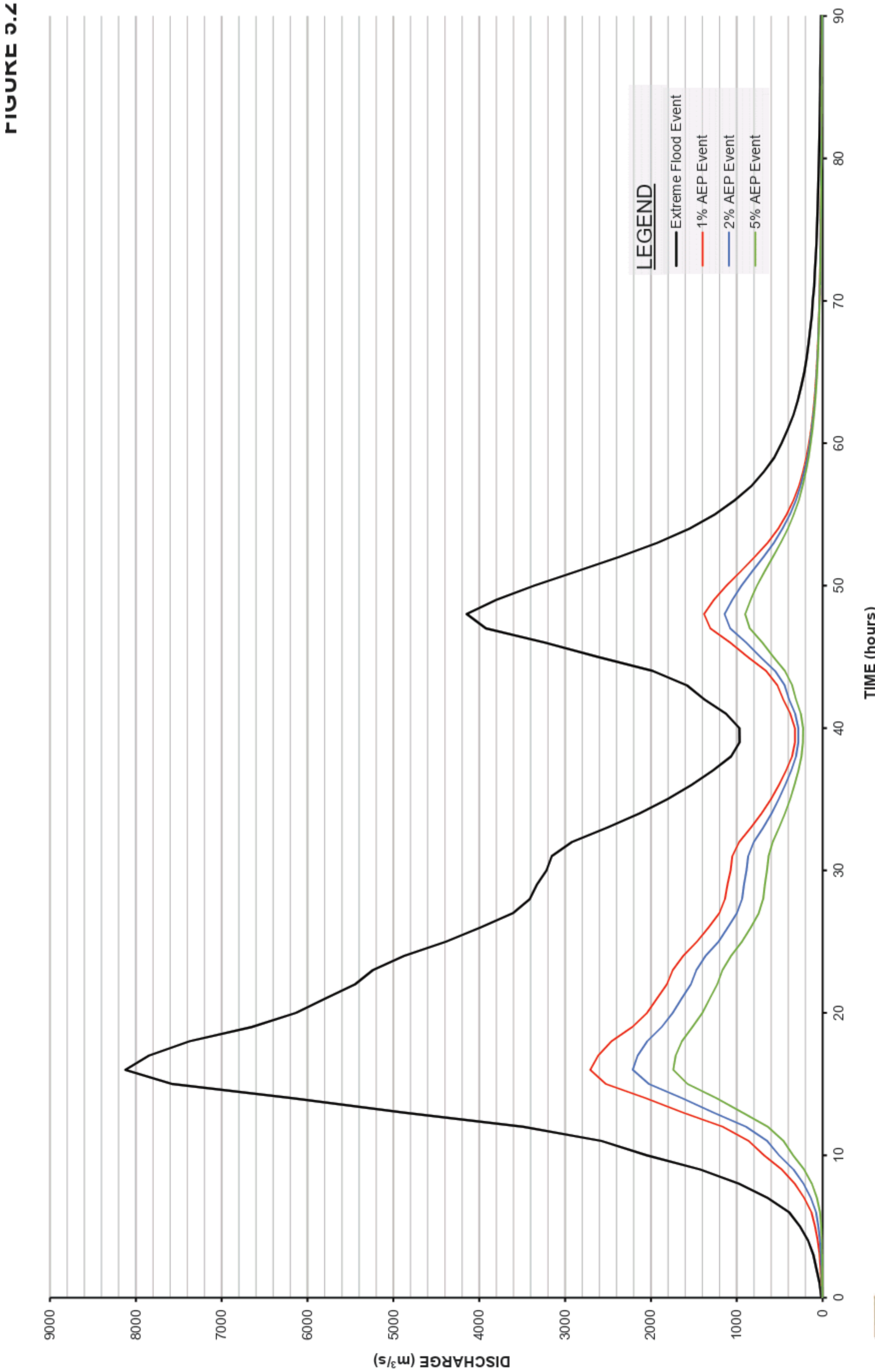


FIGURE 5.
HYDROGRAPHS FOR THE HASTINGS RIVER AT BAINS BRIDGE
LEGEND
Extreme Flood Event
1% AEP Event
2% AEP Event
5% AEP Event
DISCHARGE (m³/s)
TIME(hours)
0
10
20
30
40
50
60
70
80
90
100
110
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
9500
10000
10500
11000
11500
12000
12500
13000
13500
14000
14500
15000
15500
16000
16500
17000
17500
18000
18500
19000
19500
20000
20500
21000
21500
22000
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS
fg301015-03826rg190315_Fig 5.1 - Hastings River Hydrographs

FIGURE 5.2



HYDROGRAPHS FOR THE WILSON RIVER UPSTREAM OF PACIFIC HIGHWAY

Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS
fg301015-03826rg190315_Fig 5.2 - Wilson River Hydrographs

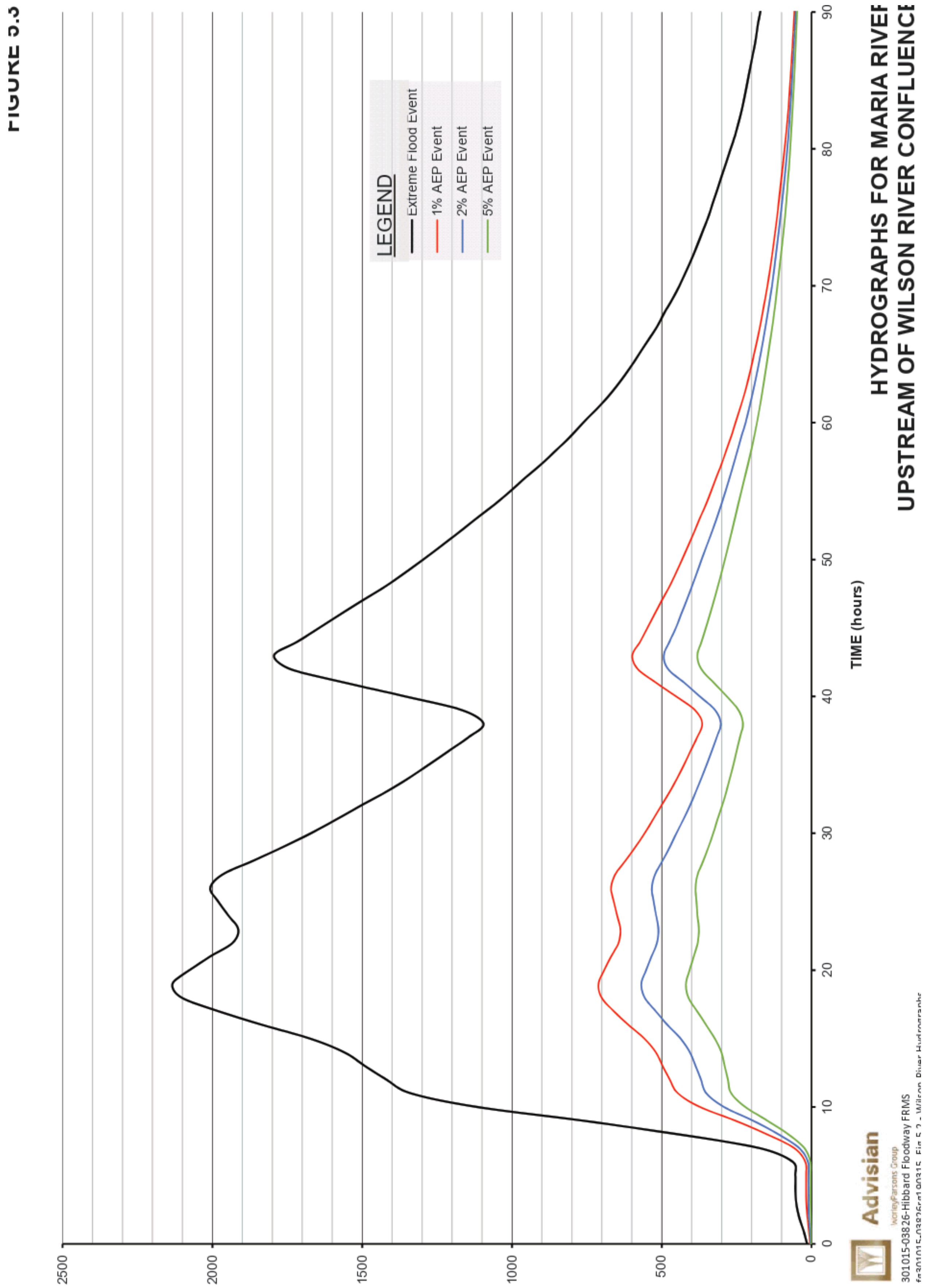
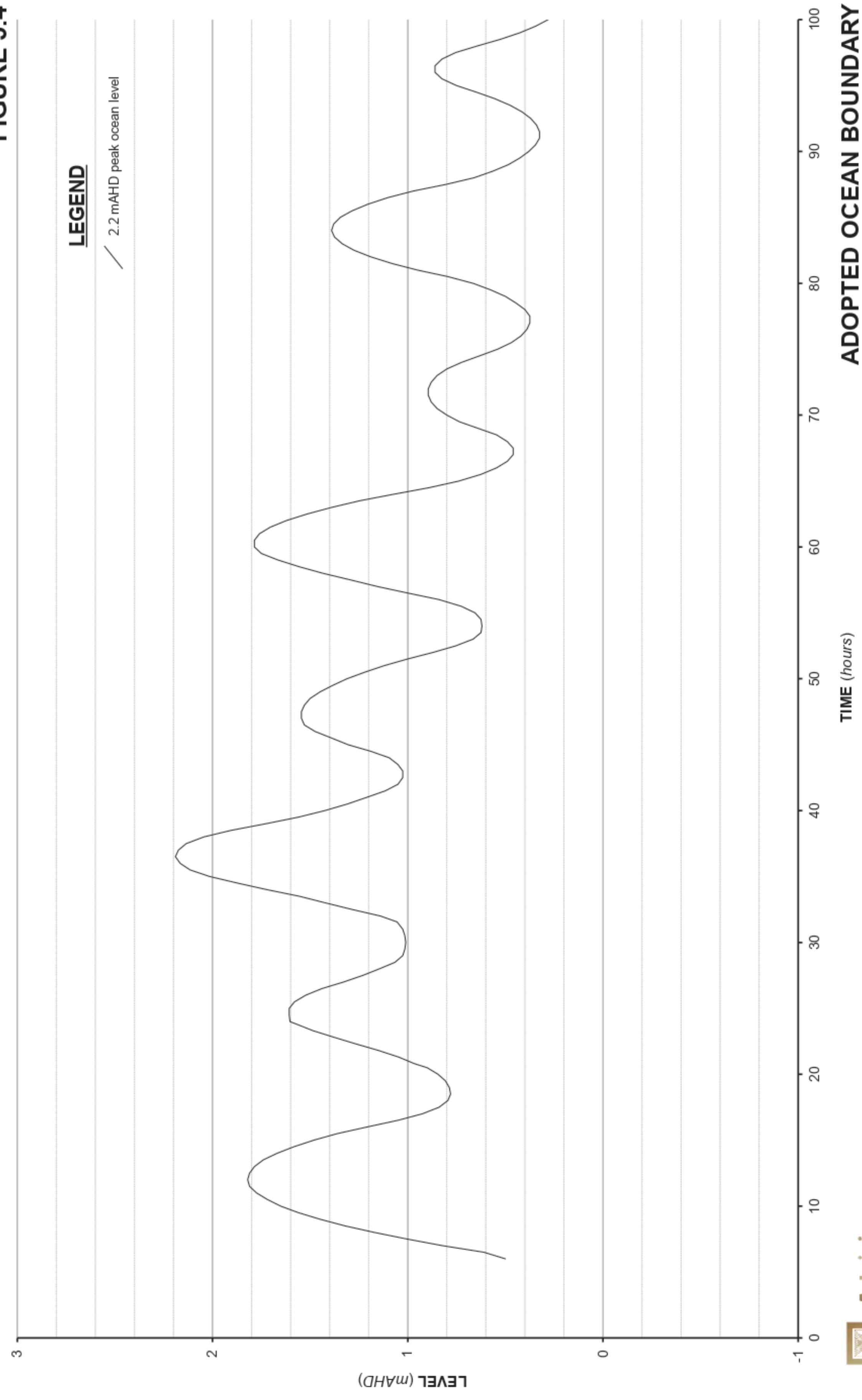

HYDROGRAPHS FOR MARIA RIVER
UPSTREAM OF WILSON RIVER CONFLUENCE
LEGEND
Extreme Flood Event
1% AEP Event
2% AEP Event
5% AEP Event
TIME (hours)
DISCHARGE (m³/s)
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS

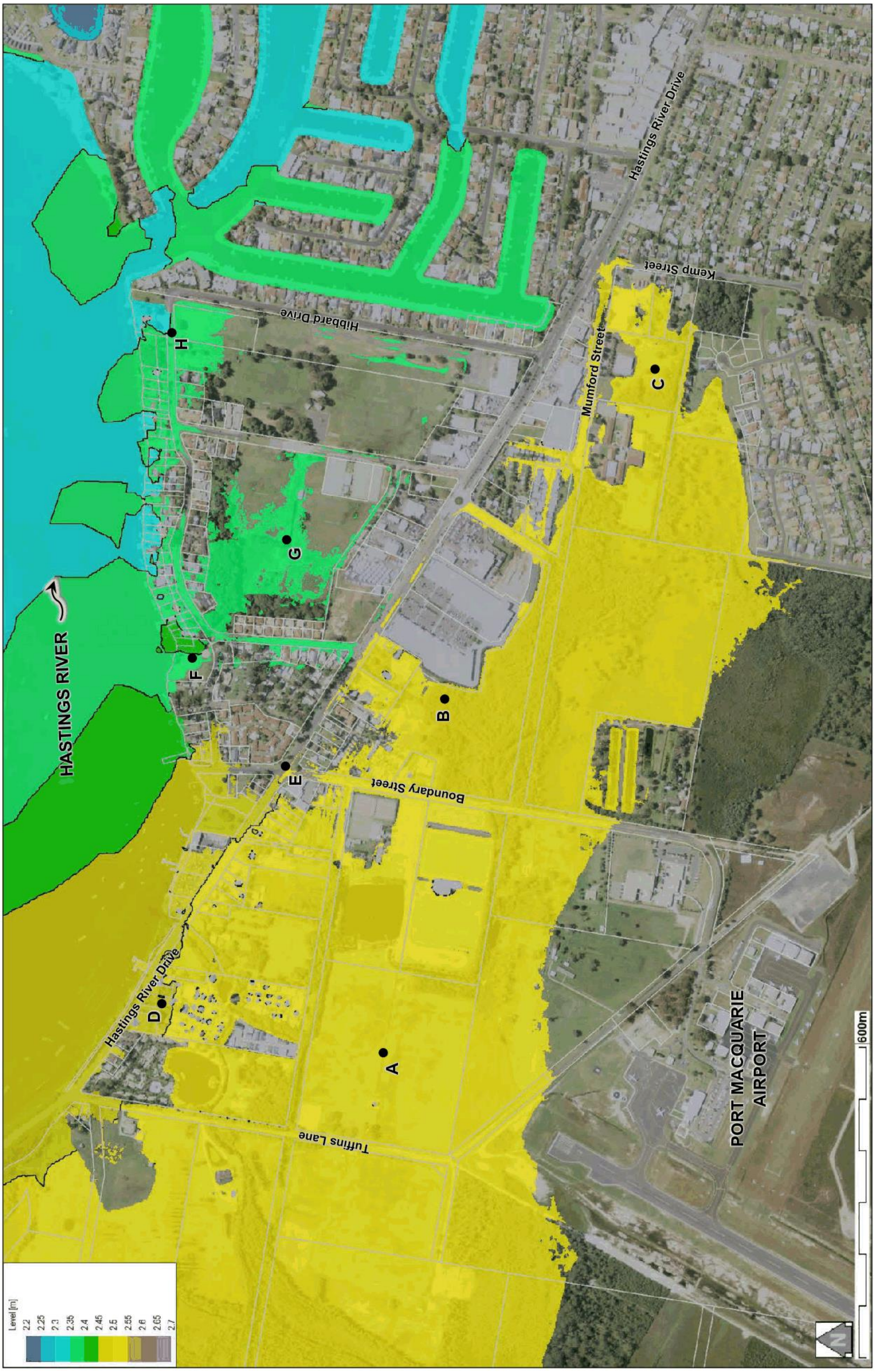
FIGURE 5.4



ADOPTED OCEAN BOUNDARY CONDITIONS FOR DESIGN FLOOD SIMULATIONS

Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS
fg301015-03826rg190315_Fig 5.4 - Ocean Water Levels

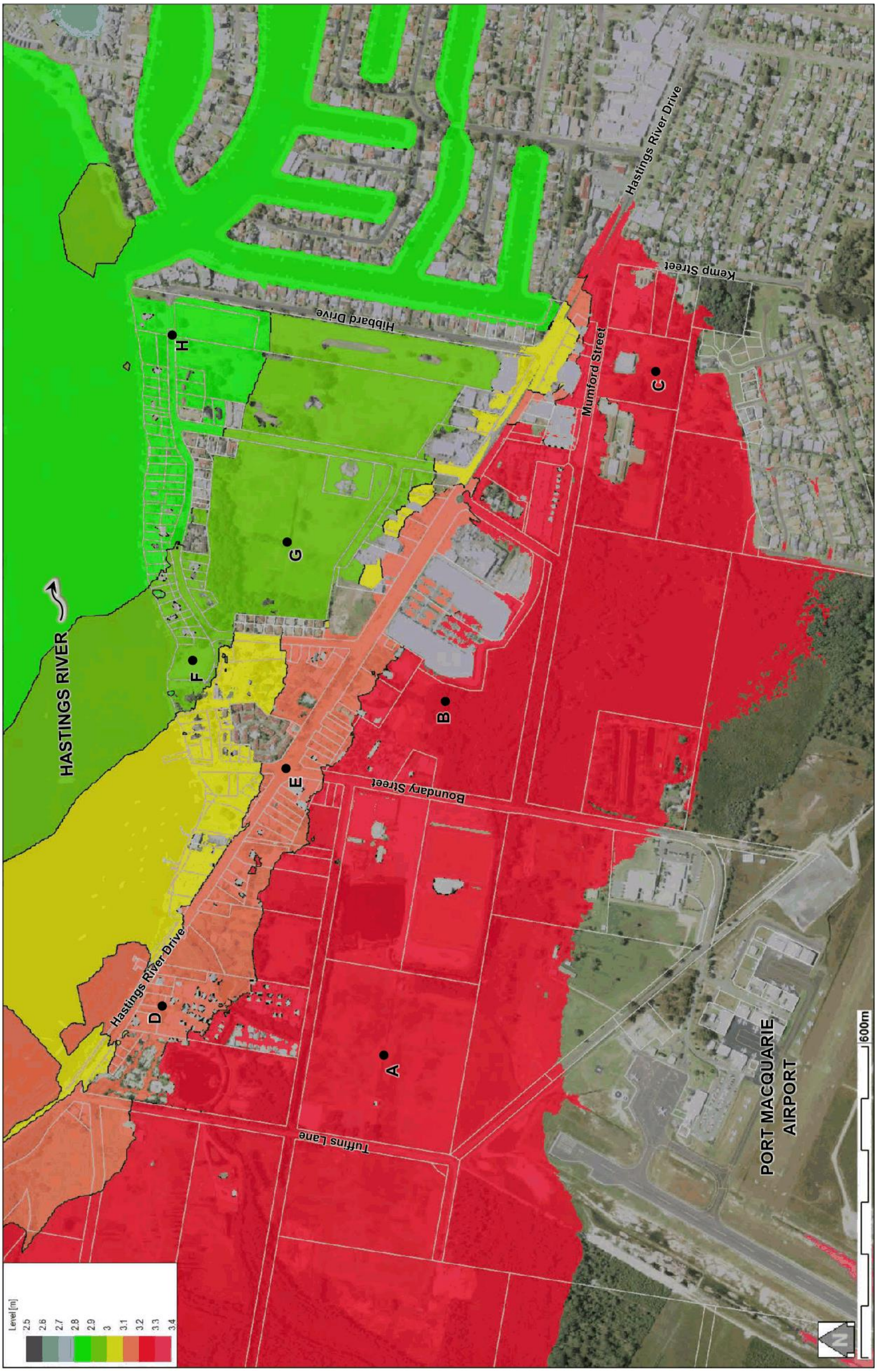
FIGURE 5.5



PREDICTED PEAK FLOOD LEVELS DURING THE 5% AEP FLOOD

Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS

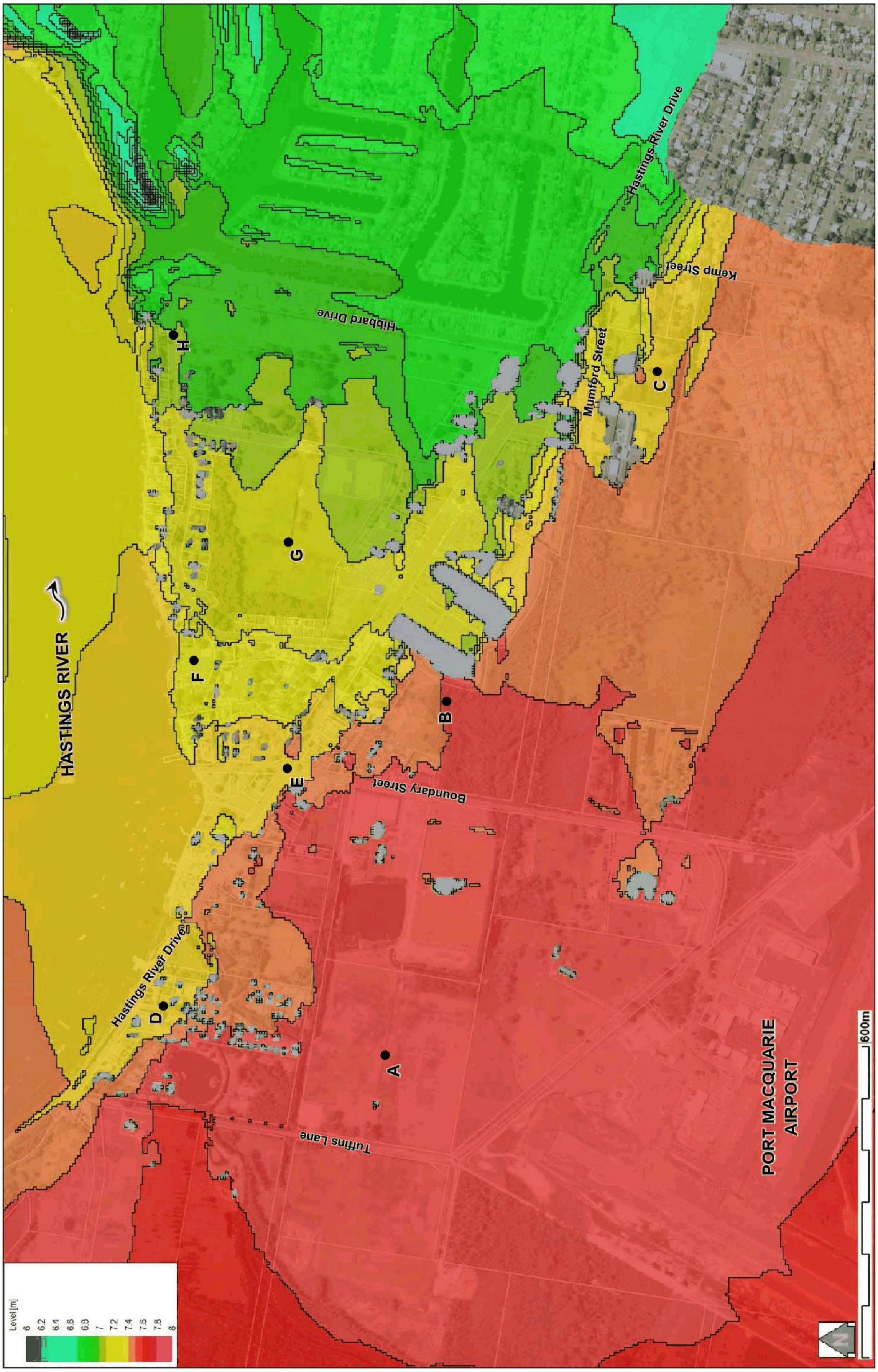
FIGURE 5.6



PREDICTED PEAK FLOOD LEVELS DURING THE 1% AEP FLOOD

Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS

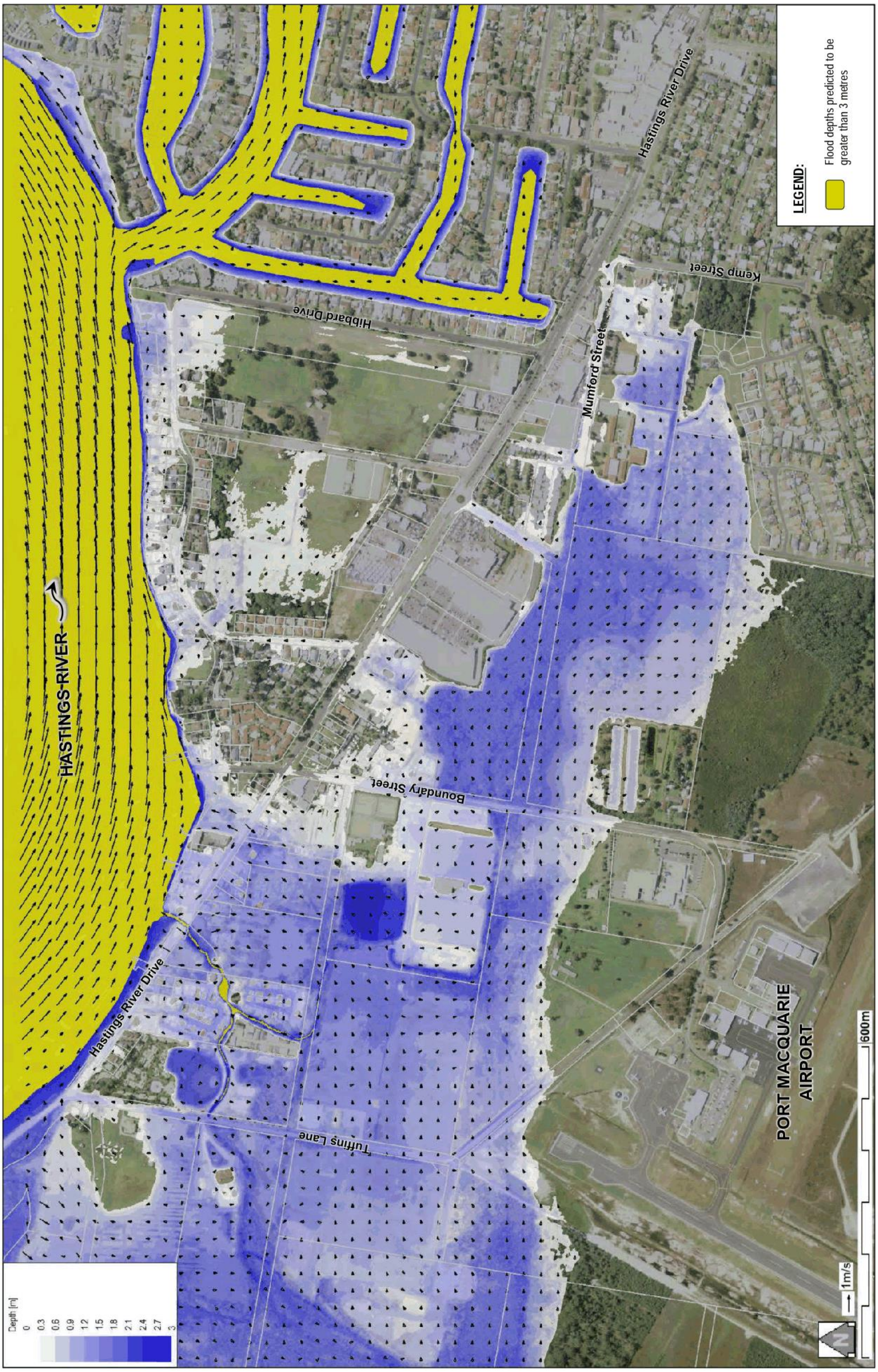
FIGURE 5.7



PREDICTED PEAK FLOOD LEVELS DURING THE EXTREME FLOOD EVENT

Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS

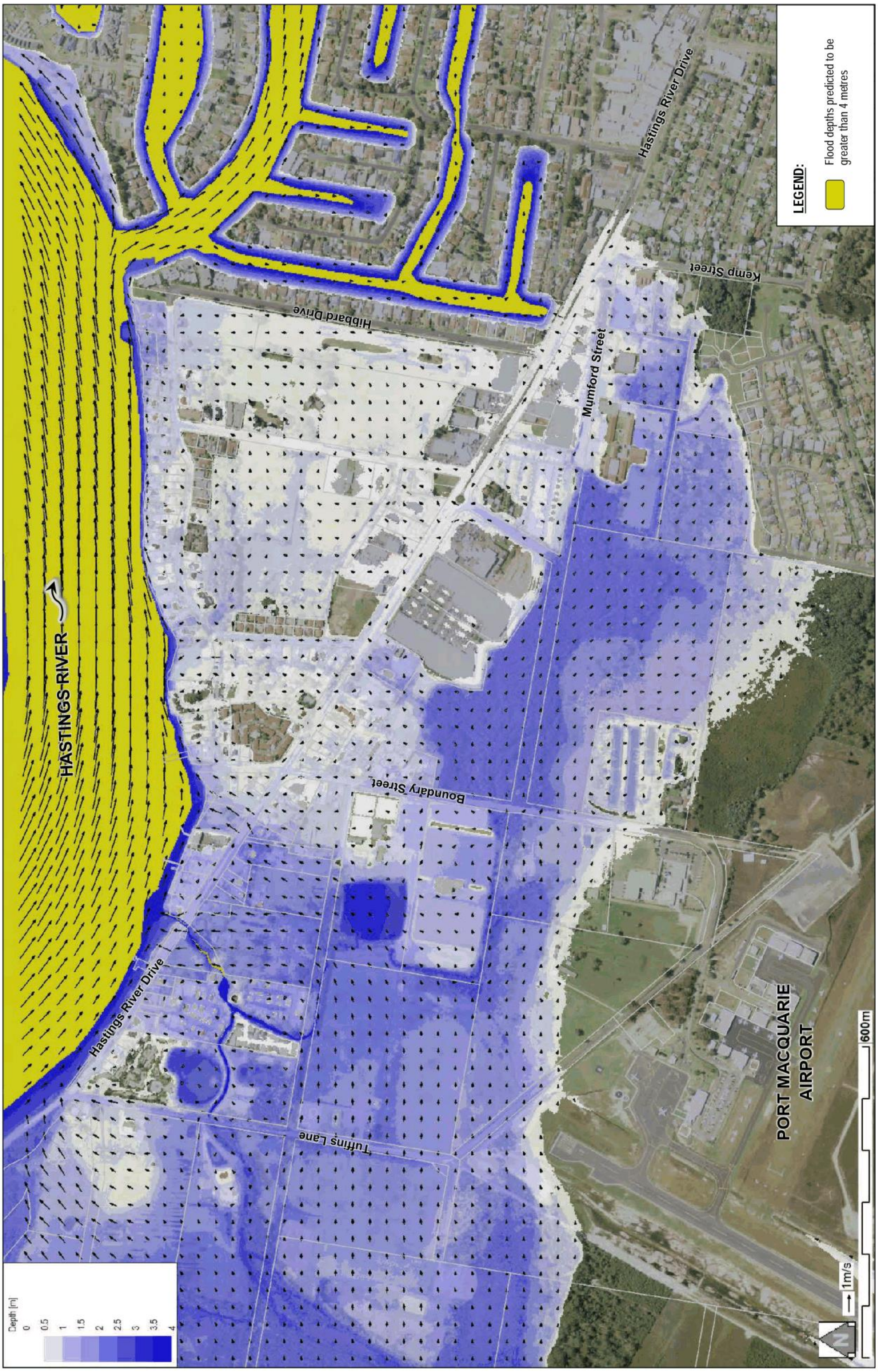
FIGURE 5.8



PREDICTED PEAK FLOOD DEPTHS DURING THE 5% AEP FLOOD

Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS

FIGURE 5.9



PREDICTED PEAK FLOOD DEPTHS DURING THE 1% AEP FLOOD

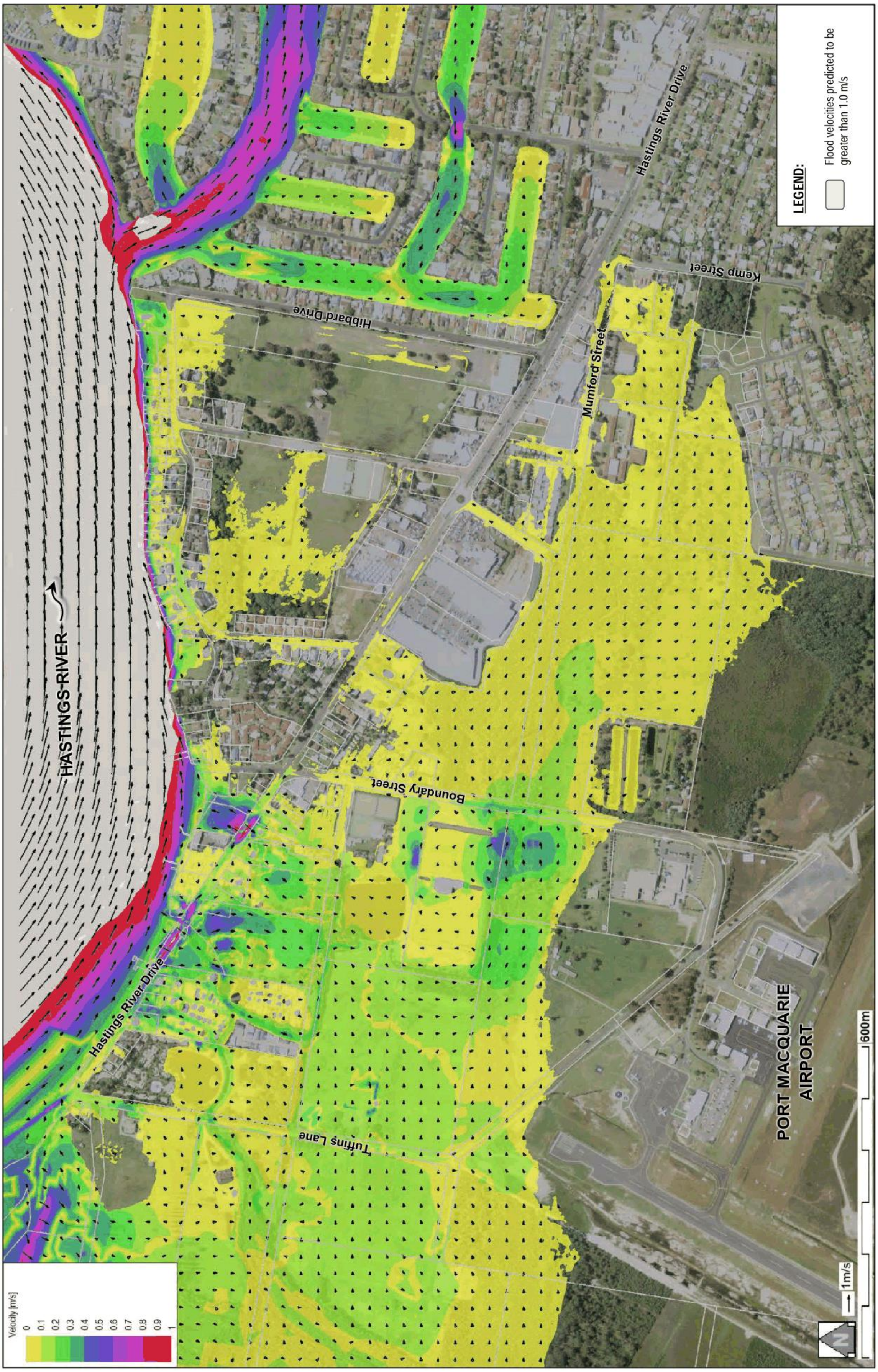
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS

FIGURE 5.10

PREDICTED PEAK FLOOD DEPTHS DURING THE EXTREME FLOOD EVENT

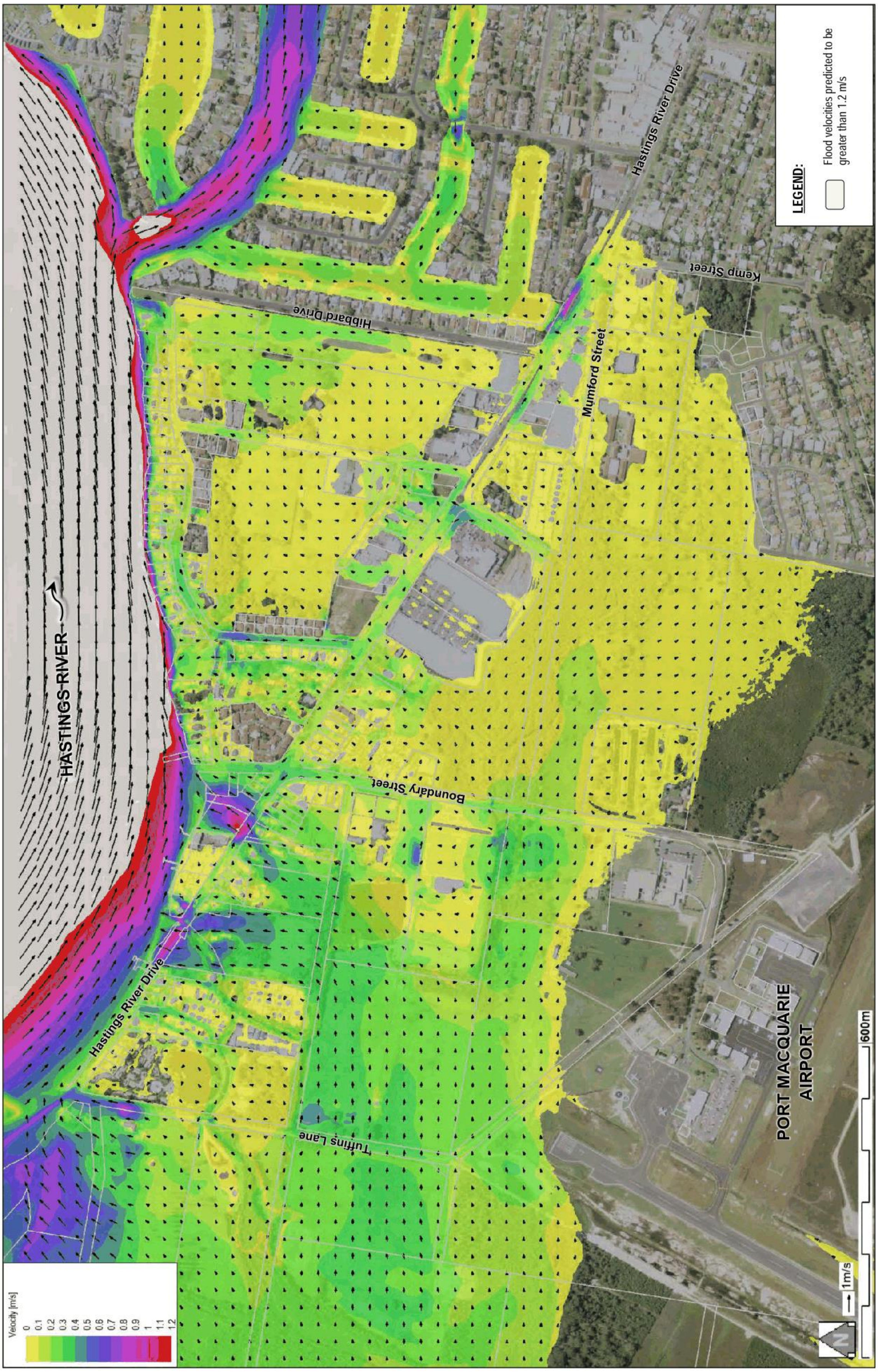
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS

FIGURE 5.11



PREDICTED PEAK FLOW VELOCITIES DURING THE 5% AEP FLOOD

FIGURE 5.12



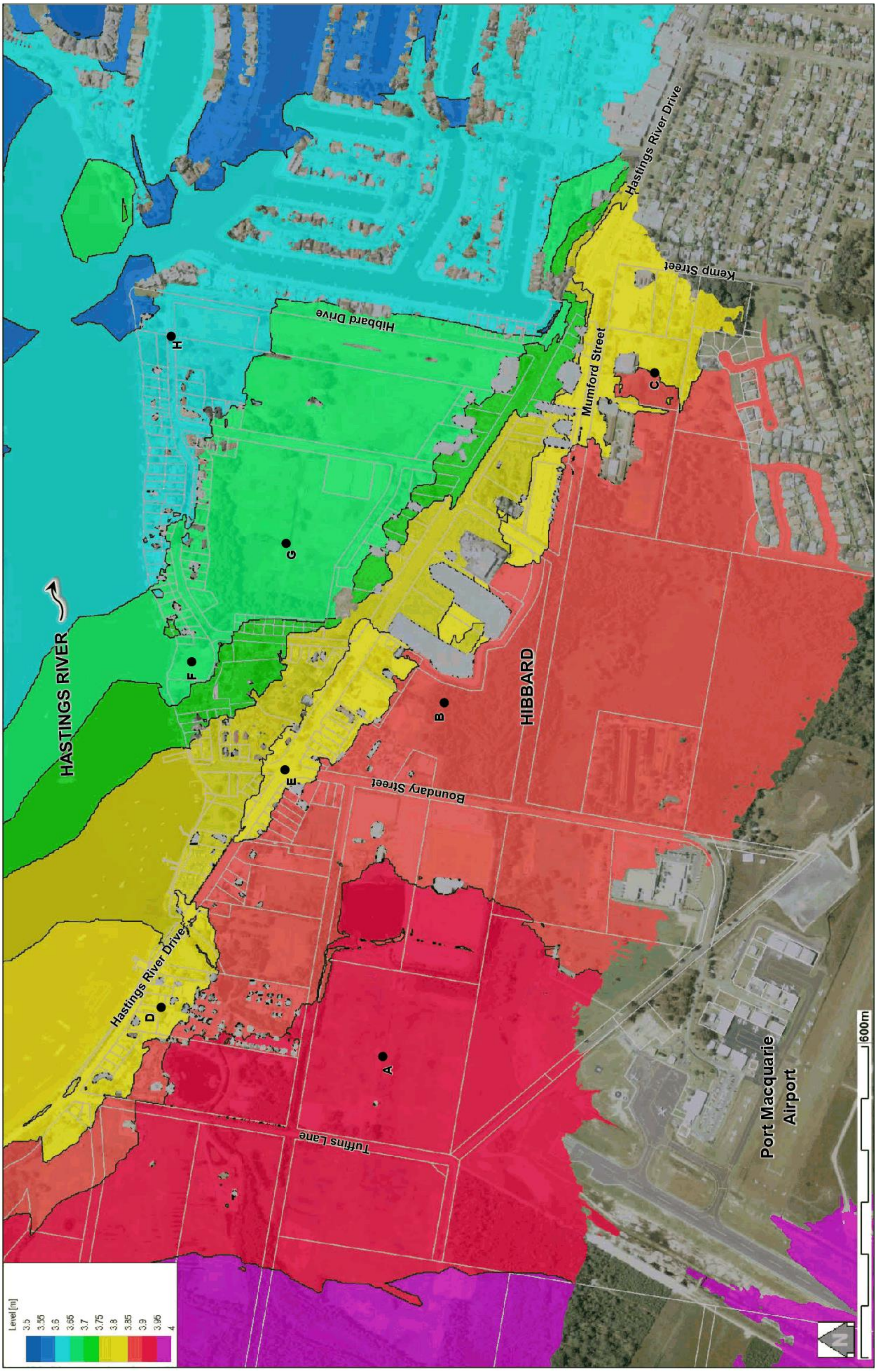
PREDICTED PEAK FLOW VELOCITIES DURING THE 1% AEP FLOOD

FIGURE 5.13

PREDICTED PEAK FLOW VELOCITIES DURING THE EXTREME FLOOD EVENT

Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS

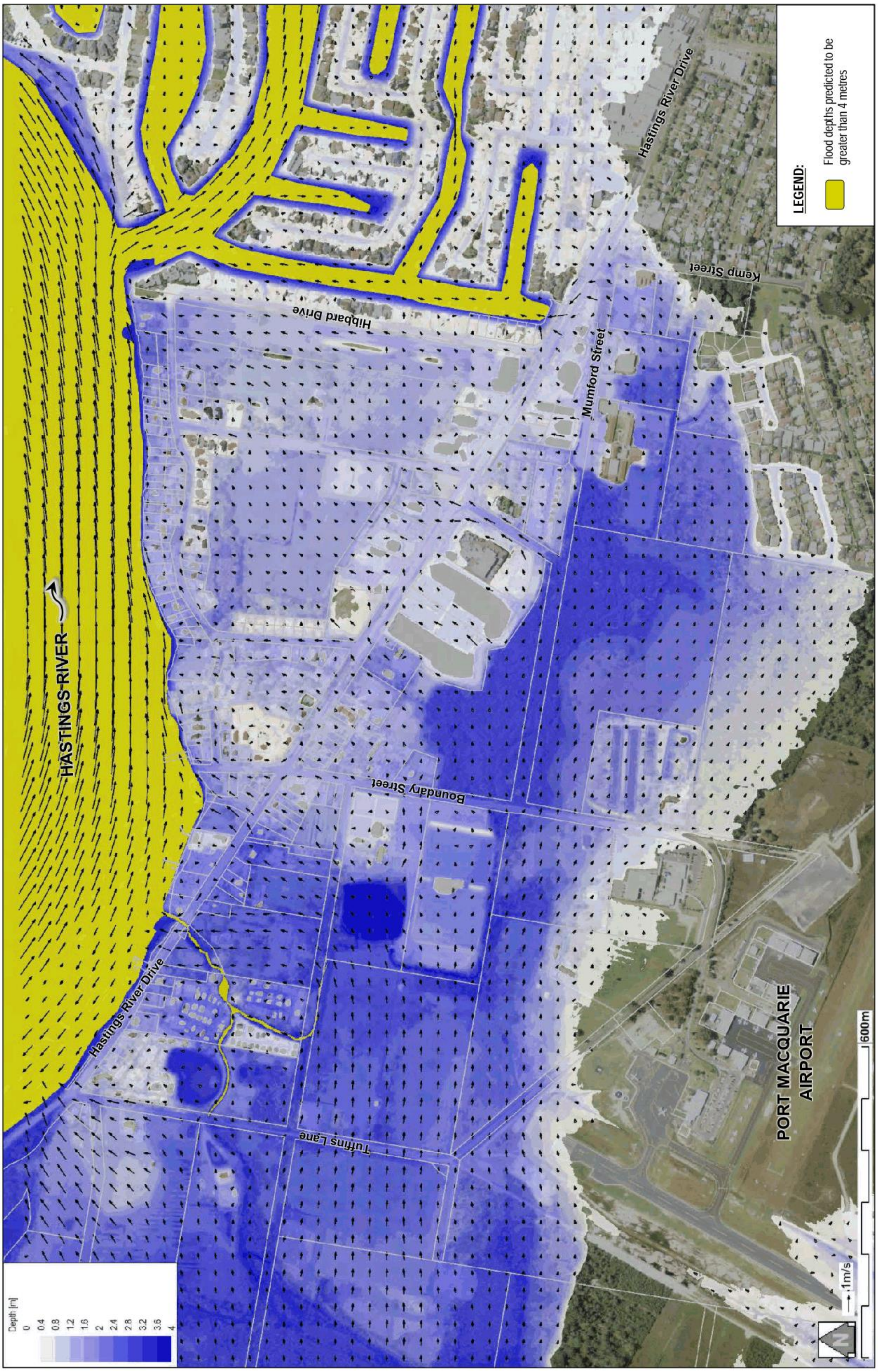
FIGURE 6.1



PREDICTED PEAK FLOOD LEVELS FOR THE RECOMMENDED CLIMATE CHANGE SCENARIO

Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS

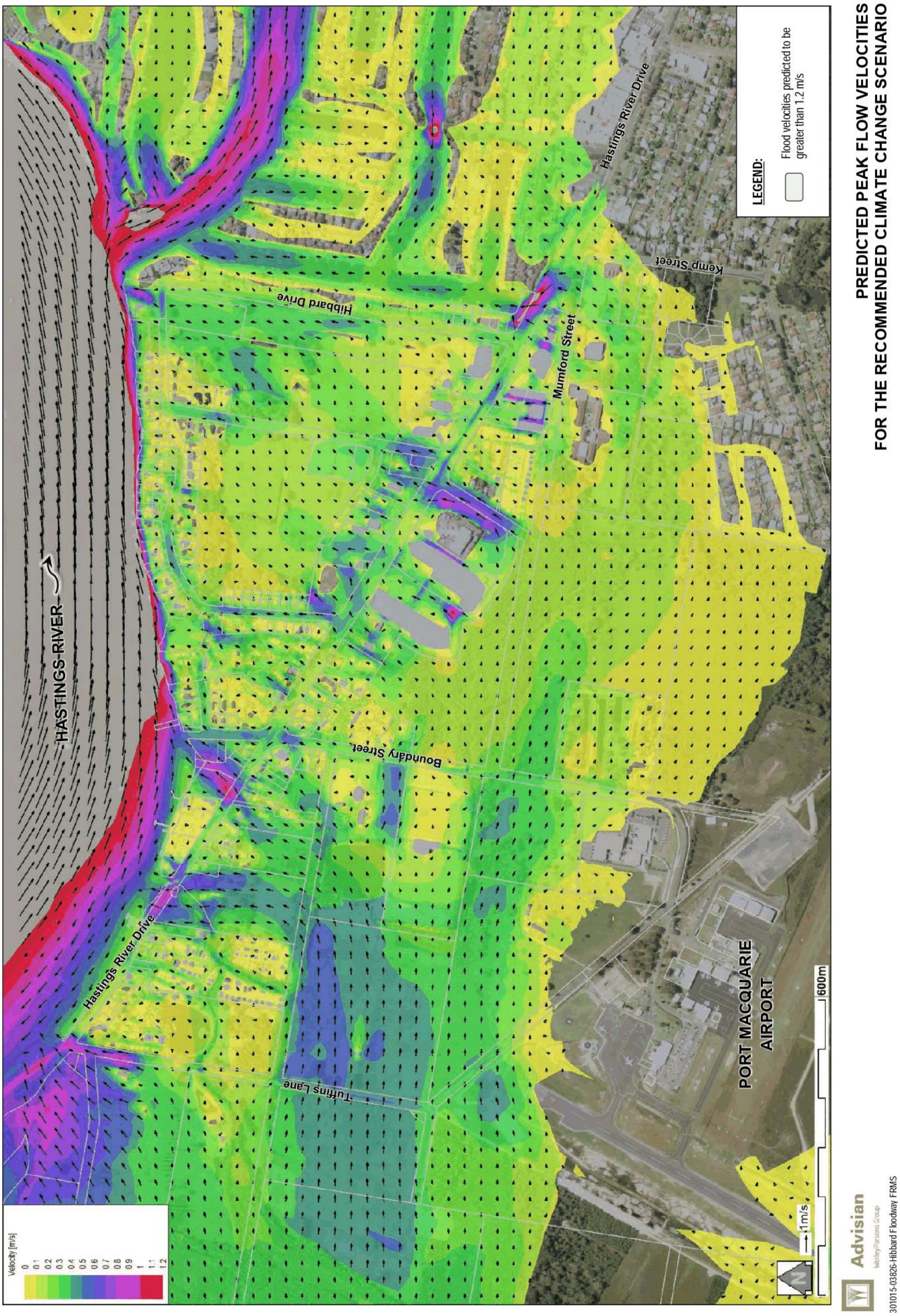
FIGURE 6.2



PREDICTED PEAK FLOOD DEPTHS
FOR THE RECOMMENDED CLIMATE CHANGE SCENARIO

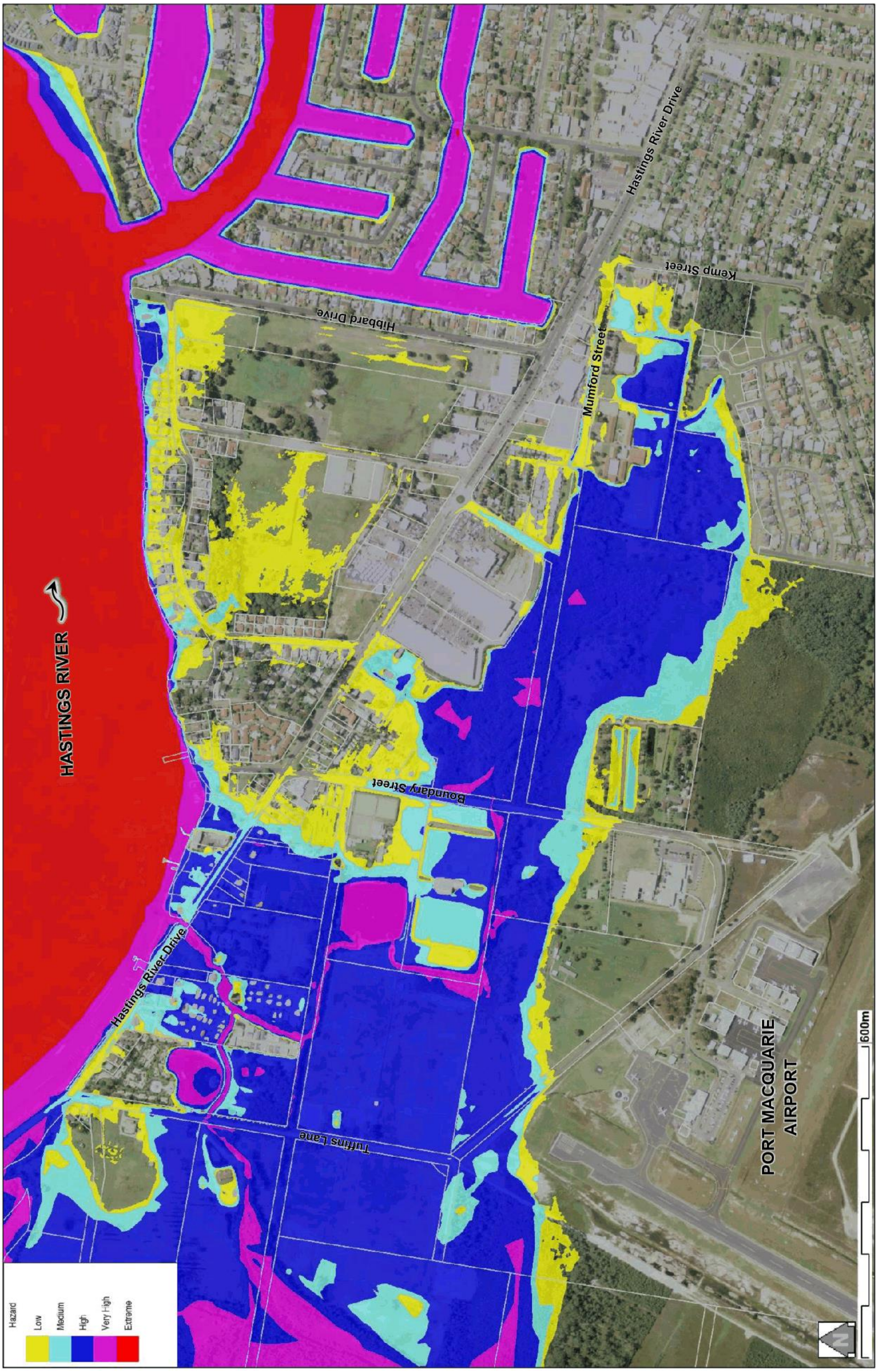
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS

FIGURE 6.3



PREDICTED PEAK FLOW VELOCITIES FOR THE RECOMMENDED CLIMATE CHANGE SCENARIO

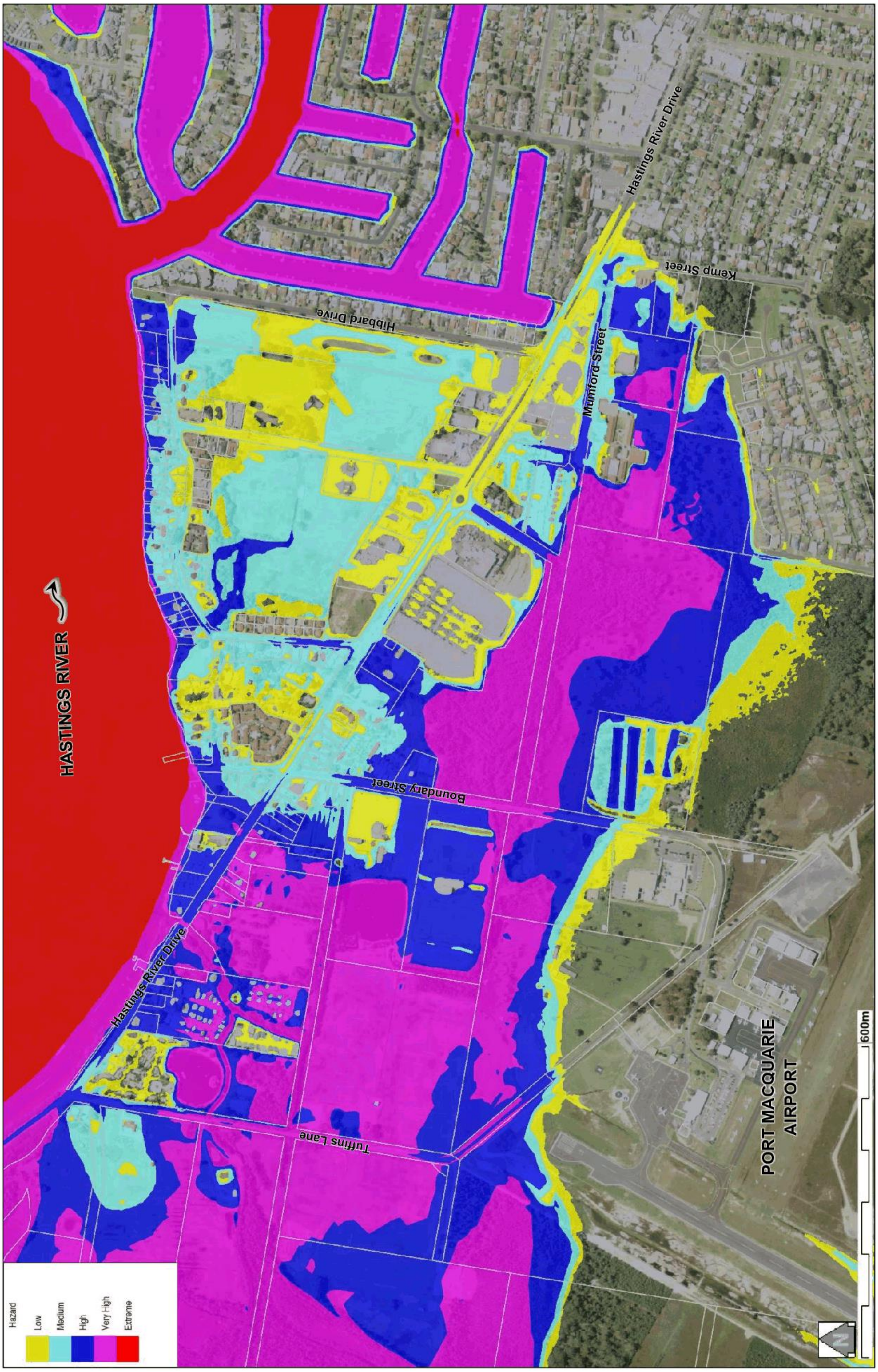
FIGURE 7.1



PREDICTED HAZARD CATEGORIES
FOR THE 5% AEP FLOOD

Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS

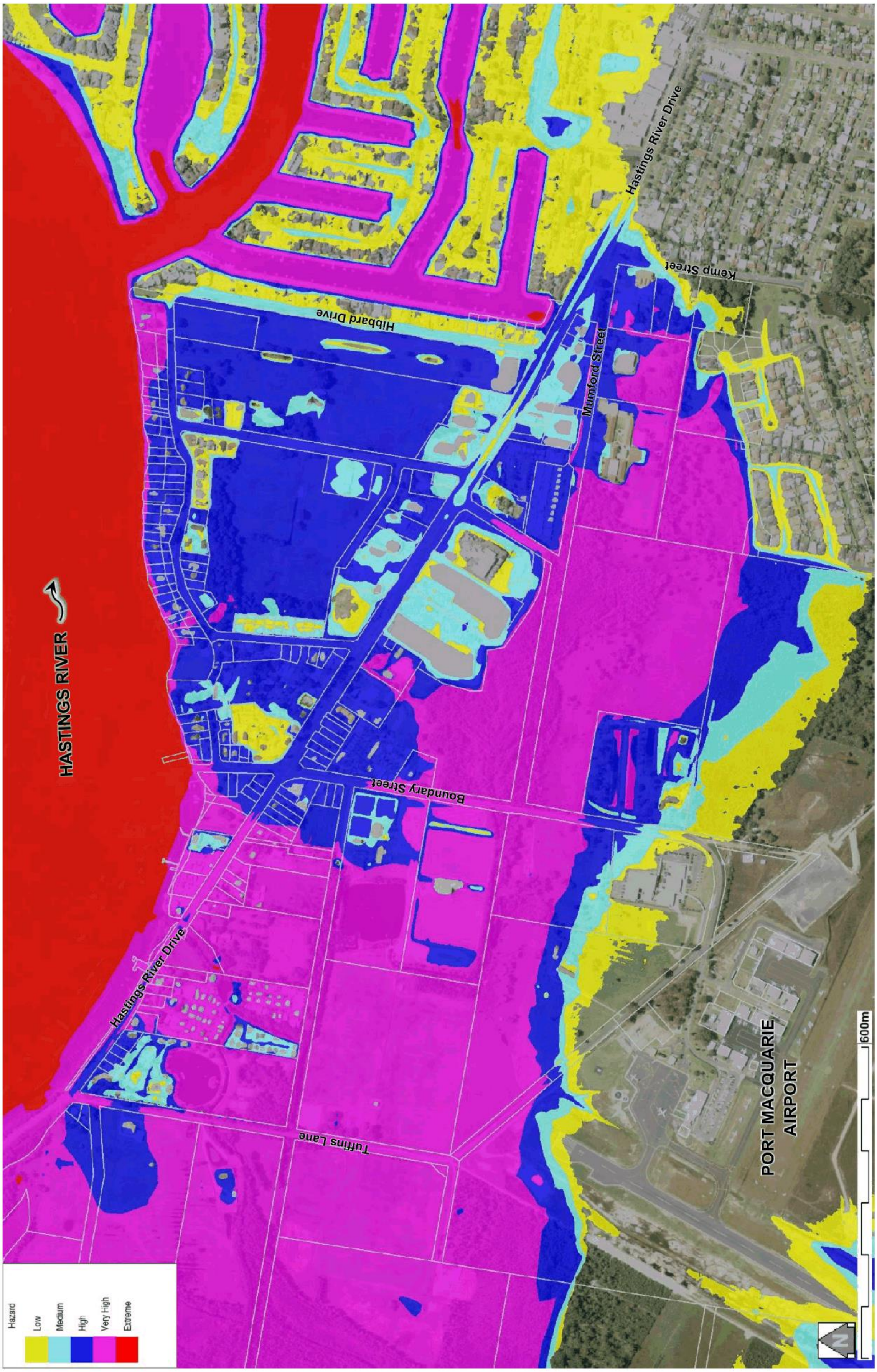
FIGURE 7.2



PREDICTED HAZARD CATEGORIES FOR THE 1% AEP FLOOD

Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS

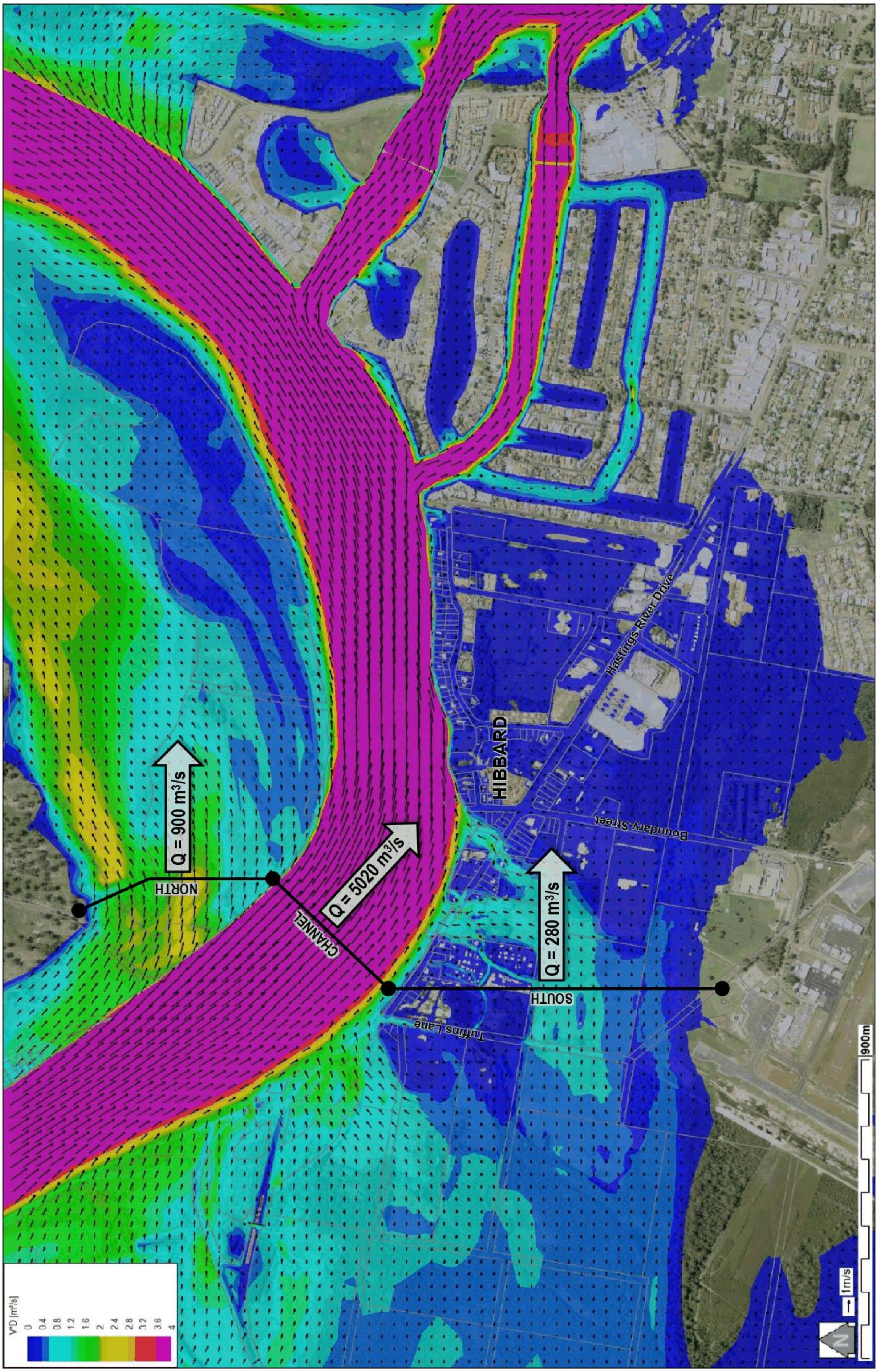
FIGURE 7.3



PREDICTED HAZARD CATEGORIES FOR THE RECOMMENDED CLIMATE CHANGE SCENARIO

Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS

FIGURE 8.1



1% AEP FLOWS & VELOCITY-DEPTH PRODUCT PREDICTED IN THE VICINITY OF HIBBARD

Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS

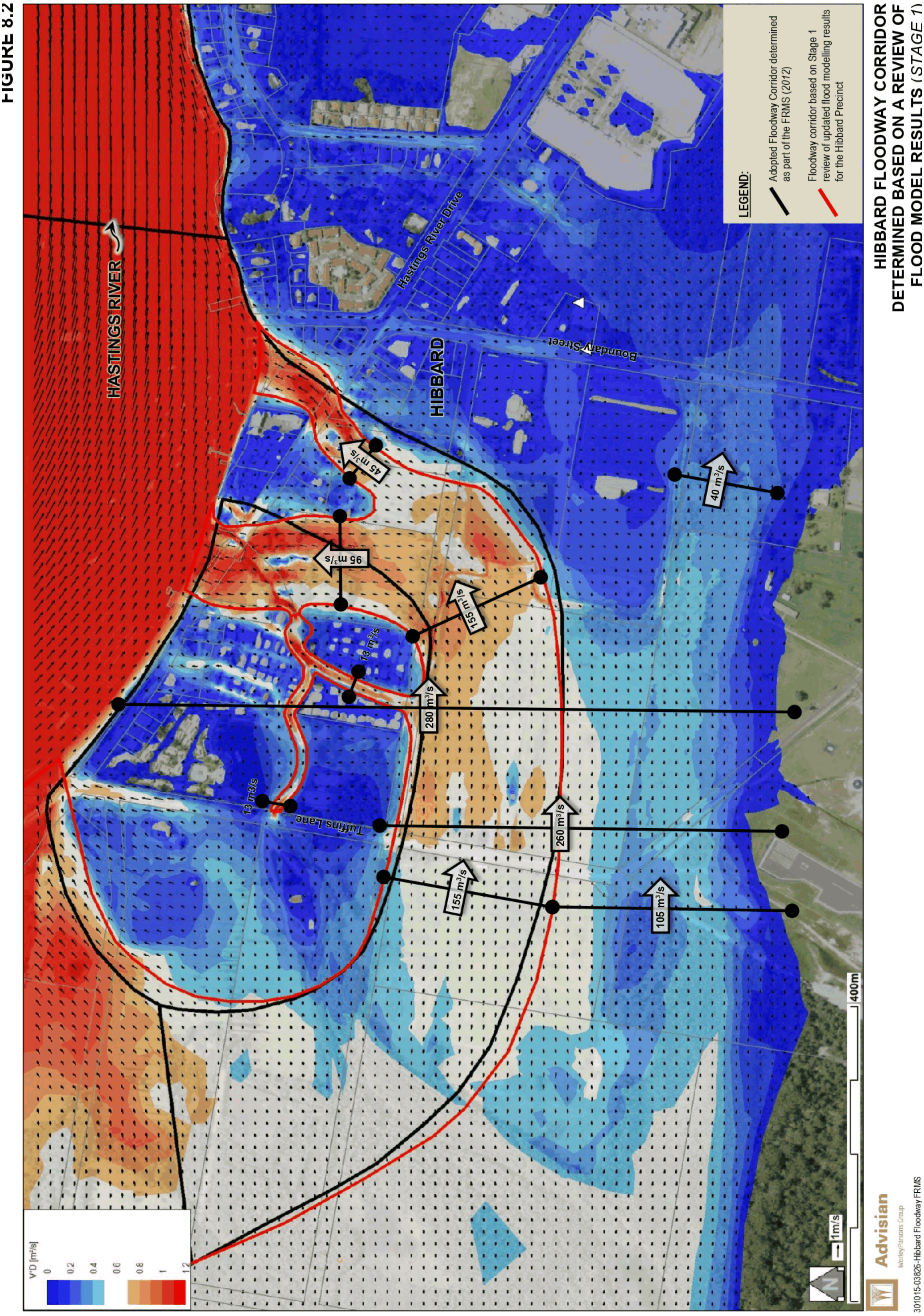
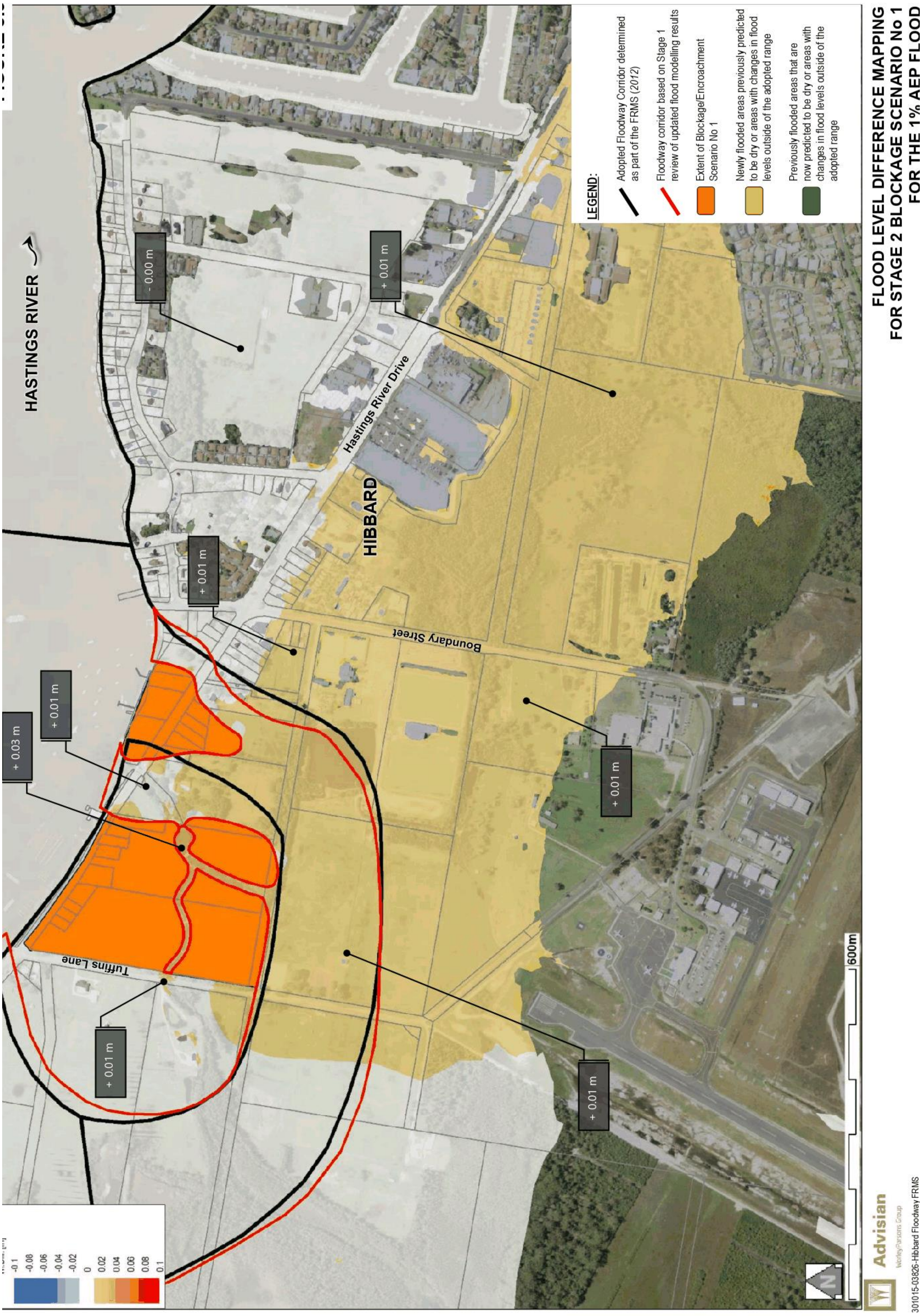
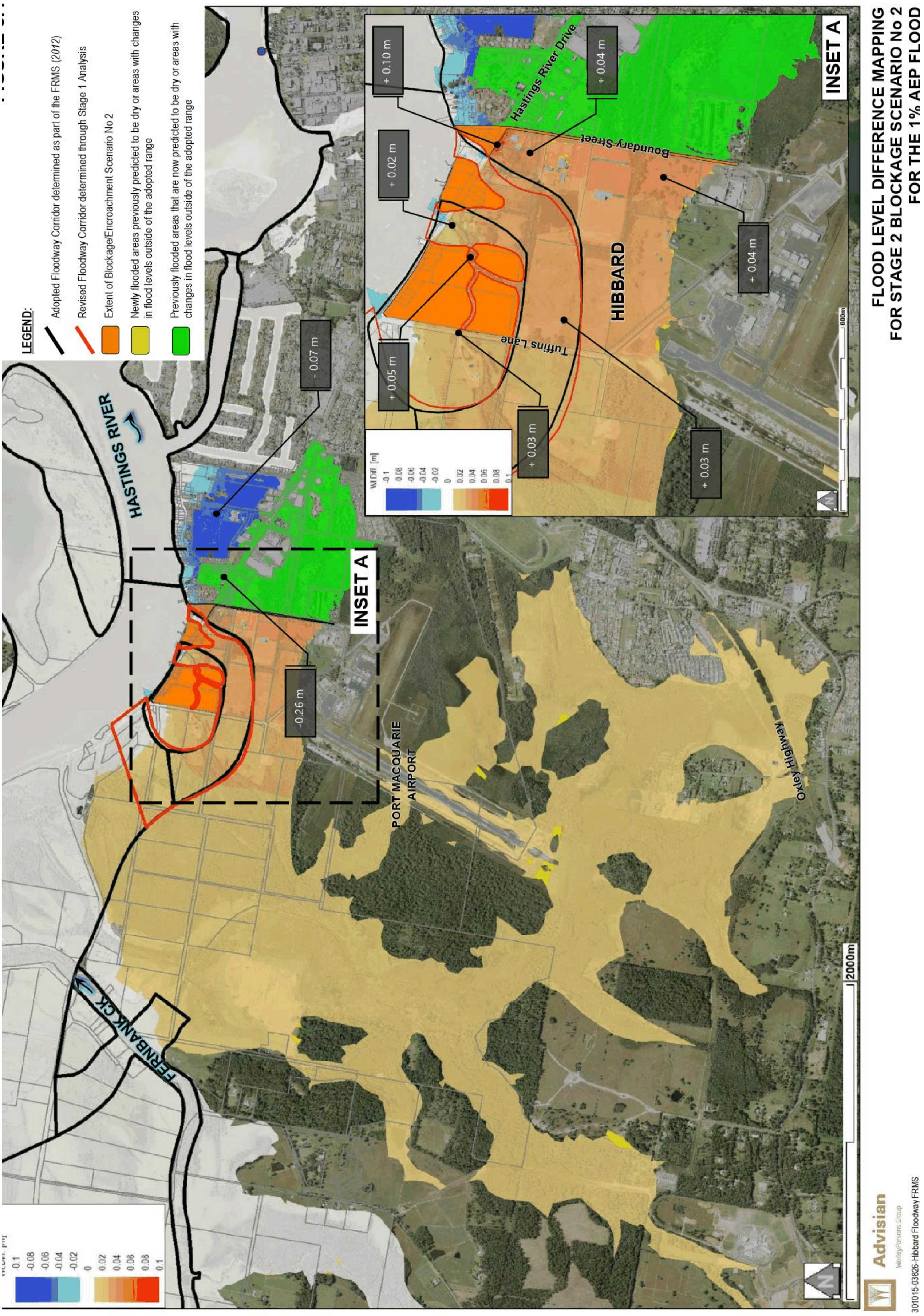
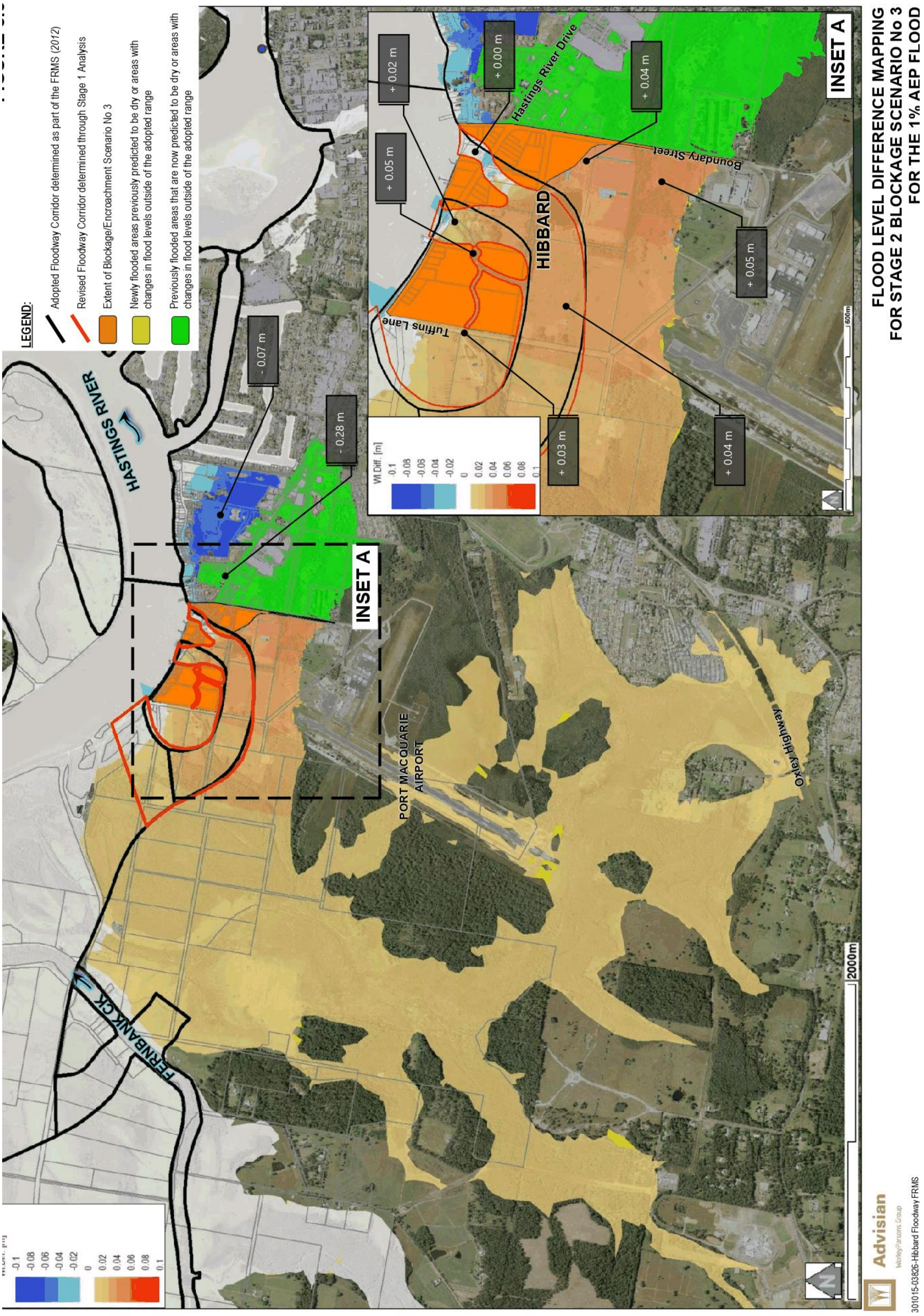
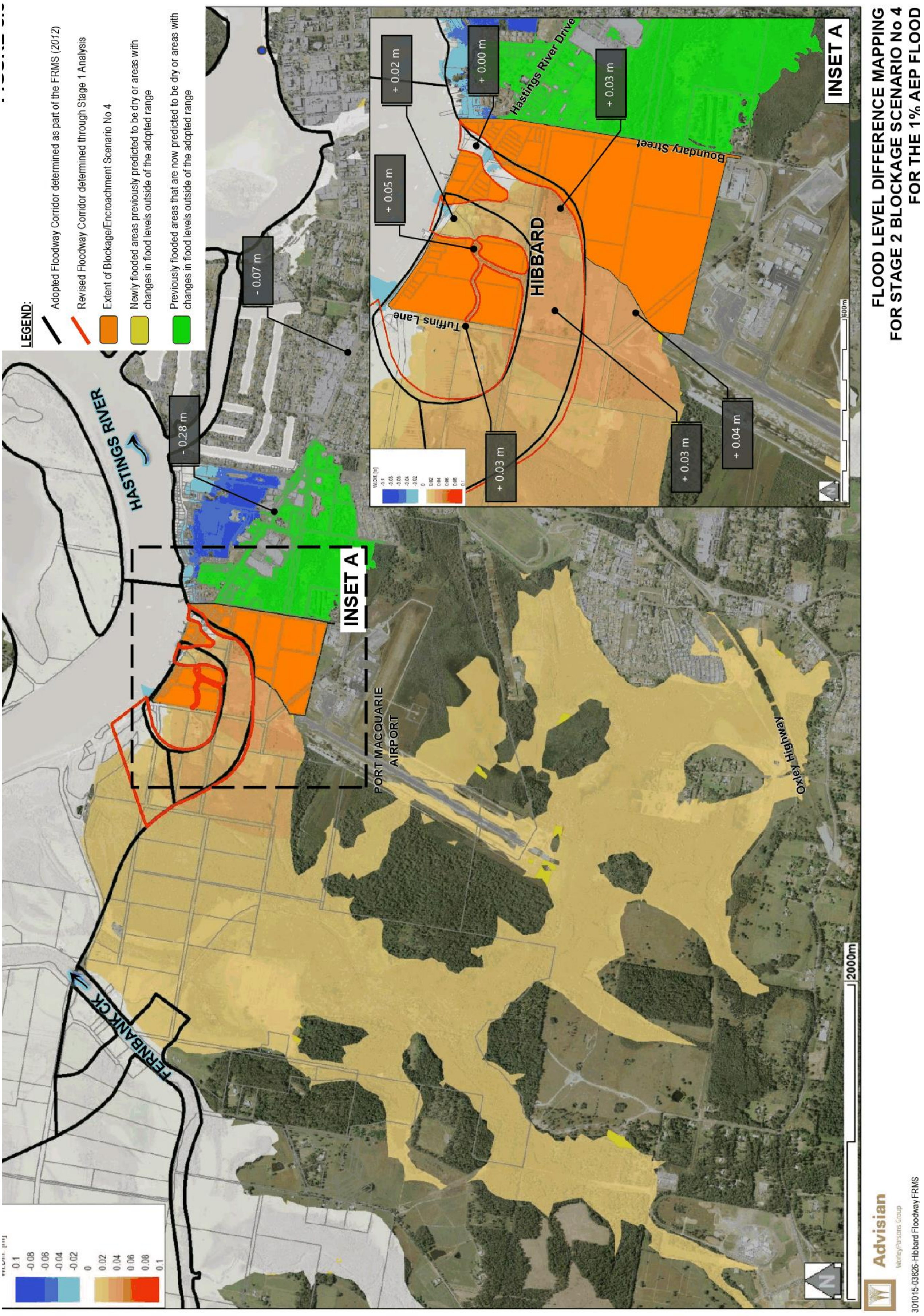


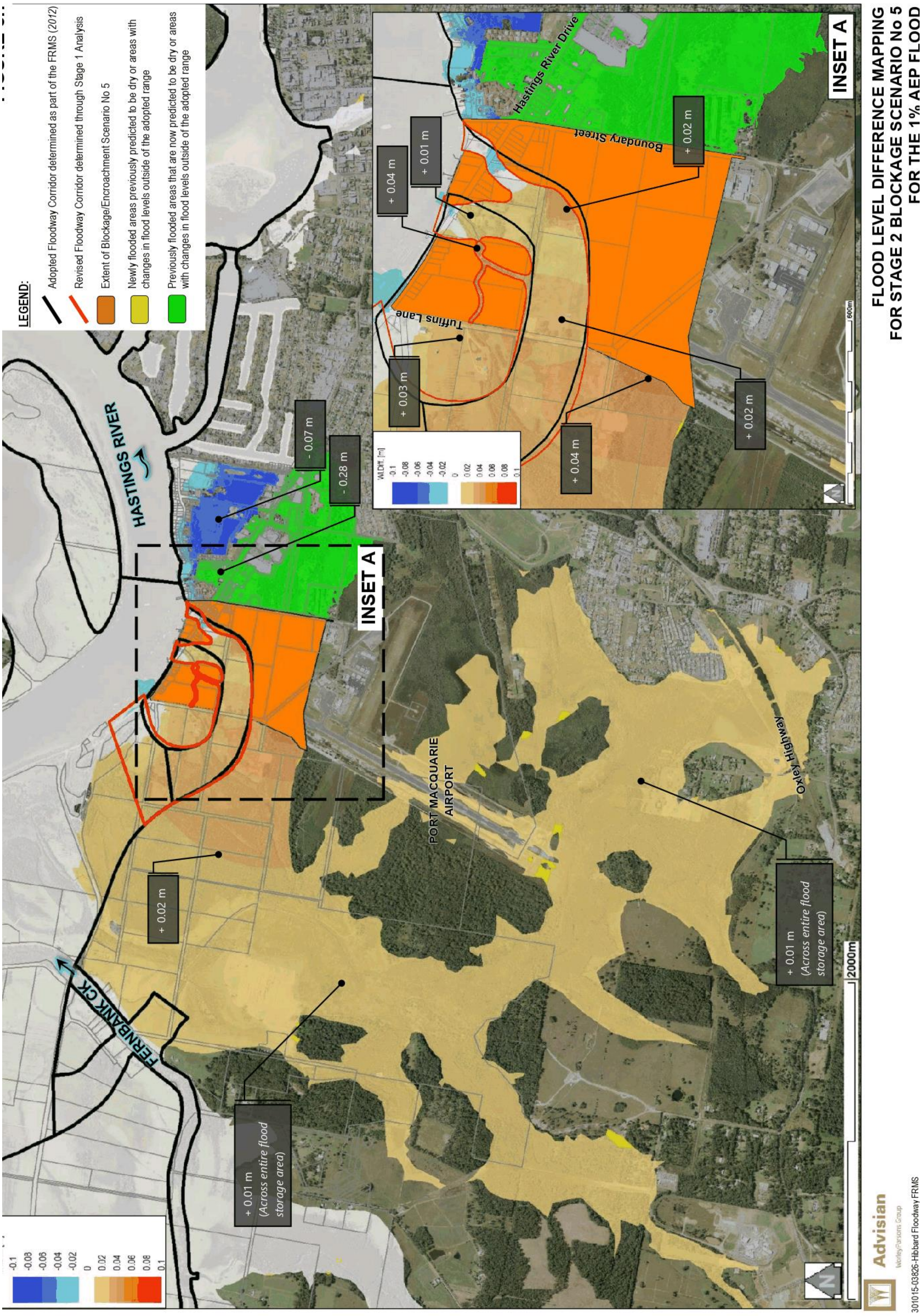
FIGURE 8.2
HIBBARD FLOODWAY CORRIDOR
DETERMINED BASED ON A REVIEW OF
FLOOD MODEL RESULTS (STAGE 1)
LEGEND:
Adopted Floodway Corridor determined as part of the FRMS (2012)
Floodway corridor based on Stage 1 review of updated flood modelling results for the Hibbard Precinct
HASTINGS RIVER
HIBBARD
Hastings River Drive
Boundary Street
Tuffins Lane
45 m³/s
95 m³/s
155 m³/s
13 m³/s
280 m³/s
13 m³/s
260 m³/s
155 m³/s
40 m³/s
105 m³/s
400m
1m/s
V*D [m²/s]
0
0.2
0.4
0.6
0.8
1
1.2
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS


FLOOD LEVEL DIFFERENCE MAPPING
FOR STAGE 2 BLOCKAGE SCENARIO No 1
FOR THE 1% AEP FLOOD
LEGEND:
Adopted Floodway Corridor determined as part of the FRMS (2012)
Floodway corridor based on Stage 1 review of updated flood modelling results
Extent of Blockage/Encroachment Scenario No 1
Newly flooded areas previously predicted to be dry or areas with changes in flood levels outside of the adopted range
Previously flooded areas that are now predicted to be dry or areas with changes in flood levels outside of the adopted range
HASTINGS RIVER
HIBBARD
Hastings River Drive
Boundary Street
Tuffins Lane
- 0.00 m
+ 0.01 m
+ 0.03 m
600m
Advisian
301015-03826-Hibbard Floodway FRMS


LEGEND:
Adopted Floodway Corridor determined as part of the FRMS (2012)
Revised Floodway Corridor determined through Stage 1 Analysis
Extent of Blockage/Encroachment Scenario No 2
Newly flooded areas previously predicted to be dry or areas with changes in flood levels outside of the adopted range
Previously flooded areas that are now predicted to be dry or areas with changes in flood levels outside of the adopted range
HASTINGS RIVER
FERNBANK CK
INSET A
PORT MACQUARIE AIRPORT
Oxley Highway
-0.07 m
-0.26 m
2000m
Wl.Diff. [m]
-0.1
-0.08
-0.06
-0.04
-0.02
0
0.02
0.04
0.06
0.08
0.1
Hastings River Drive
Boundary Street
Tuffins Lane
HIBBARD
+ 0.10 m
+ 0.04 m
+ 0.02 m
+ 0.04 m
+ 0.05 m
+ 0.03 m
+ 0.03 m
600m
FLOOD LEVEL DIFFERENCE MAPPING
FOR STAGE 2 BLOCKAGE SCENARIO No 2
FOR THE 1% AEP FLOOD
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS


LEGEND:
Adopted Floodway Corridor determined as part of the FRMS (2012)
Revised Floodway Corridor determined through Stage 1 Analysis
Extent of Blockage/Encroachment Scenario No 3
Newly flooded areas previously predicted to be dry or areas with changes in flood levels outside of the adopted range
Previously flooded areas that are now predicted to be dry or areas with changes in flood levels outside of the adopted range
HASTINGS RIVER
FERNBANK CK
PORT MACQUARIE AIRPORT
Oxley Highway
INSET A
- 0.07 m
- 0.28 m
HIBBARD
Hastings River Drive
Boundary Street
Tuffins Lane
+ 0.02 m
+ 0.00 m
+ 0.04 m
+ 0.05 m
+ 0.05 m
+ 0.03 m
+ 0.04 m
WI Diff. [m]
-0.1
-0.08
-0.06
-0.04
-0.02
0
0.02
0.04
0.06
0.08
0.1
2000m
600m
FLOOD LEVEL DIFFERENCE MAPPING
FOR STAGE 2 BLOCKAGE SCENARIO No 3
FOR THE 1% AEP FLOOD
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS


LEGEND:
Adopted Floodway Corridor determined as part of the FRMS (2012)
Revised Floodway Corridor determined through Stage 1 Analysis
Extent of Blockage/Encroachment Scenario No 4
Newly flooded areas previously predicted to be dry or areas with changes in flood levels outside of the adopted range
Previously flooded areas that are now predicted to be dry or areas with changes in flood levels outside of the adopted range
HASTINGS RIVER
FERNBANK CK
PORT MACQUARIE AIRPORT
Oxley Highway
INSET A
HIBBARD
Hastings River Drive
Boundary Street
Tuffins Lane
- 0.28 m
- 0.07 m
+ 0.02 m
+ 0.00 m
+ 0.03 m
+ 0.05 m
+ 0.04 m
2000m
600m
FLOOD LEVEL DIFFERENCE MAPPING
FOR STAGE 2 BLOCKAGE SCENARIO No 4
FOR THE 1% AEP FLOOD
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS


LEGEND:
Adopted Floodway Corridor determined as part of the FRMS (2012)
Revised Floodway Corridor determined through Stage 1 Analysis
Extent of Blockage/Encroachment Scenario No 5
Newly flooded areas previously predicted to be dry or areas with changes in flood levels outside of the adopted range
Previously flooded areas that are now predicted to be dry or areas with changes in flood levels outside of the adopted range
HASTINGS RIVER
FERNBANK CK
PORT MACQUARIE AIRPORT
Oxley Highway
INSET A
- 0.07 m
- 0.28 m
+ 0.02 m
+ 0.01 m (Across entire flood storage area)
Hastings River Drive
Boundary Street
Tuffins Lane
+ 0.04 m
+ 0.01 m
+ 0.03 m
+ 0.02 m
2000m
600m
FLOOD LEVEL DIFFERENCE MAPPING FOR STAGE 2 BLOCKAGE SCENARIO No 5 FOR THE 1% AEP FLOOD
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS

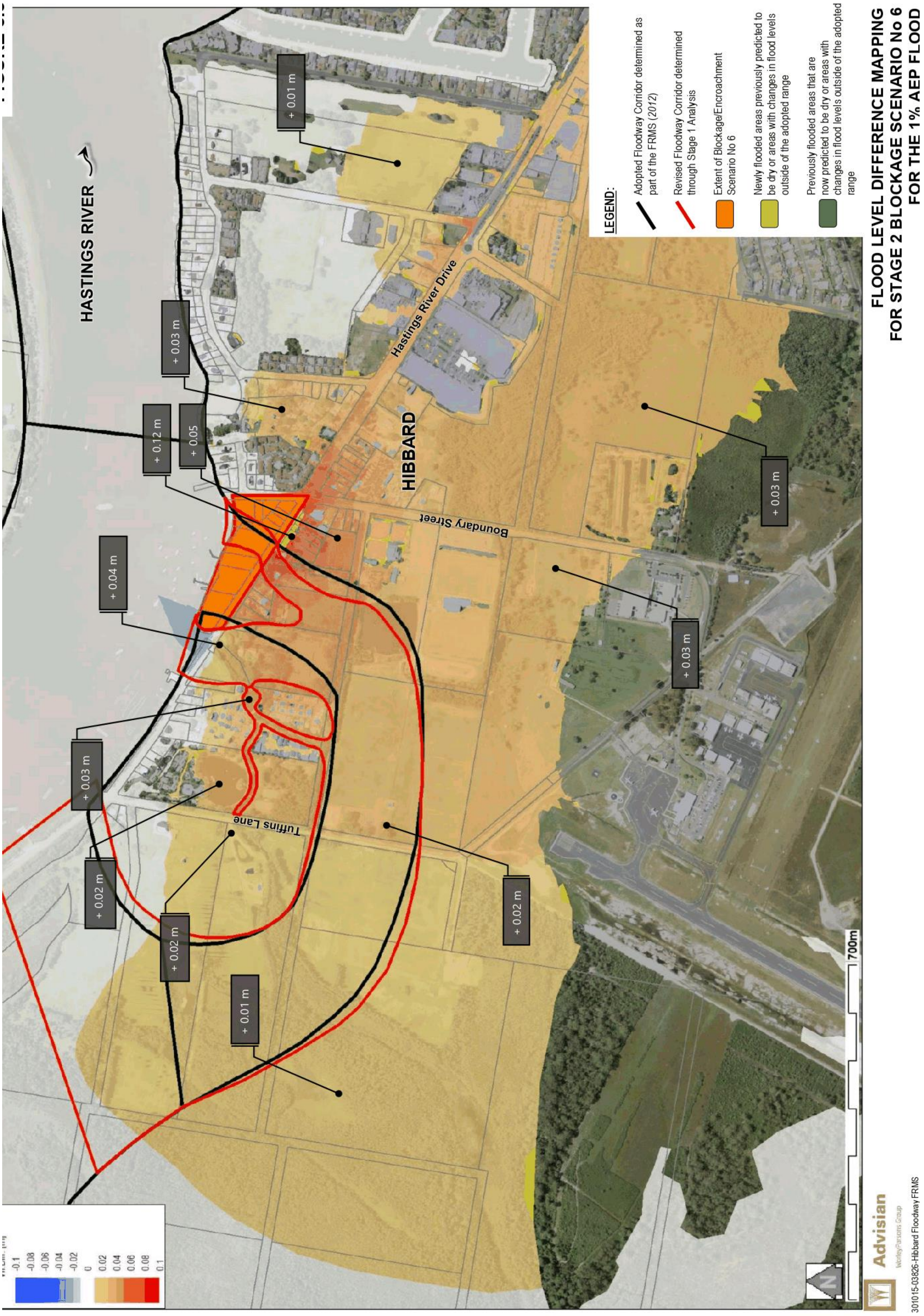
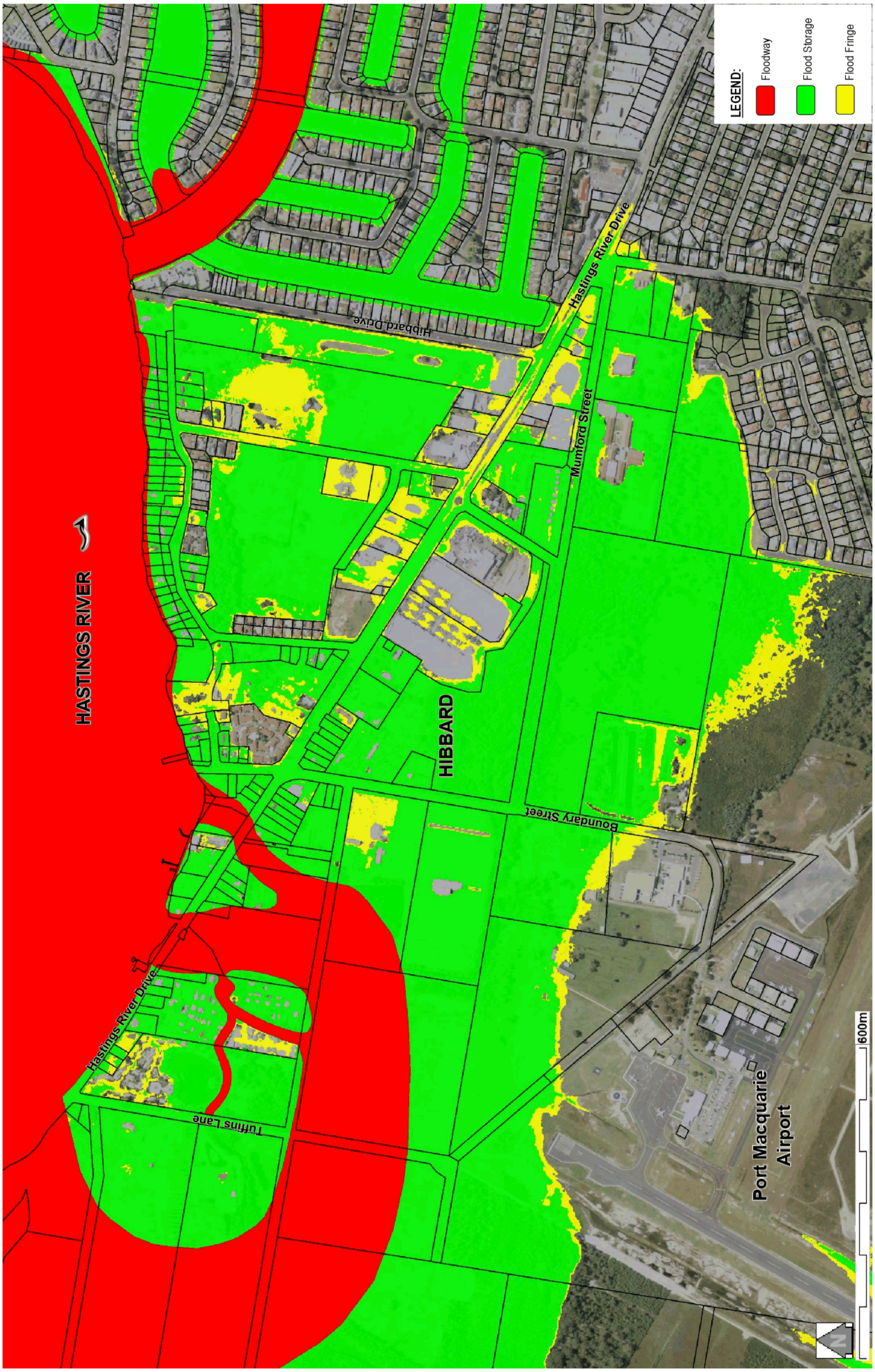

HASTINGS RIVER
HIBBARD
Hastings River Drive
Boundary Street
Tuffins Lane
+ 0.01 m
+ 0.03 m
+ 0.12 m
+ 0.05
+ 0.04 m
+ 0.03 m
+ 0.02 m
+ 0.02 m
+ 0.01 m
+ 0.02 m
+ 0.03 m
+ 0.03 m
700m
LEGEND:
Adopted Floodway Corridor determined as part of the FRMS (2012)
Revised Floodway Corridor determined through Stage 1 Analysis
Extent of Blockage/Encroachment Scenario No 6
Newly flooded areas previously predicted to be dry or areas with changes in flood levels outside of the adopted range
Previously flooded areas that are now predicted to be dry or areas with changes in flood levels outside of the adopted range
FLOOD LEVEL DIFFERENCE MAPPING
FOR STAGE 2 BLOCKAGE SCENARIO No 6
FOR THE 1% AEP FLOOD
-0.1
-0.08
-0.06
-0.04
-0.02
0
0.02
0.04
0.06
0.08
0.1
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS

FIGURE 8.9

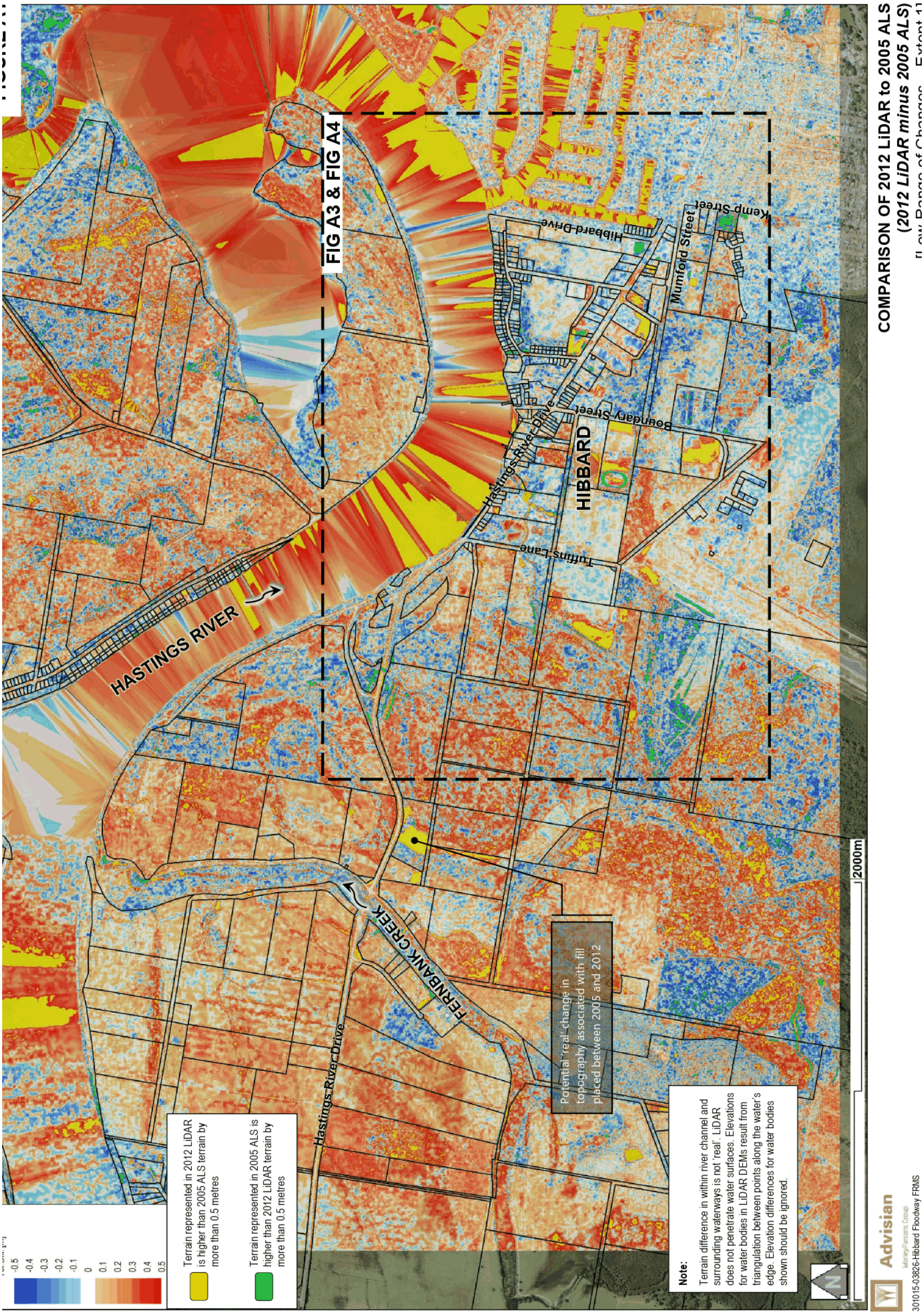


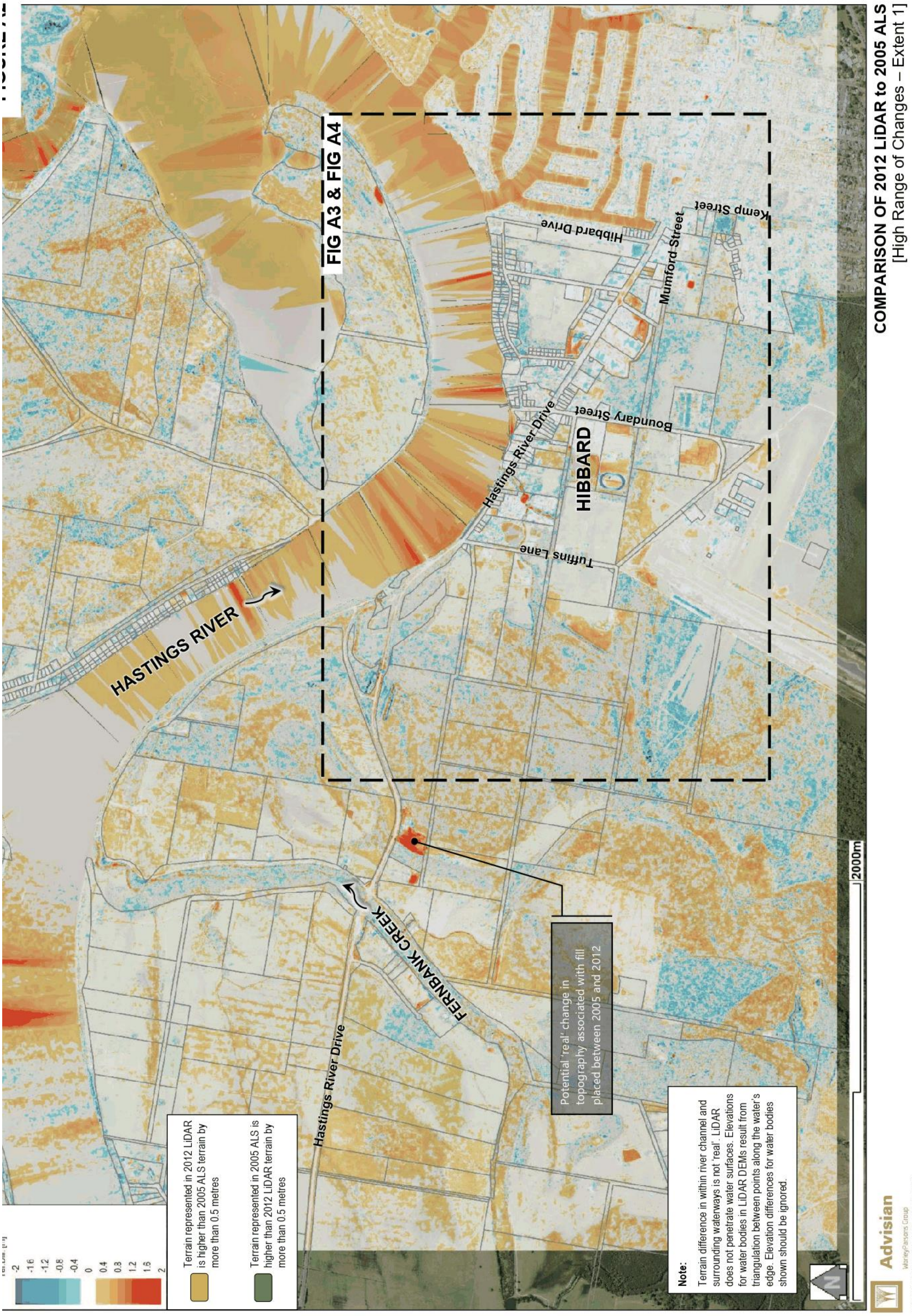
HYDRAULIC CATEGORIES FOR THE 1% AEP FLOOD

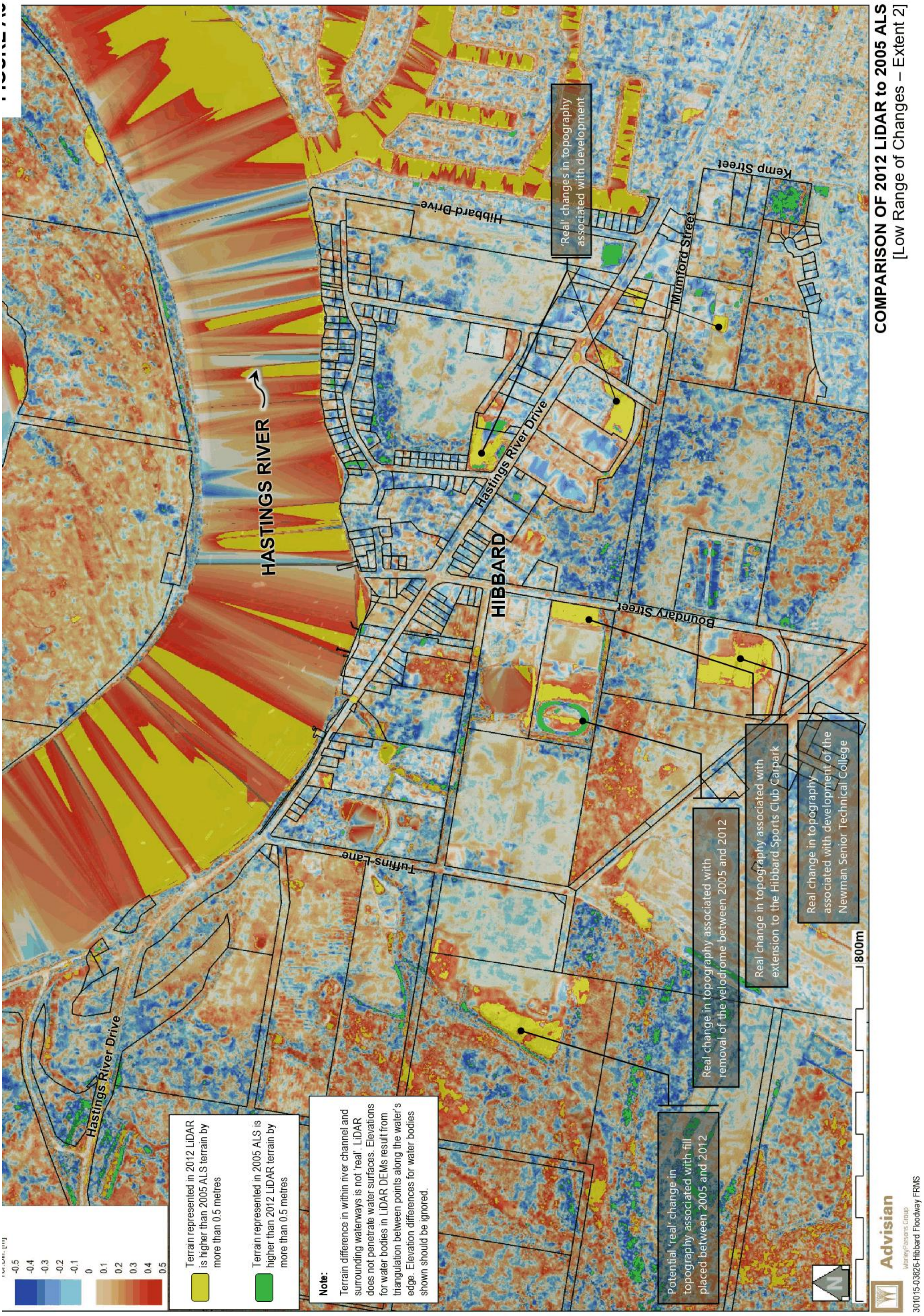
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS

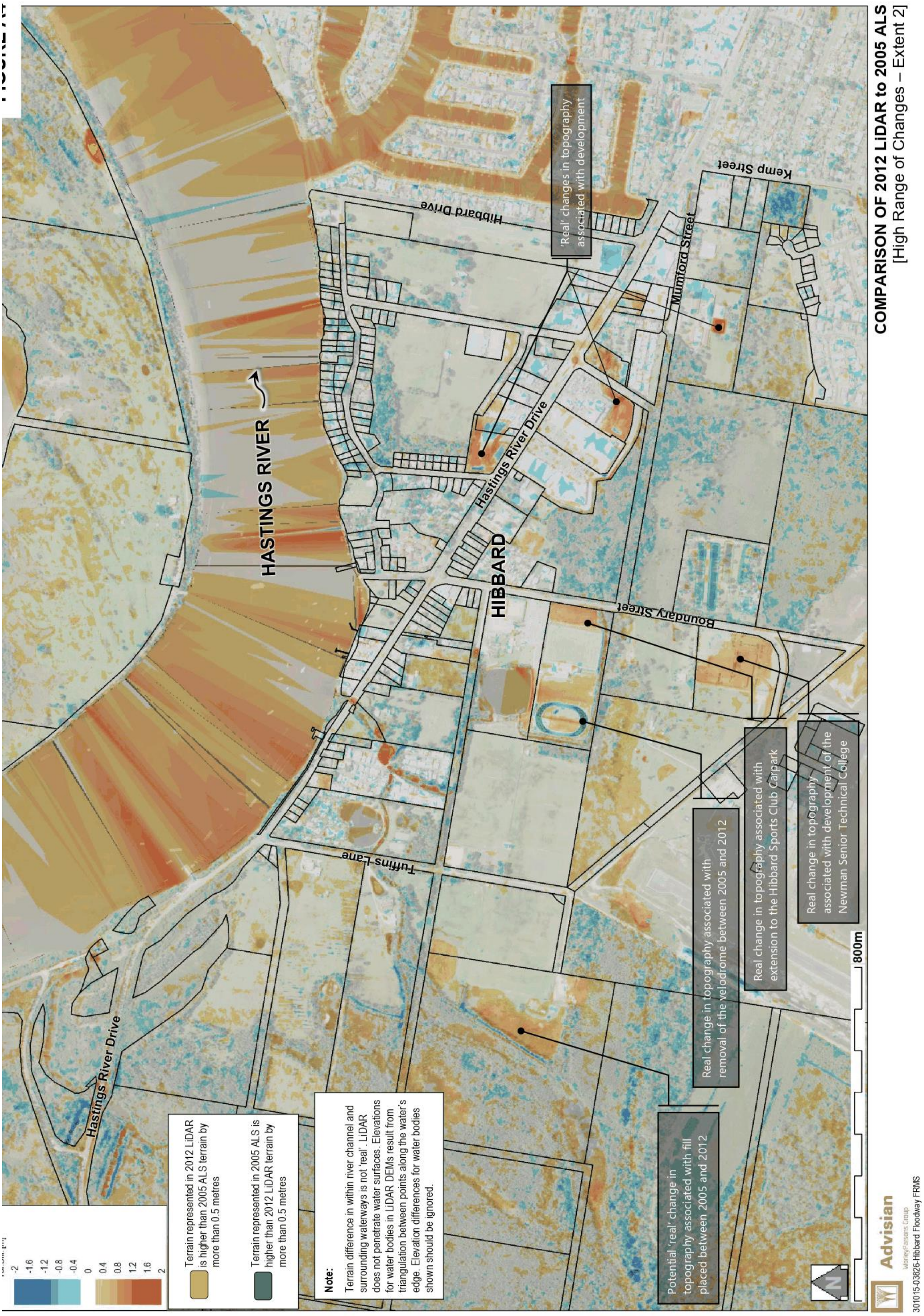
Appendix A

Comparison of 2005 ALS Survey and 2012 LiDAR Topographic Data


COMPARISON OF 2012 LiDAR to 2005 ALS
(2012 LiDAR minus 2005 ALS)
FIG A3 & FIG A4
HIBBARD
HASTINGS RIVER
FERNBANK CREEK
Hastings River Drive
Hastings River Drive
Hibbard Drive
Kemp Street
Mumford Street
Boundary Street
Tuffins Lane
Potential 'real' change in topography associated with fill placed between 2005 and 2012
2000m
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
Terrain represented in 2012 LiDAR is higher than 2005 ALS terrain by more than 0.5 metres
Terrain represented in 2005 ALS is higher than 2012 LiDAR terrain by more than 0.5 metres
Note:
Terrain difference in within river channel and surrounding waterways is not 'real'. LiDAR does not penetrate water surfaces. Elevations for water bodies in LiDAR DEMs result from triangulation between points along the water's edge. Elevation differences for water bodies shown should be ignored.
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS


COMPARISON OF 2012 LiDAR to 2005 ALS
[High Range of Changes – Extent 1]
FIG A3 & FIG A4
HASTINGS RIVER
HIBBARD
Hastings River Drive
Boundary Street
Tuffins Lane
Hibbard Drive
Mumford Street
Kemp Street
FERNBANK CREEK
Hastings River Drive
Potential 'real' change in topography associated with fill placed between 2005 and 2012
-2
-1.6
-1.2
-0.8
-0.4
0
0.4
0.8
1.2
1.6
2
Terrain represented in 2012 LiDAR is higher than 2005 ALS terrain by more than 0.5 metres
Terrain represented in 2005 ALS is higher than 2012 LiDAR terrain by more than 0.5 metres
Note:
Terrain difference in within river channel and surrounding waterways is not 'real'. LiDAR does not penetrate water surfaces. Elevations for water bodies in LiDAR DEMs result from triangulation between points along the water's edge. Elevation differences for water bodies shown should be ignored.
2000m
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS


COMPARISON OF 2012 LiDAR to 2005 ALS
[Low Range of Changes – Extent 2]
HASTINGS RIVER
HIBBARD
Hastings River Drive
Hibbard Drive
Kemp Street
Mumford Street
Boundary Street
Tuffins Lane
'Real' changes in topography associated with development
Real change in topography associated with removal of the velodrome between 2005 and 2012
Real change in topography associated with extension to the Hibbard Sports Club Carpark
Real change in topography associated with development of the Newman Senior Technical College
Potential 'real' change in topography associated with fill placed between 2005 and 2012
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
Terrain represented in 2012 LiDAR is higher than 2005 ALS terrain by more than 0.5 metres
Terrain represented in 2005 ALS is higher than 2012 LiDAR terrain by more than 0.5 metres
Note:
Terrain difference in within river channel and surrounding waterways is not 'real'. LiDAR does not penetrate water surfaces. Elevations for water bodies in LiDAR DEMs result from triangulation between points along the water's edge. Elevation differences for water bodies shown should be ignored.
800m
Advisian
301015-03826-Hibbard Floodway FRMS

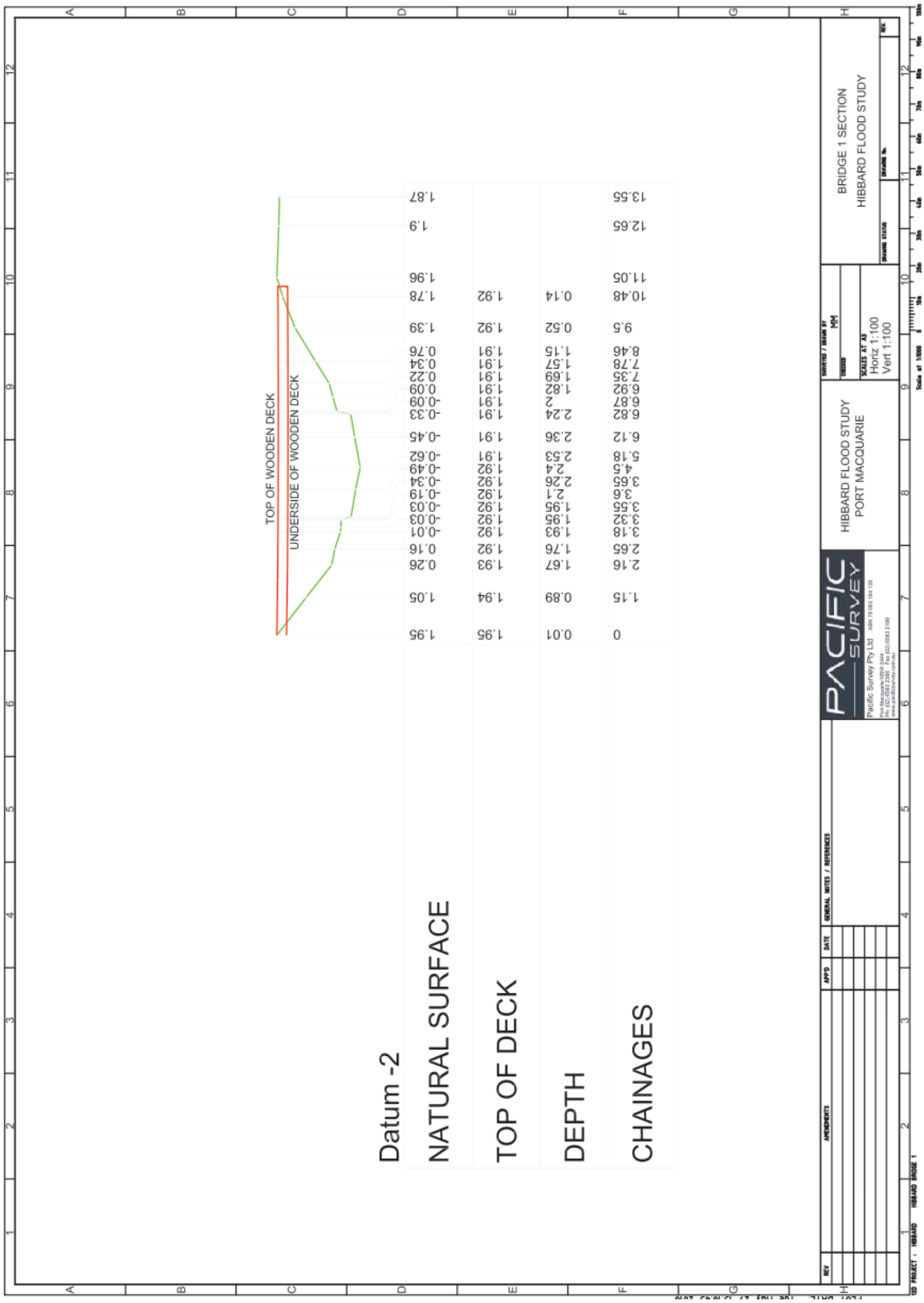

COMPARISON OF 2012 LiDAR to 2005 ALS
[High Range of Changes – Extent 2]
HASTINGS RIVER
HIBBARD
Hastings River Drive
Hibbard Drive
Kemp Street
Mumford Street
Boundary Street
Tuffins Lane
'Real' changes in topography associated with development
Real change in topography associated with removal of the velodrome between 2005 and 2012
Real change in topography associated with extension to the Hibbard Sports Club Carpark
Real change in topography associated with development of the Newman Senior Technical College
Potential 'real' change in topography associated with fill placed between 2005 and 2012
-2
-1.6
-1.2
-0.8
-0.4
0
0.4
0.8
1.2
1.6
2
Terrain represented in 2012 LiDAR is higher than 2005 ALS terrain by more than 0.5 metres
Terrain represented in 2005 ALS is higher than 2012 LiDAR terrain by more than 0.5 metres
Note:
Terrain difference in within river channel and surrounding waterways is not 'real'. LiDAR does not penetrate water surfaces. Elevations for water bodies in LiDAR DEMs result from triangulation between points along the water's edge. Elevation differences for water bodies shown should be ignored.
800m
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS

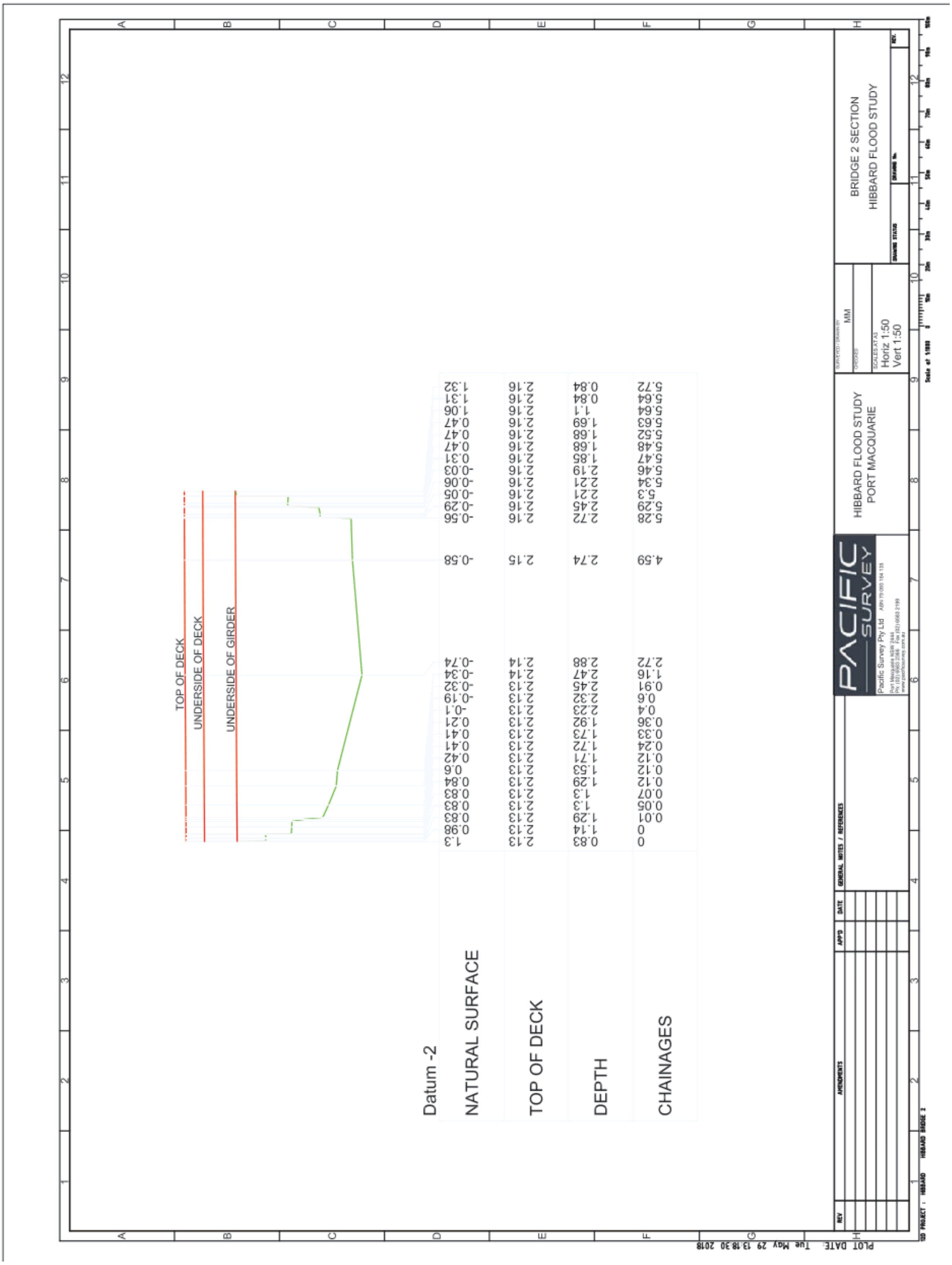
Advisian
WorleyParsons Group

Port Macquarie Hastings Council
Hibbard Precinct Flood Study

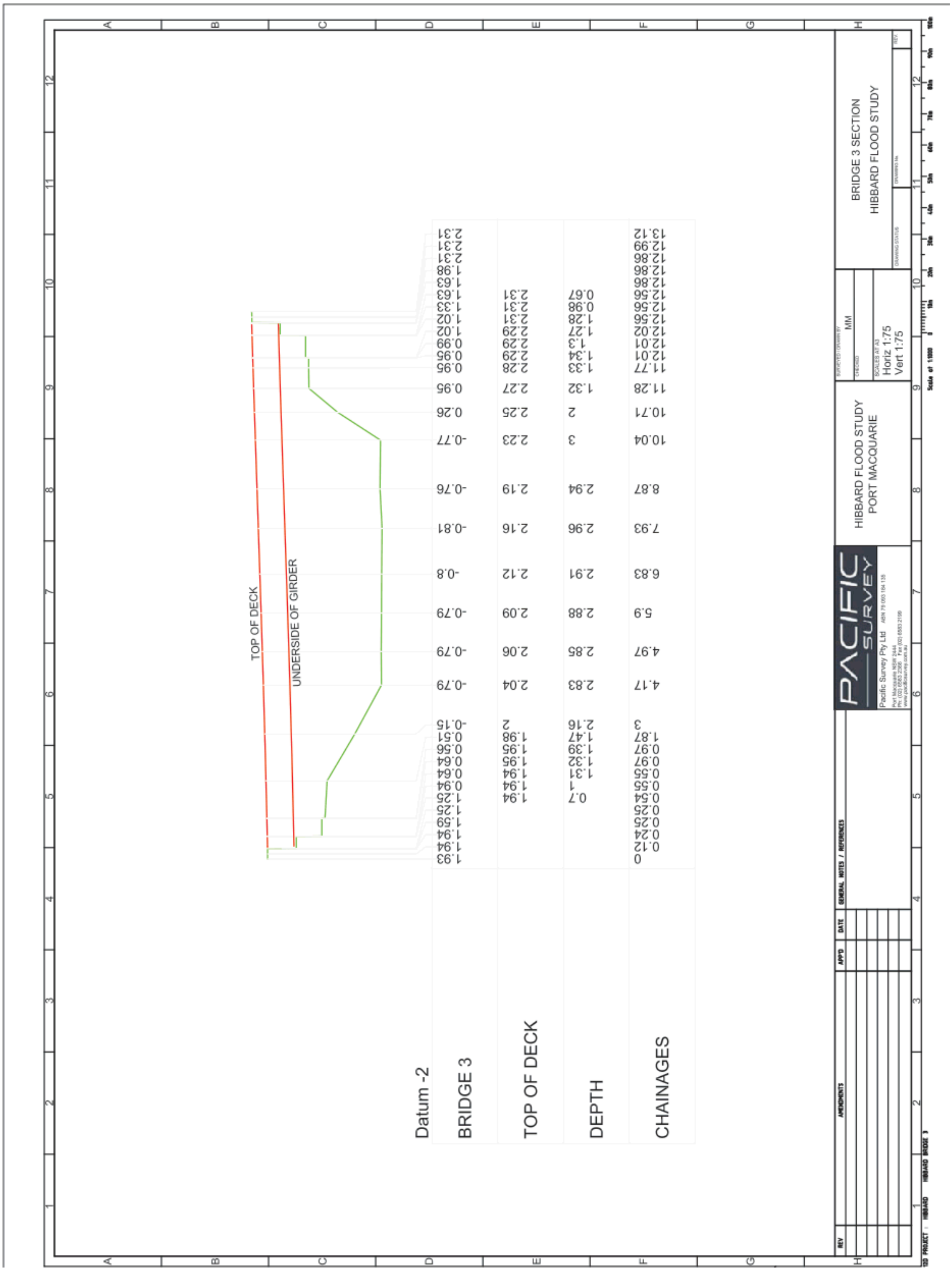
Appendix B

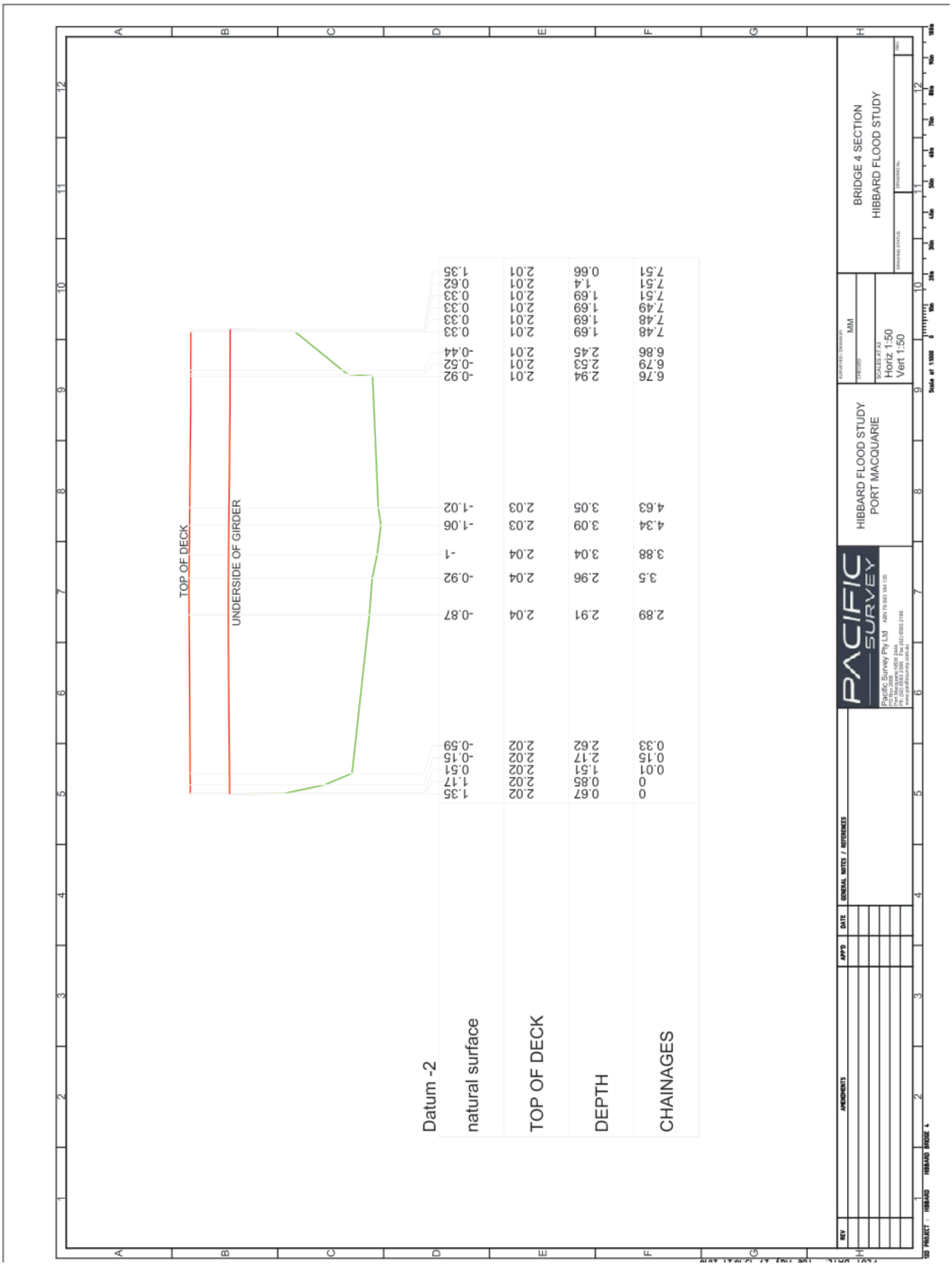
Survey Data provided by Pacific Surveys
(Bridges & Creek Cross-Sections)

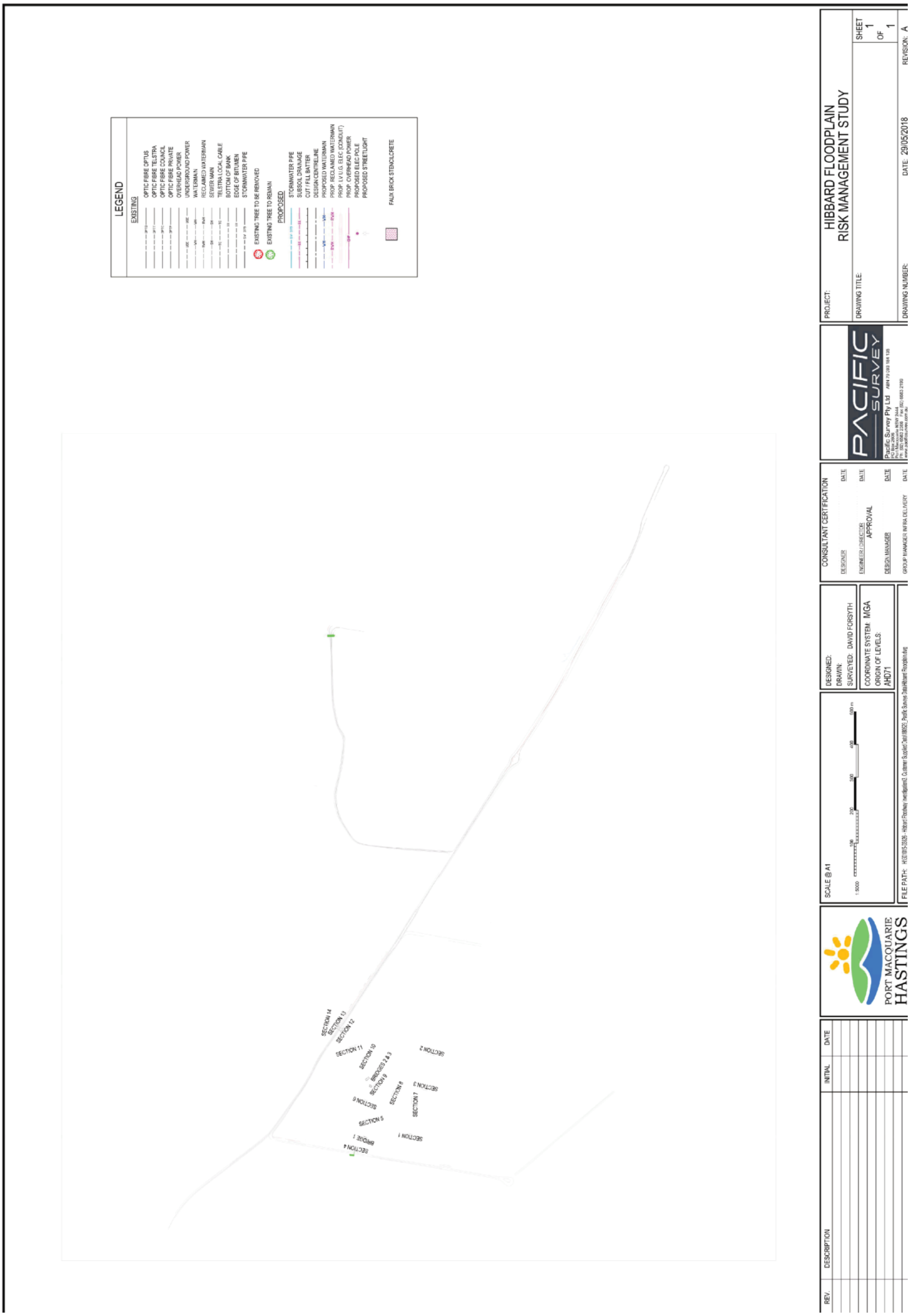

TOP OF WOODEN DECK
UNDERSIDE OF WOODEN DECK
Datum -2
NATURAL SURFACE
1.95 1.05 0.26 0.16 -0.01 -0.03 -0.03 -0.19 -0.34 -0.49 -0.62 -0.45 -0.33 -0.09 0.09 0.22 0.34 0.76 1.39 1.78 1.96 1.9 1.87
TOP OF DECK
1.95 1.94 1.93 1.92 1.92 1.92 1.92 1.92 1.92 1.92 1.91 1.91 1.91 1.91 1.91 1.91 1.91 1.91 1.92 1.92
DEPTH
0.01 0.89 1.67 1.76 1.93 1.95 1.95 2.1 2.26 2.4 2.53 2.36 2.24 2 1.82 1.69 1.57 1.15 0.52 0.14
CHAINAGES
0 1.15 2.16 2.65 3.18 3.32 3.55 3.6 3.65 4.5 5.18 6.12 6.82 6.87 6.92 7.35 7.78 8.46 9.5 10.48 11.05 12.65 13.55
REV
AMENDMENTS
APP'D
DATE
GENERAL NOTES / REFERENCES
PACIFIC SURVEY
Pacific Survey Pty Ltd
HIBBARD FLOOD STUDY
PORT MACQUARIE
SURVEYED / DRAWN BY
MM
CHECKED
SCALES AT A3
Horiz 1:100
Vert 1:100
BRIDGE 1 SECTION
HIBBARD FLOOD STUDY
DRAWING STATUS
DRAWING No.
REV.
12D PROJECT : HIBBARD HIBBARD BRIDGE 1

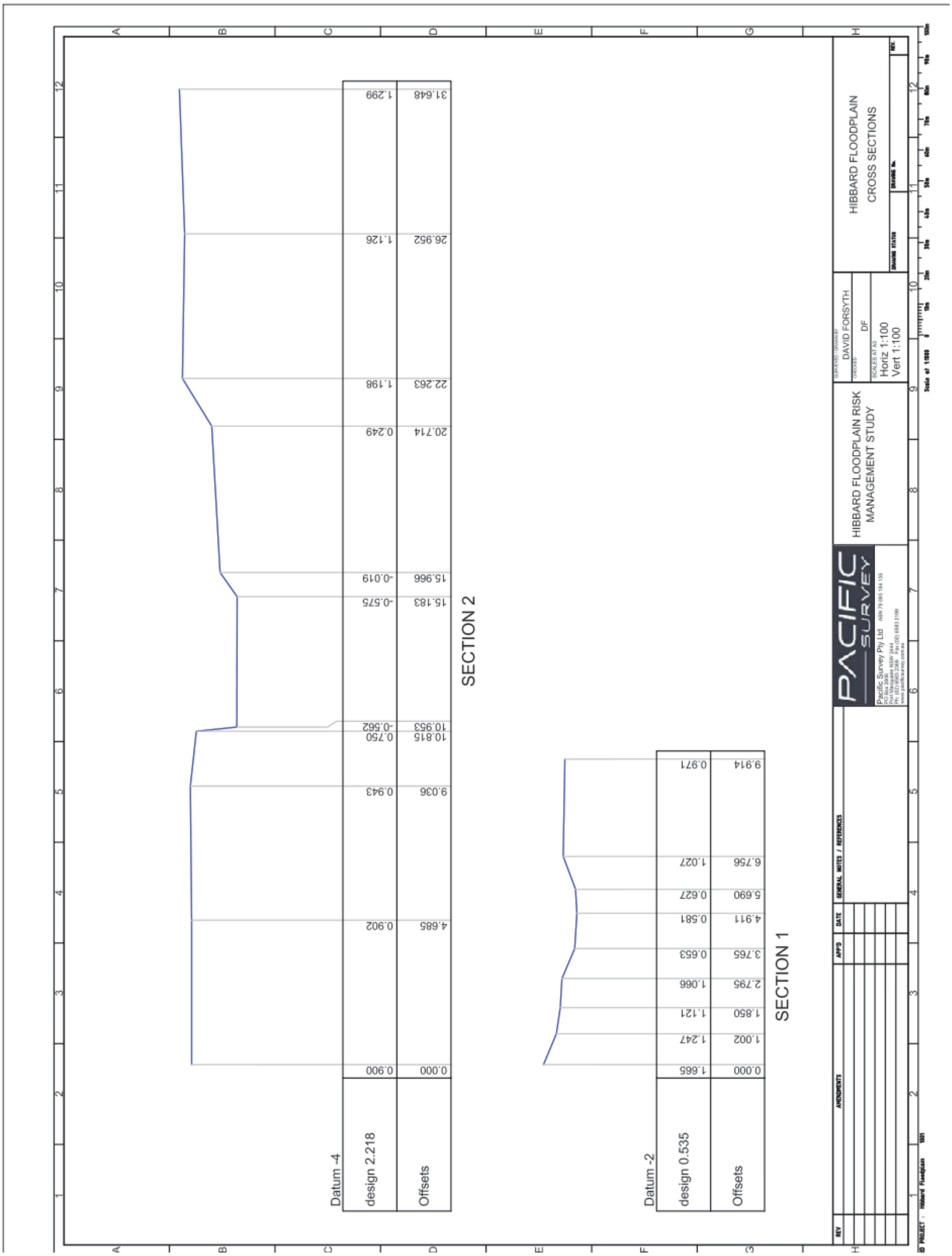


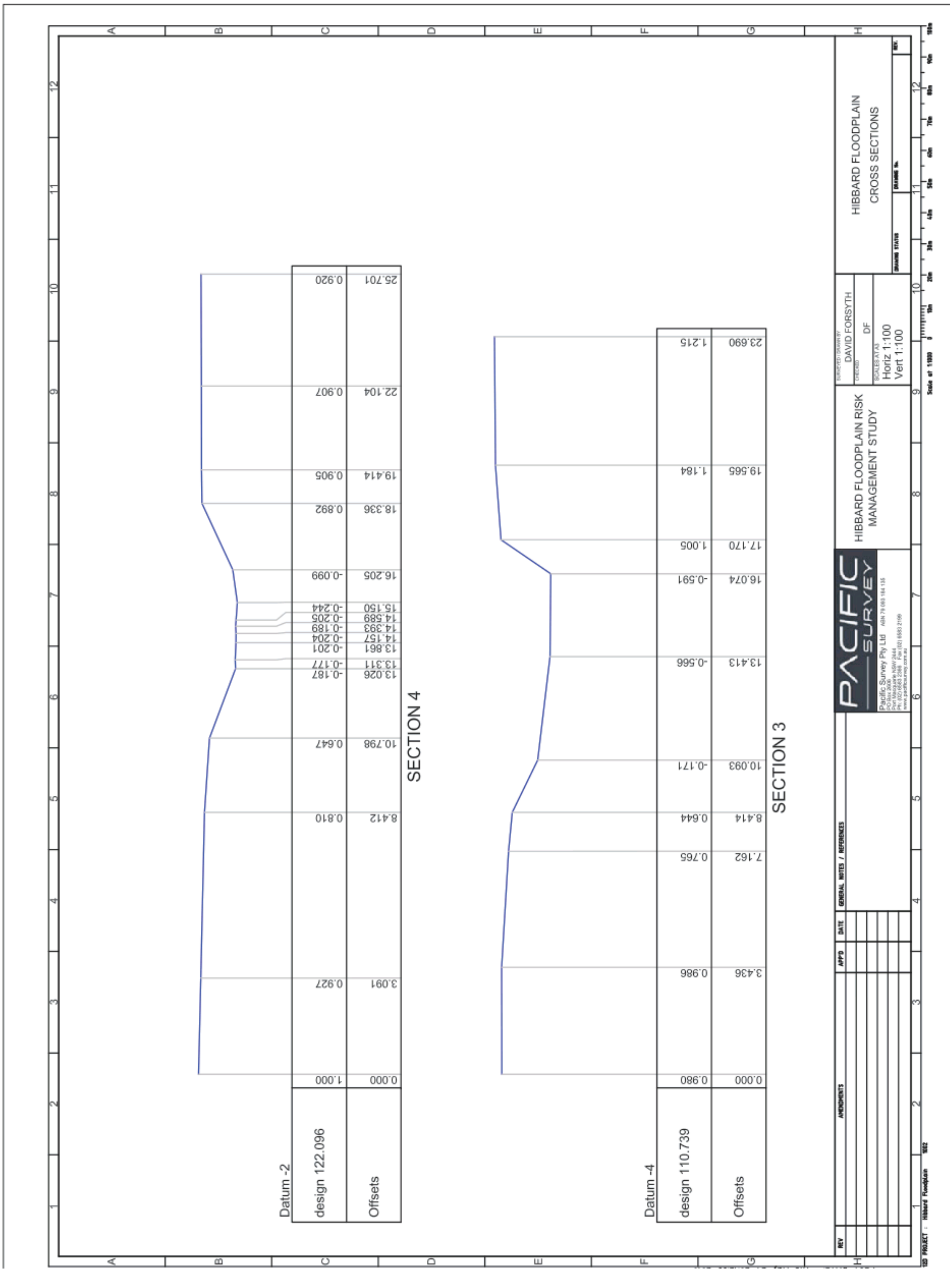
NATURAL SURFACE	1.3	0.98	0.83	0.83	0.83	0.84	0.6	0.42	0.41	0.41	0.21	-0.1	-0.19	-0.32	-0.34	-0.74	-0.58	-0.56	-0.29	-0.05	-0.06	-0.03	0.31	0.47	0.47	0.47	1.06	1.31	1.32
TOP OF DECK	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.14	2.14	2.15	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16
DEPTH	0.83	1.14	1.29	1.3	1.3	1.29	1.53	1.71	1.72	1.73	1.92	2.23	2.32	2.45	2.47	2.88	2.74	2.72	2.45	2.21	2.21	2.19	1.85	1.68	1.68	1.69	1.1	0.84	0.84
CHAINAGES	0	0	0.01	0.05	0.07	0.12	0.12	0.12	0.24	0.33	0.36	0.4	0.6	0.91	1.16	2.72	4.59	5.28	5.29	5.3	5.34	5.46	5.47	5.48	5.52	5.63	5.64	5.64	5.72

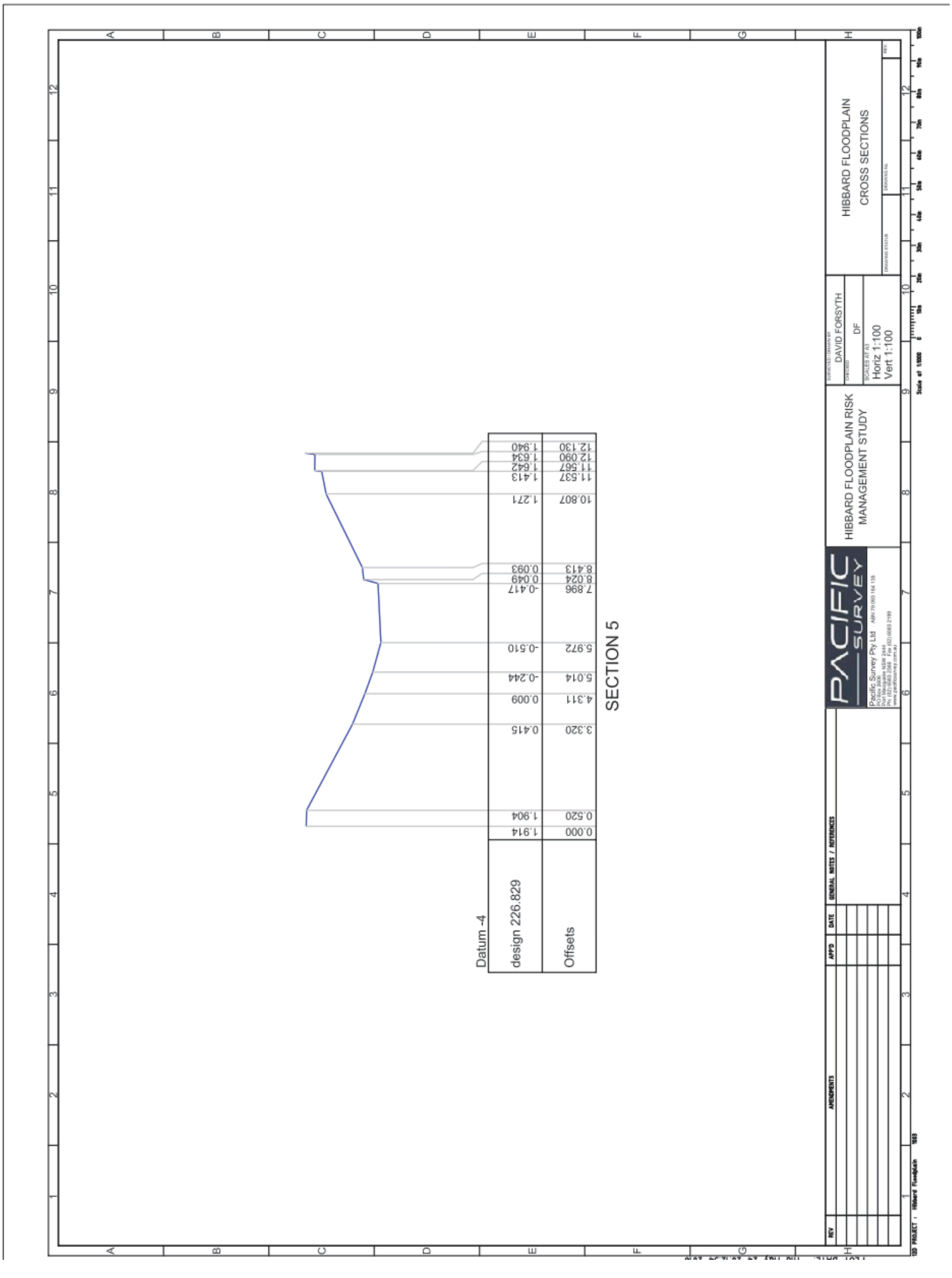

TOP OF DECK
UNDERSIDE OF GIRDER
Datum -2
BRIDGE 3
TOP OF DECK
DEPTH
CHAINAGES
HIBBARD FLOOD STUDY
PORT MACQUARIE
PACIFIC SURVEY
Horiz 1:75
Vert 1:75
BRIDGE 3 SECTION
HIBBARD FLOOD STUDY

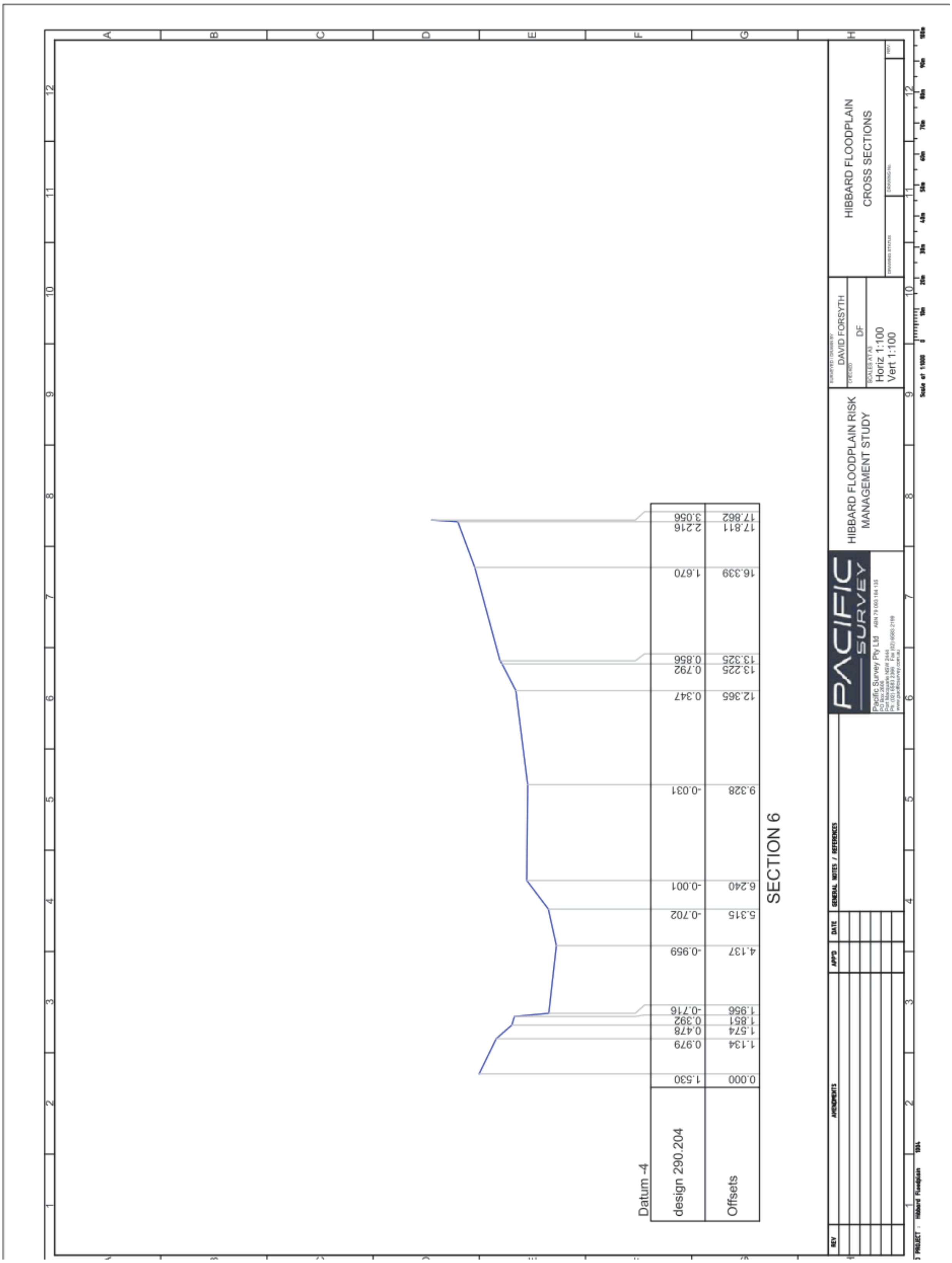

TOP OF DECK
UNDERSIDE OF GIRDER
Datum -2
natural surface
1.35 1.17 0.51 -0.15 -0.59 -0.87 -0.92 -1 -1.06 -1.02 -0.92 -0.52 -0.44 0.33 0.33 0.33 0.33 0.62 1.35
TOP OF DECK
2.02 2.02 2.02 2.02 2.02 2.04 2.04 2.04 2.03 2.03 2.01 2.01 2.01 2.01 2.01 2.01 2.01 2.01 2.01
DEPTH
0.67 0.85 1.51 2.17 2.62 2.91 2.96 3.04 3.09 3.05 2.94 2.53 2.45 1.69 1.69 1.69 1.69 1.4 0.66
CHAINAGES
0 0 0.01 0.15 0.33 2.89 3.5 3.88 4.34 4.63 6.76 6.79 6.86 7.48 7.48 7.49 7.51 7.51 7.51
PACIFIC SURVEY
Pacific Survey Pty Ltd
HIBBARD FLOOD STUDY
PORT MACQUARIE
MM
Horiz 1:50
Vert 1:50
BRIDGE 4 SECTION
HIBBARD FLOOD STUDY

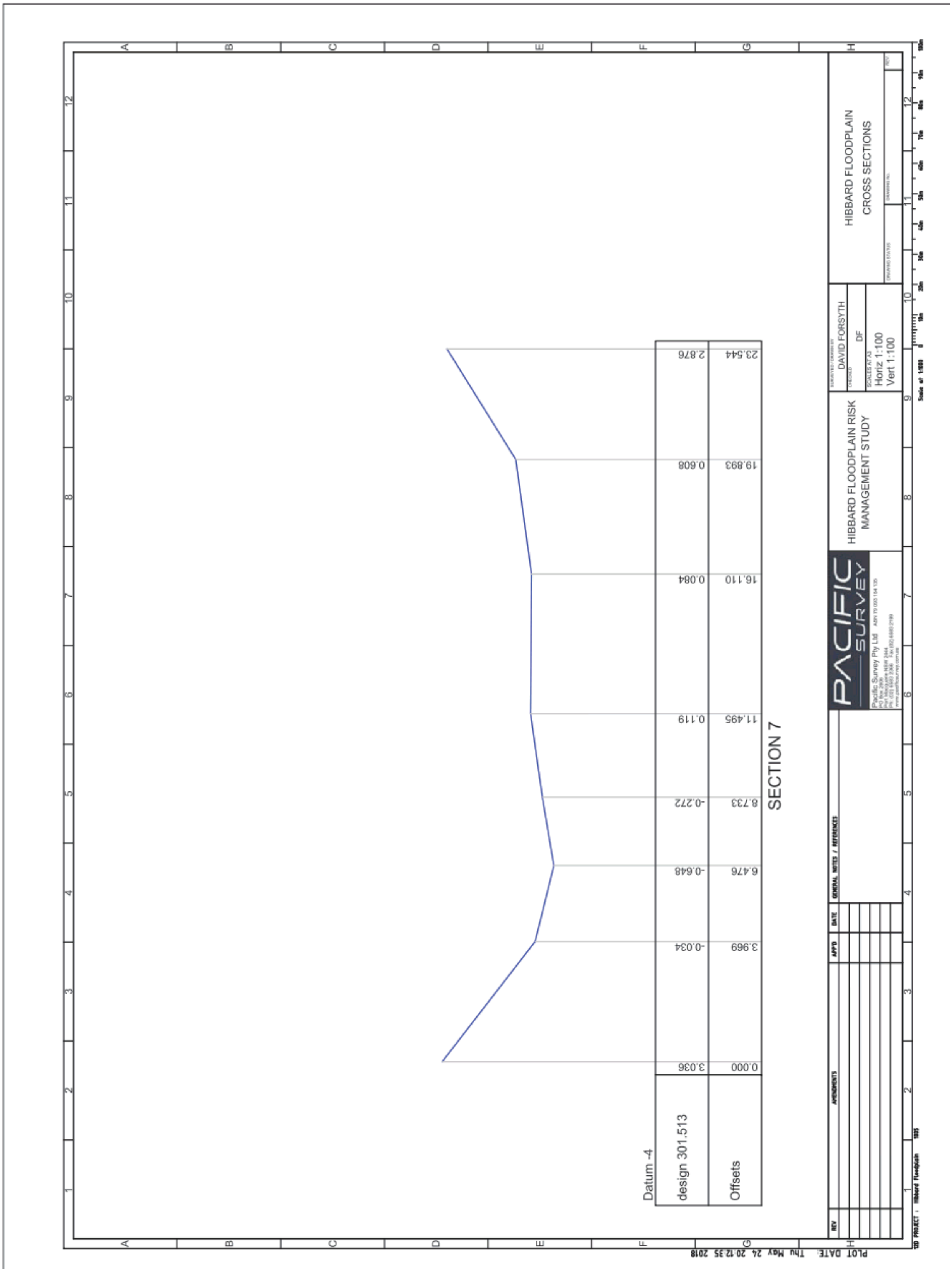

LEGEND
EXISTING
PROPOSED
HIBBARD FLOODPLAIN
RISK MANAGEMENT STUDY
PROJECT:
DRAWING TITLE:
DRAWING NUMBER:
DATE: 29/05/2018
REVISION: A
SHEET 1 OF 1
PACIFIC SURVEY
CONSULTANT CERTIFICATION
APPROVAL
SURVEYED: DAVID FORSYTH
COORDINATE SYSTEM: MGA
ORIGIN OF LEVELS: AHD71
SCALE @ A1
PORT MACQUARIE HASTINGS
REV.
DESCRIPTION
INITIAL
DATE

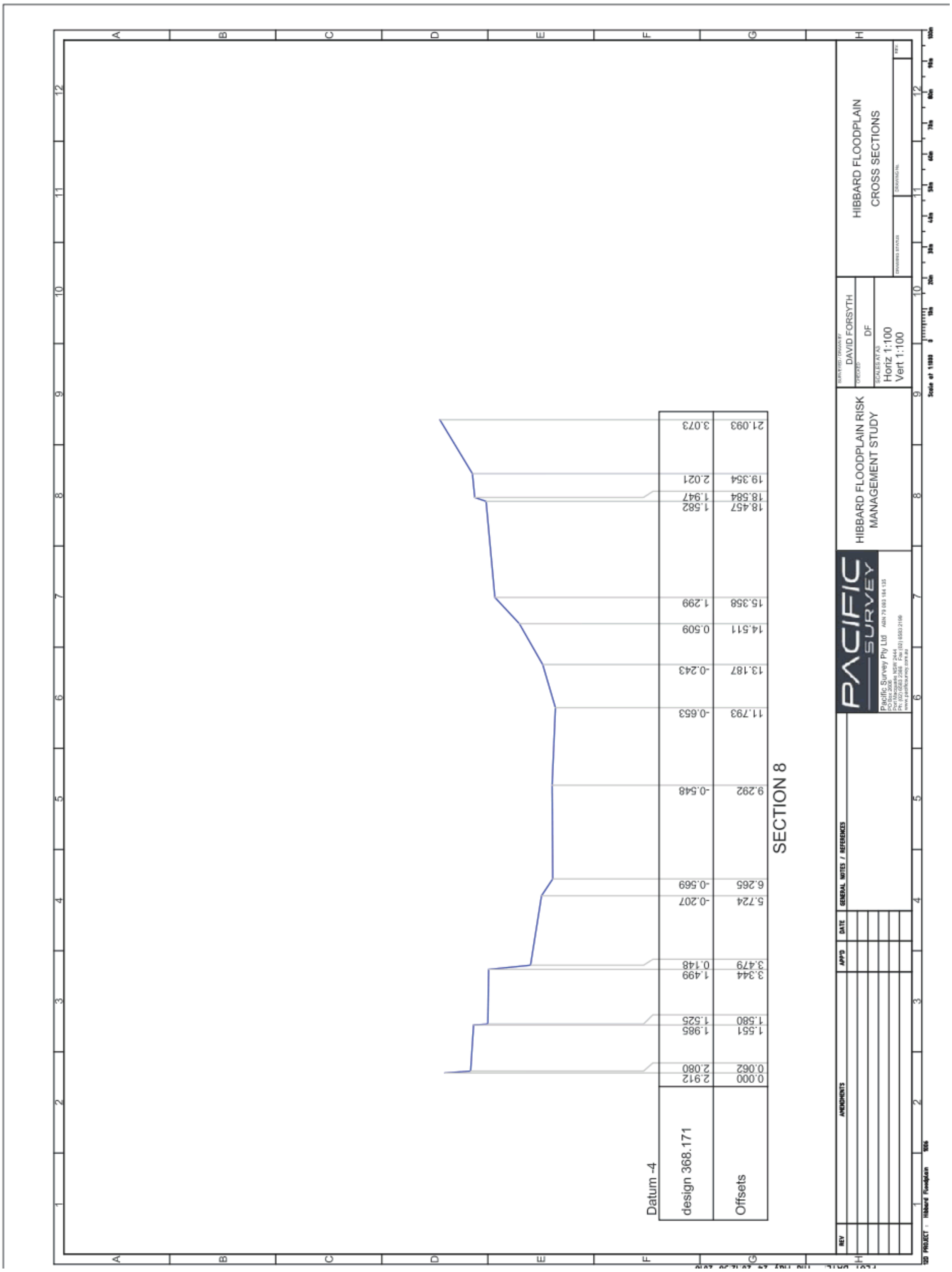

SECTION 2
Datum -4
design 2.218
Offsets
SECTION 1
Datum -2
design 0.535
Offsets
PACIFIC SURVEY
HIBBARD FLOODPLAIN RISK MANAGEMENT STUDY
DAVID FORSYTH
DF
Horiz 1:100
Vert 1:100
HIBBARD FLOODPLAIN CROSS SECTIONS

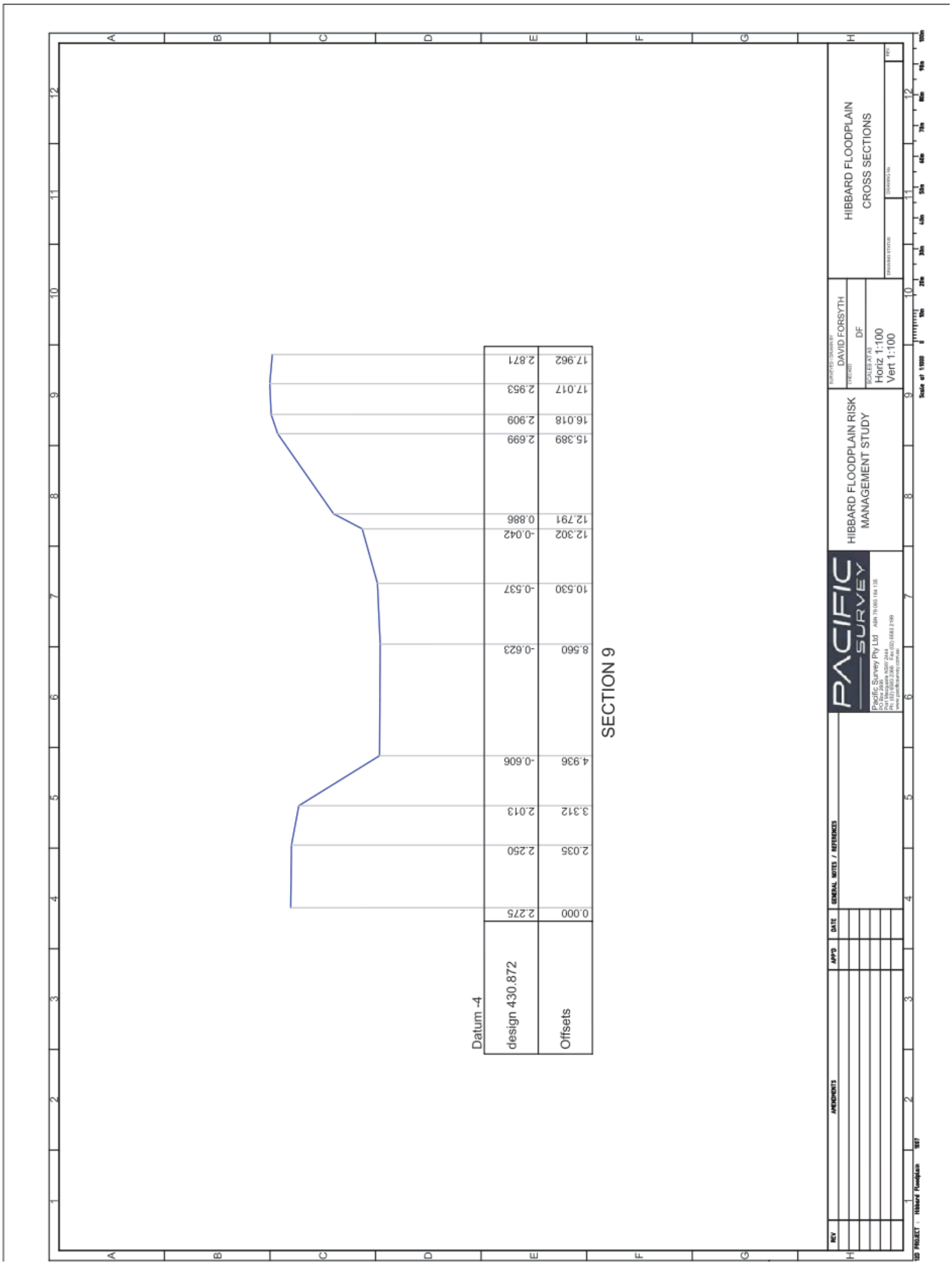

SECTION 4
Datum -2
design 122.096
Offsets
SECTION 3
Datum -4
design 110.739
Offsets
HIBBARD FLOODPLAIN RISK MANAGEMENT STUDY
HIBBARD FLOODPLAIN CROSS SECTIONS
PACIFIC SURVEY
DAVID FORSYTH
DF
Horiz 1:100
Vert 1:100

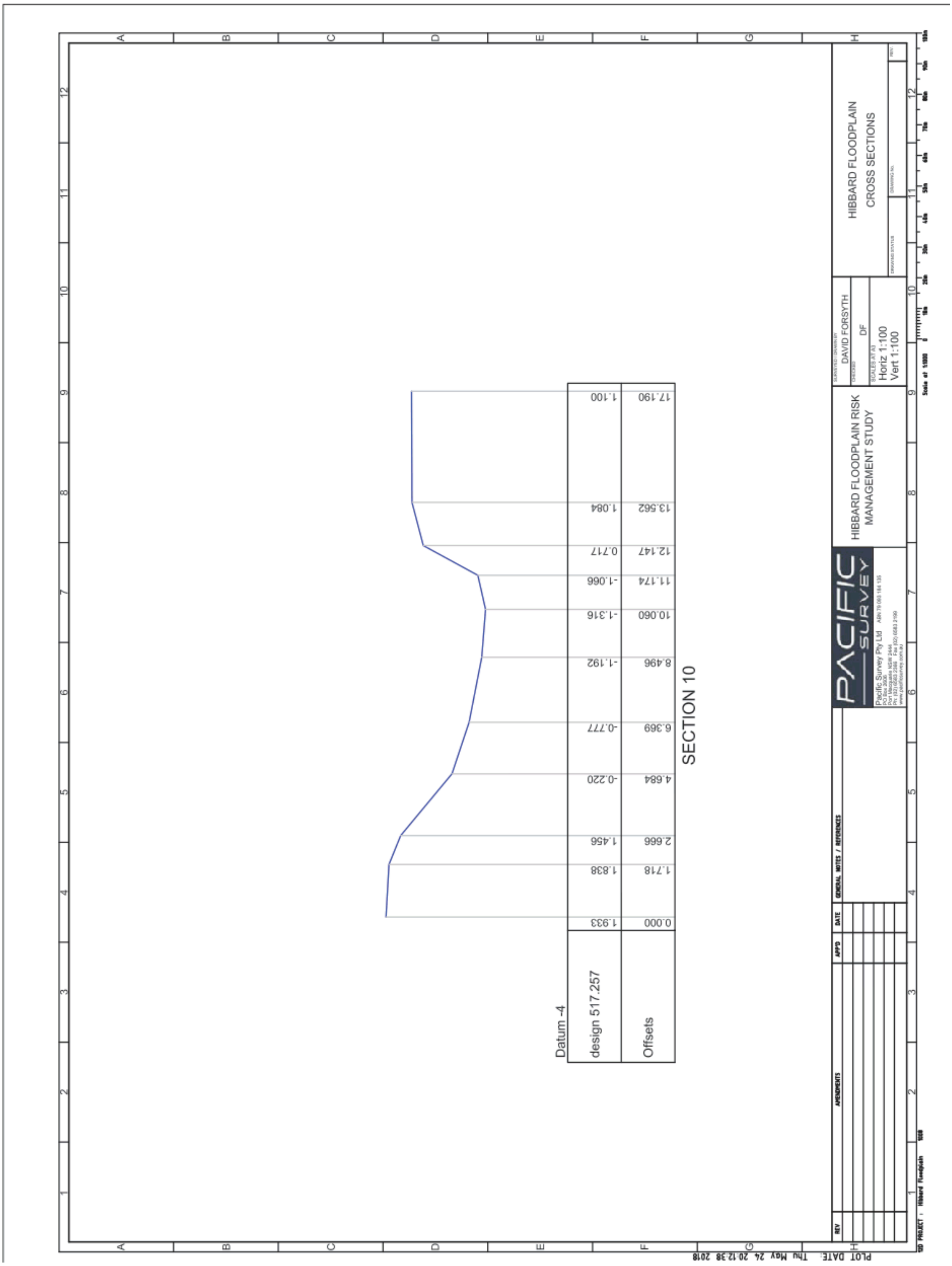

SECTION 5
Datum -4
design 226.829
1.914
1.904
0.415
0.009
-0.244
-0.510
-0.417
0.049
0.093
1.271
1.413
1.642
1.634
1.940
Offsets
0.000
0.520
3.320
4.311
5.014
5.972
7.896
8.024
8.413
10.807
11.537
11.567
12.090
12.130
HIBBARD FLOODPLAIN RISK MANAGEMENT STUDY
DAVID FORSYTH
DF
Horiz 1:100
Vert 1:100
HIBBARD FLOODPLAIN CROSS SECTIONS
PACIFIC SURVEY
Pacific Survey Pty Ltd

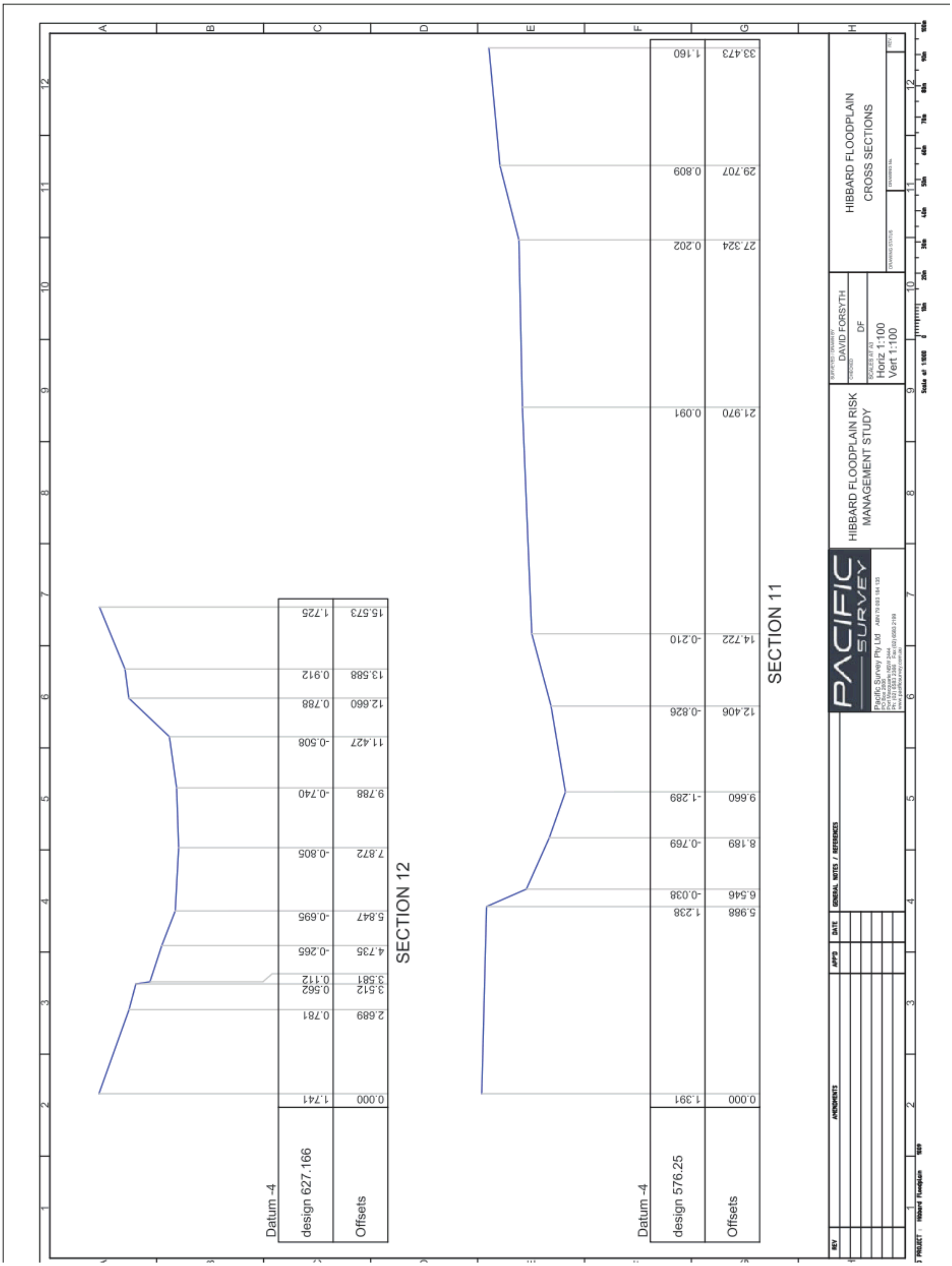

Datum -4
design 290.204
Offsets
SECTION 6
HIBBARD FLOODPLAIN RISK MANAGEMENT STUDY
DAVID FORSYTH
DF
Horiz 1:100
Vert 1:100
HIBBARD FLOODPLAIN CROSS SECTIONS
PACIFIC SURVEY
Pacific Survey Pty Ltd

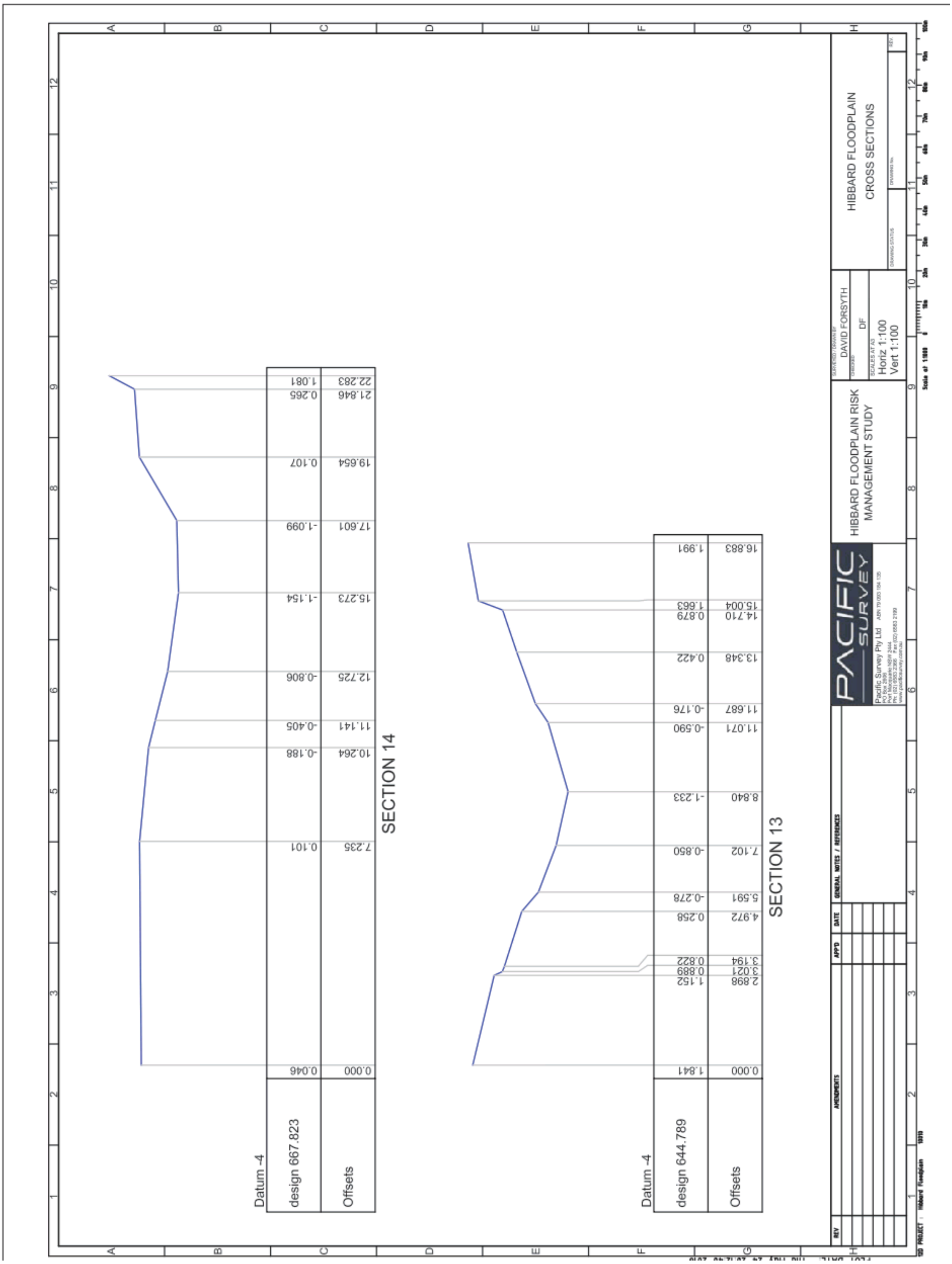

SECTION 7
Datum -4
design 301.513
Offsets
3.036
0.000
-0.034
3.969
-0.648
6.476
-0.272
8.733
0.119
11.495
0.084
16.110
0.608
19.893
2.876
23.544
HIBBARD FLOODPLAIN RISK MANAGEMENT STUDY
HIBBARD FLOODPLAIN CROSS SECTIONS
DAVID FORSYTH
DF
Horiz 1:100
Vert 1:100
PACIFIC SURVEY
Pacific Survey Pty Ltd
PLOT DATE: Thu May 24 20:12:35 2018


SECTION 8
Datum -4
design 368.171
Offsets
2.912 2.080 1.985 1.525 1.499 0.148 -0.207 -0.569 -0.548 -0.653 -0.243 0.509 1.299 1.582 1.647 2.021 3.073
0.000 0.062 1.551 1.580 3.344 3.479 5.724 6.265 9.292 11.793 13.187 14.511 15.358 18.457 18.584 19.354 21.093
PACIFIC SURVEY
Pacific Survey Pty Ltd
HIBBARD FLOODPLAIN RISK MANAGEMENT STUDY
DAVID FORSYTH
DF
Horiz 1:100
Vert 1:100
HIBBARD FLOODPLAIN CROSS SECTIONS


SECTION 9
Datum -4
design 430.872
Offsets
2.275
2.250
2.013
-0.606
-0.623
-0.537
-0.042
0.886
2.699
2.909
2.953
2.871
0.000
2.035
3.312
4.936
8.560
10.530
12.302
12.791
15.389
16.018
17.017
17.962
PACIFIC SURVEY
HIBBARD FLOODPLAIN RISK MANAGEMENT STUDY
DAVID FORSYTH
DF
Horiz 1:100
Vert 1:100
HIBBARD FLOODPLAIN CROSS SECTIONS

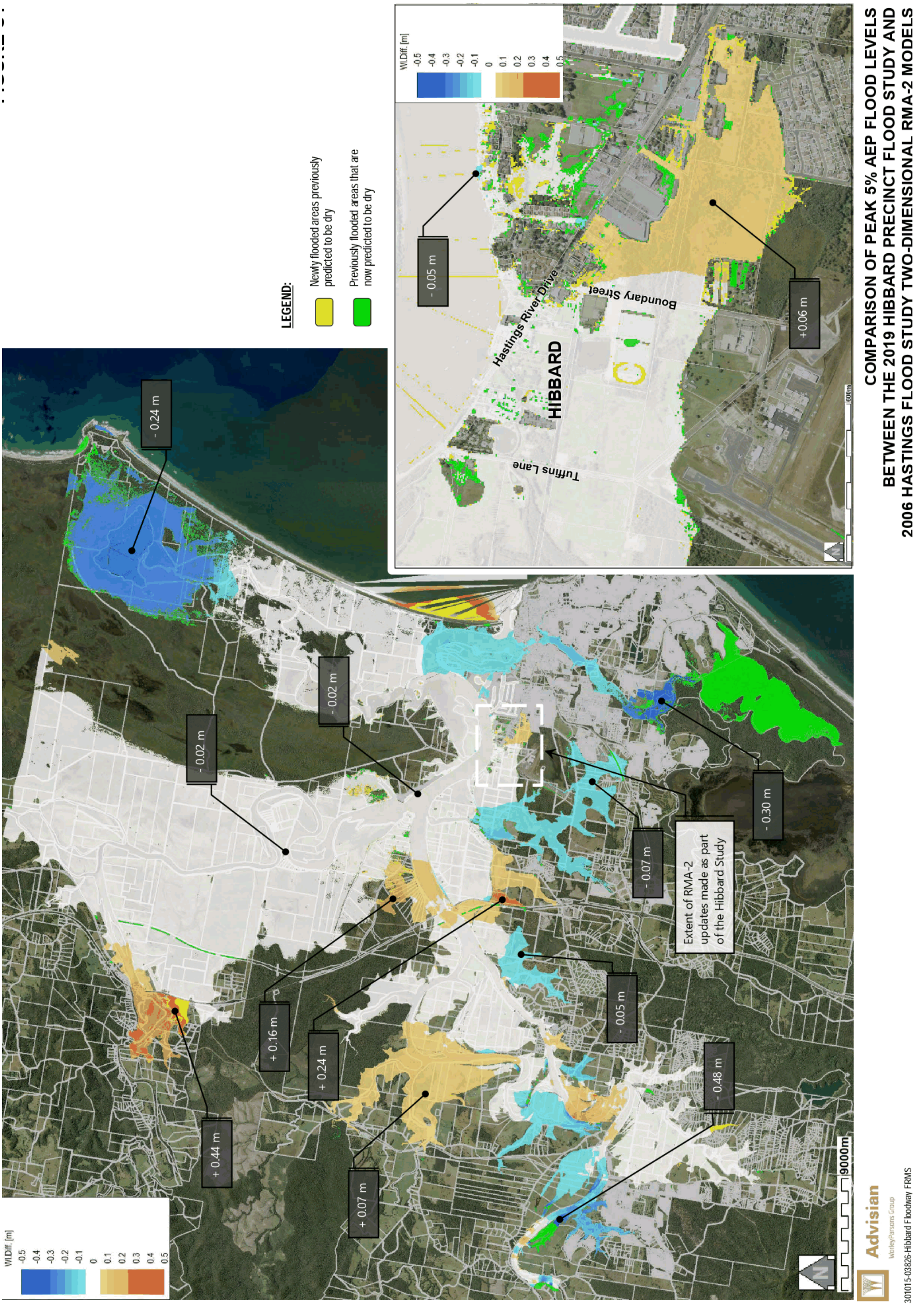

HIBBARD FLOODPLAIN CROSS SECTIONS
HIBBARD FLOODPLAIN RISK MANAGEMENT STUDY
DAVID FORSYTH
DF
Horiz 1:100
Vert 1:100
PACIFIC SURVEY
SECTION 10
Datum -4
design 517.257
1.933 1.838 1.456 -0.220 -0.777 -1.192 -1.316 -1.066 0.717 1.084 1.100
Offsets
0.000 1.718 2.666 4.684 6.369 8.496 10.060 11.174 12.147 13.562 17.190
PLOT DATE: Thu May 24 20:12:38 2018

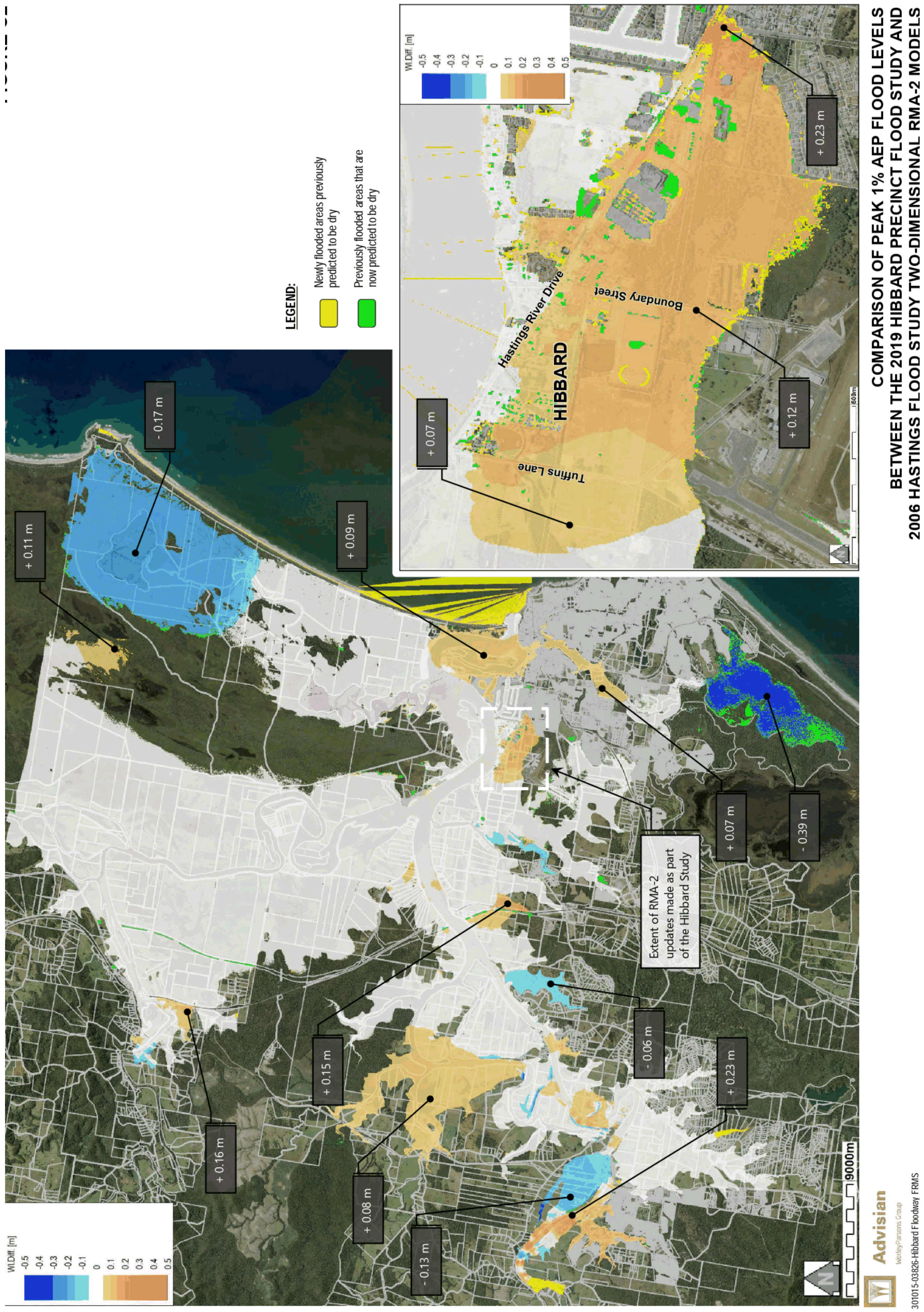

SECTION 12
Datum -4
design 627.166
Offsets
SECTION 11
Datum -4
design 576.25
Offsets
HIBBARD FLOODPLAIN RISK MANAGEMENT STUDY
DAVID FORSYTH
DF
Horiz 1:100
Vert 1:100
HIBBARD FLOODPLAIN CROSS SECTIONS
PACIFIC SURVEY
Pacific Survey Pty Ltd

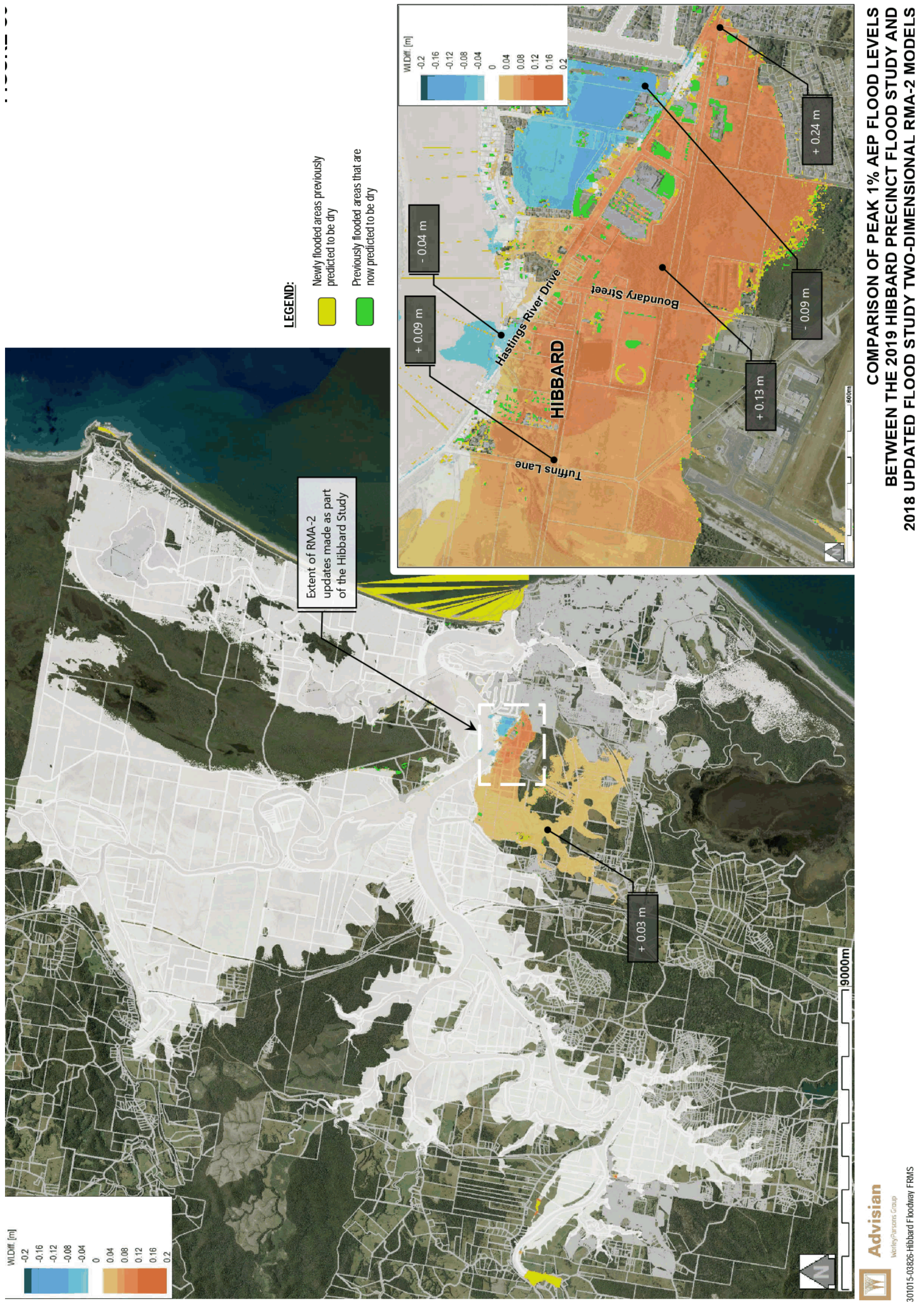

SECTION 14
Datum -4
design 667.823
Offsets
0.046 0.101 -0.188 -0.405 -0.806 -1.154 -1.099 0.107 0.265 1.081
0.000 7.235 10.264 11.141 12.725 15.273 17.601 19.654 21.846 22.283
SECTION 13
Datum -4
design 644.789
Offsets
1.841 1.152 0.889 0.822 0.258 -0.278 -0.850 -1.233 -0.590 -0.176 0.422 0.879 1.663 1.991
0.000 2.898 3.021 3.194 4.972 5.591 7.102 8.840 11.071 11.687 13.348 14.710 15.004 16.883
PACIFIC SURVEY
Pacific Survey Pty Ltd
HIBBARD FLOODPLAIN RISK MANAGEMENT STUDY
DAVID FORSYTH
DF
Horiz 1:100
Vert 1:100
HIBBARD FLOODPLAIN CROSS SECTIONS

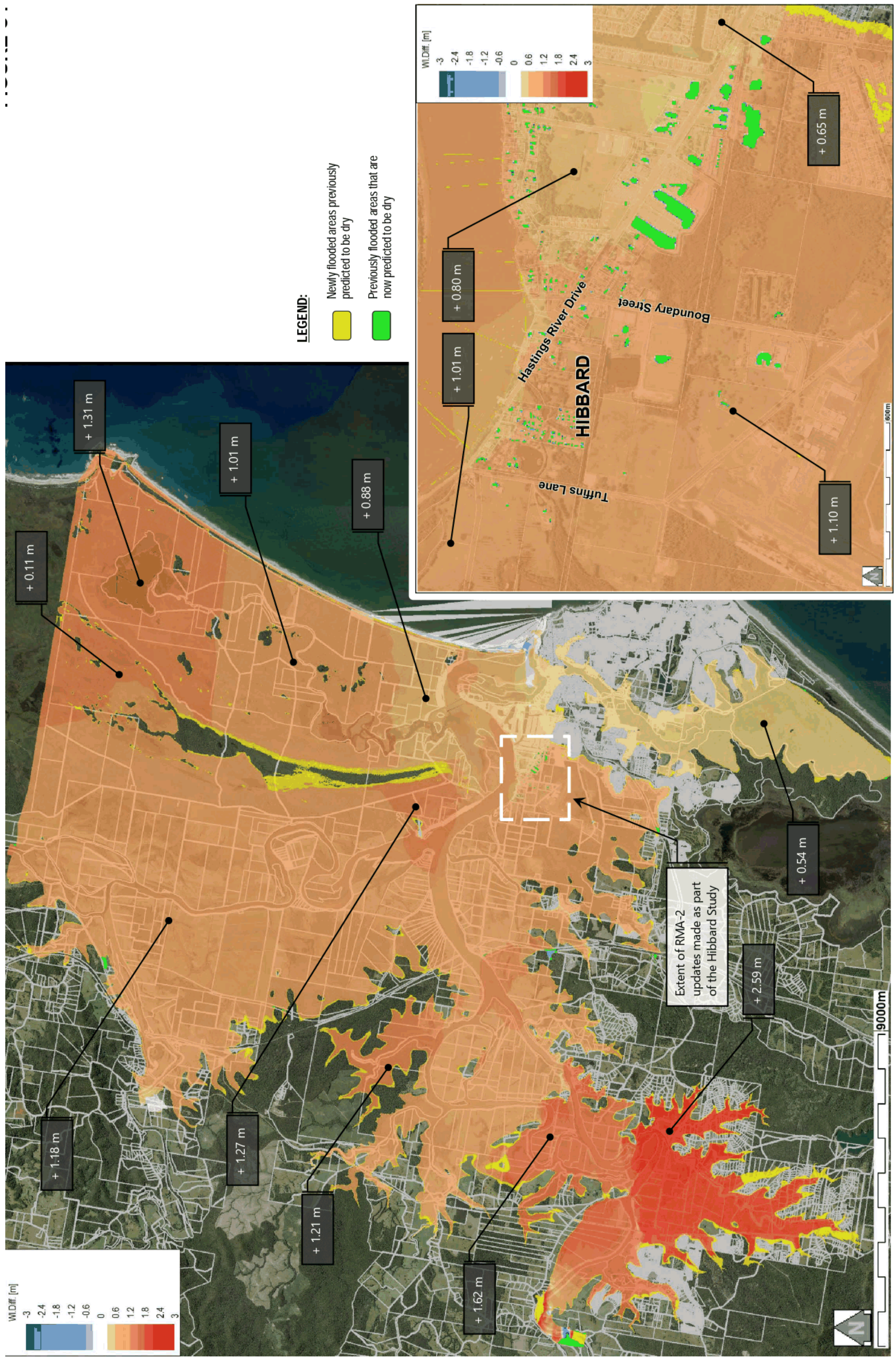
Appendix C

Comparison of Hibbard Design Flood Modelling Results to Previous Studies


COMPARISON OF PEAK 5% AEP FLOOD LEVELS
BETWEEN THE 2019 HIBBARD PRECINCT FLOOD STUDY AND
2006 HASTINGS FLOOD STUDY TWO-DIMENSIONAL RMA-2 MODELS
LEGEND:
Newly flooded areas previously predicted to be dry
Previously flooded areas that are now predicted to be dry
WLDiff. [m]
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
HIBBARD
Hastings River Drive
Boundary Street
Tuffins Lane
- 0.05 m
+0.06 m
- 0.24 m
- 0.02 m
- 0.02 m
- 0.30 m
- 0.07 m
Extent of RMA-2 updates made as part of the Hibbard Study
- 0.05 m
- 0.48 m
+ 0.16 m
+ 0.24 m
+ 0.44 m
+ 0.07 m
9000m
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS

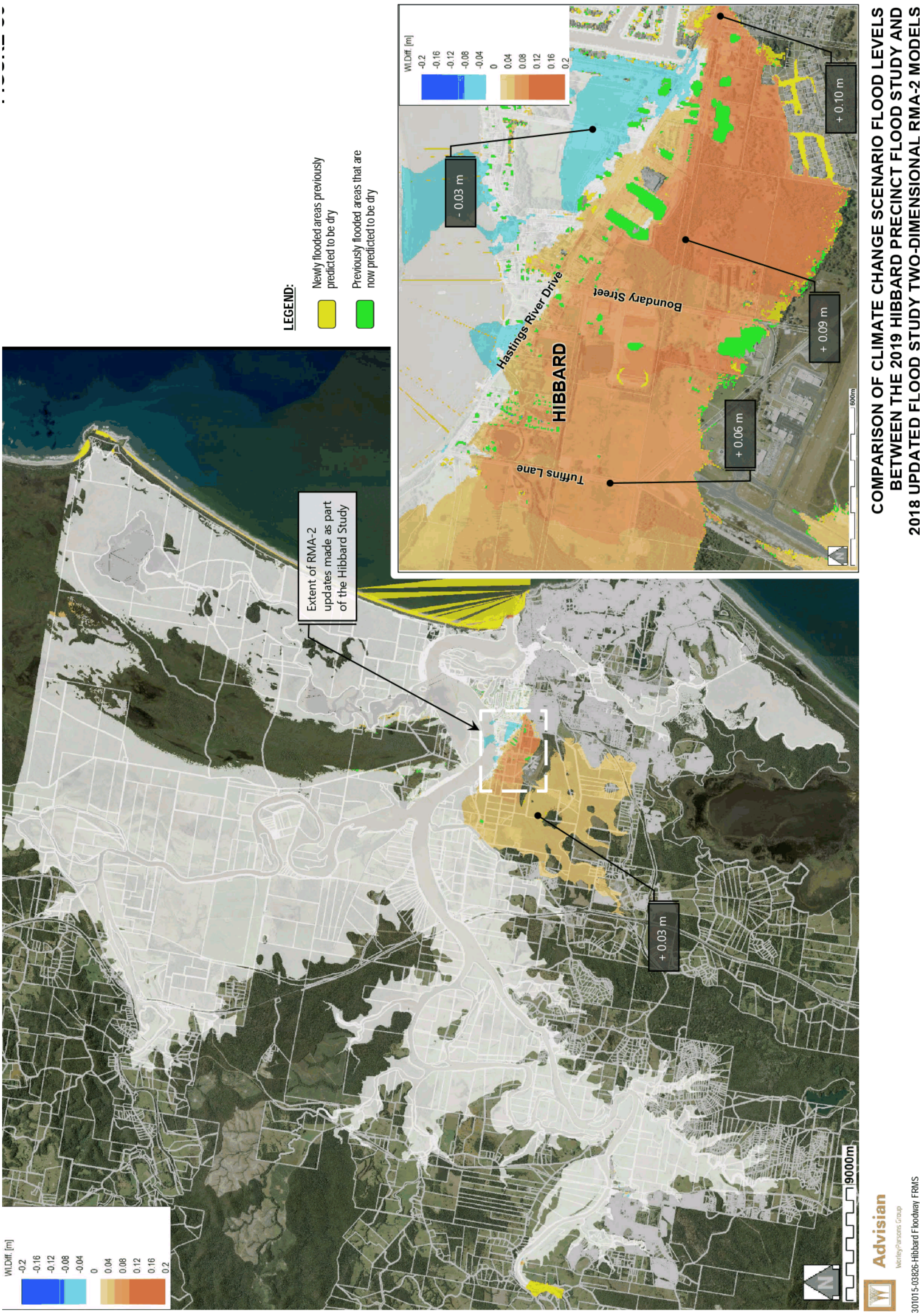

COMPARISON OF PEAK 1% AEP FLOOD LEVELS
BETWEEN THE 2019 HIBBARD PRECINCT FLOOD STUDY AND
2006 HASTINGS FLOOD STUDY TWO-DIMENSIONAL RMA-2 MODELS
LEGEND:
Newly flooded areas previously predicted to be dry
Previously flooded areas that are now predicted to be dry
WLDiff. [m]
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
HIBBARD
Hastings River Drive
Boundary Street
Tuffins Lane
+ 0.07 m
+ 0.12 m
+ 0.23 m
600m
+ 0.11 m
- 0.17 m
+ 0.09 m
+ 0.07 m
- 0.39 m
Extent of RMA-2 updates made as part of the Hibbard Study
- 0.06 m
+ 0.15 m
+ 0.16 m
+ 0.08 m
- 0.13 m
+ 0.23 m
9000m
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS


COMPARISON OF PEAK 1% AEP FLOOD LEVELS
BETWEEN THE 2019 HIBBARD PRECINCT FLOOD STUDY AND
2018 UPDATED FLOOD STUDY TWO-DIMENSIONAL RMA-2 MODELS
LEGEND:
Newly flooded areas previously predicted to be dry
Previously flooded areas that are now predicted to be dry
Extent of RMA-2 updates made as part of the Hibbard Study
WLDiff. [m]
-0.2
-0.16
-0.12
-0.08
-0.04
0
0.04
0.08
0.12
0.16
0.2
HIBBARD
Hastings River Drive
Boundary Street
Tuffins Lane
+ 0.09 m
- 0.04 m
+ 0.13 m
- 0.09 m
+ 0.24 m
+ 0.03 m
600m
9000m
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS



COMPARISON OF PEAK EXTREME FLOOD EVENT LEVELS BETWEEN THE 2019 HIBBARD PRECINCT FLOOD STUDY AND 2006 HASTINGS FLOOD STUDY TWO-DIMENSIONAL RMA-2 MODELS

Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS


COMPARISON OF CLIMATE CHANGE SCENARIO FLOOD LEVELS
BETWEEN THE 2019 HIBBARD PRECINCT FLOOD STUDY AND
2018 UPDATED FLOOD STUDY TWO-DIMENSIONAL RMA-2 MODELS
LEGEND:
Newly flooded areas previously predicted to be dry
Previously flooded areas that are now predicted to be dry
Extent of RMA-2 updates made as part of the Hibbard Study
WLDiff. [m]
-0.2
-0.16
-0.12
-0.08
-0.04
0
0.04
0.08
0.12
0.16
0.2
- 0.03 m
+ 0.10 m
+ 0.09 m
+ 0.06 m
+ 0.03 m
Hastings River Drive
Boundary Street
HIBBARD
Tuffins Lane
600m
9000m
Advisian
WorleyParsons Group
301015-03826-Hibbard Floodway FRMS

Item: 07

Subject: NORTH BROTHER LOCAL CATCHMENTS FLOOD STUDY - DRAFT REPORT

Presented by: Development and Environment, Melissa Watkins

RECOMMENDATION

That the Committee recommend to Council that the draft *North Brother Local Catchments Flood Study (2019*) be placed on public exhibition.

Background

Following the receipt of grant funding during late 2016 from the *NSW Floodplain Management Program* managed by the Office of Environment and Heritage (OEH), Jacobs Pty Ltd has been engaged by Port Macquarie – Hastings Council (PMHC) to undertake the North Brother Local Catchments Flood Study and Floodplain Risk Management Study and Plan for the North Brother local catchment area.

The *North Brother Local Catchments Flood Study* was conceived following a desire to quantify and sequentially address the range of ongoing local overland stormwater flooding issues experienced within the catchment that were occurring as a result of prior development planning.

Development within the catchment has been occurring from the early 1900's through to the present day with the majority of development having occurred between 1970-2000. The construction of associated drainage infrastructure also primarily dated from this time, with the result being that the majority of watercourses stemming from the upstream slopes of the North Brother Mountain were historically either built over, filled, redirected, piped or crossed by road embankments, often resulting in urban development occurring in extremely unsuitable locations.

Localised flooding occurs within the catchments on a frequent bases to varying degrees and commonly leads to damage to properties and infrastructure.

Whilst PMHC is aware of numerous stormwater overland flooding issues within the catchment, a holistic catchment wide approach to the identification and assessment of those issues is required to ensure that remedial actions and funding for those actions is prioritised appropriately based on an assessment of catchment wide risks.

Study Area

The study area includes parts of the villages of Kew, Lakewood, West Haven, Laurieton and Deauville which are situated at the foot of North Brother Mountain. The study area is shown in **Figure 1** below and generally comprises the northern and eastern faces of the North Brother Mountain and the associated urban areas between the foot of the mountain and the adjoining receiving waters.

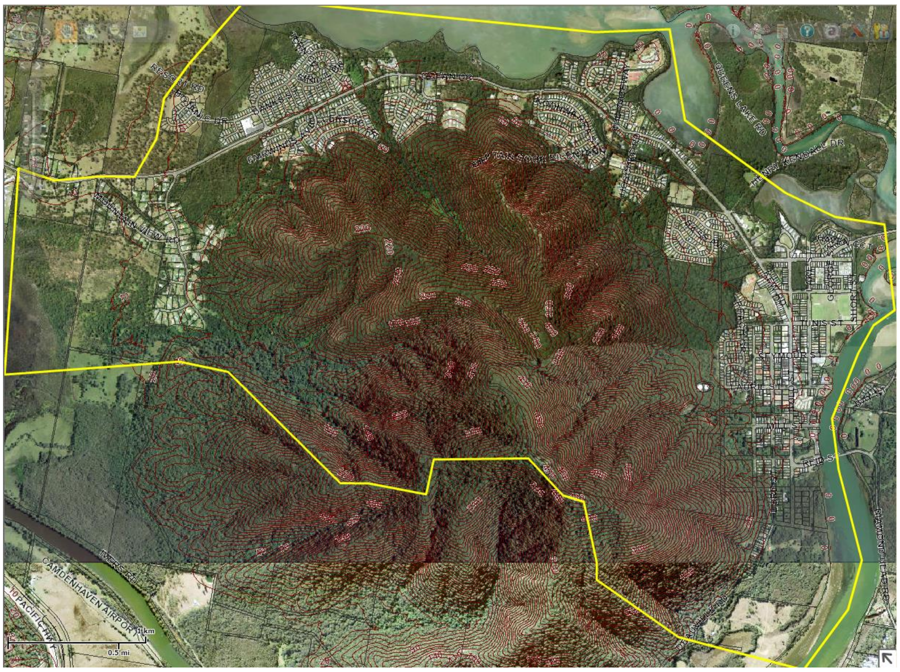


Figure 1 – Study catchment area

The study area has an approximate area of 1,852.2 Ha, with the North Brother Mountain extending to a height of 490 meters, dominating the landscape.

The upper reaches of the study area are predominantly the Dooragan National Park, containing the North Brother Mountain itself, below which is situated the Laurieton CBD, various vegetated natural gullies and flow paths as well as significant established low and medium density residential, caravan parks and holiday accommodation precincts.

From the North Brother Mountain, stems a number of small, steep and unnamed local catchments which discharge to one of the many waterways surrounding the mountain.

The relatively short flow path between the foot of the North Brother Mountain and the adjoining downstream receiving waters mean that stormwater flows are characteristically high energy and fast flowing.

Urban development at the foot of the North Brother Mountain is typically bounded by diversion drains and natural gullies which direct the large volumes of stormwater runoff safely around developed lands and into the downstream waterways. There are a number of locations where flows are captured and conveyed via a traditional pit and piped drainage system through the downstream urban areas.

The North Brother Local Catchments Flood Study

The development of Floodplain Management Plans follow guidelines established in the NSW Government's *Floodplain Development Manual (2005)*. The manual outlines the steps involved in the process, and the activities required to develop a Floodplain Management Plan in flood affected areas.

The Floodplain Risk Management process involves the following stages:

STAGE	DESCRIPTION
1. Flood Study	Determines the nature and extent of the flood problem.
2. Floodplain Risk Management Study	Evaluates management options for the floodplain in respect of both existing and proposed developments.
3. Floodplain Risk Management Plan	Involves formal adoption by Council of a plan of management for the floodplain.
4. Implementation of Plan	Results in construction of flood mitigation works to protect existing development and the application of environmental and planning controls to ensure that new development is compatible with the hazard.

This report details the results of the first phase of this project, being the completion of the draft *North Brother Local Catchment Flood Study*.

Pending the endorsement of the Coast, Estuary and Floodplain Advisory Sub-Committee, it is proposed to report the draft study to Council and for the study to be placed on public exhibition, prior to future adoption and progression to the Floodplain Risk Management Study phase of the project.

The draft *North Brother Local Catchments Flood Study* is the culmination of significant data collection and analysis, community consultation, survey, analysis and hydraulic modelling and serves to define the flood behaviour within the catchment.

Design flood events including the 20% and 5%, 2%, 1% and 0.5% AEP and the Probable Maximum Flood (PMF) have been modelled. In this regard, the 20% event has been added to the suite of events historically modelled for riverine type flooding (Hastings and Camden Haven Rivers) on the basis that many of the issues within the catchment will require a solution (at least in part) involving an upgraded local stormwater drainage system. PMHCs *AUSPEC Standards* required that stormwater drainage systems in residential areas typically achieve compliance with the 'Major/Minor' drainage principals of *Australian Rainfall and Runoff 2016* (ARR 2016), whereby the piped drainage system conveys storm flows generated by a 5% AEP event, and larger flows are conveyed safely within the road reserve or other designated flow paths.

In addition to the above, flood behaviour was estimated for a climate change scenario comprising the 1% AEP plus 10% increase in rainfall plus 0.9m sea level rise. The climate change scenario modelled for this study again differed to the methodology adapted by PMHC for riverine flood study. In this regard, whereas the *Camden Haven River Flood Study* adopted a climate change scenario of a 10% increase in rainfall intensity coupled with a tail-water equivalent to the 1% flood level plus 900mm sea level rise, it was felt that this approach would be not reflect the specific North Brother Mountain catchment conditions.

The likelihood of coincident flooding within the two catchments is considered low based on differing times of concentration and the type of flooding being assessed by each study is also different – with the *Camden Haven River Study* investigating and assessing riverine flood flows, whereas the *North Brother Local Catchments Flood Study* is assessing the risks associated with short duration flash flooding type events offering within the local catchment only.

Further, with the Camden Haven River climate change flood levels being around 3 – 4m AHD, these levels resulted in the inundation of many low lying areas in the catchment. This resulted in the modelling not identifying the risks of localised flash flooding in those low lying areas.

Consequently, a lower tail-water level equal to an ocean storm surge of 2.1m AHD (20yr Camden Haven river), plus 0.9m sea level rise and no coinciding river flooding was adopted for the draft *North Brother Local Catchments Flood Study*.

Flood mapping of depth and flow velocity was undertaken for all event AEPs.

The draft *North Brother Local Catchments Flood Study* clearly highlights the extent of the existing local overland stormwater flood issues and highlights those areas where the greatest flood risks are likely to occur.

Following future adoption, the study will form the basis of the future North Brother Floodplain Risk Management Study and Plan.

The general approach and methodology employed in preparing the draft *North Brother Local Catchments Flood Study* is as follows:

<u>Compilation of available information</u>
A range of data was obtained by Jacobs in July/August 2017 and is summarised in Table 3-1 of the attached report. Data collection generally included:

- Copies of numerous previously completed stormwater and flood studies in the catchment,
- Historic rainfall data obtained from within the catchment as obtained by PMHC,
- Daily rainfall data for five stations in the vicinity of the study area from the BoM,
- Topographic mapping of the catchment,
- LiDAR data for the study area,
- Detailed design plans for all existing subdivisions and infrastructure,
- Records of historic customer requests, photographs and information pertaining to local flooding events,
- Relevant GIS mapping data including stormwater and drainage infrastructure
- Aerial photography (current and historic),
- Relevant council policies (including *Flood Policy 2015*),

Site inspections were undertaken on 27 July 2017 to gain a detailed understanding of the catchment characteristics, the nature of existing development and hydraulic conditions (including flow patterns, drainage arrangements, hydraulic features etc.) in known flood problem areas, and likely flood risk.

<u>Data gap analysis</u>
A data analysis and gap analysis was undertaken to assess the adequacy of existing information and to determine the suitability of the information for use in completing the Flood Study. This analysis identified the need for more detailed topographic data in many locations to assist with the local scale definition of topography and key physical features.

In particular, the LiDAR data set was reviewed for key drainage areas, and it was observed that in areas with a thick tree canopy or in-channel vegetation there was generally a low density of data points as shown in **Figure 2** below.

This data analysis led to the preparation of a detailed site survey plan to capture missing data and ensured that sufficient information was available to accurately represent existing hydraulic controls such as open drains, diversion mounds, creek cross-sections and details of bridge and culvert crossings.

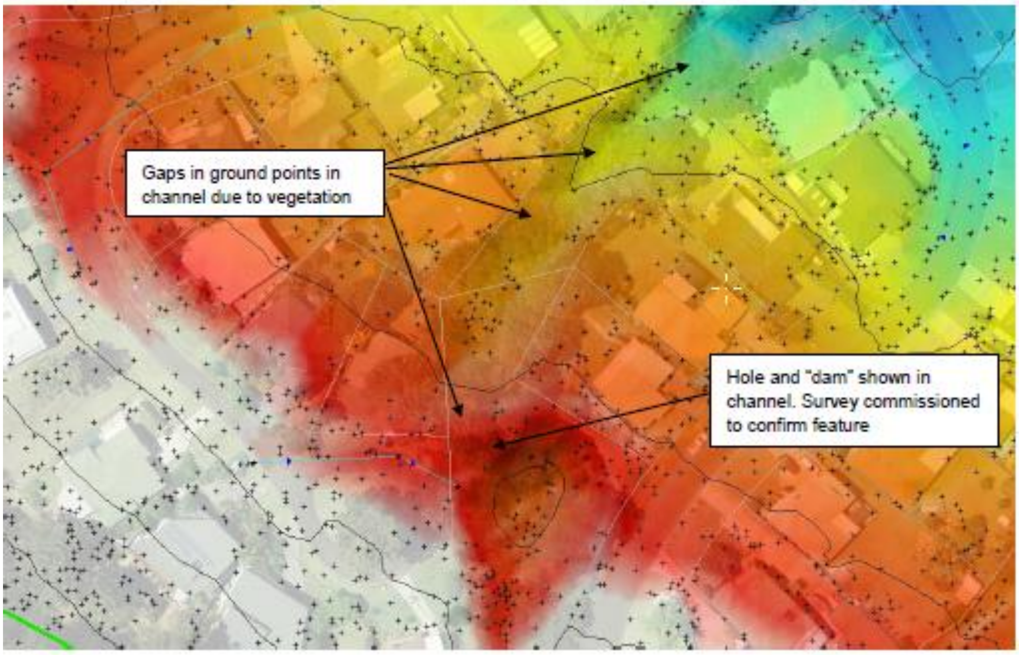


Figure 2 – Example of sparse LiDAR ground points

In addition to topographical features, the availability of historic rainfall data was also reviewed. Historic daily rainfall data was obtained from the Bureau of Meteorology's (BOM) website. Data from five sites in the vicinity of North Brother Mountain was obtained and is summarised in **Figure 3** below. All five sites are located at or below 55m AHD and the sites are unlikely to represent rainfall on the 490m high North Brother Mountain due to orographic effects.

Gauge Number	Gauge Name and Elevation	Distance from Study Area (km)	Start Date	End Date	Length of record (years)	Completeness (%)
060022	Laurieton (Eloura St) 12m AHD	0	1/1/1885	31/07/2017	132.7	87.0
060027	Lorne (Lorne Rd) 55m AHD	17	1/01/1938	30/06/2016	78.6	97.5
060024	Moorland (Denro-an) 5m AHD	19	1/11/1885	31/07/2017	131.8	90.3
060017	Hannam Vale (Hannam Vale Rd) 33m AHD	21	1/02/1926	31/07/2017	91.6	97.1
0600139	Port Macquarie Airport AWS 4m AHD	25	26/07/1995	17/08/2017	22.1	98.0

Figure 3 – BoM Rainfall Gauges

Pluviograph data for specific historic storm events was obtained for model calibration. Pluviograph data is available from PMHC-operated sewage treatment plants (STP) and sewer pumping stations (SPS), with the closest and most relevant gauge locations to the study area being:

- Camden Haven SPS #1 (Wharf Street, Laurieton)
- Camden Haven STP (Dunbogan), and
- Kew – Kendall STP (Pacific Highway, Herons Creek).

Community consultation

Newsletters, media releases and information posted on PMHCs webpage was undertaken to announce the commencement and provide background on the study.

Following a review of the available data and site inspections, a community survey was mailed out to residents with the study newsletter asking residents for information on previous flooding events that they experienced in the study area.

A total of 302 responses were received. The responses assisted the project team in identifying the most significant flooding events in recent history which would be suitable for model calibration and verification. Submissions included flood depths, flow patterns and durations of flooding. Residents also submitted photographs and videos of flooding during the events.

The survey identified numerous flooding events over the past 20 years with no particular standout events. The March 2013 event was reported in six responses, while the April 2008 event, which resulted in the most intense rainfall for the storm event data available, was reported twice. The February 2002 event was reported four times, however sub-daily rainfall data is not available for that event.

Further analysis of the rainfall events that occurred during the March 2013 and April 2008 events indicated that those two events corresponded approximately with the 20% AEP (5yr) and 10% AEP (10yr) events respectively. On the basis that good rainfall records were available for those two events, that the community had provided responses and records of those events, and that the timing was relatively recent, these two events were selected for model calibration and verification purposes.

The responses and information received was utilised in both model calibration and to assist in assessing the completeness of the available topographic data

Detailed feature survey

Following the completion of the data review and community consultation, Jacobs engaged local surveying firm, Local Government Engineering Services to undertake detailed topographic survey of a number of features in the catchment in order to develop a representative digital elevation model (DEM) of the study area, focusing on areas where the existing data was not representative of site conditions or complete.

Hydrologic Modelling

A hydrologic model was prepared to estimate storm and flood flows for the study area for the historic and design rainfall storm events.

The hydrologic modelling adopted involved a 'lumped catchment modelling approach' for the watercourses draining off the mountain, and a direct rainfall approach for the more dispersed overland flow catchment areas at the foot of the mountain.

In this regard, the steep and well defined gullies stemming from the North Brother Mountain and upstream of the urban areas at the base of the mountain were modelled separately to the lower catchments.

This lumped hydrologic modelling was undertaken using the RAFTS hydrology module in the DRAINS modelling software and resulted in simplified model of the upper steep and forested catchments and a number of defined points of discharge for those upper catchments into the downstream 2D TUFLOW model.

The RAFTS module is considered to be suitable for assessment of sub-catchments with areas up to 100 hectares and permits routing of runoff through the catchment. The DRAINS software is one of the few modelling packages that currently incorporate ARR 2016 design rainfalls and procedures.

These upper catchment areas on North Brother Mountain were divided into 56 sub-catchments which drain to the gullies and watercourses running off the mountain through the study area. Mapping of the sub-catchment boundaries is shown on **Figure 4** below. These sub-catchments are natural vegetated areas and a nominal impervious fraction of 5% was assumed.

Sub-catchment flow path slopes are steep to very steep, with catchment flow path slopes ranging from 15 – 70%. DRAINS/RAFTS and most other hydrologic models have an upper limited slope parameter value of 30%, and this is adopted for the sub-catchments with slopes exceeding this value. It is likely that that catchment slopes steeper than 30% would result in faster catchment flow travel times producing higher peak flows, however this is able to be compensated for via model calibration and the adjustment of other factors such as rainfall losses, orographic rainfall scaling factor, blockage factors, and roughness within the model at the model calibration and verification phase.

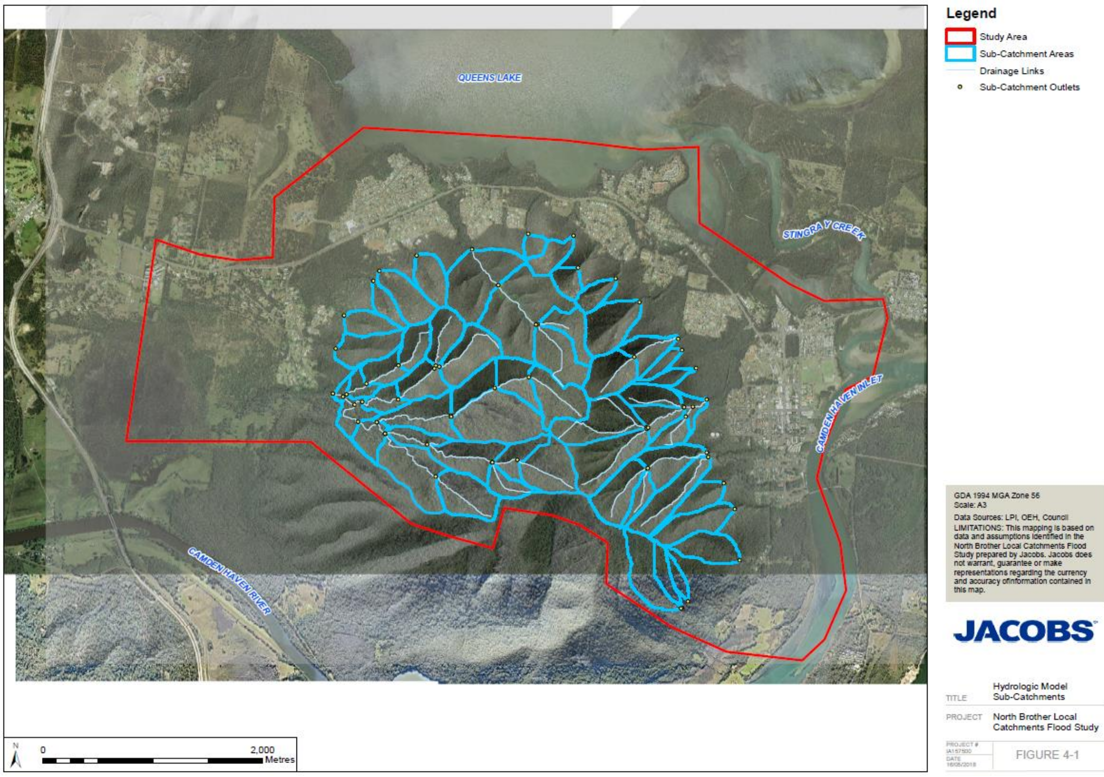


Figure 4 – Model Sub Catchments

Detailed information on the model parameters can be found in section 4 of the draft Flood Study.

The lumped catchment model provided inputs into the downstream 2D model.

<u>Hydraulic Modelling</u>
A TUFLOW combined one-dimensional (1D) and two-dimensional (2D) hydrodynamic model was developed for this study.

The TUFLOW model comprised of:

- A 2D domain of the study area surface reflecting the catchment topography, with varying roughness as dictated by land use. The watercourses were in general modelled in 2D. Diversion drains are in 2D.
- A 1D network of pits, pipes and culverts representing the stormwater network. Inflow capacities for pits were defined based on their type and size.
- Obstructions to flow are represented as 2D objects, including existing buildings.

The model extent covered an area of 12.6km^2 and includes the foot of the North Brother Mountain along its western, northern and eastern sides and the adjacent developed lower-lying areas down to the receiving waters at Camden Haven River, Queens Lake and Stingray Creek.

The various features in the TUFLOW model are shown on **Figure 5** below:

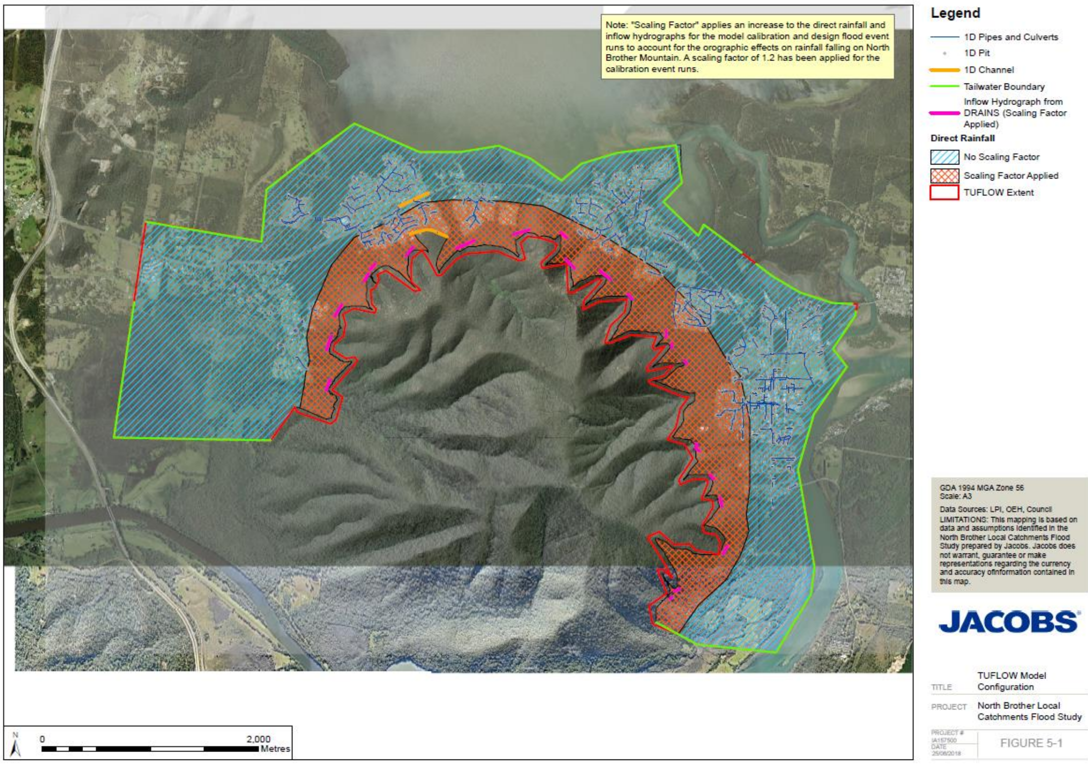


Figure 5 – TUFLOW Model Configuration

The topography of the catchment was represented in the model using a 2m grid. This level of precision in the grid was considered necessary in order to represent detailed flood behaviour in a fully developed catchment. Finer model grid sizes such as 1m grid were not considered practical given the large size and expected excessively long computing times.

The stormwater pit and pipe network was modelled as a 1D network, coupled to the 2D TUFLOW Model domain with building polygons identified form aerial photography and modelled as solid objects in the floodplain.

All surfaces within the model were assigned an appropriate roughness based on zoning and ground cover as viewed from aerial photographs. The roughness values utilised were based on engineering experience and typical values used in previous flood studies and are considered representative of the study area.

In addition to the model inflows at the upper ends of the catchments, a rainfall hyetograph (rainfall depth per time interval) was directly input into the TUFLOW model in the areas where direct rainfall applied.

<u>Model Calibration and Verification</u>
Rigorous model calibration of overland flood models cannot generally be carried out because direct measurements of overland flows and accurate measurements of flood levels are usually not available. Localised features may also be present which influence flow patterns but are not detected in the catchment-scale topographic data.

Hence, overland flood models are often verified using observations of flood depths and flood behaviour as a way of “sanity-checking” the modelling and confirming its reliability.

This study relied mainly on observed depths of flooding during past flood events given by local residents. This anecdotal information was generally considered indicative as often only the general location of the observation was usually given, and approximate depths of flooding. The reported flood observations were also from numerous separate storm events, while the model calibration focussed on only two events selected based on availability and quality of observed data. However, the reported flood depths were still useful information for validating the general behaviour of flooding simulated by the flood models.

The general approach involved running the hydrologic and hydraulic models and comparing the flood depths and flow patterns to reported observations. The model configuration and parameter values were adjusted as necessary with the aim of achieving a satisfactory fit to the observations.

Flooding was reported for numerous individual storm events occurring over the last 20 years from the community survey responses. Two historic storm events were selected for model calibration and verification based on the number of responses for each event and the magnitude of the storm event. These events included:

- **24 April 2008**. The most intense rainfall recorded based on the available data. Significant number of photographs are available for this event.
- **2 March 2013**. This is a relatively intense storm with the majority number of survey responses.

Characteristics of the selected storm events are provided in **Figure 6** below:

Event Date	Daily Rainfall Depth	Main Storm Burst Rainfall Depth and Duration	Approximate Event AEP	Comment
24 April 2008	136mm	49mm in 45 mins 65mm in 60 mins	10% AEP	Rainfall data available from Camden Haven SPS (Laurieton)
2 March 2013	152mm	43mm in 60 mins 61mm in 1.5 hrs	20% AEP	Rainfall available from Camden Haven STP (Dunbogan)

Figure 6 – Calibration storm event characteristics

The above two rainfall events were modelled for model calibration purposes and resulted in the refinement of a number of key modelling parameters including:

- Rainfall losses,
- Orographic rainfall scaling factor,
- Blockage factors, and,
- Roughness

The *Model calibration and verification report* (2018) (attached) details the results of this process. This report was placed on public exhibition during 2018 via PMHCs website and a targeted mail out to those residents who had responded to the prior consultation survey.

Two community information sessions were undertaken as part of this process.

Comparing the model results and observed/reported information, it is considered that the TUFLOW model provides a reasonable match to the observed flood behaviour in the historic events and is therefore considered to be suitable for the estimation of design flood behaviour in the study area.

<u>Estimation of Design Floods</u>
This flood study is based on *ARR 2016* design rainfalls and procedures. Each design storm AEP and duration consists of an ensemble of 10 storm temporal patterns which define the timing and intensity of rainfall throughout a given storm event. Each storm in the 10 temporal pattern ensemble has an equal probability of occurring.

Design rainfall data was downloaded from the BOM website, including ARR 2016 design rainfall depths and temporal patterns relevant to the study area.

Tail-water conditions were based on the OEH guidance in "*Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways*" (OEH, 2015).

In the design flood estimation for North Brother Mountain overland flooding, local catchment flood events were coincided with elevated ocean water level, rather than a coinciding river flood event. There is considered to be a higher probability that the local catchment storm would coincide with a storm surge event. Local catchment flooding occurred sometime (0.5-2 days) before the river flooding occurred or peaked during the flood events of 2008 and 2013. Hence, peak river flood levels as coinciding tail-water conditions is considered overly conservative.

The storm events modelled include the 0.2 Exceedances per Year ("EY") (20%), 5%, 2%, 1% and 0.5% AEP and Probable Maximum Flood (PMF) events for current climate conditions. The storm durations that were initially assessed include the 15 and 30 minute and 1, 1.5, 2 and 3 hour durations for up to the 0.5% AEP events.

The critical durations (those that gave the maximum flood levels) varied for the different AEPs. The 15, 30 and 45 minute and 1 hour durations were modelled for the PMF event.

A climate change flood scenario was also assessed, consisting of the existing 1% AEP storm plus a 10% increase in rainfall intensity, combined with a 1% AEP ocean level with a 0.9m sea level rise.

<u>Design Flood Results</u>

1. Provisional Flood Mapping
   -

Utilising the calibrated model and design Rainfall Events, flood modelling to determine of peak water levels and flow velocities throughout the study area for the design flood events including the 20% and 5%, 2%, 1% and 0.5% AEP and the PMF events, plus a climate change scenario were undertaken, with mapping presented within Appendix E of the report.

Overland flow depths on properties are typically up to 0.3m in up to the 1% AEP event. Depths exceed 0.5m in a number of locations in the 20% event, and exceed 1m in the 5% and 1% AEP events. Areas of deeper flows include main flow paths and drainage low points in a number of roads.

During the PMF event, property and road flooding exceeding 0.5m depth is widespread, with property and road flooding of 1m depth also common. Depths of flooding exceeding 2m occur on approximately 20 properties in the study area.

Flow velocities are swift in a number of overland flow paths through properties and particularly in roads. Typical flow velocities are 0.5 – 1m/s in the 20% event, and 1 – 1.5m/s in the 1% AEP event.

High flow velocities of 2 – 3m/s occur in a number of locations including roads and properties. These flows are likely to be highly hazardous to people and risk significant damage to buildings and property.

Flow velocities of 3 – 4m/s are commonplace in the PMF, with some locations experiencing velocities over 4m/s.

Overland flooding in the study area is generally a result of intense short-duration rainfall events. As a result, the duration of inundation of roads and built areas is typically short, limited to 1 – 2 hours in up to the 0.5% AEP event.

Durations of inundation are likely to be up to 4 hours in the PMF event particularly in some flood storage locations, affecting roads including Botanic Drive and Ocean Drive west of Lakewood shopping centre.

The change in flood levels in the 1% AEP event due to climate change were mapped with most areas affected by overland flow experiencing flood level increases of up to 0.1m due to increased rainfall and reduced drainage capacity from higher tail-water levels caused by sea level rise. Locations along the river and lakes would be impacted by 0.9m increases in flood levels directly due to sea level rise, while adjacent areas would be impacted typically by up to 0.5m increases in flood level.

Typical flood extent map excerpts from the Flood Study are copied below:

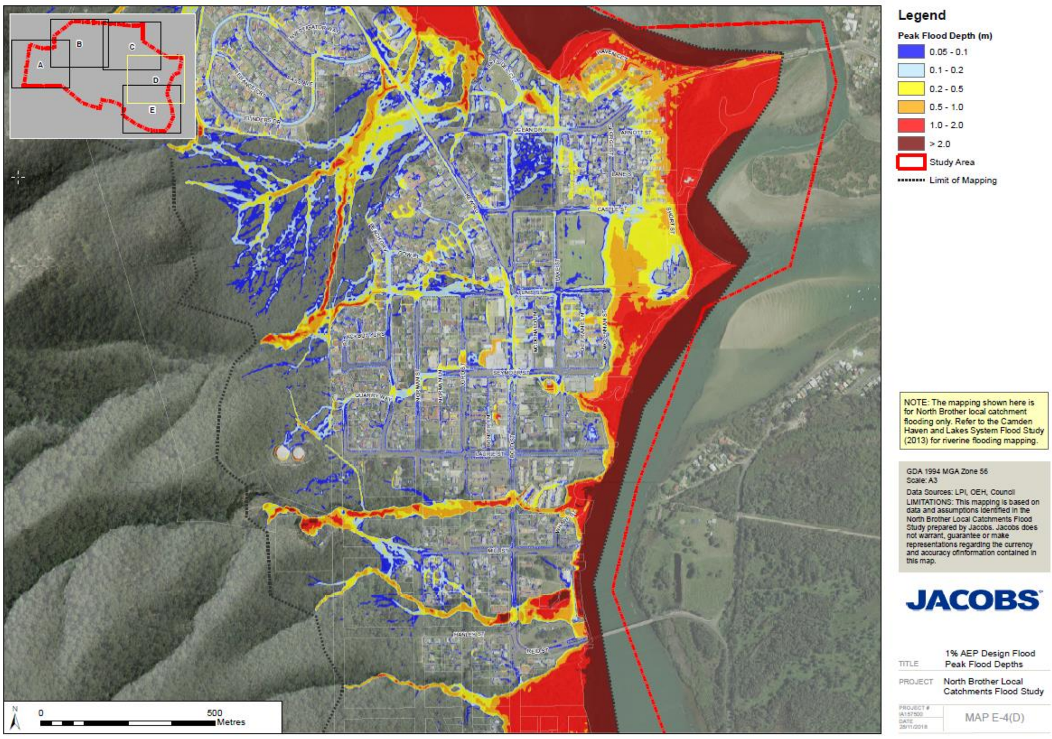


Figure 7 – Sample flood depth mapping for Laurieton

2. Provisional Hazard Mapping

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Following the completion of the velocity and depth mapping for the design events, flood Hazard mapping was prepared for the 1% AEP event (current conditions) and for the 1% AEP event under the adopted climate change scenario (increased rainfall intensity by 10% and with 0.9m sea level rise).

Flood hazards were assessed based on the criteria as outlined within the *Australian Disaster Resilience Handbook 7. Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia* (AIDR, 2017a) and as follows:

- 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 and vehicles. Buildings require special engineering design and construction; and
- H6 – Unsafe for people or vehicles. All buildings types considered vulnerable to failure.

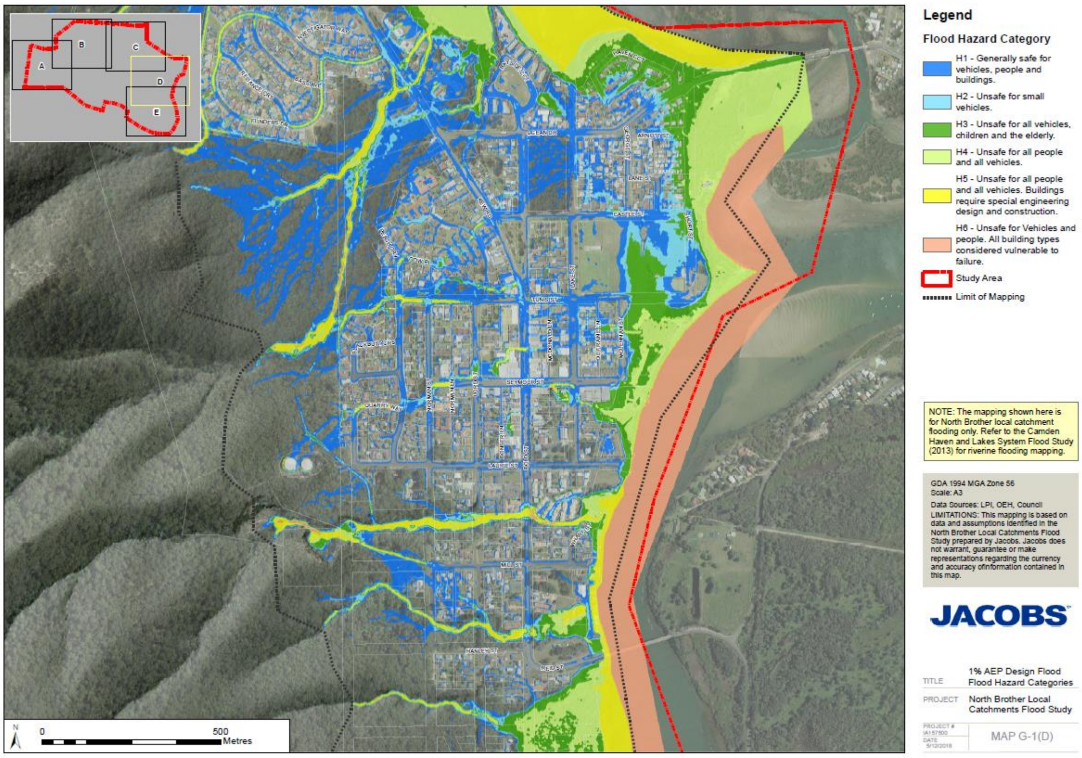

Figure 8 – Sample Provisional Hazard Mapping for Laurieton

3. Provisional Hydraulic Categories Mapping

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Three flood hydraulic categories are identified in the *Floodplain Development Manual* (NSW Government, 2005).

These are also defined in PMHCs *Flood Policy* (2015):

- **Floodway**, where significant discharge of water occurs during floods and blockage could cause redirection of flows. Generally characterised by relatively high flow rates; depths and velocities;
- **Flood storage**, characterised by relatively deep areas of floodwater and low flow velocities. Floodplain filling of these areas can cause adverse impacts to flood levels in adjacent areas; and
- **Flood fringe**, areas of the floodplain characterised by shallow flows at low velocity.

For the purposes of this study, the criteria used to define the provisional hydraulic categories are shown in **Figure 8**.

Hydraulic Category	Criteria
Floodway	Area within the flood extent where: • Velocity x Depth > 0.3m²/s AND • Velocity > 0.5m/s AND • Depth > 0.15m.
Flood Storage	Remaining area within 1% AEP flood extent where Depth > 0.15m
Flood Fringe	Remaining area in the floodplain (i.e. area within PMF extent) outside the Floodway and Flood Storage areas.

Figure 8 – Provisional Hydraulic Categories Criteria

The provisional hydraulic categories mapping is presented in Appendix G of the report (excerpt in **Figure 9** below) for both the 1% AEP design flood and for the 1% AEP event with climate change. The mapping is provisional and will need to be considered in further detail in the Floodplain Risk Management Study phase.

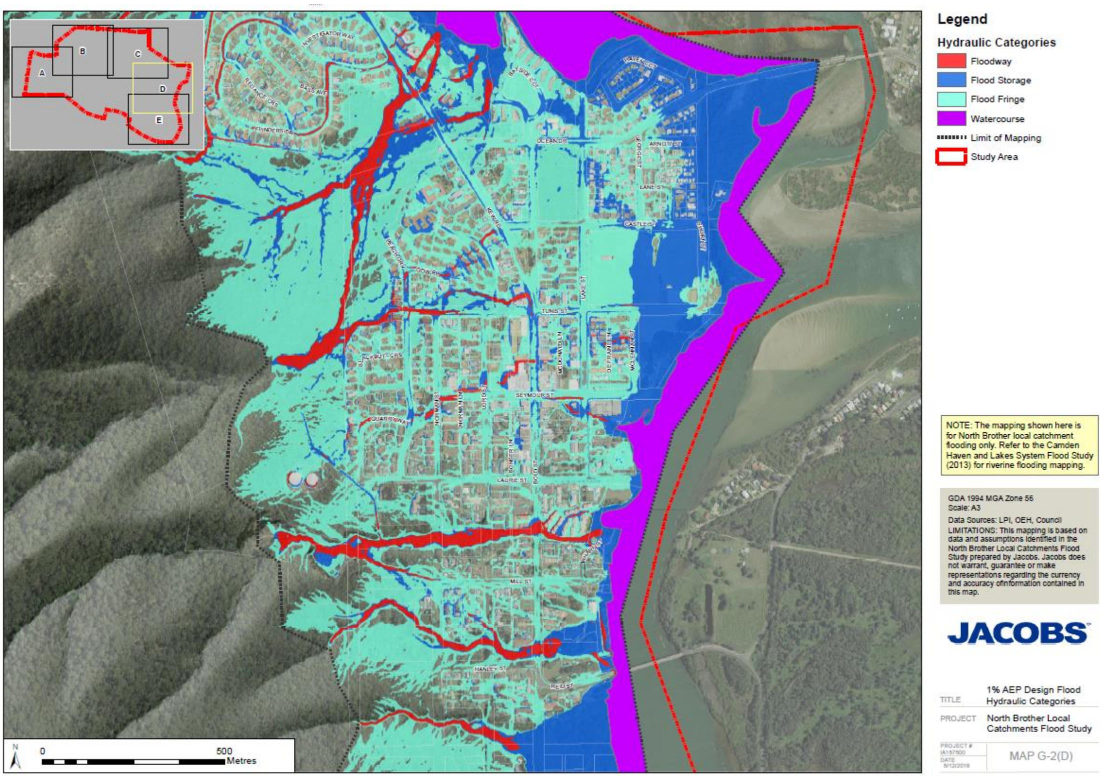

Figure 9 – Sample Provisional Hydraulic Categories Mapping for Laurieton

Conclusions

Hydrologic and hydraulic models were developed with a focus on local catchment and overland flooding originating from runoff from the North Brother Mountain and study area catchment. The modelling did not focus on mainstream flooding from the Camden Haven River and other waterways.

The model has been calibrated to historical floods confirming its ability to reproduce historical flood behaviour on the catchment.

The updated flood study provides PMHC with a suitable platform for undertaking the subsequent stages of the Floodplain Management process, flood planning, and development of flood risk management strategies for the study area.

The draft *North Brother Local Catchments Flood Study* is attached for consideration.

Attachments

1View. Model Calibration and Verification Report
2View. North Brother Local Catchment Flood Study (2019)

JACOBS

North Brother Local Catchments Flood Study

Port Macquarie Hastings Council

Model Calibration and Verification Report

Version A

25 June 2018

IA157500

Model Calibration and Verification Report

JACOBS

North Brother Local Catchments Flood Study

Project no:	IA157500
Document title:	Model Calibration and Verification Report
Document No.:	1
Revision:	A
Date:	25 June 2018
Client name:	Port Macquarie Hastings Council
Project manager:	Lih Chong
Author:	Lih Chong
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Document history and status

Revision	Date	Description	By	Review	Approved
A	25/06/2018	Draft	L Chong	A Hossain	A Hossain

Contents

Appendices

Foreword

The primary objective of the New South Wales Government's Flood Prone Land Policy is to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods, utilising ecologically positive methods, wherever possible. Under the Policy, the management of flood prone land remains the responsibility of local government.

The policy provides for a floodplain management system comprising the following five sequential stages:

1. **Data Collection**	Involves compilation of existing data and collection of additional data
2. **Flood Study**	Determines the nature and extent of the flood problem
3. **Floodplain Risk Management Study**	Evaluates management options in consideration of social, ecological and economic factors relating to flood risk with respect to both existing and future development
4. **Floodplain Risk Management Plan**	Involves formal adoption by Council of a plan of management for the floodplain
5. **Implementation of the Plan**	Implementation of flood, response and property modification measures (including mitigation works, planning controls, flood warnings, flood preparedness, environmental rehabilitation, ongoing data collection and monitoring by Council

Port Macquarie Hastings Council is undertaking this study for the North Brother Local Catchments study area to investigate the existing and future flood risks in the study area in accordance with the NSW Government's *Floodplain Development Manual*. The study will also identify and assess potential flood mitigation options and guide land use planning and future development on the floodplain in the study area.

This study represents Stages 1 to 4 of the management process and has been prepared for Council by Jacobs. This report is a progress report of Stage 2 Flood Study.

Important note about this report

The sole purpose of this report and the associated services performed by Jacobs is to undertake a flood study for the North Brother Local Catchments study area located in New South Wales in accordance with the scope of services set out in the contract between Jacobs and Port Macquarie Hastings Council (the Client). That scope of services, as described in this report, was developed with the Client.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

Jacobs derived the data in this report from information sourced from the Client, third parties, and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in any other context.

Topographic data used in this study included that sourced from a LiDAR survey and ground survey which were undertaken by third parties. Undertaking independent checks on the accuracy of the data was outside Jacobs's scope of work for this study.

This report has been prepared on behalf of, and for the exclusive use of, Jacobs's Client, and is subject to, and issued in accordance with, the provisions of the contract between Jacobs and the Client. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

1. Introduction

1.1 Background

Jacobs has been engaged by Port Macquarie Hastings Council (Council) to undertake a flood study and floodplain risk management study of the North Brother Local Catchments area. The study area is located on the Mid North Coast of NSW, and includes parts of the villages of Kew, Lakewood, West Haven, Laurieton and Deauville which are situated at the foot of North Brother Mountain (Figure 1-1). Development in the area has occurred in sometimes unsuitable locations as a result of poor drainage planning, leading to localised nuisance flooding on residential properties at a number of locations on a regular basis. Numerous gullies and watercourses drain from North Brother Mountain through the developed areas, which over time have been piped, filled, crossed by road embankments or redirected, contributing to the existing flooding problems. Localised flooding in some areas may interact with and be exacerbated by mainstream flooding in Queens Lake, Stingray Creek and Camden Haven River.

Objectives of the study include:

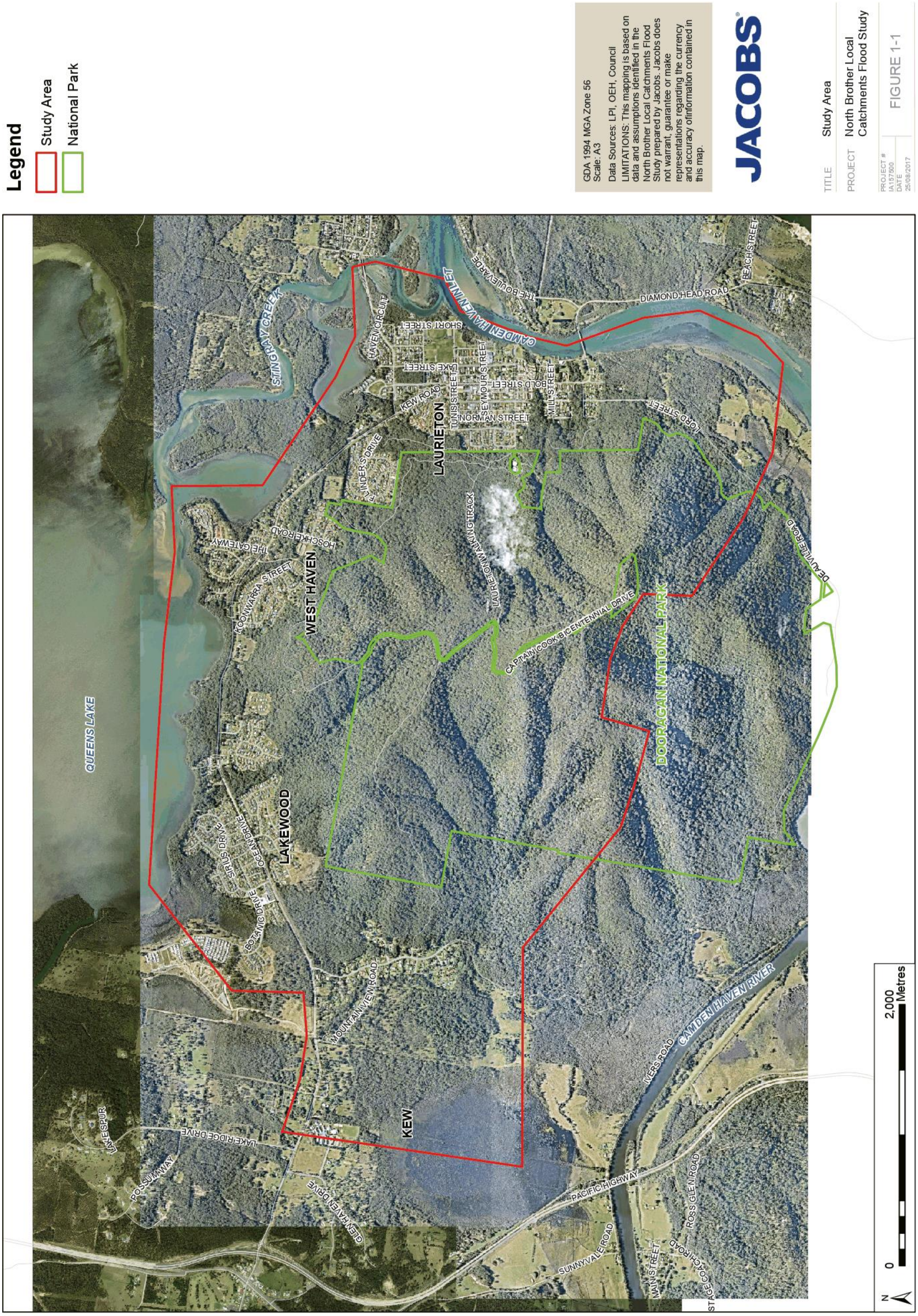
- Develop and calibrate hydrologic and hydraulic modelling to estimate flooding conditions for a range of design events
- Identify flood problem priority areas and identify and assess structural and non-structural mitigation measures to manage flood risk.
- Review existing planning, policy and emergency management for gaps and inconsistencies relating to floodplain planning, then develop proposed amendments to address residual flood risk
- Prioritise the works and measures, including economic and multi criteria appraisal of options.
- Develop an implementation program for recommended works and measures including timing, responsibility and sources of funding.
- Conduct consultation with the community and key stakeholders throughout the study to obtain information and intelligence for input into the study. Gauges the perceptions of the community on flooding matters. Obtain feedback on the findings and recommendations of the study.

This report documents the development, calibration and verification of hydrologic and hydraulic models for estimating flooding behaviour in the study area. Sensitivity testing of model parameter values is also discussed. The models will be used in the subsequent estimation of design flooding conditions and in the identification and assessment of flood mitigation works.

1.2 Structure of this Report

This report is structured by the following sections:

- Section 2 lists the available data
- Section 3 describes the site visits undertaken for the study
- Section 4 reviews and describes relevant aspects of the available data
- Section 5 describes the hydrologic modelling approach
- Section 6 details the development of the hydraulic model
- Section 7 discusses the calibration of the flood modelling to historic flood events, including sensitivity testing of key model parameters and assumptions
- Section 8 provides conclusions and recommendations to this phase of the study.


Legend
Study Area
National Park
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE Study Area
PROJECT North Brother Local Catchments Flood Study
FIGURE 1-1
QUEENS LAKE
LAURIETON
WEST HAVEN
LAKEWOOD
KEW
DOORAGAN NATIONAL PARK
CAMDEN HAVEN RIVER
CAMDEN HAVEN INLET
PACIFIC HIGHWAY
0
2,000
Metres

2. Available Data

A range of data was obtained by Jacobs or provided by Council and other agencies in July/August 2017 and is summarised in **Table 2-1** below. The data includes reports of studies that have been undertaken in the area, drainage models, spatial data including stormwater assets, zoning and other GIS layers, photographs and resident reports of previous flooding in the study area. Discussion on key datasets is provided in Section 4.

Table 2-1 Data inventory

Data	Description	Source
Reports		
West Haven System Analysis report	Hydrologic and hydraulic analysis of West Haven stormwater system and catchment	GHD 2007
West Haven Concept Design Report	Concept design report of proposed mitigation works in West Haven	GHD 2007
Camden Haven and Lakes System Flood Study	Mainstream flood study - river design flood levels Adopted 2013.	Worley Parsons 2013
Port Macquarie Hastings Council Flood Plicy	PMHC flood policy adopted 2015. Includes guidelines for development, hydraulic classification, climate change, flood planning level allowances for different development, development controls.	PMHC
Spatial and Design Data		
Study area	Study area extent	PMHC
LiDAR data	Classified C3 LAS and thinned ground point data	NSW LPI 2012 (via PMHC)
LiDAR data	1m gridded DEM obtained for LPI dataset (available within Jacobs). Merged for study area	NSW LPI 2012 (via Jacobs)
Aerial photography	Nearmap 7cm res. Use this for existing case modelling	NearMap May 2017(via PMHC)
Aerial photography	Other older datasets available, varying resolution	NearMap, LPI (via PMHC)
Stormwater infrastructure	Bridges Culverts	PMHC

	Stormwater Box Culvert Stormwater End Structure Stormwater Junction Sideline Stormwater Open Drain Stormwater Pipe Stormwater Pit Stormwater SQID (Stormwater Quality Improvement Device)	
Zoning	Land use zoning	PMHC
Cadastre	Lot parcels	PMHC
Ecology	Endangered ecological communities 2014 Vegetation Management Plans SEPP14 Coastal Wetlands	PMHC
Erosion risk	Soil Erosion Risk	PMHC
Road feature	Road Surface (road centreline) Kerb/Gutter line Footpaths	PMHC
Flood and sea level rise	Camden Haven River flood and sea level rise extents	Flood and sea level rise
Drainage plans - Historic	Various drainage/stormwater/WQ designs, various locations and ages	PMHC
Hydrographic and Dredging Plans - Camden Haven Area - historic	River bathymetry, dredging, tidal analysis. 1970s 1980s.	PMHC
Parks and Reserve Plans	Parks and reserves layouts 1980s - 2000	PMHC
Rural roads plans	Ocean Drive - historical plans	PMHC
Subdivision plans	Historic subdivision plans dated 2006 and 2010	PMHC
Urban Roads	Urban roads- historic plans	PMHC

Hydrologic Soil Group	NSW wide GIS layer on hydrologic soils group (classification A to D reflecting permeability and runoff potential)	OEH (online)
Recorded Data		
Daily Rainfall Data	Daily rainfall data for five stations in the vicinity of North Brother	BoM
Pluviograph Data	Pluvio data 5 minute intervals 1/03/2012 to 1/02/2016 at various sewage treatment plants and pumping stations in Port Macquarie Hastings LGA. Pluvio data is also available from Manly Hydraulics Laboratory (MHL) for Locans Crossing	PMHC MHL
Modelling Data		
West Haven DRAINS models	DRAINS models of existing and mitigated cases relating to West Haven System Analysis report and West Haven Concept Design Report	GHD 2007
Historic Flooding		
Flood mapping	Historic flood outlines and flood prone land/ flood planning mapping for mainstream flooding	PMHC
Flood marks	Historic flood marks for Camden Haven River flooding	PMHC
Photographs	Photos of previous flooding (various locations and events)	PMHC
Flooding complaints	Flooding and drainage complaints from residents and logged on Council register	PMHC

3. Site Visit

Site inspections were undertaken on 27 July 2017. The purpose of the site inspection was to gain a further understanding of the catchment characteristics, the nature of existing development and hydraulic conditions (including flow patterns, drainage arrangements, hydraulic features etc.) in known flood problem areas, and likely flood risk. Members of the Jacobs project team were accompanied by Council officers. Locations inspected on the site visit included trouble spots identified by Council and significant drainage locations:

- Black Swan Terrace, West Haven
- Ringtail Cl, Lakewood
- Lilli Pilli Cl, Lakewood
- Mission Terrace, Lakewood
- Kirmington Terrace, and Pelican Ct, Westhaven
- Flinders Dr Estate, Laurieton
- Bold Street, Laurieton
- Quarry Way, Laurieton
- Lake Street, Laurieton
- St Joseph's School, Laurieton.

Observations made during the site visit included:

- The terrain in the developed sections of the study area, at the foot of North Brother Mountain, is generally flat to moderately sloped (grades of 5 – 15%) with elevations from less than 2m AHD up to 50m AHD.
- The middle and upper catchment areas, upstream of the developed areas, are densely forested and generally within Dooragan National Park. Terrain is generally very steep, with watercourse grades of up to 50% and ground elevations up to 490m AHD.
- There were no permanently flowing watercourses observed at the time of the site visit, which occurred following a month of dry weather conditions. Most minor flow paths have been piped to pass through residential development. The larger watercourses have been maintained in a generally natural state and development has not encroached on these watercourses. All of the flow paths and watercourses are crossed by Ocean Drive and other roads with culverts as they drain to Queens Lake and Stingray Creek.
- Many watercourses and other drainage features are covered by dense rainforest vegetation.
- Soil landscapes along watercourses were observed to include high permeability gravel and rubble beds in the stream beds and along some stream banks. Council officers described that during storm events, in some locations the stream flows infiltrate into these gravel and rubble beds, flowing sub-surface and then resurfacing in different locations. This is reflected in residents' reports and accompanying photos.

An additional site visit was undertaken on 30 April 2018 during the model setup and calibration to inspect selected drainage features and confirm the model performance and representation of flood behaviour.

Figure 3-1 Eastern side of north Brother Mountain, illustrating steepness of the terrain

Figure 3-2 Shotcrete-lined informal channel in Lakewood

Figure 3-3 Natural flow path through forested area in West Haven

Figure 3-4 Driveway crossing of flow path, which passes next to dwelling, West Haven

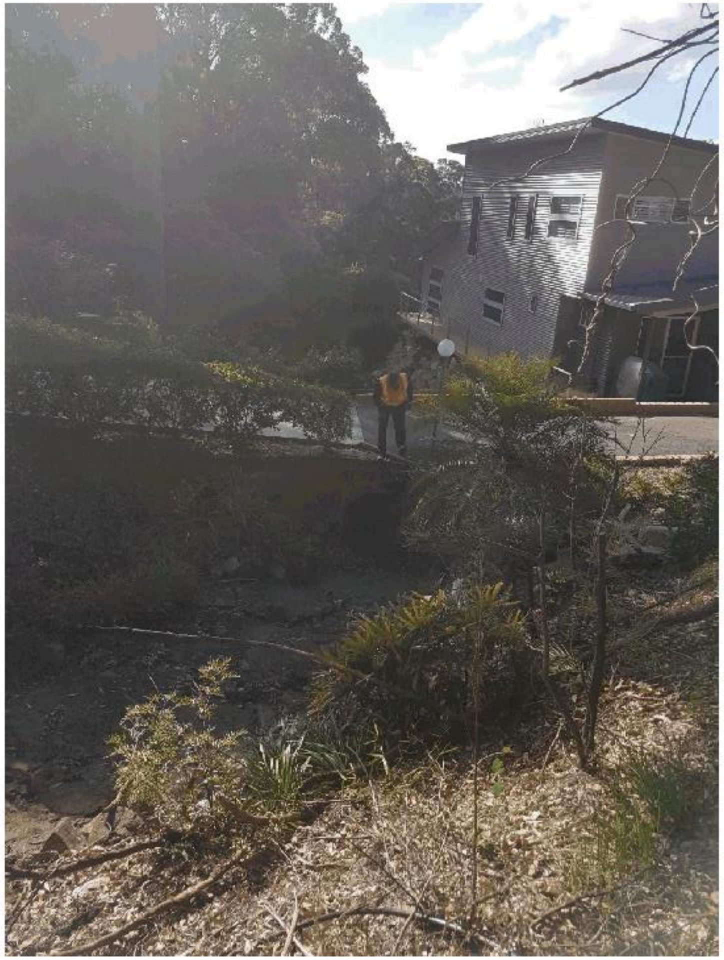


Figure 3-5 Grated trunk drainage headwall inlet, West Haven

Figure 3-6 Upstream side of flow path road crossing, West Haven

Figure 3-7 Trunk drainage open channel through property, Laurieton

Figure 3-8 Trunk drainage culvert discharging to open channel next to development, Laurieton

Figure 3-9 Flow diversion berm and swale upstream of development, Laurieton

4. Review of Available Data

4.1 Port Macquarie Hastings Council Flood Policy (2015)

Council's Flood Policy (adopted 21 October 2015) outlines the considerations to be made by Council in exercising its environmental assessment and planning functions in relation to development in the Port Macquarie Hastings Local Government Area (LGA). It reflects the direction of flood risk management in NSW Government's *Flood Prone Land Policy* and draws on the guidance on this provided in the *Floodplain Development Manual* (2005). It outlines a number of objectives in achieving sound flood management, namely:

I. To maintain the existing Flood regime and flow conveyance capacity;

II. to reduce the impact of Flooding and Flood liability on individual owners and occupiers of Flood prone property;

III. to reduce private and public losses resulting from Floods;

IV. to increase public safety with respect to Flood events;

V. to protect the operational capacity of emergency services and emergency response facilities during Flood events;

VI. to increase public awareness of the potential for Flooding across the range of Flood events up to the Probable Maximum Flood level;

VII. to inform the community of Council's policy in relation to the use and Development of Flood Prone Land;

VIII. to ensure that planning and Development of essential services and land use makes appropriate provision for Flood related risk;

IX. to utilise best engineering practice for determination of Flood conditions, impact and risk.

X. to utilise ecologically positive methods of Flood protection wherever possible;

XI. to ensure that any New Development or modifications to existing Development must, as far as practical, result in a reduction in the existing Flood Risk, and in no circumstances should the Flood Risk be made worse; and,

XII. to deal equitably and consistently with all matters requiring Council approval on land affected by potential floods, in accordance with the principles contained in the NSW Government's Floodplain Development Manual (2005).

The flood policy provides definitions for the different hydraulic classifications of the floodplain, flood planning level categories and provisions for different types of development (permissible development types, minimum floor levels), filling, fencing, boundary adjustments, rezoning and subdivision in the different hydraulic zones in the floodplain.

4.2 Previous Studies

4.2.1 GHD Stormwater Analysis and Design Studies (2007)

In response to previous poor performance of the drainage system, a stormwater hydrologic and hydraulic study was undertaken by GHD for Council for the West Haven area, and a concept design prepared for a proposed drainage upgrade and flood mitigation program. These are documented in the following reports:

- West Haven Stormwater Study Area Final Systems Analyses Report (GHD, April 2007)

- Report for Buller Street and West Haven Stormwater Catchment Studies S.600.110.05.61 Concept Design Report - West Haven Study Area (GHD, September 2007).

DRAINS models were developed for the study for the existing and proposed design cases to quantify system flows and identify/confirm system constraints. The models were not calibrated to historic flooding events. Design event flows were validated against rational method estimates. Relatively conservative hydrologic parameters were assumed for the catchment hydrology, including assumptions on the soil type (soil type 4 or D, high runoff and very low infiltration rates).

The existing case modelling indicated flood problem areas in the following locations

- South of No. 9 Black Swan Terrace / No. 20 Kirmington Terrace;
- Koonwarra Street drainage easement Lot 29;
- Ocean Drive cross culverts adjacent No. 374 – No. 384 Ocean Drive; and
- DRAINS also indicated problems with the Elouera Place cross culvert.

The concept design proposed a range of pit and pipe network upgrades and modifications, formalisation of two existing flood storages (referred to as “detention basins” in the GHD study) and construction of a large diversion channel upstream of Black Swan Terrace. The works were designed to achieve compliance for the minor (5 year) storm event with a review of the effect on the 100 year capacity.

The works were costed with a Net Present Value of $4.7 million (2007 dollars) excluding GST. It has not been confirmed with Council if any of the proposed mitigation works were implemented.

Sub-catchment boundaries are not available as spatial layers. The pit and pipe names in the DRAINS model are not consistent with the drainage asset layer provided by Council. Hence, the DRAINS model data is not directly suitable for the development of flood models in this study, but the results may be useful for model validation purposes.

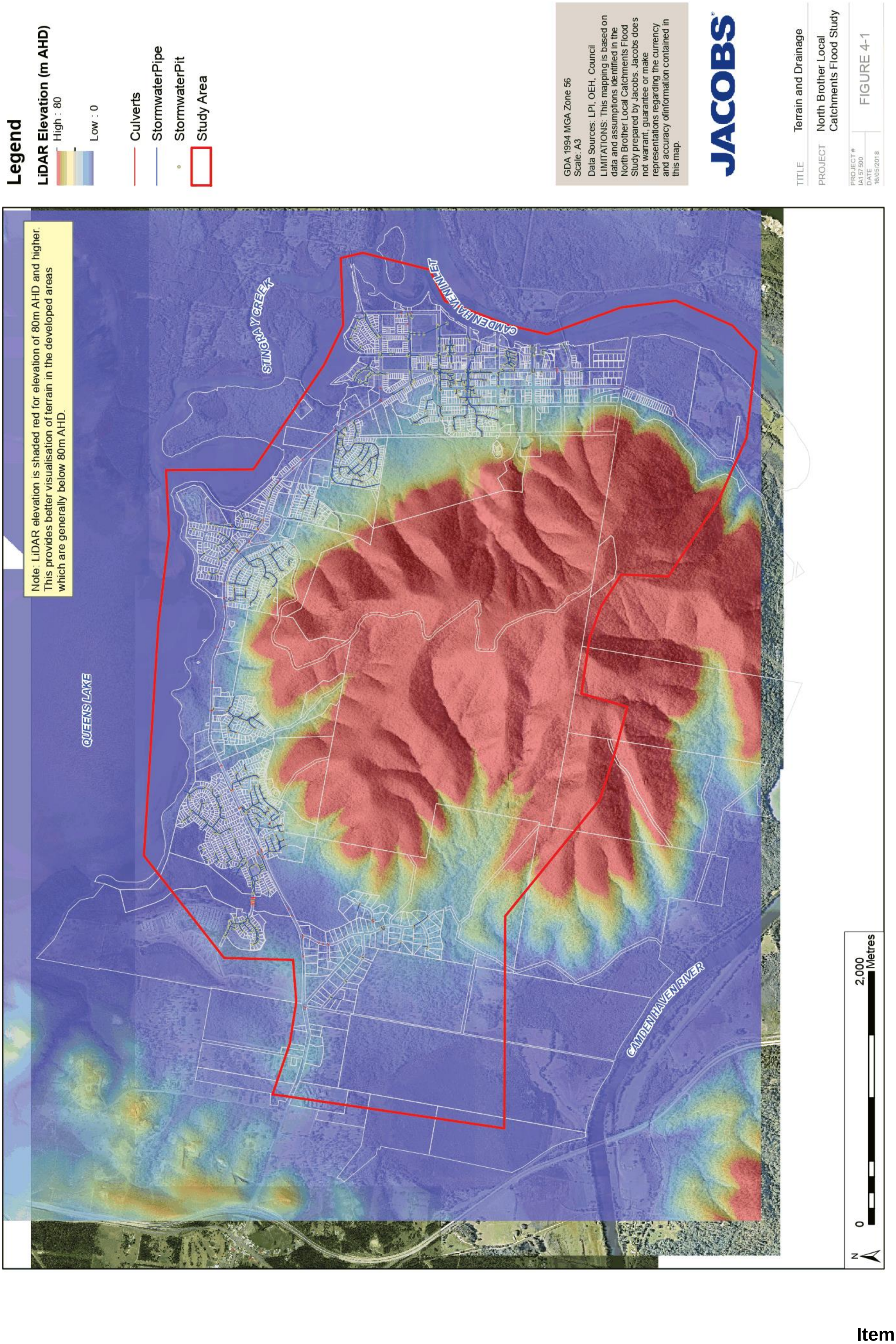
4.2.2 Camden Haven River and Lakes System Flood Study (Worley Parsons, 2013)

This flood study estimated existing flooding conditions for mainstream flooding in Camden Haven River, Camden Haven Inlet, Queens Lake, Stingray Creek and Watsons Taylor Lake in the study area. The study was based on hydrologic and hydraulic modelling in XP-RAFTS and RMA-2, respectively, for the 5, 20, 50, 100 and 200 year floods and Probable Maximum Flood (PMF). The study estimated 100 year flood levels of approximately 2.9 – 3m AHD in Camden Haven Inlet, Stingray Creek and Queens Lake affecting parts of the study area, and 4.3m AHD in Camden Haven River near the Pacific Highway bridge, potentially affecting the south-western portion of the study area.

4.3 Spatial and Design Data

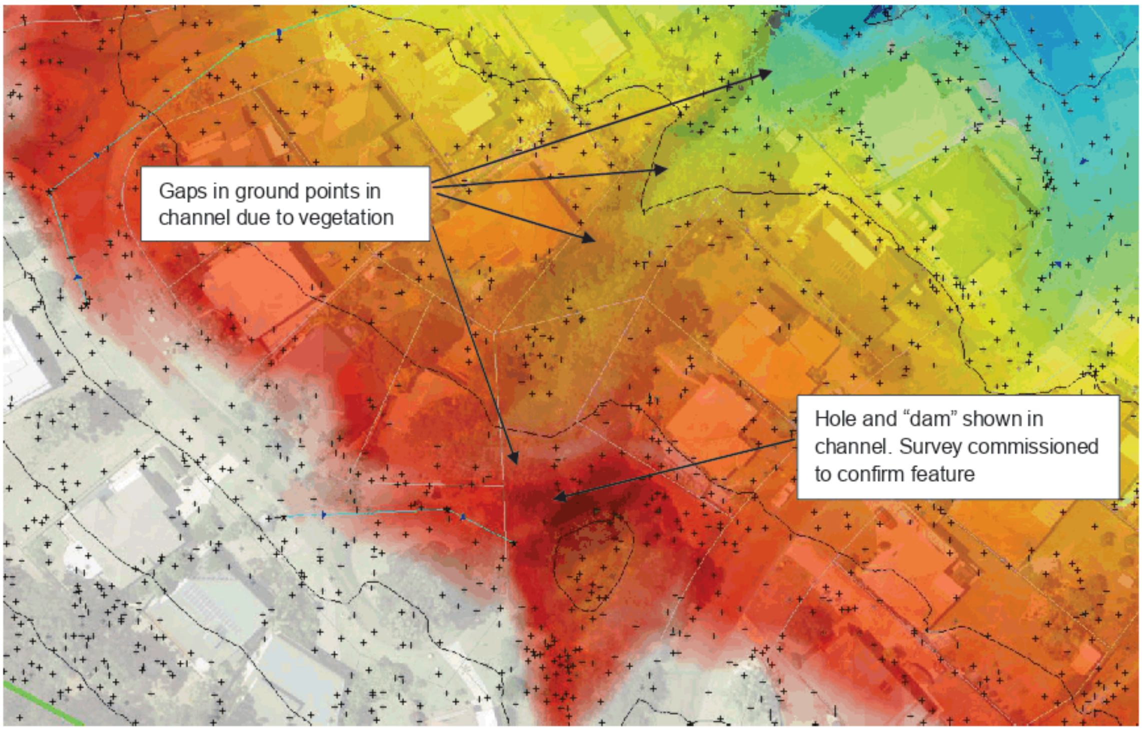
4.3.1 Topographic Data

Topographic data across the study area consists of LiDAR data captured by NSW Land and Property Information (LPI) in 2012. The dataset has a vertical accuracy of 0.15m (one standard deviation). Council provided classified and thinned ground point data for the study. Jacobs obtained the 1m digital elevation model (DEM) grid developed by LPI from this data, which is held in-house. The data tiles were merged together by Jacobs to form a continuous DEM across the study area and surrounds. The DEM showing the study area terrain is presented on Figure 4-1.


Legend
LiDAR Elevation (m AHD)
High : 80
Low : 0
Culverts
StormwaterPipe
StormwaterPit
Study Area
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE Terrain and Drainage
PROJECT North Brother Local Catchments Flood Study
FIGURE 4-1
Note: LiDAR elevation is shaded red for elevation of 80m AHD and higher. This provides better visualisation of terrain in the developed areas which are generally below 80m AHD.
QUEENS LAKE
STINGRAY CREEK
CAMDEN HAVEN INLET
CAMDEN HAVEN RIVER
0
2,000 Metres
N

The thinned ground points data set was reviewed for key drainage areas, and it was observed that in areas with a thick tree canopy or in-channel vegetation there was generally a low density of data points. This indicates that the LiDAR was only able to penetrate the tree canopy in sparsely spaced locations, and that the DEM is unlikely to accurately represent any drainage features which may be beneath the tree canopy. A similar issue is expected for channels with standing water or in-channel vegetation. Review of the DEM confirmed that some channel and drainage features are not represented in detail and do not match site observations.. Examples are shown on Figure 4-2 below. Ground survey was commissioned to collect more accurate topographic information of the study area terrain and features.

Figure 4-2 Example – sparse LiDAR ground points in vegetated areas and potentially inaccurate channel definition. Kirmington Terrace – Koonwarra Street, West Haven



4.3.2 Aerial Photography

Several different aerial photograph data sets were provided by Council, the most recent and highest resolution being NearMap imagery (May 2017, 7cm resolution). This imagery covers the developed areas at base of North Brother Mountain, and is supplemented with other imagery supplied by Council (dated 2012 and 2013) to cover the entire study area and surrounds.

4.3.3 Stormwater and Drainage Infrastructure

Layers for a range of stormwater drainage assets and features have been provided by Council including pits, pipes, culverts, headwalls and water quality improvement devices. Details (dimensions and levels) are missing for a number of the drainage assets and require survey. The source and accuracy of those assets with details is not known, although it is noted that the network layout is consistent with recent subdivision road layouts (e.g. Fairwinds Avenue detention basin and Wedgetail Drive, both in Lakewood). Data entry dates are also observed to be recent (up to 2015). The locations and details of open drains and swales in the study area are not included in the spatial layers.

4.3.4 Historical Subdivision Design

Sub-division designs are available from Council for a number of developments in the study area as pdf files. Most are dated pre-2010 and review of the locations of these developments against recent aerial photos indicates that the majority have been constructed.

Designs for drainage features including the flow path and berms downstream of the Fairwinds Avenue detention basin are reflected in the LiDAR and stormwater spatial layers.

4.3.5 Additional GIS data

Additional GIS layers obtained include:

- Road centrelines, kerb/gutter lines, footpaths
- Cadastre
- LEP and zoning
- Land use
- Ecological features.

4.4 Recorded Data

4.4.1 Rainfall Data

4.4.1.1 Daily Rainfall

Historic daily rainfall data was obtained from the Bureau of Meteorology's (BOM) website. Data from five sites in the vicinity of North Brother was obtained and is summarised in Table 4-1: Site locations for the selected gauges and other regional gauges are shown on Figure 4-3. It is to be noted that all five sites are located at or below RL 55m and the sites are unlikely to represent rainfall on the 490m high North Brother Mountain due to orographic effects.

The steep and smaller nature of the catchments in the study area mean that intense short duration (sub-daily) storm events or storm bursts are more likely to be critical in causing peak flooding during flash flood events. Mainstream flooding is more likely to result from multi-day duration events. Hence, the reported daily rainfall depths may not indicate the critical historic storm events which resulted in peak flash flooding. Those short (say, less than 6 hours in duration) and intense rainfall events may result in the worst flash flooding conditions but are not reflected by exceedingly high daily rainfall depths. The daily rainfall data is therefore of limited use in indicating when the worst flash flooding events occurred, although it is useful for showing general trends of when wet periods occurred, during which the critical storm events may have happened. The data is also useful for validating any recorded sub-daily rainfall data.

Table 4-1 Daily Rainfall Data

Gauge Number	Gauge Name and Elevation	Distance from Study Area (km)	Start Date	End Date	Length of record (years)	Completeness (%)
060022	Laurieton (Eloura St) 12m AHD	0	1/1/1885	31/07/2017	132.7	87.0
060027	Lorne (Lorne Rd) 55m AHD	17	1/01/1938	30/06/2016	78.6	97.5
060024	Moorland (Denro-an) 5m AHD	19	1/11/1885	31/07/2017	131.8	90.3
060017	Hannam Vale (Hannam Vale Rd) 33m AHD	21	1/02/1926	31/07/2017	91.6	97.1
0600139	Port Macquarie Airport AWS 4m AHD	25	26/07/1995	17/08/2017	22.1	98.0

Figure 4-3 BOM Rainfall Gauges in Laurieton region (source: BoM website. http://www.bom.gov.au/climate/data/index.shtml?bookmark=136)

The daily rainfall data from the BOM Laurieton rainfall gauge has been analysed and summarised for the top-ranking 1-day and 2-day recorded rainfall depths in Table 4-2. Rainfall values are based on daily rainfall recorded to 9am as per BOM convention. Hence, the peak flooding may have occurred a day previous to the reported rainfall depth.

Table 4-2 Highest ranked recorded 1-day and 2-day rainfall depths at Laurieton rainfall gauge (060022).

Rank	1 day		2 day	
	Start date	Depth (mm)	Start date	Depth (mm)
1	29/04/1963	448.3	29/04/1963	462.3
2	5/01/1959	325.1	28/04/1963	448.3
3	22/1/1895	310.6	12/03/1974	389
4	20/03/1978	279.6	21/1/1895	384.8
5	28/02/1983	250	27/2/1892	377.7
6	16/3/1887	241.3	11/03/1974	368.6
7	28/03/1978	232	22/1/1895	328.4
8	6/02/2002	232	4/01/1959	325.1
9	9/11/2004	222	5/01/1959	325.1
10	6/04/1934	217.9	2/8/1899	318.7

4.4.1.2 Pluviograph data

Pluviograph data for specific historic storm events has been obtained from Council for model calibration. The historic storm events of interest were identified from the responses from the community survey. Pluviograph data is available from Council-operated sewage treatment plants (STP) and sewer pumping stations (SPS), with the closest and most relevant gauge locations to the study area including:

- Camden Haven SPS #1 (Wharf Street, Laurieton)
- Camden Haven STP (Dunbogan), and
- Kew – Kendall STP (Pacific Highway, Herons Creek).

The pluviograph stations are in the immediate vicinity (up to 3km) from the study area. Manly Hydraulics Laboratory (MHL) operates as pluviograph station at Logans Crossing, approximately 6km from the study area. This site is located further away from the study area than the Council STP gauge sites. The data from this gauge was obtained for selected storm events for comparison purposes. Refer to Figure 4-4 for locations of pluviograph stations in the vicinity of the study area.

Figure 4-4 Pluviograph locations in vicinity of the study area

4.4.2 Water Level Data

Water levels are recorded by MHL at several locations in the vicinity of the study area:

- Lakewood (Queens Lake)
- West Haven (Stingray Creek)
- Laurieton (Camden Haven River).

Data from these sites will be obtained for model calibration to historic storm events.

4.5 Topographic and Hydraulic Structures Survey

Survey of drainage and topographic features and hydraulic structures was commissioned for this study and undertaken in January – February 2018. The survey data has been incorporated into the hydraulic modelling of the study area. Features surveyed included selected stormwater pits, pipes and culverts, earthen diversion drains and berms, natural channels and concrete channels. A summary map of surveyed features is provided in Appendix B

Survey of drainage and topographic features in the vicinity of Black Swan Terrace was previously undertaken and supplied by Council.

4.6 Reports and Photographs of Historic Flooding and Drainage Issues

Council provided a number of photographs and written submissions from residents reporting drainage and flooding problems during historic storm events. Dates of the reported events are listed below. The Annual Exceedance Probability (AEP) of the 2013 and 2016 storm events were estimated by Jacobs from the Council pluviograph data from Camden Haven sewer pumping station.

- 18 October 2004. 127mm recorded daily depth.
- 25 February 2008. 112mm recorded daily depth.
- 24 April 2008 (10% AEP event). 49mm in 45minutes; 65mm in 60 minutes; 136mm in 24 hours.

- 14 June 2011. 96mm recorded 2-day depth.
- 2 March 2013 (20% AEP) 61mm in 1.5 hours; 152mm in 24 hours.
- 5 January 2016 (20 – 50% AEP) 54mm in 1.5 hours.

Rainfall data for the 2008, 2013 and 2016 events has been analysed and is plotted in Appendix A. Notable flooding reports are from locations including:

- Black Swan Terrace and Waterview Drive. Watercourse is piped through properties. The existing pipe inlet is undersized and the inlet debris screen regularly blocks. Overflows pass through residential yards, with paling fences having been washed away in previous floods.
- St Josephs's School, Laurieton. Video footage taken of significant flows along walkways between school buildings in the March 2013 event, which was a relatively frequent flood event.
- Ocean Drive. Flooding in numerous locations where a number of flow paths draining off North Brother Mountain cross this main road through the study area.
- Flooding to depths of up to 1m in low points in roads at a number of locations in the study area. This has been reported at Lilli Pilli Close, Sirius Drive, Mahogany Close and Honeysuckle Avenue, Lakewood; and Pelican Court, West Haven, among others.
- Flooding through Laurieton town centre including Bold Street, Lake Street and Tunis Street.
- Kirmington Terrace. Storm flows occurring within adjacent diversion drains further up the mountain have infiltrated into the soil and then resurfaced as groundwater “springs” in residential yards and under buildings. Note that the flood models developed in this study would not be able to represent this phenomenon as a flood flow. However, remediation measures may be suggested as a part of the study.
- Numerous photos of overland flooding were taken by Murray Dalton surveyors during the April 2008 storm, summarised in Table 4-3 below.

It is noted that the storm events resulting in the reported flooding and drainage complaints and problems have been relatively frequent and smaller magnitude events. Local flooding events of similar frequency and magnitude to planning flood events (i.e. the 1% AEP) or even moderate frequency (e.g. 5% AEP) have not been experienced in the study area in recent times.

Table 4-3 Summary list of photographs taken during 24 April 2008 storm event by Murray Dalton Surveyors

LAURIETON LOCAL STORM EVENT
24th APRIL, 2008 @ 8 am

Photo catalogue

2008_010	Queens Lake Village – flow down pathway
2008_011	Queens Lake Village – western grated inlet pit
2008_012	Queens Lake Village – pathway flow
2008_013	Queens Lake Village – culvert flows
2008_014	Queens Lake Village – Eastern Culvert
2008_015	Mission Terrace – Gutter in front of Anglican Rectory
2008_016	Ocean Drive looking west to Flinders Drive
2008_017	Culvert east of Flinders Drive
2008_018	2nd Culvert east of Flinders Drive
2008_019	Creek at 416 Ocean Drive, West Haven
2008_020	Ocean Drive intersection with Mission Terrace
2008_021	Mission Terrace – gutter in front of Anglican Rectory
2008_022	Ocean Drive looking at Laurieton Cemetery
2008_023	Ocean Drive looking east at Flinders Drive, Laurieton
2008_024	Flinders Drive intersection with Ocean Drive
2008_025	Culvert at St Josephs
2008_026	Western culvert above Queens Lake Village
2008_027	Wollworths culvert at Lakewood
2008_028	Sirius Drive from temporary access to Ringtail, Lakewood
2008_029	Drain above Woolworths culvert from Ringtail Access
2008_030	Drain above Woolworths culvert
2008_031	Sag pit in Ringtail Close
2008_032	Ringtail Close looking towards cul-de-sac
2008_033	Ocean Drive culverts west of Woolworths – looking east
2008_034	Creek below Fairwinds at Ocean Drive
2008_035	Creek below Fairwinds at Ocean Drive – watermain
2008_036	Flow above Amaroo detention basin – headwall blocked by ply
2008_042	Creek at 416 Ocean Drive, West Haven
2008_043	View up driveway at 414 Ocean Drive, West Haven
2008_044	Western culvert at St Josephs
2008_045	Sewer Manhole at Laurieton Caltex
2008_046	Sewer Manhole at Caltex
2008_047	Rosewood Court and Mission Terrace intersection
2008_048	Rosewood Court at top of hill
2008_049	Queens Lake village drains

Figure 4-5 Infiltrated floodwaters emanating as a "spring" from the ground in residential yard, Kirmington Terrace, June 2011.

Figure 4-6 Residents unblocking culvert inlet upstream of Black Swan Terrace properties, April 2008.

Figure 4-7 Overland flows from creek across Ocean Drive, West Haven, April 2008

Figure 4-8 Overland flows, Ocean Drive at Flinders Drive, April 2008

4.7 Floor Level Survey

Floor level survey is currently not available for residential and commercial buildings in the study area. These data are required for the flood damages assessment to be undertaken during this study, and will be collected for selected properties based on their flood affectation and historic flooding.

4.8 Community Consultation

4.8.1 Initial Consultation

Community consultation has been undertaken throughout this study, including distribution of newsletters and media releases and the hosting of a website on Council's webpage to announce the commencement and provide background on the study.

4.8.2 Community Survey

A community survey was mailed out to residents with the study newsletter asking residents for information on previous flooding events that they experienced in the study area, refer to Appendix B for the survey. A total of 302 responses were received. The responses assisted the project team in identifying the most significant flooding events in recent history which would be suitable for model calibration and verification. Observations including noted flood depths, flow patterns and durations of flooding were reported. Residents also submitted photographs and videos of flooding during the events.

The survey identified numerous flooding events over the past 20 years with no particular standout events. The March 2013 event was reported in six responses, while the April 2008 event, which resulted in the most intense rainfall for the storm event data available, was reported two times. The February 2002 event was reported four times, however, sub-daily rainfall data is not available for that event.

5. Hydrologic Modelling

5.1 Modelling Approach

A hydrologic model is required to estimate storm and flood flows for the study area for the historic and design rainfall storm events. The terrain of the study area is such that:

- There are numerous natural watercourses and gullies which flow down the face of North Brother Mountain and then through the developed areas of the study area.
- On the flatter areas at and below the foot of the mountain and away from the watercourses, drainage paths are often less defined, with more dispersed overland flows affecting existing development.

The hydrologic modelling adopted involved lumped catchment modelling approach for the watercourses draining off the mountain, and a direct rainfall approach for the more dispersed overland flow catchment areas at the foot of the mountain. The lumped catchment modelling estimates inflow hydrographs (flow versus time) which are input into the hydraulic model in the watercourses. The direct rainfall approach inputs rainfall versus time data onto the modelled catchment surface in the hydraulic model itself, which then generates estimated flows internally in the model. This report section describes the lumped hydrologic modelling. Refer to Section 6.3.2 for further discussion.

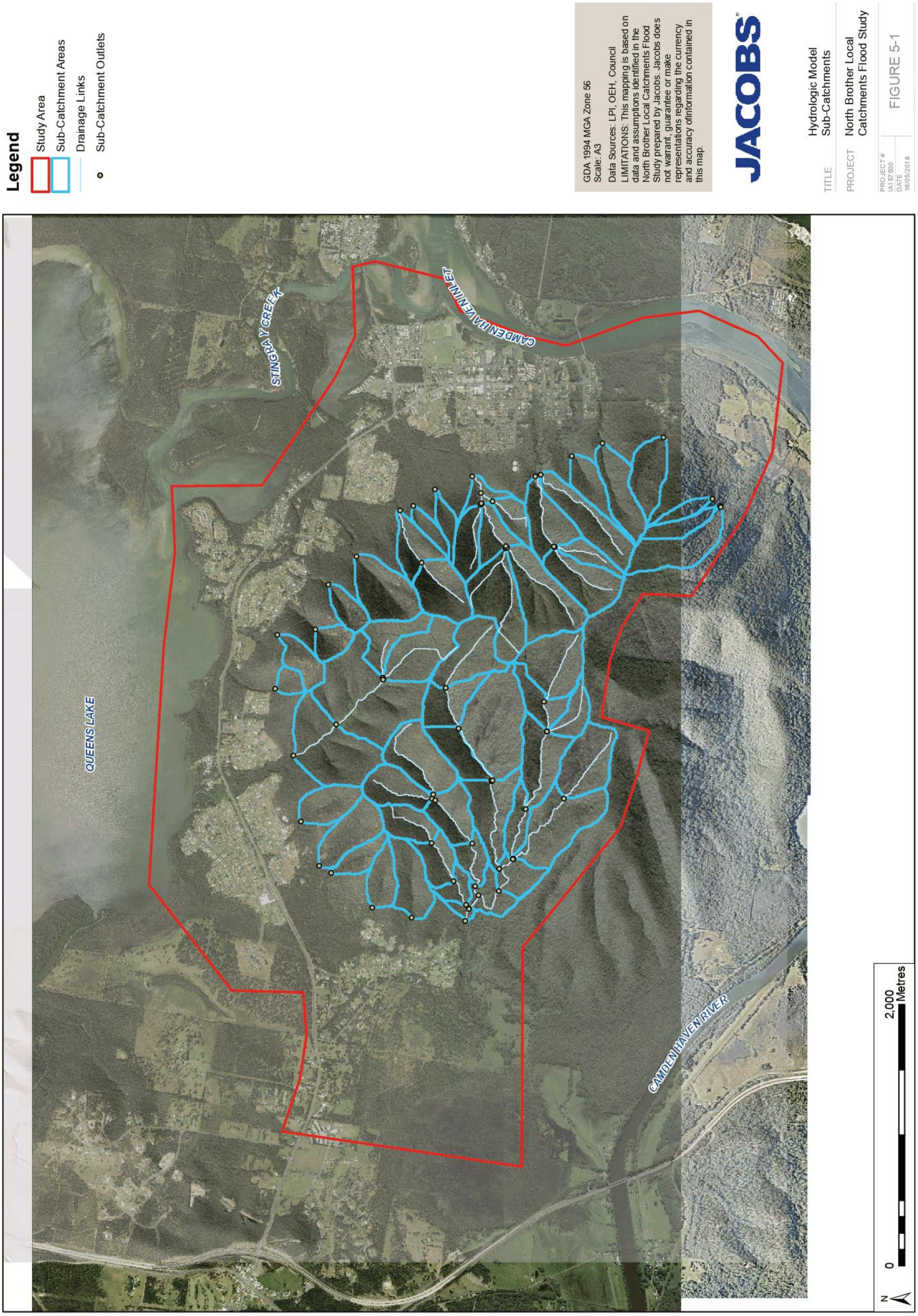
The lumped hydrologic modelling has been undertaken using the RAFTS hydrology module in the DRAINS modelling software. The RAFTS module is suitable for assessment of sub-catchments with areas up to 100 hectares and permits routing of runoff through the catchment. The DRAINS software is one of the few modelling packages that currently incorporate Australian Rainfall and Runoff 2016 (ARR 2016) design rainfalls and procedures.

5.2 Sub-Catchment Data

The catchment areas on North Brother Mountain are divided into 56 sub-catchments which drain to the gullies and watercourses running off the mountain through the study area. Mapping of the sub-catchment boundaries is shown on **Figure 5-1**. These sub-catchments are natural vegetated areas and a nominal impervious fraction of 5% is assumed.

Sub-catchment flow path slopes are steep to very steep, with catchment flow path slopes ranging from 15 – 70%. DRAINS/RAFTS and most other hydrologic models have an upper limited slope parameter value of 30%, and this is adopted for the sub-catchments with slopes exceeding this value. It is likely that that catchment slopes steeper than 30% may result in faster catchment flow travel times producing higher peak flows. However, limited information is available rainfall runoff generation from very steep catchments.

A PERN catchment roughness value of 0.1 was adopted for the forested sub-catchment areas.


Legend
Study Area
Sub-Catchment Areas
Drainage Links
Sub-Catchment Outlets
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
TITLE Hydrologic Model Sub-Catchments
PROJECT North Brother Local Catchments Flood Study
FIGURE 5-1
QUEENS LAKE
STINGRAY CREEK
CAMDEN HAVEN INLET
CAMDEN HAVEN RIVER
0
2,000 Metres
N

5.3 Hydrologic Parameters

5.3.1 Rainfall Losses

An initial and continuing loss model is utilised in the RAFTS module which represents rainfall losses during storm events such as depression storage and soil infiltration. The following loss values are proposed for the design event runs:

- Pervious areas: Initial loss 15mm, continuing loss 2.5mm/hr
- Impervious areas: Initial loss 1mm, continuing loss 0mm/hr.

Soil characteristics on the mountain are observed and reported to be very impermeable, and lower rainfall losses could normally be considered for such soils. Due to the steepness of the catchment areas and limited slope parameter values in the modelling these moderately low rainfall losses were retained.

Rainfall losses adopted for the calibration events are discussed in Section 7.3.1.

5.3.2 Storage Routing Factor

RAFTS includes the "Bx" storage routing factor which can be adjusted to chance the runoff response of the catchment. With a default value of 1.0, the factor can be reduced to increase the runoff response, resulting in a more peaky flood. It is usually adjusted when there is sufficient data, such as flow gauging, to validate the adjustments.

Reducing the Bx value was considered to account for the very steep slopes on North Brother Mountain and the limited slope parameter value of 30% in the hydrologic modelling. However as there is no flow gauging for the mountain an adjustment of the Bx factor could not be justified for this study. Sensitivity runs also indicated minimal increases in peak flows for sample sub-catchments for Bx values of down to 0.2, which is not considered to be a reasonable adjusted value for this parameter. Modest increases in peak flows were observed for a Bx value of 0.1, but this is also considered a highly unreasonable value.

6. Hydraulic Modelling

6.1 Model Selection

A TUFLOW combined one-dimensional (1D) and two-dimensional (2D) hydrodynamic model has been developed for this study. TUFLOW is an industry-standard flood modelling platform, which was selected for this assessment as it has:

- Capability in representing complex flow patterns on the floodplain, including flows through street networks and around buildings.
- Capability in representing the stormwater drainage network, including pit inlet capacities and interflows between the network and floodplain including system surcharges.
- Capability in accurately modelling flow behaviour in 1D channel, bridge and culvert structures and interflows with adjacent 2D floodplain areas.
- Easy interfacing with GIS and capability to present the flood behaviour in easy-to-understand visual outputs.

The model was developed and run in TUFLOW 2018-03-AA-iDP-w64, in the Heavily Parallelised Compute (HPC) module. The HPC module was preferred over TUFLOW “Classic” as it permits significantly faster run times, which are required for this relatively large model extent and with direct rainfall being applied.

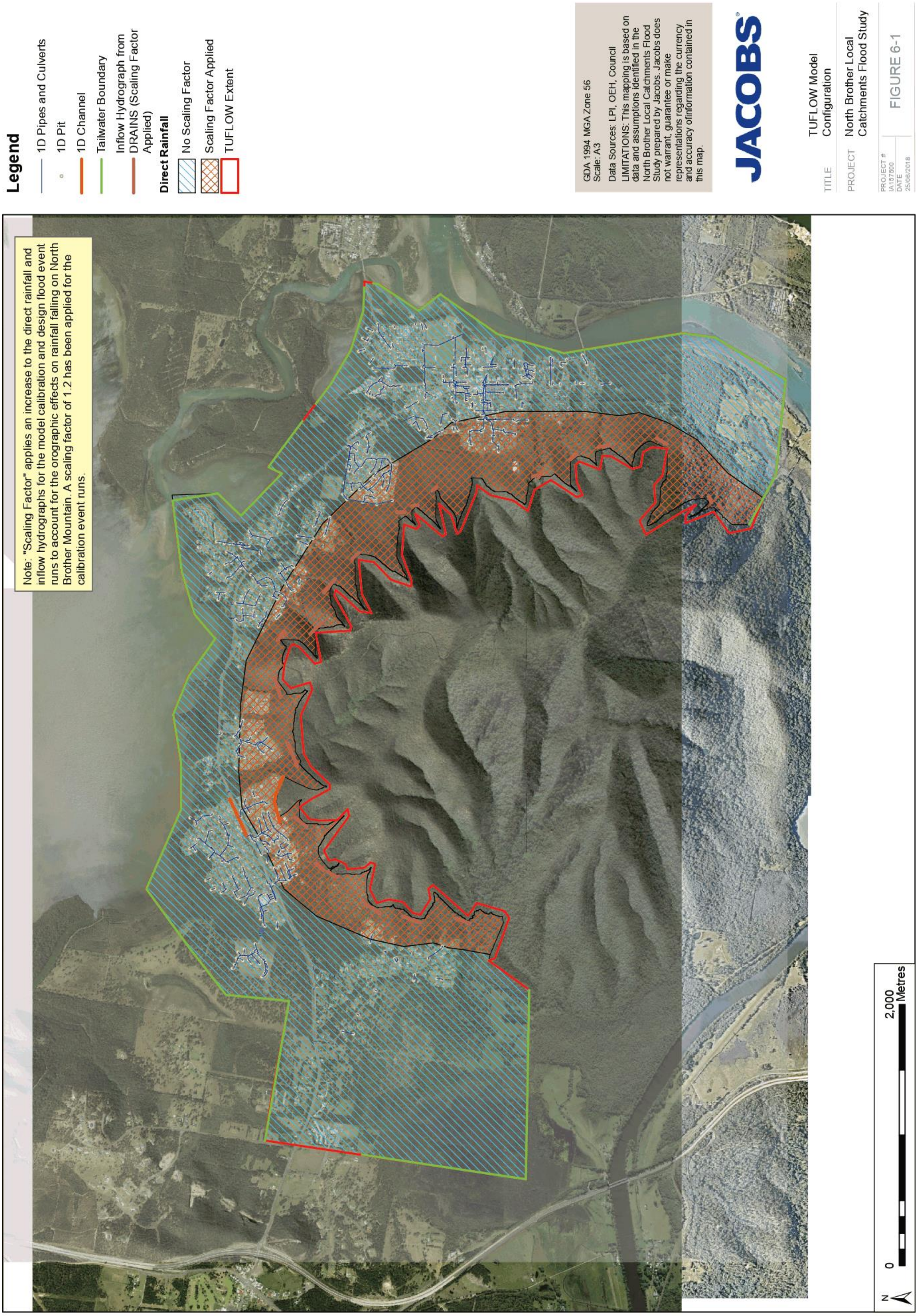
6.2 Configuration of Hydraulic Model

6.2.1 Extent and Structure

The TUFLOW model is comprised of:

- A 2D domain of the study area surface reflecting the catchment topography, with varying roughness as dictated by land use. The watercourses are in general modelled in 2D. Diversion drains are in 2D.
- A 1D network of pits, pipes and culverts representing the stormwater network. The pits have a defined inflow capacity as dictated by their type and size.
- Obstructions to flow are represented as 2D objects, including existing buildings.

The model extent covers an area of 12.6km^2 and includes the foot of North Brother Mountain along its western, northern and eastern sides and the adjacent developed lower-lying areas down to the receiving waters at Camden Haven River, Queens Lake and Stingray Creek. Refer to the following report sections for details on these features. The model domain and locations of various features in the TUFLOW model are shown on Figure 6-1.


Legend
1D Pipes and Culverts
1D Pit
1D Channel
Tailwater Boundary
Inflow Hydrograph from DRAINS (Scaling Factor Applied)
Direct Rainfall
No Scaling Factor
Scaling Factor Applied
TUFLOW Extent
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE TUFLOW Model Configuration
PROJECT North Brother Local Catchments Flood Study
FIGURE 6-1
Note: "Scaling Factor" applies an increase to the direct rainfall and inflow hydrographs for the model calibration and design flood event runs to account for the orographic effects on rainfall falling on North Brother Mountain. A scaling factor of 1.2 has been applied for the calibration event runs.
0
2,000
Metres
N

6.2.2 Model Topography

The topography of the catchment is represented in the model using a 2m grid. This level of precision in the grid is considered necessary in order to represent detailed flood behaviour in a fully developed catchment. Finer model grid sizes such as 1m grid are not considered practical given the large size and expected excessively long computing times. The basis of the topographic grid used in the TUFLOW model is the LiDAR data set in addition to ground survey.

6.2.3 Stormwater Pits

The stormwater pits provide a dynamic linkage between the underground drainage network and the 2D TUFLOW model domain, representing the floodplain. Water is able to flow between the drainage network and floodplain, depending on the hydraulic conditions.

The location of the stormwater pits and associated attributes were available from Council in GIS format. Pit inflow relationships were defined in terms of flow depths versus pit inflow.

TUFLOW automatically calculates hydraulic energy losses in the pits based on the alignment of pipes connected to each pit and the flows in each pipe. The calculations are based on the Engelhund manhole loss approach (*TUFLOW User Manual*, BMT WBM, 2017).

6.2.4 Stormwater Conduits

Stormwater pits and pipes identified in Council's data base and from survey are also modelled in the TUFLOW models. Several pipes down to a diameter of 225mm are represented but are typically larger than 300mm. The conduits are represented as circular pipes or rectangular culverts with dimensions matching those adopted in the DRAINS models.

6.2.5 Building Polygons

This study considers buildings as solid objects in the floodplain. This means that buildings form impermeable boundaries within the model, and while water can flow around buildings, it cannot flow across their footprint. The building footprints in the TUFLOW model were digitised based on the 2017 aerial imagery. The building polygons were superimposed on the model grid to make model computational cells under the footprints inactive.

6.2.6 Surface Hydraulic Roughness

All parts of the study area within the TUFLOW model were assigned hydraulic roughness values in a "materials layer" according to the LEP zoning and ground cover. These are based on engineering experience and typical values used in previous flood studies undertaken in the Sydney Region by Jacobs and other consultants. A moderately high Manning's n value of 0.05 for the residential land use accounts for expected obstructions such as minor features (steps, planter boxes etc.) and landscaping, which are typically not detected by LiDAR survey. The adopted Manning's n values are mapped on and summarised in Table 6-1.

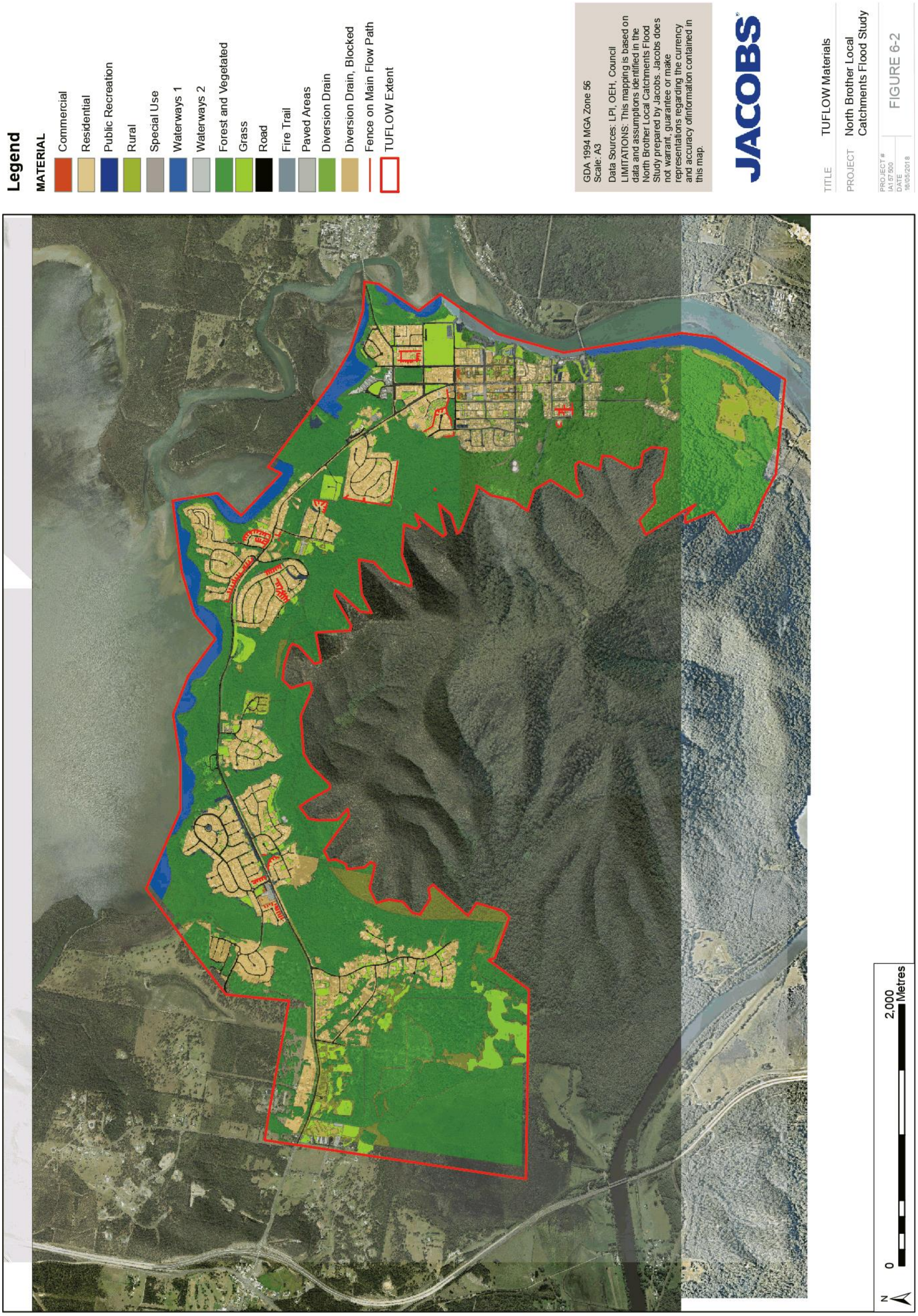

Legend
MATERIAL
Commercial
Residential
Public Recreation
Rural
Special Use
Waterways 1
Waterways 2
Forest and Vegetated
Grass
Road
Fire Trail
Paved Areas
Diversion Drain
Diversion Drain, Blocked
Fence on Main Flow Path
TUFLOW Extent
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE TUFLOW Materials
PROJECT North Brother Local Catchments Flood Study
FIGURE 6-2
0
2,000
Metres
N

Table 6-1 TUFLOW Model Grid Hydraulic Roughness Values

Land Use Type/Material	Manning's n	Comment
Commercial	0.035	Zoning B2, B4
Residential	0.05	Zoning R1, R2, including schools
Public Recreation	0.1	Zoning RE1
Rural	0.035	Zoning RU1
Special Use	0.05	Zoning SP2. Cemetery, water supply
Waterways 1	0.05	Zoning W1
Waterways 2	0.035	Zoning W2
Forest and vegetated areas	0.1	Zoning E1, E2, E3 and E4 and other vegetated areas
Road	0.025	Where present, overwrites land use zoning areas listed above
Paved areas	0.02	Where present, overwrites land use zoning areas listed above
Fire Trail	0.035	Where present, overwrites land use zoning areas listed above
Diversion drain	0.04	Diversion drain, maintained, clear
Diversion drain with blockages	0.20	Unmaintained, heavy vegetation and fallen trees etc. Prone to further blockages from flood-borne debris
Property fence lines	0.30	Paling and Colourbond fences which are initially solid but prone to failure and flow-through

6.2.7 Property Fence Lines

Fence lines have typically not been explicitly represented in the model and floodwaters are allowed to flow across them freely. Although fences may obstruct overland flood flows in some parts of the catchment, experience indicates that representing fences in the hydraulic model requires making unvalidated assumptions about depths at which fences overflow or fail.

The potential obstruction to flow caused by fences was represented in the model by increasing the cell roughness (Manning's n values) along selected property fence lines on and adjacent to main flow paths to a value of n = 0.3. This approach provides some resistance to flows against and along a fence, although it probably does not represent the full obstructing effect of a fence before it fails under the force of flood flows. There are other approaches which can represent a fence as a solid obstruction which dynamically fails in the model once flow depths become great, but this approach is somewhat impractical to implement on a catchment scale, requiring significant effort and detail. The adopted approach was considered a more practical means of representing the hydraulic effects on flood flows. The modelled fence lines are shown on .

6.3 Boundary Conditions and Tailwater Conditions

6.3.1 Model Inflows

The inflow hydrographs from the DRAINS/RAFTS model are input into the watercourses and gullies upstream of the developed areas of the study area. The inflow boundaries are shown on Figure 6-1.

6.3.2 Direct Rainfall

A rainfall hyetograph (rainfall depth per time interval) is directly input into the TUFLOW model in the areas where direct rainfall applies. Similarly to the catchment hydrologic modelling discussed in Section 5.3.1, rainfall losses are applied in the conversion of direct rainfall to runoff in the TUFLOW model. The rainfall losses proposed for design flood estimation are:

- Pervious areas: Initial loss 15mm, continuing loss 2.5mm/hr
- Impervious areas: Initial loss 1mm, continuing loss 0mm/hr.

Most impervious areas in the study area are explicitly represented including road areas, roof areas and other large paved areas. The remaining developed areas for which impervious areas have not been digitised are assumed to be 20% impervious to account for driveways and other small paved areas, and the rainfall losses have been accordingly reduced to account for this partial imperviousness.

As discussed in Section 6.2.5, the model cells covering building footprints are made inactive. The rainfall falling on the roof areas of these buildings is therefore applied to the area immediately surrounding each building. Roofs are considered to be impervious areas with the corresponding rainfall losses applied.

Areas where direct rainfall is applied are shown on Figure 6-1. The areas where direct rainfall is scaled up for orographic effects (refer Section 7.3.2 for discussion) are also indicated.

6.3.3 Tailwater Boundaries

Tailwater boundaries are located along the shoreline on the receiving waterways including Camden Haven River, Stingray Creek, Queens Lake and Watsons Taylor Lake. Refer to the discussion in the subsequent model calibration section and the design event modelling section for details on the adopted tailwater levels.

7. Model Calibration and Verification

7.1 Overview

Rigorous model calibration of overland flood models cannot generally be carried out because direct measurements of overland flows and accurate measurements of flood levels are usually not available. Localised features may also be present which influence flow patterns but are not detected in the catchment-scale topographic data. Hence, overland flood models are often verified using observations of flood depths and flood behaviour as a way of "sanity-checking" the modelling and confirming its reliability.

This study has relied mainly on observed depths of flooding during past flood events given by local residents. This anecdotal information is generally considered indicative as often only the general location of the observation is usually given, and approximate depths of flooding. The reported flood observations are also from numerous separate storm events, while the model calibration focusses on only two events selected based on availability and quality of data. However, the reported flood depths are still useful information for validating the general behaviour of flooding simulated by the flood models.

Photographs and video of flooding have also been provided which offer more detailed information of the flooding behaviour at specific locations. Consideration is needed on whether the photos were taken at the peak of the flooding.

The general approach involved running the hydrologic and hydraulic models and comparing the flood depths and flow patterns to reported observations. The model configuration and parameter values were adjusted as necessary with the aim of achieving a satisfactory fit to the observations.

7.2 Selection of Verification Events

Flooding was reported for numerous individual storm events occurring over the last 20 years from the community survey responses. Two historic storm events were selected for model calibration and verification based on the number of responses for each event and the magnitude of the storm event. These events included:

- 24 April 2008. The most intense rainfall recorded based on the available data. Significant number of photographs are available with Council for this event.
- 2 March 2013. This is a relatively intense storm with the majority number of survey responses.

Characteristics of the selected storm events are provided in Table 7-1. The cumulative rainfall depths are plotted in Appendix A. A comparison of the recorded rainfall against the design IFD is also shown in Appendix A. Although the April 2008 storm event resulted in a lower daily rainfall depth than the March 2013 event, it produced a significantly more intense burst of rainfall over a period of one hour. Given the nature the flash flooding catchments in the study area these short duration bursts are the critical events for peak flooding. Hence, the April 2008 storm is considered to be a rarer and greater magnitude event than the March 2013 event, based on rainfall records.

Table 7-1 Calibration storm event characteristics

Event Date	Daily Rainfall Depth	Main Storm Burst Rainfall Depth and Duration	Approximate Event AEP	Comment
24 April 2008	136mm	49mm in 45 mins 65mm in 60 mins	10% AEP	Rainfall data available from Camden Haven SPS (Laurieton)
2 March 2013	152mm	43mm in 60 mins 61mm in 1.5 hrs	20% AEP	Rainfall available from Camden Haven STP (Dunbogan)

Note that several storm events in circa 2000 and 2002 were reported by long-term residents as being the most severe that they have experienced. However, suitable rainfall data for the model calibration were not available for these earlier storm events and hence these were not selected for the model calibration and verification.

7.3 Adopted Parameter Values for Model Verification

7.3.1 Rainfall Losses

Rainfall losses reflect the ability for the catchment to absorb some rainfall during a storm event due to capture on vegetation and trapped low points and from infiltration into the soil. The magnitude of the rainfall losses depends largely on how wet the catchment is due to preceding rainfall and the soil types in the catchment, with sandy soils generally being more permeable and hence water can infiltrate into the soil column at faster rates.

The assumed rainfall loss parameter values are selected based on a review of daily rainfall records and initial runs of the modelling for the calibration events. Both the April 2008 and the March 2013 storm events occurred after significant preceding rainfall:

- Approximately 200mm of rainfall fell in the week before the 24 April 2008 flood event.
- Over 280mm of rainfall fell in approximately the two weeks before the 2 March 2013 flood (from 17 – 27 February) followed by an additional 39mm on 28 February and 1 March, prior to the main flood event on 2 March.

Hence it is highly likely that the catchment was saturated prior to the two calibration storm events with little to no capacity to absorb further rainfall. The following rainfall loss values are therefore adopted for the model calibration and verification:

- Pervious areas: Initial loss 0mm, continuing loss 2.5mm/hr
- Impervious areas: Initial loss 0mm, continuing loss 0mm/hr.

Higher initial losses were initially tested in the hydrologic and hydraulic modelling. However, sufficiently high rates and volumes of runoff could not be produced to achieve a good match to the reported flooding at several locations. Other hydrologic factors such as the methods for representing the high catchment slopes and runoff, blockages, drainage patterns etc. were also considered and trialled but did not produce reasonable matches for observed flood behaviour, and hence were discounted from the model calibration process and informed the selection of the assumed rainfall losses.

7.3.2 Orographic Rainfall Scaling

North Brother Mountain, being a significant topographic feature of over 450m elevation and with steep slopes, has the potential to result in orographic enhancement of rainfall during storm events as the wind flow carrying rain-bearing clouds rises over the mountain and results in increased precipitation. Hence, rainfall intensities on the mountain, away from the rainfall gauge locations, may be higher than those at the gauge locations situated on lower areas at some distance away from the mountain.

BMT WBM (2018) has undertaken the Coffs Creek and Park Beach Flood Study at Coffs Harbour, where the catchment is bounded by a steep escarpment along its western and north-western sides to elevations over 400m. As a part of the model calibration for that study rainfall data from numerous rain gauges in the catchment were analysed for the March/April 2009 flood event, and a marked rainfall gradient was observed between the coastal part of the catchment and the middle and upper sections of the catchment. Rainfall depths recorded for the 24 hours to 9am on 1 April 2009 ranged from 260 – 280mm in the coastal areas, up to 530mm at gauges in the upper section of the catchment, with maximum estimated rainfall depths in this zone of up to 560mm (or double the rainfall recorded in the coastal areas). Analysis of the November 1996 storm event observed rainfall depths 2.5 times higher in the upper section compared to the coastal zone.

As a result of the rainfall analyses and model calibration in the Coffs Creek study, BMT WBM (2018) adopted scaling factors of 1.2 to 1.6 for the design flood estimation in that study, whereby the design rainfall intensities adopted for the coastal areas were increased by 1.2 to 1.6 times for application on the escarpment areas and foothills of the catchment. The study cited that the previous Coffs Creek Flood Study (WMA, 2001) adopted significantly higher scaling factors of up to 2.25, depending on the ground elevation of a particular location.

The topography for North Brother Mountain differs from Coffs Creek catchment, in that the Coffs Creek catchment is an incised valley which would funnel wind flows up the valley, concentrating the rain clouds. The same funnelling effect is unlikely to occur at North Brother Mountain due to its shape as a peak protruding from the surrounding coastal plain rather than a valley feature. To account for the orographic effects in the study area and to provide a better calibration fit the catchment inflows from North Brother Mountain and the rainfall on the foothills of the mountain were increased by 20% (i.e. an orographic scaling factor of 1.2),based on the recorded rainfall and design rainfall being derived for the coastal plains area. Accordingly, rainfall on the low areas below the foot of the mountain was not adjusted from the recorded depths.

As per the selection of rainfall losses, other model parameters and assumptions were initially tested and analysed in the calibration process but could not replicate the observed flooding depths and flow patterns, as the model is generally less sensitive to these other parameters. Hence these preliminary runs informed the scaling of rainfall for the model calibration. There is some uncertainty about the actual increased rainfall depths and spatial distribution of the increases during the historic events since there are no rainfall gauges on North Brother Mountain, however, a uniform scaling factor of 1.2 appeared to provide the best fit to observed flooding across the study area for the calibration events. A higher scaling factor could be considered appropriate for the design event runs.

7.3.3 Blockage of Hydraulic Structures

Guidance on blockage of hydraulic structures has generally been sought from *Australian Rainfall and Runoff Revision Project 11– Blockage of Hydraulic Structures Stage 2* (Engineers Australia, 2013).

Culverts were generally assumed to be 50% blocked for the model calibration events. There are photos and observations during historic flood events of large gravel and rocks being washed down the watercourses and deposited in drainage lines, and recurring blockage due to debris. Blockages at a few specific structures were reduced or increased to provide a better calibration fit.

Assumed blockage of stormwater pit inlets are generally consistent with guidance in ARR 2016. The large majority of pits in the study area are observed to be combination kerb inlet and grated pits. The assumed blockages are:

- Sag pits: kerb inlet assumed clear and grate 100% blocked.
- On-grade pits: 90% of the combined kerb inlet and grate flow capacity (i.e. 10% blockage factor).

7.3.4 Blockages in Flow Diversion Drains

Several respondents reported and provided photographs of overgrown vegetation and fallen trees in adjacent flow diversion drains at the foot of the mountain contributing to the drains overflowing and causing flooding of properties and dwellings. Observations on site also indicated localised build-up of rock rubble and tree trunks in the larger drains and watercourses. Blockages of these drains are represented in the model to replicate these flooding patterns.

7.3.5 Tailwater Conditions

Recorded water level hydrographs for the receiving waterways are adopted as tailwater boundaries for the calibration events.

7.4 Comparison to Observed Flooding

The community survey responses were reviewed for observations of flooding behaviour including dates of storm events, depths of flooding, flow patterns and resulting damage to property. Photos and videos provided with the responses or separately were also reviewed. Notes from Council on flooding problem spots were also considered.

The modelled flood behaviour was compared to the residents' observations and were generally found to be consistent with the observations. Refer to Table C-1 in Appendix D for comparison of modelled flood behaviour to the reported observations. Mapping of flood depths for the historic events is also shown in Appendix D.

The modelling generally produced reasonable matches to the observed flood behaviour along main flow paths and ponding/storage areas. Areas affected by shallow sheet overland flows were more difficult to replicate observations during previous storms, as such shallow flows are more sensitive to small-scale ground and built features which could not be picked up in the topographic model on a catchment-wide scale. The main flow paths and storage areas are the focus of the flood study as this is where flood risk and hazards are greatest.

There are some locations where a good match could not be achieved and this may be attributed to localised factors which may have occurred such as blockages of drains and drainage infrastructure by debris and sediment but which were omitted from the modelling if there were no specific reports of blockages. Information was sought whether any maintenance or upgrade works were conducted on the flow diversion drains uphill of the residential properties at the foot of the mountain which may have altered flow capacities and behaviour. Drains may have been cleared in recent times and reflected in survey of the drains, but may have been blocked by debris and vegetation at the time of historic flood events. However, Council and National Parks and Wildlife Service (NPWS) stated they did not undertake works in recent years. Council advised that Crown Lands Department may have undertaken works but no specific information was available.

There is also some uncertainty in the exact rainfall which fell on the mountain catchments as the orographic effects are likely to have caused localised and non-uniform enhancement of rainfall. While the rainfall data is sourced from gauges which are in or relatively close to the study area, these are located relatively at lower elevations in or to the east of the study area and may have varied from rainfall in the west of the study area or on the mountain.

Overall, the TUFLOW model provides a reasonable match to the observed flood behaviour in the historic events and is therefore considered to be suitable for the estimation of design flood behaviour in the study area.

7.5 Sensitivity Testing of Calibration Parameters

A number of scenarios have been assessed for the April 2008 flood event to test the sensitivity of the model results to changes in the adopted parameter values. The tested parameters include:

- Rainfall and flow Scaling
- Rainfall losses
- Blockage of hydraulic structures
- Surface hydraulic roughness

The scenarios are described and the impacts summarised in Table 7-2. Flood levels and depths are relatively sensitive in particular to the changes in rainfall scaling (both increase and decrease) with changes of +/- 200mm, and to blockages (both fully open and fully blocked) with changes of up to +/- 700mm, mainly upstream and downstream of culvert structures. The flood levels are also moderately sensitive to the assumed changes in Manning's n on the main flow paths, which are assumed to be of high roughness in forested areas, with resulting changes in flood levels of +/- 150mm. Flood levels are typically insensitive to changes in rainfall losses (+/- 30mm), although flooding in selected storage areas are more sensitive to the increased rainfall losses (-280mm) than to the decreased losses (+80mm).

Table 7-2 Sensitivity Analysis Description and Results

Scenario	Description	Change in Flood Level
Rainfall and Flow Scaling – Zero	Scaling factor of 1.0. (Base case adopts scaling factor of 1.2)	☐ Up to -150mm on major flow paths ☐ Typically less than -50mm on other flow paths.
Rainfall and Flow Scaling – Increase by 20% points	Scaling factor of 1.4. (Base case adopts scaling factor of 1.2)	☐ Up to +150mm on major flow paths (east of Ellerslie Cres and south of Brotherglen Dr) ☐ Typically less than +50mm on other flow paths. ☐ +100mm to +200mm in some storage areas (between Botanic Dr and Ocean Dr, Lakewood shops car park, car park west of Laurieton Hotel) and isolated areas on some properties.
Rainfall Losses – Increase	Pervious area: 15mm initial loss (burst loss: define burst as starting at 7AM 24 April 2008. Peak intensity at 8:35AM), 4mm/hr continuing loss. Impervious area: 2mm initial loss, 0mm/hr continuing loss.	☐ Typically less than -30mm in most flow paths and overland flow areas. ☐ Up to -280mm in storage area between Botanic Dr and Ocean Dr.
Rainfall Losses – Decrease	Pervious area: 0mm initial loss, 0mm/hr continuing loss. Impervious area: retain calibration values (0mm initial loss, 0mm/hr continuing loss.)	☐ Typically less than +20mm in most flow paths and overland flow areas. ☐ Up to +80mm in storage area between Botanic Dr and Ocean Dr.
Blockage of Hydraulic Structures – Fully Blocked	All pipes, culverts and pits 100% blocked.	☐ Typically +150mm to +300mm in main road low points and storage areas (between Botanic Dr and Ocean Dr; Sirius Dr, Pelican Crt, and others) ☐ Up to +400mm in Lakewood shops car park, car park west of Laurieton Hotel. ☐ Decreases of -100mm in some locations downstream of the storage areas ☐ Typically less than +/-50mm on other flow paths.

Blockage of Hydraulic Structures – All Clear	All pipes, culverts and pits 0% blocked.	□ Typically less than +/-100mm in affected areas. □ Localised reductions of up to -700mm upstream of culverts. □ Localised increases of up to +300mm downstream of culverts including on properties in Pelican Crt.
Surface Hydraulic Roughness – Plus 20%	Surface Manning's n values increased by 20%.	□ Up to +150mm on major flow paths (east of Ellerslie Cres and south of Brotherglen Dr) □ Typically less than +50mm on other flow paths. □ Less than +/-20mm in other overland flow areas.
Surface Hydraulic Roughness – Minus 20%	Surface Manning's n values decreased by 20%.	□ Up to +-50mm on major flow paths (east of Ellerslie Cres and south of Brotherglen Dr) □ Typically less than -30mm on other flow paths and overland flow areas.

8. Conclusions and Recommendations

Hydrologic and hydraulic models for the North Brother Local Catchments study area have been developed based on available data from Council and other sources, and topographic and hydraulic structures survey collected during this study. The models have been developed with a focus on local catchment and overland flooding originating from runoff from North Brother Mountain and from within the study area itself. The modelling does not focus on mainstream flooding from the Camden Haven River and other waterways.

The models have been calibrated to the April 2008 and March 2013 local catchment flood events based on responses to the community consultation survey and other reports and flooding complaints lodged with Council. Model parameters adjusted to achieve a satisfactory fit to historic flood observations include rainfall losses, hydraulic roughness of the floodplain surface and blockages of hydraulic structures and of diversion drains. An orographic scaling factor of 1.2 has been adopted to increase rainfall and catchment flows by 20% to achieve a satisfactory calibration. This factor accounts for increased rainfall intensities during storm events due to the orographic effects resulting from the North Brother Mountain topography, and is relative to the unscaled recorded rainfall from gauges on the coastal plain away from the mountain.

A number of scenarios have been assessed for the April 2008 flood event to test the sensitivity of the model results to changes in the adopted parameter values. The tested parameters include:

- Rainfall and flow scaling
- Rainfall losses
- Blockage of hydraulic structures
- Surface hydraulic roughness

Flood levels and depths are relatively sensitive in particular to the changes in rainfall scaling (both increase and decrease) with changes of +/- 200mm, and to blockages (both zeroed and fully blocked) with changes of up to +/- 700mm, mainly upstream and downstream of culvert structures. The flood levels are also moderately sensitive to the assumed changes in Manning's n on the main flow paths, which are assumed to be of high roughness in forested areas, with resulting changes of +/- 150mm. Flood levels are typically insensitive to changes in rainfall losses (+/- 30mm), although flooding in selected storage areas is more sensitive to the increased rainfall losses (-280mm) than to the decreased losses (+80mm).

It is recommended that the community be consulted to obtain concurrence on the model calibration. The calibrated hydrologic and hydraulic models would then be used for the estimation of flood behaviour for the selected design flood events.

9. References

BMT WBM (2018) Coffs Creek and Park Beach Flood Study, Draft Report for Public Exhibition. February 2018.

Engineers Australia (2013) *Australian Rainfall and Runoff Revision Project 11– Blockage of Hydraulic Structures Stage 2*

GHD (2007a) West Haven Stormwater Study Area Final Systems Analyses Report. April 2007.

GHD (2007b) Report for Buller Street and West Haven Stormwater Catchment Studies S.600.110.05.61 Concept Design Report - West Haven Study Area, September 2007.

Port Macquarie Hastings Council (2015) Port Macquarie Hastings Council Flood Policy. Adopted 21 October 2015.

Worley Parsons (2013) Camden Haven River and Lakes System Flood Study.

Webb McKeown and Associates (2001) Coffs Creek Flood Study.

10. Glossary

Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. In this study AEP has been used consistently to define the probability of occurrence of flooding. It is to be noted that design rainfalls used in the estimation of design floods up to and including 100 year ARI (ie. 1% AEP) events was derived from 1987 Australian Rainfall and Runoff. Hence the flowing relationship between AEP and ARI applies to this study. 20% AEP = 5 year ARI; 10% AEP = 10 year ARI; 5% AEP = 20 year ARI; 2% AEP = 50 year ARI; 1% AEP = 100 year 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 occurrences of a flood as big as or larger than the selected event. For example, floods with a discharge as great as or greater than the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
Catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
Development	Is defined in Part 4 of the EP&A Act <u>In fill development</u>: 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. Eg. The urban subdivision of an area previously used for rural purposes. New developments involve re-zoning and typically require major extensions of exiting urban services, such as roads, water supply, sewerage and electric power. Redevelopment: refers to rebuilding in an area. Eg. As urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either re-zoning or major extensions to urban services.
Effective Warning Time	The time available after receiving advise 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.

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 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 susceptibility to flooding by the PMF event. Note that the term flooding liable land covers the whole floodplain, not just that part below the FPL (see flood planning area)
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 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 include both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defines objectives.
Flood plan (local)	A sub-plan of a disaster plan that deals specifically with flooding. They can exist at state, division and local levels. Local flood plans are prepared under the leadership of the SES.
Flood planning levels (FPLs)	Are the combination 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 "designated flood" or the "flood standard" used in earlier studies.
Flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings and structures subject to flooding, to reduce or eliminate flood damages.
Flood readiness	Readiness is an ability to react within the effective warning time.
Flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. Existing flood risk: the risk a community is exposed to as a result of its location on the floodplain. Future flood risk: the risk a community may be exposed to as a result of new development on the floodplain.

	Continuing flood risk: the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.
Flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas
Floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.
Freeboard	Provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
Hazard	A source of potential harm or 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.
Local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
m AHD	Metres Australian Height Datum (AHD)
m/s	Metres per second. Unit used to describe the velocity of floodwaters.
m^3/s	Cubic metres per second or "cumecs". A unit of measurement of creek or river flows or discharges. It is the rate of flow of water measured in terms of volume per unit time.
Mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
Modification measures	Measures that modify either the flood, the property or the response to flooding.
Overland flow path	The path that floodwaters can follow as they are conveyed towards the main flow channel or if they leave the confines of the main flow channel. Overland flow paths can occur through private property or along roads.
Probable Maximum Flood (PMF)	The largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation couplet 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.
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.
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 a streamflow, also known as rainfall excess.
Stage	Equivalent to water level (both measured with reference to a specified datum)
TUFLOW	TUFLOW is a computer program which is used to simulate free-surface flow for flood and tidal wave propagation. It provides coupled 1D and 2D hydraulic solutions using a powerful and robust computation. The engine has seamless interfacing with GIS and is widely used across Australia.
XP-RAFTS	XP-RAFTS is a computer program which is used to simulate catchment rainfall-runoff and is widely used across Australia.

Appendix A. Analysis of Historic Rainfall Event Data

Cumulative rainfall depths have been plotted for two recent storm events for which data is currently available. These include:

- 24 April 2008 (10% AEP) 49mm in 45minutes; 65mm in 60 minutes; 136mm in 24 hours.
- 2 March 2013 (20% AEP) 61mm in 1.5 hours; 152mm in 24 hours.
- 5 January 2016 (20 – 50% AEP) 54mm in 1.5 hours.

Figure A-1 Cumulative event rainfall depth, 24 – 26 April 2008

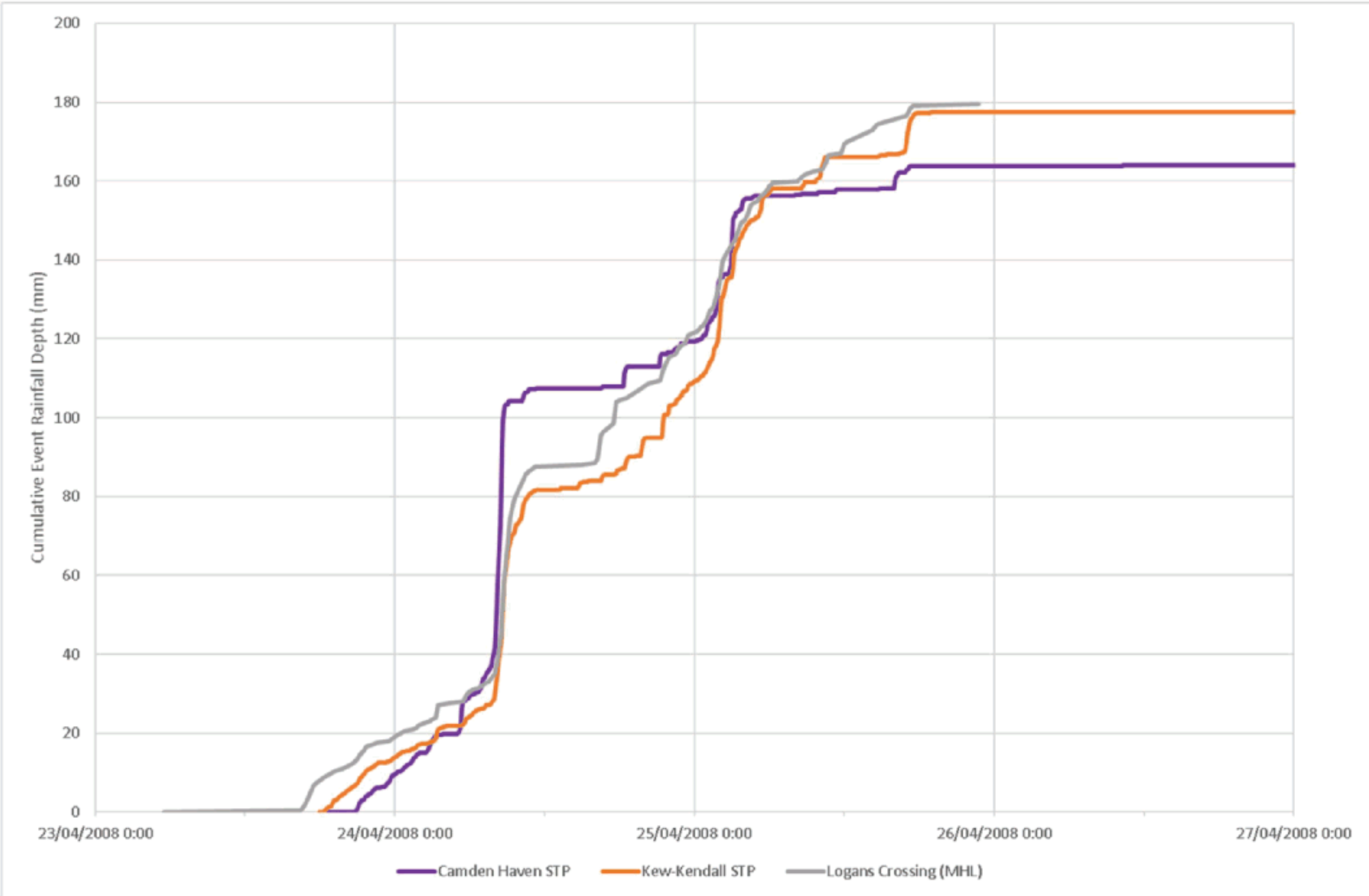


Figure A-2 Cumulative event rainfall depth, 2-3 March 2013

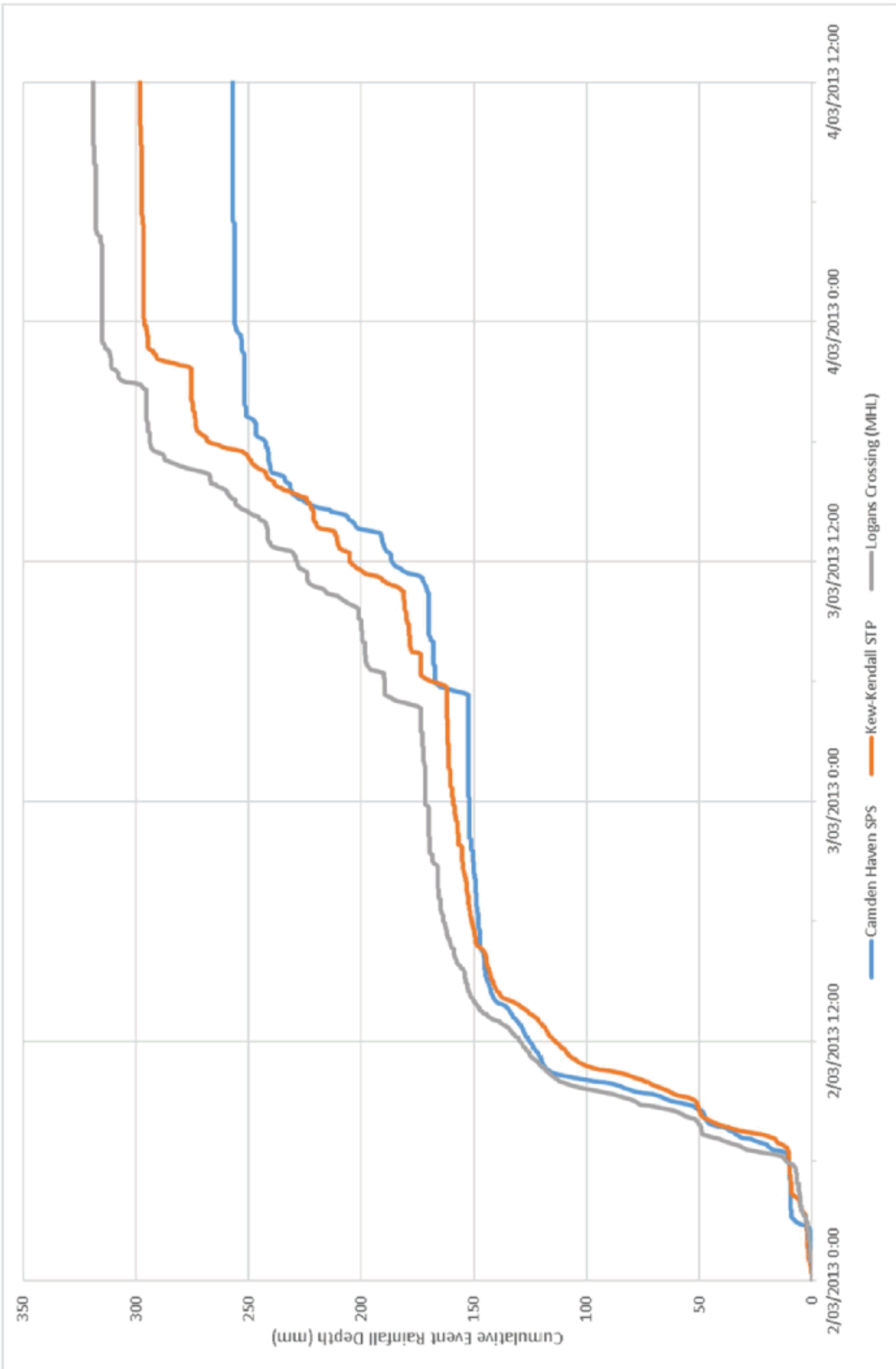


Figure A-3 Cumulative event rainfall depth, 4 – 5 January 2016

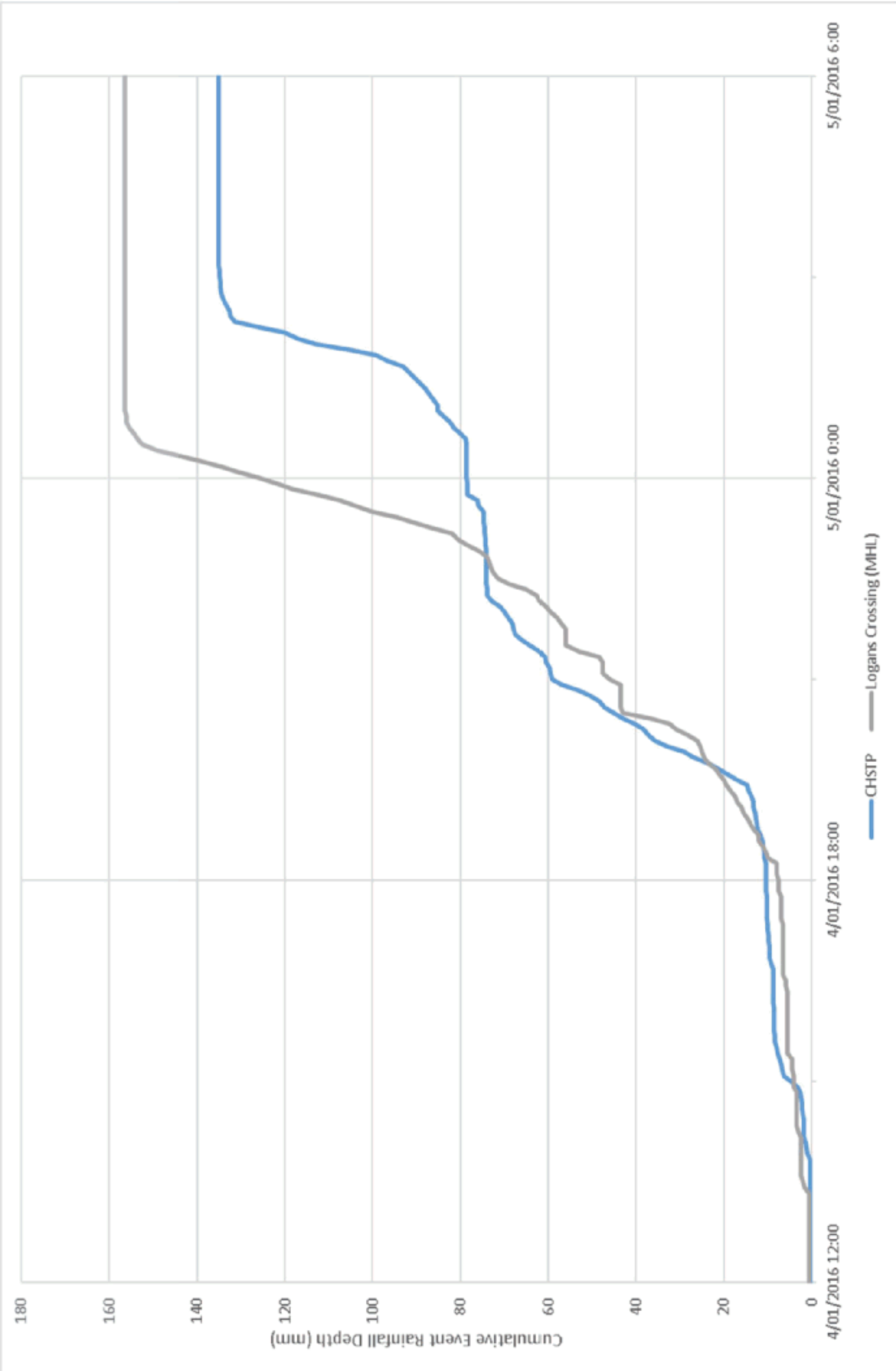
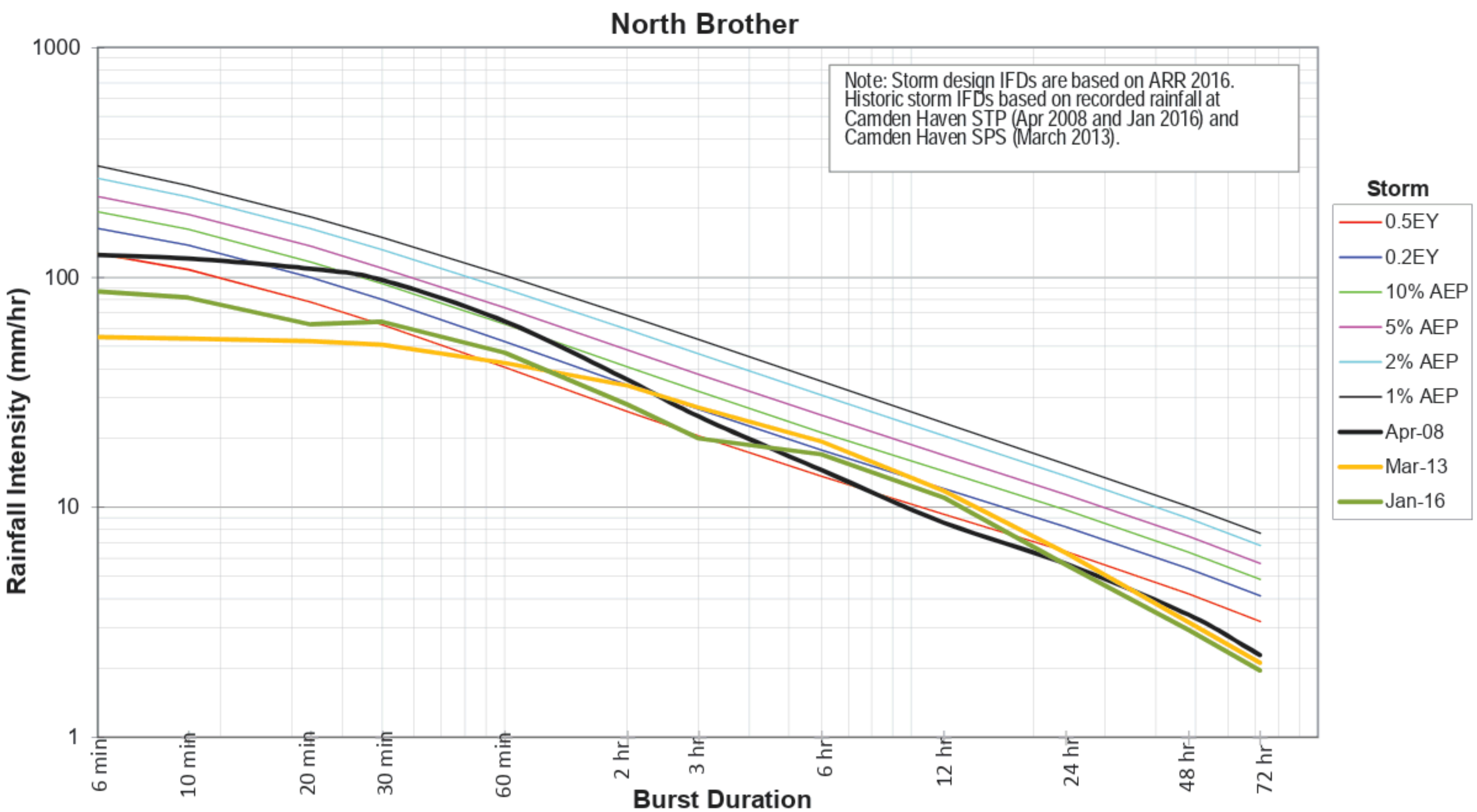
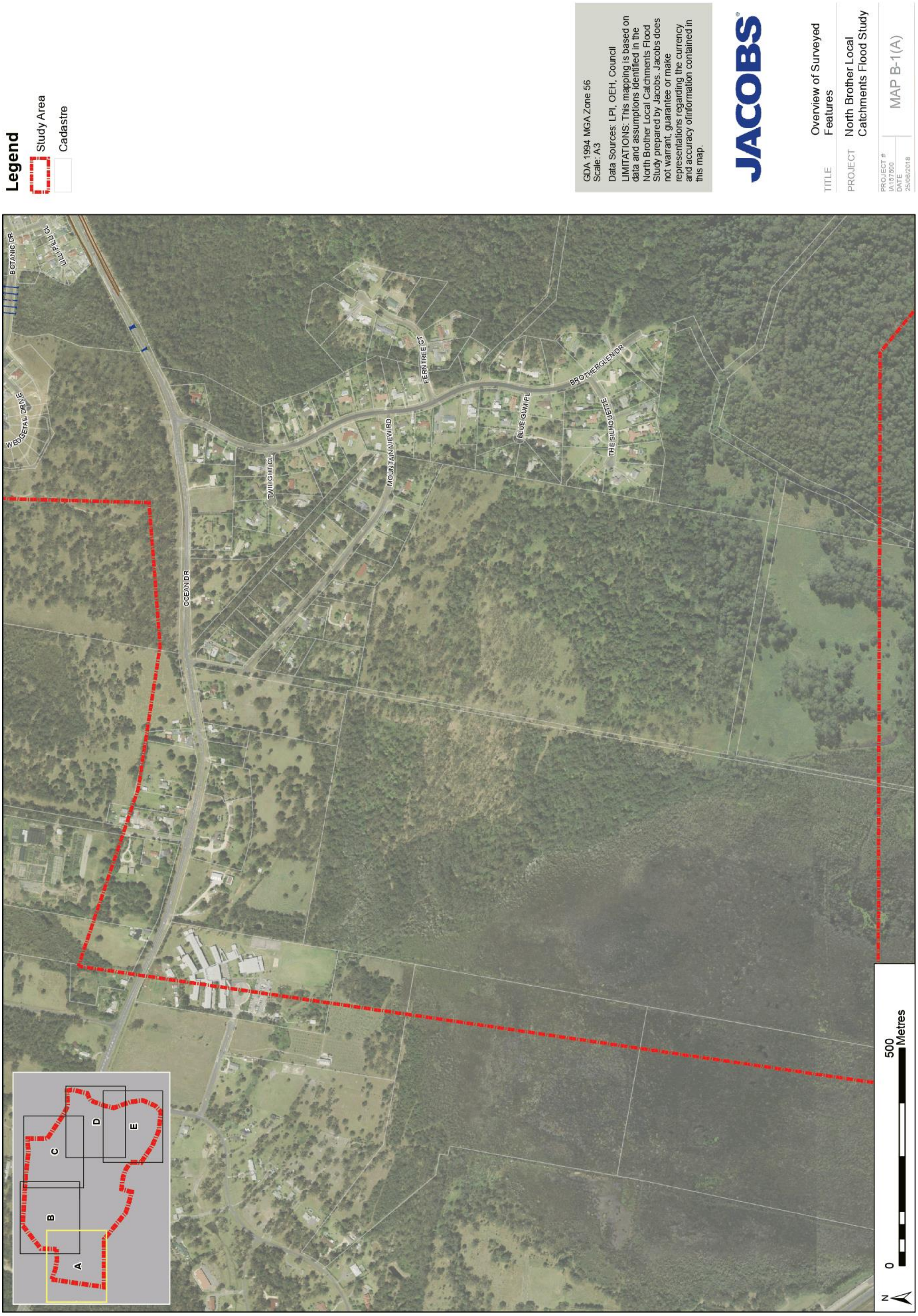


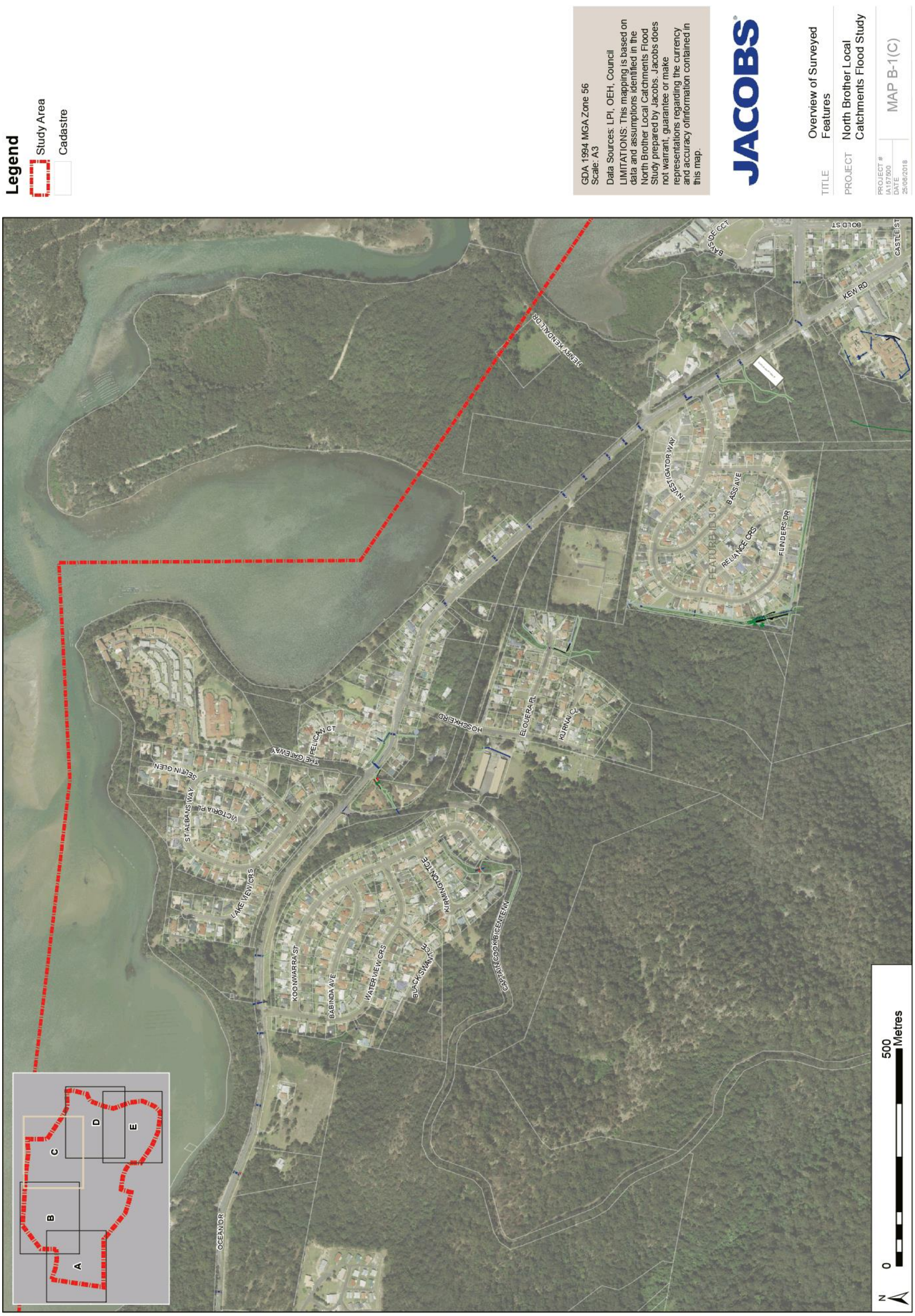
Figure A-4 North Brother Design Rainfall Intensity-Frequency-Duration versus Historic Storm Events

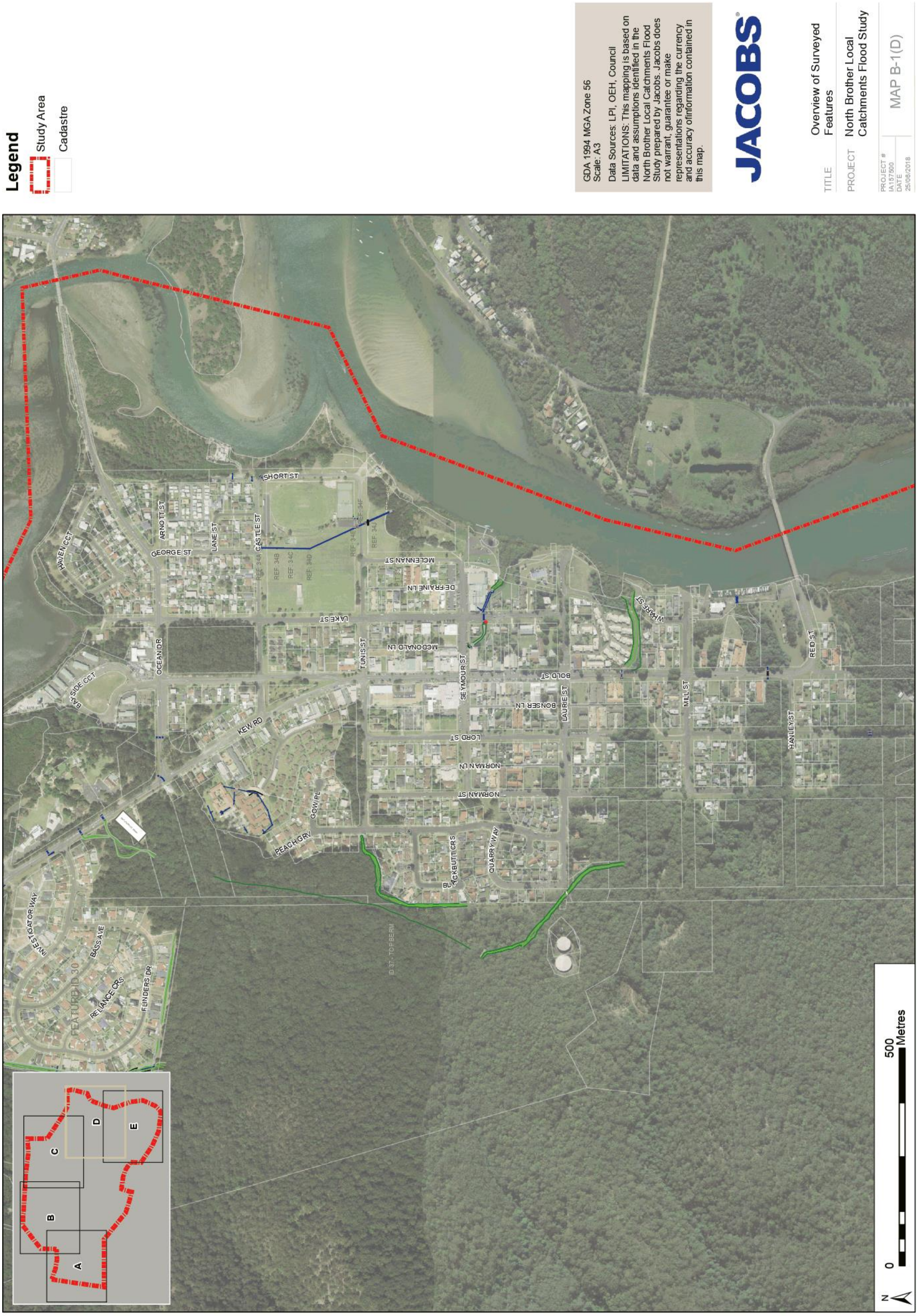


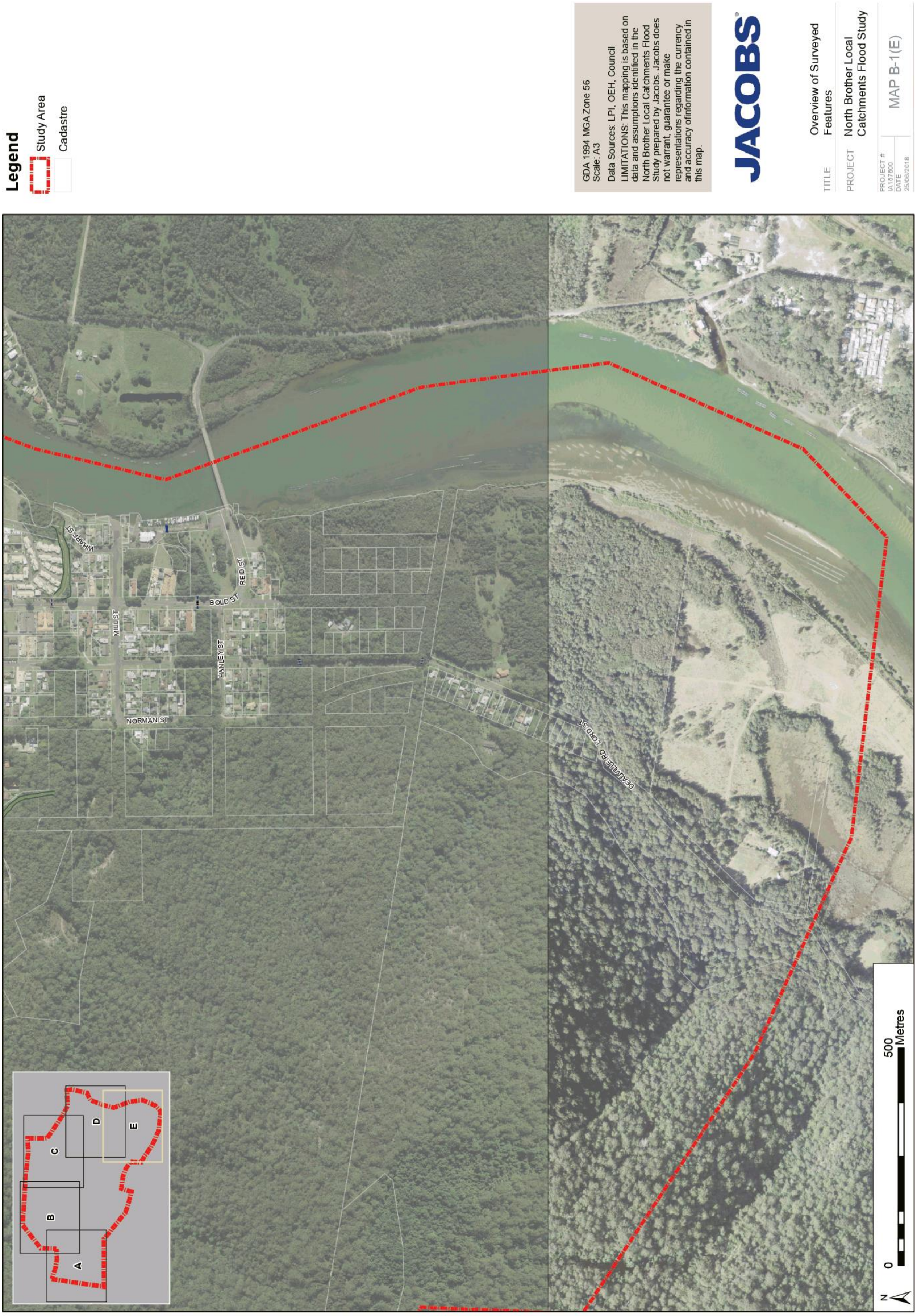
Appendix B. Summary of Topographic Survey


Legend
Study Area
Cadastre
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
TITLE Overview of Surveyed Features
PROJECT North Brother Local Catchments Flood Study
MAP B-1(A)
OCEAN DR
MOUNTAIN VIEW RD
TWILIGHT CL
FERNTREE CT
BROTHERGLEN DR
BLUE GUM PL
THE SILHOUETTE
BOTANIC DR
0
500 Metres
A
B
C
D
E


Legend
Study Area
Cadastre
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
TITLE Overview of Surveyed Features
PROJECT North Brother Local Catchments Flood Study
MAP B-1(B)
OCEAN DR
MISSION TCE
ROSEWOOD CT
CASUARINA DR
HERON PL
EGRET PL
DIAMENTINA WAY
ELLERSLIE CRS
ADMIRALS CIR
SIRIUS DR
TERN CL
PHILLIP CL
TEAL CL
TEATREE CL
BANKSIA CL
BANKS ST
OAK CL
RINGTAIL CL
HONEYSUCKLE AVE
LILLI PILLI CT
BOTANIC DR
WREN CL
BOTANIC DRIVE
WEDGETAIL DRIVE
BROTHERGLEN DR
FERNTREE CT
MOUNTAIN VIEW RD
TWILIGHT CL
A
B
C
D
E
0
500 Metres
N


Legend
Study Area
Cadastre
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE Overview of Surveyed Features
PROJECT North Brother Local Catchments Flood Study
MAP B-1(C)
0
500
Metres
A
B
C
D
E
KEW RD
INVESTIGATOR WAY
BASS AVE
RELIANCE CRS
FLINDERS DR
HOSCHKE RD
ELOUERA PL
KURNAI CL
PELICAN CT
THE GATEWAY
SEFTIN GLEN
ST ALBANS WAY
VICTORIA PL
LAKE VIEW CRS
KOONWARRA ST
BABINDA AVE
WATER VIEW CRS
KIRKINGTON TCE
CAPTAIN COOK BICENTENN
OCEAN DR
CASTLE ST
BOLD ST


Legend
Study Area
Cadastre
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE Overview of Surveyed Features
PROJECT North Brother Local Catchments Flood Study
MAP B-1(D)
SHORT ST
ARNOTT ST
LANE ST
CASTLE ST
GEORGE ST
HAVEN CCT
MCLENNAN ST
DEFRAINE LN
LAKE ST
OCEAN DR
TUNIS ST
MCDONALD LN
SEYMOUR ST
BOLD ST
BONSER LN
LAURIE ST
MILL ST
WHARF ST
RED ST
HANLEY ST
BAYSIDE CCT
KEW RD
LORD ST
NORMAN LN
NORMAN ST
GOW PL
PEACH GRV
BLACKBUTT CRS
QUARRY WAY
INVESTIGATOR WAY
BASS AVE
RELIANCE CRS
FLINDERS DR
A
B
C
D
E
0
500
Metres
N


Legend
Study Area
Cadastre
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE Overview of Surveyed Features
PROJECT North Brother Local Catchments Flood Study
MAP B-1(E)
WHARF ST
REID ST
BOLD ST
MILL ST
HANLEY ST
NORMAN ST
LORD ST
BEAUTIEU RD
A
B
C
D
E
0
500
Metres
N

Appendix C. Community Consultation

PORT MACQUARIE-HASTINGS COUNCIL

Community Bulletin No. 1 - October 2017

JACOBS

North Brother Local Catchments Flood Study

Port Macquarie Hastings Council is currently conducting the North Brother Local Catchments Flood Study. This Community Bulletin is the first in a series of Bulletins aimed at informing residents of the status of the project and how they can be involved in the process. Council has engaged consultants, Jacobs Group Australia, to undertake the Study.

The focus of the study is to understand the behaviour of local catchment flash flooding from North Brother Mountain and the flood risk that it poses to the community. This will assist Council to develop measures to manage the impact of flooding and guide strategic planning for future development of the area. It includes areas of the villages of Laurieton, West Haven, Lakewood, Kew and Deauville.

An integral part of the study process is community consultation and involvement. This element of the process aims to inform the community of the study and invite residents to provide information on their views and experiences with flooding in the area. The management of flood prone land is primarily the responsibility of Councils and follows a number of stages as shown below. The project is currently in the Flood Study stage, and will later move to the Floodplain Risk Management Study and Floodplain Risk Management Plan stages as the project progresses.

The Stages of Floodplain Risk Management

Objectives of the Study

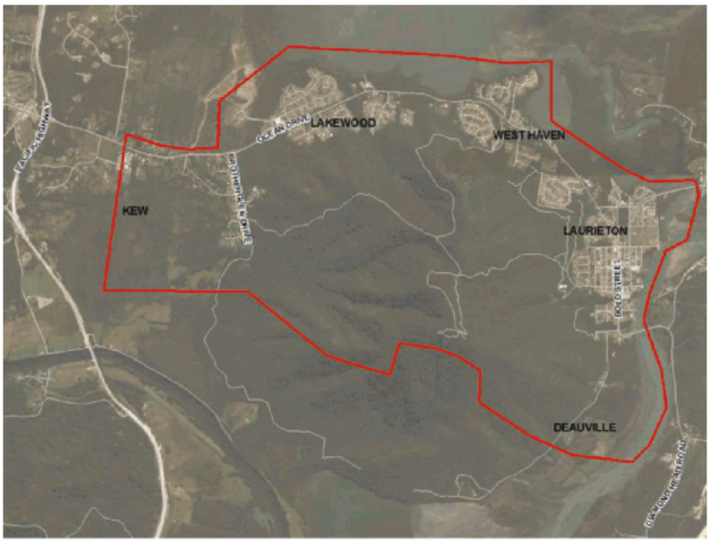
The objectives of the study are to:

1. Define the overland and flash flooding behaviour in the study area. Computer flood modelling will be undertaken to do this during the current flood study stage.
2. Identify and evaluate possible flood mitigation and management measures to reduce the flood risk. These may be structural and planning measures or “response” measures.
3. Develop a staged plan for implementing these measures.

Community Survey

We are seeking feedback from the community on previous flooding events in the area and views on possible management measures via the attached survey. The results of the survey will help inform a flood study for the area, which will be placed on public exhibition in early 2018, and a subsequent floodplain risk management study. The information that you provide will improve the flood model being developed.

Study Area



The Flood Problem

The study area typically experiences short duration flooding, which occurs when intense rainfall exceeds the capacity of the stormwater network or creek channel. In urbanised areas, this flooding has the potential to cause major damage to property and risk to life. Notable local flash flooding in the study area recently occurred in:

- April 2008
- June 2011
- March 2013
- January 2016.

How can you get involved?

Engagement of the community in the floodplain risk management process is very important to Council. We will be providing a number of opportunities for the community to have input during the course of this study.

Some of the most important information for the study is collected from residents and local business operators. We would be very interested to receive records of flooding in your area including photographs, observations of flood depths or some comments on your experience. You can help us with this information by completing the questionnaire for your area and returning the completed community survey by 31 October 2017. The questionnaires can be found in Council's web site www.haveyoursay.pmhc.nsw.gov.au/ Port Macquarie Hastings Council appreciates your cooperation and will keep you informed with ongoing community bulletins.

Community Bulletins
- Background to the study and context
- Bulletins to update community on the project progress

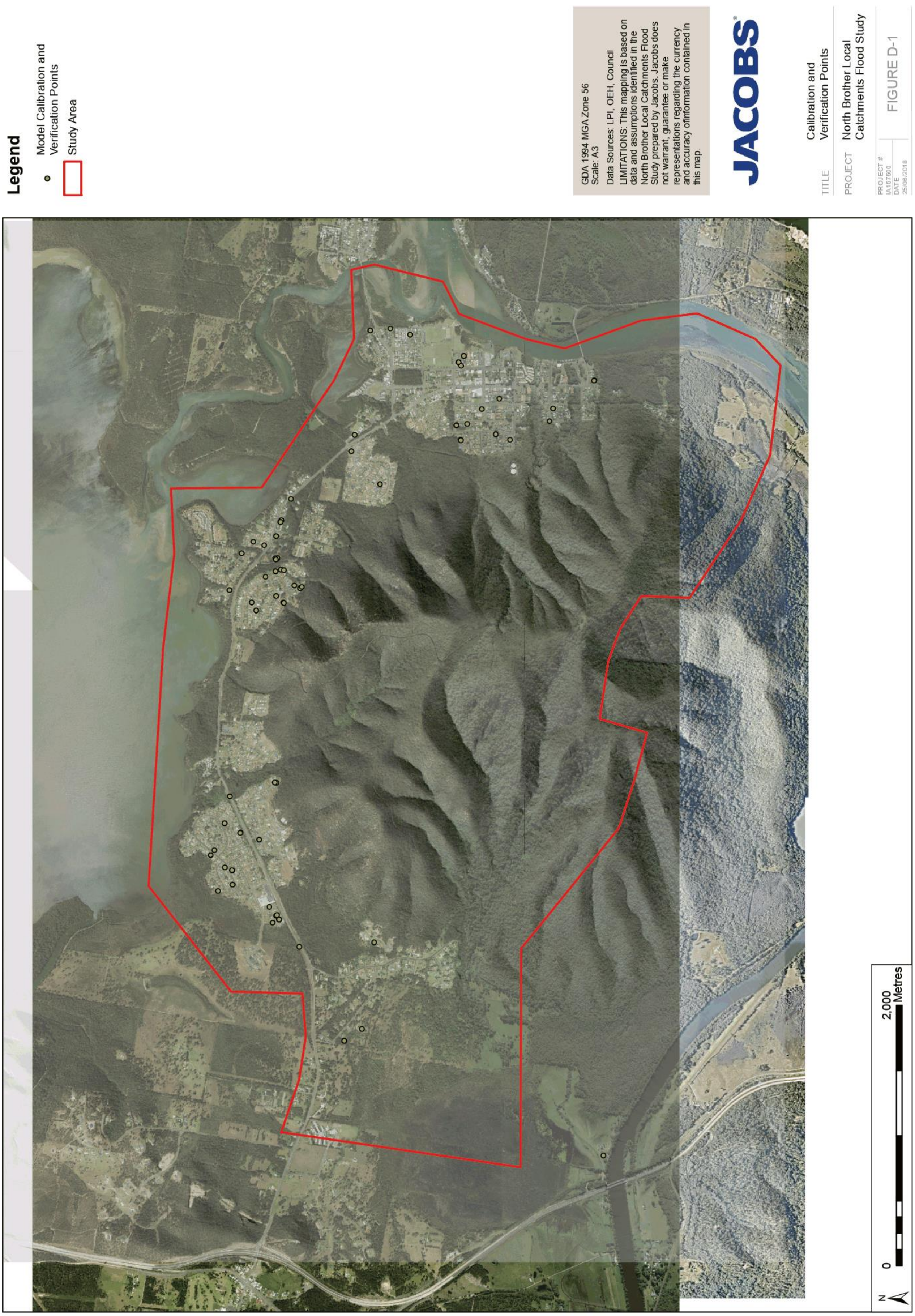
Flood Data
- An opportunity to tell us about flooding in your area (via the attached survey)

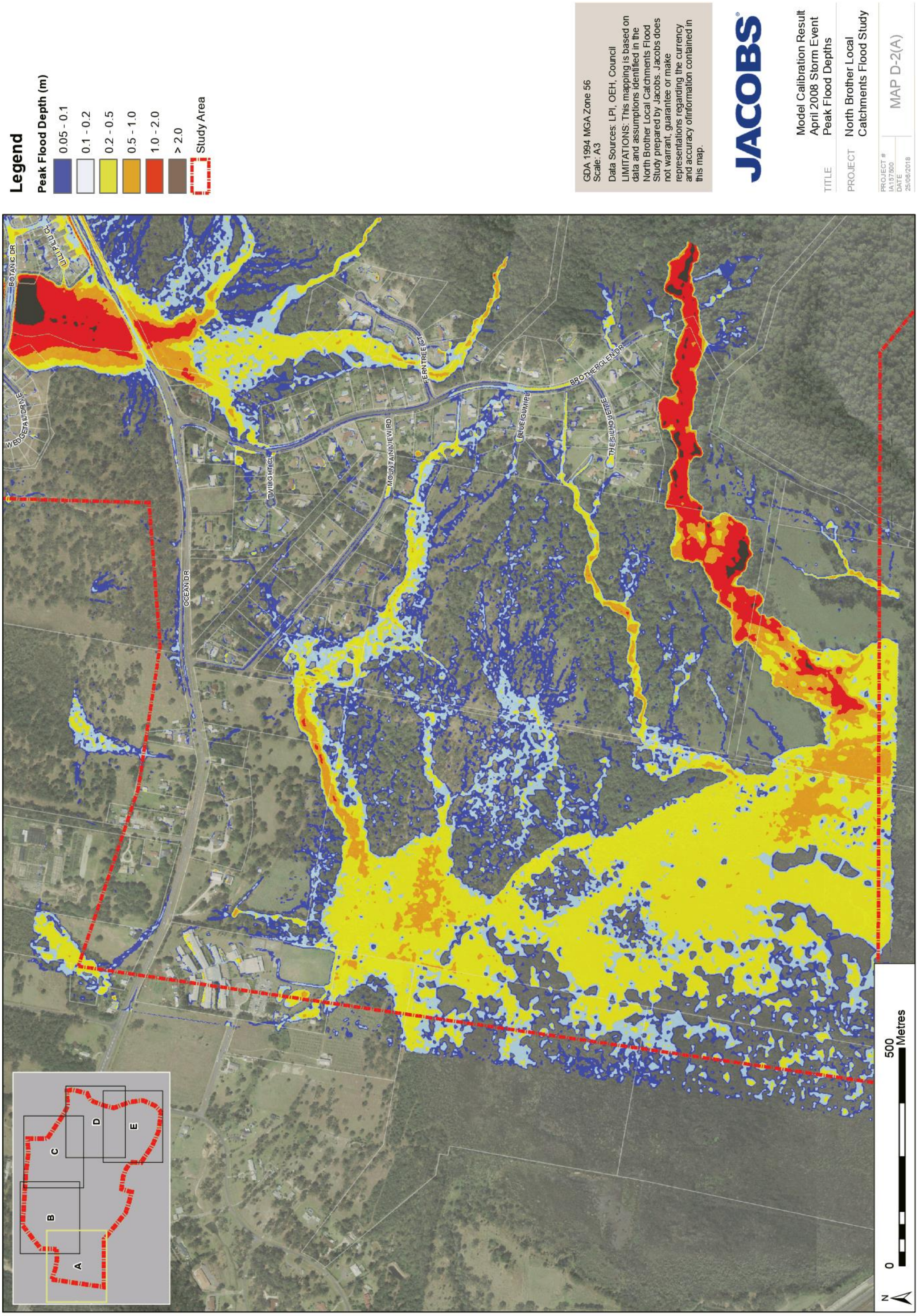
Community Forums
- Opportunity to find out more about flood studies for your area and provide some feedback

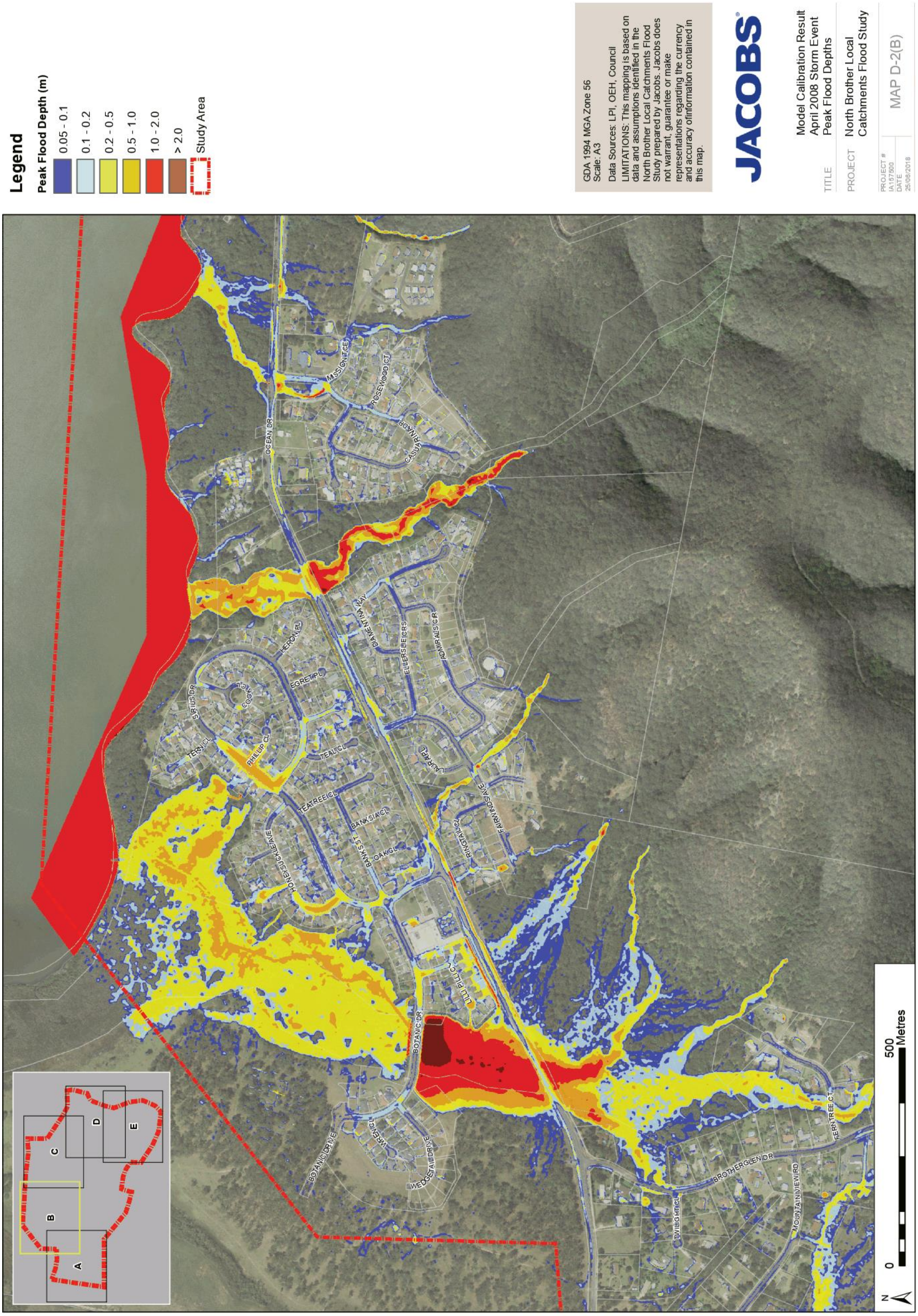
Council Website
- Contact details for queries relating to the study and how you can be involved.

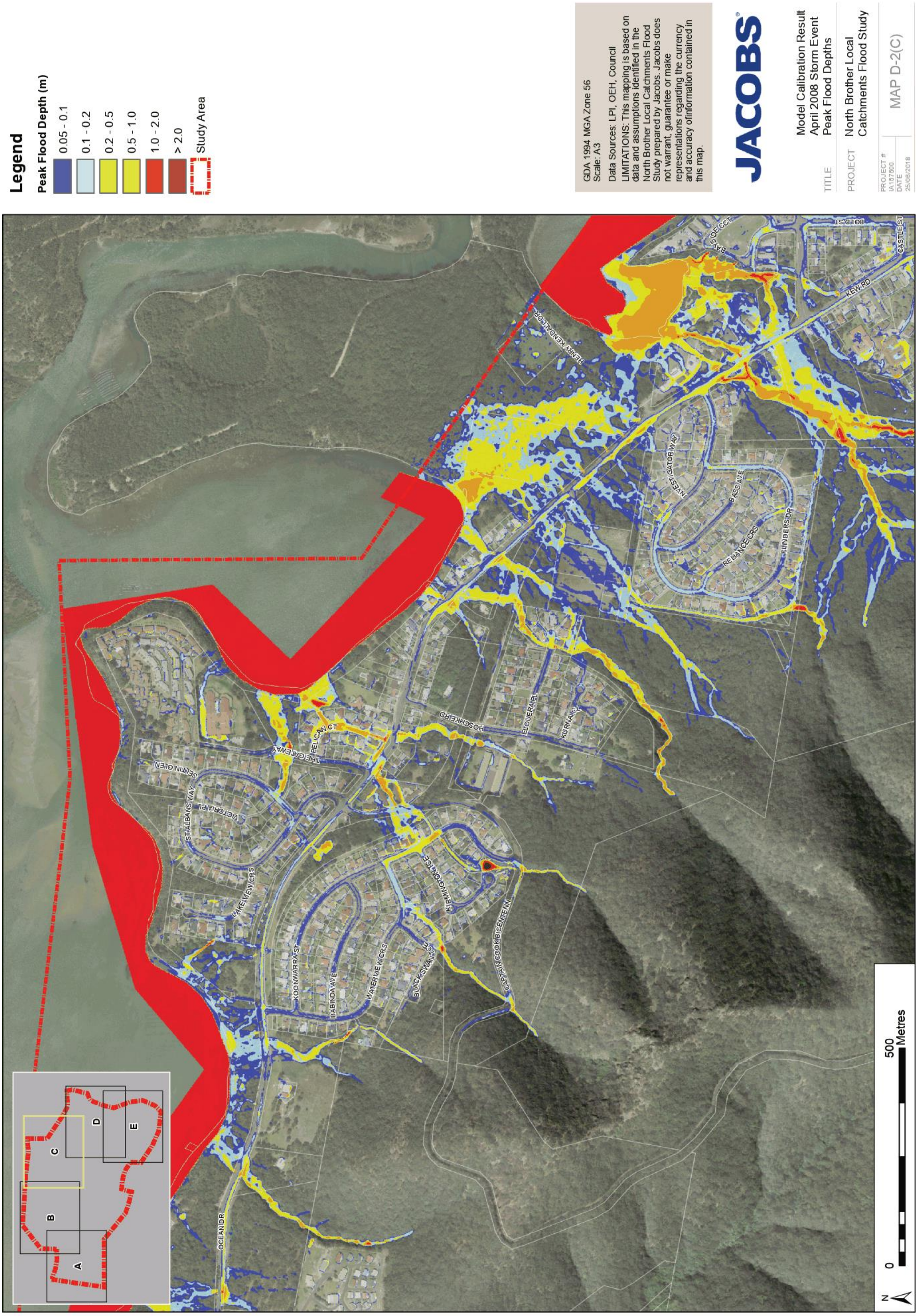
For more information contact Port Macquarie Hastings Council on (02) 6581 8111 or visit **haveyoursay.pmhc.nsw.gov.au**

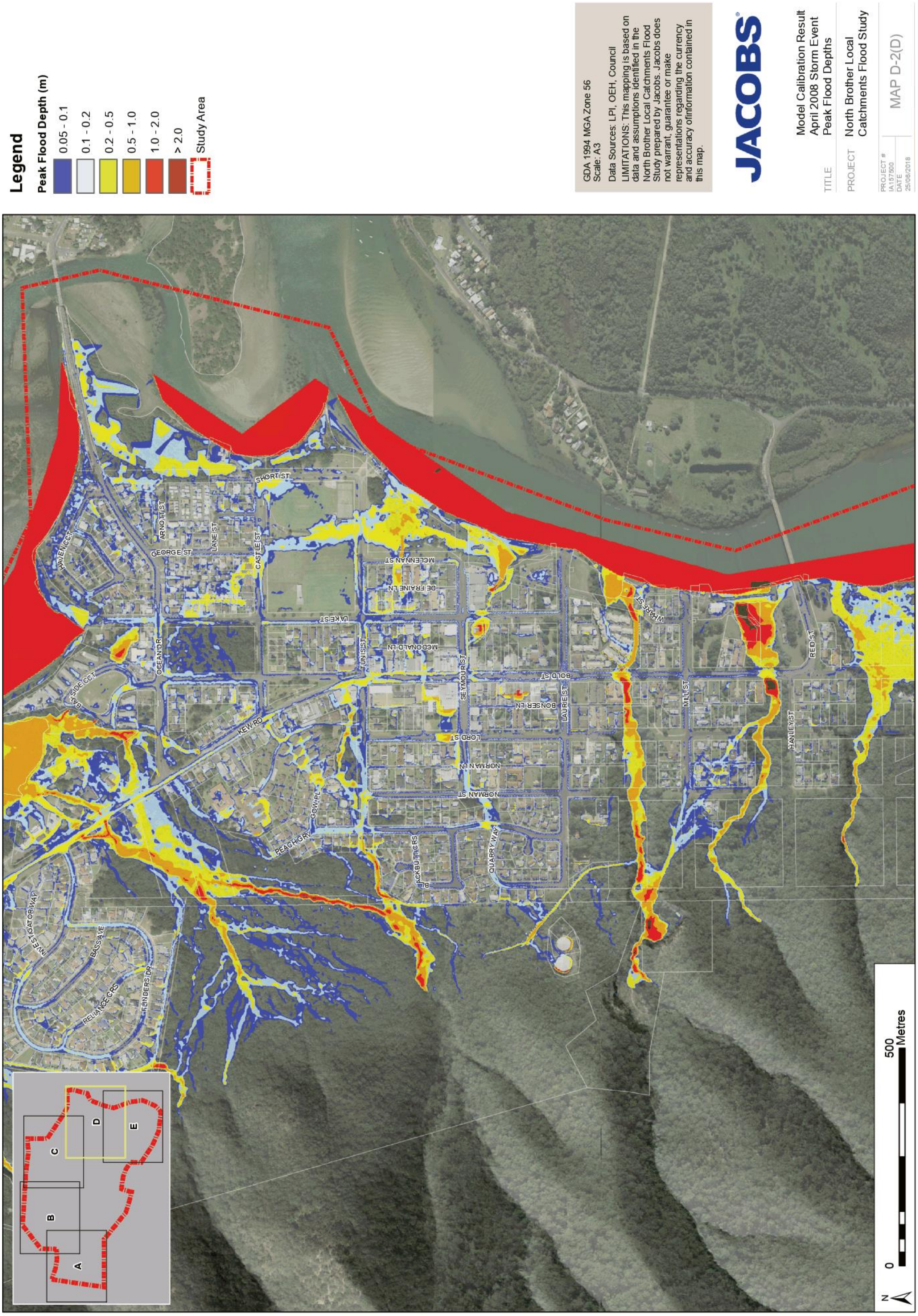
Appendix D. Verification of Model Flood Behaviour

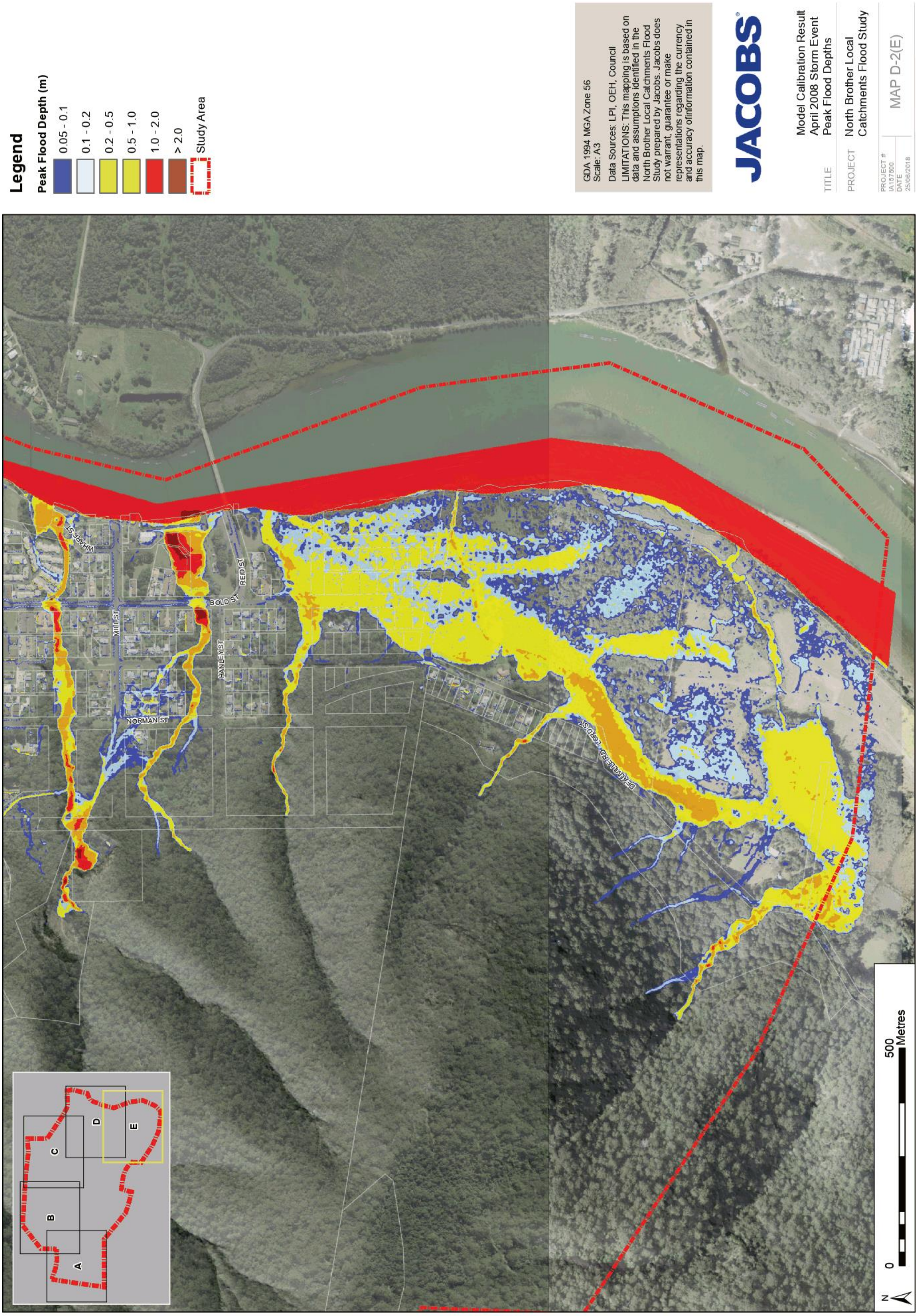

Legend
Model Calibration and Verification Points
Study Area
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE
Calibration and Verification Points
PROJECT
North Brother Local Catchments Flood Study
FIGURE D-1
0
2,000 Metres
N

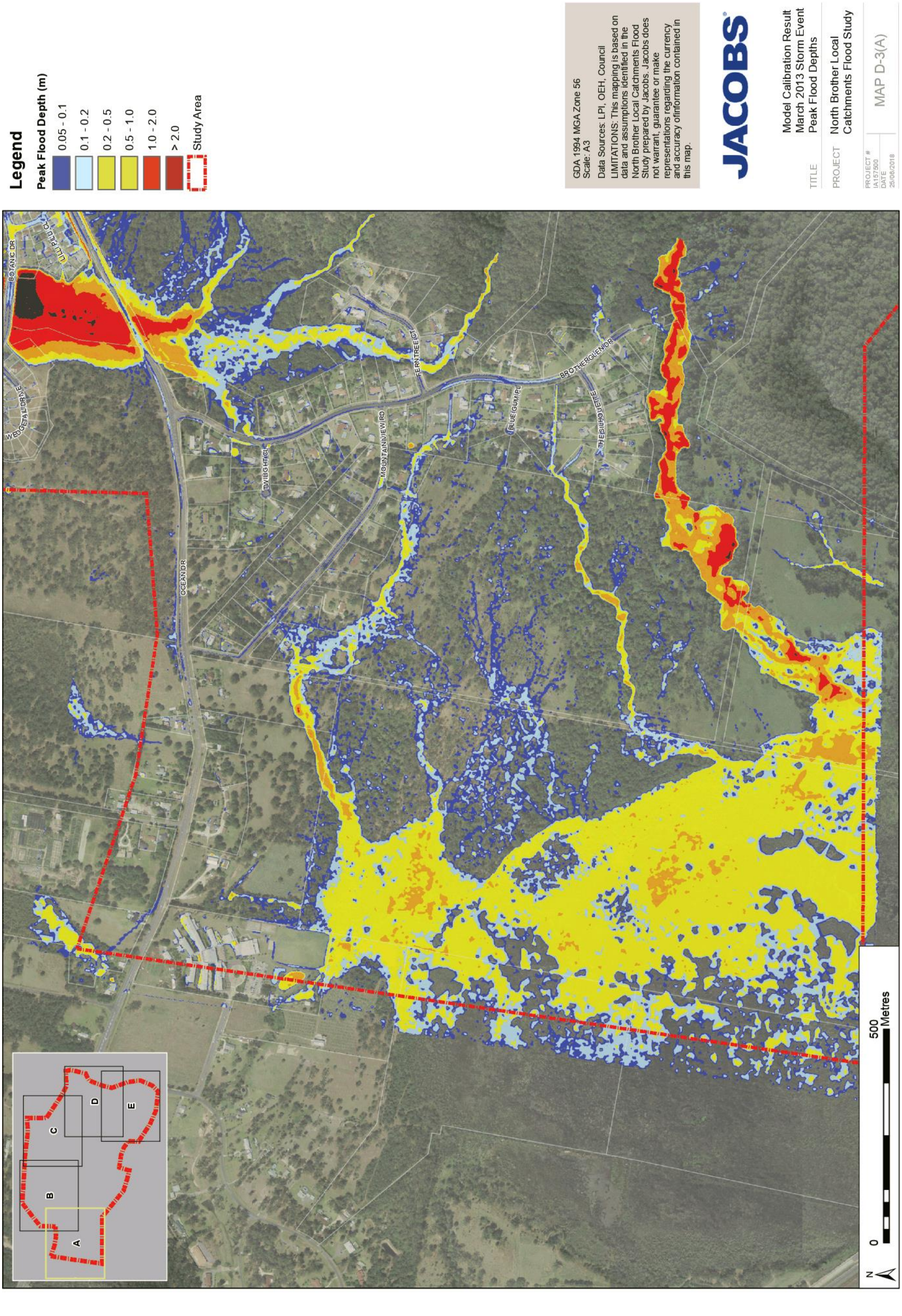

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE
Model Calibration Result
April 2008 Storm Event
Peak Flood Depths
PROJECT
North Brother Local
Catchments Flood Study
MAP D-2(A)
OCEAN DR
MOUNTAIN VIEW RD
FERNTREE CT
BROTHERGLEN DR
TWILIGHT CL
THE SILHOUETTE
BOTANIC DR
A
B
C
D
E
0
500
Metres
N

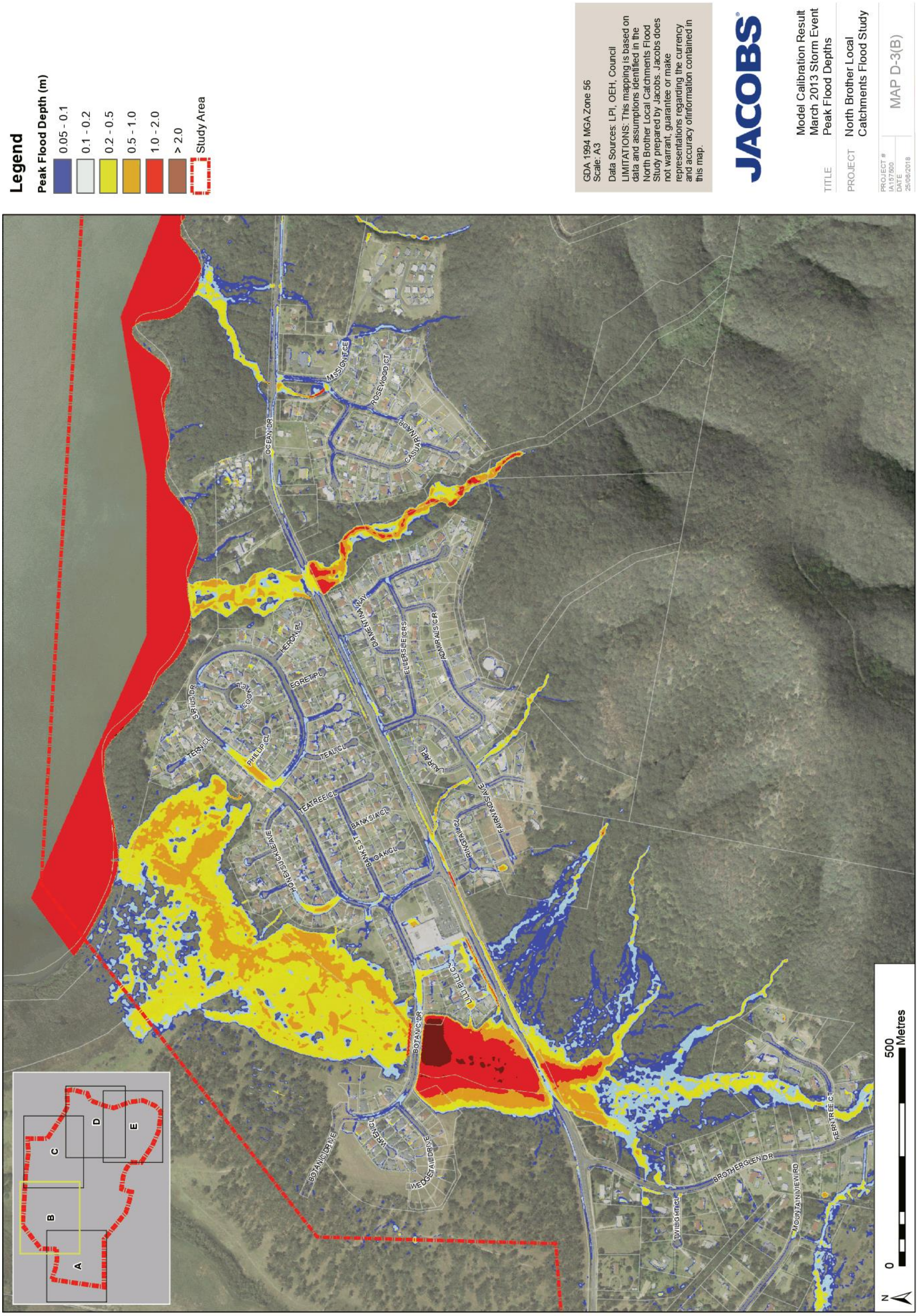

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE Model Calibration Result April 2008 Storm Event Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP D-2(B)
0
500 Metres
N

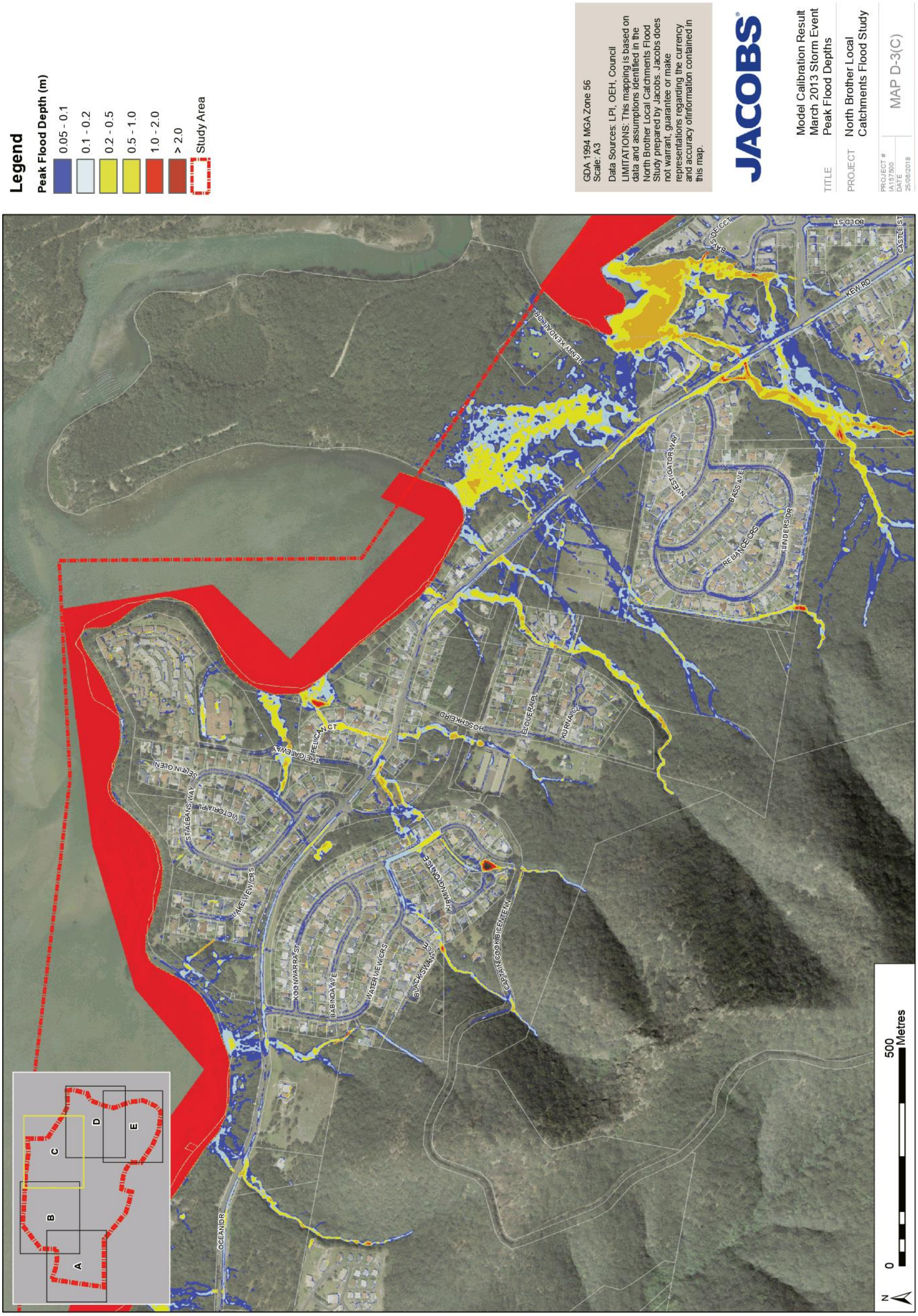

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE Model Calibration Result April 2008 Storm Event Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP D-2(C)
0
500 Metres
N
A
B
C
D
E

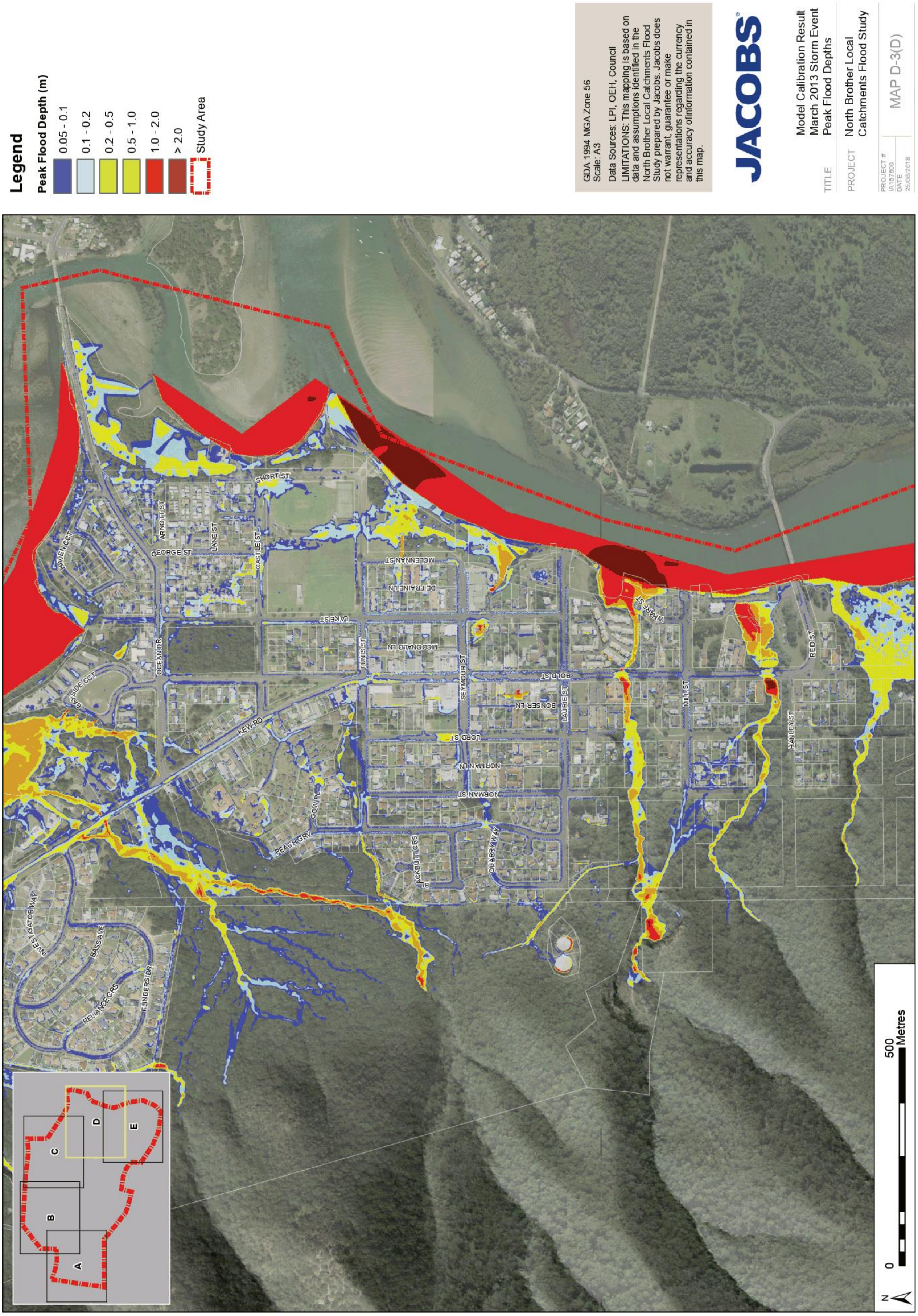

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE Model Calibration Result April 2008 Storm Event Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP D-2(D)
SHORT ST
ARNOTT ST
GEORGE ST
LANE ST
CASTLE ST
MCLENNAN ST
DE FRAINE LN
LAKE ST
MCDONALD LN
TUNIS ST
SEYMOUR ST
BOLD ST
BONSER LN
LAURIE ST
LORD ST
NORMAN LN
NORMAN ST
WHARF ST
MILL ST
REID ST
HANLEY ST
OCEAN DR
KEW RD
PEACH GR
QUARRY WAY
BASS AVE
RELIANCE CRS
A
B
C
D
E
0
500
Metres
N

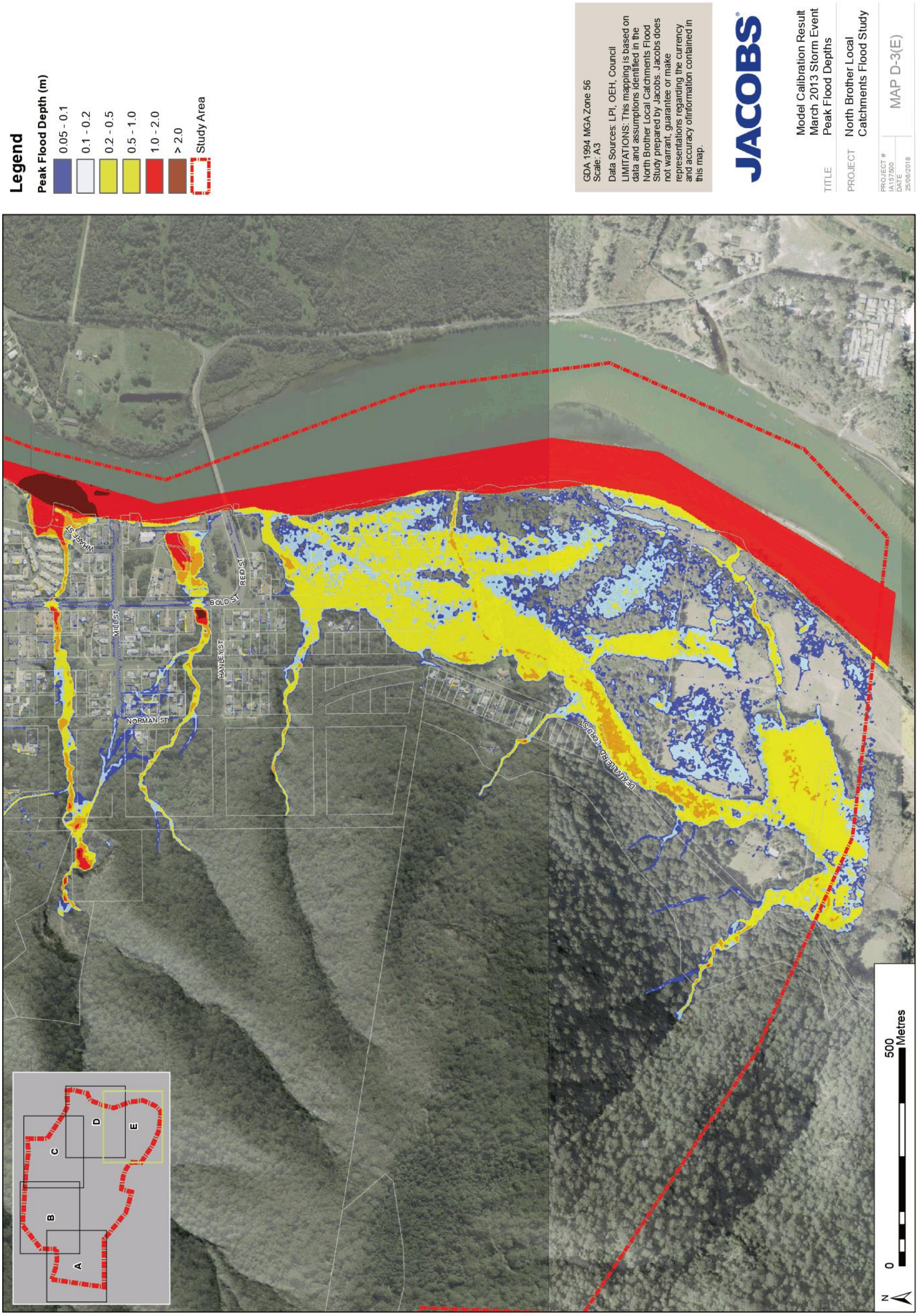

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE
Model Calibration Result
April 2008 Storm Event
Peak Flood Depths
PROJECT
North Brother Local
Catchments Flood Study
MAP D-2(E)
BOLD ST
REID ST
HANLEY ST
NORMAN ST
A
B
C
D
E
0
500
Metres
N


Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE Model Calibration Result March 2013 Storm Event Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP D-3(A)
BOTANIC DR
LILLI PILLI CL
WEDGETAIL DRIVE
FERNTREE CT
BROTHERGLEN DR
BLUE GUM PL
THE SILHOUETTE
MOUNTAIN VIEW RD
TWILIGHT CL
OCEAN DR
A
B
C
D
E
0
500
Metres
N


Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE Model Calibration Result March 2013 Storm Event Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP D-3(B)
0
500 Metres
N
A
B
C
D
E


Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE Model Calibration Result March 2013 Storm Event Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP D-3(C)
0
500
Metres
N


Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE Model Calibration Result March 2013 Storm Event Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP D-3(D)
SHORT ST
ARNOTT ST
LAKE ST
CASTLE ST
GEORGE ST
HAVEN CCT
MCLENNAN ST
DE FRAINE LN
MCDONALD LN
TUNIS ST
SEYMOUR ST
BOLD ST
BONSER LN
LAURIE ST
WHARF ST
MILL ST
RED ST
HANLEY ST
LORD ST
NORMAN LN
NORMAN ST
OCEAN DR
BAYSIDE CCT
KEW RD
PEACH GRV
QUARRY WAY
INVESTIGATOR WAY
BASS AVE
RELIANCE CRS
A
B
C
D
E
0
500
Metres
N



Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
GDA 1994 MGA Zone 56
Scale: A3
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LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE
Model Calibration Result
March 2013 Storm Event
Peak Flood Depths
PROJECT
North Brother Local
Catchments Flood Study
MAP D-3(E)
WHARF ST
BOLD ST
REID ST
MILL ST
HANLEY ST
NORMAN ST
0
500
Metres
N
A
B
C
D
E

Table C-1 Verification of Model to Flooding Reports and Observations

Note – Addresses of properties with flooding generally have been suppressed in case of community sensitivity to such information being released.

ID	Event date/s	Description of Previous Flooding	Modelled Flood Behaviour
2	2004, 2008, 2011, 2013, 2015, 2016	Depths about 2/3 metre with exceedingly strong flow. Duration from 2 to 5 hours approx. depending on strength of storm. Locations from blocked drain - around and under house with sandbags keeping water out. Flooding around and in house on at least 3 occasions with major water damage	Ok, 0.55m in 2008 simulation
3	2015?	"Moderate" damage to garage, garden/yard. photos show large flow of water through garage and trying to exit via closed roller door. Door panel is bowing due to force of water. Approx. 1-2 brick courses deep at front/leeward side of house/garage	Model shows flows 0.2 m deep at west side of house
4	No flood event specified	Some flood dates: 5/11/2010, 13/6/2011, 8/10/2011, 28/1/2013.Had to sandbag near garage door. Photo of 8/10/2011 shows shallow ponding, to say 50mm deep in backyard.	Model results show 0.05 - 0.12m ponding in backyard
5	No flood event specified	Property reported as flood affected	Affected by overflows from fire trail. Shallow depths
9	No flood event specified	Have installed extra drainage and downpipes and regraded concrete driveway to try to improve drainage but has not been enough.	Overflows from grassed swale in street into driveway and property
10	No flood event specified	Shallow sheet flow on front lawn. Retaining wall collapse	Model shows shallow flows on lawn. Retaining wall collapse appears to be due to slumping of saturated soil.
18	2002, 2004, 2013	Photos March 2013, 2002 and 2004 of flow through yard and down driveway of neighbouring property then down road. 100-200mm deep at hills hoist in 2004 flood. Approx. 500mm deep against fence in 2004 flood. Timber paling fence panels washed out. 100 - 200mm diameter rock rubble deposited in yard.	160mm at hills hoist, 400mm at fence in 2008 sim. Flood patterns similar to 2013 simulation. Photos including depths and flows from front of property around side of house to back, also swift flows in next door driveway
23	5/2/2002, 11/2004, 2011, 2013	There is creek/waterhole at the back fence and in June our yard went under as this broke its banks and flowed across the property to the drain which was in when I bought the place in 2013.	Breaks out of flow path and flows across property
26	No flood event specified	Carpets replaced in 2000 due to flooding, no flooding reported for other years.	Model shows flooding at front of house 0.2m in 2008 simulation. Ok, probably not high enough to get into house.
34	Mar 2013, June 2017	NONE- PARKED CAR MOVED WITH WATER ON ROAD- MARCH 2013	Significant depths in 2008 simulation
38	March 2013	back patio approx. 50mm depth, sandbagged to prevent ingress to house. Backyard to 100mm approx.	50 - 100mm in backyard and patio

42	2001 (not consistent with BOM daily), 30/11/2011	2001- 313mm in one hour. End house (No 8) had water right through- ruined floor coverings, about 0.5m to 0.6m of water over the street, and Honeysuckle as well. 30/10/2011- Huge storm- hail and rain	0.5 - 0.6m in street in 2008 simulation, reasonable match
60	2015	There was also 2 black plastic grated pits that also could not cope with this deluge resulting in water 4 - 6 inches deep running over pebblecrete and concrete. Internal damage. The water entered through weep holes in lounge room only.	Report appears mostly property drainage related. Some localised ponding around dwelling
61	2-3/3/2013	water rushing through and down properties next door and down the street flooding, the water was coming down from across Ocean Drive into the back of said properties. Houses down the street were being	Depths 0.2 - 0.4m in the area
65	No flood event specified	Reports of significant surcharge from stormwater pit	Model shows surcharge flows of 0.9m³/s
68	2013?	Road was flooded approx. 6 years ago due to very heavy rain and blocked storm drains.	Flooding 0.3 - 0.5m deep in 2013 event
79	June 2008	The water from no. 7 unit 2, then streamed down in front of unit 2 and into no. 6, which together with the water from no. 1 flooded unit 2. (SES attended, leaving sandbags). Resulting in resident in 2/6 getting out of bed into 10cm of water. Carpet was replaced throughout and some lounge furniture was ruined.	Model shows overflow from drain and flooding around Unit 2 to depths of 0.3m and adjacent properties but no overflows through no 7 (or 5). Possibly improvements made to drain in recent years
86	No flood event specified	Flows emerge into yard via piping in subsoil from drain uphill of property	TUFLOW model does not simulate subsoil flows but shows surface flows overflowing from drain
87	5/02/2002	There has only been one occasion that water has gone through my yard, that was due to a cloud burst that produced around 10 inches in a short amount of time. The gully above me could not cope with this downfall. Not sure of the year, think it was either 2002 or 2003. Date of downpour 5th Feb 2002- record from local historians.	Minimal overflow in 2008 sim. Observation was 2002. Condition of gully may have changed over time
89	No flood event specified	Overflowing drainage at Ocean Drive past Christmas Cove Caravan park and before Fairwinds on Southside of road. Threatening water just east of Brother Glen Road on south side of road. See markings on map I have made to indicate where flooding has occurred.	Significant flooding over Ocean Drive west of Lake
90	2001	The February 2001 event was the worst one we have had with the stormwater rushing down the Pelican Court extension road halfway up my thighs, about 2'6" deep.	0.6m in walkway. unsure if current drainage was th
93	03/2013, 3/2014	Both march 2013 and 2014 the reserve was flooded behind us, see photos.	Model shows similar flood behaviour.
95	15/03/2017	No problems observed in 6 years of residing at this address.	No flooding - ok

100	No flood event specified	Map indicates flooding around Quarry and Mill Street area	Model indicates flood flows from fire trail and adjacent areas 3cumecs in 2008 simulation
102	No flood event specified	House #1 has had water lapping their premises and I have seen photo's of #3 flooded. The last flood we had seen the water lapping the fence lines and flooding the Haven Caravan Park. Everyone moved their cars in our drive. We need something done with the open gully running down the Street to the river.	Model shows ponding and overflows from roadside drain
114	No flood event specified	The block where the units are was taking all the water into its yard, now it is coming our way more than ever.	Model replicates observed flood behaviour
124	No flood event specified	Garage floods every time there is heavy rain- suspected underground watercourse	TUFLOW model does not simulate subsoil flows but shows surface flows overflowing from drain
129	5/02/2002	As we live on the corner of Laurie Street and Quarry Way we only suffered surface water on the lawn. however, units on the corner of Lord Street and Seymour Street had a brick fence washed away, the Hotel bottle shop, as well as the shops in the arcade were flooded and Bold Street was underwater.	Significant flooding in Bold St and at Seymour/Lord St in 2008 simulation
132	No flood event specified	When heavy rain is falling consistently, our courtyard floods from the house behind our villa	Model shows overflows from Peach Grove and through adjacent property with depths over 200mm in 2008
142	No flood event specified	Property reported as flood affected. No specific observation given.	Model shows flooding of property
157	No flood event specified	Marked as property flooded but no specific report	Not on flow path. Minor ponding of local runoff on uphill side of house
159	No flood event specified	Marked as property flooded but no specific report	Not on flow path. Minor ponding of local runoff on uphill side of house
167	No flood event specified	In the past damage has occurred to the cyclone mesh fence parallel to the gateway Rd in the vicinity	Significant depths of flow against fence likely to result in damage
170	No flood event specified	Trees and debris in drain behind house contribute to flooding into backyard	Model shows flooding into backyard and also overflows from street, ok
176	April 2000	April 2000. Approx. 1/2 metre deep in roadway. Did not get into our house but came close	1m in road in 2008 sim need to trial with rerun si
183	No flood event specified	Flooded several times in the past. Washed away reconstructed bitumen driveway next door.	Whole property flooded including depths of up to 0.3m around the dwelling in 2008, 0.2 in 2013. Ok
187	No flood event specified	Property Almost flooded - top side of land adjoining house about 15cm deep in water	Not on flow path. Model shows ponding to 0.2m on high side of house
199	No flood event specified	In 16 years of living in the said address I have experienced flooding of the road on 2 occasions. Water to the base of my dwelling to a depth of 1m on the road.	Flood depths to 1m in road sag nearby. Minor ponding at subject house.

202	No flood event specified	Overflows from laneway resulting in damage and damp in the house	Not adjacent to a flow path or significant drain. May be local or road runoff directed to the path a
205	March 2016	March 2016 the street outside my property was under approx. 500mm water. The easement down the side was a river. This occurred about 2am. By 9am the water had subsided. Following the drain being cleared of debris the drain has been flowing OK since then however the event happened again around the same time this year.	0.5-0.6m in street 2008, significant flow in easement, ok
209	No flood event specified	Creek through property between villas breaks banks and floods through properties, debris blockages of channel.	Model replicates flooding of property in each calibration event
215	No flood event specified	Property reported as flood affected.	Flooding of property and road
218	2011 2013	The fire trail behind this property was flooded twice after two separate rain storms when 250mm of rain fell about 2011 and 2013. The fire trail was overgrown with vegetation and tree branches which resulted in water about 100mm deep running over the bank and into adjacent properties. This runoff ran under the homes and into the garages. the water in the side of my house banked up and ran into the weep holes in the brickwork.	Flows down side of house. Shallow to 0.1m, some lo
219	No flood event specified	Stormwater drain on Peach Grove (located on the kerb closest to the reserve and opposite the intersection often floods in heavy rain	Sag is flooded to depths of 0.3m in the 2008 simulation
222	No flood event specified	Stormwater overflows from road	model reflects observations
228	No flood event specified	Nuisance flooding apart from river flooding	Shallow ponding and model matches observations
232	No flood event specified	Flooding damage required repairs by insurer	Model shows flooding at rear of house to 0.3m
252	No flood event specified	Photos will show as the watercourse is not sufficient to handle the amount of water and bursts its banks and floods several properties	Model replicates this flood behaviour in 2008 and 2013 simulations.
256	No flood event specified	Property flood affected - minor	Shallow ponding in backyard 0.05 - 0.1m
262	No flood event specified	The corner intersection of Tunis Street and Lake Street always has problems with flooding.	Widespread shallow flooding at intersection of Lake St and Tunis St and flooding of adjacent property
280	No flood event specified	Creek through property between villas breaks banks and floods through properties	Model replicates flooding of property in each calibration event
285	No flood event specified	Property flooded	Significant flooding of property
1001	March 2013 daytime	Swift flows in walkways between buildings. Approx. 300mm deep, >1m/s down walkway	Flow depths 0.3m and velocities 1.5-2m/s in 2013 simulation

Flinders Drive Laurieton	No flood event specified	Previous work done with drainage and regrading verge. Flooding Feb 2008 into garage and nearly front door. Concern that runoff from next door new development is being directed to subject property.	Overflows from road and ponding in driveway and front yard to 0.3-0.4m. in April 2008 simulation.
Lake Street Laurieton	No flood event specified	Water covering Lake Street, Ocean Drive. 50-100mm in car port of property. Five properties in Lake St and Laurieton Gardens Caravan Park also Ocean Dr affected. Photos provided.	100mm flood depths in the driveway of property and car port
Lake Street Laurieton	No flood event specified	Property has flooded 4 times since 2010. Not until units next door were built 2 properties up the street.	Model replicates observed flood behaviour
Flinders Drive Laurieton	2008	Photos attached. Significant flows in rear swale and through fences into property, rubble deposited	Model results of flow depths up to 0.3 – 0.5m with flow patterns (flows through fence) match the April 2008 photos.
Quarry Way Laurieton	2013	Heavily overgrown, many trees down in drain. Reported up to 1m depths in March 2013 on adjacent properties. Sections very porous with springs popping up	Flows in drain immediately behind properties to 0.2m in the March 2013 event, maximum depths of 0.7m on properties.
Castle Street Laurieton	No flood event specified	Excessive stormwater onto property, lapping at back steps and under house	Flood depths 0.2 – 0.3m on low side of house. Reasonable match to observation.
Dalton photo 2008_010 to 014, 049	2008	Flows in swales draining to Pelican Court appear to be 0.3 – 0.5m deep but after peak of storm	Model shows depths of 0.7 – 1.2m at peak of storm.
Dalton photo 2008_015	2008	Photo shows flooding over road verge to property fence line, depths of 0.1-0.2m against brick wall	Model shows depths to 0.1m and similar extent
Dalton photo 2008_019	2008	Photo shows large quantity of rubble and gravel deposited on driveway from adjacent creek	Good match by model to observed flood behaviour with depths 0.3-0.4m in peak
Dalton photo 2008_016	2008	Photo shows S/W side of Ocean Drive east of Flinders Drive flooded, flows just overtopping crown of road, after peak of storm	Peak depths overtopping crown are 0.15m in 2008 simulation
Dalton photo 2008_024	2008	Flooding of Flinders Drive/Ocean Drive intersection to estimated 0.2-0.3m after peak of storm	Peak depths overtopping crown are 0.3-0.4m in 2008 simulation
Dalton photo 2008_047	2008	Rosewood Court at Mission Terrace, flows in road up to approx. 0.2m	Peak depths in intersection 0.3-0.4m in 2008 simulation

JACOBS

North Brother Local Catchments Flood Study

Port Macquarie Hastings Council

Draft Flood Study Report

Version A

14 January 2019

IA157500

Draft Flood Study Report

JACOBS

North Brother Local Catchments Flood Study

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Document history and status

Revision	Date	Description	By	Review	Approved
A	14/01/2019	Draft Report	L Chong	A Hossain	A Hossain

Contents

Appendices

Foreword

The primary objective of the New South Wales Government's Flood Prone Land Policy is to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods, utilising ecologically positive methods, wherever possible. Under the Policy, the management of flood prone land remains the responsibility of local government.

The policy provides for a floodplain management system comprising the following five sequential stages:

1.	**Data Collection**	Involves compilation of existing data and collection of additional data
2.	**Flood Study**	Determines the nature and extent of the flood problem
3.	**Floodplain Risk Management Study**	Evaluates management options in consideration of social, ecological and economic factors relating to flood risk with respect to both existing and future development
4.	**Floodplain Risk Management Plan**	Involves formal adoption by Council of a plan of management for the floodplain
5.	**Implementation of the Plan**	Implementation of flood, response and property modification measures (including mitigation works, planning controls, flood warnings, flood preparedness, environmental rehabilitation, ongoing data collection and monitoring by Council

Port Macquarie Hastings Council is undertaking this study for the North Brother Local Catchments study area to investigate the existing and future flood risks in accordance with the NSW Government's *Floodplain Development Manual*. The study identifies and assesses potential flood mitigation options and guides land use planning and future development on the floodplain in the study area.

This study represents Stages 1 to 4 of the management process and has been prepared for Council by Jacobs. This is the Draft Report of the Stage 1 and Stage 2 of the study.

Executive Summary

Background

Jacobs was engaged by Port Macquarie Hastings Council (Council) to undertake a flood study and a floodplain risk management study of the North Brother Local Catchments area. The study area is located on the Mid North Coast of NSW, and includes parts of the villages of Kew, Lakewood, West Haven, Laurieton and Deauville which are situated at the foot of North Brother Mountain.

Study Area

The study area comprises the northern and eastern faces of the North Brother Mountain and the associated urban areas between the foot of the mountain and the adjoining receiving waters. It has an approximate area of 1,852ha, with the North Brother Mountain extending to a height of 490m AHD, dominating the landscape. The upper reaches of the study area are predominantly the Dooragan National Park, containing the North Brother Mountain itself, below which is situated the Laurieton CBD, various vegetated natural gullies and flow paths as well as significant established low and medium density residential, caravan parks and holiday accommodation precincts. The topography within the catchment varies significantly with the upper parts of the catchment being very steep in nature (grades of up to 50%), the mid zone is moderately graded (slopes in the order of 10-15%), and lower areas adjoining the Camden Haven River floodplain being reasonably flat (grades averaging 5%). The relatively short flow path lengths between the foot of the North Brother Mountain and the adjoining downstream receiving waters mean that stormwater flows are fast flowing.

Development of the study area has been occurring from the early 1900's through to the present day with the majority of development having occurred between 1970 - 2000. The construction of associated drainage infrastructure has also primarily dated from this time, with the result being that the majority of watercourses stemming from the North Brother Mountain have either been built over, filled, redirected, piped or crossed by road embankments, often resulting in urban development occurring on flood prone lands. Urban development at the foot of the Mountain is typically bounded by diversion drains and largely natural gullies which generally direct large volumes of stormwater runoff safely around developed lands and into the downstream waterways. However, developments have occurred in some locations in close proximity to natural watercourses and man-made surface drainage and are at risk to flooding when the drainage capacities are exceeded. In addition, localised flooding in some areas are exacerbated by mainstream flooding in Queens Lake, Stingray Creek and Camden Haven River.

Available DataA range of data was obtained by Jacobs or provided by Council and other agencies for this study. The data includes reports of studies that have been undertaken in the area; spatial data including stormwater assets, aerial photography and other GIS layers; recorded rainfall, water level and tide data; and flood modelling data including drainage models of West Haven. Additional topographic survey as collected of selected hydraulic structures, open channels and other topographic features in January – February 2018

Community Consultation

Community consultation undertaken for the study included overviews and updates of the study posted on Council's website, a newsletter and questionnaire mailed out to the community, and community information sessions during the calibration stage of the flood model.

Hydrologic and Hydraulic Modelling

The hydrologic modelling adopted in the study to estimate rainfall-runoff involved lumped catchment modelling approach for the watercourses draining off the mountain, and a direct rainfall approach for the more dispersed overland flow catchment areas at the foot of the mountain. The lumped catchment modelling was undertaken in DRAINS software with the RAFTS hydrologic module estimates inflow hydrographs (flow versus time) which were input into the hydraulic model for the watercourses and overland flow paths. The direct rainfall approach input rainfall versus time data onto the modelled catchment surface in the hydraulic model itself, which then generated estimated flows internally in the model.

A TUFLOW combined one-dimensional (1D) and two-dimensional (2D) hydrodynamic model was developed for this study. The TUFLOW model is comprised of:

- A 2D domain of the study area surface reflecting the catchment topography, with varying roughness as dictated by land use. The watercourses are in general modelled in 2D and diversion drains are modelled in 2D.
- A 1D network of pits, pipes and culverts representing the stormwater network. The pits have a defined inflow capacity as dictated by their type and size.
- Obstructions to flow are represented as 2D objects, including existing buildings.

The flood model was calibrated and verified to the historic flood events of April 2008 and March 2013, based on residents' observations during these flood events reported in the community questionnaire.

Design flood events including the 0.2EY and 5%, 2%, 1% and 0.5% AEP and the Probable Maximum Flood (PMF) events were analysed for current climate conditions. Flood behaviour was estimated for a climate change scenario comprising the 1% AEP plus 10% increase in rainfall plus 0.9m sea level rise. Flood mapping of depth and flow velocity was undertaken for all event AEPs.

Flood Behaviour

Overland flow depths on properties are typically up to 0.3m in the 1% AEP event. Depths exceed 0.5m in a number of locations in the 0.2EY event, and exceed 1m in the 5% and 1% AEP events. Areas of deeper flows include main flow paths and drainage low points in a number of roads. During the PMF event, property and road flooding exceeding 0.5m depth is widespread, with property and road flooding of 1m depth also common. Depths of flooding exceeding 2m occur on approximately 20 properties in the study area.

Flow velocities are fast in a number of overland flow paths through properties and particularly on roads. Typical flow velocities are 0.5 – 1m/s in the 0.2EY event, and 1 – 1.5m/s in the 1% AEP event. High flow velocities of 2 – 3m/s occur in a number of locations including roads and properties. These flows are likely to be highly hazardous to people and risk significant damage to buildings and property. Flow velocities of 3 – 4m/s are commonplace in the PMF, with some locations experiencing velocities over 4m/s.

Overland flooding in the study area is generally a result of intense short-duration rainfall events. As a result, the duration of inundation of roads and built areas is typically short, limited to 1 – 2 hours in up to the 0.5% AEP event. Flood storage areas such as road sag points in Sirius Drive and Lilli Pilli Close in Lakewood may be inundated for longer durations of up to 3 hours due to constrained capacities of stormwater drainage servicing these areas. Durations of inundation are likely to be 1 – 4 hours in the PMF with longer durations affecting some flood storage locations and roads including Botanic Drive and Ocean Drive west of Lakewood shopping centre. Note that the duration of flooding for depths greater than 0.3m, at which stage floodwaters become impassable for most passenger vehicles, is generally limited to approximately 1 hour duration in most roads. A river flooding event may occur shortly after overland flooding in the study area, in which case the low-lying areas of the study area may experience extended durations of flooding.

In the climate change scenario, most areas affected by overland flow experience flood level increases of up to 0.1m due to increased rainfall and reduced drainage capacity from higher tailwater levels caused by sea level rise. Locations along the river and lakes would be impacted by 0.9m increases in flood levels directly due to sea level rise, while adjacent areas would be impacted typically by up to 0.5m increases in flood level. Note that these impacts are estimated based on the overland flooding assessment of North Brother. Increases in flood levels due to climate change effects on riverine flooding may be different, refer to the Camden Haven River and Lakes Flood Study (Worley Parsons, 2013).

Flood Hazard Mapping

The flood hazard categories were defined based on the Australian Institute of Disaster Resilience (AIDR) categories and mapped for the 1% AEP current climate and climate change scenarios. There are numerous areas of high flood hazard (>H5) typically reflect the swift overland flows in watercourses and flow paths including roadways.

Flood hydraulic categories were mapped for the 1% AEP current climate and climate change scenarios. Floodway areas are generally located within the natural watercourses and flow paths, although there are a number of roads which contain floodways throughout the study area. Floodways pass through properties on Black Swan Terrace, Koonwarra Street, Pelican Court, Elouera Place, Flinders Drive, St Joseph's School, Peach Grove, Gow Place, Kew Road and in Laurieton between Quarry Place and Bold Street, among others.

Flood Problem Areas

Flooding hot spots are identified in the flood study, confirming problem areas previously identified by Council. The hot spots are summarised in Table 1 below. Critical areas with consideration of high flood depths, velocities or hazard are highlighted with orange cell or text shading. In summary, the identified critical locations include:

- Black Swan Terrace, West Haven
- Kirmington Terrace, Koonwarra Street, Captain Cook Drive villas and Ocean Street property and Pelican Court, West Haven
- Bold Street, Laurieton
  - Laurieton Hotel and adjoining areas
  - Harbourside Crescent villas
- Lake Street property, Laurieton. Corner Seymore Street
- St Joseph's School, Laurieton
- Lilli Pilli Close, Lakewood (road flooding).
- Sirius Drive, Honeysuckle Avenue and Mahogany Close, Lakewood (road flooding).
- Ocean Drive between Fairwinds Avenue and Mission Terrace (road flooding).
- Pelican Court, West Haven (road flooding).
- Waterview Crescent, Kirmington Terrace and Koonwarra Drive, West Haven (road flooding).
- Bold Street between Laurie Street and Mill Street (road flooding).
- Lord Street at Seymour Street, Laurieton (road flooding).

Table 1 Description of Flooding Hot Spots

Location	Description
Property flooding	
Black Swan Terrace, West Haven	Flow depths on properties of up to 0.5m in the 0.2EY event and up to 0.7m in the 1% AEP event. Swift flows of 2m/s. Flood hazard up to H5 rating in the 1% AEP event.
Ringtail Cl, Lakewood	Overflows from open channel onto properties with flooding in backyards to depths 0.2 – 0.3m in the 1% AEP event. Relatively low flooding impact.
Lilli Pilli Cl, Lakewood	Flooding in backyards to depths of 0.3 – 0.5m in the 1% AEP event from open drain overflows. Flooding in cul-de-sac to depths up to 0.8m. Also significant flooding of car park around Lakewood shopping centre.
Mission Terrace, Lakewood	Overflows with depths of 0.1 – 0.3m in the 1% AEP event from cul-de-sac onto downhill property. Overflows from the overland flow path on to uphill side properties with depths up to 0.2m
Kirmington Terrace to Pelican Court, West Haven	Flows through properties on low side of Koonwarra Street of 0.3m in the 0.2EY event and exceeding 0.5m in the 1% AEP event. Velocities up to 2m/s in the 1% AEP. Flood hazard up to H4 (some localised H5) rating in the 1% AEP. Flow depths 0.5m in the 0.2EY event and up to 0.8m in the 1% AEP event on Captain Cook Bicentennial Drive villas and Ocean Drive property, at dwellings. Flood hazard up to H4 rating in the 1% AEP event. Flood depths of 0.6 – 0.8m in the 0.2EY event within Pelican Court roadway and pedestrian walkway. Depths up to 0.6m at dwellings in 1% AEP event. Flood hazard up to H4 rating on properties and H5 in roadway in the 1% AEP event. Groundwater springs occur in this area but are not directly related to the surface water flood risk. These springs appear to be a spatially random occurrence.
Flinders Dr Estate, Laurieton	Overflows from drainage easement swale onto properties with depths to 0.3m in the 0.2EY event and 0.5m in the 1% AEP event. Overflows from Reliance Crescent sag point onto properties to depths of 0.2m in the 0.2EY event and 0.4m in the 1% AEP event.
Bold Street area, Laurieton	Significant flows through Laurieton Hotel with H4 hazard rating. Trapped drainage point on western side of commercial properties with significant depths, though local drainage may be present which would mitigate the flood depths. Overflows down fire trail at Norman Street/ Mill Street affecting properties with depths up to 0.3m in the 1% AEP. Overflows onto units on Harbourside Crescent from trunk drainage channel to depths exceeding 0.5m in the 1% AEP event, with H5 hazard rating.
Quarry Way, Laurieton	Overflows from flow diversion drain to depths of 0.5m in the 1% AEP event on properties. The drain is reported to be affected by significant debris blockage.

Lake Street, Laurieton	Flood depths up to 1m in the 1% AEP event affecting dwelling corner Lake Street and Seymour Street, unsure if above floor flooding. To be confirmed. Overflows from Lake Street onto properties between Ocean Drive and Castle Street to depths of 0.3m in the 1% AEP.
St Joseph's School, Laurieton.	Swift flows in overland flow paths to depths of 0.8m and velocities exceeding 2m/s in the 1% AEP event. Flows between buildings are 0.4m in the 0.2EY event and 0.6m in the 1% AEP event, with velocities up to 2m/s. Flood hazard rating of H4 in pedestrian walkways and H5 in overland flow paths in the 1% AEP event.
Properties adjacent to Stingray Creek and Camden Haven River, Laurieton	Numerous properties on low-lying land at risk of oceanic inundation during storm surge events. Estimated depths on the flood mapping expected to be conservative due to likely attenuation of ocean inflows through the river mouth.
Blackbutt Crescent and Peach Grove, Laurieton	Overflows from flow diversion drain to depths of 0.5m in the 1% AEP event on properties. The drain form and capacity significantly reduces near its discharge point onto Peach Grove at Tunis Street. Flows into the drain originate from natural watercourse further uphill, which is significantly affected by rubble and debris blockage.
Elouera Place, West Haven	Overflows from watercourse and diversion drain. Depths over 0.3m in the 0.2EY event and 0.5m in the 1% AEP event.
Sirius Drive, Honeysuckle Avenue and Mahogany Close, Lakewood	Flood depths on properties 0.3 – 0.5m in the 1% AEP event, built up from road ponding areas.
Sirius Drive and Oak Close, Lakewood	Depths 0.3 – 0.4m and velocities 1m/s in the 1% AEP event.
Sandpiper Close	Overflows from concrete channel along Ocean Drive. Depths 0.3 – 0.4m and velocities 1m/s in the 1% AEP event.
Properties on lower side of Ocean Drive, 200m east of Hoschke Road, West Haven	Road low point overflows onto properties with depths of 0.5m and velocities of 1m/s in the 1% AEP event.
Roads	
Ocean Drive west of Lakewood shopping centre	5% AEP event flood depths of 0.4m 1% AEP event flood depths of 0.5m, H3 hazard rating
Botanic Drive, Lakewood	1% AEP event flood depths of 0.4m, H2 hazard rating
Lilli Pilli Close, Lakewood	5% AEP event flood depths of 0.6m 1% AEP event flood depths of 0.7m, H3 hazard rating
Ocean Drive east of Lakewood shopping centre	5% AEP event flood depths of 0.3m 1% AEP event flood depths of 0.35m, >H4 hazard rating
Sirius Drive, Honeysuckle Avenue and Mahogany Close, Lakewood	0.2EY event flood depths of 0.6 – 0.7m 1% AEP flood depths 1m, H3 hazard rating
Ocean Drive between Fairwinds Avenue and Mission Terrace	0.2EY events flood depths of 0.5m 1% AEP event flood depths of 0.7m, >H4 hazard rating
Ocean Drive and Mission Terrace intersection	0.2EY event flood depths of 0.4m 1% AEP event flood depths of 0.6m, H3 hazard rating
Ocean Drive near Waterview Crescent	5% AEP event flood depths of 0.2 – 0.3m

	1% AEP event flood depths of 0.3m, low hazard rating but long section of flooding
Ocean Drive near Pelican Court	5% AEP event flood depths of 0.3m 1% AEP event flood depths of 0.4m, H3 hazard rating
Pelican Court, West Haven	0.2EY event flood depths 0.6m 1% AEP event flood depths of 1m, H5 hazard rating
Waterview Crescent, Kirmington Terrace and Koonwarra Drive, West Haven	0.2EY event flood depths of 0.2m with 2m/s velocity; max 0.6m depths (low velocity) 1% AEP event flood depths up to 0.7m, H5 – H6 hazard rating
Ocean Drive east of Hoshcke Road	0.2EYevent flood depths of 0.4m 1% AEP event flood depths of 0.5m, H3 hazard rating
Ocean Drive east of Flinders Drive	5% AEP event flood depths of 0.3m 1% AEP event flood depths of 0.4m, H3 hazard rating
Kew Road/Bold Street near Tunis Street, Laurieton	1% AEP event flood depths of 0.5m, H2 hazard rating
Bold Street between Laurie Street and Mill Street	0.2EY event flood depths over 0.5m 1% AEP event flood depths 0.6 – 0.8m, H5 hazard rating
Bold Street north of Hanley Street, Laurieton	0.2EYevent flood depths of 0.3m with 1m/s velocity 1% AEP event flood depths up to 0.5m, H3 hazard rating
Lord Street at Seymour Street, Laurieton	0.2EY event flood depths of 0.5m 1% AEP event flood depths up to 0.7m, H3 hazard rating
Flinders Drive, Laurieton Tunis Street, Laurieton Rosewood Court and Mission Terrace, Lakewood Diamentina Way, Lakewood	H5 hazard rating on steep sections of road (1% AEP event)

Recommendations

Recommendations from this flood study include:

- It is recommended that this report be reviewed by Council prior to being placed on public exhibition for feedback from the community.
- It is recommended that Council considers the adoption of this Flood Study and the outputs to guide floodplain management and land use planning in the North Brother local catchments study area. The subsequent Floodplain Risk Management Study should consider the management of flood risk in the catchment, particularly at the identified flooding “hot spots”, which may include the development of flood mitigation strategies.
- Council should consider geological and geotechnical investigations to assess the groundwater spring issues in the study area which result in surface water discharge and subsequent property damage or are otherwise nuisance occurrences.

Important note about this report

The sole purpose of this report and the associated services performed by Jacobs is to undertake a flood study for the North Brother Local Catchments study area located in New South Wales in accordance with the scope of services set out in the contract between Jacobs and Port Macquarie Hastings Council (the Client). That scope of services, as described in this report, was developed with the Client.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

Jacobs derived the data in this report from information sourced from the Client, third parties, and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in any other context.

Topographic data used in this study included that sourced from a LiDAR survey and ground survey which were undertaken by third parties. Undertaking independent checks on the accuracy of the data was outside Jacobs's scope of work for this study.

This report has been prepared on behalf of, and for the exclusive use of, Jacobs's Client, and is subject to, and issued in accordance with, the provisions of the contract between Jacobs and the Client. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

1. Introduction

1.1 General

Jacobs was engaged by Port Macquarie Hastings Council (Council) to undertake a flood study and floodplain risk management study of the North Brother Local Catchments area. The study area is located on the Mid North Coast of NSW, and includes parts of the villages of Kew, Lakewood, West Haven, Laurieton and Deauville which are situated at the foot of North Brother Mountain. Development in the area has occurred in sometimes unsuitable locations as a result of poor drainage planning, leading to localised nuisance flooding on residential properties at a number of locations on a regular basis. Numerous gullies and watercourses drain from the North Brother Mountain through the developed areas, which over time have been piped, filled, crossed by road embankments or redirected, contributing to the existing flooding problems. Localised flooding in some areas may interact with and be exacerbated by mainstream flooding in Queens Lake, Stingray Creek and Camden Haven River.

Objectives of the study include:

- Develop and calibrate hydrologic and hydraulic models to estimate flooding conditions for a range of design events.
- Identify flood problem priority areas and identify and assess structural and non-structural mitigation measures to manage flood risk.
- Review existing planning, policy and emergency management for gaps and inconsistencies relating to floodplain planning, then develop proposed amendments to address residual flood risk.
- Prioritise the works and measures, including economic and multi criteria appraisal of options.
- Develop an implementation program for recommended works and measures including timing, responsibility and sources of funding.
- Conduct consultation with the community and key stakeholders throughout the study to obtain information and intelligence for input into the study. Gauges the perceptions of the community on flooding matters. Obtain feedback on the findings and recommendations of the study.

This Draft Flood Study Report documents the collection and review of relevant data and the development and calibration of hydrologic and hydraulic models for the purpose of defining flood behaviour for the full range of design flood events in the study area. The design flood conditions, the flood risk and flood hazard are estimated, and flooding trouble areas confirmed. Note that this study focusses on overland flooding resulting from runoff from North Brother Mountain and surrounding areas. Riverine flooding is addressed separately in the Camden Haven and Lakes System Flood Study (Worley Parsons, 2013), prepared for Council.

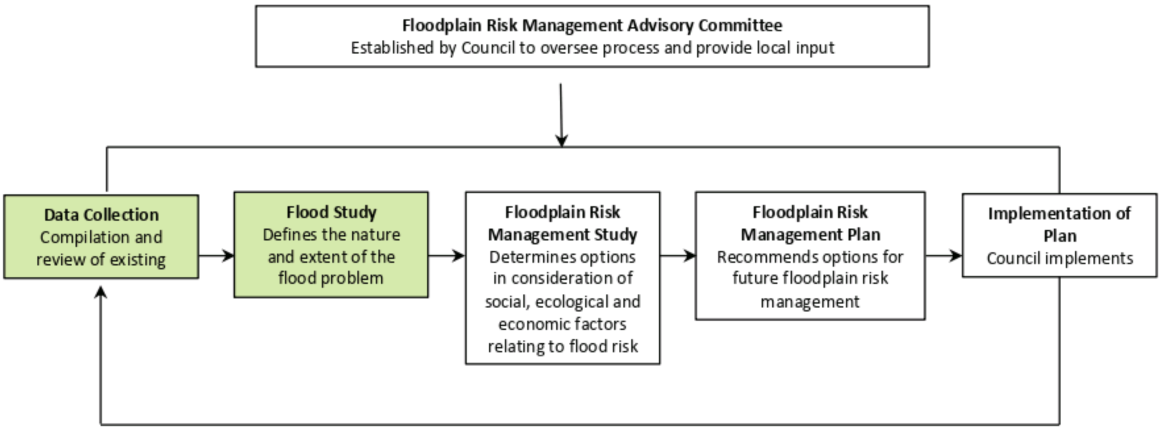
The outcomes from this flood study will form the basis for the identification, assessment and prioritisation of management measures during the subsequent floodplain risk management study and plan.

1.2 Floodplain Risk Management

Council is responsible for managing the existing, continuing and future flood risk for its Local Government Area (LGA). The floodplain risk management planning process, as set out in the *Floodplain Development Manual* (NSW Government, 2005) has a number of steps which are illustrated in Figure 1-1. The current Flood Study phase of this study defines the flooding problem. Once the Flood Study has been endorsed by Council, the study moves to the Floodplain Risk Management Study and Plan phase, which seeks to identify and prioritise feasible options for mitigating the flood risk.

The Floodplain Risk Management Advisory Committee for Council was established in 2018 and includes a number of Council Representatives, staff from the Office of Environment and Heritage (OEH), the State Emergency Services (SES), in addition to local stakeholders including community representatives.

Figure 1-1 Floodplain Risk Management Process



1.3 Structure of this Report

This report is structured by the following sections:

- Section 2 provides background on the study area.
- Section 3 reviews and describes relevant aspects of the available data
- Section 4 describes the hydrologic modelling undertaken for this study.
- Section 5 details the development of the hydraulic model.
- Section 6 discusses the calibration of the flood modelling to historic flood events, including sensitivity testing of key model parameters and assumptions.
- Section 7 discusses the approach in estimating the design flooding conditions.
- Section 8 describes the study results and flood mapping, including the scale of the flooding problem in the area.
- Section 9 provides conclusions and recommendations to this phase of the study.
- Section 10 acknowledges those agencies and organisations who assisted with the study.
- Section 11 cites the literature references.
- Section 12 provides a glossary of terms.

2. Background on the Study Area

2.1 Catchment Description

The study area is shown on Figure 2-1 and generally comprises the northern and eastern faces of the North Brother Mountain and the associated urban areas between the foot of the mountain and the adjoining receiving waters.

The study area has an approximate area of 1,852ha, with the North Brother Mountain extending to a height of 490m AHD, dominating the landscape. The upper reaches of the study area is predominantly the Dooragan National Park, containing the North Brother Mountain itself, below which is situated the Laurieton CBD, various vegetated natural gullies and flow path as well as significant established low and medium density residential, caravan parks and holiday accommodation precincts.

From the North Brother Mountain, stems a number of small, steep and unnamed local catchments which discharge to one of the many waterways surrounding the mountain:

- On the north side of North Brother Mountain is Queens Lake,
- On the east is the Pacific Ocean.
- To the south is Watson Taylors Lake (through which Camden Haven River flows), and
- On the west is the Camden Haven River

The topography within the catchment varies significantly with the upper parts of the catchment being very steep in nature (grades of up to 50%), the mid zone is moderately graded (slopes in the order of 10-15%), and lower areas adjoining the Camden Haven River floodplain being reasonably flat (grades averaging 5%).

Ground cover within the study area also varies considerably and is generally varied in accordance with slope changes. The upper portions of the catchment are heavily forested, with the mid and lower areas consisting of lawns, residential gardens, pavements and roof areas. The relatively short flow path lengths between the foot of the North Brother Mountain and the adjoining downstream receiving waters mean that stormwater flows are characteristically high energy and fast flowing.

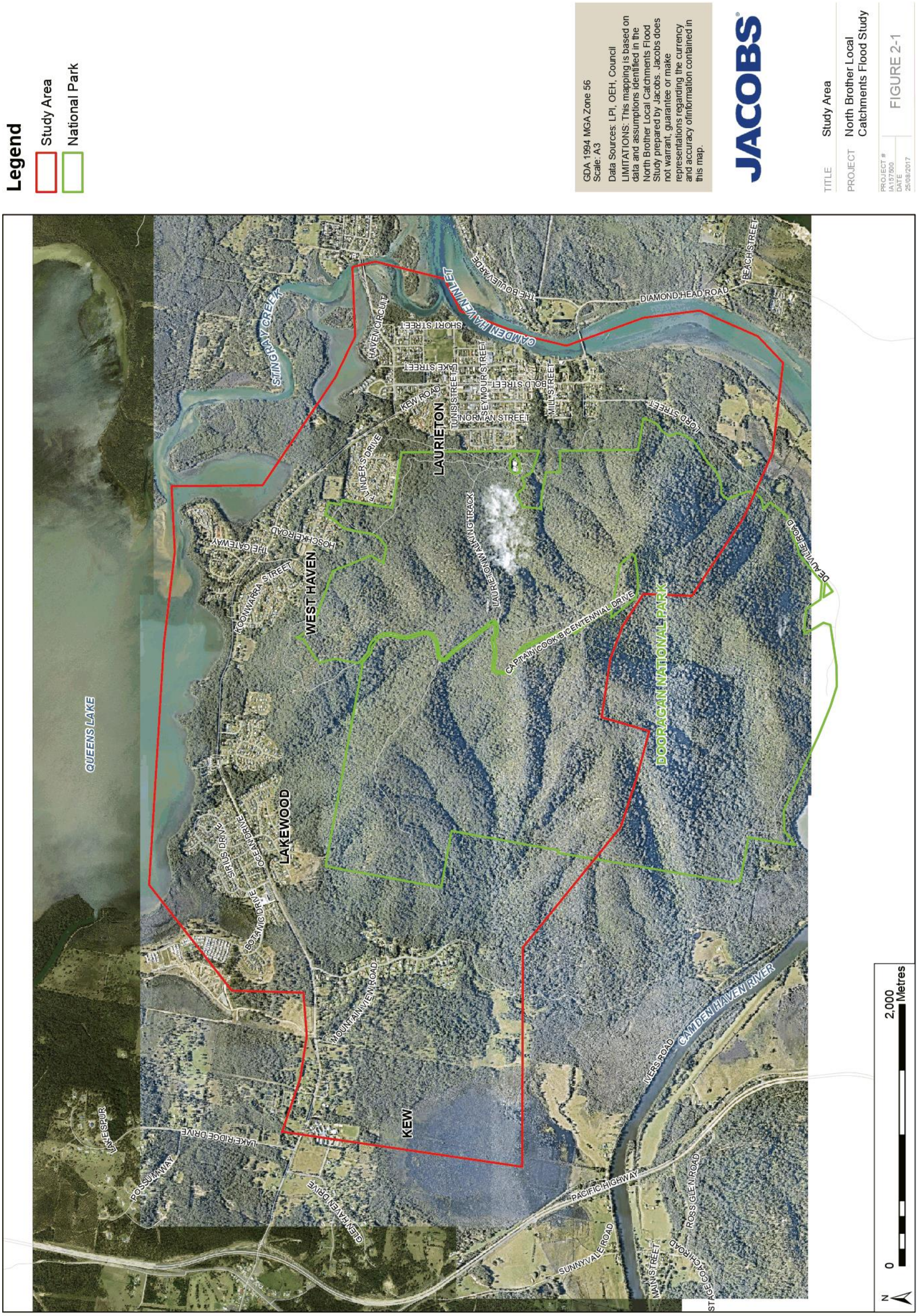
The study area experiences overland flooding originating from North Brother Mountain runoff, while areas at lower elevations are also at risk from riverine flooding from the Camden Haven River and lakes system.

2.2 Existing Development

Development of the study area has been occurring from the early 1900's through to the present day with the majority of development having occurred between 1970 - 2000. The construction of associated drainage infrastructure has also primarily dated from this time, with the result being that the majority of watercourses stemming from the North Brother Mountain have either been built over, filled, redirected, piped or crossed by road embankments, often resulting in urban development occurring in unsuitable locations.

Urban development at the foot of the North Brother Mountain is typically bounded by diversion drains and largely natural gullies which direct the large volumes of stormwater runoff generated safely around developed lands and into the downstream waterways. However as mentioned above, development has occurred in some location in close proximity to natural watercourses and man-made surface drainage and is at risk to flooding when the drainage capacity is exceeded.

Development in the study area is predominantly low-density residential, with some higher density developments located in West Haven and Laurieton, including retirement villages. Residential development is ongoing, notably in parts of Lakewood. Commercial areas are located in Lakewood and Laurieton.


Legend
Study Area
National Park
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE Study Area
PROJECT North Brother Local Catchments Flood Study
FIGURE 2-1
QUEENS LAKE
STINGRAY CREEK
CAMDEN HAVEN INLET
LAURIETON
WEST HAVEN
LAKEWOOD
KEW
DOORAGAN NATIONAL PARK
CAMDEN HAVEN RIVER
PACIFIC HIGHWAY
0
2,000 Metres

2.3 History of Flooding

A number of trouble spots and significant drainage locations were identified by Council based on previous flooding and include:

- Black Swan Terrace, West Haven
- Ringtail Cl, Lakewood
- Lilli Pilli Cl, Lakewood
- Mission Terrace, Lakewood
- Kirmington Terrace, and Pelican Ct, Westhaven
- Flinders Dr Estate, Laurieton
- Bold Street, Laurieton
- Quarry Way, Laurieton
- Lake Street, Laurieton
- St Joseph's School, Laurieton.

In several locations there are localised existing features such as open drains and diversion berms which are not currently performing properly. The heavily-vegetated upper catchments contribute significant volumes of flood debris which impacts on the capacity of the existing drainage and hydraulic structures.

Overland flooding was experienced in numerous times in recent history, with events occurring in 2002, 2004, 2008, 2011, 2013, 2015 and 2016, among others. Photos of previous flooding are shown in Section 3.7.

3. Review of Available Data

3.1 Summary of Data

A range of data was obtained by Jacobs or provided by Council and other agencies in July/August 2017 and is summarised in Table 3-1 below. The data includes reports of studies that have been undertaken in the area, drainage models, spatial data including stormwater assets, zoning and other GIS layers, photographs and resident reports of previous flooding in the study area. Discussion on key datasets is provided in Section 2.

Table 3-1 Data inventory

Data	Description	Source
Reports		
West Haven System Analysis report	Hydrologic and hydraulic analysis of West Haven stormwater system and catchment	GHD 2007
West Haven Concept Design Report	Concept design report of proposed mitigation works in West Haven	GHD 2007
Camden Haven and Lakes System Flood Study	Mainstream flood study - river design flood levels Adopted 2013.	Worley Parsons 2013
Port Macquarie Hastings Council Flood Policy	PMHC flood policy adopted 2015. Includes guidelines for development, hydraulic classification, climate change, flood planning level allowances for different development, development controls.	PMHC
Spatial and Design Data		
Study area	Study area extent	PMHC
LiDAR data	Classified C3 LAS and thinned ground point data	NSW LPI 2012 (via PMHC)
LiDAR data	1m gridded DEM obtained for LPI dataset (available within Jacobs). Merged for study area	NSW LPI 2012 (via Jacobs)
Aerial photography	Nearmap 7cm res. Use this for existing case modelling	NearMap May 2017(via PMHC)
Aerial photography	Other older datasets available, varying resolution	NearMap, LPI (via PMHC)

Stormwater infrastructure	Bridges Culverts Stormwater Box Culvert Stormwater End Structure Stormwater Junction Sideline Stormwater Open Drain Stormwater Pipe Stormwater Pit Stormwater SQID (Stormwater Quality Improvement Device)	PMHC
Zoning	Land use zoning	PMHC
Cadastre	Lot parcels	PMHC
Ecology	Endangered ecological communities 2014 Vegetation Management Plans SEPP14 Coastal Wetlands	PMHC
Erosion risk	Soil Erosion Risk	PMHC
Road feature	Road Surface (road centreline) Kerb/Gutter line Footpaths	PMHC
Flood and sea level rise	Camden Haven River flood and sea level rise extents	Flood and sea level rise
Drainage plans - Historic	Various drainage/stormwater/WQ designs, various locations and ages	PMHC
Hydrographic and Dredging Plans - Camden Haven Area - historic	River bathymetry, dredging, tidal analysis. 1970s 1980s.	PMHC
Parks and Reserve Plans	Parks and reserves layouts 1980s - 2000	PMHC
Rural roads plans	Ocean Drive - historical plans	PMHC
Subdivision plans	Historic subdivision plans dated 2006 and 2010	PMHC

Urban Roads	Urban roads- historic plans	PMHC
Hydrologic Soil Group	NSW wide GIS layer on hydrologic soils group (classification A to D reflecting permeability and runoff potential)	OEH (online)
Recorded Data		
Daily Rainfall Data	Daily rainfall data for five stations in the vicinity of North Brother	BoM
Pluviograph Data	Pluviograph data 5 minute intervals 1/03/2012 to 1/02/2016 at various sewage treatment plants and pumping stations in Port Macquarie Hastings LGA. Pluviograph data is also available from Manly Hydraulics Laboratory (MHL) for Locans Crossing	PMHC MHL
Modelling Data		
West Haven DRAINS models	DRAINS models of existing and mitigated cases relating to West Haven System Analysis report and West Haven Concept Design Report	GHD 2007
Historic Flooding		
Flood mapping	Historic flood outlines and flood prone land/ flood planning mapping for mainstream flooding	PMHC
Flood marks	Historic flood marks for Camden Haven River flooding	PMHC
Photographs	Photos of previous flooding (various locations and events)	PMHC
Flooding complaints	Flooding and drainage complaints from residents and logged on Council register	PMHC

3.2 Port Macquarie Hastings Council Flood Policy (2015)

Council's Flood Policy (adopted 21 October 2015) outlines the considerations to be made by Council in exercising its environmental assessment and planning functions in relation to development in the Port Macquarie Hastings Local Government Area (LGA). It reflects the direction of flood risk management in NSW

Government's *Flood Prone Land Policy* and draws on the guidance on this provided in the *Floodplain Development Manual* (2005). It outlines a number of objectives in achieving sound flood management, namely:

I. To maintain the existing flood regime and flow conveyance capacity;

II. to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property;

III. to reduce private and public losses resulting from floods;

IV. to increase public safety with respect to flood events;

V. to protect the operational capacity of emergency services and emergency response facilities during flood events;

VI. to increase public awareness of the potential for flooding across the range of flood events up to the Probable Maximum Flood level;

VII. to inform the community of Council's policy in relation to the use and development of flood prone land;

VIII. to ensure that planning and development of essential services and land use makes appropriate provision for flood related risk;

IX. to utilise best engineering practice for determination of flood conditions, impact and risk.

X. to utilise ecologically positive methods of flood protection wherever possible;

XI. to ensure that any new development or modifications to existing development must, as far as practical, result in a reduction in the existing flood risk, and in no circumstances should the flood risk be made worse; and,

XII. to deal equitably and consistently with all matters requiring Council approval on land affected by potential floods, in accordance with the principles contained in the NSW Government's Floodplain Development Manual (2005).

The flood policy provides definitions for the different hydraulic classifications of the floodplain, flood planning level categories and provisions for different types of development (permissible development types, minimum floor levels), filling, fencing, boundary adjustments, rezoning and subdivision in the different hydraulic zones in the floodplain.

3.3 Previous Studies

3.3.1 GHD Stormwater Analysis and Design Studies (2007)

In response to previous poor performance of the drainage system, a stormwater hydrologic and hydraulic study was undertaken by GHD for Council for the West Haven area, and a concept design prepared for a proposed drainage upgrade and flood mitigation program. These are documented in the following reports:

- West Haven Stormwater Study Area Final Systems Analyses Report (GHD, April 2007)
- Report for Buller Street and West Haven Stormwater Catchment Studies S.600.110.05.61 Concept Design Report - West Haven Study Area (GHD, September 2007).

DRAINS models were developed for the study for the existing and proposed design cases to quantify system flows and identify/confirm system constraints. The models were not calibrated to historic flooding events. Design event flows were validated against rational method estimates. Relatively conservative hydrologic parameters were assumed for the catchment hydrology, including assumptions on the soil type (soil type 4 or D, high runoff and very low infiltration rates).

The existing case modelling indicated flood problem areas in the following locations

- South of No. 9 Black Swan Terrace / No. 20 Kirmington Terrace;
- Koonwarra Street drainage easement Lot 29;
- Ocean Drive cross culverts adjacent No. 374 – No. 384 Ocean Drive; and
- DRAINS also indicated problems with the Elouera Place cross culvert.

The concept design proposed a range of pit and pipe network upgrades and modifications, formalisation of two existing flood storages (referred to as "detention basins" in the GHD study) and construction of a large diversion channel upstream of Black Swan Terrace. The works were designed to achieve compliance for the minor (5 year) storm event with a review of the effect on the 100 year capacity.

The works were costed with a Net Present Value of $4.7 million (2007 dollars) excluding GST. It has not been confirmed with Council if any of the proposed mitigation works were implemented.

Sub-catchment boundaries are not available as spatial layers. The pit and pipe names in the DRAINS model are not consistent with the drainage asset layer provided by Council. Hence, the DRAINS model data is not directly suitable for the development of flood models in this study, but the results may be useful for model validation purposes.

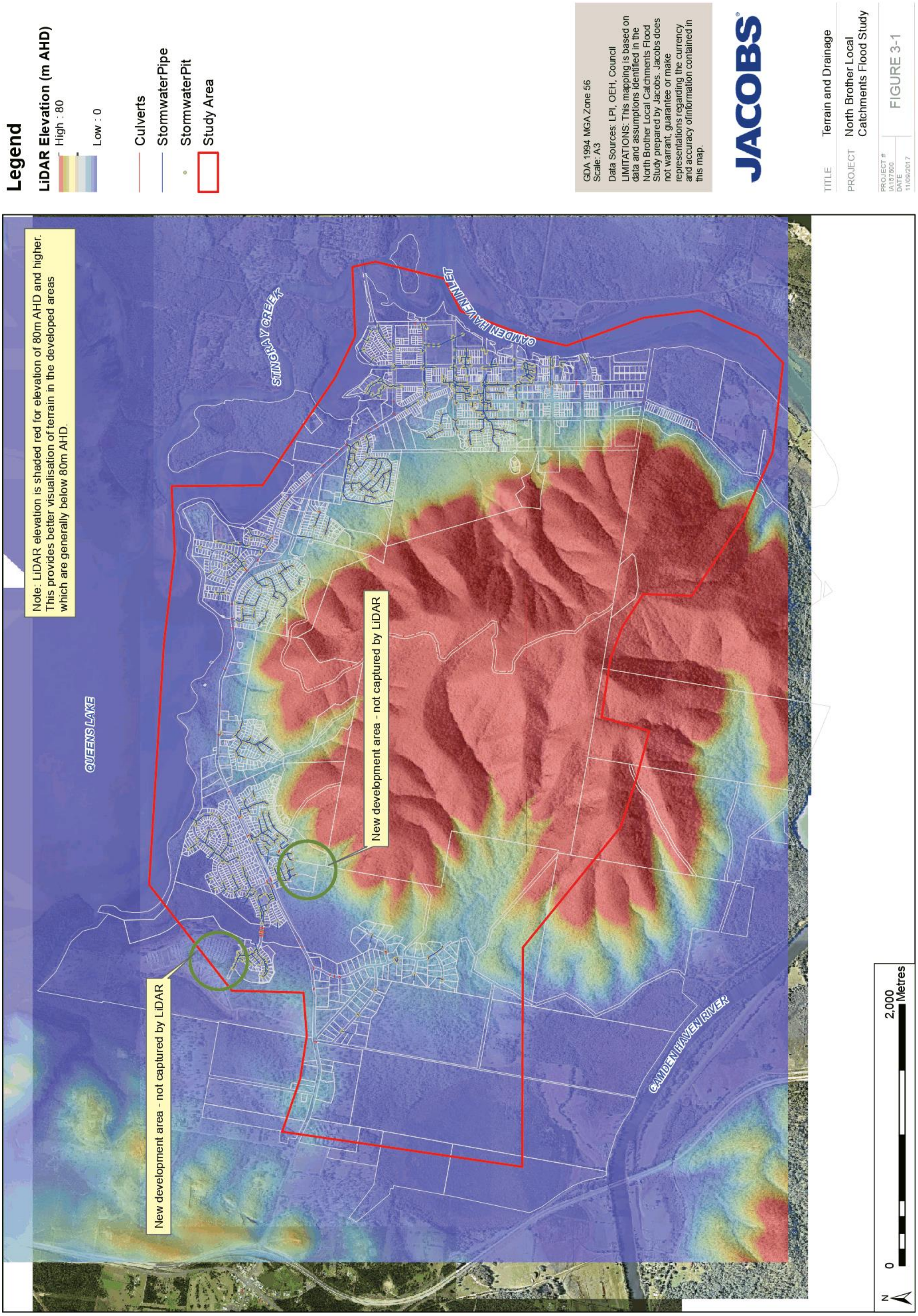
3.3.2 Camden Haven and Lakes System Flood Study (Worley Parsons, 2013)

This flood study estimated existing flooding conditions for mainstream flooding in Camden Haven River, Camden Haven Inlet, Queens Lake, Stingray Creek and Watsons Taylor Lake in the study area. The study was based on hydrologic and hydraulic modelling in XP-RAFTS and RMA-2, respectively, for the 5, 20, 50, 100 and 200 year floods and Probable Maximum Flood (PMF). The study estimated 100 year flood levels of approximately 2.9 – 3m AHD in Camden Haven Inlet, Stingray Creek and Queens Lake affecting parts of the study area, and 4.3m AHD in Camden Haven River near the Pacific Highway bridge, potentially affecting the south-western portion of the study area.

3.4 Spatial and Design Data

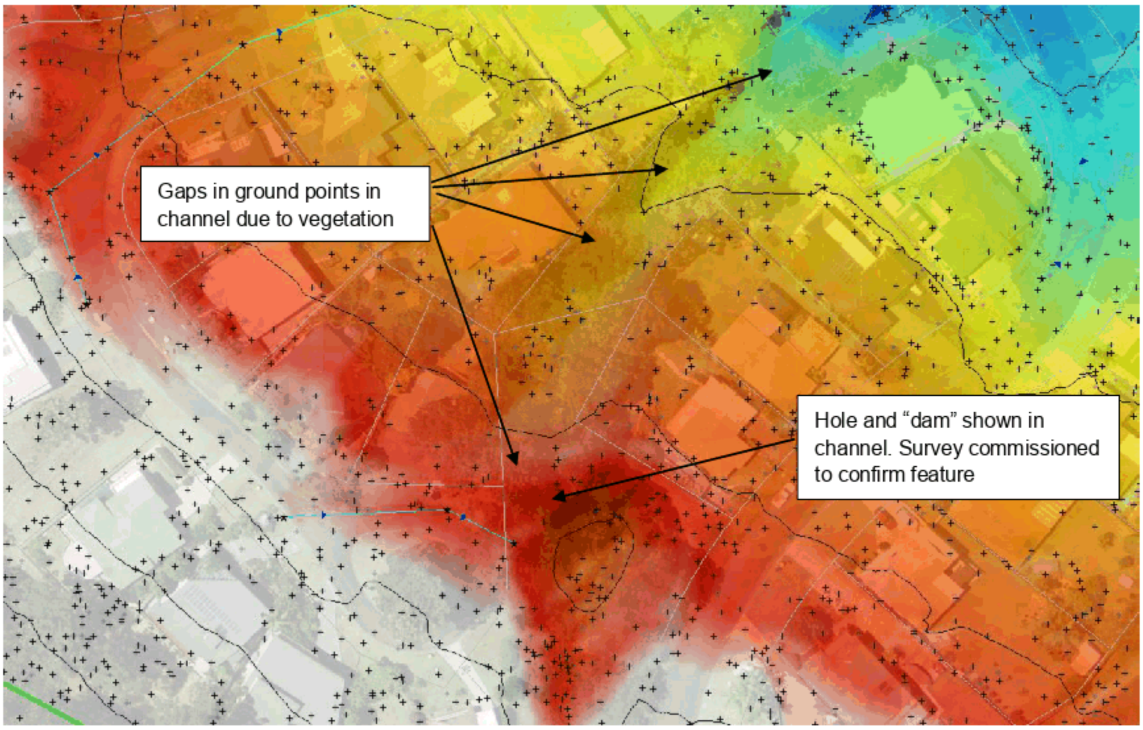
3.4.1 Topographic Data

Topographic data across the study area consists of LiDAR data captured by NSW Land and Property Information (LPI) in 2012. The dataset has a vertical accuracy of 0.15m (one standard deviation). Council provided classified and thinned ground point data for the study. Jacobs obtained the 1m digital elevation model (DEM) grid developed by LPI from this data, which is held in-house. The data tiles were merged together by Jacobs to form a continuous DEM across the study area and surrounds. The DEM showing the study area terrain is presented on Figure 3-1.


Legend
LiDAR Elevation (m AHD)
High : 80
Low : 0
Culverts
StormwaterPipe
StormwaterPit
Study Area
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE Terrain and Drainage
PROJECT North Brother Local Catchments Flood Study
FIGURE 3-1
Note: LiDAR elevation is shaded red for elevation of 80m AHD and higher. This provides better visualisation of terrain in the developed areas which are generally below 80m AHD.
STINGRAY CREEK
CAMDEN HAVEN INLET
QUEENS LAKE
New development area - not captured by LiDAR
New development area - not captured by LiDAR
CAMDEN HAVEN RIVER
0
2,000
Metres
N

The thinned ground points data set was reviewed for key drainage areas, and it was observed that in areas with a thick tree canopy or in-channel vegetation there was generally a low density of data points. This indicates that the LiDAR was only able to penetrate the tree canopy in sparsely spaced locations, and that the DEM is unlikely to accurately represent any drainage features which may be beneath the tree canopy. A similar issue is expected for channels with standing water or in-channel vegetation. Review of the DEM confirmed that some channel and drainage features are not represented in detail and do not match site observations.. Examples are shown on Figure 3-2 below. Ground survey was commissioned to collect more accurate topographic information of the study area terrain and features.

Figure 3-2 Example – sparse LiDAR ground points in vegetated areas and potentially inaccurate channel definition. Kirmington Terrace – Koonwarra Street, West Haven



3.4.2 Aerial Photography

Several different aerial photograph data sets were provided by Council, the most recent and highest resolution being NearMap imagery (May 2017, 7cm resolution). This imagery covers the developed areas at base of North Brother Mountain, and is supplemented with other imagery supplied by Council (dated 2012 and 2013) to cover the entire study area and surrounds.

3.4.3 Stormwater and Drainage Infrastructure

Layers for a range of stormwater drainage assets and features have been provided by Council including pits, pipes, culverts, headwalls and water quality improvement devices. Details (dimensions and levels) are missing for a number of the drainage assets and require survey. The source and accuracy of those assets with details is not known, although it is noted that the network layout is consistent with recent subdivision road layouts (e.g. Fairwinds Avenue detention basin and Wedgetail Drive, both in Lakewood). Data entry dates are also observed to be recent (up to 2015). The locations and details of open drains and swales in the study area are not included in the spatial layers.

3.4.4 Historical Subdivision Design

Sub-division designs are available from Council for a number of developments in the study area as pdf files. Most are dated pre-2010 and review of the locations of these developments against recent aerial photos indicates that the majority have been constructed.

Designs for drainage features including the flow path and berms downstream of the Fairwinds Avenue detention basin are reflected in the LiDAR and stormwater spatial layers.

3.4.5 Additional GIS data

Additional GIS layers obtained include:

- Road centrelines, kerb/gutter lines, footpaths
- Cadastre
- LEP and zoning
- Land use
- Ecological features.

3.5 Recorded Data

3.5.1 Rainfall Data

3.5.1.1 Daily Rainfall

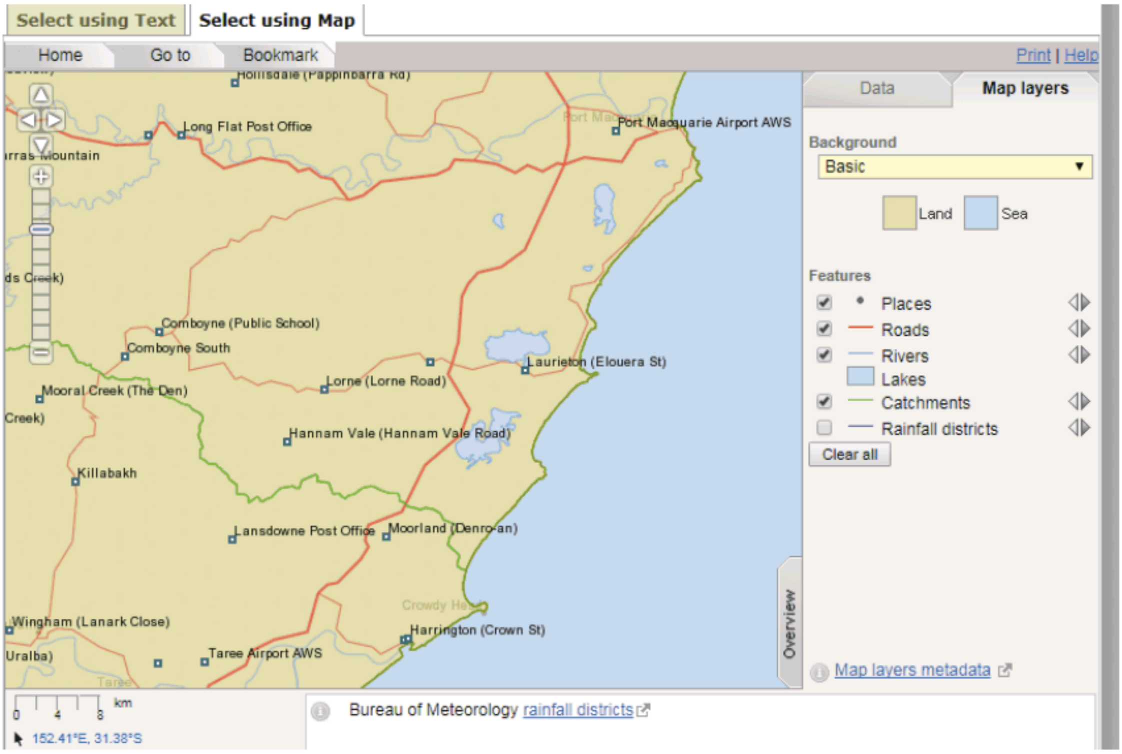
Historic daily rainfall data was obtained from the Bureau of Meteorology's (BOM) website. Data from five sites in the vicinity of North Brother was obtained and is summarised in Table 3-2: Site locations for the selected gauges and other regional gauges are shown on Figure 3-3. It is to be noted that all five sites are located at or below RL 55m and the sites are unlikely to represent rainfall on the 490m high North Brother Mountain due to orographic effects.

The steep and smaller nature of the catchments in the study area mean that intense short duration (sub-daily) storm events or storm bursts are more likely to be critical in causing peak flooding during flash flood events. Mainstream flooding is more likely to result from multi-day duration events. Hence, the reported daily rainfall depths may not indicate the critical historic storm events which resulted in peak flash flooding. Those short (say, less than 6 hours in duration) and intense rainfall events may result in the worst flash flooding conditions but are not reflected by exceedingly high daily rainfall depths. The daily rainfall data is therefore of limited use in indicating when the worst flash flooding events occurred, although it is useful for showing general trends of when wet periods occurred, during which the critical storm events may have happened. The data is also useful for validating any recorded sub-daily rainfall data.

Table 3-2 Daily Rainfall Data

Gauge Number	Gauge Name and Elevation	Distance from Study Area (km)	Start Date	End Date	Length of record (years)	Completeness (%)
060022	Laurieton (Eloura St) 12m AHD	0	1/1/1885	31/07/2017	132.7	87.0
060027	Lorne (Lorne Rd) 55m AHD	17	1/01/1938	30/06/2016	78.6	97.5
060024	Moorland (Denro-an) 5m AHD	19	1/11/1885	31/07/2017	131.8	90.3
060017	Hannam Vale (Hannam Vale Rd) 33m AHD	21	1/02/1926	31/07/2017	91.6	97.1
0600139	Port Macquarie Airport AWS 4m AHD	25	26/07/1995	17/08/2017	22.1	98.0

Figure 3-3 BOM Rainfall Gauges in Laurieton region (source: BoM website. http://www.bom.gov.au/climate/data/index.shtml?bookmark=136)



The daily rainfall data from the BOM Laurieton rainfall gauge was analysed and summarised for the top-ranking 1-day and 2-day recorded rainfall depths in Table 3-3. Rainfall values are based on daily rainfall recorded to 9am as per BOM convention. Hence, the peak flooding may occurred one day prior to the reported rainfall depth.

Table 3-3 Highest ranked recorded 1-day and 2-day rainfall depths at Laurieton rainfall gauge (060022).

Rank	1 day		2 day	
	Start date	Depth (mm)	Start date	Depth (mm)
1	29/04/1963	448.3	29/04/1963	462.3
2	5/01/1959	325.1	28/04/1963	448.3
3	22/1/1895	310.6	12/03/1974	389
4	20/03/1978	279.6	21/1/1895	384.8
5	28/02/1983	250	27/2/1892	377.7
6	16/3/1887	241.3	11/03/1974	368.6
7	28/03/1978	232	22/1/1895	328.4
8	6/02/2002	232	4/01/1959	325.1
9	9/11/2004	222	5/01/1959	325.1
10	6/04/1934	217.9	2/8/1899	318.7

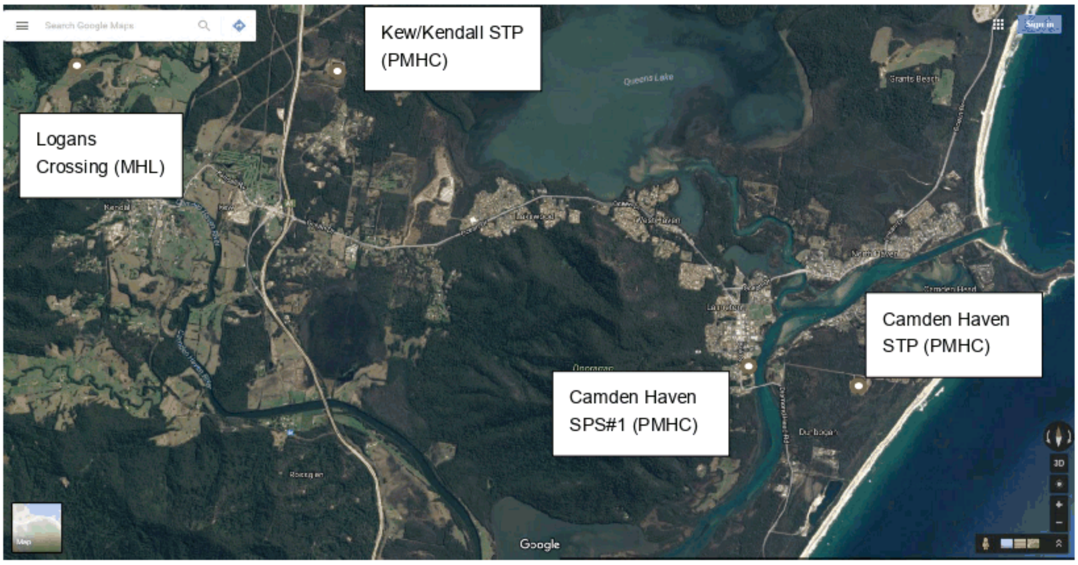
3.5.1.2 Pluviograph data

Pluviograph data for specific historic storm events was obtained from Council for model calibration. The historic storm events of interest were identified from the responses from the community survey. Pluviograph data is available from Council-operated sewage treatment plants (STP) and sewer pumping stations (SPS), with the closest and most relevant gauge locations to the study area including:

- Camden Haven SPS #1 (Wharf Street, Laurieton)
- Camden Haven STP (Dunbogan), and
- Kew – Kendall STP (Pacific Highway, Herons Creek).

The pluviograph stations are in the immediate vicinity (up to 3km) from the study area. Manly Hydraulics Laboratory (MHL) operates as pluviograph station at Logans Crossing, approximately 6km from the study area. This site is located further away from the study area than the Council STP gauge sites. The data from this gauge was obtained for selected storm events for comparison purposes. Refer to Figure 3-4 for locations of pluviograph stations in the vicinity of the study area.

Figure 3-4 Pluviograph locations in vicinity of the study area



3.5.2 Water Level Data

Water levels are recorded by MHL at several locations in the vicinity of the study area:

- Lakewood (Queens Lake)
- West Haven (Stingray Creek)
- Laurieton (Camden Haven River).

Data from these sites will be obtained for model calibration to historic storm events.

3.6 Topographic and Hydraulic Structures Survey

Survey of drainage and topographic features and hydraulic structures was commissioned for this study and undertaken in January – February 2018. The survey data was incorporated into the hydraulic modelling of the study area. Features surveyed included selected stormwater pits, pipes and culverts, earthen diversion drains and berms, natural channels and concrete channels. A summary map of surveyed features is provided in Appendix B.

Survey of drainage and topographic features in the vicinity of Black Swan Terrace was previously undertaken and supplied by Council.

3.7 Reports and Photographs of Historic Flooding and Drainage Issues

Council provided a number of photographs and written submissions from residents reporting drainage and flooding problems during historic storm events. Dates of the reported events are listed below. The Annual Exceedance Probability (AEP) of the 2013 and 2016 storm events were estimated by Jacobs from the Council pluviograph data from Camden Haven sewer pumping station.

- 18 October 2004. 127mm recorded daily depth.
- 25 February 2008.112mm recorded daily depth.
- 24 April 2008 (10% AEP event). 49mm in 45minutes; 65mm in 60 minutes; 136mm in 24 hours.

- 14 June 2011. 96mm recorded 2-day depth.
- 2 March 2013 (20% AEP) 61mm in 1.5 hours; 152mm in 24 hours.
- 5 January 2016 (20 – 50% AEP) 54mm in 1.5 hours.

Rainfall data for the 2008, 2013 and 2016 events was analysed and is plotted in Appendix A. Notable flooding reports are from locations including:

- Black Swan Terrace and Waterview Drive. Watercourse is piped through properties. The existing pipe inlet is undersized and the inlet debris screen regularly blocks. Overflows pass through residential yards, with paling fences washed away in previous floods.
- St Josephs's School, Laurieton. Video footage taken of significant flows along walkways between school buildings in the March 2013 event, which was a relatively frequent flood event.
- Ocean Drive. Flooding in numerous locations where a number of flow paths draining off North Brother Mountain cross this main road through the study area. Significant amount of cobblestones and other debris washed from watercourses and deposited on road.
- Flooding to depths of up to 1m in low points in roads at a number of locations in the study area. This was reported at Lilli Pilli Close, Sirius Drive, Mahogany Close and Honeysuckle Avenue, Lakewood; and Pelican Court, West Haven, among others.
- Flooding through Laurieton town centre including Bold Street, Lake Street and Tunis Street.
- Kirmington Terrace. Storm flows occurring within adjacent diversion drains further up the mountain infiltrated into the soil and then resurfaced as groundwater "springs" in residential yards and under buildings. Note that the flood models developed in this study would not be able to represent this phenomenon as a flood flow. However, remediation measures may be suggested as a part of the study.
- Numerous photos of overland flooding were captured by Murray Dalton surveyors during the April 2008 storm, summarised in Table 3-4 below.

It is noted that the storm events resulting in the reported flooding and drainage complaints and problems were relatively frequent and smaller magnitude events. Local flooding events of similar frequency and magnitude to planning flood events (i.e. the 1% AEP) or even moderate frequency (e.g. 5% AEP) are yet to be experienced in the study area in recent times.

Table 3-4 Summary list of photographs taken during 24 April 2008 storm event by Murray Dalton Surveyors

LAURIETON LOCAL STORM EVENT
24th APRIL, 2008 @ 8 am

Photo catalogue

2008_010	Queens Lake Village – flow down pathway
2008_011	Queens Lake Village – western grated inlet pit
2008_012	Queens Lake Village – pathway flow
2008_013	Queens Lake Village – culvert flows
2008_014	Queens Lake Village – Eastern Culvert
2008_015	Mission Terrace – Gutter in front of Anglican Rectory
2008_016	Ocean Drive looking west to Flinders Drive
2008_017	Culvert east of Flinders Drive
2008_018	2nd Culvert east of Flinders Drive
2008_019	Creek at 416 Ocean Drive, West Haven
2008_020	Ocean Drive intersection with Mission Terrace
2008_021	Mission Terrace – gutter in front of Anglican Rectory
2008_022	Ocean Drive looking at Laurieton Cemetery
2008_023	Ocean Drive looking east at Flinders Drive, Laurieton
2008_024	Flinders Drive intersection with Ocean Drive
2008_025	Culvert at St Josephs
2008_026	Western culvert above Queens Lake Village
2008_027	Wollworths culvert at Lakewood
2008_028	Sirius Drive from temporary access to Ringtail, Lakewood
2008_029	Drain above Woolworths culvert from Ringtail Access
2008_030	Drain above Woolworths culvert
2008_031	Sag pit in Ringtail Close
2008_032	Ringtail Close looking towards cul-de-sac
2008_033	Ocean Drive culverts west of Woolworths – looking east
2008_034	Creek below Fairwinds at Ocean Drive
2008_035	Creek below Fairwinds at Ocean Drive – watermain
2008_036	Flow above Amaroo detention basin – headwall blocked by ply
2008_042	Creek at 416 Ocean Drive, West Haven
2008_043	View up driveway at 414 Ocean Drive, West Haven
2008_044	Western culvert at St Josephs
2008_045	Sewer Manhole at Laurieton Caltex
2008_046	Sewer Manhole at Caltex
2008_047	Rosewood Court and Mission Terrace intersection
2008_048	Rosewood Court at top of hill
2008_049	Queens Lake village drains

Figure 3-5 Infiltrated floodwaters emanating as a "spring" from the ground in residential yard, Kirmington Terrace, June 2011.

Figure 3-6 Residents unblocking culvert inlet upstream of Black Swan Terrace properties, April 2008.

Figure 3-7 Overland flows from creek across Ocean Drive, West Haven, April 2008

Figure 3-8 Overland flows, Ocean Drive at Flinders Drive, April 2008

3.8 Floor Level Survey

Floor level survey is currently not available for residential and commercial buildings in the study area. These data are required for the flood damages assessment to be undertaken during this study, and will be collected for selected properties based on their flood affectation and historic flooding.

3.9 Site Inspections

Site inspections were undertaken on 27 July 2017. The purpose of the site inspection was to gain a further understanding of the catchment characteristics, the nature of existing development and hydraulic conditions (including flow patterns, drainage arrangements, hydraulic features etc.) in known flood problem areas, and likely flood risk. Members of the Jacobs project team were accompanied by Council officers. Locations inspected on the site visit included those flood problem areas previously identified by Council and described in Section 2.3.

Observations made during the site visit included:

- The terrain in the developed sections of the study area, at the foot of North Brother Mountain, was generally flat to moderately sloped (grades of 5 – 15%) with elevations from less than 2m AHD up to 50m AHD.
- The middle and upper catchment areas, upstream of the developed areas, were densely forested and generally within Dooragan National Park. Terrain was generally very steep, with watercourse grades of up to 50% and ground elevations up to 490m AHD.
- There were no permanently flowing watercourses observed at the time of the site visit, which occurred following a month of dry weather conditions. Most minor flow paths were piped to pass through residential development. The larger watercourses were maintained in a generally natural state and development did not encroach these watercourses. All of the flow paths and watercourses were crossed by Ocean Drive and other roads with culverts as they drain to Queens Lake and Stingray Creek.
- Many watercourses and other drainage features were covered by dense rainforest vegetation.
- Soil landscapes along watercourses were observed to include high permeability gravel and rubble beds in the stream beds and along some stream banks. Council officers described that during storm events, in some locations the stream flows infiltrate into these gravel and rubble beds, flowing sub-surface and then resurfacing in different locations. This is reflected in residents' reports and accompanying photos.

An additional site visit was undertaken on 30 April 2018 during the model setup and calibration to inspect selected drainage features and confirm the model performance and representation of flood behaviour.

Figure 3-9 Eastern side of north Brother Mountain, illustrating steepness of the terrain

Figure 3-10 Shotcrete-lined informal channel in Lakewood

Figure 3-11 Natural flow path through forested area in West Haven

JACOBS

Figure 3-12 Driveway crossing of flow path, which passes next to dwelling, West Haven

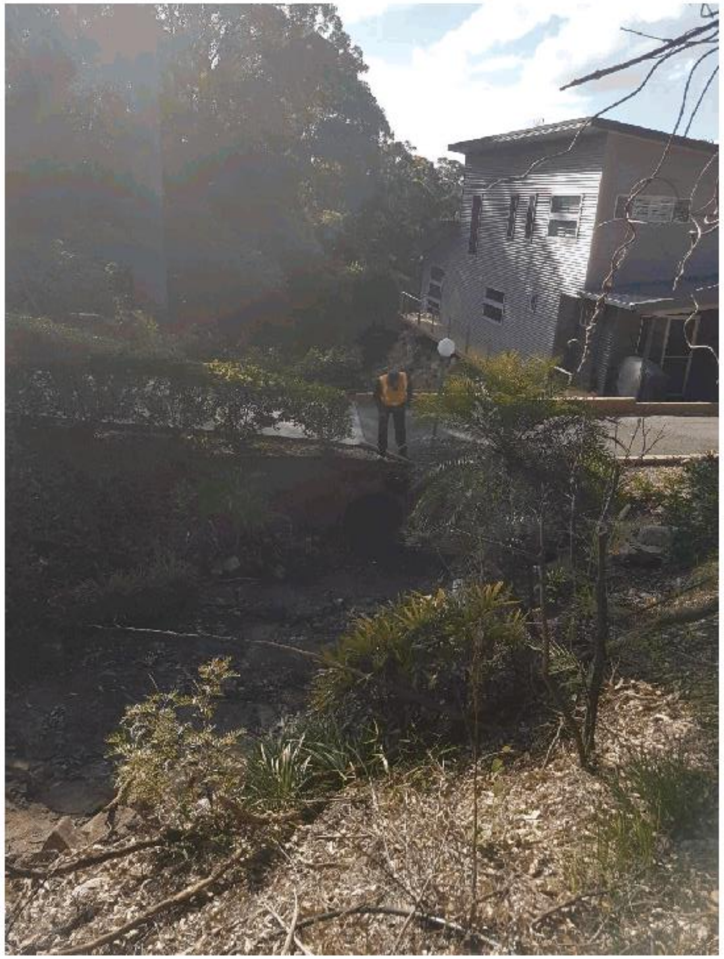


Figure 3-13 Grated trunk drainage headwall inlet, West Haven

Figure 3-14 Upstream side of flow path road crossing, West Haven

Figure 3-15 Trunk drainage open channel through property, Laurieton

Figure 3-16 Trunk drainage culvert discharging to open channel next to development, Laurieton

Figure 3-17 Flow diversion berm and swale upstream of development, Laurieton

3.10 Community Consultation

3.10.1 Initial Consultation

Community consultation was undertaken throughout this study, including distribution of newsletters and media releases and the hosting of a website on Council's webpage to announce the commencement and provide background on the study.

3.10.2 Community Survey

A community survey was mailed out to residents with the study newsletter asking residents for information on previous flooding events that they experienced in the study area, refer to Appendix B for the survey. A total of 302 responses were received. The responses assisted the project team in identifying the most significant flooding events in recent history which would be suitable for model calibration and verification. Observations including noted flood depths, flow patterns and durations of flooding were reported. Residents also submitted photographs and videos of flooding during the events.

The survey identified numerous flooding events over the past 20 years with no particular standout events. The March 2013 event was reported in six responses, while the April 2008 event, which resulted in the most intense rainfall for the storm event data available, was reported two times. The February 2002 event was reported four times, however, sub-daily rainfall data is not available for that event.

3.10.3 Community Information Sessions

Two community information sessions were held at Laurieton Library in August 2018. Residents were invited to view flood mapping for the model calibration and provide feedback on the results and other general concerns relating to flooding in the study area. Approximately 40 residents attended over the two sessions. The modelling was updated based on several resident comments for the final model calibration runs and design flood estimation.

4. Hydrologic Modelling

4.1 Modelling Approach

A hydrologic model was required to estimate storm and flood flows for the study area for the historic and design rainfall storm events. The terrain of the study area is such that:

- There are numerous natural watercourses and gullies which flow down the face of North Brother Mountain and then through the developed areas of the study area.
- On the flatter areas at and below the foot of the mountain and away from the watercourses, drainage paths are often less defined, with more dispersed overland flows affecting existing development.

The hydrologic modelling adopted involved lumped catchment modelling approach for the watercourses draining off the mountain, and a direct rainfall approach for the more dispersed overland flow catchment areas at the foot of the mountain. The lumped catchment modelling estimated inflow hydrographs (flow versus time) which were input into the hydraulic model in the watercourses. The direct rainfall approach input rainfall versus time data onto the modelled catchment surface in the hydraulic model itself, which then generated estimated flows internally in the model. This report section describes the lumped hydrologic modelling. Refer to Section 5.3.2 for further discussion.

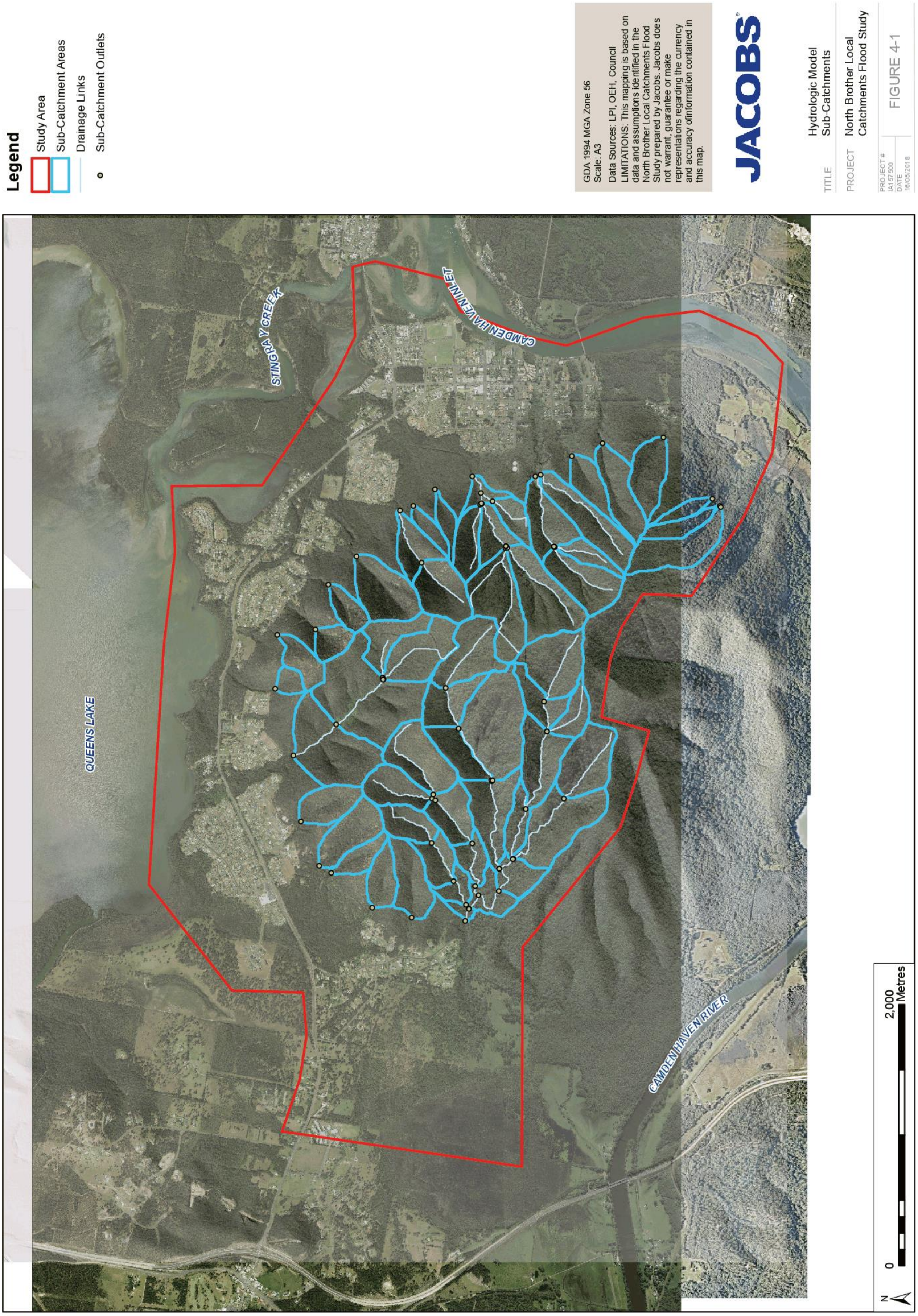
The lumped hydrologic modelling was undertaken using the RAFTS hydrology module in the DRAINS modelling software. The RAFTS module is suitable for assessment of sub-catchments with areas up to 100 hectares and permits routing of runoff through the catchment. The DRAINS software is one of the few modelling packages that currently incorporate Australian Rainfall and Runoff 2016 (ARR 2016) design rainfalls and procedures.

4.2 Sub-Catchment Data

The catchment areas on North Brother Mountain were divided into 56 sub-catchments which drain to the gullies and watercourses running off the mountain through the study area. Mapping of the sub-catchment boundaries is shown on Figure 4-1. These sub-catchments are natural vegetated areas and a nominal impervious fraction of 5% was assumed.

Sub-catchment flow path slopes are steep to very steep, with catchment flow path slopes ranging from 15 – 70%. DRAINS/RAFTS and most other hydrologic models have an upper limited slope parameter value of 30%, and this is adopted for the sub-catchments with slopes exceeding this value. It is likely that that catchment slopes steeper than 30% would result in faster catchment flow travel times producing higher peak flows. However, limited information is available rainfall runoff generation from very steep catchments.

A PERN catchment roughness value of 0.1 was adopted for the forested sub-catchment areas.


Legend
Study Area
Sub-Catchment Areas
Drainage Links
Sub-Catchment Outlets
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
TITLE
Hydrologic Model Sub-Catchments
PROJECT
North Brother Local Catchments Flood Study
FIGURE 4-1
QUEENS LAKE
STINGRAY CREEK
CAMDEN HAVEN INLET
CAMDEN HAVEN RIVER
0
2,000 Metres
N

4.3 Hydrologic Parameters

4.3.1 Rainfall Losses

An initial and continuing loss model was utilised in the RAFTS module which represented rainfall losses during storm events such as depression storage and soil infiltration. The following loss values were adopted for the design event runs:

- Pervious areas: Initial loss 15mm, continuing loss 2.5mm/hr
- Impervious areas: Initial loss 1mm, continuing loss 0mm/hr.

Soil characteristics on the mountain were observed and reported to be very impermeable, and lower rainfall losses could normally be considered for such soils. Due to the steepness of the catchment areas and limited slope parameter values in the modelling these moderately low rainfall losses were retained.

Rainfall losses adopted for the calibration events are discussed in Section 6.3.1.

4.3.2 Storage Routing Factor

RAFTS includes the "Bx" storage routing factor which can be adjusted to change the runoff response of the catchment. With a default value of 1.0, the factor can be reduced to increase the runoff response, resulting in a more peaky flood. It is usually adjusted when there is sufficient data, such as flow gauging, to validate the adjustments.

Reducing the Bx value was considered to account for the very steep slopes on North Brother Mountain and the limited slope parameter value of 30% in the hydrologic modelling. However as there were no flow gauging data for the mountain, an adjustment of the Bx factor could not be justified for this study. Sensitivity runs also indicated minimal increases in peak flows for sample sub-catchments for Bx values of down to 0.2, which was not considered to be a reasonable adjusted value for this parameter. Modest increases in peak flows were observed for a Bx value of 0.1, but this was also considered a highly unreasonable value.

5. Hydraulic Modelling

5.1 Model Selection

A TUFLOW combined one-dimensional (1D) and two-dimensional (2D) hydrodynamic model was developed for this study. TUFLOW is an industry-standard flood modelling platform, which was selected for this assessment as it has:

- Capability in representing complex flow patterns on the floodplain, including flows through street networks and around buildings.
- Capability in representing the stormwater drainage network, including pit inlet capacities and interflows between the network and floodplain including system surcharges.
- Capability in accurately modelling flow behaviour in 1D channel, bridge and culvert structures and interflows with adjacent 2D floodplain areas.
- Easy interfacing with GIS and capability to present the flood behaviour in easy-to-understand visual outputs.

The model was developed and run in TUFLOW 2018-03-AA-iDP-w64, in the Heavily Parallelised Compute (HPC) module. The HPC module was preferred over TUFLOW “Classic” as it permits significantly faster model run times, which was required for this relatively large model extent and with direct rainfall being applied.

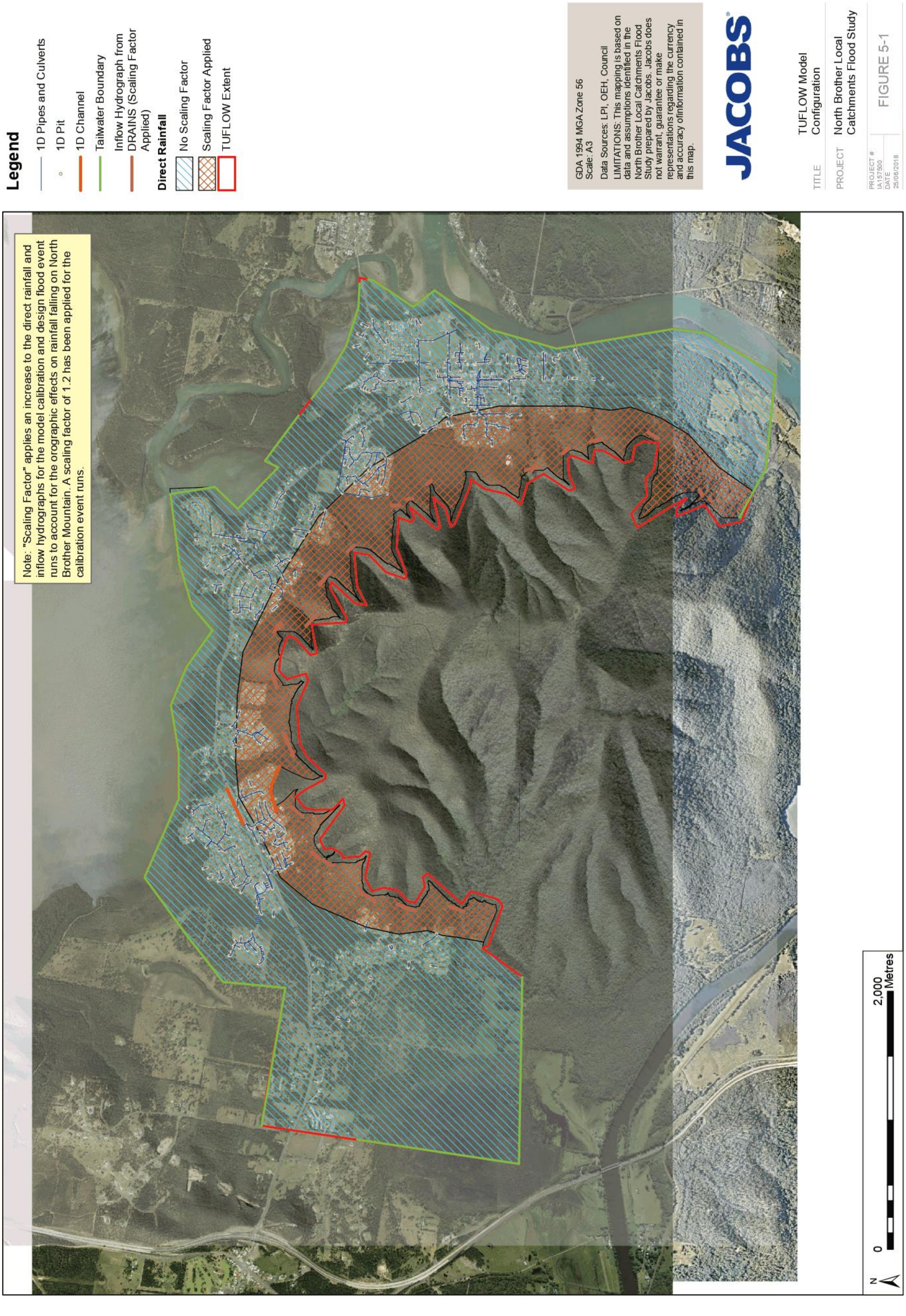
5.2 Configuration of Hydraulic Model

5.2.1 Extent and Structure

The TUFLOW model comprised of:

- A 2D domain of the study area surface reflecting the catchment topography, with varying roughness as dictated by land use. The watercourses were in general modelled in 2D. Diversion drains are in 2D.
- A 1D network of pits, pipes and culverts representing the stormwater network. Inflow capacities for pits were defined based on their type and size.
- Obstructions to flow are represented as 2D objects, including existing buildings.

The model extent covered an area of 12.6km^2 and includes the foot of the North Brother Mountain along its western, northern and eastern sides and the adjacent developed lower-lying areas down to the receiving waters at Camden Haven River, Queens Lake and Stingray Creek. Refer to the following report sections for details on these features. The model domain and locations of various features in the TUFLOW model are shown on Figure 5-1.


Legend
1D Pipes and Culverts
1D Pit
1D Channel
Tailwater Boundary
Inflow Hydrograph from DRAINS (Scaling Factor Applied)
Direct Rainfall
No Scaling Factor
Scaling Factor Applied
TUFLOW Extent
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE TUFLOW Model Configuration
PROJECT North Brother Local Catchments Flood Study
FIGURE 5-1
Note: "Scaling Factor" applies an increase to the direct rainfall and inflow hydrographs for the model calibration and design flood event runs to account for the orographic effects on rainfall falling on North Brother Mountain. A scaling factor of 1.2 has been applied for the calibration event runs.
0
2,000
Metres
N

5.2.2 Model Topography

The topography of the catchment was represented in the model using a 2m grid. This level of precision in the grid was considered necessary in order to represent detailed flood behaviour in a fully developed catchment. Finer model grid sizes such as 1m grid were not considered practical given the large size and expected excessively long computing times. The basis of the topographic grid used in the TUFLOW model was the LiDAR data set in addition to ground survey.

5.2.3 Stormwater Pits

The stormwater pits provide a dynamic linkage between the underground drainage network and the 2D TUFLOW model domain, representing the floodplain. Water is able to flow between the drainage network and floodplain, depending on the hydraulic conditions.

The location of the stormwater pits and associated attributes were available from Council in GIS format. Pit inflow relationships were defined in terms of flow depths versus pit inflow.

TUFLOW automatically calculates hydraulic energy losses in the pits based on the alignment of pipes connected to each pit and the flows in each pipe. The calculations are based on the Engelhund manhole loss approach (*TUFLOW User Manual*, BMT WBM, 2017).

5.2.4 Stormwater Conduits

Stormwater pits and pipes identified in Council's data base and from survey were also modelled in the TUFLOW models. Several pipes down to a diameter of 225mm were represented but are typically larger than 300mm. The conduits were represented as circular pipes or rectangular culverts with dimensions matching those adopted in the DRAINS models.

5.2.5 Building Polygons

This study considered buildings as solid objects in the floodplain. This means that buildings form impermeable boundaries within the model, and while water would flow around buildings, it could not flow across their footprints. The building footprints in the TUFLOW model were digitised based on the 2017 aerial imagery. The building polygons were superimposed on the model grid to make model computational cells under the footprints inactive.

5.2.6 Surface Hydraulic Roughness

All parts of the study area within the TUFLOW model were assigned hydraulic roughness values in a "materials layer" according to the LEP zoning and ground cover. These were based on engineering experience and typical values used in previous flood studies undertaken in the Sydney Region by Jacobs and other consultants. A moderately high Manning's n value of 0.05 for the residential land use accounts for expected obstructions such as minor features (steps, planter boxes etc.) and landscaping, which are typically not detected by LiDAR survey. The adopted Manning's n values are mapped on Figure 5-2 and summarised in Table 5-1.

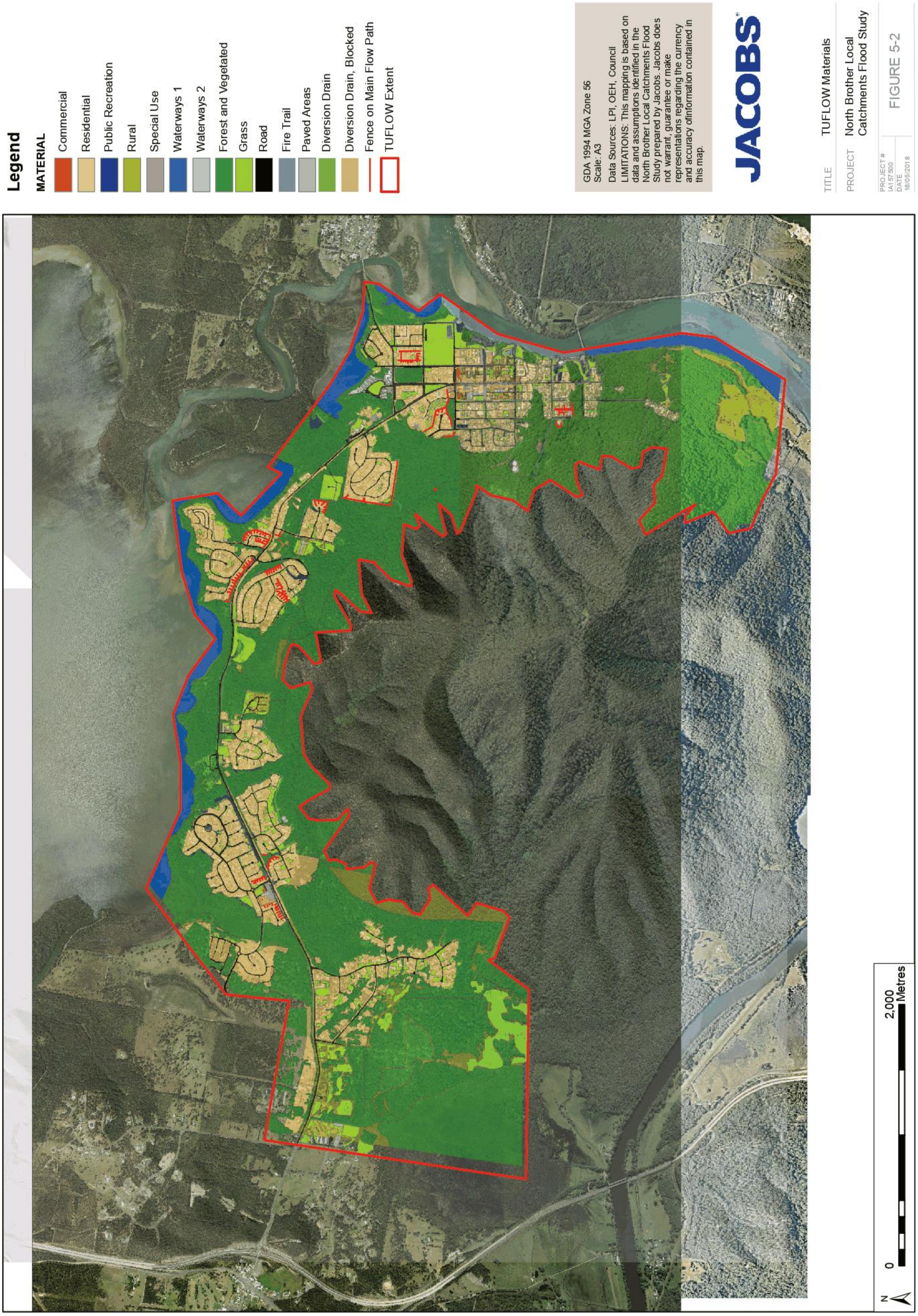

Legend
MATERIAL
Commercial
Residential
Public Recreation
Rural
Special Use
Waterways 1
Waterways 2
Forest and Vegetated
Grass
Road
Fire Trail
Paved Areas
Diversion Drain
Diversion Drain, Blocked
Fence on Main Flow Path
TUFLOW Extent
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE TUFLOW Materials
PROJECT North Brother Local Catchments Flood Study
FIGURE 5-2
0
2,000 Metres
N

Table 5-1 TUFLOW Model Grid Hydraulic Roughness Values

Land Use Type/Material	Manning's n	Comment
Commercial	0.035	Zoning B2, B4
Residential	0.05	Zoning R1, R2, including schools
Public Recreation	0.1	Zoning RE1
Rural	0.035	Zoning RU1
Special Use	0.05	Zoning SP2. Cemetery, water supply
Waterways 1	0.05	Zoning W1
Waterways 2	0.035	Zoning W2
Forest and vegetated areas	0.1	Zoning E1, E2, E3 and E4 and other vegetated areas
Road	0.025	Where present, overwrites land use zoning areas listed above
Paved areas	0.02	Where present, overwrites land use zoning areas listed above
Fire Trail	0.035	Where present, overwrites land use zoning areas listed above
Diversion drain	0.04	Diversion drain, maintained, clear
Diversion drain with blockages	0.20	Unmaintained, heavy vegetation and fallen trees etc. Prone to further blockages from flood-borne debris
Property fence lines	0.30	Paling and Colourbond fences which are initially solid but prone to failure and flow-through

5.2.7 Property Fence Lines

Fence lines were typically not explicitly represented in the model and floodwaters were allowed to flow across them freely. Although fences would obstruct overland flood flows in some parts of the catchment, experience indicates that representing fences in the hydraulic model requires making unvalidated assumptions about flood depths at which fences would overflow or fail.

The potential obstruction to flow caused by fences was represented in the model by increasing the cell roughness (Manning's n values) along selected property fence lines on and adjacent to main flow paths to a value of n = 0.3. This approach would provide some resistance to flows against and along a fence, although it probably would not represent the full obstructing effect of a fence before it fails under the force of flood flows. There are other approaches which could represent a fence as a solid obstruction which would dynamically fail in the model once flow depths become great, but this approach was considered somewhat impractical to implement on a catchment scale, requiring significant effort and detail. The adopted approach was considered a more practical means of representing the hydraulic effects on flood flows. The modelled fence lines are shown on Figure 5-2.

5.3 Boundary Conditions and Tailwater Conditions

5.3.1 Model Inflows

The inflow hydrographs from the DRAINS/RAFTS model were input into the watercourses and gullies upstream of the developed areas of the study area. The inflow boundaries are shown on Figure 5-1.

5.3.2 Direct Rainfall

A rainfall hyetograph (rainfall depth per time interval) was directly input into the TUFLOW model in the areas where direct rainfall applied. Similarly to the catchment hydrologic modelling discussed in Section 4.3.1, rainfall losses were applied in the conversion of direct rainfall to runoff in the TUFLOW model. The rainfall losses proposed for design flood estimation were:

- Pervious areas: Initial loss 15mm, continuing loss 2.5mm/hr
- Impervious areas: Initial loss 1mm, continuing loss 0mm/hr.

Most impervious areas in the study area were explicitly represented including road areas, roof areas and other large paved areas. The remaining developed areas for which impervious areas were not digitised were assumed to be 20% impervious to account for driveways and other small paved areas, and the rainfall losses were reduced accordingly to account for this partial imperviousness.

As discussed in Section 5.2.5, the model cells covering building footprints were made inactive. The rainfall falling on the roof areas of these buildings was therefore applied to the area immediately surrounding each building. Roofs were considered to be impervious areas with the corresponding rainfall losses applied.

Areas where direct rainfall was applied are shown on Figure 5-1. The areas where direct rainfall was scaled up for orographic effects (refer Section 6.3.2 for discussion) are also indicated.

5.3.3 Tailwater Boundaries

Tailwater boundaries were located along the shoreline on the receiving waterways including Camden Haven River, Stingray Creek, Queens Lake and Watsons Taylor Lake. Refer to the discussion in the subsequent model calibration section and the design event modelling section for details on the adopted tailwater levels.

6. Model Calibration and Verification

6.1 Overview

Rigorous model calibration of overland flood models cannot generally be carried out because direct measurements of overland flows and accurate measurements of flood levels are usually not available. Localised features may also be present which influence flow patterns but are not detected in the catchment-scale topographic data. Hence, overland flood models are often verified using observations of flood depths and flood behaviour as a way of "sanity-checking" the modelling and confirming its reliability.

This study relied mainly on observed depths of flooding during past flood events given by local residents. This anecdotal information was generally considered indicative as often only the general location of the observation was usually given, and approximate depths of flooding. The reported flood observations were also from numerous separate storm events, while the model calibration focussed on only two events selected based on availability and quality of observed data. However, the reported flood depths were still useful information for validating the general behaviour of flooding simulated by the flood models.

Photographs and video of flooding were also provided which offer more detailed information of the flooding behaviour at specific locations. Consideration was needed on whether the photos were taken at the peak of the flooding.

The general approach involved running the hydrologic and hydraulic models and comparing the flood depths and flow patterns to reported observations. The model configuration and parameter values were adjusted as necessary with the aim of achieving a satisfactory fit to the observations.

6.2 Selection of Verification Events

Flooding was reported for numerous individual storm events occurring over the last 20 years from the community survey responses. Two historic storm events were selected for model calibration and verification based on the number of responses for each event and the magnitude of the storm event. These events included:

- 24 April 2008. The most intense rainfall recorded based on the available data. Significant number of photographs are available with Council for this event.
- 2 March 2013. This is a relatively intense storm with the majority number of survey responses.

Characteristics of the selected storm events are provided in Table 6-1. The cumulative rainfall depths are plotted in Appendix A. A comparison of the recorded rainfall against the design IFD is also shown in Appendix A. Although the April 2008 storm event resulted in a lower daily rainfall depth than the March 2013 event, it produced a significantly more intense burst of rainfall over a period of one hour. Given the nature the flash flooding catchments in the study area these short duration bursts are the critical events for peak flooding. Hence, the April 2008 storm is considered to be a rarer and greater magnitude event than the March 2013 event, based on rainfall records.

Table 6-1 Calibration storm event characteristics

Event Date	Daily Rainfall Depth	Main Storm Burst Rainfall Depth and Duration	Approximate Event AEP	Comment
24 April 2008	136mm	49mm in 45 mins 65mm in 60 mins	10% AEP	Rainfall data available from Camden Haven SPS (Laurieton)
2 March 2013	152mm	43mm in 60 mins 61mm in 1.5 hrs	20% AEP	Rainfall available from Camden Haven STP (Dunbogan)

Note that several storm events in circa 2000 and 2002 were reported by long-term residents as being the most severe that they experienced. However, suitable rainfall data for the model calibration were not available for these earlier storm events and hence these were not selected for the model calibration and verification.

6.3 Adopted Parameter Values for Model Verification

6.3.1 Rainfall Losses

Rainfall losses reflect the ability for the catchment to absorb some rainfall during a storm event due to capture on vegetation and trapped low points and from infiltration into the soil. The magnitude of the rainfall losses depends largely on how wet the catchment is due to preceding rainfall and the soil types in the catchment, with sandy soils generally being more permeable and hence water can infiltrate into the soil column at faster rates.

The assumed rainfall loss parameter values were selected based on a review of daily rainfall records and initial runs of the modelling for the calibration events. Both the April 2008 and the March 2013 storm events occurred after significant preceding rainfall:

- Approximately 200mm of rainfall was recorded in the week before the 24 April 2008 flood event.
- Over 280mm of rainfall was recorded approximately two weeks before the 2 March 2013 flood (from 17 – 27 February) followed by an additional 39mm rainfall on 28 February and 1 March, prior to the main flood event on 2 March.

Hence it is highly likely that the catchment was saturated prior to the two calibration storm events with little to no capacity to absorb further rainfall. The following rainfall loss values are therefore adopted for the model calibration and verification:

- Pervious areas: Initial loss 0mm, continuing loss 2.5mm/hr
- Impervious areas: Initial loss 0mm, continuing loss 0mm/hr.

Higher initial losses were initially tested in the hydrologic and hydraulic modelling. However, sufficiently high rates and volumes of runoff could not be produced to achieve a good match to the reported flooding at several locations. Other hydrologic factors such as the methods for representing the high catchment slopes and runoff, blockages, drainage patterns etc. were also considered and trialled but did not produce reasonable matches for observed flood behaviour, and hence were discounted from the model calibration process and informed the selection of the assumed rainfall losses.

6.3.2 Orographic Rainfall Scaling

The North Brother Mountain, being a significant topographic feature of over 450m elevation and with steep slopes, has the potential to result in orographic enhancement of rainfall during storm events as the wind flow carrying rain-bearing clouds rises over the mountain and results in increased precipitation. Hence, rainfall intensities on the mountain, away from the rainfall gauge locations, may be higher than those at the gauge locations situated on lower areas at some distance away from the mountain.

BMT WBM (2018) has undertaken the Coffs Creek and Park Beach Flood Study at Coffs Harbour, where the catchment is bounded by a steep escarpment along its western and north-western sides to elevations over 400m. As a part of the model calibration for that study rainfall data from numerous rain gauges in the catchment were analysed for the March/April 2009 flood event, and a marked rainfall gradient was observed between the coastal part of the catchment and the middle and upper sections of the catchment. Rainfall depths recorded for the 24 hours to 9am on 1 April 2009 ranged from 260 – 280mm in the coastal areas, up to 530mm at gauges in the upper section of the catchment, with maximum estimated rainfall depths in this zone of up to 560mm (or double the rainfall recorded in the coastal areas). Analysis of the November 1996 storm event observed rainfall depths 2.5 times higher in the upper section compared to the coastal zone.

As a result of the rainfall analyses and model calibration in the Coffs Creek study, BMT WBM (2018) adopted scaling factors of 1.2 to 1.6 for the design flood estimation in that study, whereby the design rainfall intensities adopted for the coastal areas were increased by 1.2 to 1.6 times for application on the escarpment areas and foothills of the catchment. The study cited that the previous Coffs Creek Flood Study (WMA, 2001) adopted significantly higher scaling factors of up to 2.25, depending on the ground elevation of a particular location.

The topography for the North Brother Mountain differs from Coffs Creek catchment, in that the Coffs Creek catchment is an incised valley which would funnel wind flows up the valley, concentrating the rain clouds. The same funnelling effect is unlikely to occur at the North Brother Mountain due to its shape as a peak protruding from the surrounding coastal plain rather than a valley feature. To account for the orographic effects in the study area and to provide a better calibration fit the catchment inflows from the North Brother Mountain and the rainfall on the foothills of the mountain were increased by 20% (i.e. an orographic scaling factor of 1.2),based on the recorded rainfall and design rainfall being derived for the coastal plains area. Accordingly, rainfall on the low areas below the foot of the mountain was not adjusted from the recorded depths.

As per the selection of rainfall losses, other model parameters and assumptions were initially tested and analysed in the calibration process but could not replicate the observed flooding depths and flow patterns, as the model was generally less sensitive to these other parameters. Hence these preliminary runs informed the scaling of rainfall for the model calibration. There was some uncertainty about the actual increased rainfall depths and spatial distribution of the increases during the historic events since there were no rainfall gauges on the North Brother Mountain, however, a uniform scaling factor of 1.2 appeared to provide the best fit to observed flooding across the study area for the calibration events.

6.3.3 Blockage of Hydraulic Structures

Guidance on blockage of hydraulic structures was generally sought from *Australian Rainfall and Runoff Revision Project 11– Blockage of Hydraulic Structures Stage 2* (Engineers Australia, 2013).

Culverts were generally assumed to be 50% blocked for the model calibration events. There are photos and observations during historic flood events of large gravel and rocks being washed down the watercourses and deposited in drainage lines, and recurring blockage due to debris. Blockages at a few specific structures were reduced or increased to provide a better calibration fit.

Assumed blockage of stormwater pit inlets are generally consistent with guidance in ARR 2016. The large majority of pits in the study area were observed to be combination kerb inlet and grated pits. The assumed blockages were:

- Sag pits: kerb inlet assumed clear and grate 100% blocked.
- On-grade pits: 90% of the combined kerb inlet and grate flow capacity (i.e. 10% blockage factor).

6.3.4 Blockages in Flow Diversion Drains

Several respondents reported and provided photographs of overgrown vegetation and fallen trees in adjacent flow diversion drains at the foot of the mountain contributing to the drains overflowing and causing flooding of properties and dwellings. Observations on site also indicated localised build-up of rock rubble and tree trunks in the larger drains and watercourses. Blockages of these drains were represented in the model to replicate these flooding patterns.

6.3.5 Tailwater Conditions

Recorded water level hydrographs for the receiving waterways were adopted as tailwater boundaries for the calibration events.

6.4 Comparison to Observed Flooding

The community survey responses were reviewed for observations of flooding behaviour including dates of storm events, depths of flooding, flow patterns and resulting damage to property. Photos and videos provided with the responses or separately were also reviewed. Notes from Council on flooding problem spots were also considered.

The modelled flood behaviour was compared to the residents' observations and were generally found to be consistent with the observations. Refer to Table D-1 in Appendix D for comparison of modelled flood behaviour to the reported observations. Mapping of flood depths for the historic events is also shown in Appendix D.

The modelling generally produced reasonable matches to the observed flood behaviour along main flow paths and ponding/storage areas. Areas affected by shallow sheet overland flows were more difficult to replicate observations during previous storms, as such shallow flows are more sensitive to small-scale ground and built features which could not be picked up in the topographic model on a catchment-wide scale. The main flow paths and storage areas are the focus of the flood study as this is where flood risk and hazards are greatest.

There are some locations where a good match could not be achieved and this may be attributed to localised factors which may have occurred such as blockages of drains and drainage infrastructure by debris and sediment but which were omitted from the modelling if there were no specific reports of blockages. Information was sought whether any maintenance or upgrade works were conducted on the flow diversion drains uphill of the residential properties at the foot of the mountain which may have altered flow capacities and behaviour. Drains could be cleared in recent times and reflected in survey of the drains, but could be blocked by debris and vegetation at the time of historic flood events. However, Council and National Parks and Wildlife Service (NPWS) stated they did not undertake works in recent years. Council advised that Crown Lands Department may have had undertaken works but no specific information was available.

There is also some uncertainty in the exact rainfall which fell on the mountain catchments as the orographic effects are likely to have caused localised and non-uniform enhancement of rainfall. While the rainfall data is sourced from gauges which are in or relatively close to the study area, these are located relatively at lower elevations in or to the east of the study area and may have varied from rainfall in the west of the study area or on the mountain.

Overall, the TUFLOW model provides a reasonable agreement to the observed flood behaviour in the historic events and is therefore considered to be suitable for the estimation of design flood behaviour in the study area.

6.5 Sensitivity Testing of Calibration Parameters

A number of scenarios were assessed for the April 2008 flood event to test the sensitivity of the model results to changes in the adopted parameter values. The tested parameters included:

- Rainfall and flow Scaling
- Rainfall losses
- Blockage of hydraulic structures
- Surface hydraulic roughness

The scenarios are described and the impacts summarised in Table 6-2. Flood levels and depths are relatively sensitive in particular to the changes in rainfall scaling (both increase and decrease) with changes of +/- 0.2m, and to blockages (both fully open and fully blocked) with changes of up to +/- 0.7m, mainly upstream and downstream of culvert structures. The flood levels are also moderately sensitive to the assumed changes in Manning's n on the main flow paths, which are assumed to be of high roughness in forested areas, with resulting changes in flood levels of +/- 0.15m. Flood levels are typically insensitive to changes in rainfall losses (+/- 0.03m), although flooding in selected storage areas are more sensitive to the increased rainfall losses (-0.28m) than to the decreased losses (+0.8m).

Table 6-2 Sensitivity Analysis Description and Results

Scenario	Description	Change in Flood Level
Rainfall and Flow Scaling – Zero	Scaling factor of 1.0. (Base case adopts scaling factor of 1.2)	• Up to -0.15m on major flow paths • Typically less than -0.05m on other flow paths.
Rainfall and Flow Scaling – Increase by 20% points	Scaling factor of 1.4. (Base case adopts scaling factor of 1.2)	• Up to +0.15m on major flow paths (east of Ellerslie Cres and south of Brotherglen Dr) • Typically less than +0.05m on other flow paths. • +0.1m to +0.2m in some storage areas (between Botanic Dr and Ocean Dr, Lakewood shops car park, car park west of Laurieton Hotel) and isolated areas on some properties.
Rainfall Losses – Increase	Pervious area: 15mm initial loss (burst loss: define burst as starting at 7AM 24 April 2008. Peak intensity at 8:35AM), 4mm/hr continuing loss. Impervious area: 2mm initial loss, 0mm/hr continuing loss.	• Typically less than -0.03m in most flow paths and overland flow areas. • Up to -0.28m in storage area between Botanic Dr and Ocean Dr.
Rainfall Losses – Decrease	Pervious area: 0mm initial loss, 0mm/hr continuing loss. Impervious area: retain calibration values (0mm initial loss, 0mm/hr continuing loss.)	• Typically less than +0.02m in most flow paths and overland flow areas. • Up to +0.08m in storage area between Botanic Dr and Ocean Dr.
Blockage of Hydraulic Structures – Fully Blocked	All pipes, culverts and pits 100% blocked.	• Typically +0.15m to +0.3m in main road low points and storage areas (between Botanic Dr and Ocean Dr; Sirius Dr, Pelican Crt, and others) • Up to +0.4m in Lakewood shops car park, car park west of Laurieton Hotel. • Decreases of -0.1m in some locations downstream of the storage areas

		• Typically less than +/-0.05m on other flow paths.
Blockage of Hydraulic Structures – All Clear	All pipes, culverts and pits 0% blocked.	• Typically less than +/-0.1m in affected areas. • Localised reductions of up to -0.7m upstream of culverts. • Localised increases of up to +0.3m downstream of culverts including on properties in Pelican Crt.
Surface Hydraulic Roughness – Plus 20%	Surface Manning's n values increased by 20%.	• Up to +0.15m on major flow paths (east of Ellerslie Cres and south of Brotherglen Dr) • Typically less than +0.05m on other flow paths. • Less than +/-0.02m in other overland flow areas.
Surface Hydraulic Roughness – Minus 20%	Surface Manning's n values decreased by 20%.	• Up to +-0.05m on major flow paths (east of Ellerslie Cres and south of Brotherglen Dr) • Typically less than -0.03m on other flow paths and overland flow areas.

7. Estimation of Design Floods

7.1 Adopted Model Parameters for Design Events

7.1.1 Design Rainfall

This flood study is based on Australian Rainfall and Runoff (ARR) 2016 design rainfalls and procedures. Each design storm AEP and duration consists of an ensemble of 10 storm temporal patterns which define the timing and intensity of rainfall throughout a given storm event. Each storm in the 10 temporal pattern ensemble has an equal probability of occurring.

Design rainfall data was downloaded from the Bureau of Meteorology website, including ARR 2016 design rainfall depths and temporal patterns relevant to the study area. The data was extracted for a representative location in the study area (West Haven; 31.6375° S, 152.7875° E).

Design rainfall time series were derived for the Probable Maximum Precipitation (PMP) events, based on the Generalised Short Duration Method (GSDM) in *The Estimation of Probable Maximum Precipitation in Australia: Generalised Short Duration Method* (BOM, 2003).

The design rainfall depths for design events up to 0.5% AEP adopted in this study are summarised in Table 7-1. The PMP depths for the events assessed with durations up to 1 hour are summarised in Table 7-2.

Table 7-1 Design Rainfall Depths for Selected Storms

Storm Duration	Rainfall Depth (mm)				
	0.2EY	5% AEP	2% AEP	1% AEP	0.5% AEP*
15 minute	28.9	39.3	46.7	52.4	57.6
30 minute	40	55.1	65.9	74.5	82.0
1 hour	52.7	73.8	89.5	102	112.2
1.5 hour	61.4	86.6	106	122	134.2
2 hour	68.4	97	119	137	150.7
3 hour	80.1	114	140	161	177.1

* Initially estimated for sub-daily durations as 10% greater than the 1% AEP design rainfall depths, based on BOM data for 24 hour and longer durations. Sub-daily design rainfall depths for the 0.5% and other rare storms were released by BOM in November 2018 which confirmed this assumption. The design rainfall depths in the above table were retained.

Table 7-2 Probable Maximum Precipitation Event Rainfall Depths

Storm Duration	Rainfall Depth (mm)
15 minute	190
30 minute	280
45 minute	350
1 hour	440

7.1.2 Rainfall Losses

An initial and continuing loss model was utilised in the RAFTS module which represents rainfall losses during storm events such as depression storage and soil infiltration. The adopted loss values are summarised for the design event runs.

Table 7-3 Adopted Rainfall Losses

	Up to 1% AEP event	PMF event
Pervious areas	Initial Loss: 15mm Continuing Loss: 2.5mm/hr*	Initial Loss: 0mm Continuing Loss: 1mm/hr
Impervious areas	Initial Loss: 1mm Continuing Loss: 0mm/hr	Initial Loss: 0mm Continuing Loss: 0mm/hr

* Pervious area continuing loss estimated during model calibration and verification.

ARR 2016 recommendations for rainfall losses are also based on an initial loss/continuing loss model, with storm loss depths (pre-burst + burst losses) prescribed by the ARR Datahub for the study area as:

- Storm initial loss: 37mm, with median pre-burst loss of 0mm for a 1% AEP 1 hour storm. Therefore, burst loss = 37mm. Rainfall losses are not provided in DataHub for sub-hourly storm durations.
- Continuing loss: 5.5mm/hr.

The above rainfall losses are applicable to pervious areas in rural catchments. DataHub states that these are *not* for use in urban areas.

The initial loss values from DataHub need to be treated with caution, with consideration of the limitations of the data. The ARR 2016 losses are derived from analysis of main river catchment streamflow data, with different rainfall-runoff characteristics to local overland flow catchments such as around North Brother. The high initial loss depth of 37mm (burst only) appears exceedingly high compared to values previously used for pervious areas in similar overland flow studies (typically up to 15mm). It is not expected that in a storm event in this study area, a pervious area would only begin to generate runoff after the first 37mm of rainfall, particularly for the short-duration storm events being considered for the local overland flow areas. For these reasons the ARR 2016 initial losses are not considered appropriate for this study, and a more conservative initial loss of 15mm is adopted for pervious areas for the design flood estimation.

Similarly, the continuing loss of 5.5mm/hr from DataHub was considered relatively high for the study area. While there are likely to be areas on the mountain with highly permeable soils, the infiltrated water re-emerges as spring flows in certain locations, and hence the infiltrated water is not lost to deep groundwater and may contribute to flood flows. The adopted continuing loss of 2.5mm/hr, estimated during the model calibration and verification, attempts to strike a balance between the potentially high infiltration rates and re-emergence of spring flows.

7.1.3 Orographic Rain Scaling

As per the model calibration and verification, an orographic rain scaling factor of 1.2 was applied to areas on the North Brother mountainside, refer to Figure 5-1.

7.1.4 Blockage of Hydraulic Structures

Similar to the model verification (refer Section 6.3.3), guidance on blockage of hydraulic structures was generally sought from *Australian Rainfall and Runoff Revision Project 11– Blockage of Hydraulic Structures Stage 2* (Engineers Australia, 2013). Blockages of stormwater pits and culvert inlets were assumed as per below:

- Sag pits: kerb inlet assumed clear and grate 100% blocked.
- On-grade pits: 90% of the combined kerb inlet and grate flow capacity (i.e. 10% blockage factor).
- Culverts were generally assumed to be 50% blocked for design event runs.

7.1.5 Blockages in Flow Diversion Drains

Blockage condition of flow diversion drains due to unmanaged vegetation, based on resident reports and site observations and adopted in the model verification, was retained for the design runs.

7.1.6 Tailwater Conditions

Selection of tailwater conditions was based on the OEH guidance in "Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways" (OEH, 2015). Recommended combinations of flooding and tailwater is summarised below in Table 7-4 (excerpt from the document).

Table 7-4 Combinations of Catchment Flooding and Oceanic Inundation Scenarios

Design AEP for peak levels/velocities	Catchment Flood Scenario	Ocean Water Level Boundary Scenario	Comment/ Reference
50% AEP	50% AEP	HHWS(SS)	Dynamic hydrograph can be taken from Appendix C with peak flood to coincide with HHWS(SS) highest peak for highest water levels Peak HHWS(SS) 1.25m AHD
20%	20% AEP	HHWS(SS)	
10%	10% AEP	HHWS(SS)	
5%	5% AEP	HHWS(SS)	
2%	2% AEP	5% AEP	Dynamic ocean water level boundary hydrograph Appendices A or B for relevant waterway type
1% Envelope level	5% AEP	1% AEP	Envelope provides 1% AEP design flood estimate Dynamic ocean water level boundary hydrograph Appendices A or B for relevant waterway type
1% Envelope level	1% AEP	5% AEP	
1% Envelope velocity	1% AEP	ISLW	Dynamic hydrograph can be taken from Appendix C with peak flood to coincide with ISLW lowest trough for peak velocities in entrance. Fixed ISLW approx. -0.95m AHD
0.5%	0.5% AEP	1% AEP	Dynamic ocean water level boundary hydrograph Appendices A or B for relevant waterway type
0.2%	0.2% AEP	1% AEP	
PMF	PMF	1% AEP	
1% Catchment	1%	HHWS(SS)	Suggested envelopes for analysis of catchment flooding only
PMF Catchment	PMF	HHWS(SS)	

Note: *Individual projects are likely to specify the use of only a select number of AEPs outlined in the table.*

In the design flood estimation for North Brother overland flooding, local catchment flood events were coincided with elevated ocean water level, rather than a coinciding river flood event. There is considered to be a higher probability that the local catchment storm would coincide with a storm surge event. Local catchment flooding occurred sometime (0.5-2 days) before the river flooding occurred or peaked during the flood events of 2008 and 2013. Hence, peak river flood levels as coinciding tailwater conditions is considered overly conservative.

The adopted tailwater levels for the local catchment flood modelling are summarised in Table 7-5. Given the short duration of the local catchment flood events, a constant tailwater level was assumed.

Table 7-5 Adopted tailwater levels for North Brother local catchment flooding

Design Flood	North Brother Local Catchment Flood Event	Tailwater Condition (Ocean Water Level)	Comment
0.2EY	0.2EY	HHWS(SS)* 1.25m AHD	HHWS in the river/lakes system is 0.2 – 0.6m AHD (ref: MHL, 2012).
5% AEP	5% AEP	HHWS(SS) 1.25m AHD	
2% AEP	2% AEP	5% AEP: 2m AHD	Estuary Type B entrance. River 5% AEP flood level is higher than adopted TWL[2], at 2.3 – 2.4m AHD.
1% AEP (local flood)[1]	1% AEP		
1% AEP (storm surge)[1]	5% AEP	1% AEP: 2.1m AHD	Estuary Type B entrance. River 1% AEP flood level is significantly higher than adopted TWL[2], at 2.9 – 3m AHD ref: Worley Parsons, 2013).
0.5% AEP	0.5% AEP	1% AEP: 2.1m AHD	
PMF	PMF	1% AEP: 2.1m AHD	
1% AEP Climate Change Scenario	1% AEP (+10% increase in rainfall)	1% AEP + 0.9m sea level rise: 3.0m AHD	

1. Maximum envelope derived from 1% AEP local catchment flood and storm surge scenarios to define 1% AEP design flood.

2. HHWS(SS) = High High Water Spring (Summer Solstice) i.e. "king" tides. TWL = Tailwater Level.

7.2 Simulated Design Events

The storm events modelled include the 0.2 Exceedances per Year ("EY"), 5%, 2%, 1% and 0.5% AEP and PMF events for current climate conditions. The storm durations that were initially assessed include the 15 and 30 minute and 1, 1.5, 2 and 3 hour durations for up to the 0.5% AEP events. The critical durations (those that gave the maximum flood levels) varied for the different AEPs.

The 15, 30 and 45 minute and 1 hour durations were modelled for the PMF event. The critical duration for the PMF varies throughout the catchment.

A climate change flood scenario was also assessed, consisting of the existing 1% AEP storm plus a 10% increase in rainfall intensity, combined with a 1% AEP ocean level with a 0.9m sea level rise.

8. Design Flood Results

8.1 Final Model Runs and Processing of Results

ARR 2016 guidelines stipulate that for each ensemble of 10 storm temporal patterns it is the storm producing the just above the median flow or flood level which should be considered as the “representative” storm temporal pattern. The flood study modelling is based in part on direct rainfall hydrology, hence the selection of a median flood level from the TUFLOW results is appropriate. The TUFLOW model results for up to the 0.5% AEP were processed in the following manner:

1) Review the preliminary model results to identify the critical storm durations and representative temporal patterns for each AEP. That is, for each 10 storm ensemble identify the storm just-above median and the durations which give the maximum flood level. The representative storms are summarised in Table 8-1.
2) Undertake final model runs for the selected representative storms.
3) For each storm AEP, the maximum envelope of the flood level from each representative storm is derived to define the design flood level surface.
4) Steps 3 repeated for the flood depth, velocity and flood hazard results, and other parameters.

The PMF was run for the 15, 30 and 45 minute and 1 hour durations. Only one storm temporal pattern was applied to each PMF duration, hence only a maximum envelope of the results from each duration was derived to define the design PMF flood surface.

Table 8-1 Selected ARR 2016 Representative Storms for Design Flood Definition

AEP	Representative Storms
0.2EY	30min (TP10), 1hr (TP8), 2hr (TP10)
5%	1hr (TP10), 2hr (TP6), 3hr (TP4)
2%	30min (TP5), 1hr (TP6), 2hr (TP8)
1%	30min (TP5), 2hr (TP6) Also 5% AEP 3hr (TP4) for coincident ocean inundation flood event. Refer Table 7-5 for adopted coincident flood scenarios.
1% Climate Change	Adopt same as 1% AEP
0.5%	Adopt same as 1% AEP
PMF	All storms selected

8.2 Flood Mapping

Design flood mapping is presented in Appendix E for flood depths/extent and velocities. The flood mapping filters out areas with flood depths less than 0.05m (50mm) to exclude areas of shallow sheet flow.

8.3 Description of Flooding Conditions

8.3.1 Flood Depth

Overland flow depths on properties are typically up to 0.3m in up to the 1% AEP event. Depths exceed 0.5m in a number of locations in the 0.2EY event, and exceed 1m in the 5% and 1% AEP events. Areas of deeper flows include main flow paths and drainage low points in a number of roads.

During the PMF event, property and road flooding exceeding 0.5m depth is widespread, with property and road flooding of 1m depth also common. Depths of flooding exceeding 2m occur on approximately 20 properties in the study area.

The flood depth mapping shows relatively high depths of ponding on the upstream sides of many buildings. In most cases this is due to the model terrain not allowing free drainage of water around the buildings. In real life the ground surface around buildings is usually graded to allow water to drain off and not form trapped points. There may also be property stormwater drainage present which is not included in the model. Some care therefore needs to be taken in the review of the flood depth mapping.

8.3.2 Flow Velocity

Flow velocities are swift in a number of overland flow paths through properties and particularly in roads. Typical flow velocities are 0.5 – 1m/s in the 0.2EY event, and 1 – 1.5m/s in the 1% AEP event. High flow velocities of 2 – 3m/s occur in a number of locations including roads and properties. These flows are likely to be highly hazardous to people and risk significant damage to buildings and property.

Flow velocities of 3 – 4m/s are commonplace in the PMF, with some locations experiencing velocities over 4m/s.

8.3.3 Duration of Flooding

Overland flooding in the study area is generally a result of intense short-duration rainfall events. As a result, the duration of inundation of roads and built areas is typically short, limited to 1 – 2 hours in up to the 0.5% AEP event. Storage areas such as road sag points in Sirius Drive and Lilli Pilli Close in Lakewood may be inundated for longer durations of up to 3hrs due to constrained capacity of stormwater drainage servicing these areas.

Durations of inundation are likely to be up to 4 hours in the PMF event particularly in some flood storage locations, affecting roads including Botanic Drive and Ocean Drive west of Lakewood shopping centre.

Note that the duration of flooding for depths greater than 0.3m, at which stage floodwaters become impassable for most passenger vehicles, is generally limited to approximately 1 hour duration in most roads.

A river flooding event may occur shortly after overland flooding in the study area, in which case the lower-lying areas of the study area may experience more extensive durations of flooding. River flooding was not assessed in this study.

8.3.4 Climate Change Impacts

The change in flood levels in the 1% AEP event due to climate change are presented on Figure E-15 in Appendix E. Most areas affected by overland flow experience flood level increases of up to 0.1m due to increased rainfall and reduced drainage capacity from higher tailwater levels caused by sea level rise. Locations along the river and lakes would be impacted by 0.9m increases in flood levels directly due to sea level rise, while adjacent areas would be impacted typically by up to 0.5m increases in flood level.

Note that these impacts are estimated based on the overland flooding assessment of North Brother. Increases in flood levels due to climate change effects on riverine flooding may be different, refer to the Camden Haven River and Lakes Flood Study (Worley Parsons, 2013).

8.4 Summary of Flood Levels and Flow Conditions

Table F-1 in Appendix F summarises the peak flood levels and flow velocities at locations throughout the study area. Table F-2 in Appendix F summarises the peak flow rates for selected locations in the study area.

8.5 Provisional Flood Hazard Mapping

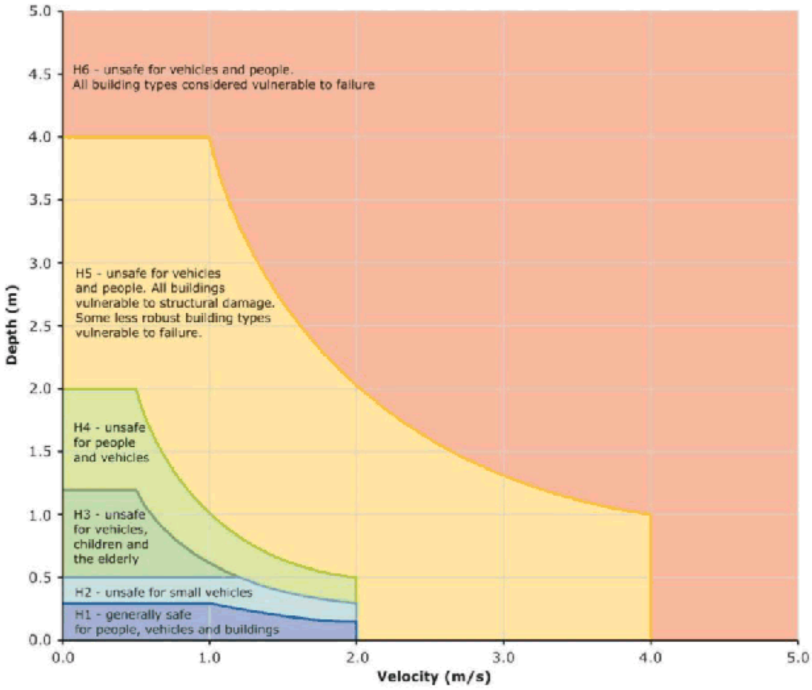
Flood hazard mapping was prepared for the 1% AEP event for current climate conditions and for the 1% AEP event under the adopted climate change scenario (increased rainfall intensity by 10% and with 0.9m sea level rise). Recent research has been undertaken into the hazard that flooding poses and the vulnerability of the public and assets when interacting with floodwaters. A combined flood hazard classification is presented in *Australian Disaster Resilience Handbook 7. Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia* (AIDR, 2017a) and *Guideline 7-3 Flood Hazard* (AIDR, 2017b) based on this research, and is illustrated in Figure 8-1. The flood hazard categories according to the AIDR definition are:

- 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 and vehicles. Buildings require special engineering design and construction; and
- H6 – Unsafe for people or vehicles. All buildings types considered vulnerable to failure.

The flood hazard classification is more discrete and provides guidance on flood hazard thresholds to different members of the community (e.g. children and elderly) and different assets (small versus larger vehicles, standard versus specialised engineered buildings). The AIDR flood hazard definition potentially provides a more suitable guideline for assessing flood hazard on the floodplain from an emergency management perspective.

The flood hazard mapping is provided in Appendix G and is denoted provisional. The provisional mapping is based on direct flood modelling outputs and was not updated to reflect the "true" flood hazard to take into consideration evacuation, isolation and other emergency management aspects. There are numerous areas of high flood hazard (>H5) typically reflect the swift overland flows in watercourses and flow paths including roadways.

Figure 8-1 General flood hazard vulnerability curves, Australian Institute for Disaster Resilience (AIDR) definition. Reproduced from Figure 6 in *Guideline 7-3: Flood Hazard* (AIDR, 2017b)



8.6 Provisional Hydraulic Categories Mapping

Three flood hydraulic categories identified in the *Floodplain Development Manual* (NSW Government, 2005). These are also defined in Council's Flood Policy (2015):

- Floodway, where significant discharge of water occurs during floods and blockage could cause redirection of flows. Generally characterised by relatively high flow rates; depths and velocities;
- Flood storage, characterised by relatively deep areas of floodwater and low flow velocities. Floodplain filling of these areas can cause adverse impacts to flood levels in adjacent areas; and
- Flood fringe, areas of the floodplain characterised by shallow flows at low velocity.

There is no firm guidance on hydraulic parameter values for defining these hydraulic categories, and appropriate parameter values may differ from catchment to catchment. For example, the minimum threshold flows and depths which might define a floodway in an overland flow catchment may be markedly lower than those for a large lowland river due to the different scale of flooding. The category definition adopted in the Hastings River Flood Study (PBP, 2006) and Hastings River Floodplain Risk Management Study (Worley Parsons, 2012) was initially considered for this study. For the Hastings River the floodways were defined as areas in the 1% AEP flood with flows greater than 2m, velocities greater than 0.5m/s and velocity x depth greater than 1m^2/s. This does not agree with the flooding conditions in the North Brother study area, where 1% AEP flows are generally less than 1.5m deep. Hence, an alternative hydraulic category system is required.

Howells et. al. (2003) suggest that consideration of flow depths, velocities and velocity x depth of flood flows can be used to help define the hydraulic category areas. Various combinations of flow, depth and velocity were trialled for appropriate threshold values for the hydraulic categories. For the purposes of this study, the hydraulic categories were defined as per the criteria in Table 8-2, which were selected following trials of different criteria values and categorisation methods. These criteria are consistent with those adopted by a number of other councils in NSW for overland flooding.

Table 8-2 Hydraulic Categories Criteria

Hydraulic Category	Criteria
Floodway	Area within the flood extent where: • Velocity x Depth > 0.3m^2/s AND • Velocity > 0.5m/s AND • Depth > 0.15m.
Flood Storage	Remaining area within 1% AEP flood extent where Depth > 0.15m
Flood Fringe	Remaining area in the floodplain (i.e. area within PMF extent) outside the Floodway and Flood Storage areas.

The provisional hydraulic categories mapping is presented in Appendix G for both the 1% AEP design flood for current climate, and for the 1% AEP event with climate change. The mapping is treated as provisional and may need to be considered in further detail to ensure a continuous floodway strip (where appropriate) and to remove/reclassify isolated areas which currently meet the floodway criteria to either flood storage or flood fringe categories. This would be achieved by manual inspection and adjustment of the mapped floodway areas.

Floodway areas are generally located within the natural watercourses and flow paths, although there are a number of roads which contain floodways throughout the study area. Floodways pass through properties on Black Swan Terrace, Koonwarra Street, Pelican Court, Elouera Place, Flinders Drive, St Joseph's School, Peach Grove, Gow Place, Kew Road and in Laurieton between Quarry Place and Bold Street, among others.

8.8 Flooding Hot Spots

This study confirms flooding issues at the locations identified by Council and listed in Section 2.3. It also identifies a number of additional locations where there is elevated potential for flooding to cause a hazard to people, damage to properties and disruption to transportation routes. These are described in Table 8-3. Critical areas with consideration of high flood depths, velocities or hazard are highlighted with orange cell or text shading.

Table 8-3 Description of Flooding Hot Spots. Critical locations are highlighted orange

Location	Description
Property flooding	
Black Swan Terrace, West Haven	Flow depths on properties of up to 0.5m in the 0.2EY event and up to 0.7m in the 1% AEP event. Swift flows of 2m/s. Flood hazard up to H5 rating in the 1% AEP event.
Ringtail Cl, Lakewood	Overflows from open channel onto properties with flooding in backyards to depths 0.2 – 0.3m in the 1% AEP event. Relatively low flooding impact.
Lilli Pilli Cl, Lakewood	Flooding in backyards to depths of 0.3 – 0.5m in the 1% AEP event from open drain overflows. Flooding in cul-de-sac to depths up to 0.8m. Also significant flooding of car park around Lakewood shopping centre.
Mission Terrace, Lakewood	Overflows with depths of 0.1 – 0.3m in the 1% AEP event from cul-de-sac onto downhill property. Overflows from the overland flow path on to uphill side properties with depths up to 0.2m
Kirmington Terrace to Pelican Court, West Haven	Flows through properties on low side of Koonwarra Street of 0.3m in the 0.2EY event and exceeding 0.5m in the 1% AEP event. Velocities up to 2m/s in the 1% AEP. Flood hazard up to H4 (some localised H5) rating in the 1% AEP. Flow depths 0.5m in the 0.2EY event and up to 0.8m in the 1% AEP event on Captain Cook Bicentennial Drive villas and Ocean Drive property, at dwellings. Flood hazard up to H4 rating in the 1% AEP event. Flood depths of 0.6 – 0.8m in the 0.2EY event within Pelican Court roadway and pedestrian walkway. Depths up to 0.6m at dwellings in 1% AEP event. Flood hazard up to H4 rating on properties and H5 in roadway in the 1% AEP event. Groundwater springs occur in this area but are not directly related to the surface water flood risk. These springs appear to be a spatially random occurrence.
Flinders Dr Estate, Laurieton	Overflows from drainage easement swale onto properties with depths to 0.3m in the 0.2EY event and 0.5m in the 1% AEP event. Overflows from Reliance Crescent sag point onto properties to depths of 0.2m in the 0.2EY event and 0.4m in the 1% AEP event.
Bold Street area, Laurieton	Significant flows through Laurieton Hotel with H4 hazard rating. Trapped drainage point on western side of commercial properties with significant depths, though local drainage may be present which would mitigate the flood depths. Overflows down fire trail at Norman Street/ Mill Street affecting properties with depths up to 0.3m in the 1% AEP. Overflows onto units on Harbourside Crescent from trunk drainage channel to depths exceeding 0.5m in the 1% AEP event, with H5 hazard rating.
Quarry Way, Laurieton	Overflows from flow diversion drain to depths of 0.5m in the 1% AEP event on properties. The drain is reported to be affected by significant debris blockage.

Lake Street, Laurieton	Flood depths up to 1m in the 1% AEP event affecting dwelling corner Lake Street and Seymour Street, unsure if above floor flooding. To be confirmed. Overflows from Lake Street onto properties between Ocean Drive and Castle Street to depths of 0.3m in the 1% AEP.
St Joseph's School, Laurieton.	Swift flows in overland flow paths to depths of 0.8m and velocities exceeding 2m/s in the 1% AEP event. Flows between buildings are 0.4m in the 0.2EY event and 0.6m in the 1% AEP event, with velocities up to 2m/s. Flood hazard rating of H4 in pedestrian walkways and H5 in overland flow paths in the 1% AEP event.
Properties adjacent to Stingray Creek and Camden Haven River, Laurieton	Numerous properties on low-lying land at risk of oceanic inundation during storm surge events. Estimated depths on the flood mapping expected to be conservative due to likely attenuation of ocean inflows through the river mouth.
Blackbutt Crescent and Peach Grove, Laurieton	Overflows from flow diversion drain to depths of 0.5m in the 1% AEP event on properties. The drain form and capacity significantly reduces near its discharge point onto Peach Grove at Tunis Street. Flows into the drain originate from natural watercourse further uphill, which is significantly affected by rubble and debris blockage.
Elouera Place, West Haven	Overflows from watercourse and diversion drain. Depths over 0.3m in the 0.2EY event and 0.5m in the 1% AEP event.
Sirius Drive, Honeysuckle Avenue and Mahogany Close, Lakewood	Flood depths on properties 0.3 – 0.5m in the 1% AEP event, built up from road ponding areas.
Sirius Drive and Oak Close, Lakewood	Depths 0.3 – 0.4m and velocities 1m/s in the 1% AEP event.
Sandpiper Close	Overflows from concrete channel along Ocean Drive. Depths 0.3 – 0.4m and velocities 1m/s in the 1% AEP event.
Properties on lower side of Ocean Drive, 200m east of Hoschke Road, West Haven	Road low point overflows onto properties with depths of 0.5m and velocities of 1m/s in the 1% AEP event.
Roads	
Ocean Drive west of Lakewood shopping centre	5% AEP event flood depths of 0.4m 1% AEP event flood depths of 0.5m, H3 hazard rating
Botanic Drive, Lakewood	1% AEP event flood depths of 0.4m, H2 hazard rating
Lilli Pilli Close, Lakewood	5% AEP event flood depths of 0.6m 1% AEP event flood depths of 0.7m, H3 hazard rating
Ocean Drive east of Lakewood shopping centre	5% AEP event flood depths of 0.3m 1% AEP event flood depths of 0.35m, >H4 hazard rating
Sirius Drive, Honeysuckle Avenue and Mahogany Close, Lakewood	0.2EY event flood depths of 0.6 – 0.7m 1% AEP flood depths 1m, H3 hazard rating
Ocean Drive between Fairwinds Avenue and Mission Terrace	0.2EY events flood depths of 0.5m 1% AEP event flood depths of 0.7m, >H4 hazard rating
Ocean Drive and Mission Terrace intersection	0.2EY event flood depths of 0.4m 1% AEP event flood depths of 0.6m, H3 hazard rating
Ocean Drive near Waterview Crescent	5% AEP event flood depths of 0.2 – 0.3m

	1% AEP event flood depths of 0.3m, low hazard rating but long section of flooding
Ocean Drive near Pelican Court	5% AEP event flood depths of 0.3m 1% AEP event flood depths of 0.4m, H3 hazard rating
Pelican Court, West Haven	0.2EY event flood depths 0.6m 1% AEP event flood depths of 1m, H5 hazard rating
Waterview Crescent, Kirmington Terrace and Koonwarra Drive, West Haven	0.2EY event flood depths of 0.2m with 2m/s velocity; max 0.6m depths (low velocity) 1% AEP event flood depths up to 0.7m, H5 – H6 hazard rating
Ocean Drive east of Hoshcke Road	0.2EYevent flood depths of 0.4m 1% AEP event flood depths of 0.5m, H3 hazard rating
Ocean Drive east of Flinders Drive	5% AEP event flood depths of 0.3m 1% AEP event flood depths of 0.4m, H3 hazard rating
Kew Road/Bold Street near Tunis Street, Laurieton	1% AEP event flood depths of 0.5m, H2 hazard rating
Bold Street between Laurie Street and Mill Street	0.2EY event flood depths over 0.5m 1% AEP event flood depths 0.6 – 0.8m, H5 hazard rating
Bold Street north of Hanley Street, Laurieton	0.2EYevent flood depths of 0.3m with 1m/s velocity 1% AEP event flood depths up to 0.5m, H3 hazard rating
Lord Street at Seymour Street, Laurieton	0.2EY event flood depths of 0.5m 1% AEP event flood depths up to 0.7m, H3 hazard rating
Flinders Drive, Laurieton Tunis Street, Laurieton Rosewood Court and Mission Terrace, Lakewood Diamentina Way, Lakewood	H5 hazard rating on steep sections of road (1% AEP event)

8.9 Groundwater Springs in the Study Area

There are a number of reports of groundwater springs occurring in the study area, with infiltrated rainwater discharging to the surface and in some cases causing damage to property. These appear to be spatially random and due to the particular soil structure on the North Brother Mountain, where accumulated groundwater causes piping through the soil and then eventually washing out the soil to form a discharge point at the ground surface. Similarly, there are locations where surface water can be observed to rapidly percolate via fissures in the ground surface.

While these groundwater springs may result in surface water discharge and subsequent property damage or are otherwise nuisance occurrences, characterising this problem was outside the scope of this flood study which deals primarily with surface runoff and flooding. Further geological and geotechnical investigations may be required to address these groundwater spring issues.

9. Conclusions and Recommendations

9.1 Conclusions

Hydrologic and hydraulic computer models for the North Brother Local Catchments study area were developed based on available data from Council and other sources, and topographic and hydraulic structures survey collected during this study. The models were developed with a focus on local catchment and overland flooding originating from runoff from the North Brother Mountain and from within the study area itself. The modelling did not focus on mainstream flooding from the Camden Haven River and other waterways.

The models were calibrated to the April 2008 and March 2013 local catchment flood events based on responses to the community consultation survey and other reports and flooding complaints lodged with Council. Model parameters were adjusted to achieve a satisfactory fit to historic flood observations include rainfall losses, hydraulic roughness of the floodplain surface and blockages of hydraulic structures and of diversion drains. An orographic scaling factor of 1.2 was adopted to increase rainfall and catchment flows by 20% to achieve a satisfactory calibration. This factor accounts for increased rainfall intensities during storm events due to the orographic effects resulting from the North Brother Mountain topography, and is relative to the unscaled recorded rainfall from gauges on the coastal plain away from the mountain.

A number of sensitivity analyses were undertaken for the April 2008 flood event to test the sensitivity of the model results to changes in the adopted parameter values. The tested parameters include:

- Rainfall and flow scaling
- Rainfall losses
- Blockage of hydraulic structures
- Surface hydraulic roughness

Flood levels and depths were relatively sensitive in particular to the changes in rainfall scaling (both increase and decrease) with changes of +/- 0.2m, and to blockages (both zeroed and fully blocked) with changes of up to +/- 0.7m, mainly upstream and downstream of culvert structures. The flood levels were also moderately sensitive to the assumed changes in Manning's n on the main flow paths, which were assumed to be of high roughness in forested areas, with resulting changes of +/- 0.15m. Flood levels were typically insensitive to changes in rainfall losses (+/- 0.03m), although flooding in selected storage areas was more sensitive to the increased rainfall losses (-0.28m) than to the decreased losses (+0.08m).

Community information sessions were held in August 2018 with feedback from the community incorporated into the final model calibration and design flood simulations. Design flood conditions were estimated based on the updated model for a range of flood events from the 0.2EY event up to the PMF event. A climate change scenario comprising the 1% AEP design event plus 10% increase in rainfall depth and 0.9m sea level rise was assessed.

Flood behaviour in the design events is characterised by typically swift flows with depths of flow in roads and properties of 0.3m in the 0.2 EY event and up to 1m in the 1% AEP event being common. During the PMF event, property and road flooding exceeding 0.5m depth is widespread, with property and road flooding of 1m depth also common. Depths of flooding exceeding 2m occur on approximately 20 properties in the study area.

Flow velocities are swift in a number of overland flow paths through properties and particularly in roads. Typical flow velocities are 0.5 – 1m/s in the 0.2EY event, and 1 – 1.5m/s in the 1% AEP event. High flow velocities of 2 – 3m/s occur in a number of locations including roads and properties. These flows are likely to be highly hazardous to people and risk significant damage to buildings and property. Flow velocities of 3 – 4m/s are commonplace in the PMF event, with some locations experiencing velocities over 4m/s.

Flood levels increase due to climate change by up to 0.1m in areas affected mainly by overland flows, grading up to 0.9m in low-lying areas directly impacted by sea level rise. Transition areas experience increases in flood levels between 0.1m and 0.9m due to varying degrees of interaction between increased overland flows and the increased sea levels.

Provisional flood hazard mapping and hydraulic categories mapping were prepared based on the 1% AEP design flood event and the 1% AEP event with climate change. The flood hazard mapping was based on hazard categories defined in the Australian Emergency Management Handbook which describes safe and hazardous flooding conditions for pedestrians, vehicles and buildings. The hydraulic category definitions were tailored to suit the overland flooding behaviour in the study area.

Flooding problem areas previously identified by Council were confirmed in the study and flooding behaviour described. Additional locations with flooding issues were also identified. Roads where flooding is likely to affect vehicular traffic were identified. Durations of flooding due to overland flows were identified as being short (2 – 3 hours) owing to the nature of the flash flooding which occurs in the study area.

9.2 Recommendations

- It is recommended that this Draft Report be reviewed by Council prior to being placed on public exhibition for feedback from the community.
- It is recommended that Council considers the adoption of this Flood Study and the outputs to guide floodplain management and land use planning in the North Brother local catchments study area. The subsequent Floodplain Risk Management Study should consider the management of flood risk in the catchment, particularly at the identified flooding “hot spots”, which may include the development of flood mitigation strategies.
- Council should consider geological and geotechnical investigations to assess the groundwater spring issues in the study area which result in surface water discharge and subsequent property damage or are otherwise nuisance occurrences.

10. Acknowledgements

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- Manly Hydraulics Laboratory, NSW Department of Finance, Services and Innovation;
- Council officers; and
- NSW Office of Environment and Heritage.

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12. Glossary

Annual Exceedance Probability (AEP)

The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. In this study AEP has been used consistently to define the probability of occurrence of flooding. It is to be noted that design rainfalls used in the estimation of design floods up to and including 100 year ARI (ie. 1% AEP) events was derived from 1987 Australian Rainfall and Runoff. The following relationships between AEP and ARI applies to this study (AR&R, 2016).

Frequency Descriptor	EY	AEP (%)	AEP (1 in x)	ARI
	12			
	6	99.75	1.002	0.17
Very frequent	**4**	98.17	1.02	0.25
	3	95.02	1.05	0.33
	2	86.47	1.16	0.50
	1	**63.2**	1.58	1.00
	0.69	**50.00**	2	1.44
Frequent	**0.5**	39.35	2.54	2.00
	0.22	**20.00**	5	4.48
	0.2	18.13	5.52	5.00
	0.11	**10.00**	10.00	9.49
	0.05	**5.00**	20	20.0
Infrequent	0.02	**2.00**	50	50.0
	0.01	**1.00**	**100**	100
	0.005	0.50	**200**	200
Rare	0.002	0.20	**500**	500
	0.001	0.10	**1000**	1000
	0.0005	0.05	**2000**	2000
	0.0002	0.02	5000	5000
			↓	
Extremely Rare				
Extreme			PMP	

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 occurrences of a flood as big as or larger than the selected event. For example, floods with a discharge as great as or greater than the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
Catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
Development	Is defined in Part 4 of the EP&A Act In fill 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. Eg. The urban subdivision of an area previously used for rural purposes. New developments involve re-zoning and typically require major extensions of exiting urban services, such as roads, water supply, sewerage and electric power. Redevelopment: refers to rebuilding in an area. Eg. As urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either re-zoning or major extensions to urban services.
DRAINS	DRAINS is a computer program which is used to simulate local catchment rainfall-runoff and stormwater system hydraulics and is widely used across Australia.
Effective Warning Time	The time available after receiving advise 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.
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 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 susceptibility to flooding by the PMF event. Note that the term flooding liable land covers the whole floodplain, not just that part below the FPL (see flood planning area)

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 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 include both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defines objectives.
Flood plan (local)	A sub-plan of a disaster plan that deals specifically with flooding. They can exist at state, division and local levels. Local flood plans are prepared under the leadership of the SES.
Flood planning levels (FPLs)	Are the combination 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 "designated flood" or the “flood standard” used in earlier studies.
Flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings and structures subject to flooding, to reduce or eliminate flood damages.
Flood readiness	Readiness is an ability to react within the effective warning time.
Flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. <u>Existing flood risk</u>: the risk a community is exposed to as a result of its location on the floodplain. <u>Future flood risk</u>: the risk a community may be exposed to as a result of new development on the floodplain. <u>Continuing flood risk</u>: 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 passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas

Floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.
Freeboard	Provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
Hazard	A source of potential harm or 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.
Local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
m AHD	Metres Australian Height Datum (AHD)
m/s	Metres per second. Unit used to describe the velocity of floodwaters.
m^3/s	Cubic metres per second or "cumecs". A unit of measurement of creek or river flows or discharges. It is the rate of flow of water measured in terms of volume per unit time.
Mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
Modification measures	Measures that modify either the flood, the property or the response to flooding.
Overland flow path	The path that floodwaters can follow as they are conveyed towards the main flow channel or if they leave the confines of the main flow channel. Overland flow paths can occur through private property or along roads.
Probable Maximum Flood (PMF)	The largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation 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.
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.
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 a streamflow, also known as rainfall excess.
Stage	Equivalent to water level (both measured with reference to a specified datum)
TUFLOW	TUFLOW is a computer program which is used to simulate free-surface flow for flood and tidal wave propagation. It provides coupled 1D and 2D hydraulic solutions using a powerful and robust computation. The engine has seamless interfacing with GIS and is widely used across Australia.
XP-RAFTS	XP-RAFTS is a computer program which is used to simulate catchment rainfall-runoff and is widely used across Australia.

Appendix A. Analysis of Historic Rainfall Event Data

Cumulative rainfall depths have been plotted for two recent storm events for which data is currently available. These include:

- 24 April 2008 (10% AEP) 49mm in 45minutes; 65mm in 60 minutes; 136mm in 24 hours.
- 2 March 2013 (20% AEP) 61mm in 1.5 hours; 152mm in 24 hours.
- 5 January 2016 (20 – 50% AEP) 54mm in 1.5 hours.

Figure A-1 Cumulative event rainfall depth, 24 – 26 April 2008

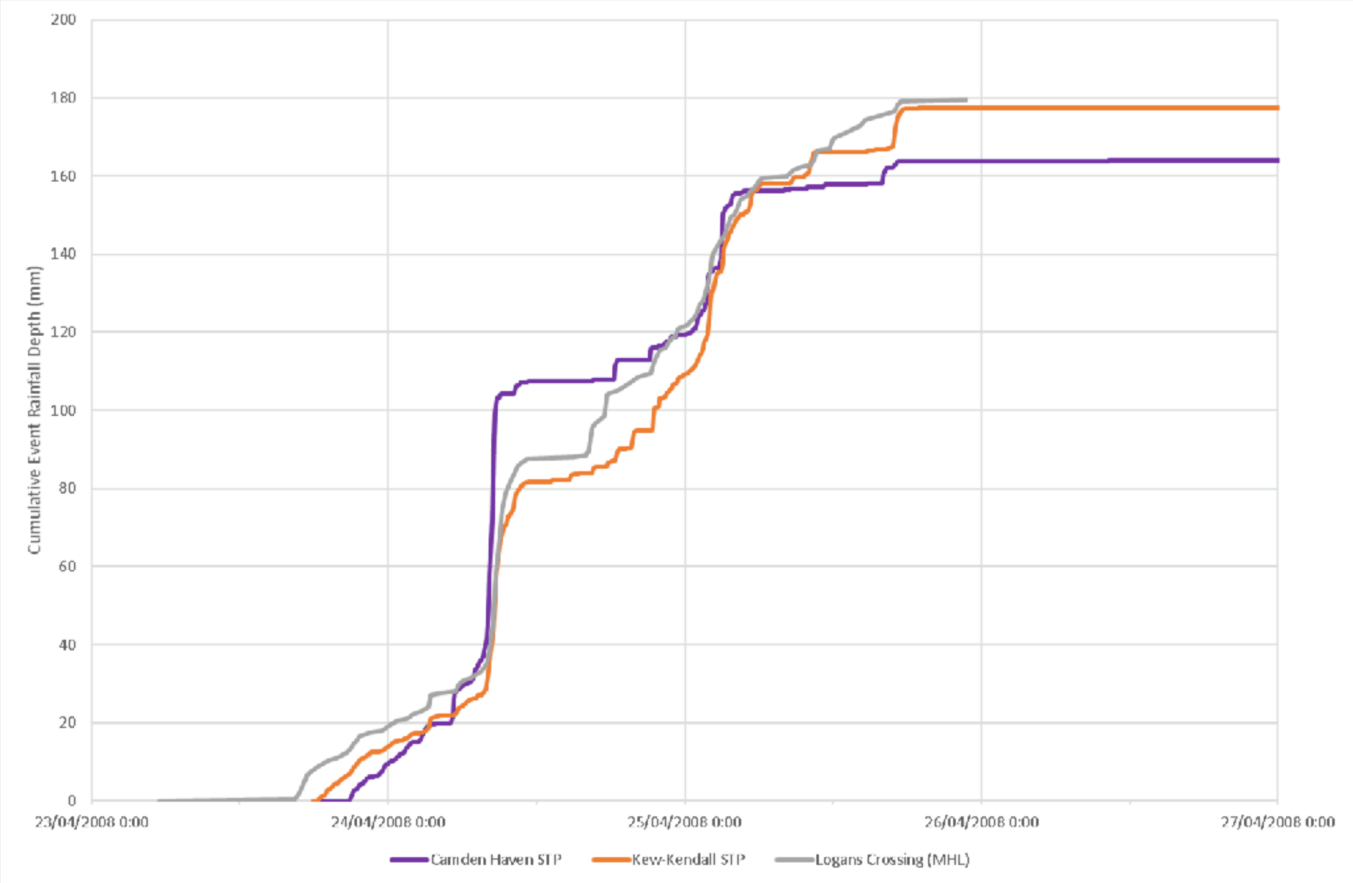


Figure A-2 Cumulative event rainfall depth, 2-3 March 2013

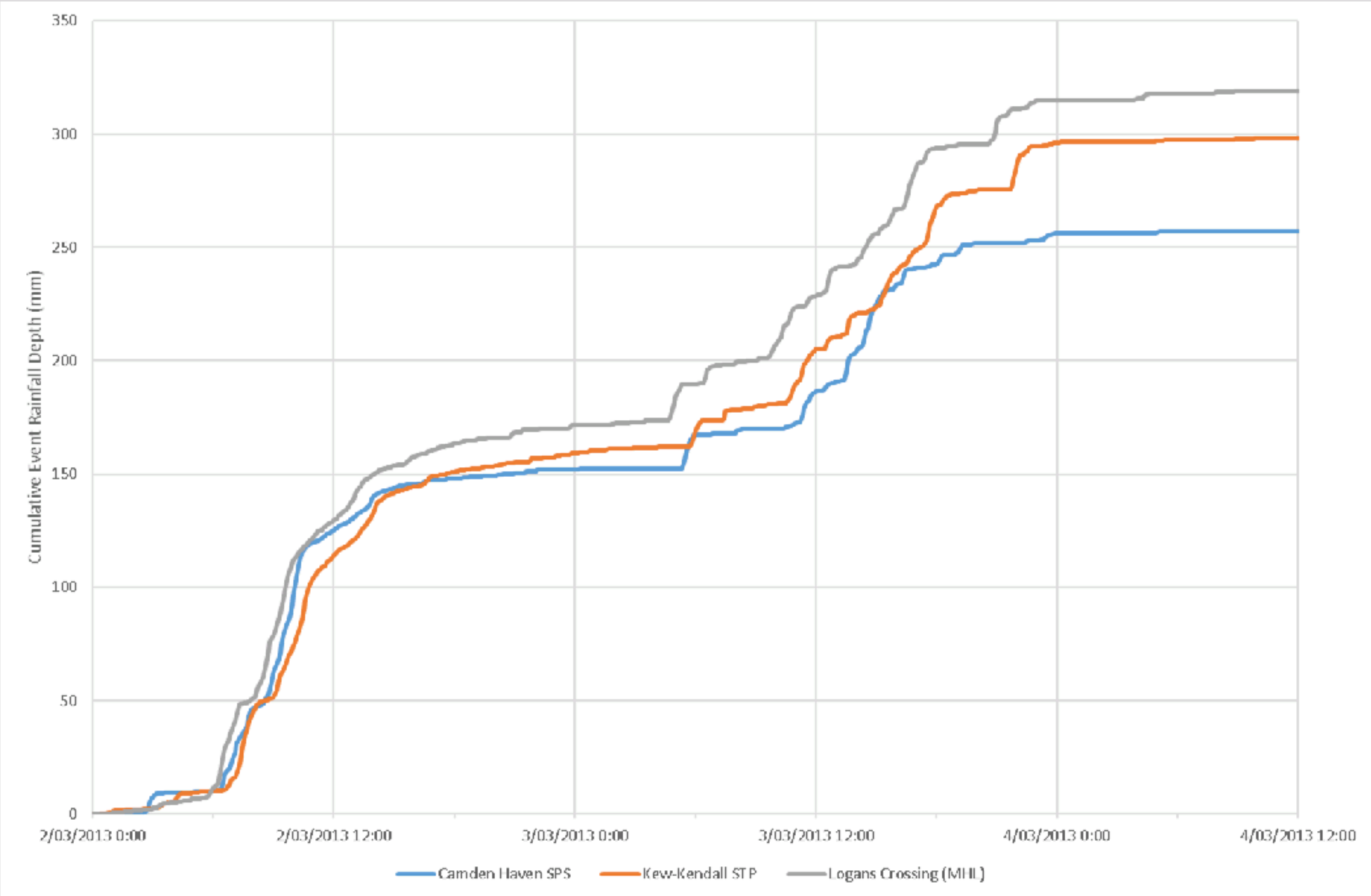


Figure A-3 Cumulative event rainfall depth, 4 – 5 January 2016

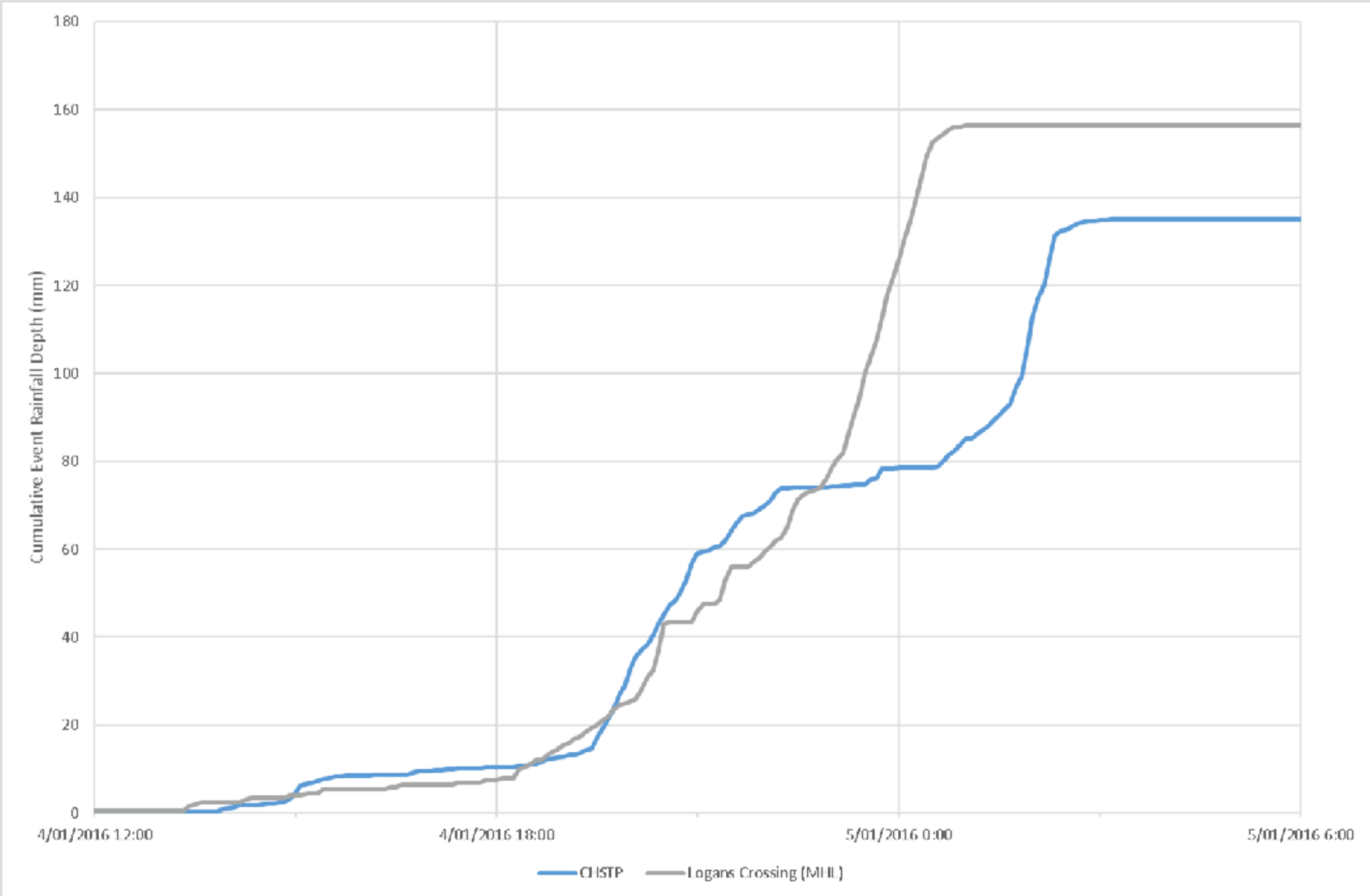
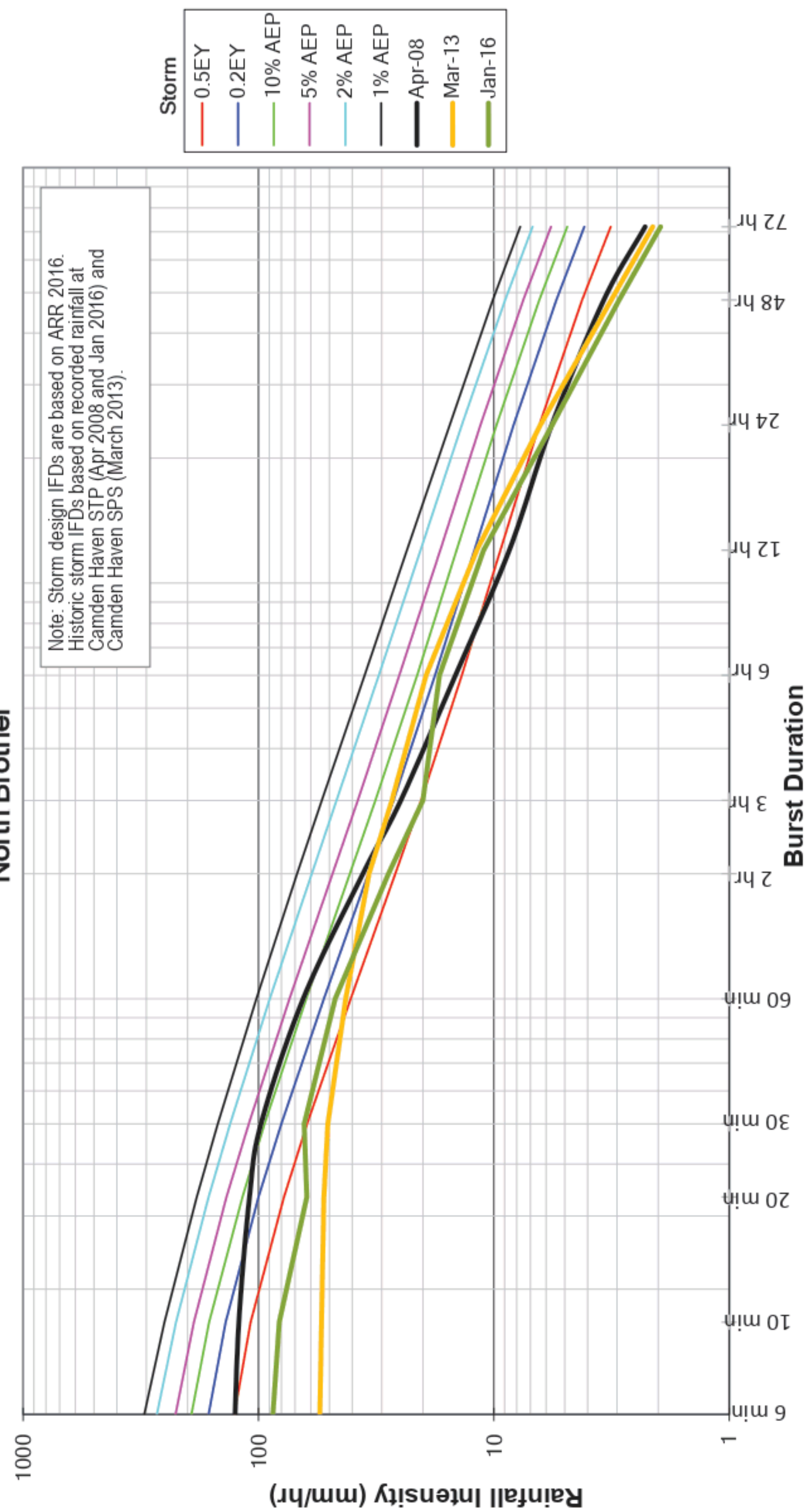
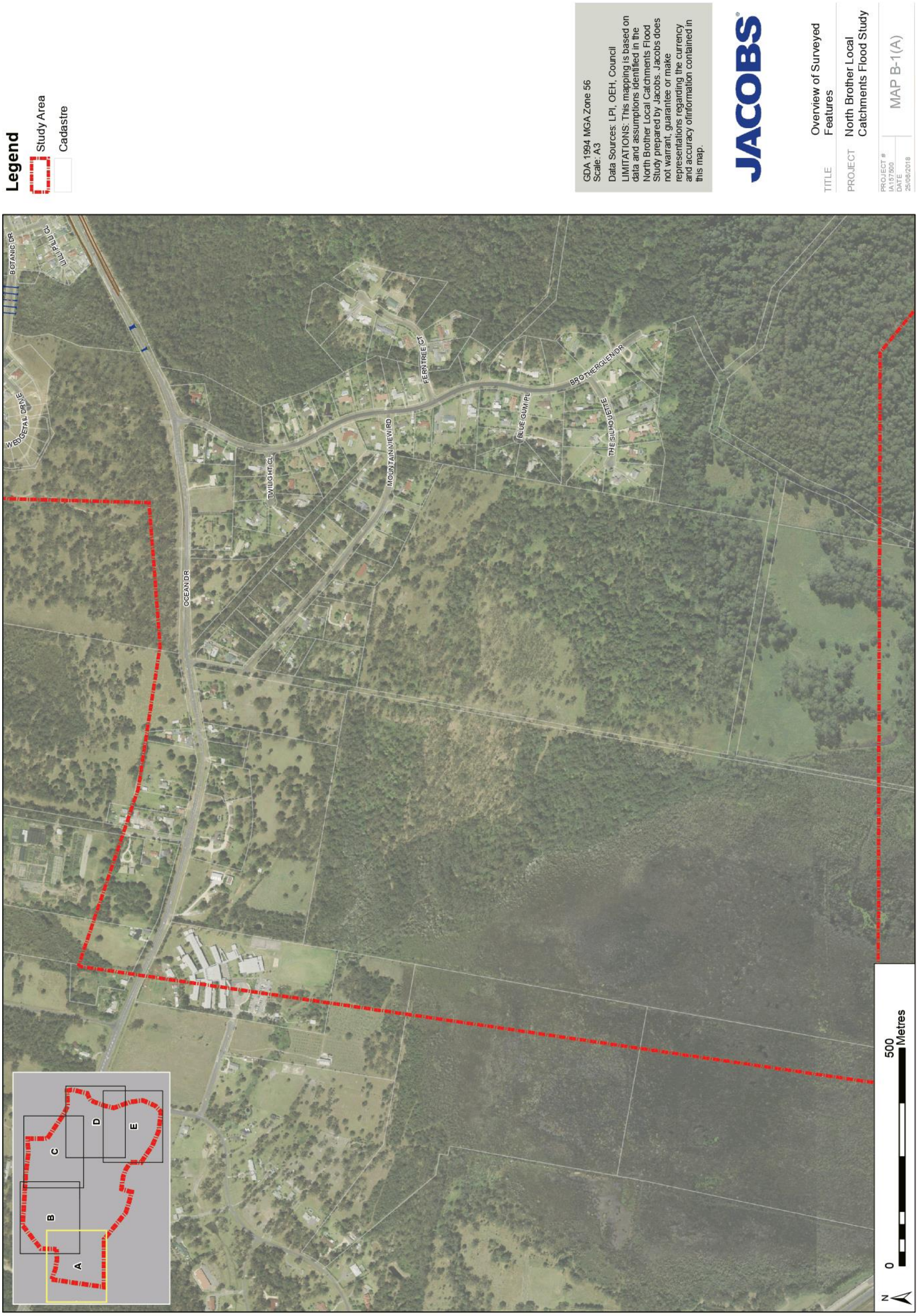


Figure A-4 North Brother Design Rainfall Intensity-Frequency-Duration versus Historic Storm Events

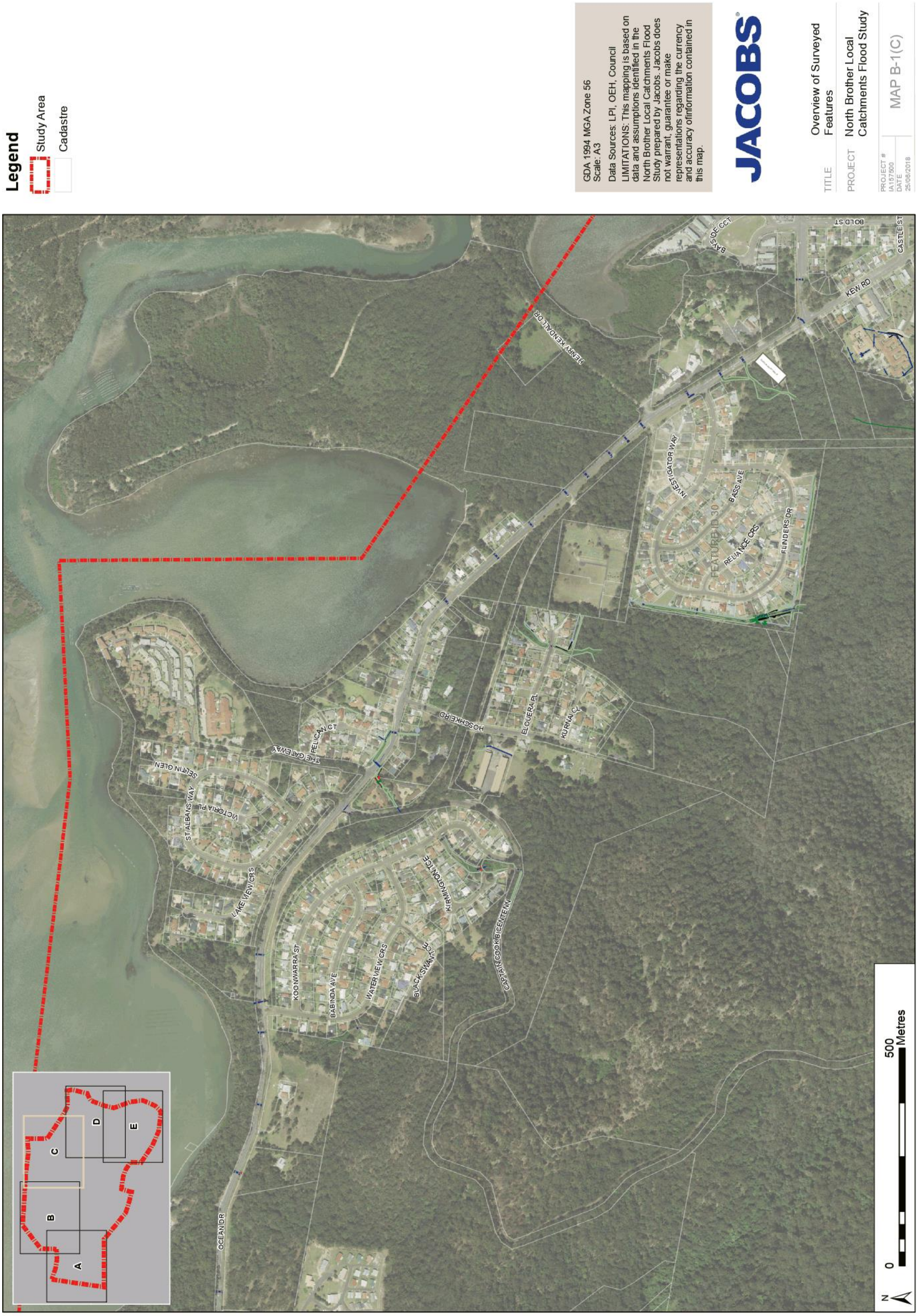


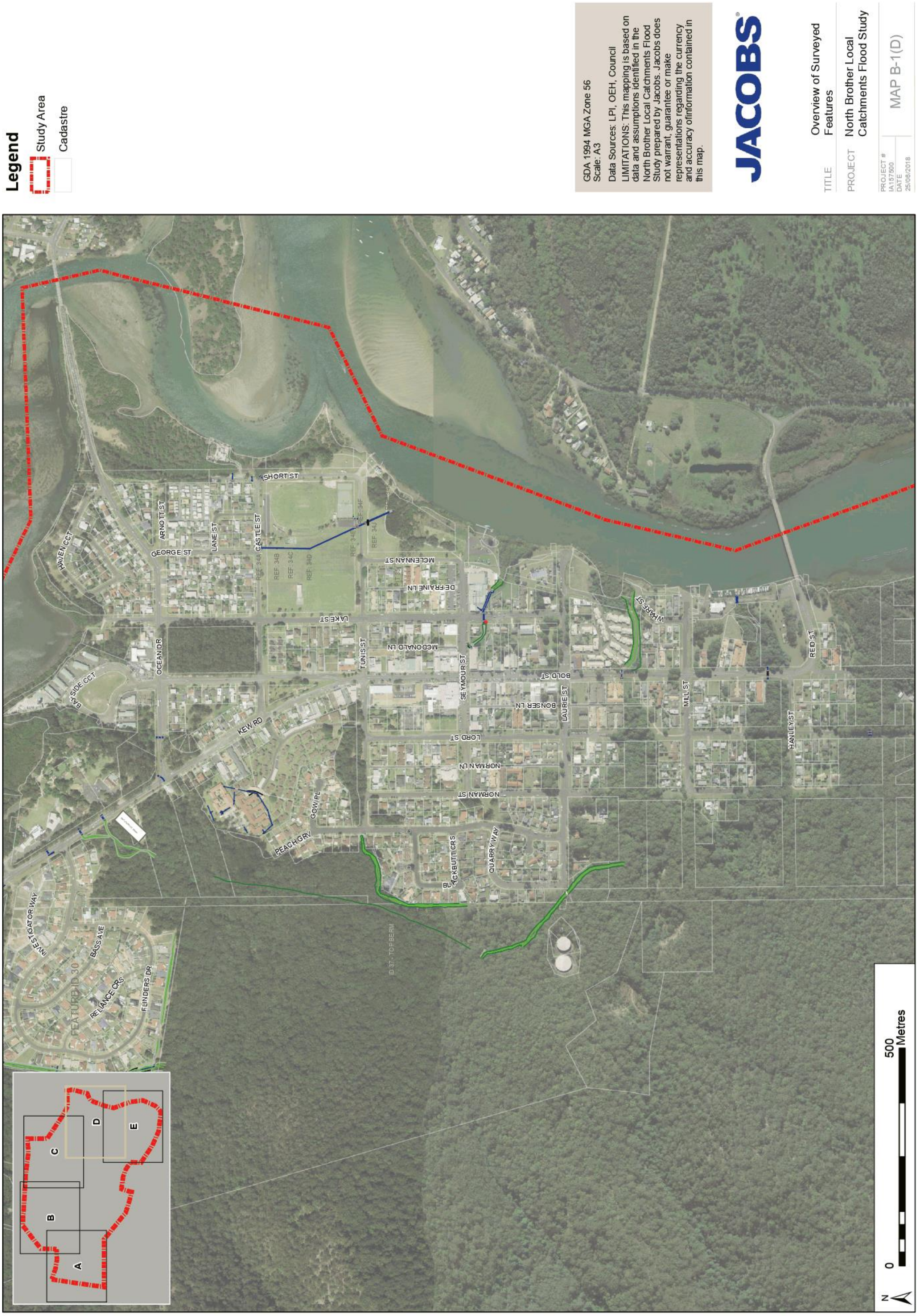
Appendix B. Summary of Topographic Survey

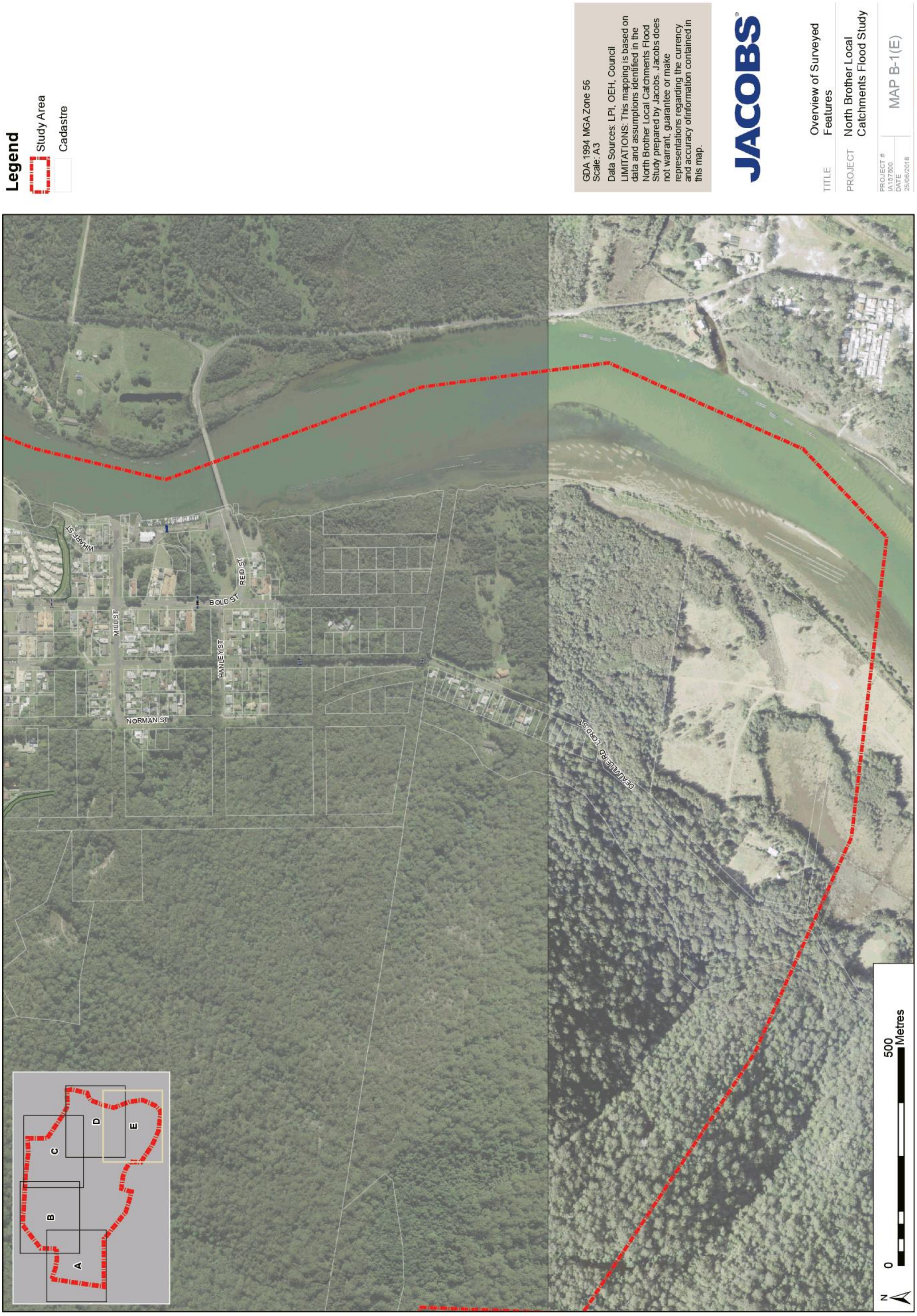


Legend
Study Area
Cadastre
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
TITLE Overview of Surveyed Features
PROJECT North Brother Local Catchments Flood Study
PROJECT # IA157500
DATE 25/08/2018
MAP B-1(A)
BOTANIC DR
LILLI PILLI CL
WEDGETAIL DRIVE
FERNTREE CT
BROTHERGLEN DR
BLUE GUM PL
THE SILHOUETTE
MOUNTAINVIEW RD
TWILIGHT CL
OCEAN DR
A
B
C
D
E
0
500
Metres
N


Legend
Study Area
Cadastre
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
TITLE Overview of Surveyed Features
PROJECT North Brother Local Catchments Flood Study
MAP B-1(B)
PROJECT # IA157500
DATE 25/06/2018
OCEAN DR
MISSION TCE
ROSEWOOD CT
CASUARINA
DIAMENTINA WAY
ELLERSLIE CRS
ADMIRALS CIR
HERON PL
EGRET PL
SIRIUS DR
COOK
TERN CL
PHILLIP CL
TEAL CL
TEATREE CL
BANKSIA CL
BANKS ST
OAK CL
RINGTAIL CL
FAIRWINDS AVE
HONEYSUCKLE AVE
LILLIPILLI CL
BOTANIC DR
WREN CL
BOTANIC DRIVE
WEDGETAIL DRIVE
BROTHERGLEN DR
FERNTREE CT
TWILIGHT CL
MOUNTAIN VIEW RD
A
B
C
D
E
0
500
Metres
N


Legend
Study Area
Cadastre
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE Overview of Surveyed Features
PROJECT North Brother Local Catchments Flood Study
MAP B-1(C)
500
Metres
0
N
A
B
C
D
E
KEW RD
CASTLE ST
BOLD ST
HENRY KENDALL DR
INVESTIGATOR WAY
BASS AVE
FLINDERS DR
RELIANCE CRS
FEATURE ID 30
HOSCHKE RD
ELOUERA PL
KURNAI CL
PELICAN CT
THE GATEWAY
SETTIN GLEN
ST ALBANS WAY
VICTORIA PL
LAKEVIEW CRS
KOONWARRA ST
BABINDA AVE
WATERVIEW CRS
KIRMINGTON TCE
BLACKSWAN CL
CAPTAIN COOK BICENTENNIAL DR
OCEAN DR


Legend
Study Area
Cadastre
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE Overview of Surveyed Features
PROJECT North Brother Local Catchments Flood Study
PROJECT # IA157500
DATE 25/06/2018
MAP B-1(D)
SHORT ST
ARNOTT ST
LANE ST
CASTLE ST
GEORGE ST
HAVEN CCT
MCLENNAN ST
DEFRAINE LN
LAKE ST
OCEAN DR
MCDONALD LN
TUNIS ST
SEYMOUR ST
WHARF ST
BOLD ST
BAYSIDE CCT
KEW RD
BONSER LN
LAURIE ST
MILL ST
HANLEY ST
RED ST
LORD ST
NORMAN LN
NORMAN ST
GOW PL
PEACH GRV
BLACKBUTT CRS
QUARRY WAY
INVESTIGATOR WAY
BASS AVE
RELIANCE CRS
FLINDERS DR
A
B
C
D
E
0
500
Metres
N


Legend
Study Area
Cadastre
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE Overview of Surveyed Features
PROJECT North Brother Local Catchments Flood Study
MAP B-1(E)
WHARF ST
REID ST
BOLD ST
MILL ST
HANLEY ST
NORMAN ST
LLOYD ST
0
500
Metres
A
B
C
D
E

Appendix C. Community Consultation

Community Bulletin No. 1 - October 2017

North Brother Local Catchments Flood Study

Port Macquarie Hastings Council is currently conducting the North Brother Local Catchments Flood Study. This Community Bulletin is the first in a series of Bulletins aimed at informing residents of the status of the project and how they can be involved in the process. Council has engaged consultants, Jacobs Group Australia, to undertake the Study.

The focus of the study is to understand the behaviour of local catchment flash flooding from North Brother Mountain and the flood risk that it poses to the community. This will assist Council to develop measures to manage the impact of flooding and guide strategic planning for future development of the area. It includes areas of the villages of Laurieton, West Haven, Lakewood, Kew and Deauville.

An integral part of the study process is community consultation and involvement. This element of the process aims to inform the community of the study and invite residents to provide information on their views and experiences with flooding in the area. The management of flood prone land is primarily the responsibility of Councils and follows a number of stages as shown below. The project is currently in the Flood Study stage, and will later move to the Floodplain Risk Management Study and Floodplain Risk Management Plan stages as the project progresses.

The Stages of Floodplain Risk Management

Objectives of the Study

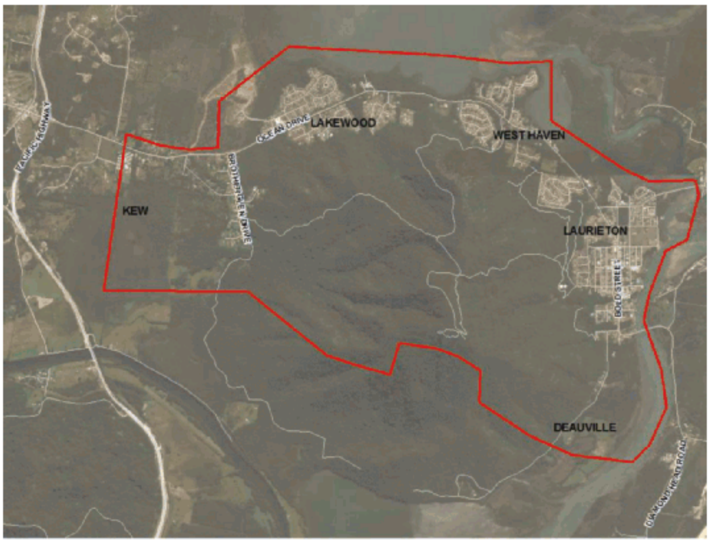
The objectives of the study are to:

1. Define the overland and flash flooding behaviour in the study area. Computer flood modelling will be undertaken to do this during the current flood study stage.
2. Identify and evaluate possible flood mitigation and management measures to reduce the flood risk. These may be structural and planning measures or "response" measures.
3. Develop a staged plan for implementing these measures.

Community Survey

We are seeking feedback from the community on previous flooding events in the area and views on possible management measures via the attached survey. The results of the survey will help inform a flood study for the area, which will be placed on public exhibition in early 2018, and a subsequent floodplain risk management study. The information that you provide will improve the flood model being developed.

Study Area



The Flood Problem

The study area typically experiences short duration flooding, which occurs when intense rainfall exceeds the capacity of the stormwater network or creek channel. In urbanised areas, this flooding has the potential to cause major damage to property and risk to life. Notable local flash flooding in the study area recently occurred in:

- April 2008
- June 2011
- March 2013
- January 2016.

How can you get involved?

Engagement of the community in the floodplain risk management process is very important to Council. We will be providing a number of opportunities for the community to have input during the course of this study.

Community Bulletins
- Background to the study and context
- Bulletins to update community on the project progress

Flood Data
- An opportunity to tell us about flooding in your area (via the attached survey)

Community Forums
- Opportunity to find out more about flood studies for your area and provide some feedback

Council Website
- Contact details for queries relating to the study and how you can be involved.

Some of the most important information for the study is collected from residents and local business operators. We would be very interested to receive records of flooding in your area including photographs, observations of flood depths or some comments on your experience. You can help us with this information by completing the questionnaire for your area and returning the completed community survey by 31 October 2017. The questionnaires can be found in Council's web site www.haveyoursay.pmhc.nsw.gov.au/ Port Macquarie Hastings Council appreciates your cooperation and will keep you informed with ongoing community bulletins.

For more information contact Port Macquarie Hastings Council on (02) 6581 8111 or visit **haveyoursay.pmhc.nsw.gov.au**

Summary of key survey questions and responses

* Note, not all responses have been included in this summary. Responses mentioning specific locations and addresses have been omitted for privacy reasons.

Do you live in the study area?

Response	Count	% of responses
No	15	5%
Yes	276	95%

Do you own or rent in the study area?

Response	Count	% of responses
Own and occupy	280	98%
Rent	6	2%

Do you own or manage a business in the study area?

Response	Count	% of responses
No	264	94%
Yes	17	6%

What kind of business?

Response	Count
Home based	6
Shop/ commercial premises	6
Industrial	1
Other	3

Are you aware of flooding in the Study Area?

Response	Count	% of responses
Aware	136	48%
Some knowledge	77	27%
Not aware	71	25%

When have you experienced significant flooding in the area?

Response	Count	% of responses
Not affected	142	51%
Property Flooded	43	15%
Minor Disruption (roads flooded by driveable)	69	25%
House or business flooded	17	6%
Access cut off	9	3%

What damage resulted from this flood in your residence?

Response	Y - no rating	Minor	Moderate	Major	None or Not Aware
Damage to garden, lawns or backyard	32	28	6	3	39
Damage to external house walls	4	1	3	1	46
Damage to internal parts of house (floor, doors, walls etc)	8	6	1	4	46
Damage to possessions (fridge, television etc)	0	0	0	5	7
Damage to car				1	49
Damage to garage	11	10	3	0	46
Other	"Minor road damage" "Back sunroom was flooded" "Had to put a drain under the garden bed to the stormwater drain" "Dirt washed into pool"				
What was the cost of repairs, if any?	Covered by insurance: 4 Up to $1000: 7 $1000 - $5000: 6 $5000 - $10000: 2 $10000 - $20000: 3 >$20000: 2 ($50K and $70K)				

What damage resulted from this flood in your business?

Response	Y - no rating	Minor	Moderate	Major	None or Not Aware
Damage to surroundings	3	6	1	0	24
Damage to Building	3	2	0	0	25
Damage to Stock	2	1	1	0	24
Other	1	-	-	-	25

Please rank the following development types according to what you consider should be assigned greatest priority in protecting from flooding (1 = greatest priority to 7 = least priority). Please identify specific items if necessary.

	Count							% of Responses						
Rating	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Commercial	12	1	71	62	8	3	138	4%	0%	24%	21%	3%	1%	47%
Heritage items	13	1	12	24	43	76	28	7%	1%	6%	12%	22%	39%	14%
Residential	98	22	71	30	11	2	0	42%	9%	30%	13%	5%	1%	0%
Community Facilities	22	13	48	62	48	26	2	10%	6%	22%	28%	22%	12%	1%
Critical utilities	59	94	40	19	8	3	0	26%	42%	18%	9%	4%	1%	0%
Emergency Facilities	110	62	24	15	8	3	2	49%	28%	11%	7%	4%	1%	1%
Recreation areas and facilities	5	2	4	5	12	46	138	2%	1%	2%	2%	6%	22%	65%

Please rank the following by placing numbers from 1 to 6 (1 = greatest priority to 6 = least priority)

	Count						% of Responses					
Rating	1	2	3	4	5	6	1	2	3	4	5	6
A) Protecting residents/business from flooding	135	30	21	19	27	12	55%	12%	9%	8%	11%	5%
B) Protecting land of residents/businesses from flooding	24	60	24	31	33	63	10%	26%	10%	13%	14%	27%
C) Maintaining an emergency flood free access	55	43	73	32	29	7	23%	18%	31%	13%	12%	3%
D) Providing flood signage for public safety	16	28	26	34	43	88	7%	12%	11%	14%	18%	37%
E) Support from SES	27	44	48	63	36	16	12%	19%	21%	27%	15%	7%
F) Providing flood warning	59	28	29	46	42	31	25%	12%	12%	20%	18%	13%

Are you aware of any works that have been carried out near you that you believe have negatively impacted on the flood behaviour at your property? (Tick all boxes that apply)

Response	Count	% of responses
A) Not aware of any measures	215	70%
B) Building or renovation activities	14	5%
C) Fencing	5	2%
D) Creek works	14	5%
E) Upgraded roads, culverts	20	6%
F) Overland flow obstructions	22	7%
G) Other (please specify)	18	6%

Comment responses

Aged Council drain does not comply with current standards & industry specification. see Council minutes 20th March, 2013.
Uphill development
Y- New bridge- sections impact on flow on Laurieton side.
Y- Rear boundary neighbour has shadehouse against back fence. This has resulted in the way the water flows, it does not follow the land contour, it hits the shadehouse and all water from surrounding properties come onto our property.
Y- We have a creek at the back of us which needs to be fixed every year this needs to be done last time they did it they enclosed the poor birds that live in the walls of the creek. We don't have enough drainage in the street of Honeysuckle.
Footpath has been raised in front of our house for the sake of the units built next door, the footpath has been partly done but still not finished and we are still getting water. Also our neighbours right through their ground floor Council was going to extend the footpath and raise the level up to the same as the units.
Y - stormwater getting into sewage pipes and overflowing sewerage problem is very bad in our Lakewood area.
Y - Laurieton reservoirs/stormwater drain - see atachments
Y - nature strip falling toward smy house and not away to the main road
erosion out front increasing in stormwater water drainage re rain driveway access affected from north brother runoff and subdivision runoff
Y - new developments have increased storm water runoff with NO increase in storm pipes lower in the system
Y - land use planning
Silting of Camden Haven River heads/bar
Stormwater drainage on eastern side of Quarry Way inadequate
Easement drains under property now out of alignment
Refer to my letter, apply better cleaning of drainage under Kew Road to allow flow to the lake
Road drainage and easements directed onto our property.

Are you aware of any works that have been carried out near you that you believe have improved the flood behaviour at your property? (Tick all boxes that apply)

Response	Count	% of responses
A) Not aware of any measures	205	68%
B) Building or renovation activities	8	3%
C) Fencing	3	1%
D) Creek works	19	6%
E) Upgraded roads, culverts	39	13%
F) Overland flow obstructions	12	4%
G) Other (please specify)	15	5%

Comment responses

Council has made efforts to improve situation but so with no success.
New stormwater drain.
The creek to creek walkway has improved our access out of town
None, no work done
Water diversion swale on crown land
Y - concrete drain installed behind our property (but it is inadequate to cope with volumes of water in heavy rain)
Y - culverts in reserve, no footpath provided for elderly
Council drainage is the only time I have concern for flooding
Y - reservoirs/stormwater drain. Lack of maintenance has caused serious concerns of flooding
River walls to improve depth of river bar
Y - foot paths
Y - nearby creek cleared of plant debris and plastic bottles etc.
Cleaning of existing storm drains
Very little of any

Which of the following measures do you think Council should consider for reducing the floodrisk at your property? (1 = greatest priority to 7 = least priority).

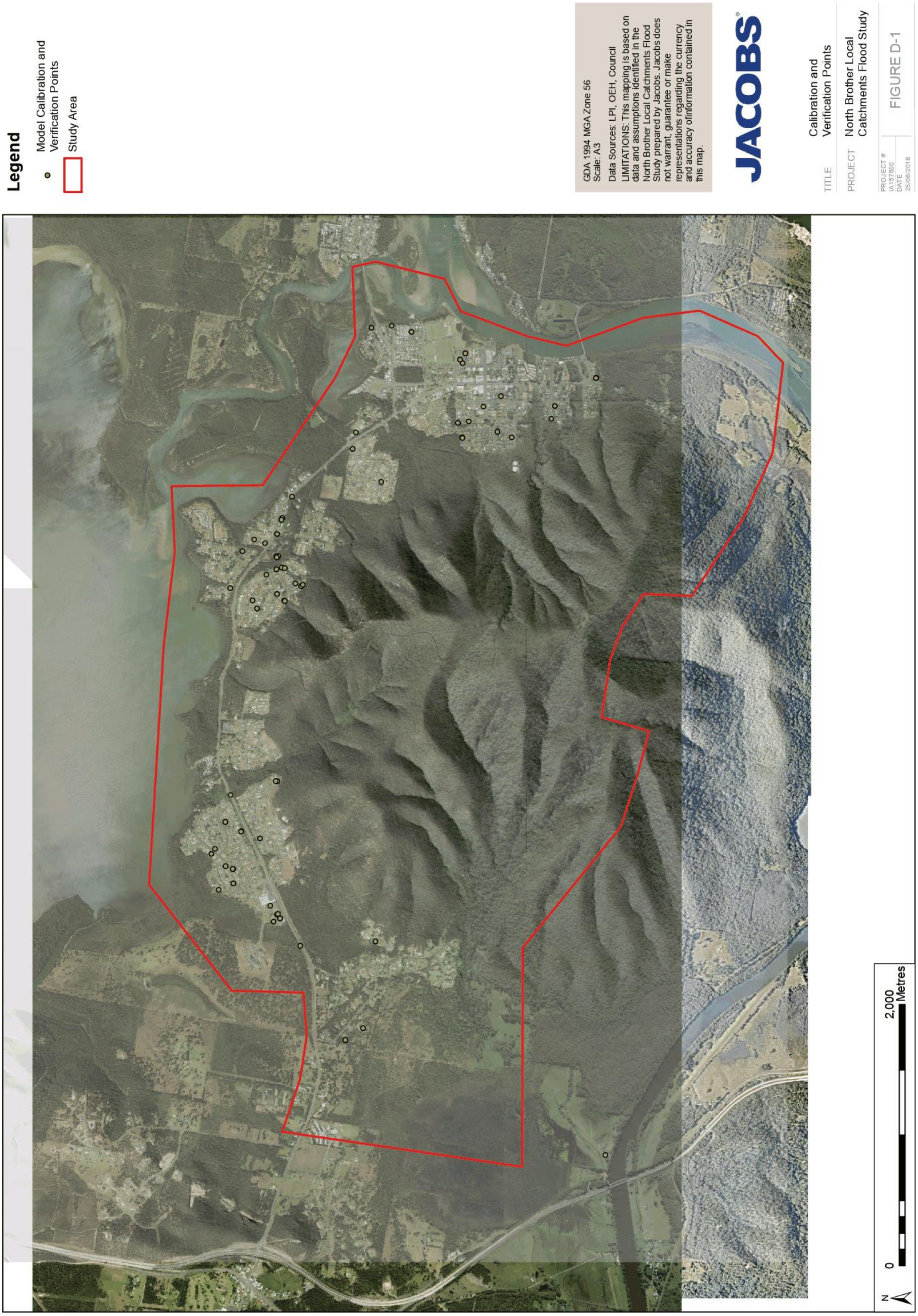
	Count					% of Responses				
Rating	1	2	3	4	5	1	2	3	4	5
A) Zoning, building & development controls, including fencing	38	46	51	23	3	24%	29%	32%	14%	2%
B) Upgrading stormwater drainage	167	33	10	0	0	80%	16%	5%	0%	0%
C) Upgrading roads	29	66	53	22	3	17%	38%	31%	13%	2%
D) Public awareness & education	13	18	36	85	7	8%	11%	23%	53%	4%
E) Other (please specify)	0	0	0	4	39	0%	0%	0%	9%	91%

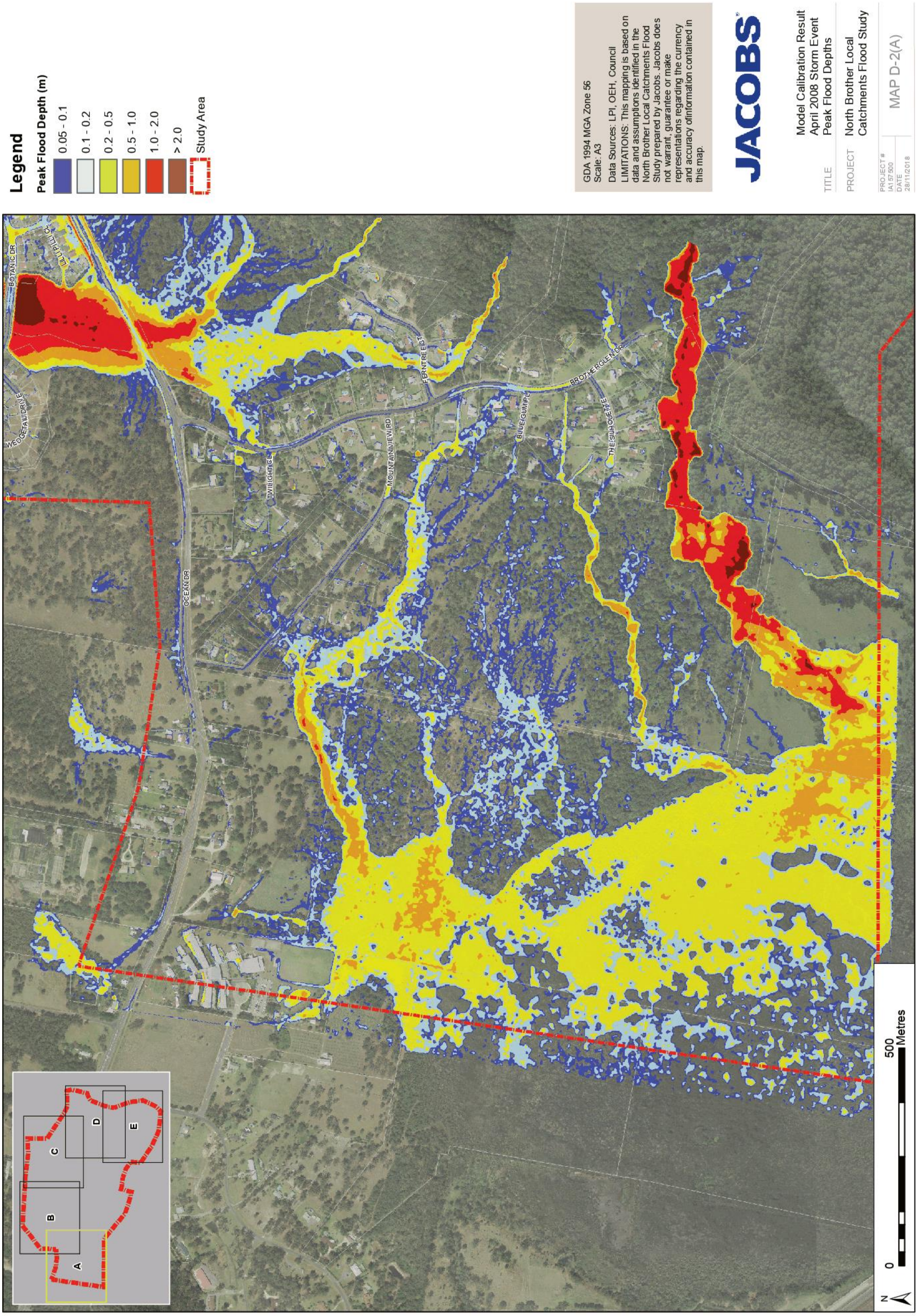
Comment responses

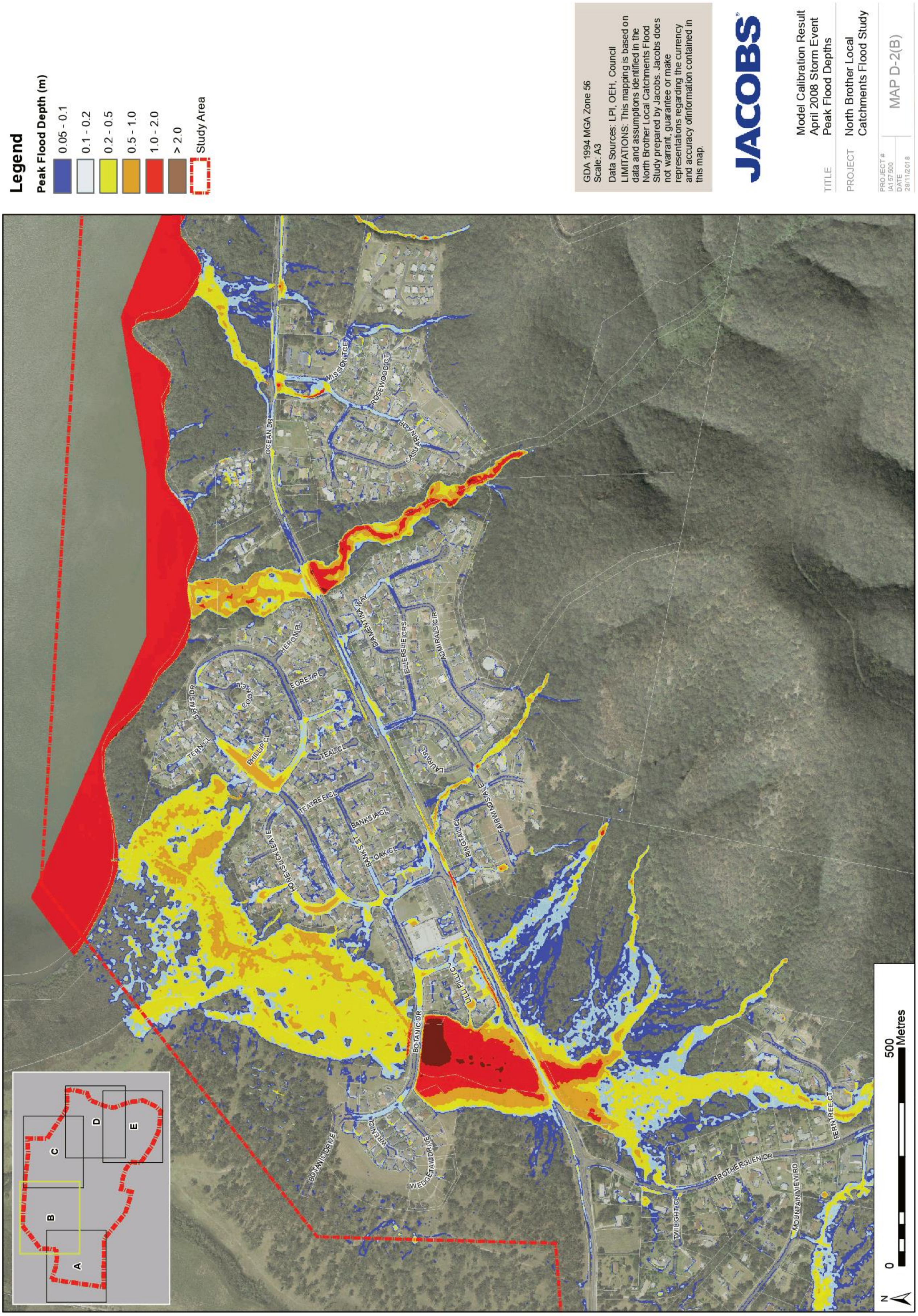
Publish max flood line not just the 100 year flood line on maps on NSW Planning Portal.
How about a levee if there is a perceived problem
Walkway to main road for elderly who can't drive and rely on walking and mobility scooter to town along the lake and public access to main road.
MAINTAIN DRAINS, EASEMENT
Planting trees on the streetside providing more parklands.
KEEP STORM DRAINS CLEAR BY REGULAR INSPECTIONS & CLEARING IF NECESSARY
Fixing the creek so the water will flow out to the lake
Keep culverts clear of vegetation and rubbish on southern side of Ocean Drive opposite the Gateway Road
Installing kerb and gutter to our street.
Clean out drains and creeks
New kerb and gutter on low side of roads.
Trees in drain behind xx, xx and xx Koonwarra Street at bend of drain blocks up. I have to keep cleaning it out, Council won't.

Putting kerb and guttering from Ocean Drive into Lake Street and Castle Street. Houses have bene built about 60 years but no kerb and gutter. Would be good to have to get rid of the water instead of having stagnant water and lots of mosquitoes
Carry out drainage maintenance work as per letter dated 13/6/13 - see attached
Actually putting in place stormwater drainage
Cleaning gutters and weed growth at joints and any other blockages on a regular basis
The open drain on Lord Street Laurieton, between Laurie Street and Seymour Street should be replaced with pipes.
Dredging the river beds
Better drainage of water coming off the mountain. Something to slow the flow.
Lift/build up the verge outside my house to the equivalent height to recent building adjacent to my property
Inappropriate building on wetlands or flood prone areas
I don't believe my property is under threat of flooding
Not a risk

Appendix D. Verification of Model Flood Behaviour


Legend
Model Calibration and Verification Points
Study Area
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE Calibration and Verification Points
PROJECT North Brother Local Catchments Flood Study
FIGURE D-1
0
2,000 Metres
N


Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE
Model Calibration Result
April 2008 Storm Event
Peak Flood Depths
PROJECT
North Brother Local
Catchments Flood Study
MAP D-2(A)
BOTANIC DR
OCEAN DR
TWILIGHT CL
MOUNTAIN VIEW RD
FERNTREE CT
BROTHERGLEN DR
BLUE GUM PL
THE SUNCOVE PL
0
500
Metres
A
B
C
D
E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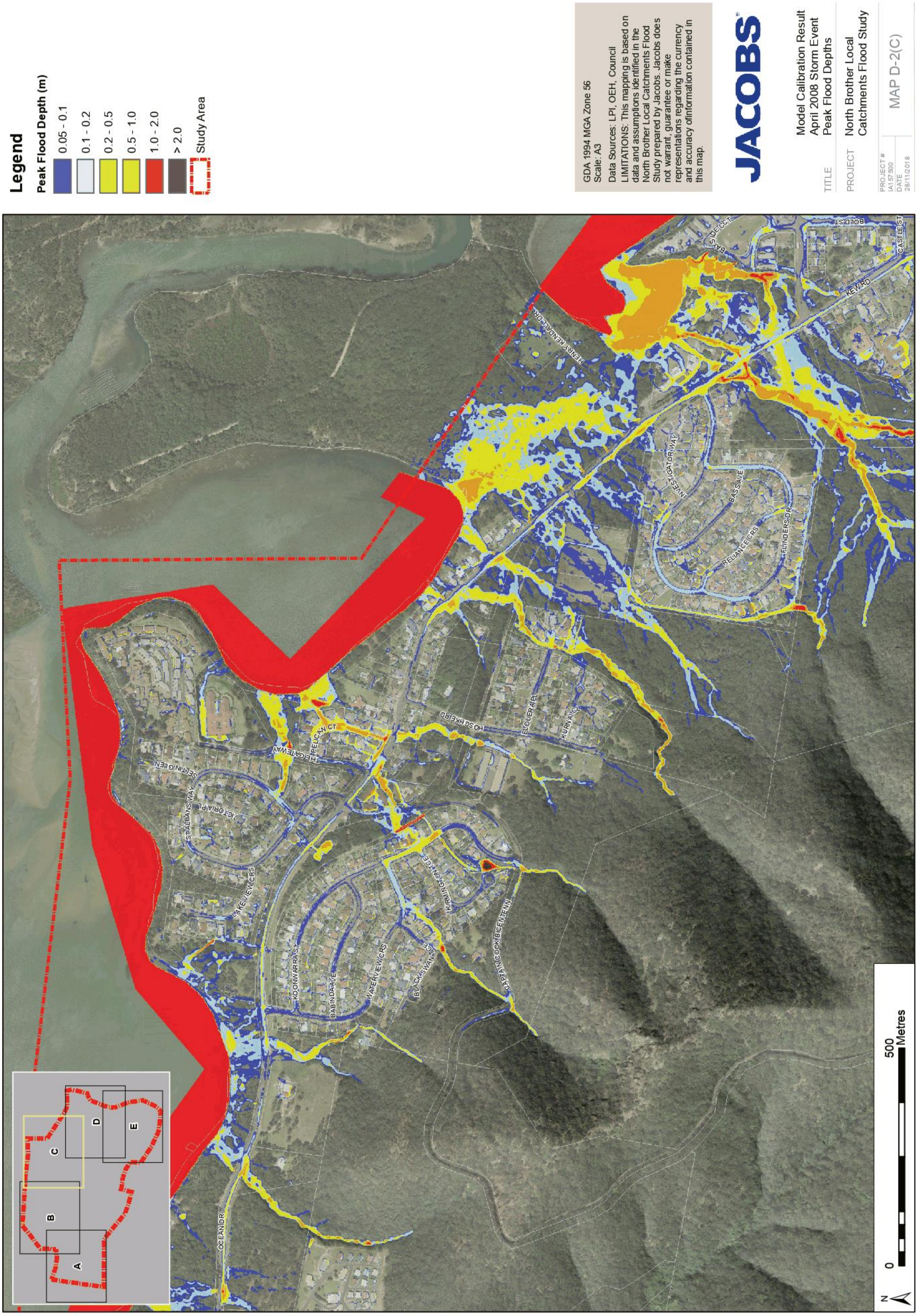
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE
Model Calibration Result
April 2008 Storm Event
Peak Flood Depths
PROJECT
North Brother Local
Catchments Flood Study
MAP D-2(B)
0
500
Metres
N
OCEAN DR
MISSION CE
ROSEWOOD CT
CASUARINA DR
BOTANIC DR
BROTHERGLEN DR
MOUNTAIN VIEW RD
FERNTREE CL
BANKSIA CL
BANKS ST
OAK CL
TEATREE CL
PHILLIP CL
TERN CL
ADMIRALS CIR
A
B
C
D
E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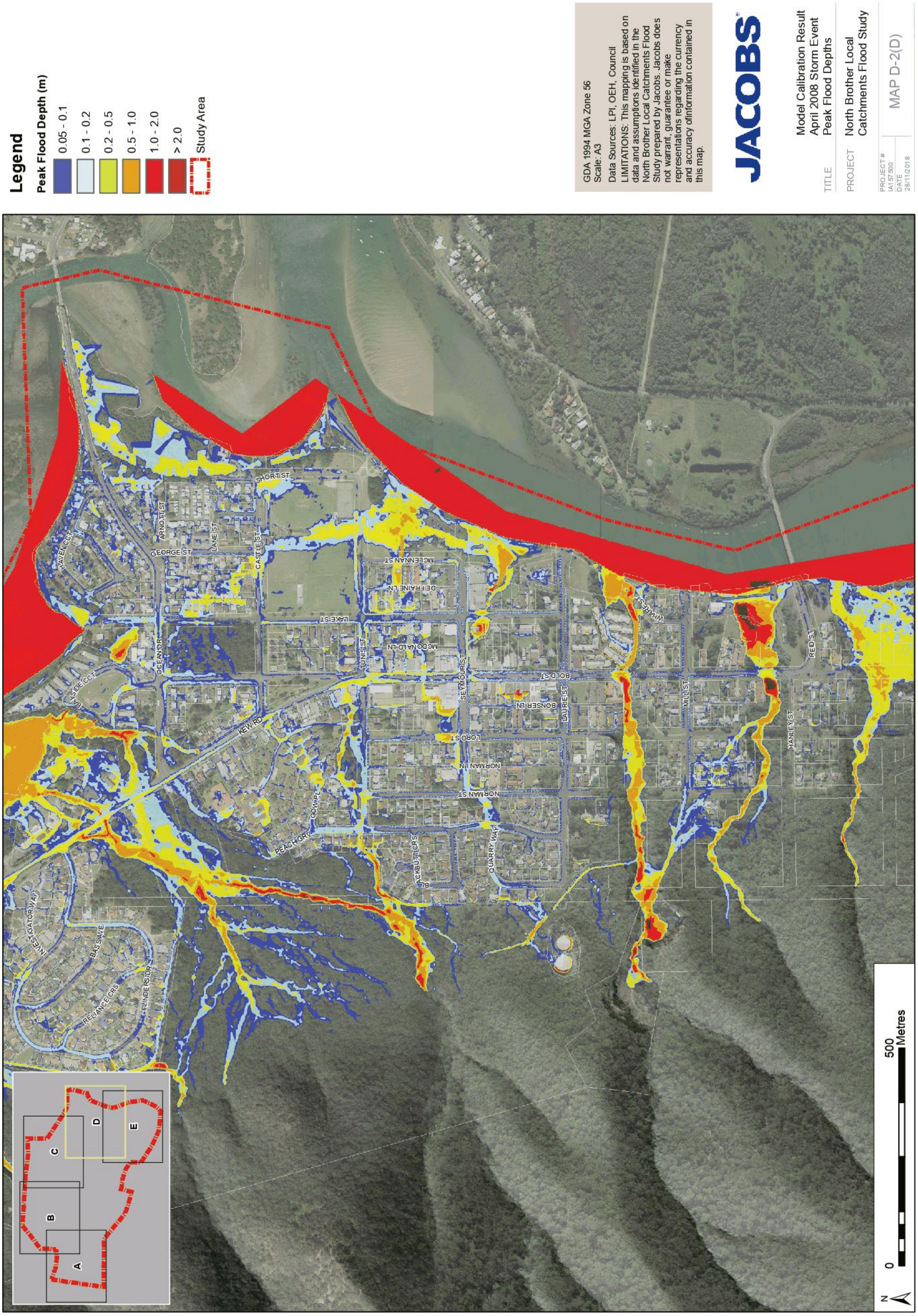
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE Model Calibration Result April 2008 Storm Event Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP D-2(C)
0
500 Metres
N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Peak Flood Depth (m)
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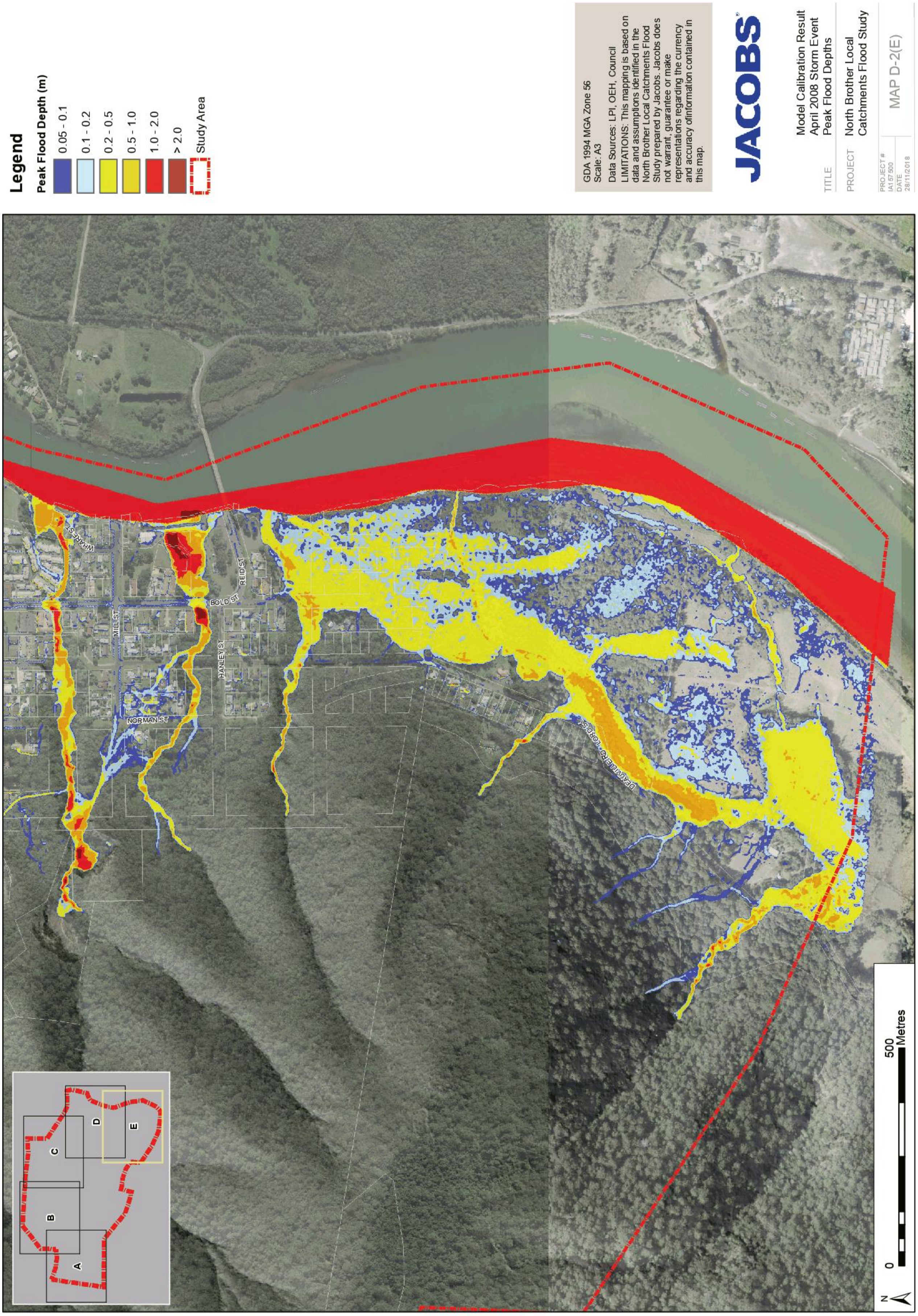
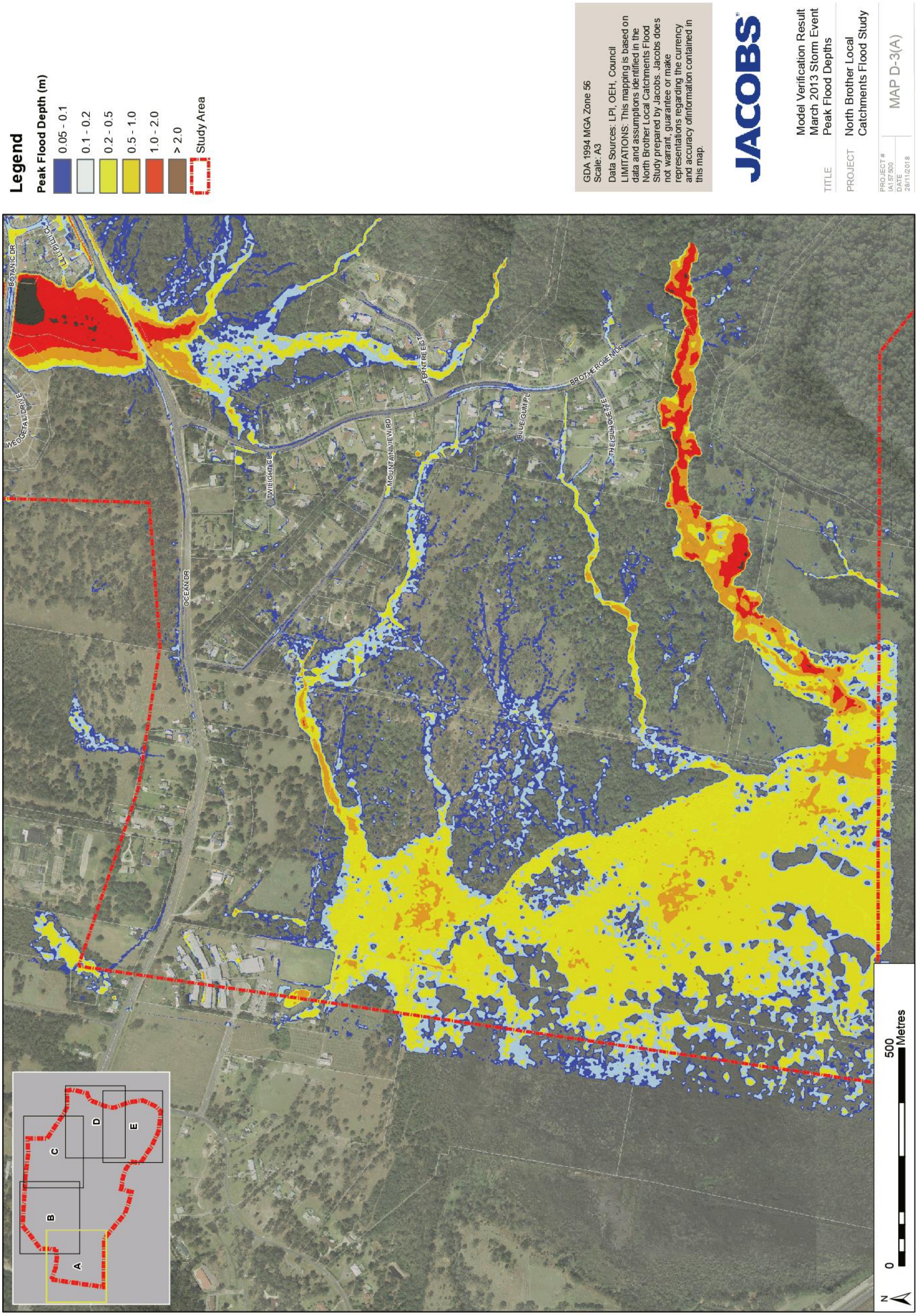
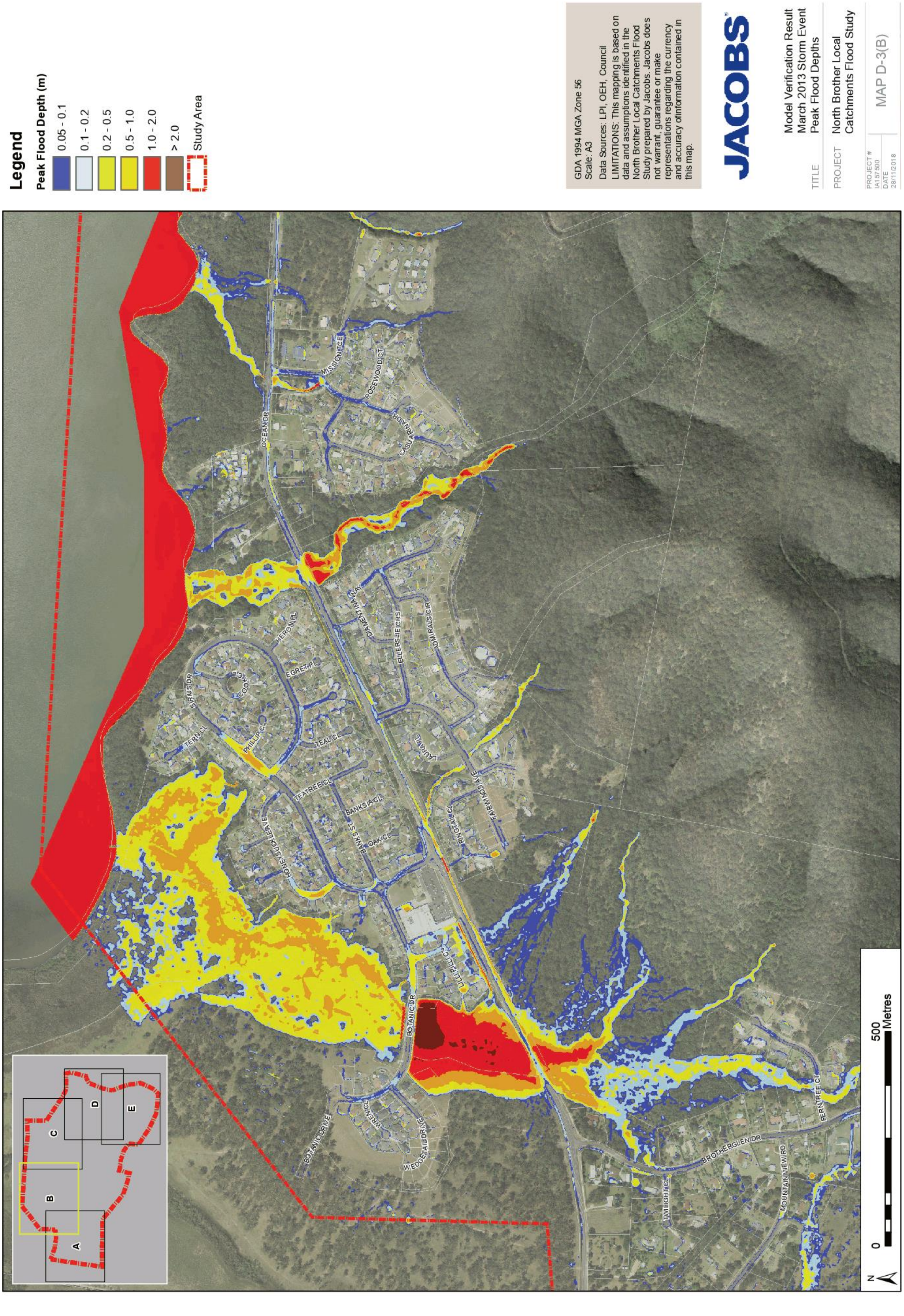
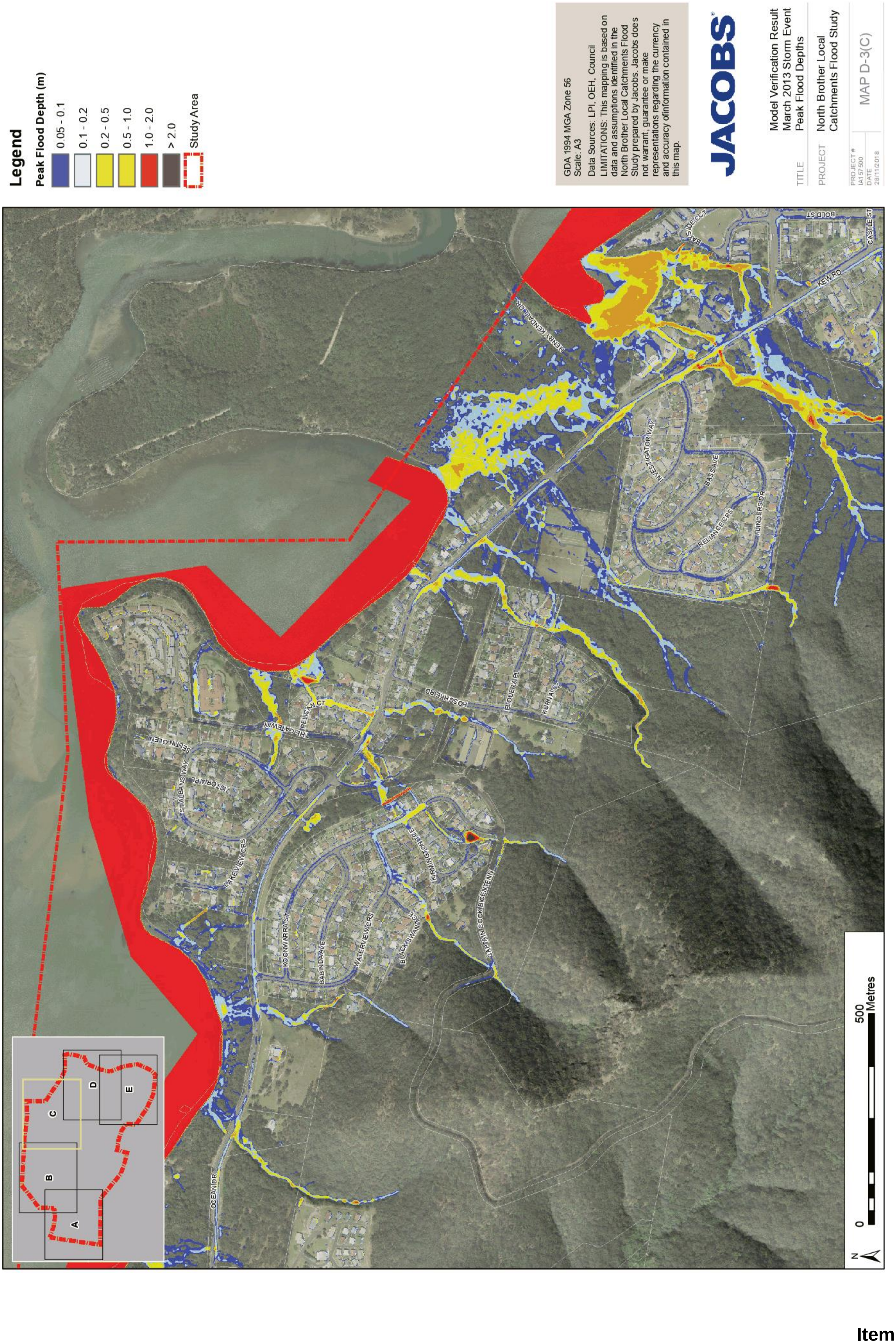
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE Model Calibration Result April 2008 Storm Event Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP D-2(D)
SHORT ST
ARNOTT ST
GEORGE ST
LAKE ST
CASTLE ST
MCLENNAN ST
DEFRAINE LN
MCDONALD LN
TUNIS ST
SEYMOUR ST
BOLD ST
BONSER LN
LORD ST
NORMAN LN
NORMAN ST
LAURIE ST
MILL ST
HANLEY ST
RED ST
OCEAN DR
KEW RD
PEACH GR
QUARRY WAY
BASS AVE
FLINDERS DR
RELIANCE CRS
A
B
C
D
E
0
500
Metres
N

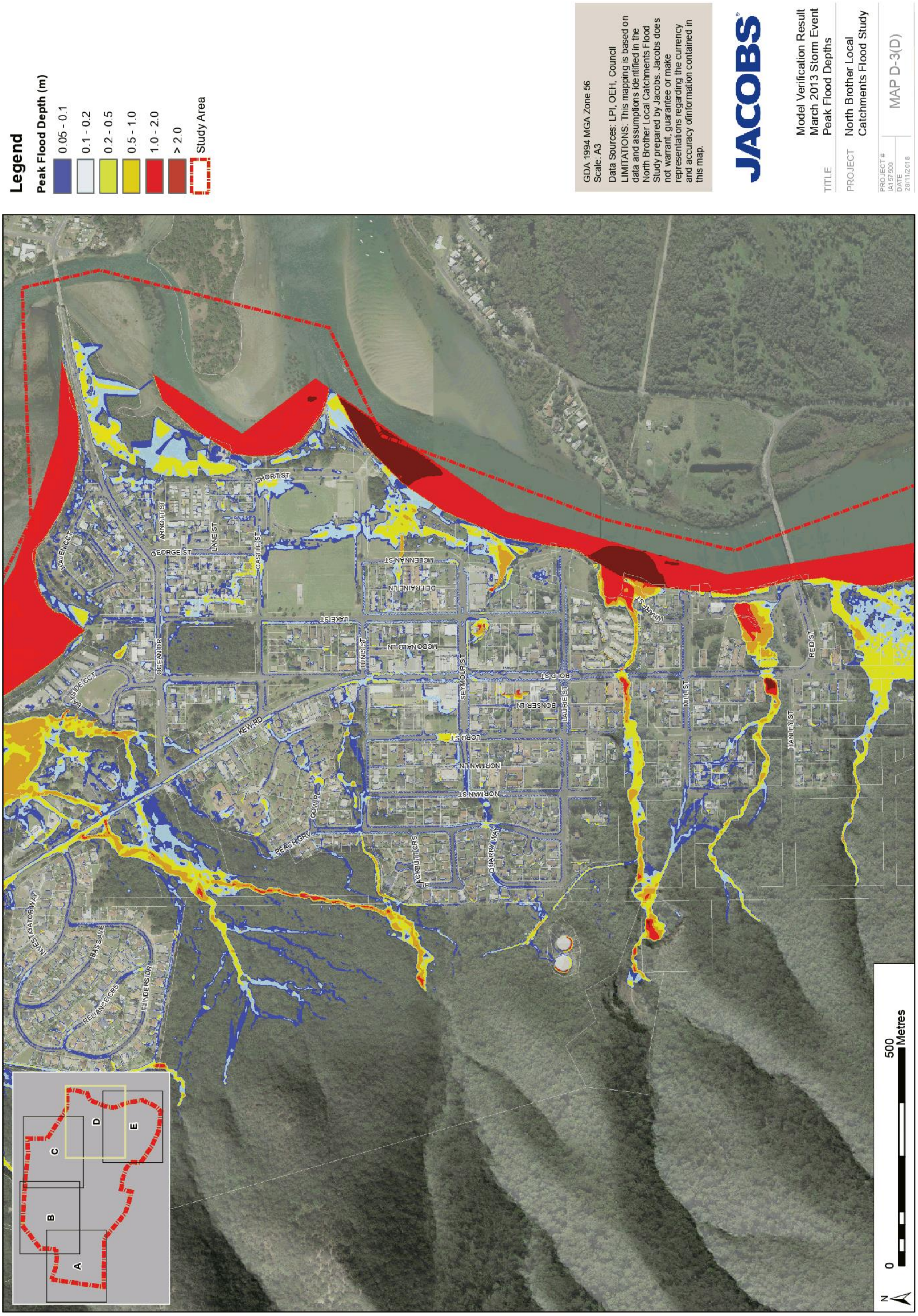

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE
Model Calibration Result
April 2008 Storm Event
Peak Flood Depths
PROJECT
North Brother Local
Catchments Flood Study
MAP D-2(E)
BOLD ST
REID ST
MILL ST
HANLEY ST
NORMAN ST
0
500
Metres
A
B
C
D
E



Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE Model Verification Result March 2013 Storm Event Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP D-3(A)
BOTANIC DR
OCEAN DR
TWILIGHT CL
MOUNTAIN VIEW RD
FERNTREE CT
BROTHERGLEN DR
BLUE GUM PL
A
B
C
D
E
0
500 Metres
N


Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE Model Verification Result March 2013 Storm Event Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP D-3(B)
0
500
Metres
N
A
B
C
D
E


Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE
Model Verification Result
March 2013 Storm Event
Peak Flood Depths
PROJECT
North Brother Local
Catchments Flood Study
MAP D-3(C)
0
500
Metres
N
A
B
C
D
E


Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE
Model Verification Result
March 2013 Storm Event
Peak Flood Depths
PROJECT
North Brother Local
Catchments Flood Study
MAP D-3(D)
0
500
Metres
N
A
B
C
D
E

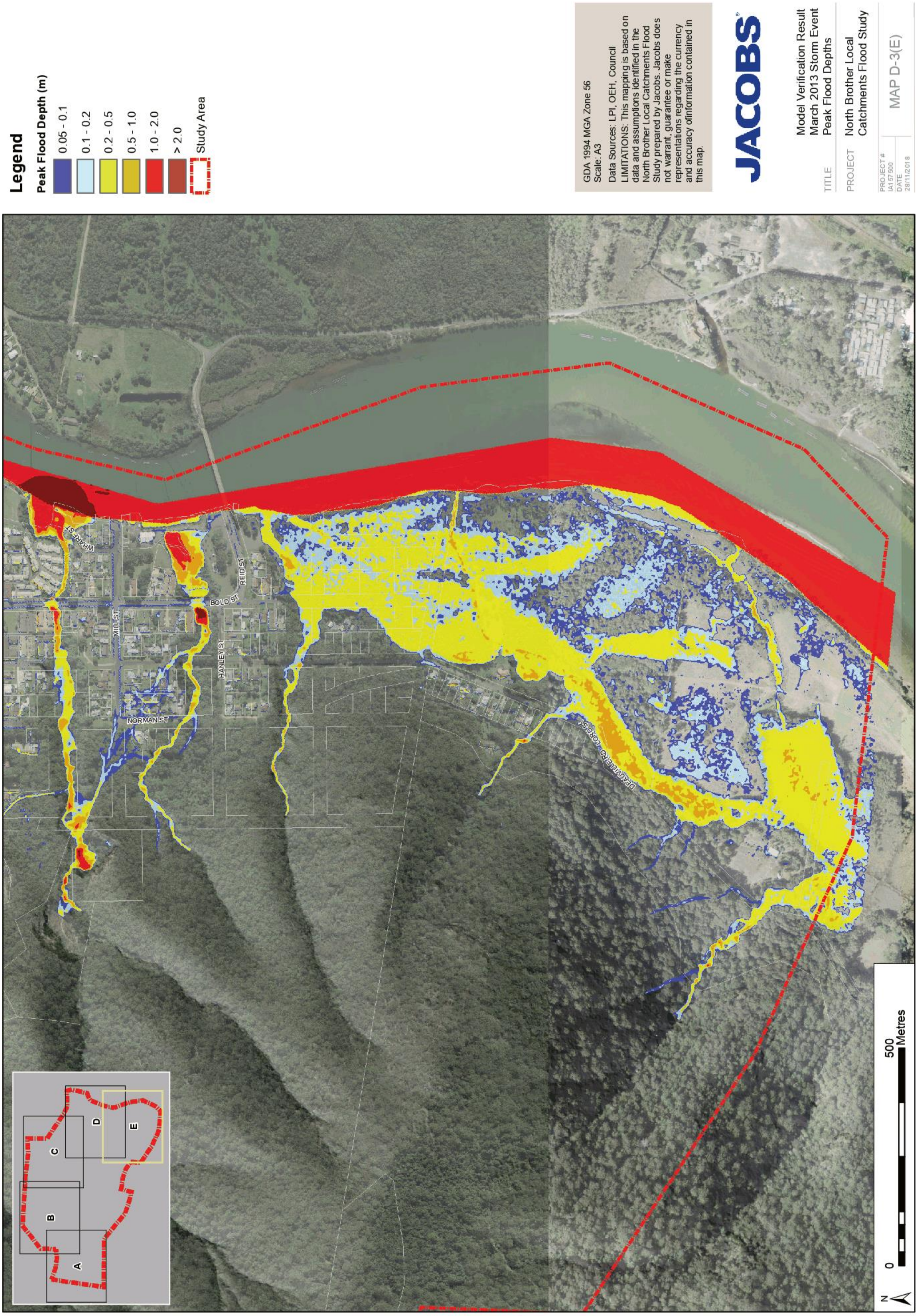

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE
Model Verification Result
March 2013 Storm Event
Peak Flood Depths
PROJECT
North Brother Local
Catchments Flood Study
PROJECT #
IA157500
DATE
28/11/2018
MAP D-3(E)
BOLD ST
REID ST
HANLEY ST
MILL ST
NORMAN ST
A
B
C
D
E
0
500
Metres
N

Table D-1 Verification of Model to Flooding Reports and Observations

Note – Addresses of properties with flooding generally have been suppressed in case of community sensitivity to such information being released.

ID	Event date/s	Description of Previous Flooding	Modelled Flood Behaviour
2	2004, 2008, 2011, 2013, 2015, 2016	Depths about 2/3 metre with exceedingly strong flow. Duration from 2 to 5 hours approx. depending on strength of storm. Locations from blocked drain - around and under house with sandbags keeping water out. Flooding around and in house on at least 3 occasions with major water damage	Ok, 0.55m in 2008 simulation
3	2015?	"Moderate" damage to garage, garden/yard. photos show large flow of water through garage and trying to exit via closed roller door. Door panel is bowing due to force of water. Approx. 1-2 brick courses deep at front/leeward side of house/garage	Model shows flows 0.2m deep at west side of house
4	No flood event specified	Some flood dates: 5/11/2010, 13/6/2011, 8/10/2011, 28/1/2013.Had to sandbag near garage door. Photo of 8/10/2011 shows shallow ponding, to say 50mm deep in backyard.	Model results show 0.05 - 0.12m ponding in backyard
5	No flood event specified	Property reported as flood affected	Affected by overflows from fire trail. Shallow depths
9	No flood event specified	Have installed extra drainage and downpipes and regraded concrete driveway to try to improve drainage but has not been enough.	Overflows from grassed swale in street into driveway and property
10	No flood event specified	Shallow sheet flow on front lawn. Retaining wall collapse	Model shows shallow flows on lawn. Retaining wall collapse appears to be due to slumping of saturated soil.
18	2002, 2004, 2013	Photos March 2013, 2002 and 2004 of flow through yard and down driveway of neighbouring property then down road. 100-200mm deep at hills hoist in 2004 flood. Approx. 500mm deep against fence in 2004 flood. Timber paling fence panels washed out. 100 - 200mm diameter rock rubble deposited in yard.	160mm at hills hoist, 400mm at fence in 2008 simulation. Flood patterns similar to 2013 simulation. Photos including depths and flows from front of property around side of house to back, also swift flows in next door driveway
23	5/2/2002, 11/2004, 2011, 2013	There is a creek/waterhole at the back fence and in June our yard went under as this broke its banks and flowed across the property to the drain which was in when I bought the place in 2013.	Flow breaks out of flow path and moves overland across property
26	No flood event specified	Carpets replaced in 2000 due to flooding, no flooding reported for other years.	Model shows flood depth of 0.2m at the front of the house in 2008 simulation. Ok, probably not high enough to get into house.
34	Mar 2013, June 2017	NONE- PARKED CAR MOVED WITH WATER ON ROAD- MARCH 2013	Significant depths in 2008 simulation
38	March 2013	back patio approx. 50mm depth, sandbagged to prevent ingress to house. Backyard to 100mm approx.	Modelled depth of flooding 50 - 100mm in backyard and patio

42	2001 (not consistent with BOM daily), 30/11/2011	2001- 313mm in one hour. End house (No 8) had water right through- ruined floor coverings, about 0.5m to 0.6m of water over the street, and Honeysuckle Ave as well. 30/10/2011- Huge storm- hail and rain	0.5 - 0.6m in street in 2008 simulation, reasonable match
60	2015	There was also 2 black plastic grated pits that also could not cope with this deluge resulting in water 4 - 6 inches deep running over pebblecrete and concrete. Internal damage. The water entered through weep holes in lounge room only.	Report appears mostly property drainage related. Some localised ponding around dwelling
61	2-3/3/2013	water rushing through and down properties next door and down the street flooding, the water was coming down from across Ocean Drive into the back of said properties. Houses down the street were being	Depths 0.2 - 0.4m in the area
65	No flood event specified	Reports of significant surcharge from stormwater pit	Model shows surcharge flows of $0.9m^3/s$
68	2013?	Road was flooded approx. 6 years ago due to very heavy rain and blocked storm drains.	Flooding 0.3 - 0.5m deep in 2013 event
79	June 2008	The water from no. 7 unit 2, then streamed down in front of unit 2 and into no. 6, which together with the water from no. 1 flooded unit 2. (SES attended, leaving sandbags). Resulting in resident in 2/6 getting out of bed into 10cm of water. Carpet was replaced throughout and some lounge furniture was ruined.	Model shows overflow from drain and flooding around Unit 2 to depths of 0.3m and adjacent properties but no overflows through no 7 (or 5). Possibly improvements made to drain in recent years
86	No flood event specified	Flows emerge into yard via piping in subsoil from drain uphill of property	TUFLOW model does not simulate subsoil flows but shows surface flows overflowing from drain
87	5/02/2002	There has only been one occasion that water has gone through my yard, that was due to a cloud burst that produced around 10 inches in a short amount of time. The gully above me could not cope with this downfall. Not sure of the year, think it was either 2002 or 2003. Date of downpour 5th Feb 2002- record from local historians.	Minimal overflow in 2008 sim. Observation was 2002. Condition of gully may have changed over time
89	No flood event specified	Overflowing drainage at Ocean Drive past Christmas Cove Caravan park and before Fairwinds on Southside of road. Threatening water just east of Brother Glen Road on south side of road. See markings on map I have made to indicate where flooding has occurred.	Significant flooding over Ocean Drive west of Lake
90	2001	The February 2001 event was the worst one we have had with the stormwater rushing down the Pelican Court extension road halfway up my thighs, about 2'6" deep.	0.6m in walkway. unsure if current drainage was the issue
93	03/2013, 3/2014	Both March 2013 and 2014 the reserve was flooded behind us, see photos.	Model shows similar flood behaviour.
95	15/03/2017	No problems observed in 6 years of residing at this address.	No flooding - ok

100	No flood event specified	Map indicates flooding around Quarry and Mill Street area	Model indicates flood flows from fire trail and adjacent areas 3cumecs in 2008 simulation
102	No flood event specified	House #1 has had water lapping their premises and I have seen photo's of #3 flooded. The last flood we had seen the water lapping the fence lines and flooding the Haven Caravan Park. Everyone moved their cars in our drive. We need something done with the open gully running down the Street to the river.	Model shows ponding and overflows from roadside drain
114	No flood event specified	The block where the units are was taking all the water into its yard, now it is coming our way more than ever.	Model replicates observed flood behaviour
124	No flood event specified	Garage floods every time there is heavy rain- suspected underground watercourse	TUFLOW model does not simulate subsoil flows but shows surface flows overflowing from drain
129	5/02/2002	As we live on the corner of Laurie Street and Quarry Way we only suffered surface water on the lawn. however, units on the corner of Lord Street and Seymour Street had a brick fence washed away, the Hotel bottle shop, as well as the shops in the arcade were flooded and Bold Street was underwater.	Significant flooding in Bold St and at Seymour/Lord St in 2008 simulation
132	No flood event specified	When heavy rain is falling consistently, our courtyard floods from the house behind our villa	Model shows overflows from Peach Grove and through adjacent property with depths over 200mm in 2008
142	No flood event specified	Property reported as flood affected. No specific observation given.	Model shows flooding of property
157	No flood event specified	Marked as property flooded but no specific report	Not on flow path. Minor ponding of local runoff on uphill side of house
159	No flood event specified	Marked as property flooded but no specific report	Not on flow path. Minor ponding of local runoff on uphill side of house
167	No flood event specified	In the past damage has occurred to the cyclone mesh fence parallel to the gateway Rd in the vicinity	Significant depths of flow against fence likely to result in damage
170	No flood event specified	Trees and debris in drain behind house contribute to flooding into backyard	Model shows flooding into backyard and also overflows from street, ok
176	April 2000	April 2000. Approx. 1/2 metre deep in roadway. Did not get into our house but came close	1m in road in 2008 sim
183	No flood event specified	Flooded several times in the past. Washed away reconstructed bitumen driveway next door.	Whole property flooded including depths of up to 0.3m around the dwelling in 2008, 0.2 in 2013. Ok
187	No flood event specified	Property Almost flooded - top side of land adjoining house about 15cm deep in water	Not on flow path. Model shows ponding to 0.2m on high side of house
199	No flood event specified	In 16 years of living in the said address I have experienced flooding of the road on 2 occasions. Water to the base of my dwelling to a depth of 1m on the road.	Flood depths to 1m in road sag nearby. Minor ponding at subject house.

202	No flood event specified	Overflows from laneway resulting in damage and damp in the house	Not adjacent to a flow path or significant drain. May be local or road runoff directed to the path a
205	March 2016	March 2016 the street outside my property was under approx. 500mm water. The easement down the side was a river. This occurred about 2am. By 9am the water had subsided. Following the drain being cleared of debris the drain has been flowing OK since then however the event happened again around the same time this year.	0.5-0.6m in street 2008, significant flow in easement, ok
209	No flood event specified	Creek through property between villas breaks banks and floods through properties, debris blockages of channel.	Model replicates flooding of property in each calibration event
215	No flood event specified	Property reported as flood affected.	Flooding of property and road
218	2011 2013	The fire trail behind this property was flooded twice after two separate rain storms when 250mm of rain fell about 2011 and 2013. The fire trail was overgrown with vegetation and tree branches which resulted in water about 100mm deep running over the bank and into adjacent properties. This runoff ran under the homes and into the garages. the water in the side of my house banked up and ran into the weep holes in the brickwork.	Flows down side of house. Shallow to 0.1m, some localised higher depths
219	No flood event specified	Stormwater drain on Peach Grove (located on the kerb closest to the reserve and opposite the intersection often floods in heavy rain	Sag is flooded to depths of 0.3m in the 2008 simulation
222	No flood event specified	Stormwater overflows from road	Model reflects observations
228	No flood event specified	Nuisance flooding apart from river flooding	Shallow ponding and model matches observations
232	No flood event specified	Flooding damage required repairs by insurer	Model shows flooding at rear of house to 0.3m
252	No flood event specified	Photos will show as the watercourse is not sufficient to handle the amount of water and bursts its banks and floods several properties	Model replicates this flood behaviour in 2008 and 2013 simulations.
256	No flood event specified	Property flood affected - minor	Shallow ponding in backyard 0.05 - 0.1m
262	No flood event specified	The corner intersection of Tunis Street and Lake Street always has problems with flooding.	Widespread shallow flooding at intersection of Lake St and Tunis St and flooding of adjacent property
280	No flood event specified	Creek through property between villas breaks banks and floods through properties	Model replicates flooding of property in each calibration event
285	No flood event specified	Property flooded	Significant flooding of property
1001	March 2013 daytime	Swift flows in walkways between buildings. Approx. 300mm deep, >1m/s down walkway	Flow depths 0.3m and velocities 1.5-2m/s in 2013 simulation

Flinders Drive Laurieton	No flood event specified	Previous work done with drainage and regrading verge. Flooding Feb 2008 into garage and nearly front door. Concern that runoff from next door new development is being directed to subject property.	Overflows from road and ponding in driveway and front yard to 0.3-0.4m. in April 2008 simulation.
Lake Street Laurieton	No flood event specified	Water covering Lake Street, Ocean Drive. 50-100mm in car port of property. Five properties in Lake St and Laurieton Gardens Caravan Park also Ocean Dr affected. Photos provided.	100mm flood depths in the driveway of property and car port
Lake Street Laurieton	No flood event specified	Property has flooded 4 times since 2010. Not until units next door were built 2 properties up the street.	Model replicates observed flood behaviour
Flinders Drive Laurieton	2008	Photos attached. Significant flows in rear swale and through fences into property, rubble deposited	Model results of flow depths up to 0.3 – 0.5m with flow patterns (flows through fence) match the April 2008 photos.
Quarry Way Laurieton	2013	Heavily overgrown, many trees down in drain. Reported up to 1m depths in March 2013 on adjacent properties. Sections very porous with springs popping up	Flows in drain immediately behind properties to 0.2m in the March 2013 event, maximum depths of 0.7m on properties.
Castle Street Laurieton	No flood event specified	Excessive stormwater onto property, lapping at back steps and under house	Flood depths 0.2 – 0.3m on low side of house. Reasonable match to observation.
Dalton photo 2008_010 to 014, 049	2008	Flows in swales draining to Pelican Court appear to be 0.3 – 0.5m deep but after peak of storm	Model shows depths of 0.7 – 1.2m at peak of storm.
Dalton photo 2008_015	2008	Photo shows flooding over road verge to property fence line, depths of 0.1-0.2m against brick wall	Model shows depths to 0.1m and similar extent
Dalton photo 2008_019	2008	Photo shows large quantity of rubble and gravel deposited on driveway from adjacent creek	Good match by model to observed flood behaviour with depths 0.3-0.4m in peak
Dalton photo 2008_016	2008	Photo shows S/W side of Ocean Drive east of Flinders Drive flooded, flows just overtopping crown of road, after peak of storm	Peak depths overtopping crown are 0.15m in 2008 simulation
Dalton photo 2008_024	2008	Flooding of Flinders Drive/Ocean Drive intersection to estimated 0.2-0.3m after peak of storm	Peak depths overtopping crown are 0.3-0.4m in 2008 simulation
Dalton photo 2008_047	2008	Rosewood Court at Mission Terrace, flows in road up to approx. 0.2m	Peak depths in intersection 0.3-0.4m in 2008 simulation

Appendix E. Design Flood Mapping

Figure E-1 – 0.2EY Design Flood - Peak Flood Depths

Figure E-2 – 5% AEP Design Flood - Peak Flood Depths

Figure E-3 – 2% AEP Design Flood - Peak Flood Depths

Figure E-4 – 1% AEP Design Flood - Peak Flood Depths

Figure E-5 – 0.5% AEP Design Flood - Peak Flood Depths

Figure E-6 – Probable Maximum Flood - Peak Flood Depths

Figure E-7 – 1% AEP Design Flood - Climate Change Scenario Peak Flood Depths

Figure E-8 – 0.2EY Design Flood - Peak Flow Velocity

Figure E-9 – 5% AEP Design Flood - Peak Flow Velocity

Figure E-10 – 2% AEP Design Flood - Peak Flow Velocity

Figure E-11 – 1% AEP Design Flood - Peak Flow Velocity

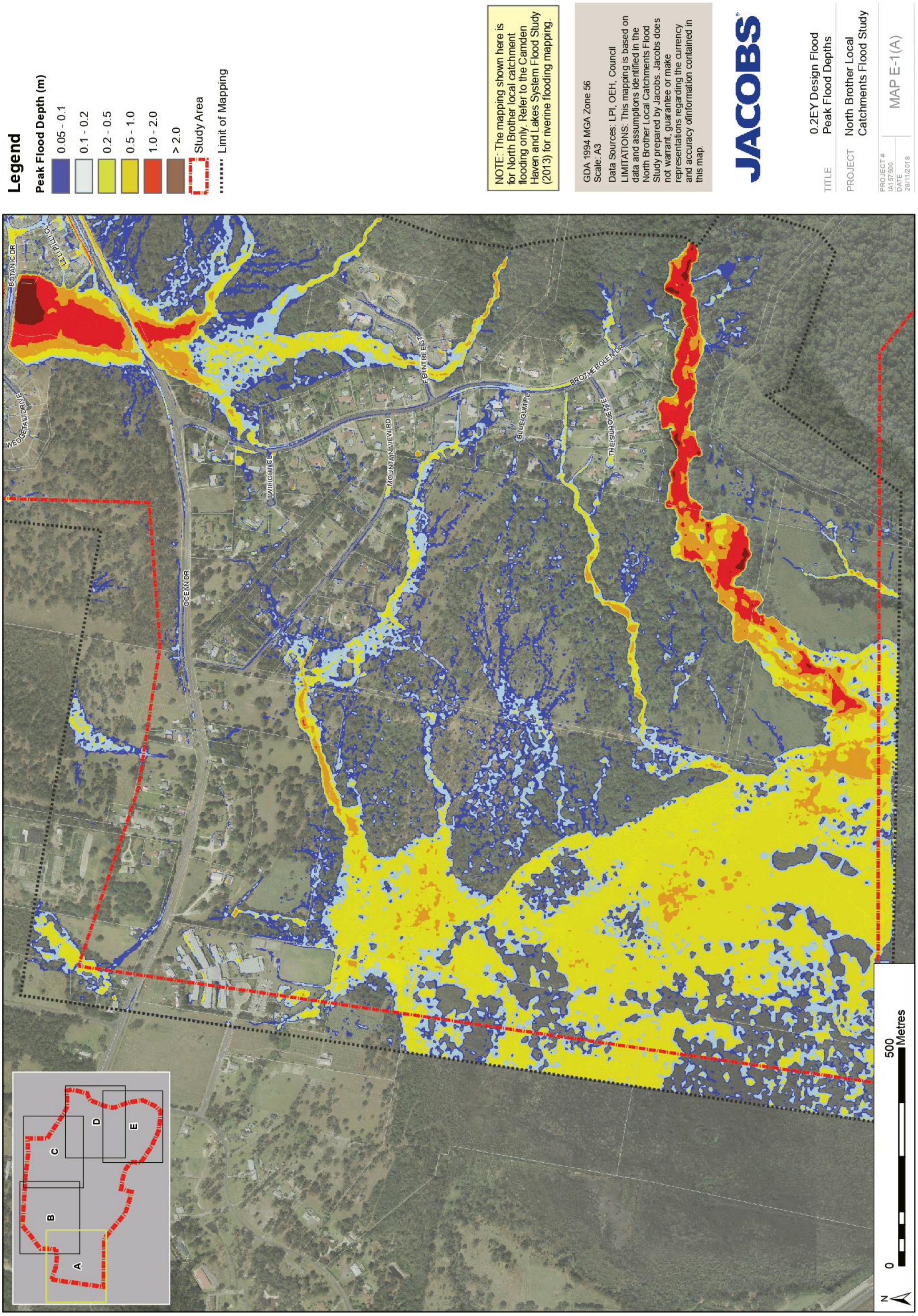
Figure E-12 – 0.5% AEP Design Flood - Peak Flow Velocity

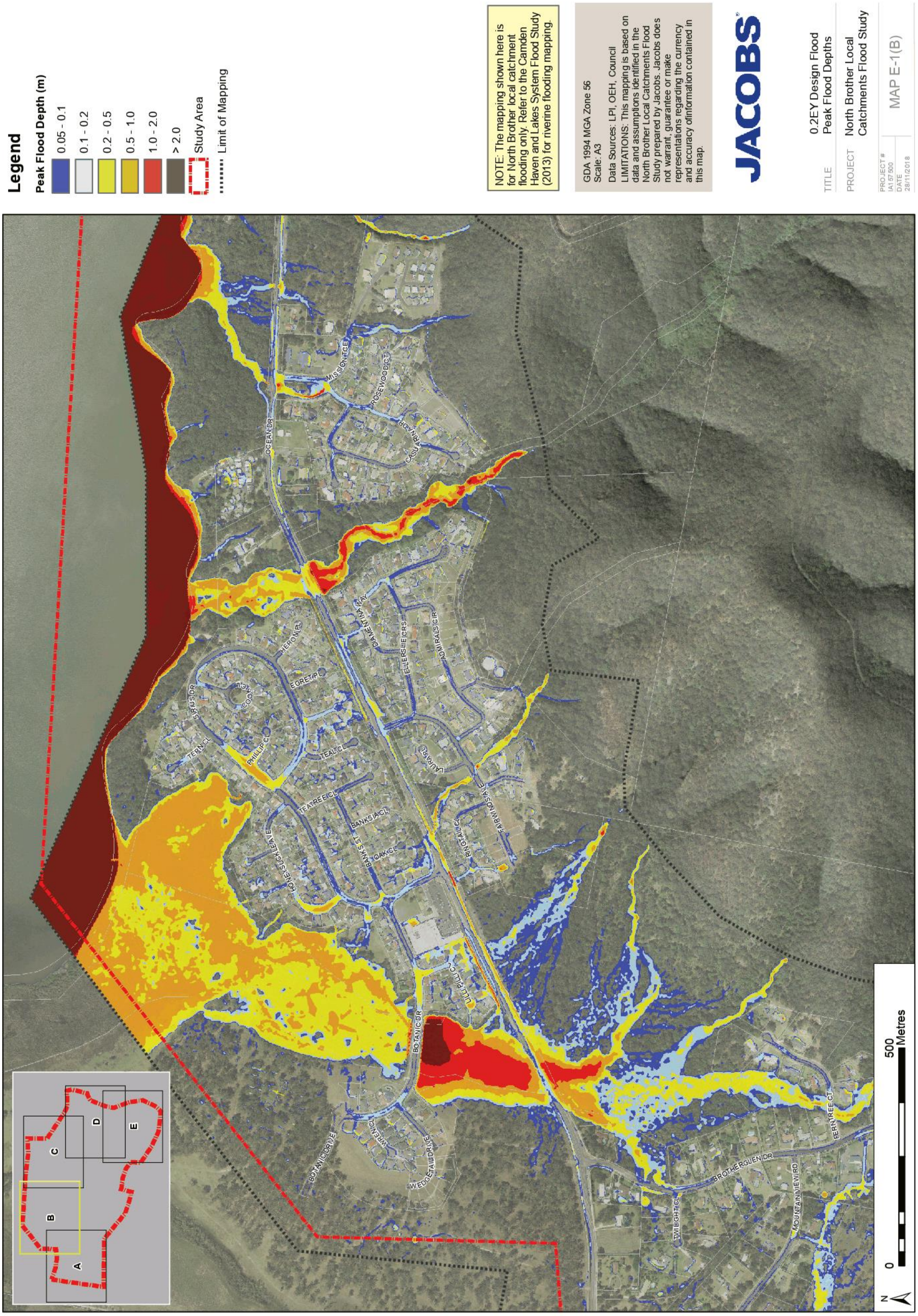
Figure E-13 – Probable Maximum Flood - Peak Flow Velocity

Figure E-14 – 1% AEP Design Flood - Climate Change Scenario Peak Flow Velocity

Figure E-15 - 1% AEP Design Flood - Climate Change Impact : Change in Flood Level

Insert flood mapping


Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 0.2EY Design Flood Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-1(A)
0
500 Metres
N


Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
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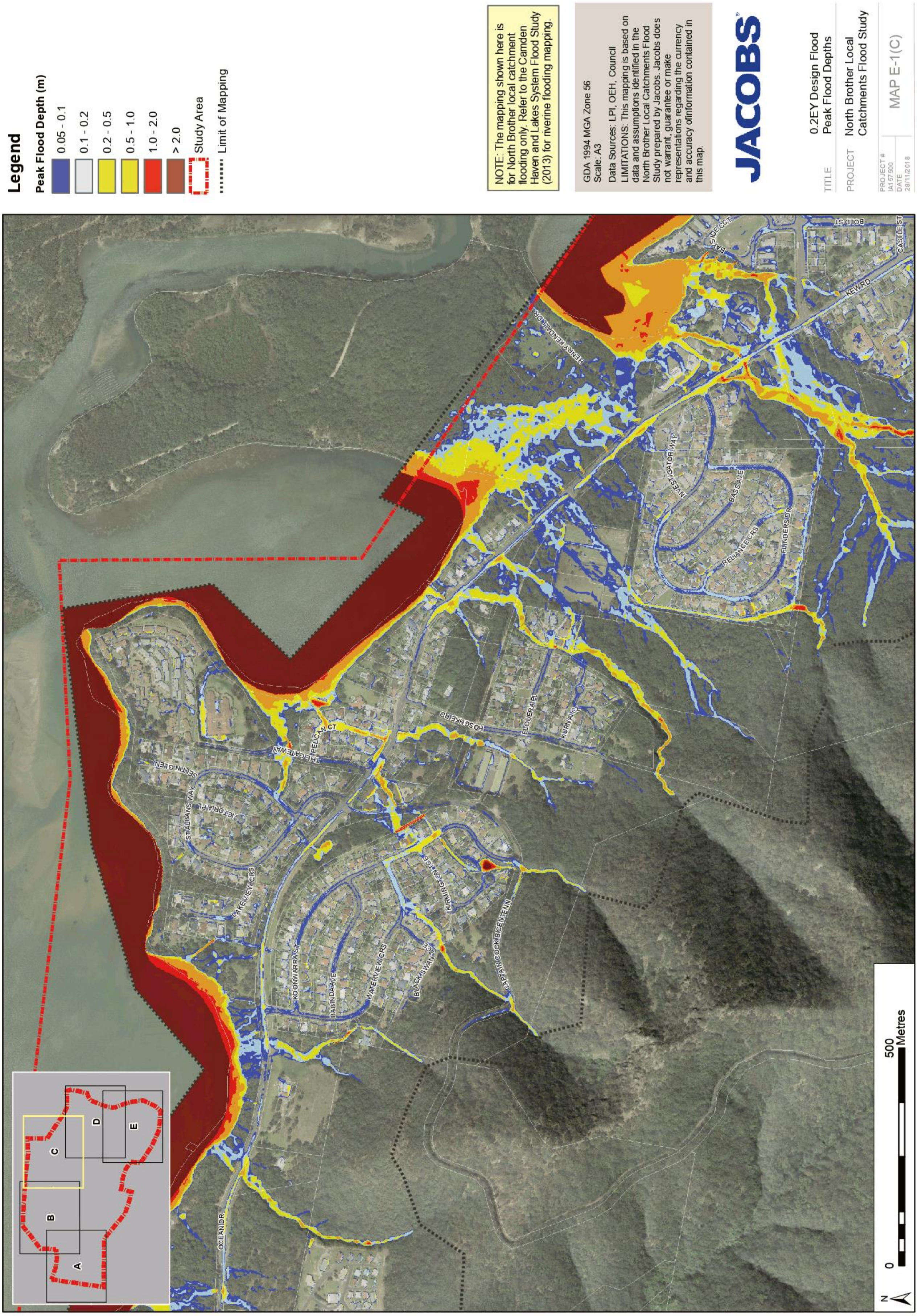
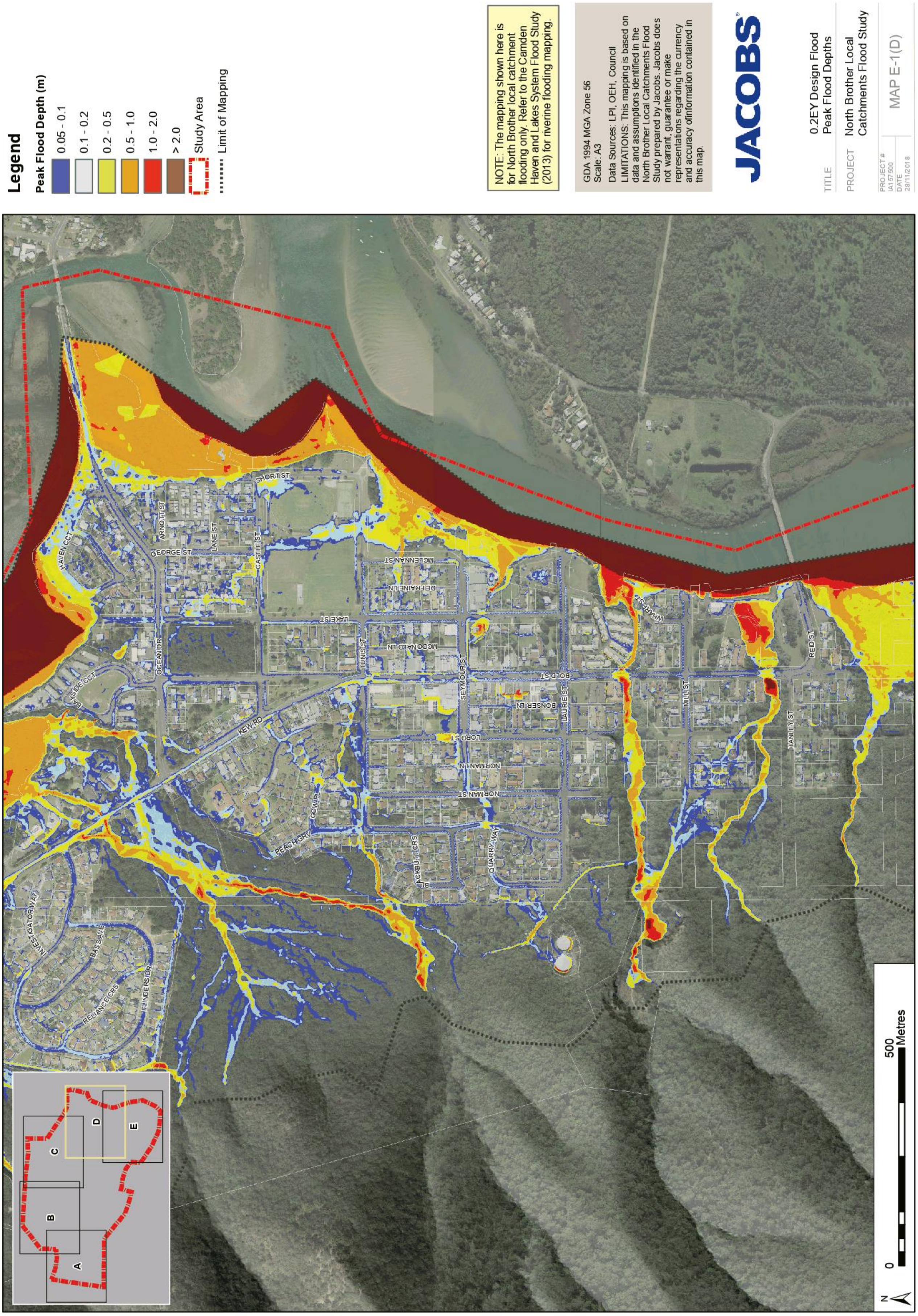
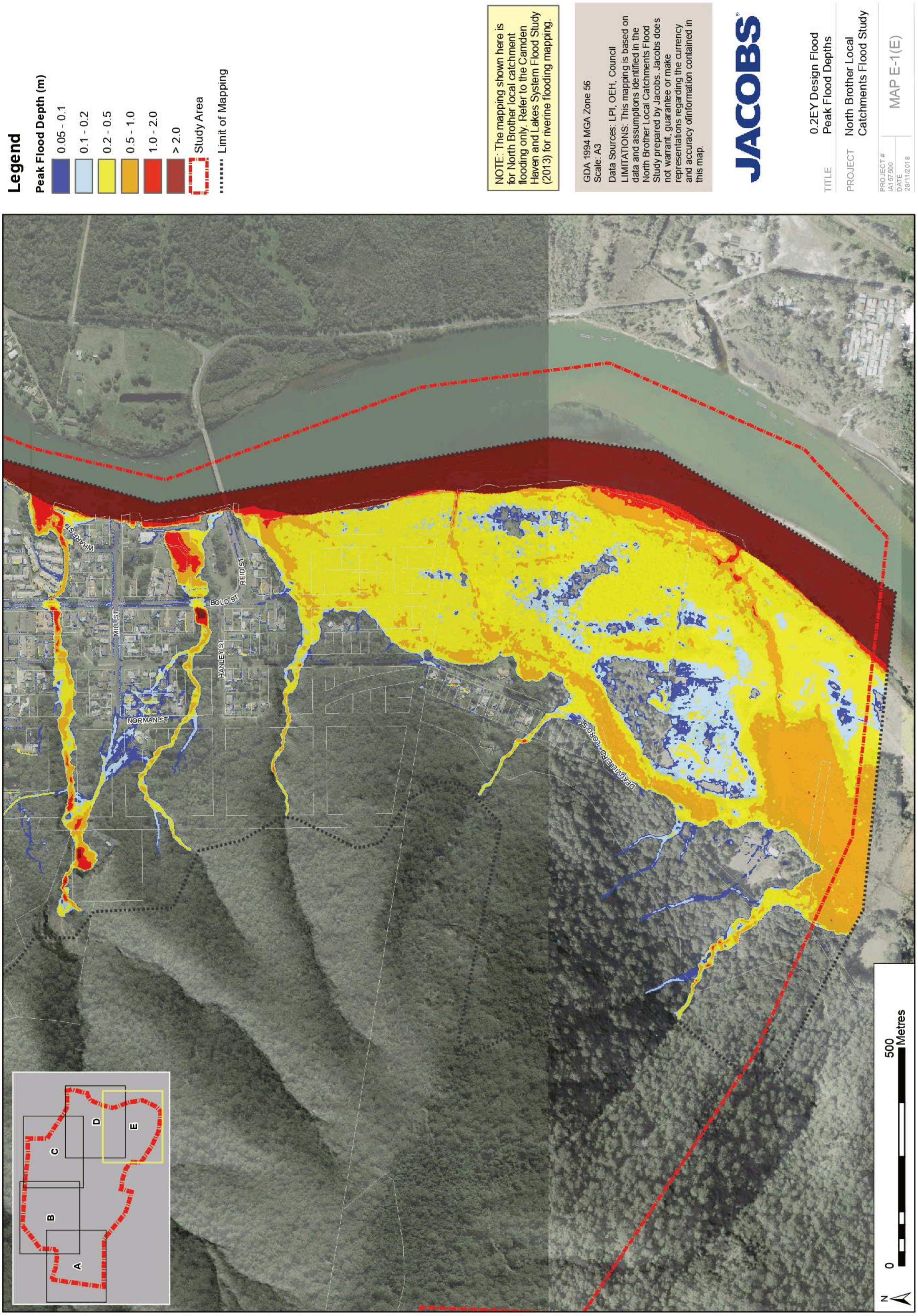
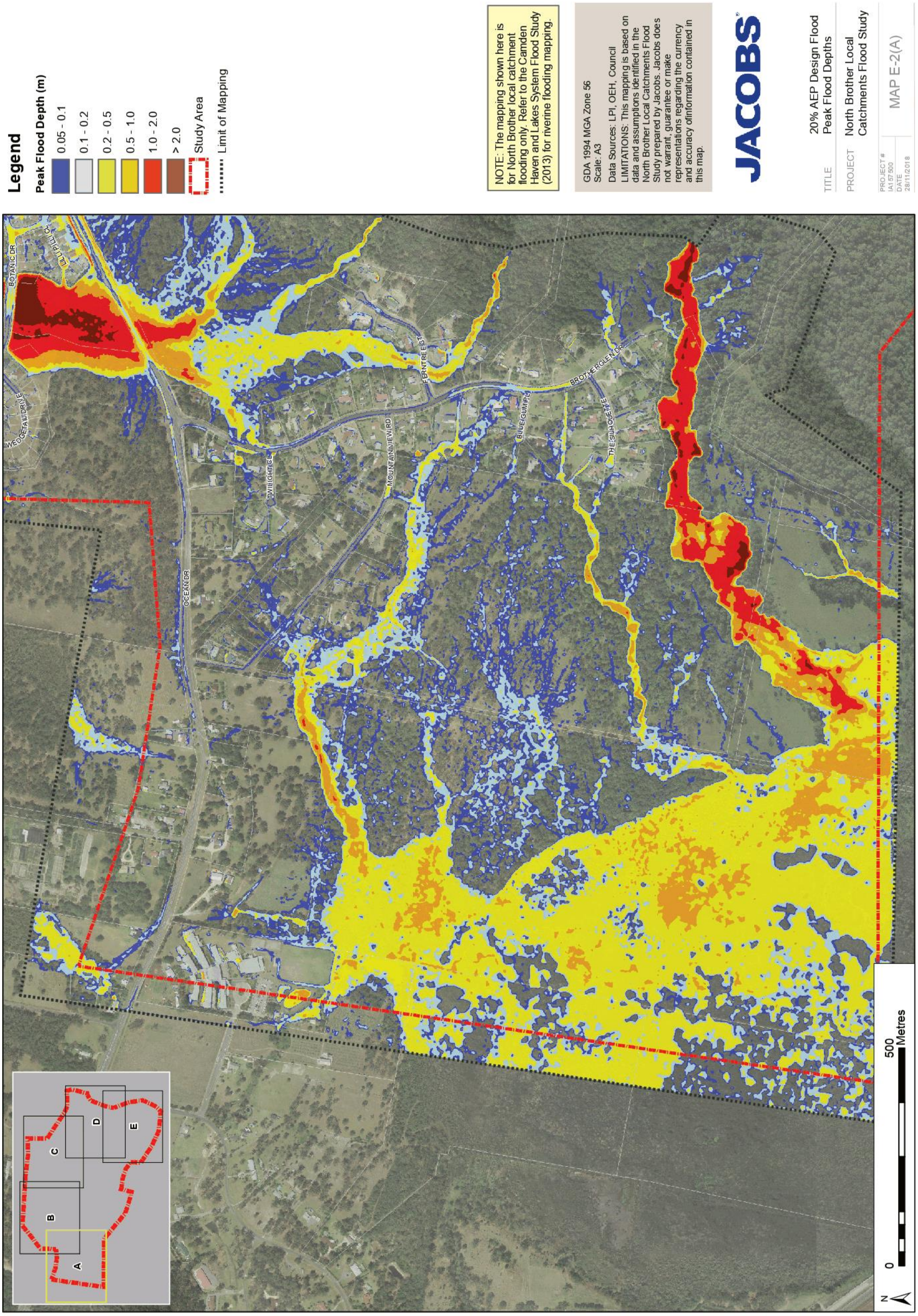
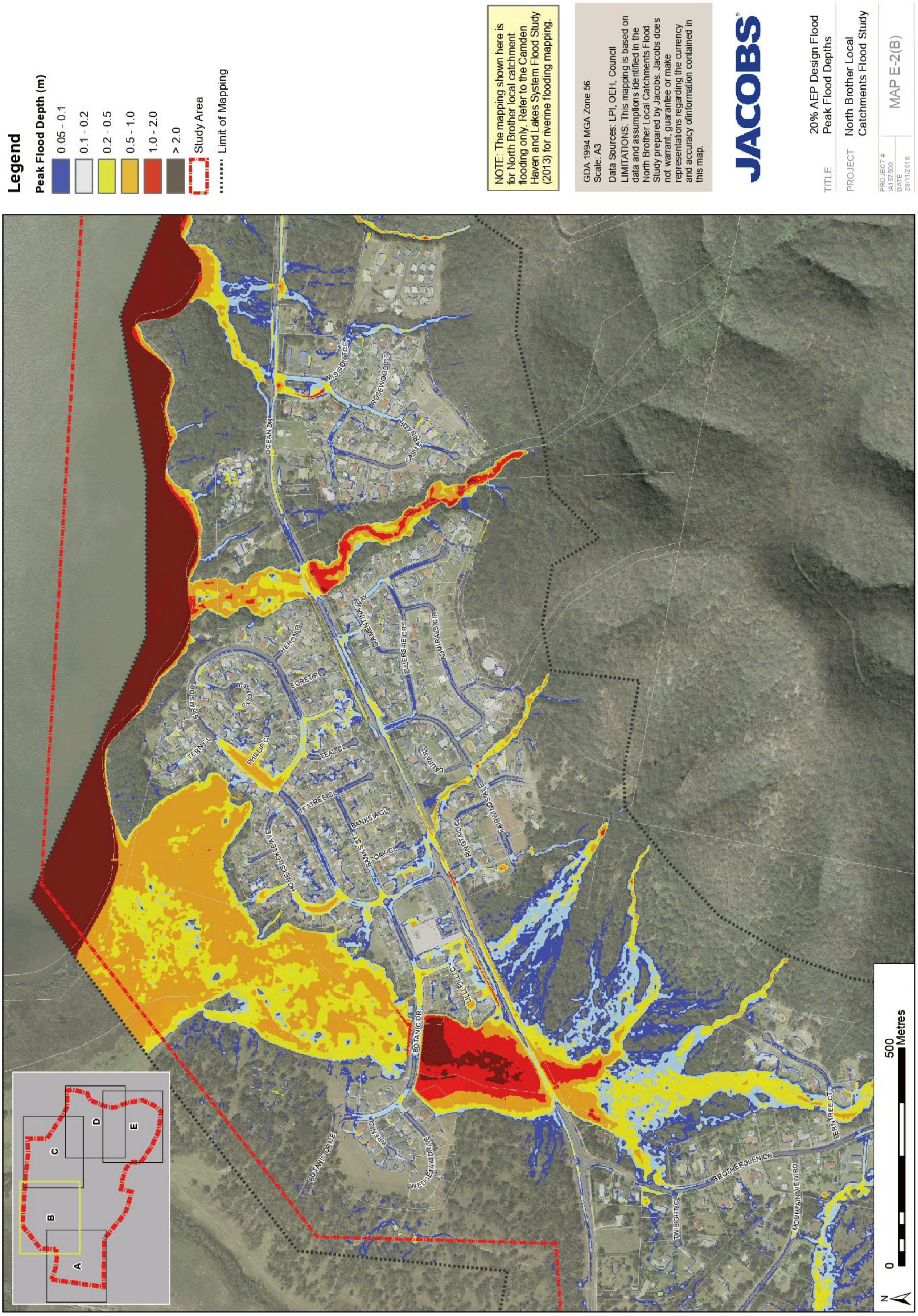
JACOBS
TITLE 0.2EY Design Flood Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-1(B)
0
500 Metres
N

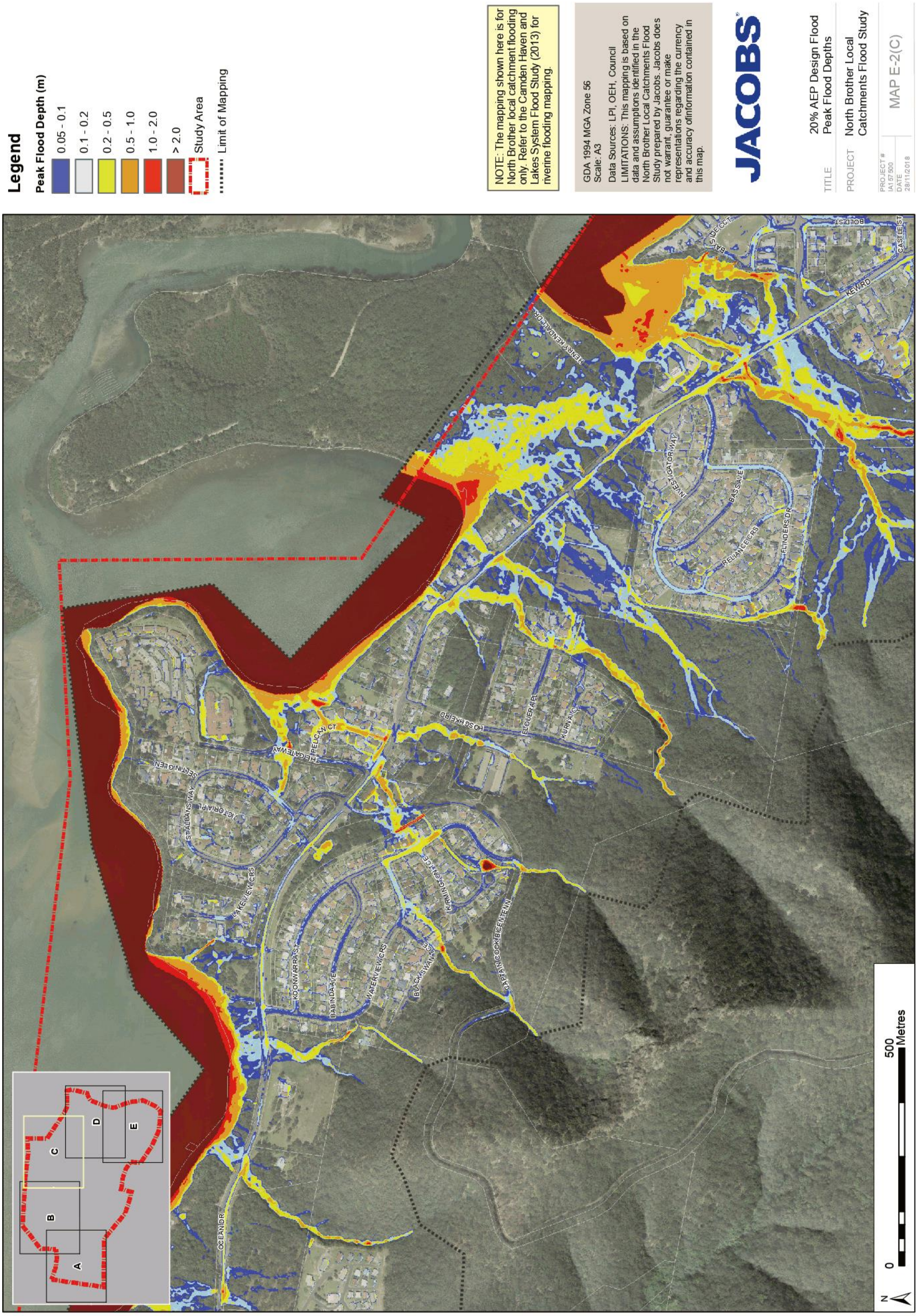

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
TITLE 0.2EY Design Flood Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-1(C)
0
500
Metres
N

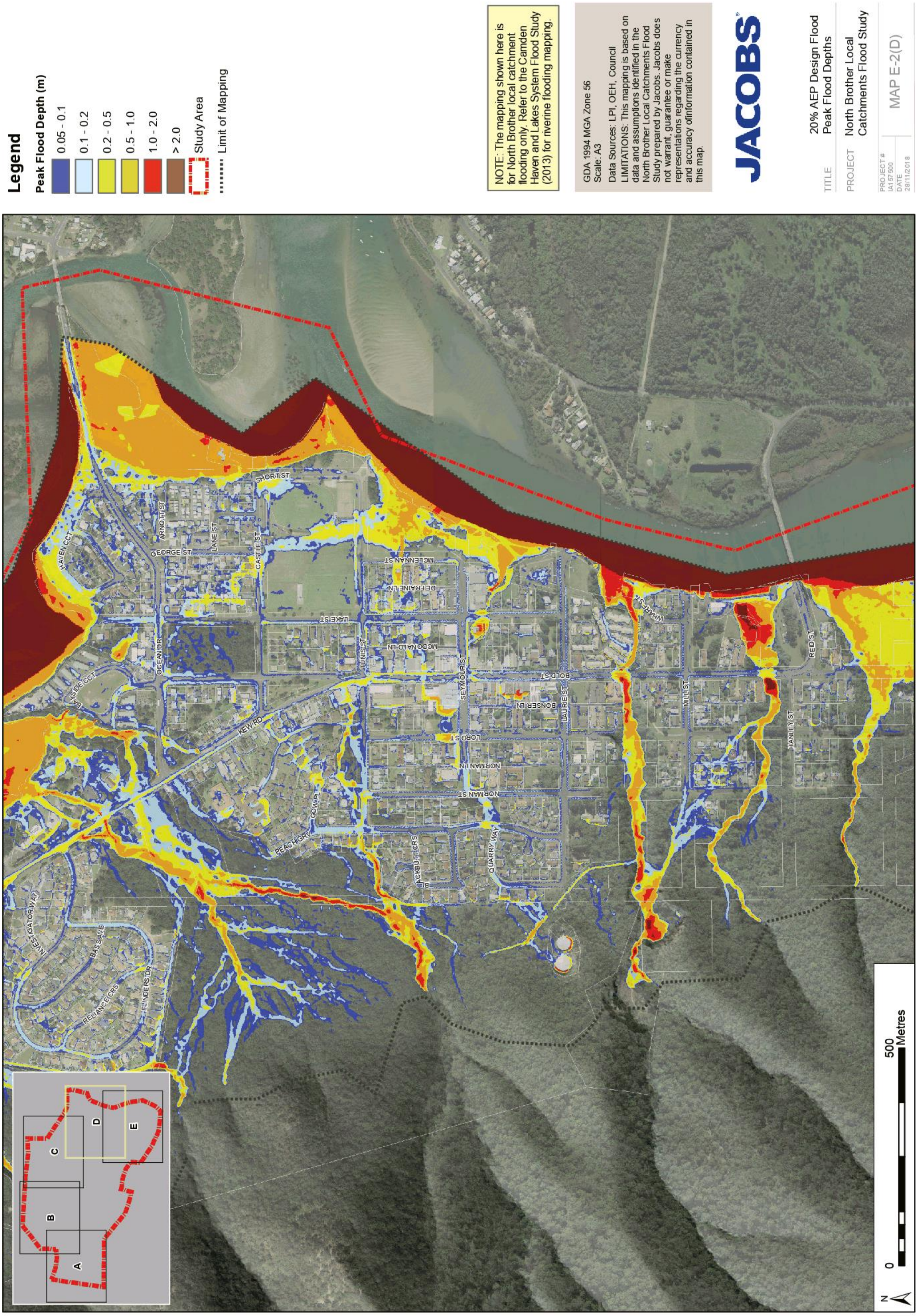

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 0.2EY Design Flood Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-1(D)
SHORT ST
GEORGE ST
ARNOTT ST
LAKE ST
CASTLE ST
HAVEN CCT
MCLENNAN ST
DE FRAINE LN
OCEAN DR
TUNIS ST
SEYMOUR ST
BOLD ST
LAURIE ST
MILL ST
HANLEY ST
RED ST
KEW RD
BONSER LN
LORD ST
NORMAN LN
NORMAN ST
PEACH GR
QUARRY WAY
BASS AVE
FLINDERS DR
0
500
Metres
N
A
B
C
D
E

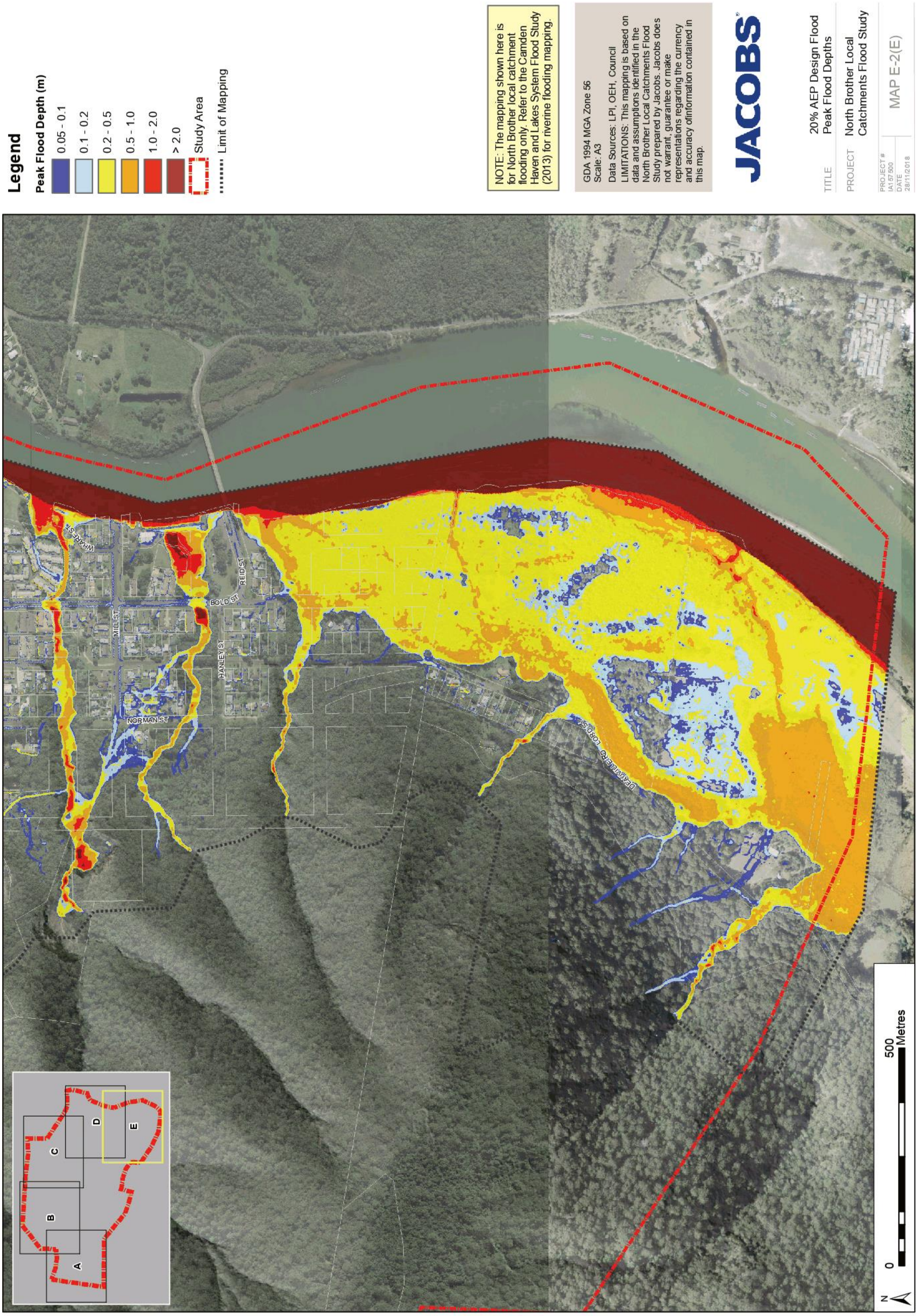

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 0.2EY Design Flood Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-1(E)
BOLD ST
MILL ST
REID ST
HANLEY ST
NORMAN ST
500 Metres
0
A
B
C
D
E

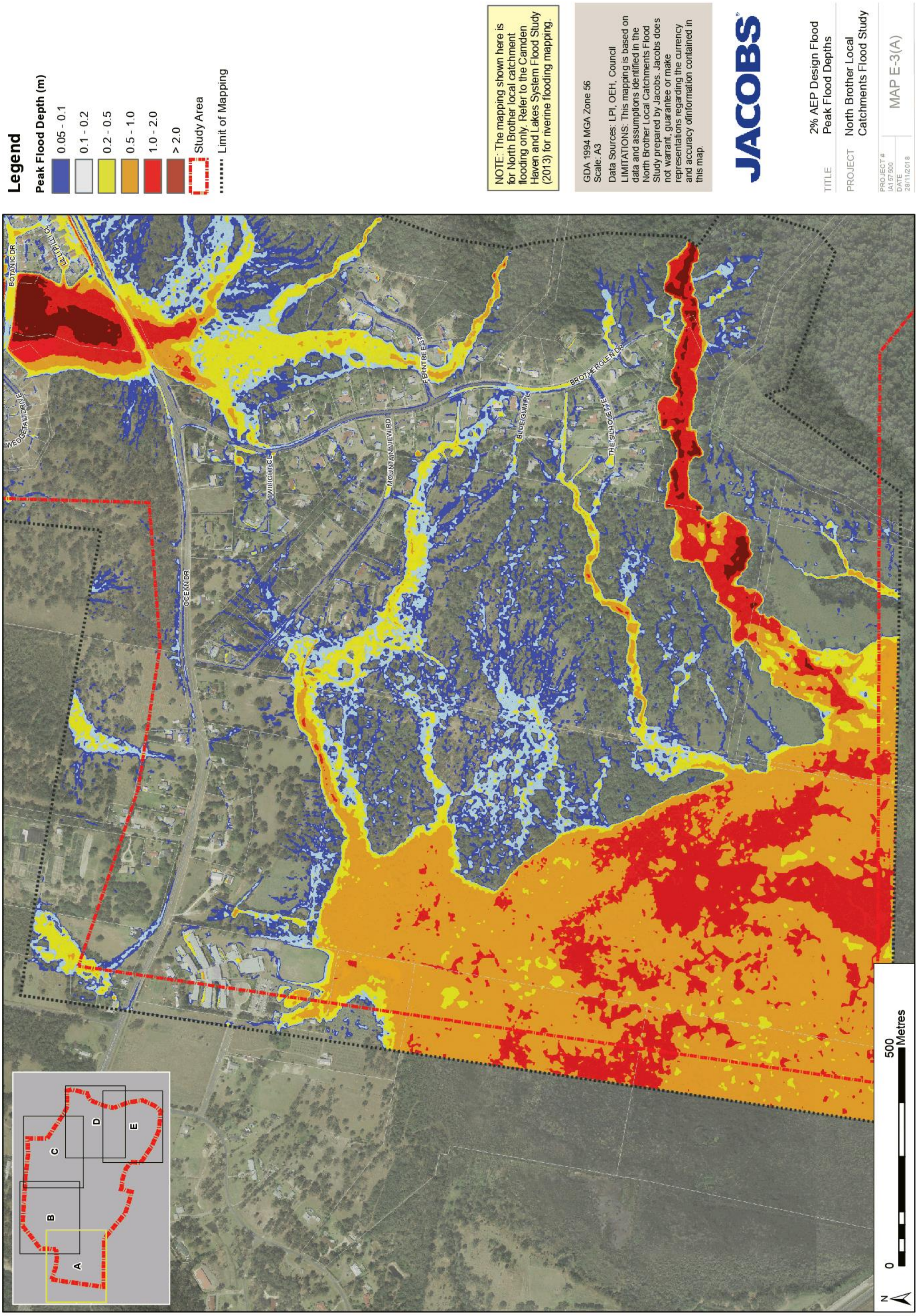

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 20% AEP Design Flood Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-2(A)
BOTANIC DR
OCEAN DR
TWILIGHT CL
MOUNTAIN VIEW RD
FERNTREE CL
BROTHERGLEN DR
BLUEGUM PL
THE SILHOUETTE
A
B
C
D
E
0
500
Metres
N

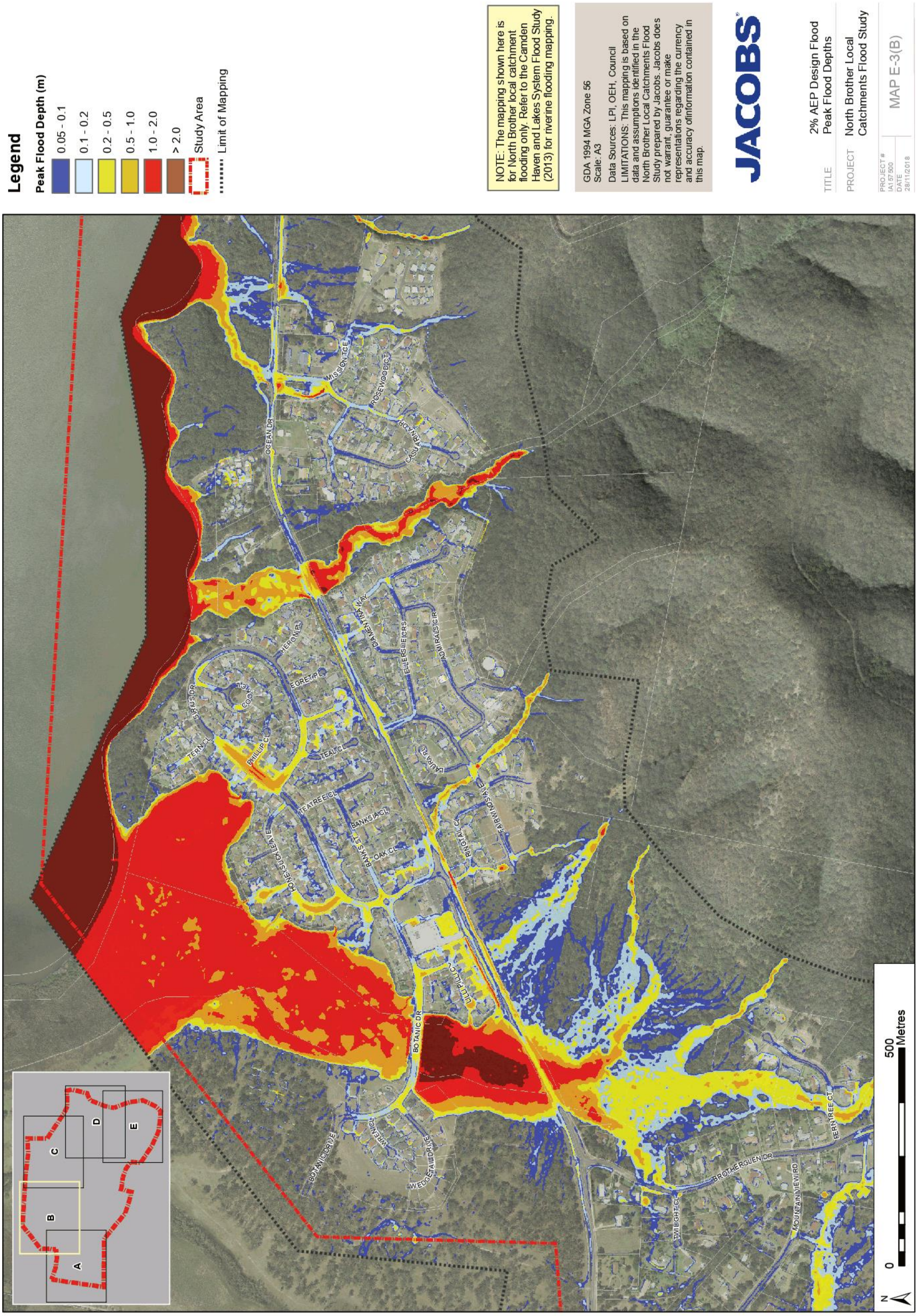

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 20% AEP Design Flood Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-2(B)
0
500 Metres
N
A
B
C
D
E

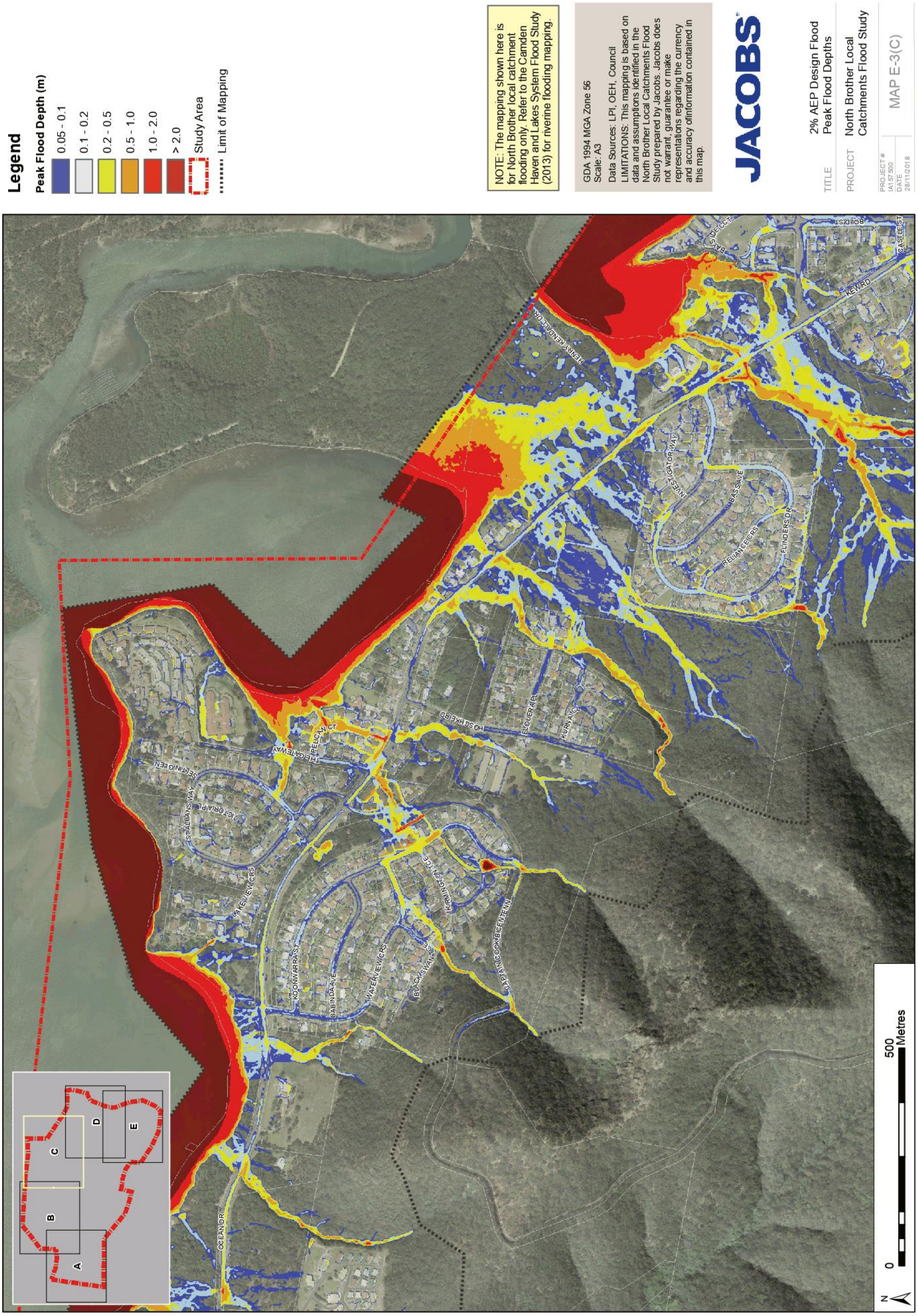

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE
20% AEP Design Flood Peak Flood Depths
PROJECT
North Brother Local Catchments Flood Study
MAP E-2(C)
0
500 Metres
N


Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE 20% AEP Design Flood Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-2(D)
SHORT ST
GEORGE ST
ARNOTT ST
LAKE ST
CASTLE ST
MCLENNAN ST
DEFRAINE LN
MCDONALD LN
SEYMOUR ST
BOLD ST
BONSER LN
LORD ST
NORMAN LN
NORMAN ST
LAURIE ST
MILL ST
HANLEY ST
REID ST
KEW RD
OCEAN DR
HAVEN CCT
BAYSIDE CCT
PEACH GR
QUARRY WAY
BASS AVE
FLINDERS DR
A
B
C
D
E
0
500
Metres
N

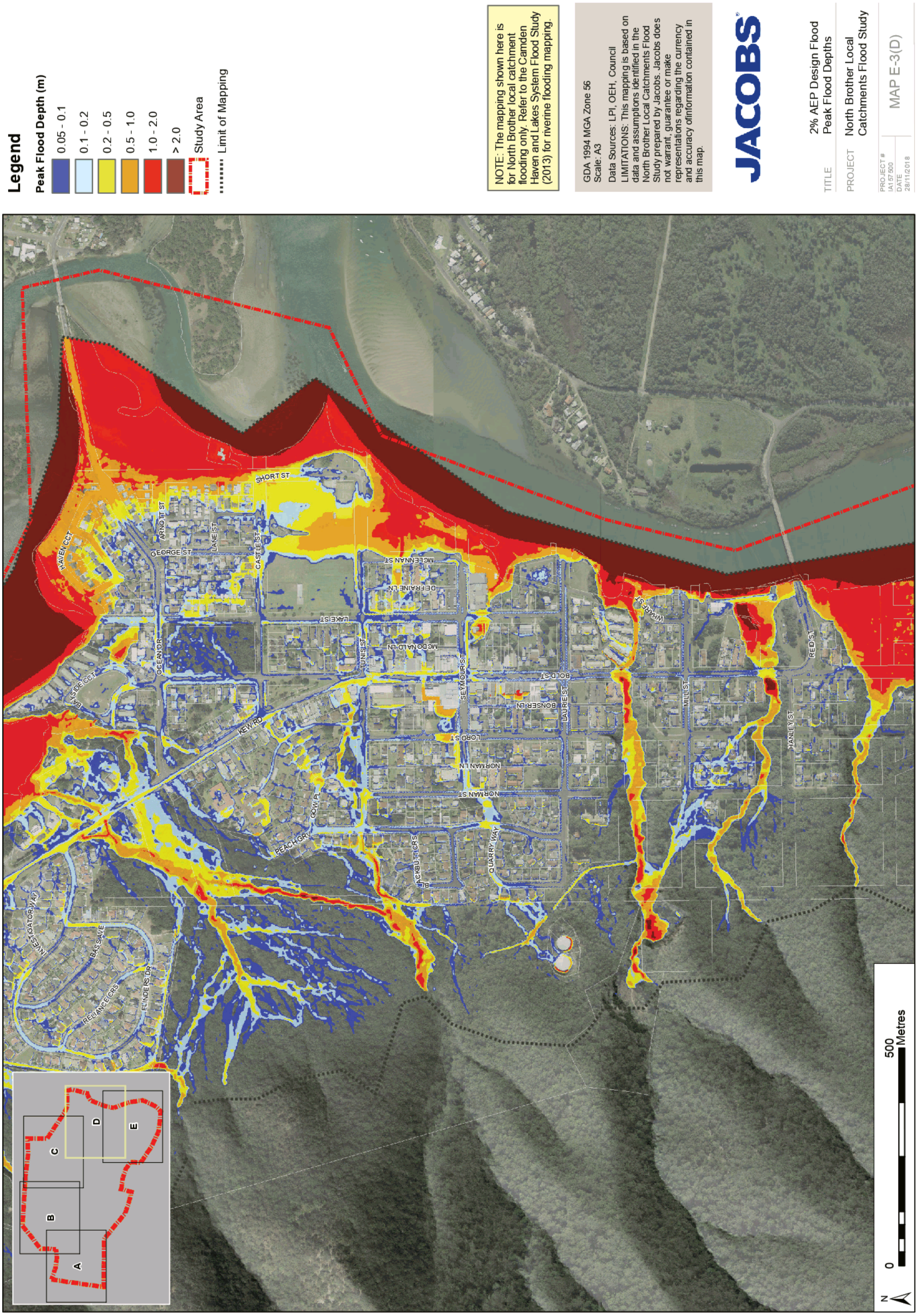

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE
20% AEP Design Flood Peak Flood Depths
PROJECT
North Brother Local Catchments Flood Study
MAP E-2(E)
MILL ST
BOLD ST
REID ST
HANLEY ST
NORMAN ST
A
B
C
D
E
0
500
Metres
N

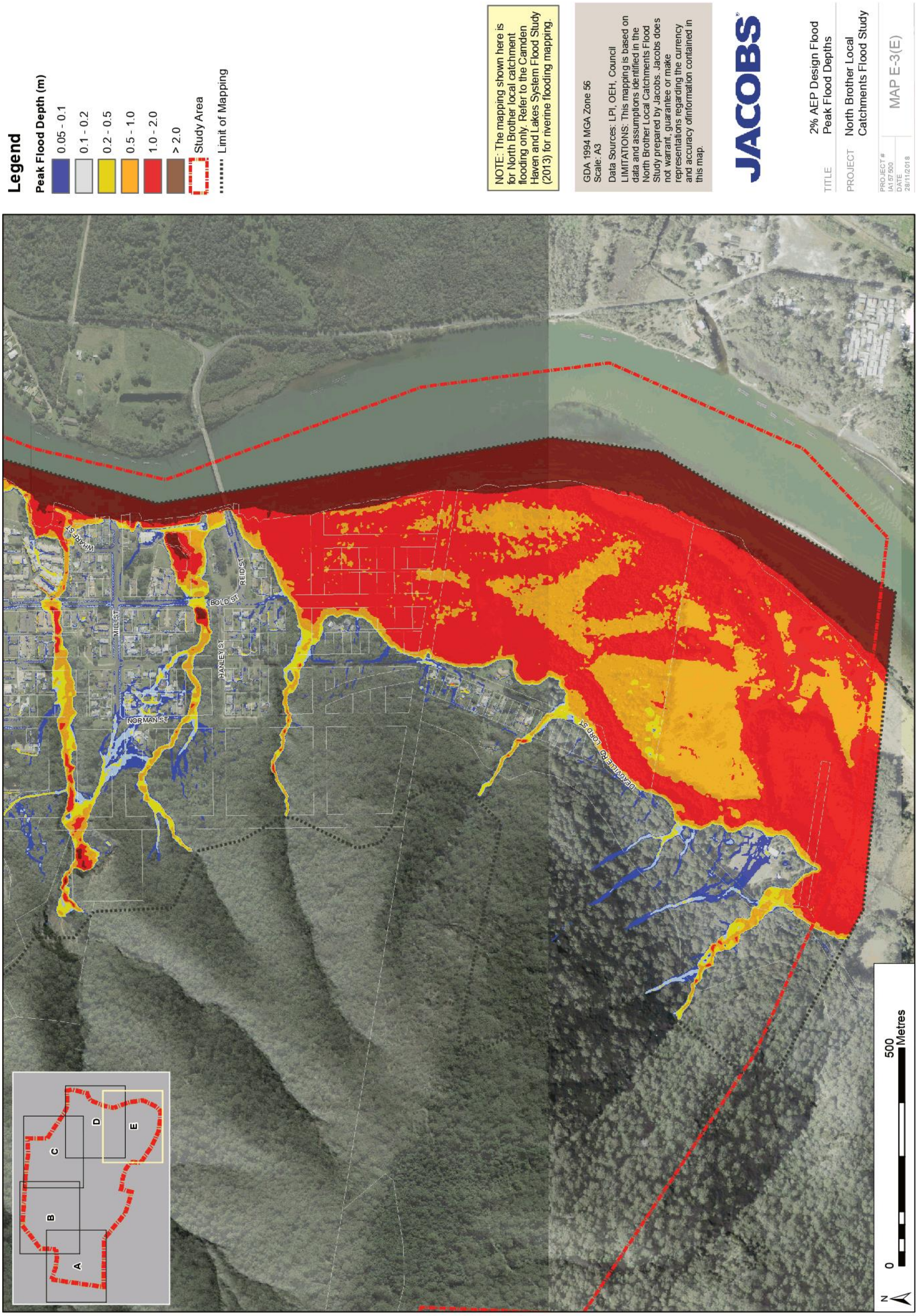

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE
2% AEP Design Flood Peak Flood Depths
PROJECT
North Brother Local Catchments Flood Study
MAP E-3(A)
BOTANIC DR
OCEAN DR
MOUNTAIN VIEW RD
TWILIGHT CL
FERNTREE ST
BROTHERGLEN DR
BLUEGUM PL
THE SILHOUETTE
A
B
C
D
E
0
500
Metres
N

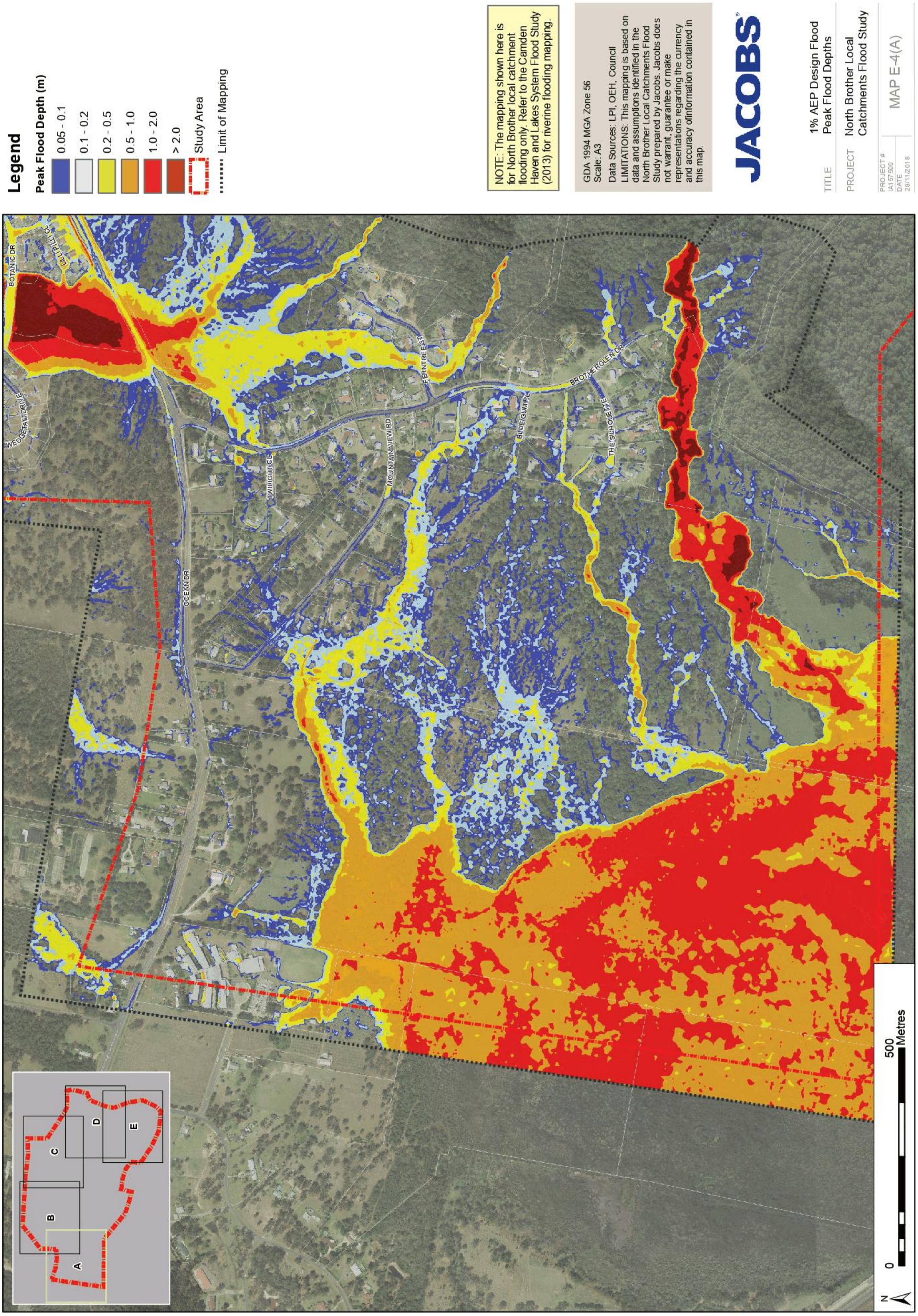

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE 2% AEP Design Flood Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-3(B)
0
500
Metres
N
A
B
C
D
E



Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 2% AEP Design Flood Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-3(C)
0
500 Metres
N
A
B
C
D
E


Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
TITLE 2% AEP Design Flood Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-3(D)
SHORT ST
GEORGE ST
ARNOTT ST
LAKE ST
CASTLE ST
MCLENNAN ST
DE FRAINE LN
MCDONALD LN
TUNIS ST
SEYMOUR ST
BONSER LN
LORD ST
NORMAN LN
NORMAN ST
QUARRY WAY
LAURIE ST
BOLD ST
MILL ST
HANLEY ST
RED ST
KEW RD
OCEAN DR
HAVEN CCT
BASS AVE
FLINDERS DR
PEACH GR
500
Metres
0
N
A
B
C
D
E


Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE 2% AEP Design Flood Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-3(E)
BOLD ST
REID ST
MILL ST
HANLEY ST
NORMAN ST
0
500 Metres
A
B
C
D
E


Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 1% AEP Design Flood Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-4(A)
OCEAN DR
BOTANIC DR
MOUNTAIN VIEW RD
TWILIGHT CL
FERNTREE ST
BROTHERGLEN DR
BLUE GUM PL
0
500
Metres
N
A
B
C
D
E

Legend

Peak Flood Depth (m)

- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0
- Study Area
- Limit of Mapping

NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.

GDA 1994 MGA Zone 56
Scale: A3

Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

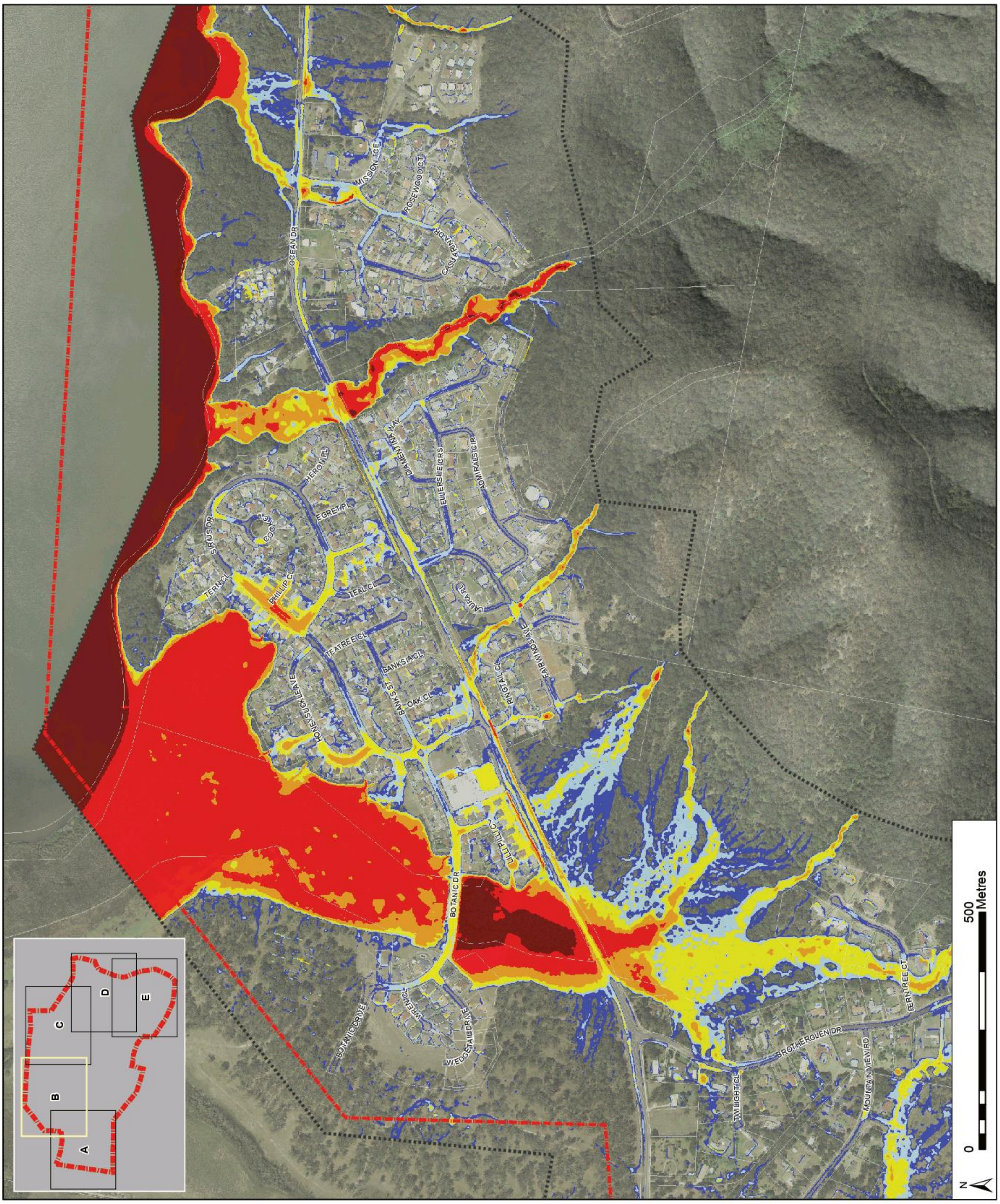
JACOBS

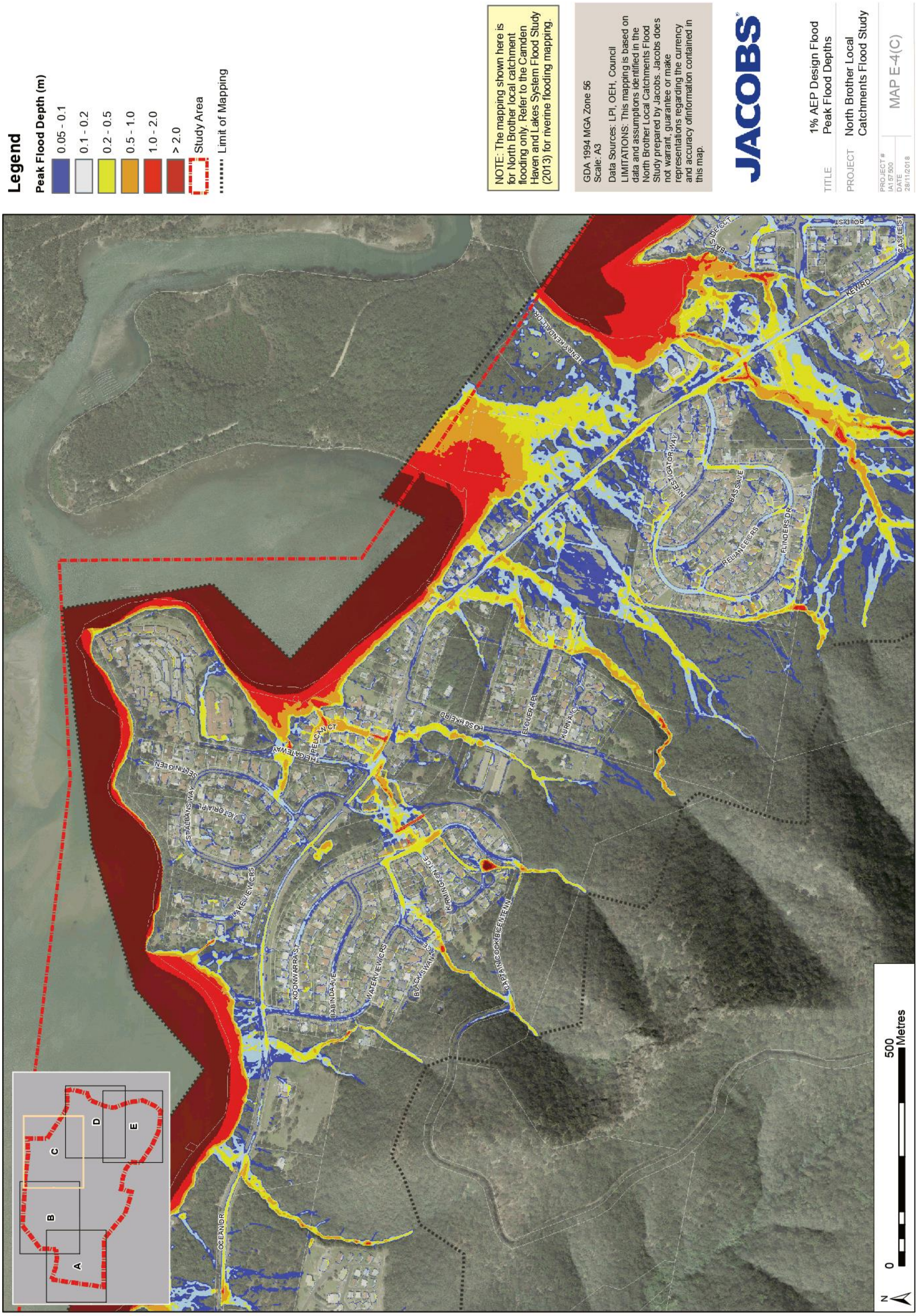
TITLE: 1% AEP Design Flood Peak Flood Depths

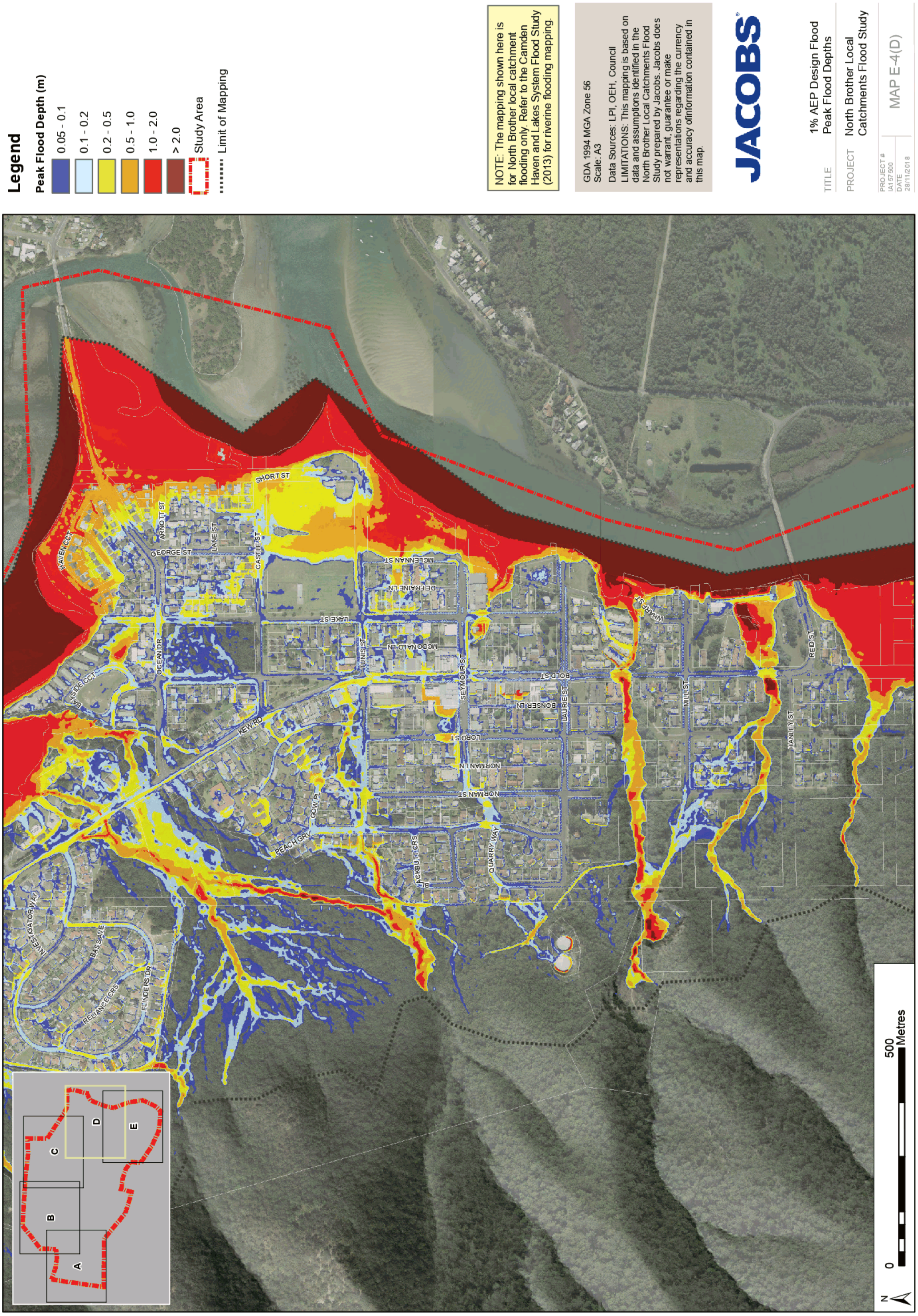
PROJECT: North Brother Local Catchments Flood Study

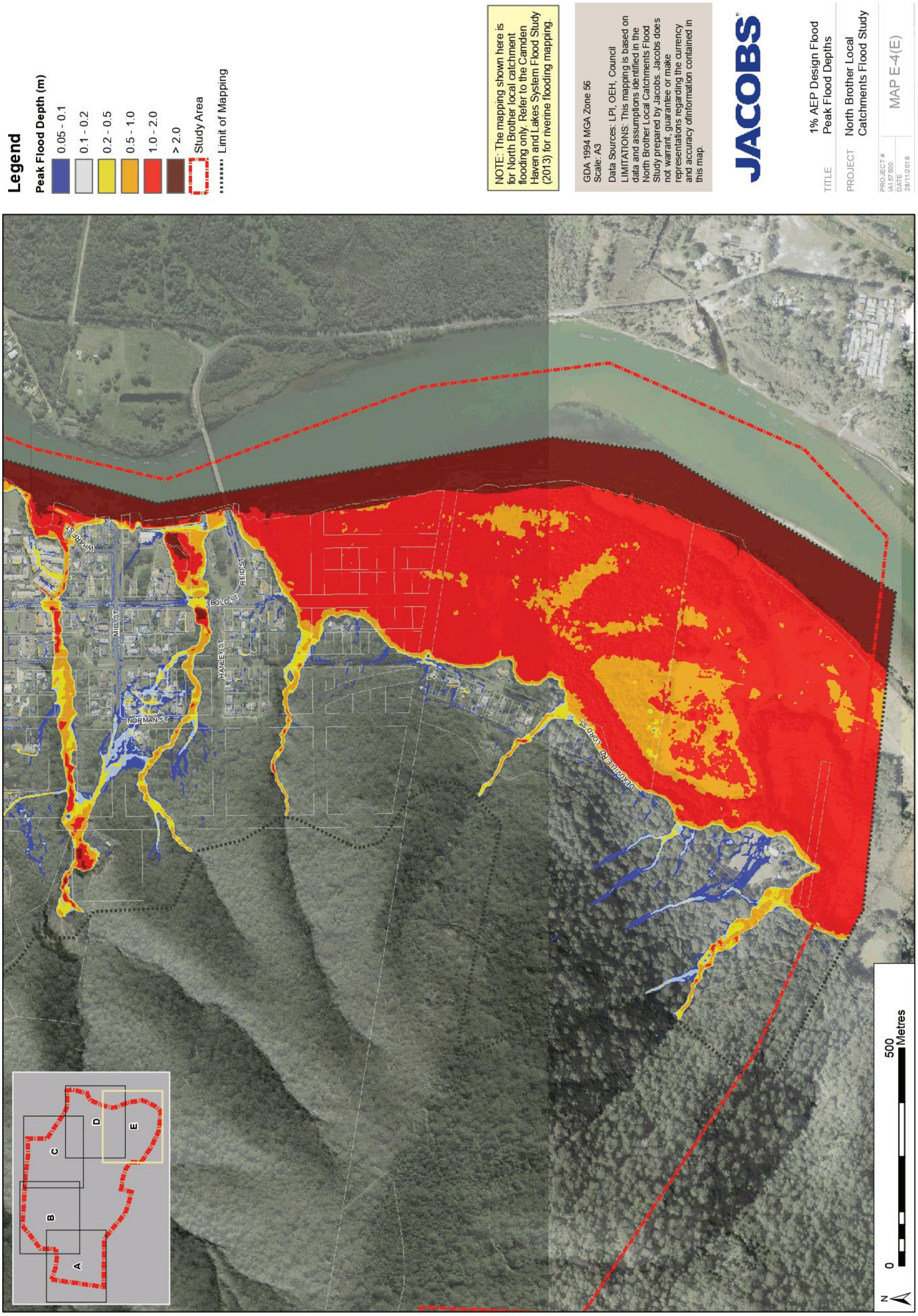
PROJECT # IA157500
DATE 28/11/2018

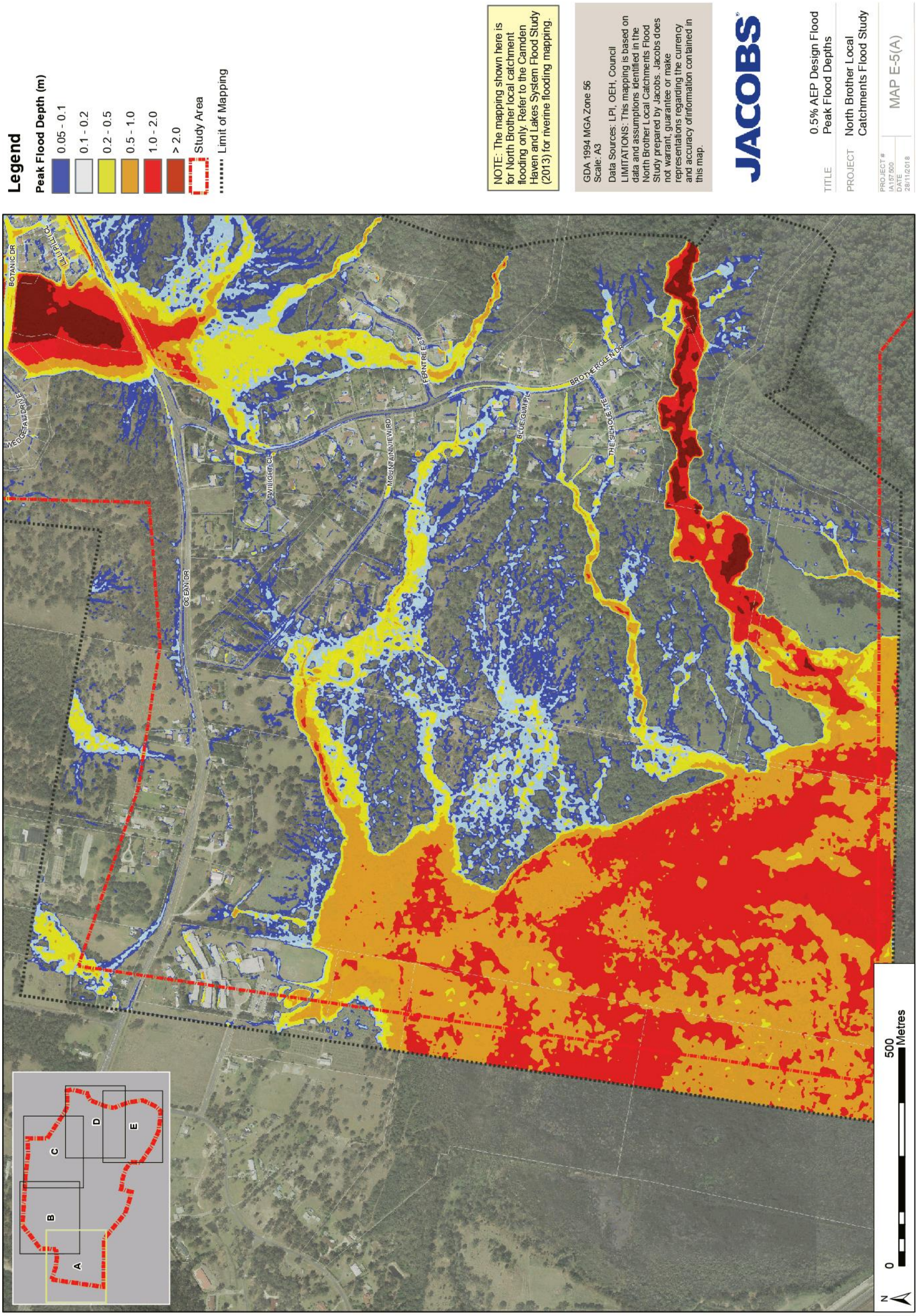
MAP E-4(B)



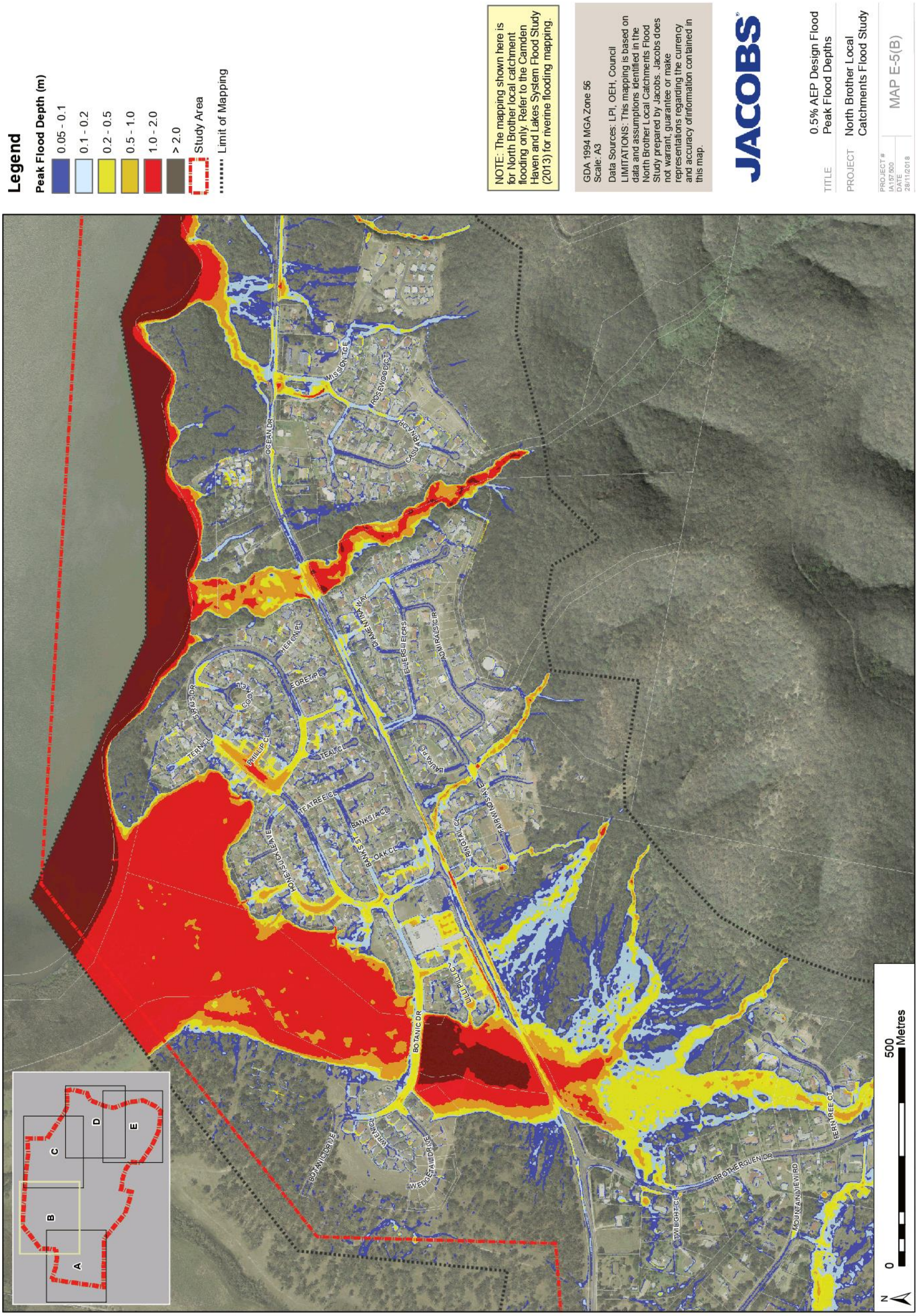

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE 1% AEP Design Flood Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-4(C)
0
500 Metres
N
A
B
C
D
E

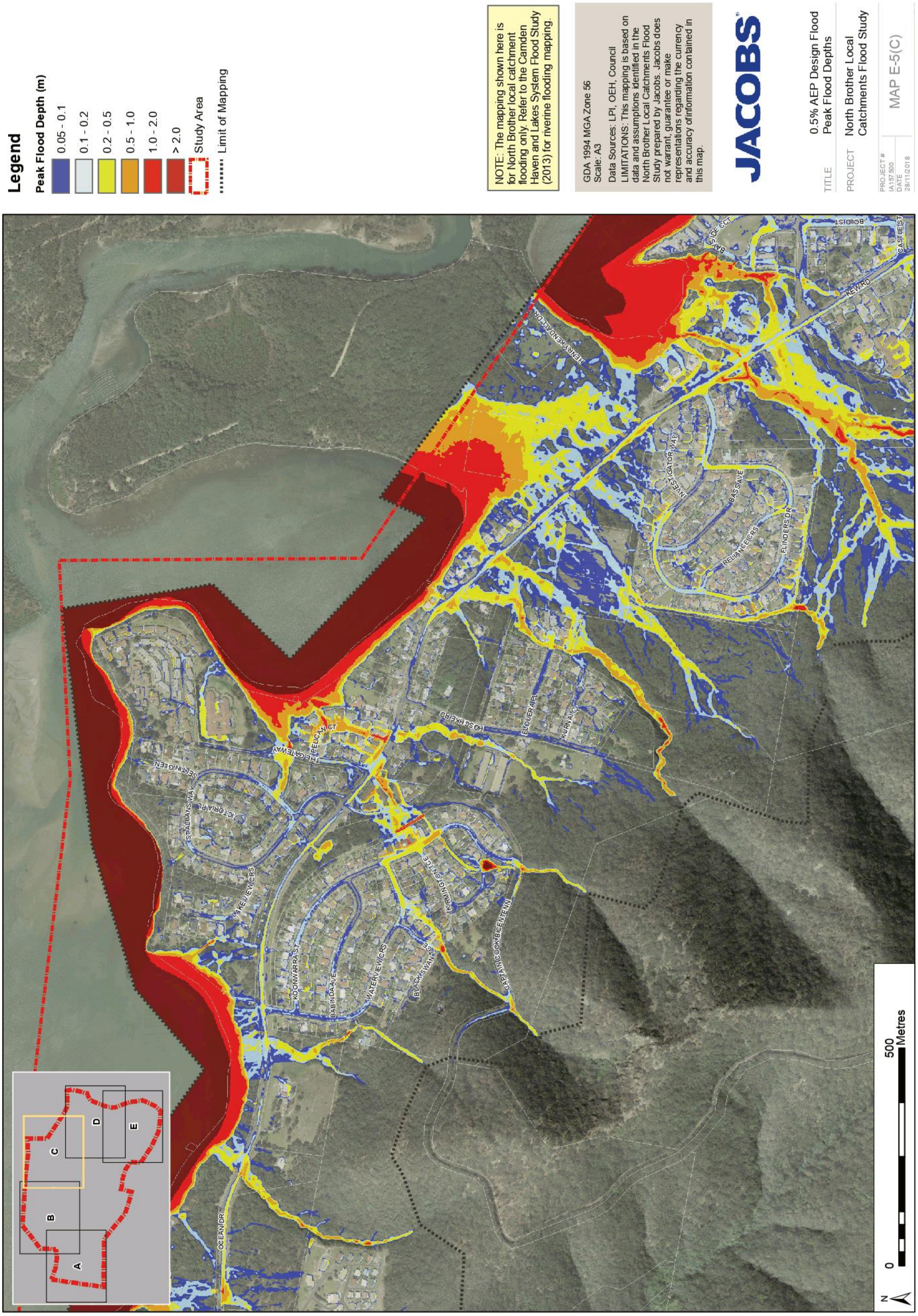

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 1% AEP Design Flood Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-4(D)
0
500
Metres
SHORT ST
ARNOTT ST
GEORGE ST
LAKE ST
CASTLE ST
HAVEN CCT
MCLENNAN ST
DE FRAINE LN
LAKE ST
MCDONALD LN
OCEAN DR
BAYSIDE CCT
KEW RD
TUNIS ST
SEYMOUR ST
BOLD ST
BONSER LN
LAURIE ST
LORD ST
NORMAN LN
NORMAN ST
QUARRY WAY
PEACH GR
MILL ST
HANLEY ST
RED ST
FLINDERS DR
BASS AVE
A
B
C
D
E

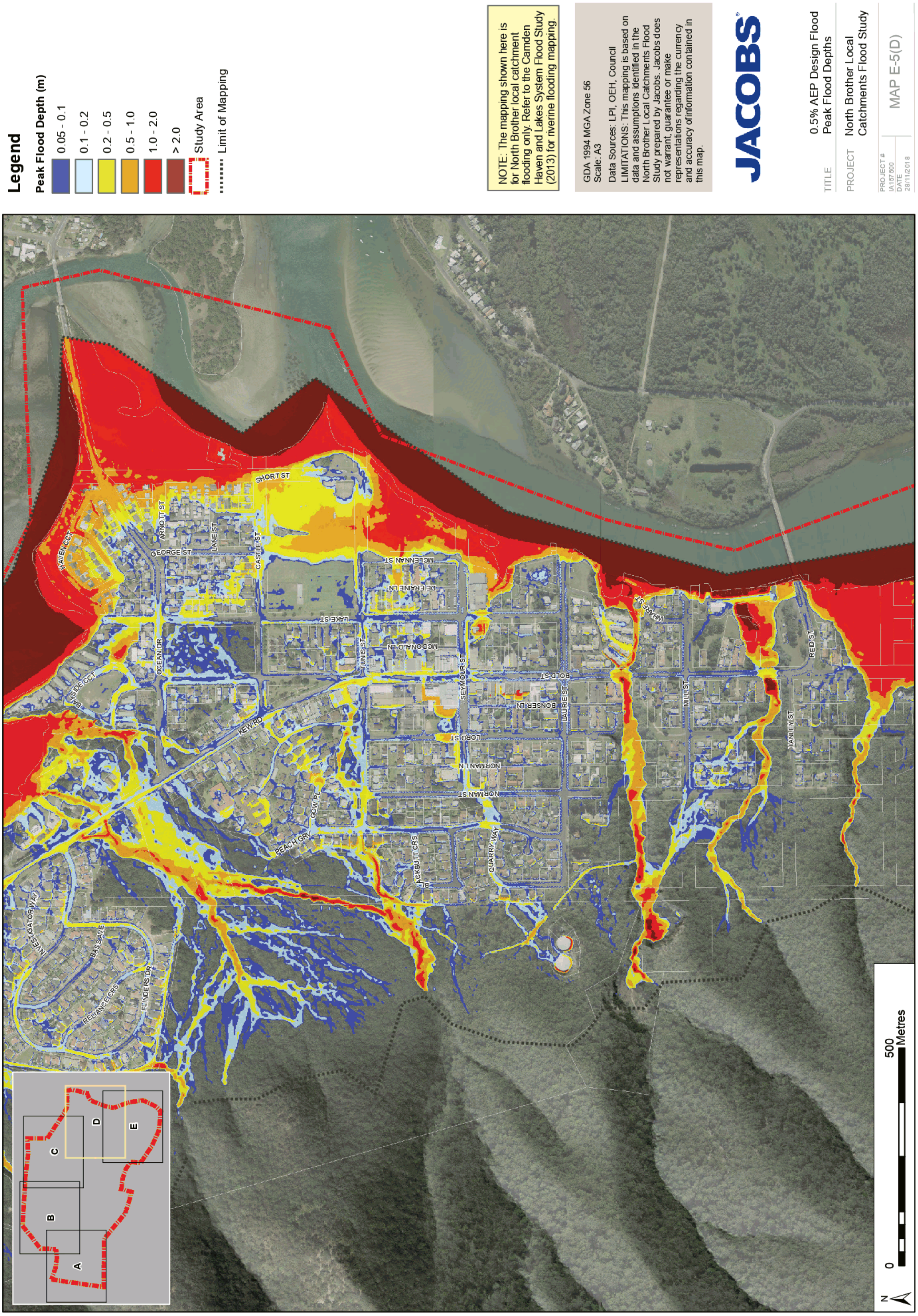

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE 1% AEP Design Flood Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-4(E)
BOLD ST
MILL ST
HANLEY ST
NORMAN ST
REID ST
LORD ST
A
B
C
D
E
0
500 Metres
N

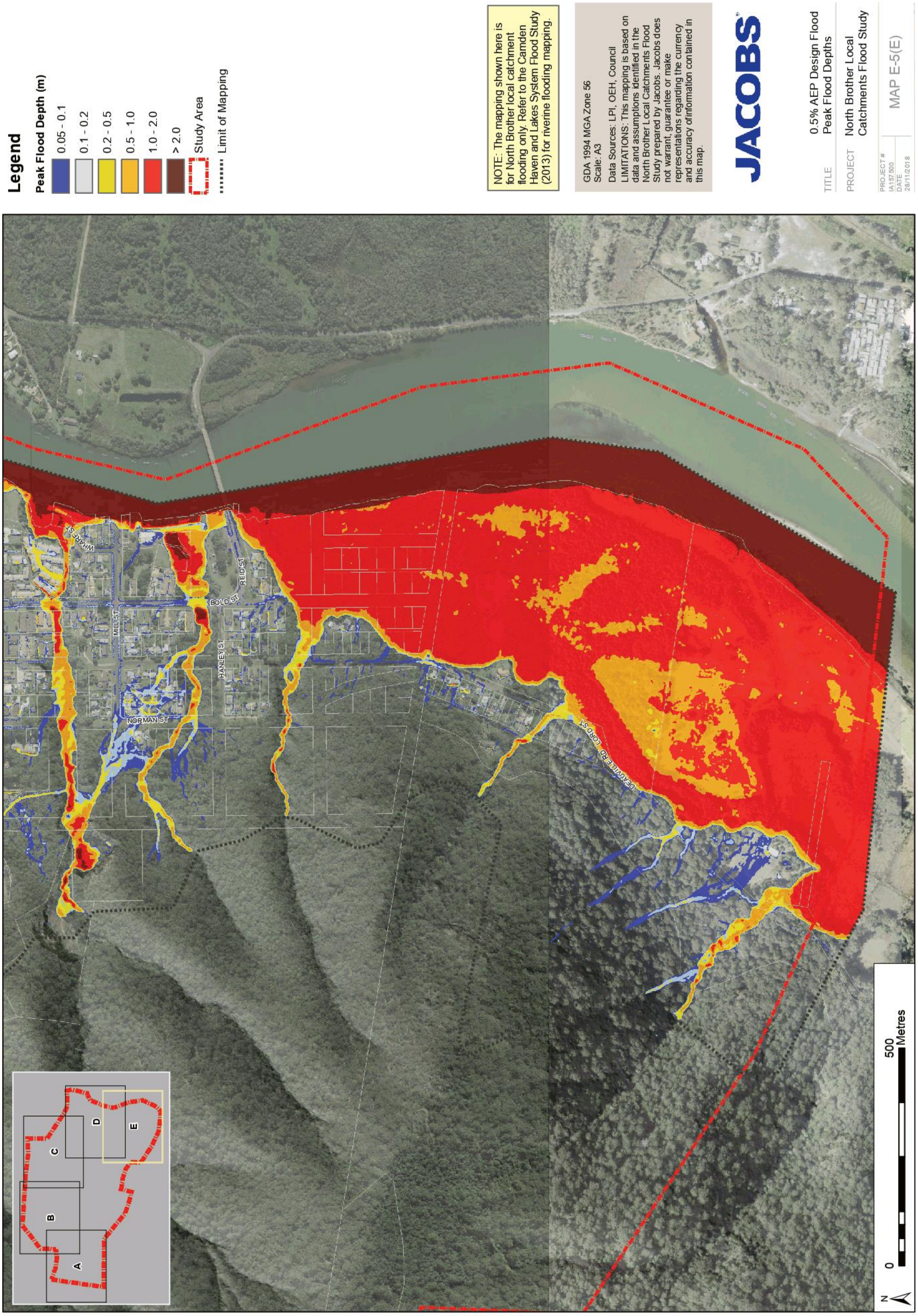


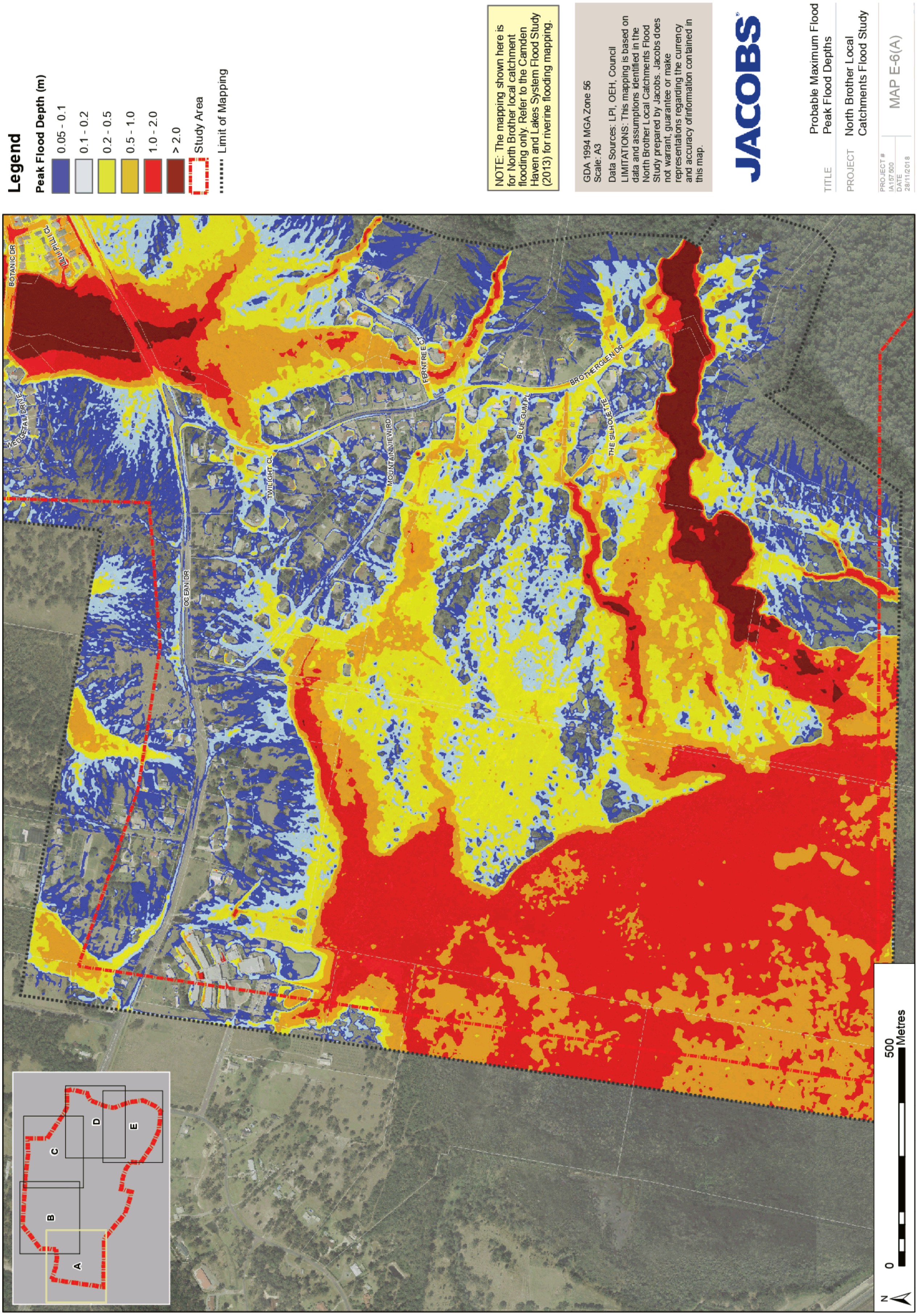
Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE
0.5% AEP Design Flood Peak Flood Depths
PROJECT
North Brother Local Catchments Flood Study
MAP E-5(A)
BOTANIC DR
OCEAN DR
TWILIGHT CL
MOUNTAIN VIEW RD
FERNTREE CT
BROTHERGLEN DR
BLUE GUM PL
THE SILHOUETTE
A
B
C
D
E
0
500
Metres
N

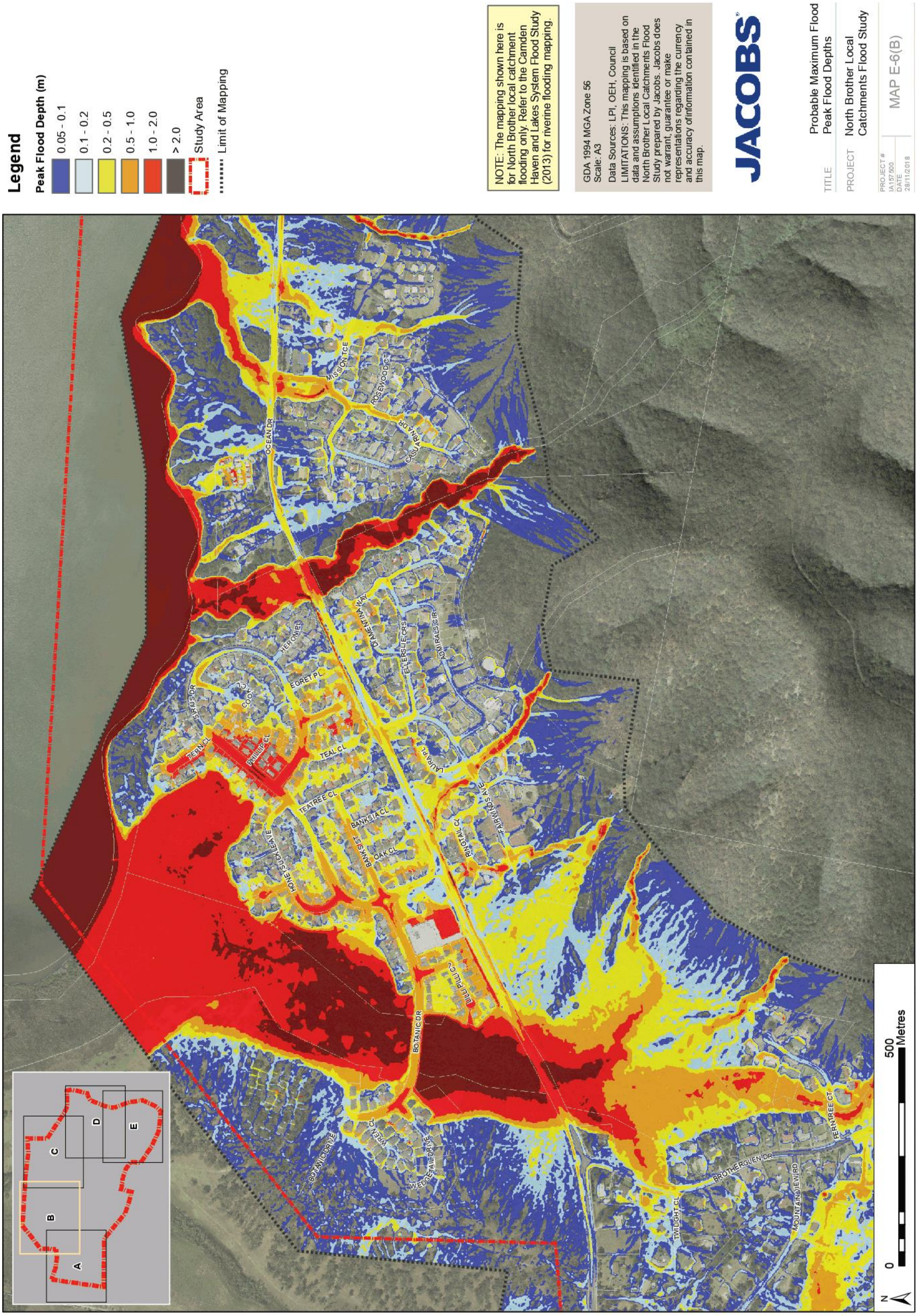

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 0.5% AEP Design Flood Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-5(B)
0
500 Metres
N

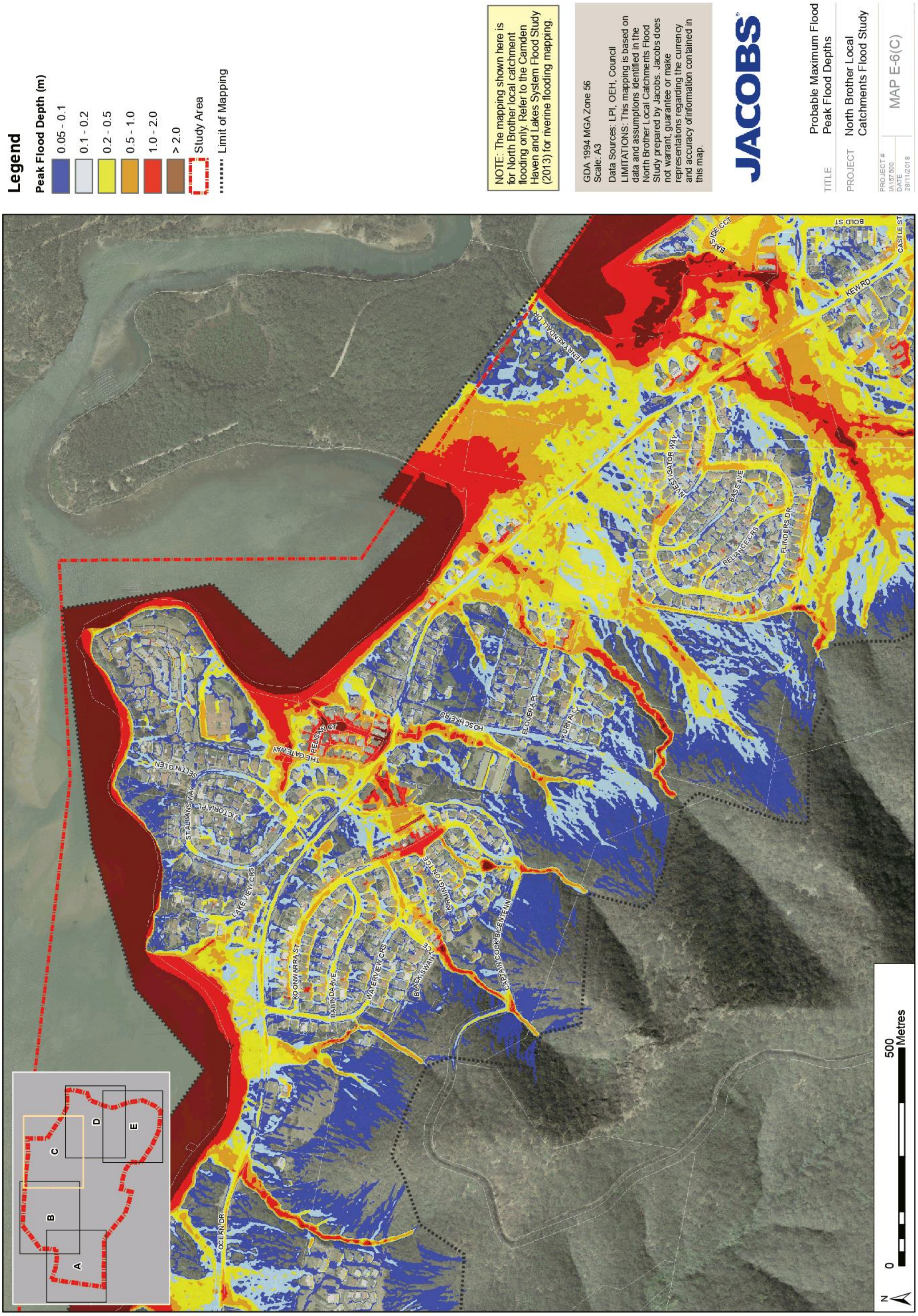

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 0.5% AEP Design Flood Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-5(C)
0
500 Metres
N

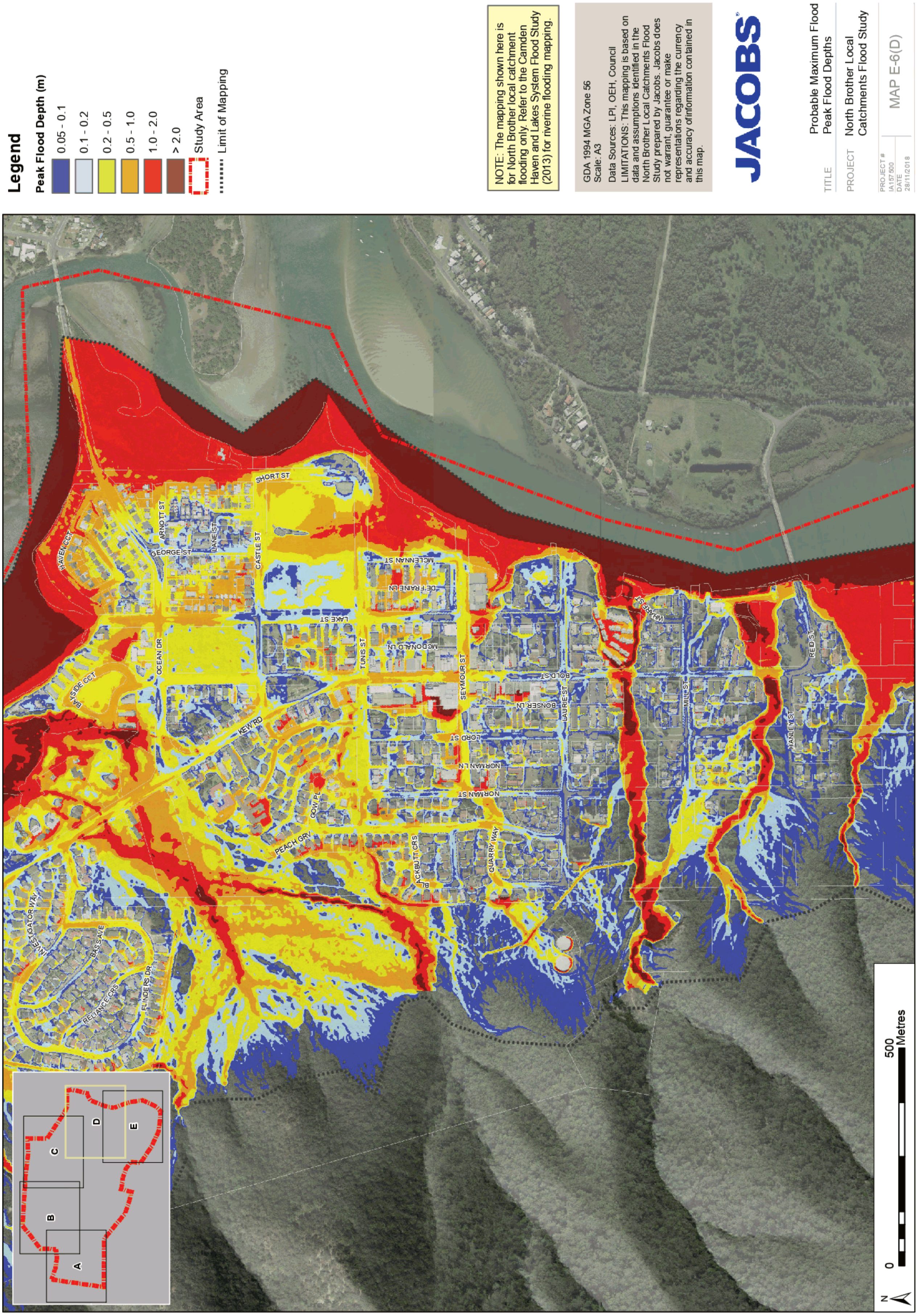

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
TITLE 0.5% AEP Design Flood Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-5(D)
0
500
Metres
N

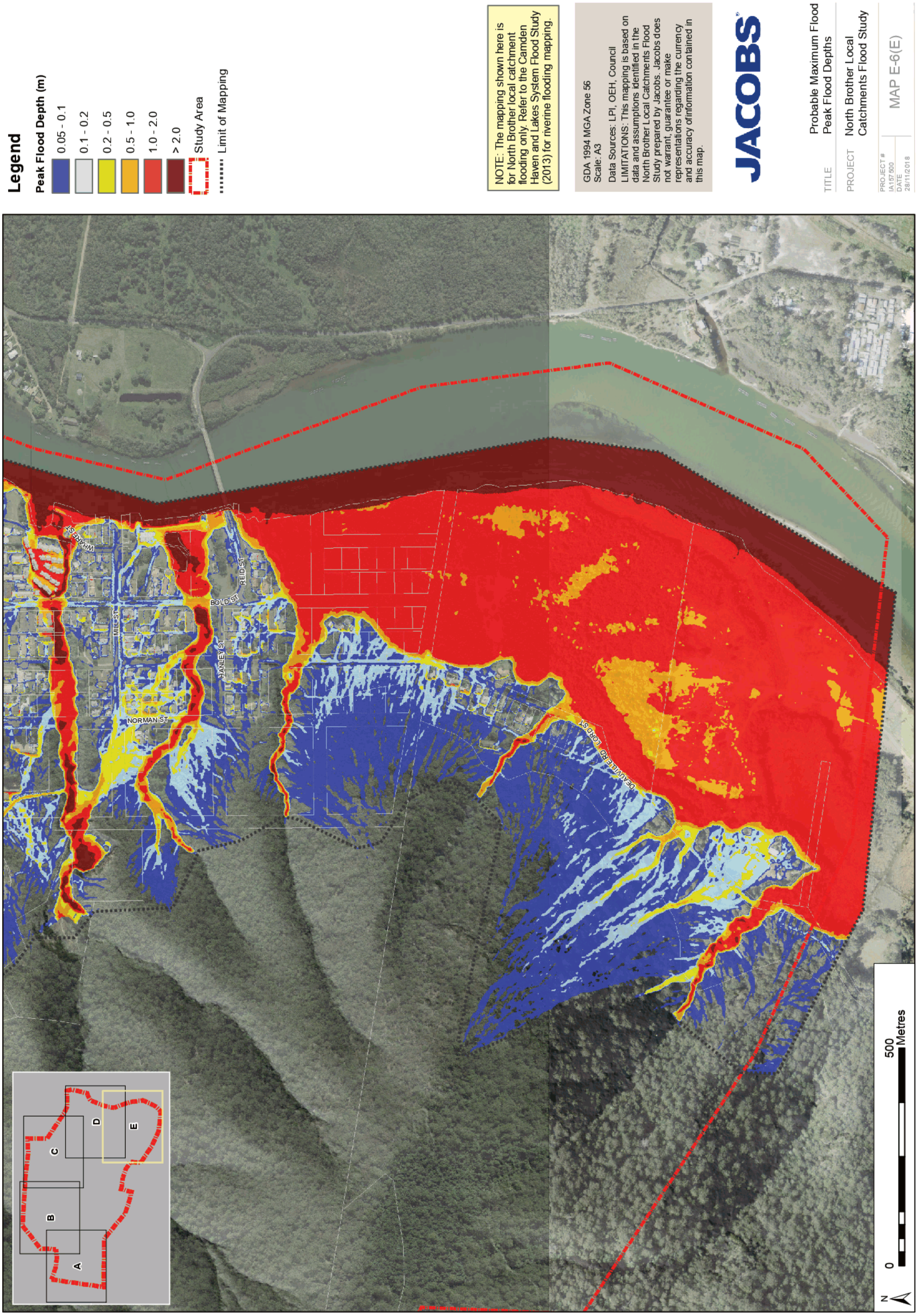

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 0.5% AEP Design Flood Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
PROJECT # IA157500
DATE 28/11/2018
MAP E-5(E)
BOLD ST
REID ST
MILL ST
HANLEY ST
NORMAN ST
A
B
C
D
E
0
500 Metres
N

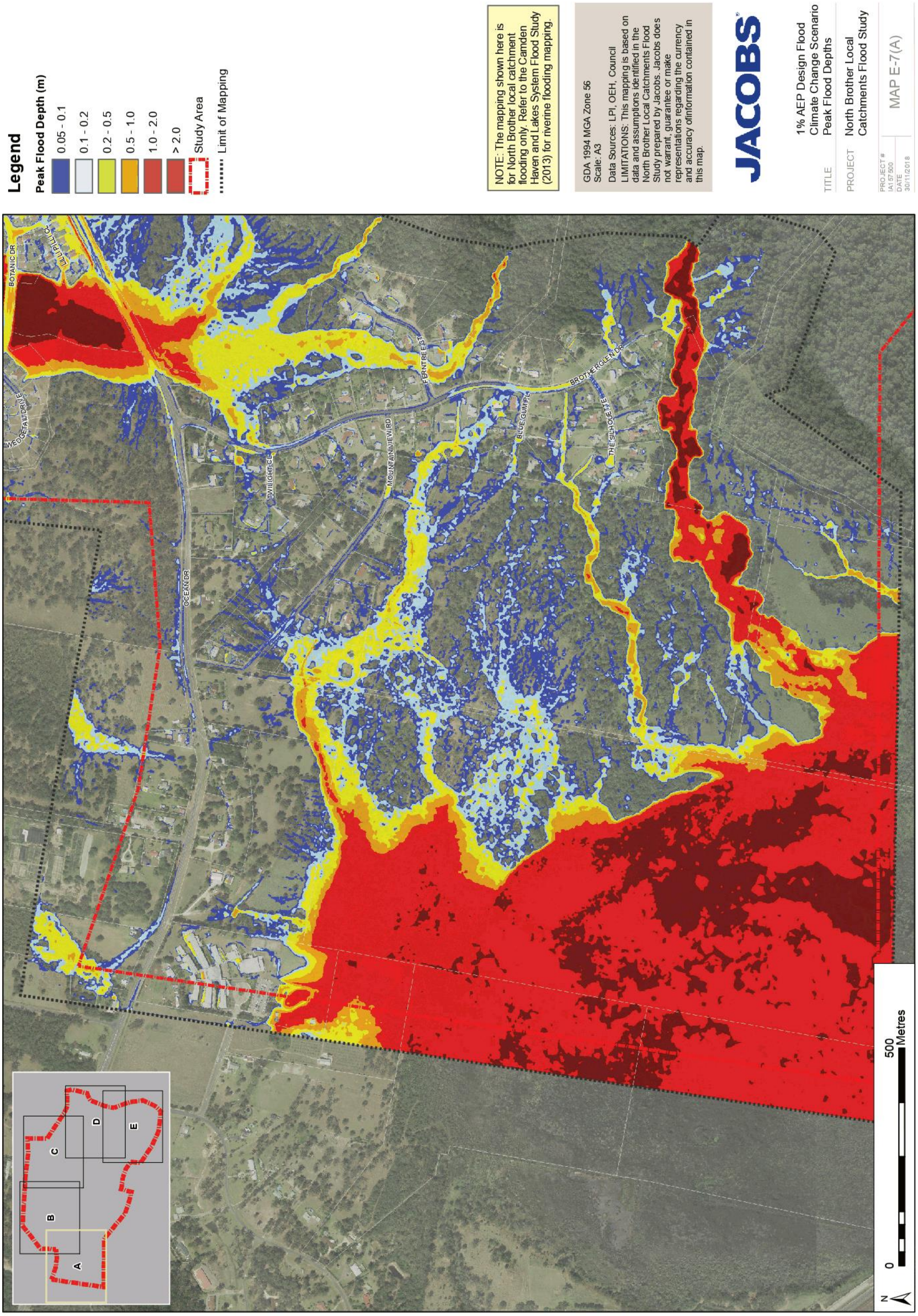

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE Probable Maximum Flood Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-6(A)
BOTANIC DR
OCEAN DR
TWILIGHT CL
MOUNTAIN VIEW RD
FERNTREE CT
BROTHERGLEN DR
THE SILHOUETTE
A
B
C
D
E
0
500
Metres
N

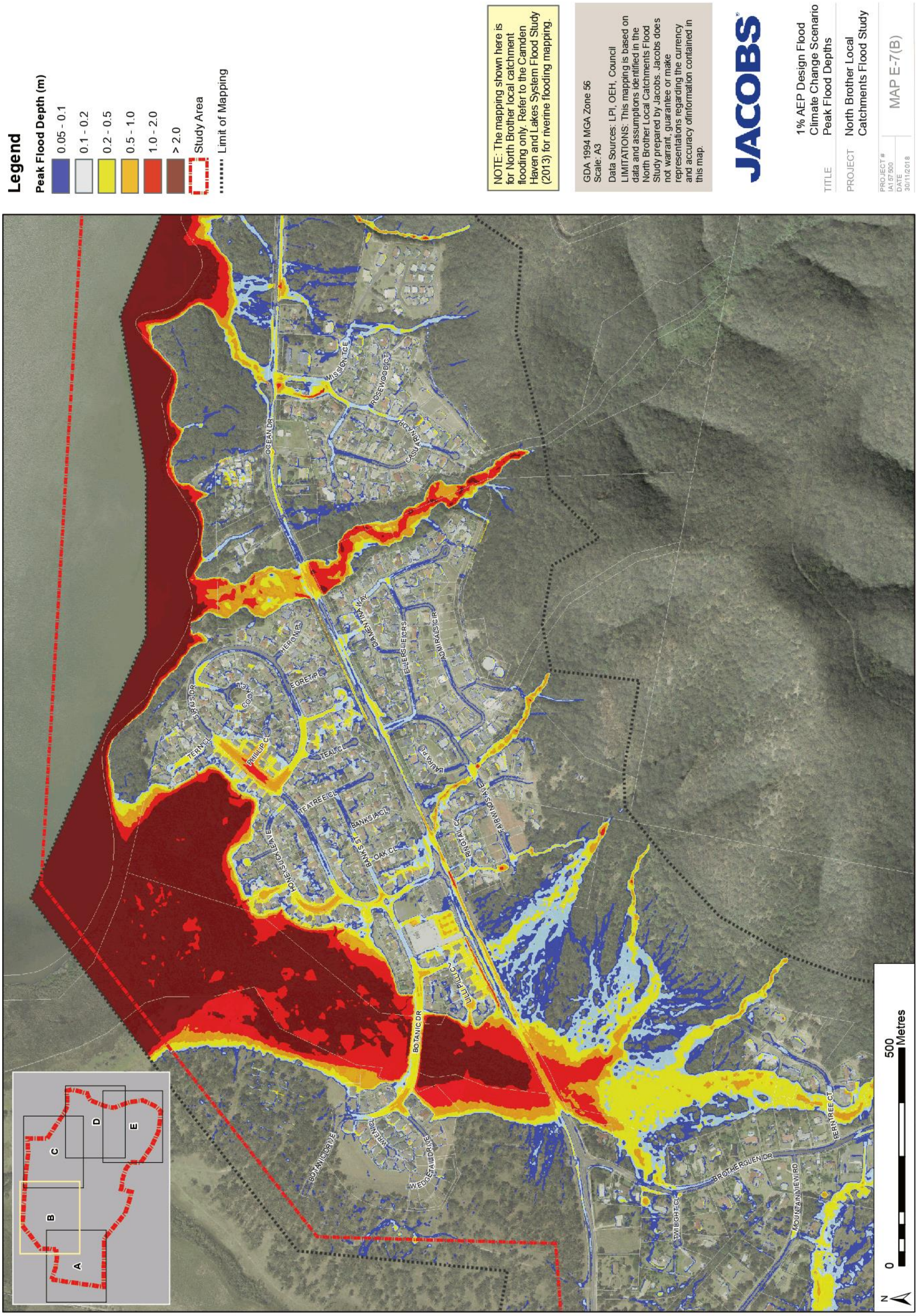

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE Probable Maximum Flood Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-6(B)
0
500
Metres
N
A
B
C
D
E

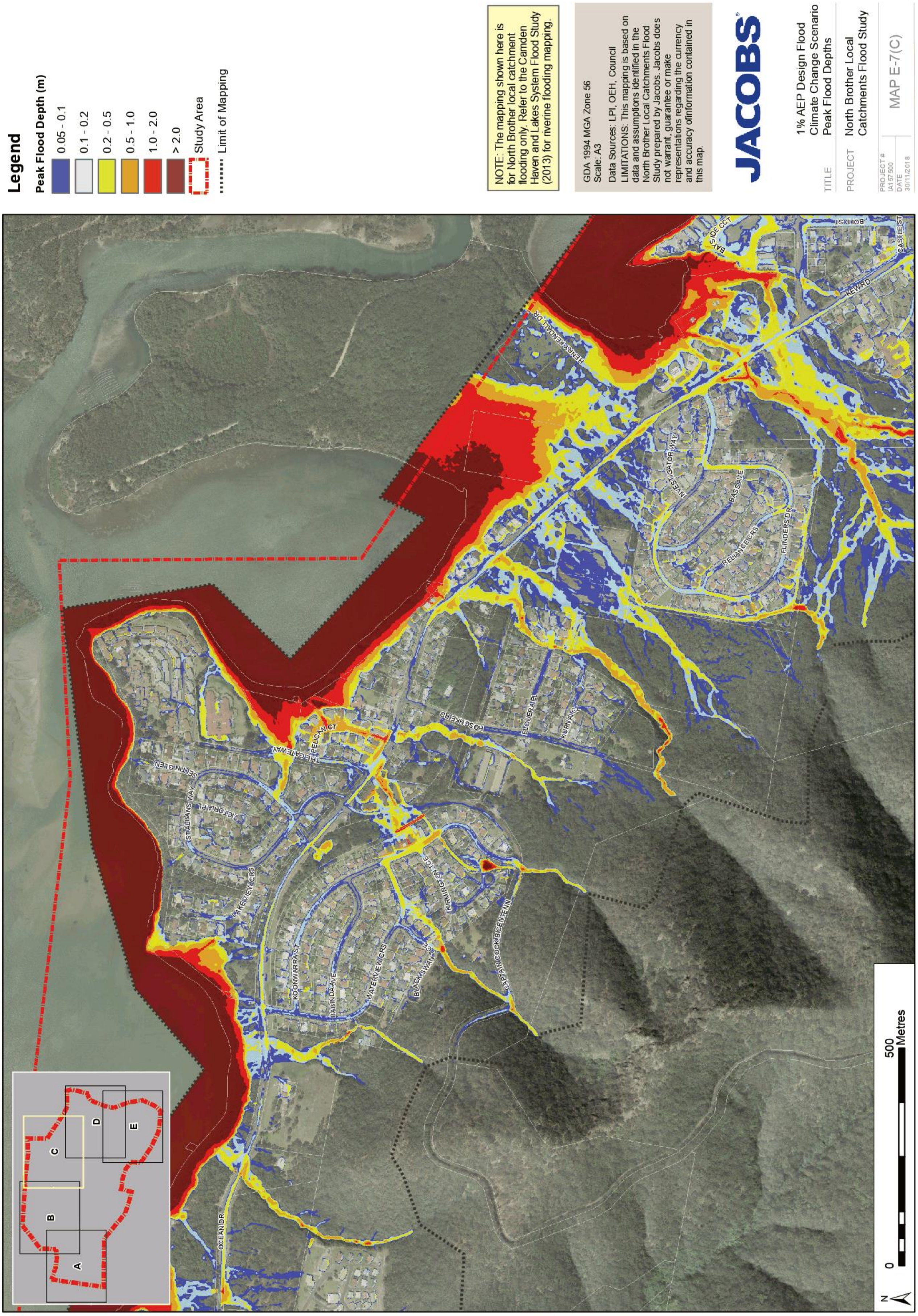

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE Probable Maximum Flood Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-6(C)
0
500
Metres
N

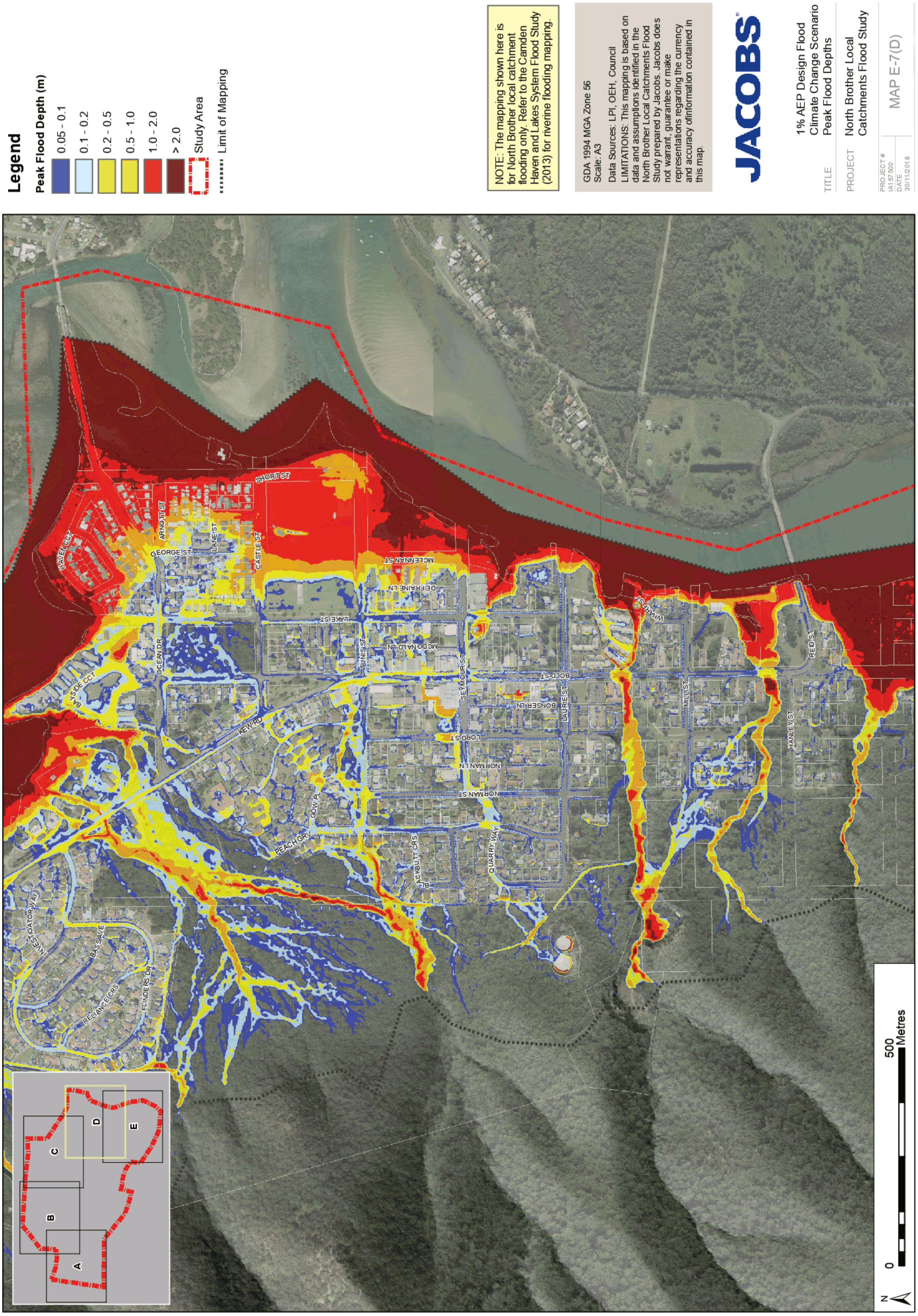

Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE Probable Maximum Flood Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-6(D)
SHORT ST
GEORGE ST
ARNOTT ST
CASTLE ST
MCLENNAN ST
DE FRAINE LN
LAKE ST
MCDONALD LN
OCEAN DR
TUNIS ST
SEYMOUR ST
BOLD ST
BONSER LN
LAURIE ST
LORD ST
NORMAN LN
NORMAN ST
KEW RD
BAYSIDE CCT
HAVEN CCT
WHARF ST
MILL ST
HARLEY ST
REID ST
PEACH GRV
QUARRY WAY
BASS AVE
FLINDERS DR
A
B
C
D
E
0
500
Metres
N


Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE Probable Maximum Flood Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-6(E)
MILL ST
HANLEY ST
BOLD ST
REID ST
NORMAN ST
A
B
C
D
E
0
500
Metres
N


Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE 1% AEP Design Flood Climate Change Scenario Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
PROJECT # IA157500
DATE 30/11/2018
MAP E-7(A)
0
500 Metres
N
A
B
C
D
E


Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE 1% AEP Design Flood Climate Change Scenario Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-7(B)
0
500
Metres
N
A
B
C
D
E
OCEAN DR
BOTANIC DR
BROTHERGLEN DR


Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 1% AEP Design Flood Climate Change Scenario Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-7(C)
0
500 Metres
N
A
B
C
D
E


Legend
Peak Flood Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 1% AEP Design Flood Climate Change Scenario Peak Flood Depths
PROJECT North Brother Local Catchments Flood Study
MAP E-7(D)
SHORT ST
ARNOTT ST
GEORGE ST
LAKE ST
CASTLE ST
MCLENNAN ST
DEFRAINE LN
MCDONALD LN
TUNIS ST
SEYMOUR ST
BOLD ST
BONSER LN
LAURIE ST
LORD ST
NORMAN LN
NORMAN ST
QUARRY WAY
MILL ST
WHARF ST
RED ST
HANLEY ST
HAVEN CCT
OCEAN DR
BAYSIDE CCT
KEW RD
PEACH GRV
BASS AVE
FLINDERS DR
RELIANCE CRS
A
B
C
D
E
0
500
Metres
N

Legend

Peak Flood Depth (m)

- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0
- Study Area
- Limit of Mapping

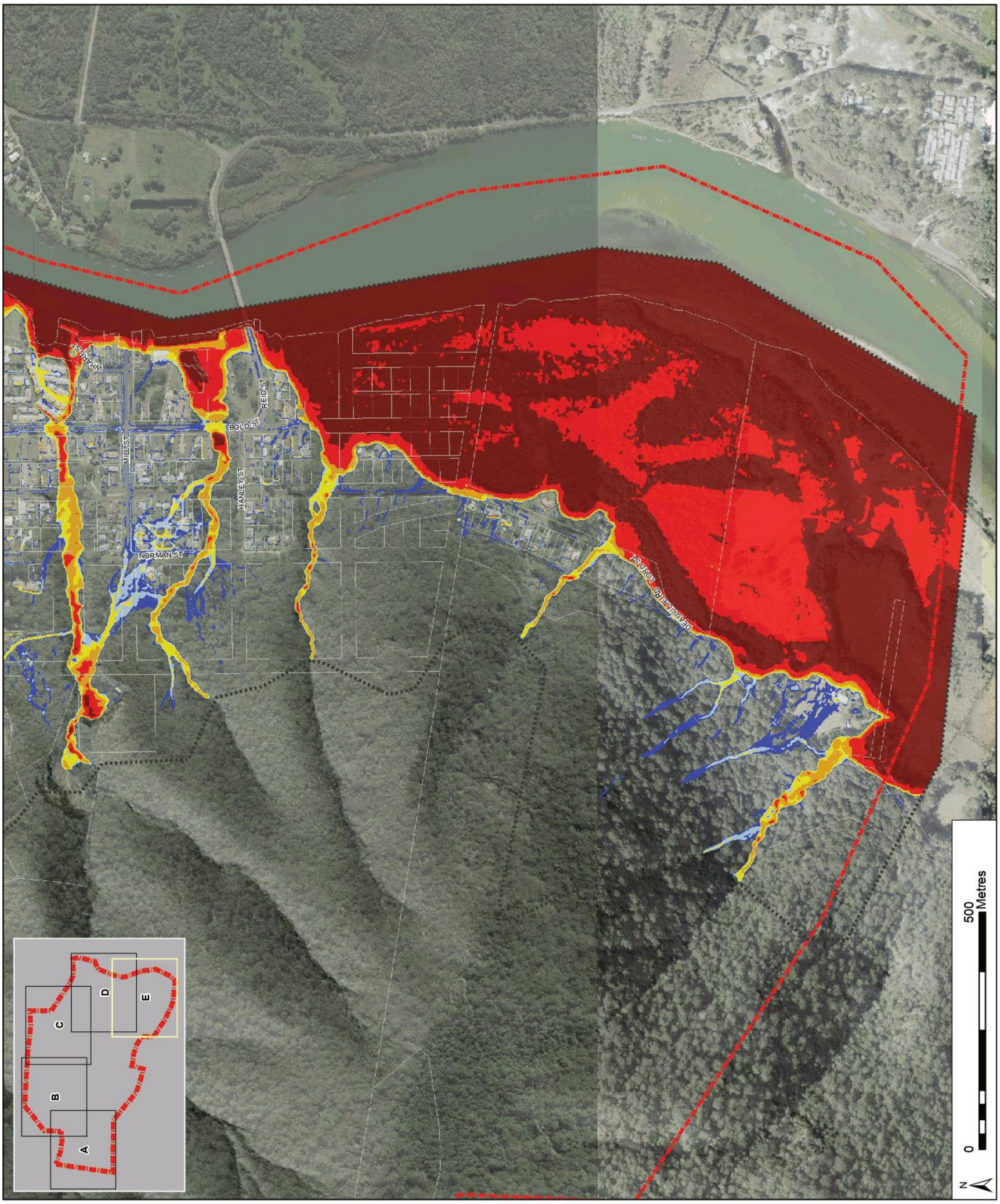
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.

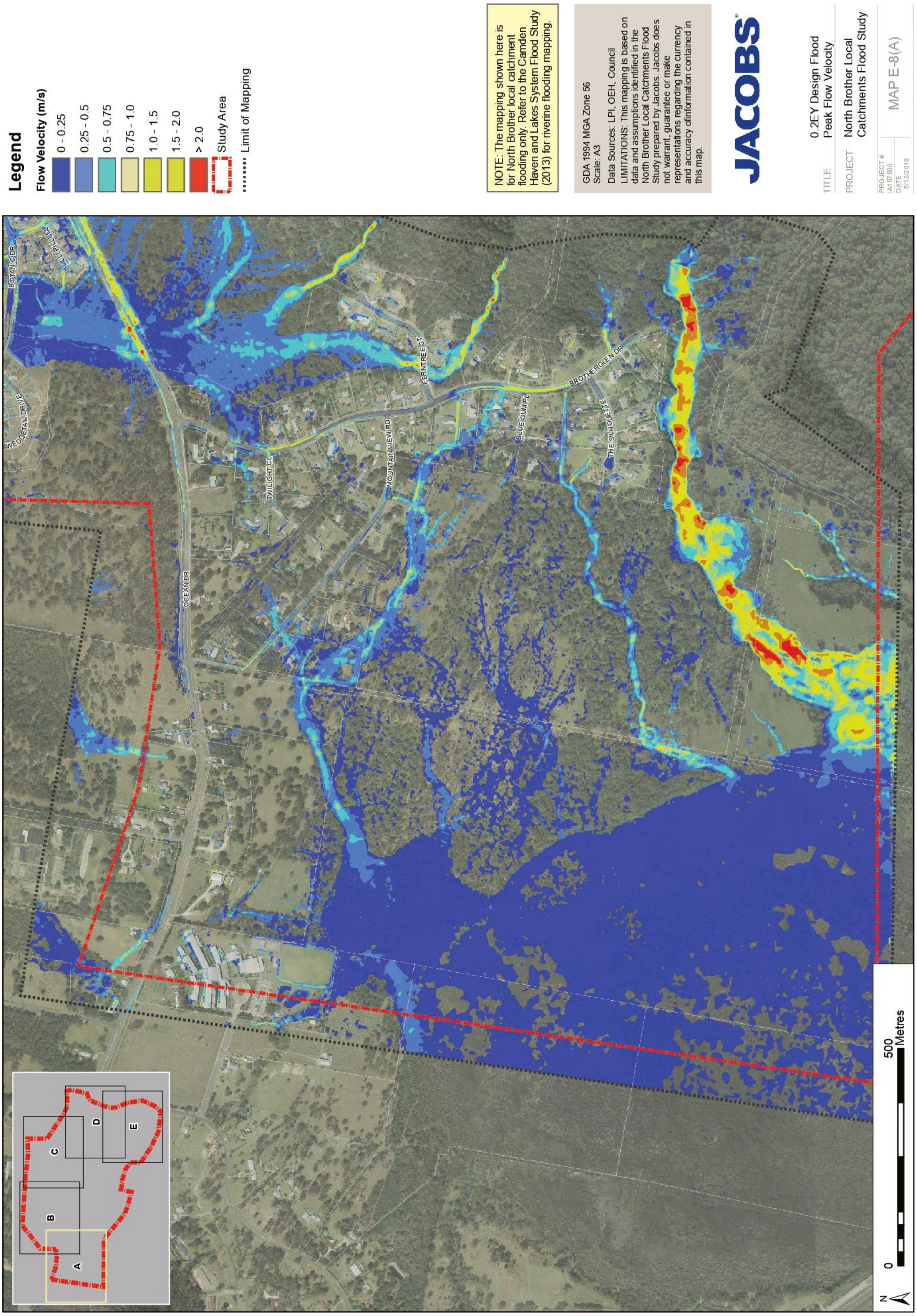
GDA 1994 MGA Zone 56
Scale: A3

Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.

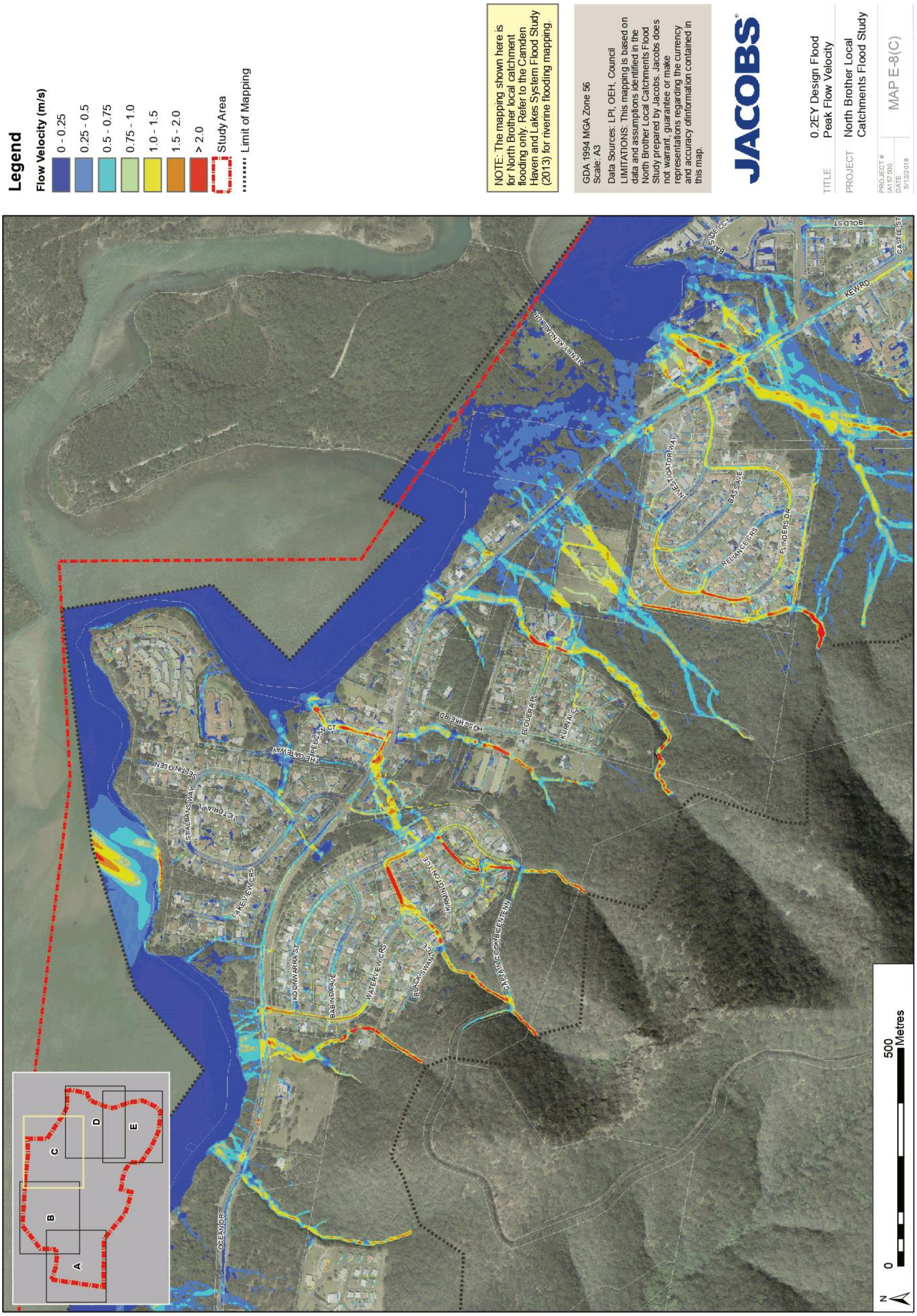
JACOBS

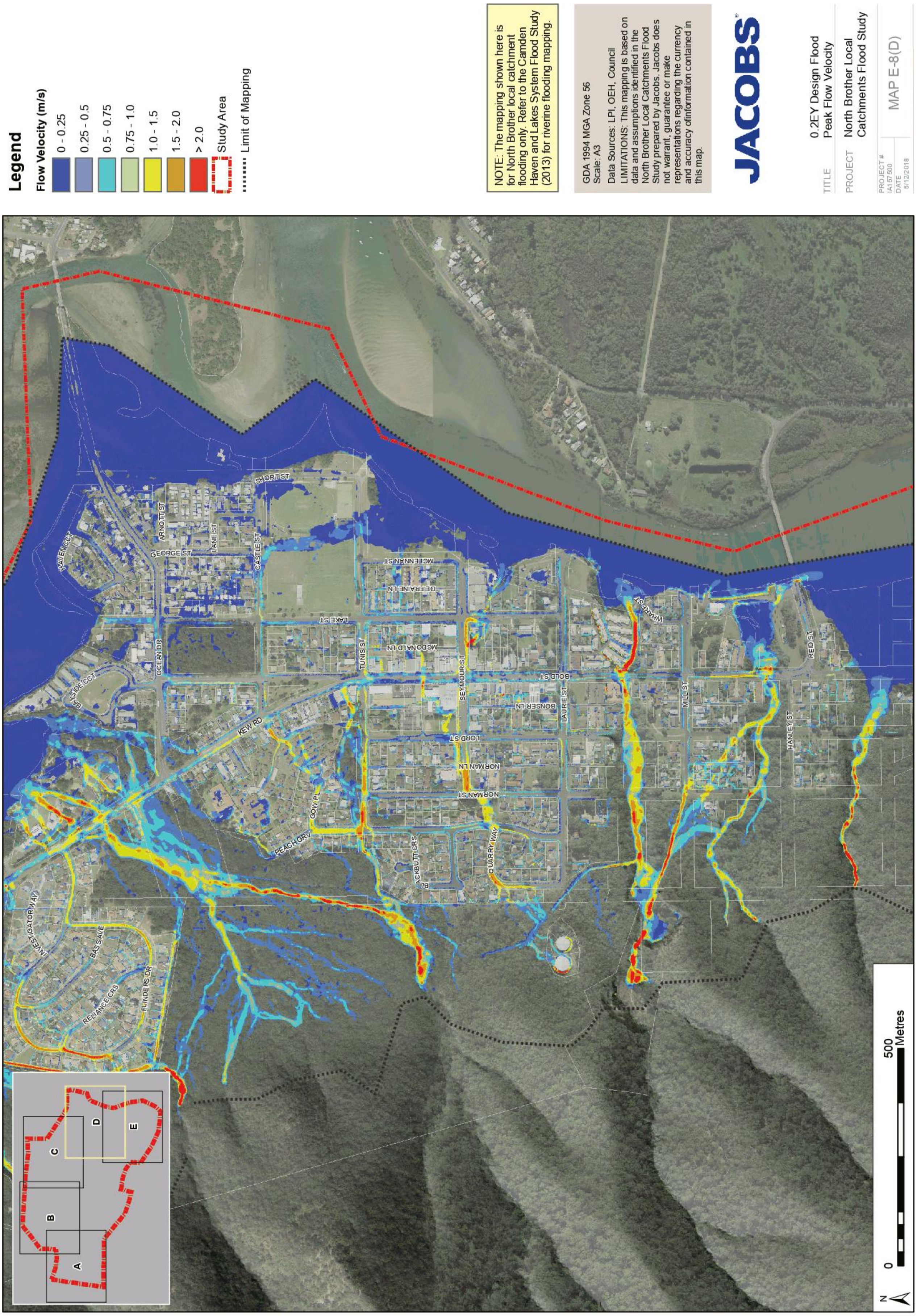
TITLE	1% AEP Design Flood Climate Change Scenario Peak Flood Depths
PROJECT	North Brother Local Catchments Flood Study
PROJECT # IA157500 DATE 30/11/2018	MAP E-7(E)

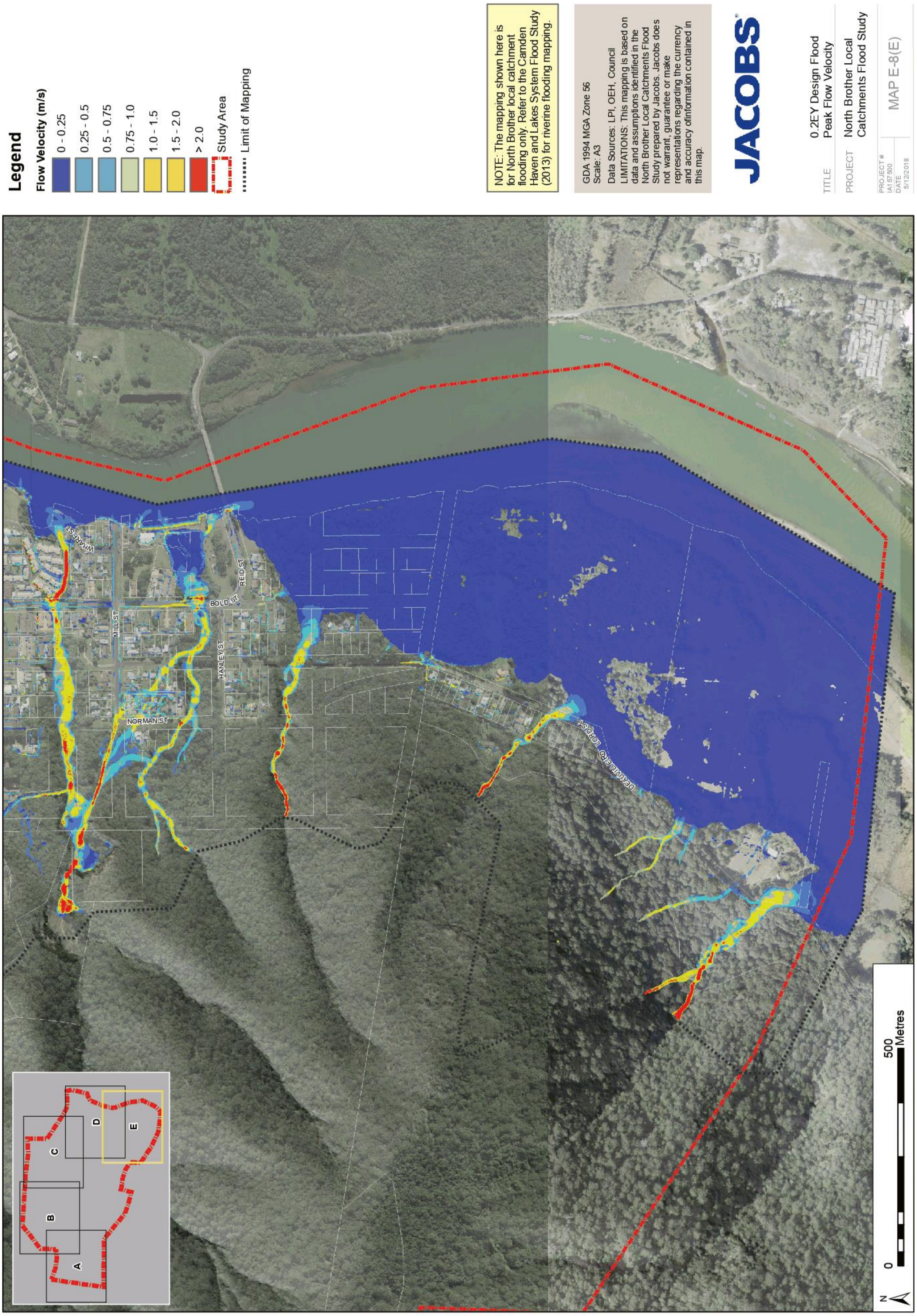


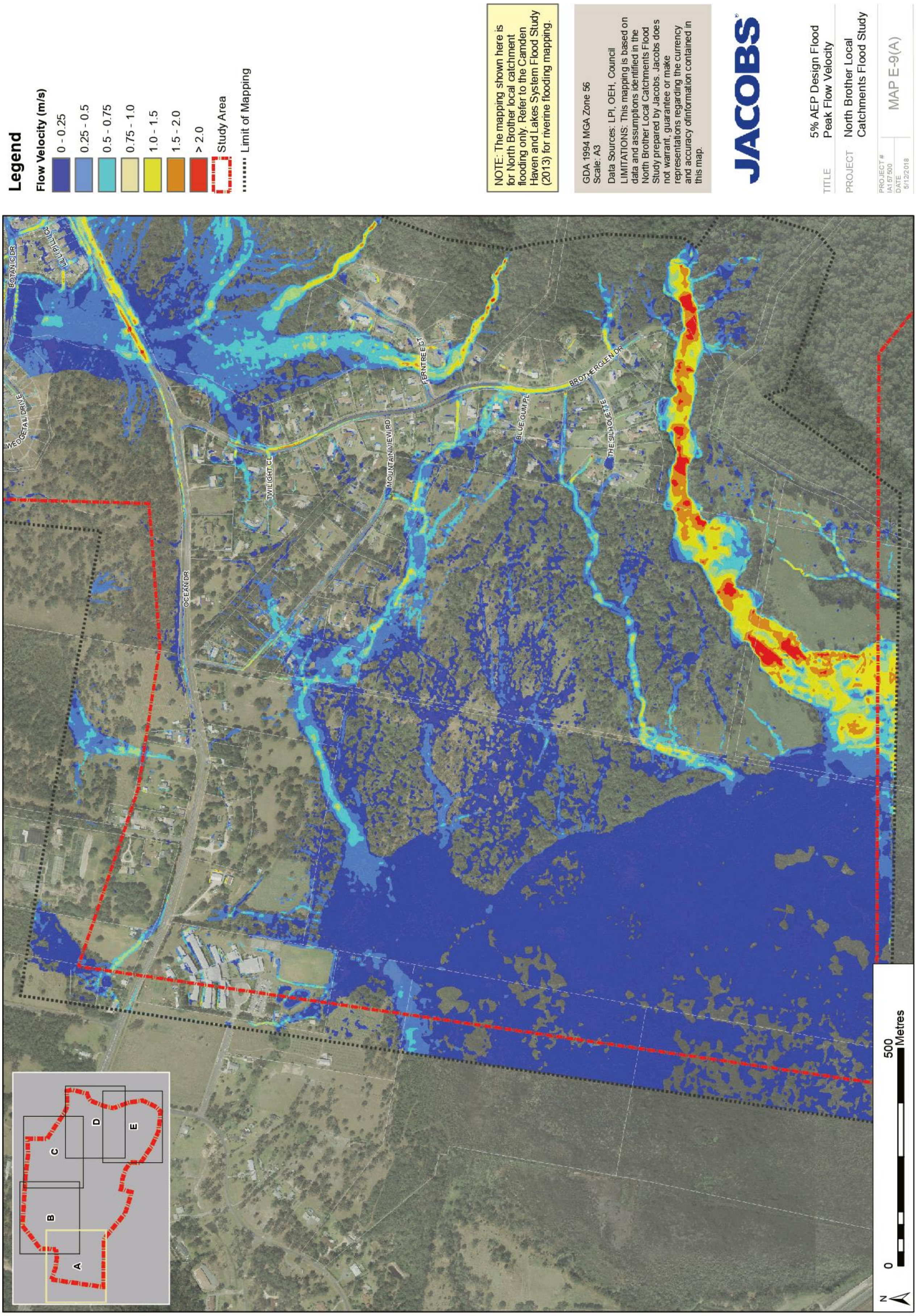

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE 0.2EY Design Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-8(A)
OCEAN DR
BROTHERGLEN DR
FERNTREE CT
MOUNTAIN VIEW RD
TWILIGHT CL
BLUE GUM PL
THE SILHOUETTE
BOTANIC DR
0
500 Metres
N
A
B
C
D
E


Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
TITLE 0.2EY Design Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-8(B)
0
500 Metres

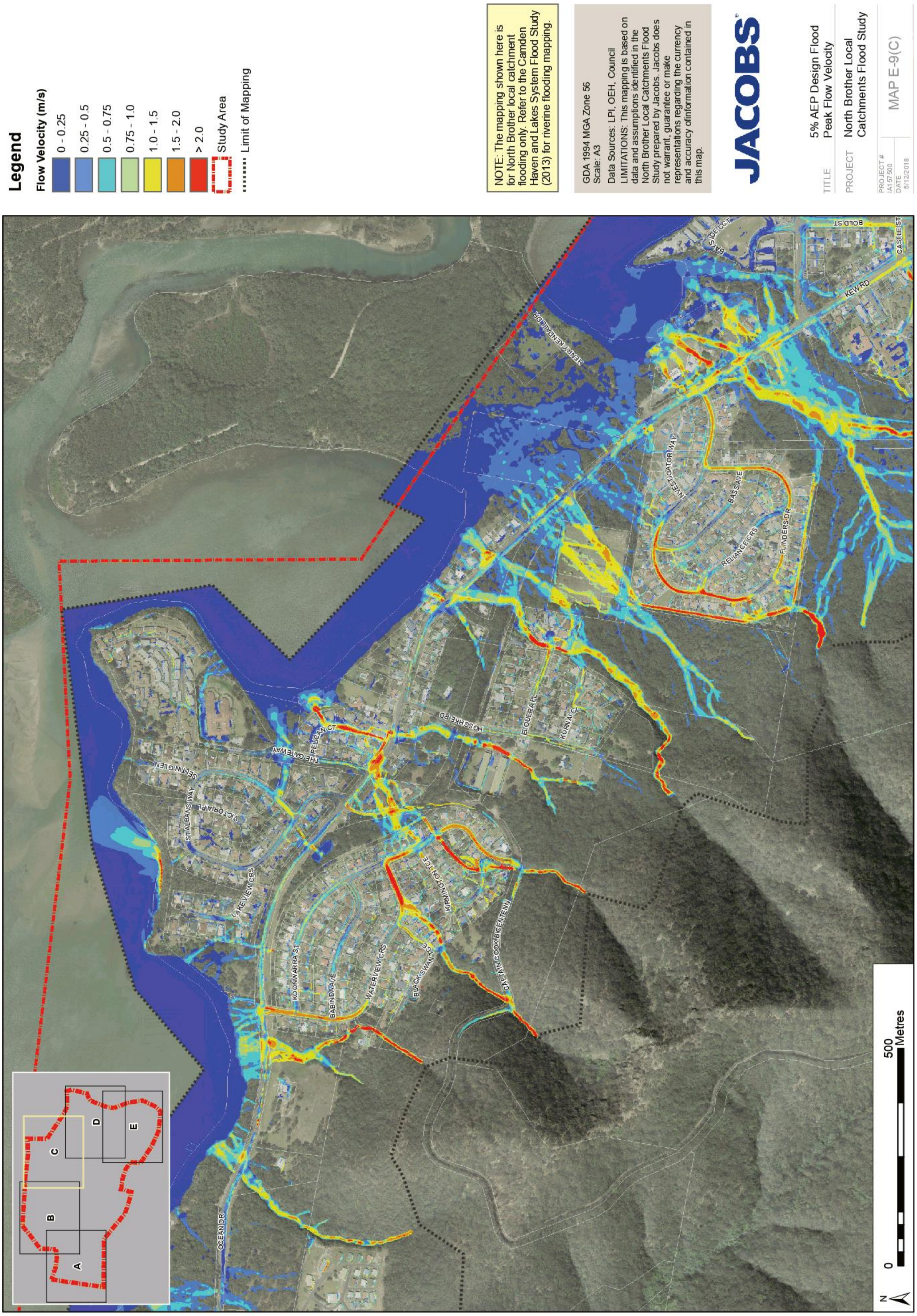

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 0.2EY Design Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-8(C)
0
500
Metres
N
A
B
C
D
E

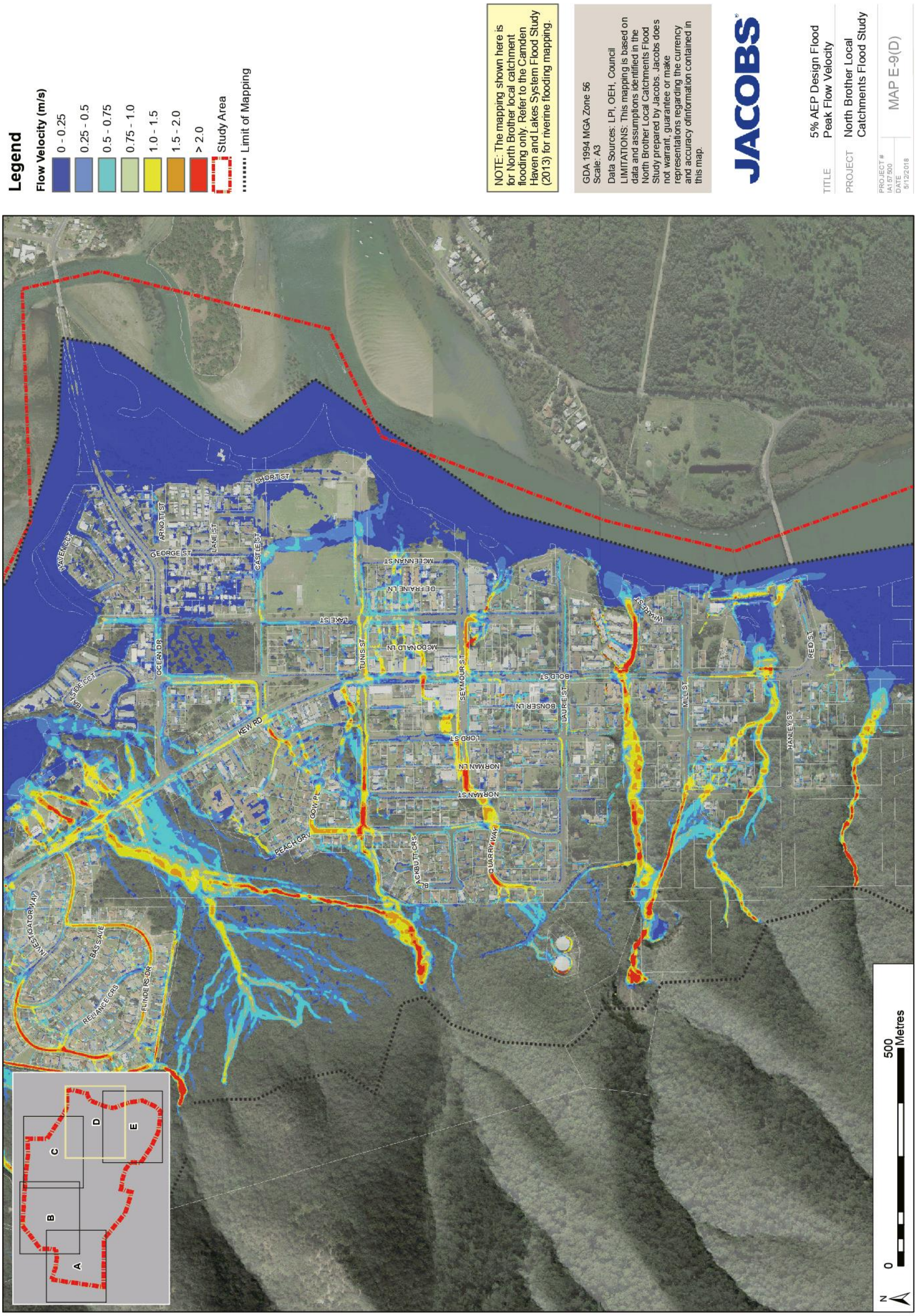

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE 0.2EY Design Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-8(D)
SHORT ST
ARNOTT ST
GEORGE ST
LAKE ST
CASTLE ST
MCLENNAN ST
DE FRAINE LN
MCDONALD LN
TUNIS ST
SEYMOUR ST
BOLD ST
BONSER LN
LAURIE ST
LORD ST
NORMAN LN
NORMAN ST
WHARF ST
MILL ST
RED ST
HANLEY ST
KEW RD
OCEAN DR
BAYSIDE CCT
PEACH GRV
COW PL
QUARRY WAY
INVESTIGATOR WAY
BASS AVE
RELIANCE CRS
FLINDERS DR
A
B
C
D
E
0
500
Metres
N

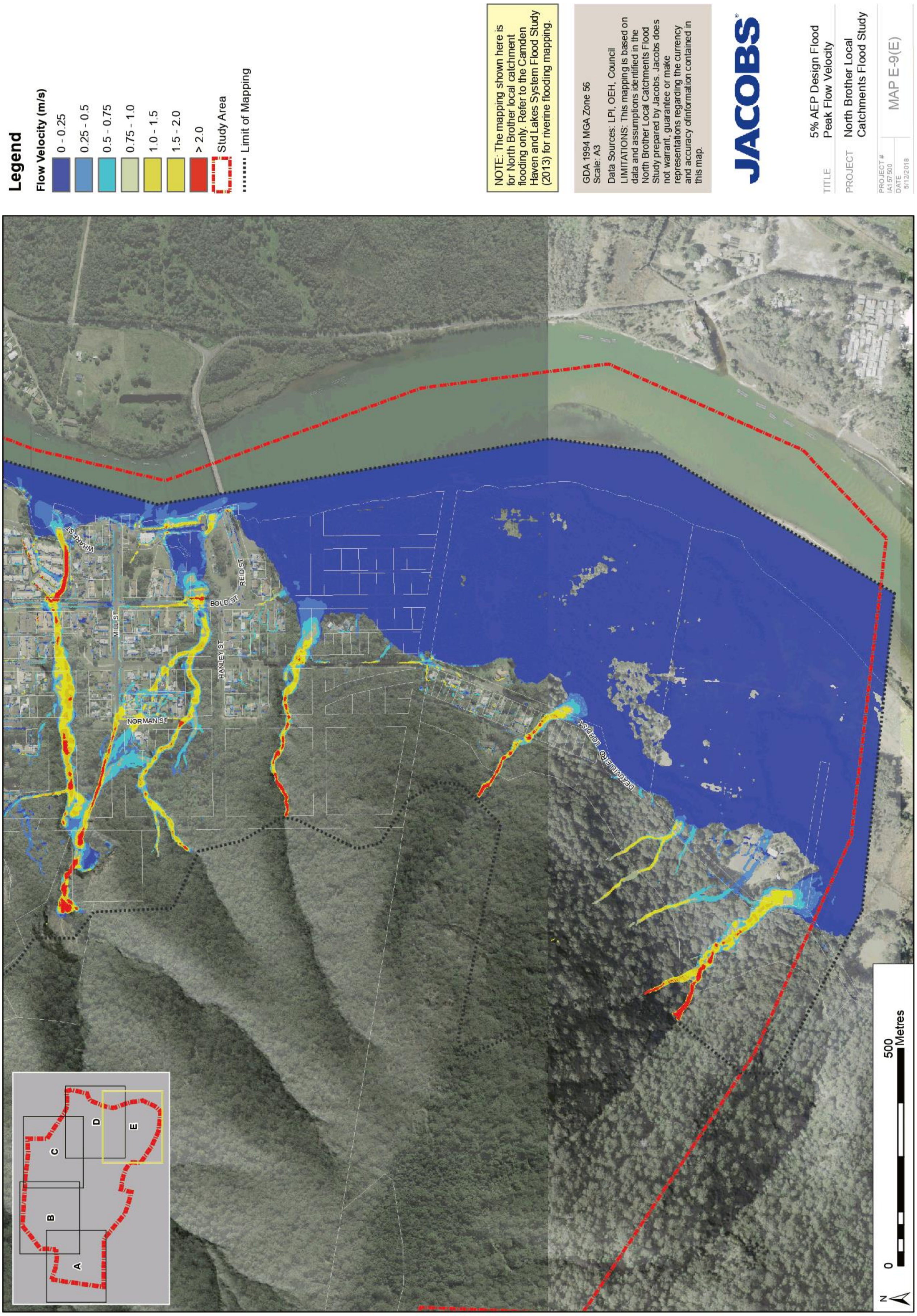

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE 0.2EY Design Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-8(E)
MILL ST
BOLD ST
REID ST
HANLEY ST
NORMAN ST
A
B
C
D
E
0
500
Metres
N

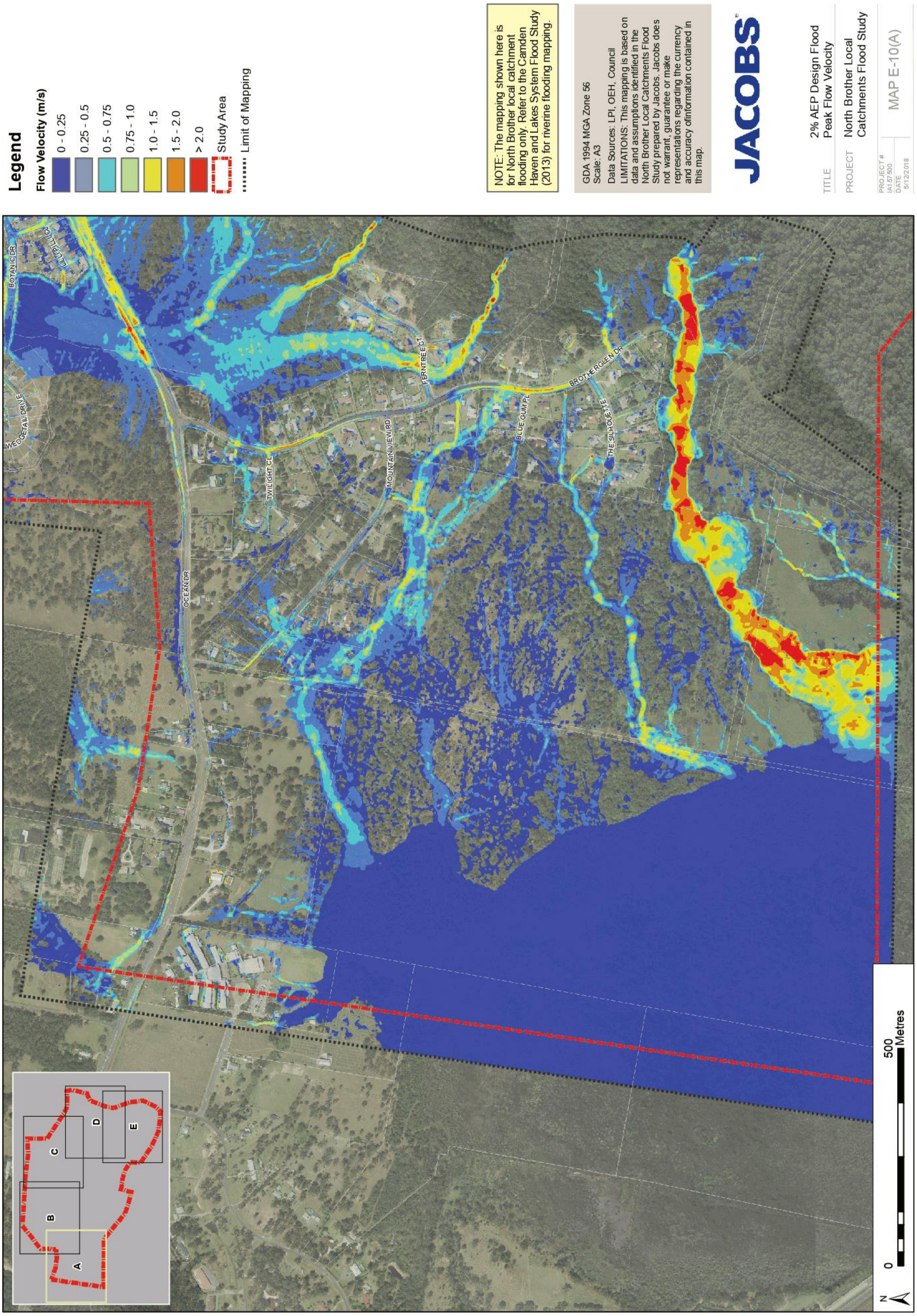

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE 5% AEP Design Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-9(A)
BOTANIC DR
EDGEWATER DRIVE
OCEAN DR
TWILIGHT CL
MOUNTAIN VIEW RD
FERNTREE CT
BROTHERGLEN DR
BLUE GUM PL
THE SILHOUETTE
A
B
C
D
E
0
500
Metres
N

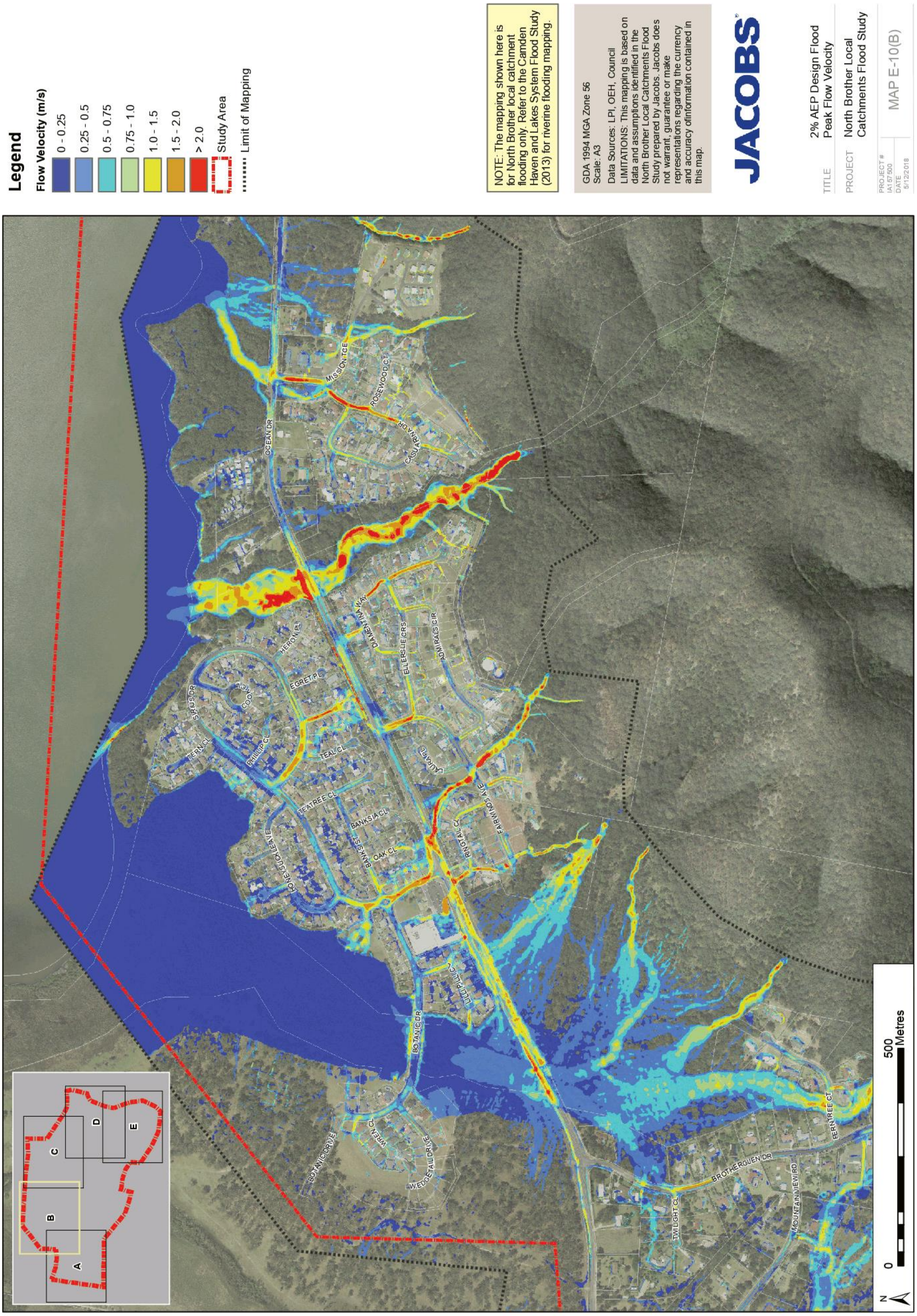

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 5% AEP Design Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-9(B)
0
500 Metres
N

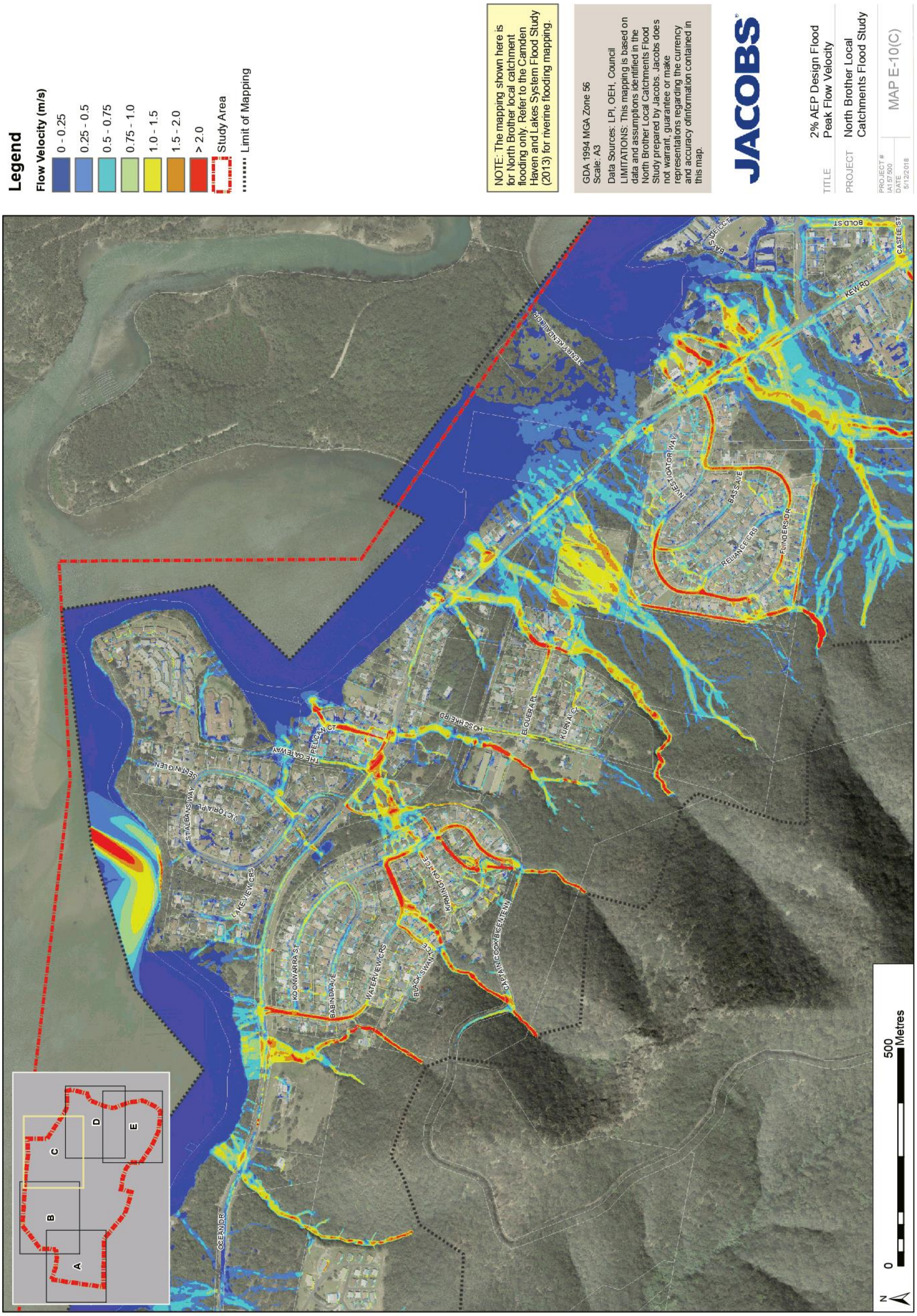

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
TITLE 5% AEP Design Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-9(C)
0
500 Metres
N
A
B
C
D
E

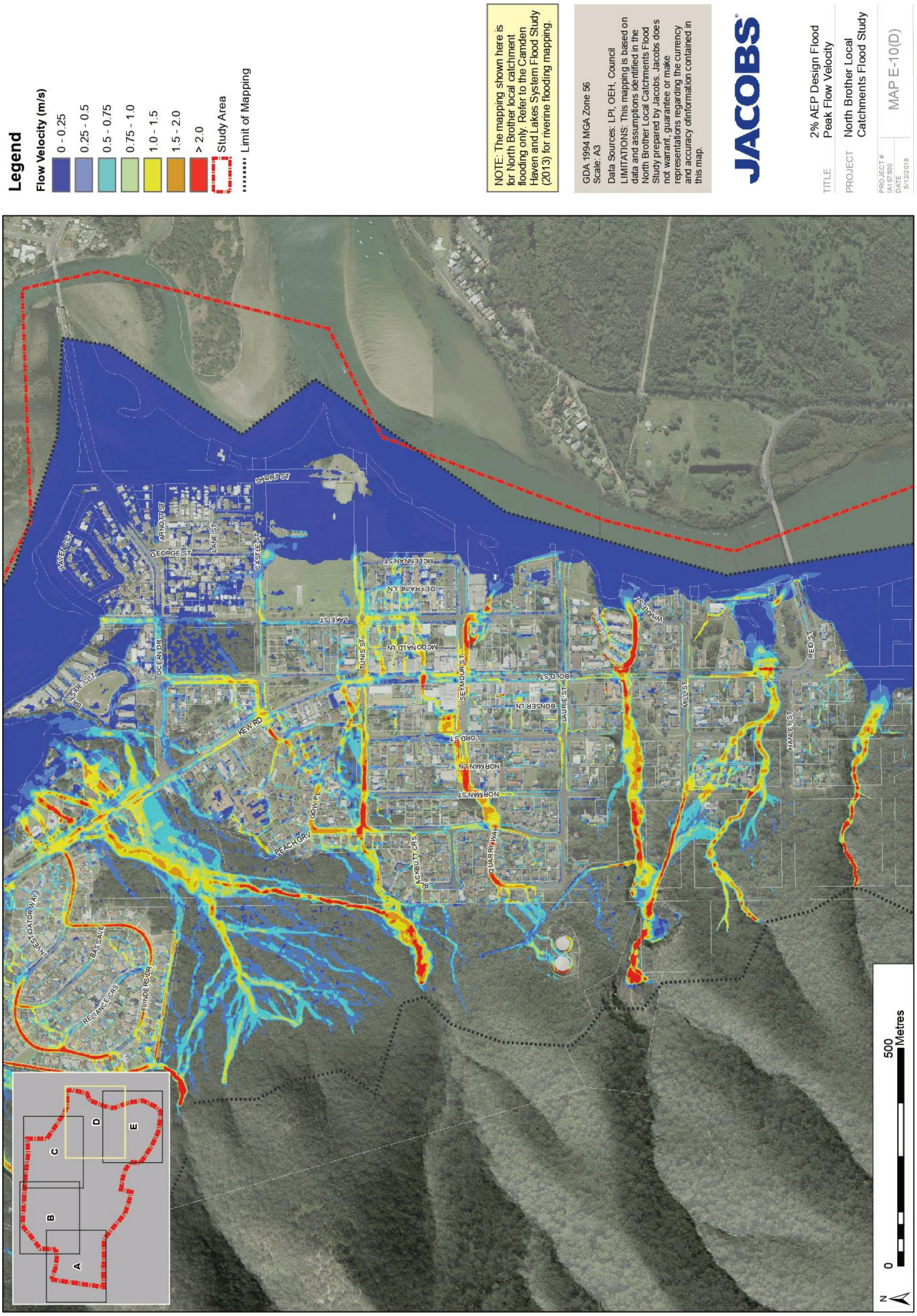

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
TITLE 5% AEP Design Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-9(D)
0
500 Metres
N

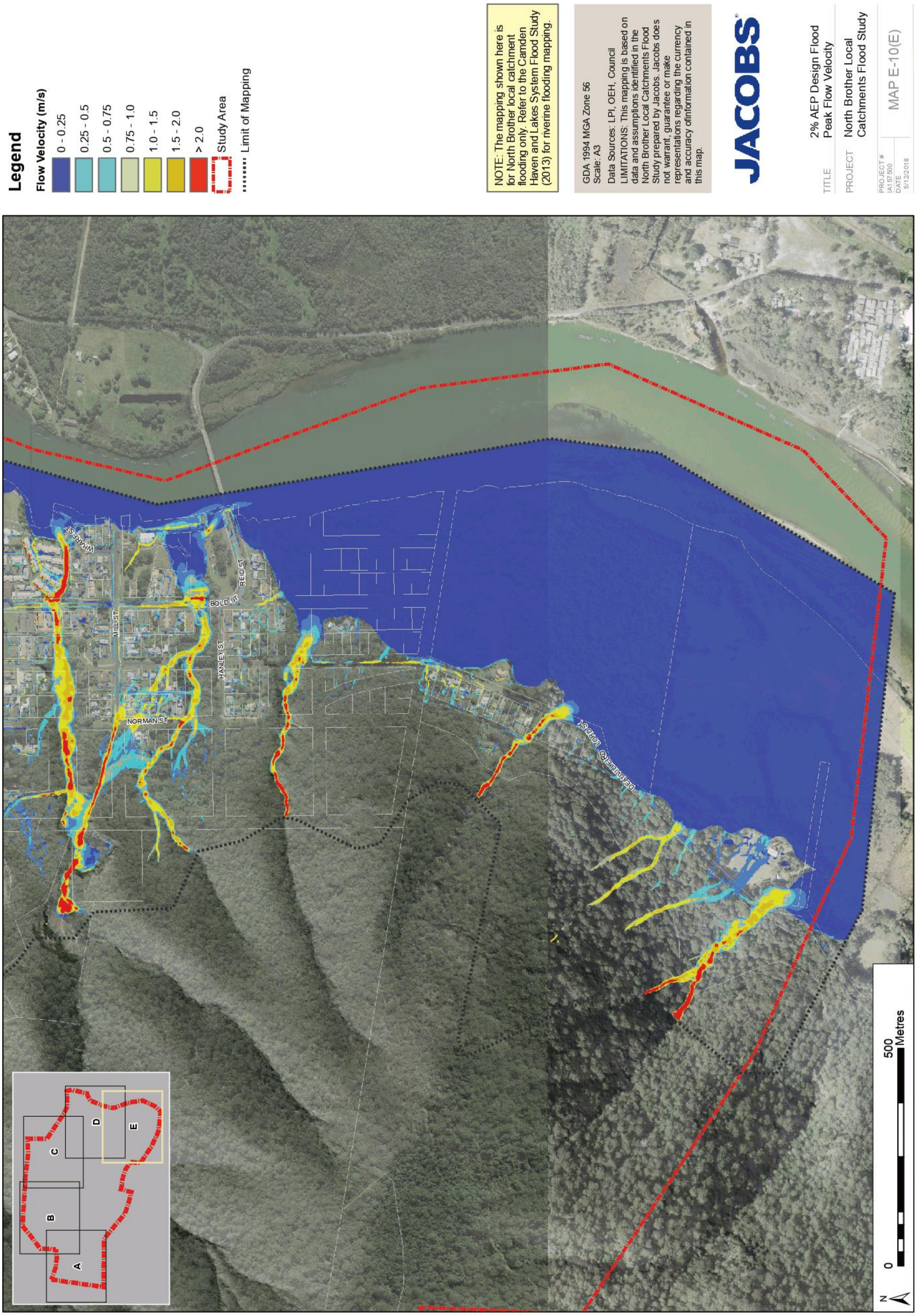

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 5% AEP Design Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-9(E)
BOLD ST
REID ST
MILL ST
HANLEY ST
NORMAN ST
0
500
Metres
A
B
C
D
E

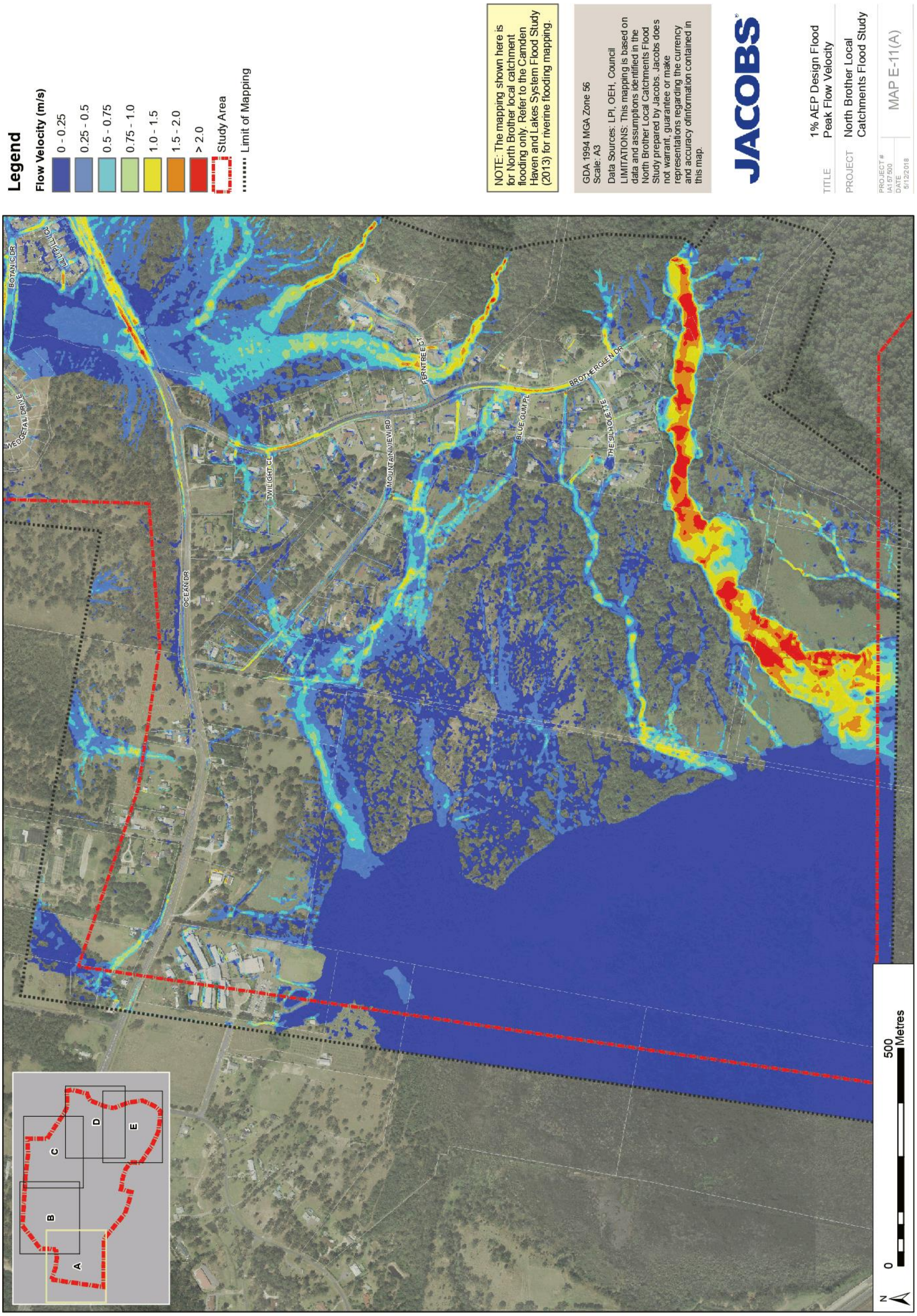

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE 2% AEP Design Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-10(A)
BOTANIC DR
OCEAN DR
TWILIGHT CL
MOUNTAIN VIEW RD
FERNTREE CT
BROTHERGLEN DR
BLUE GUM PL
THE SILHOUETTE
A
B
C
D
E
0
500
Metres
N


Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 2% AEP Design Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-10(B)
0
500 Metres
N
A
B
C
D
E

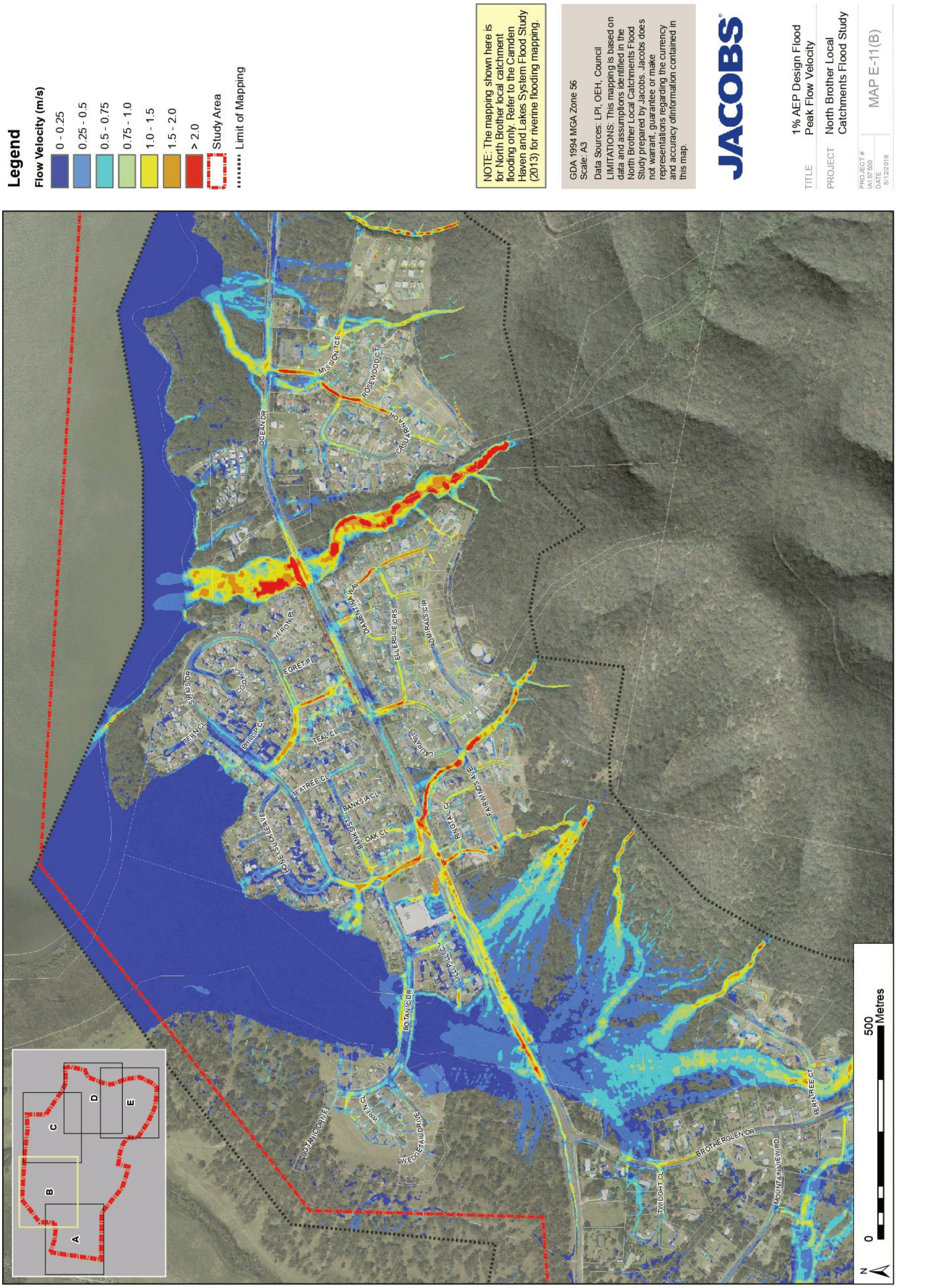

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 2% AEP Design Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-10(C)
0
500
Metres
N
A
B
C
D
E

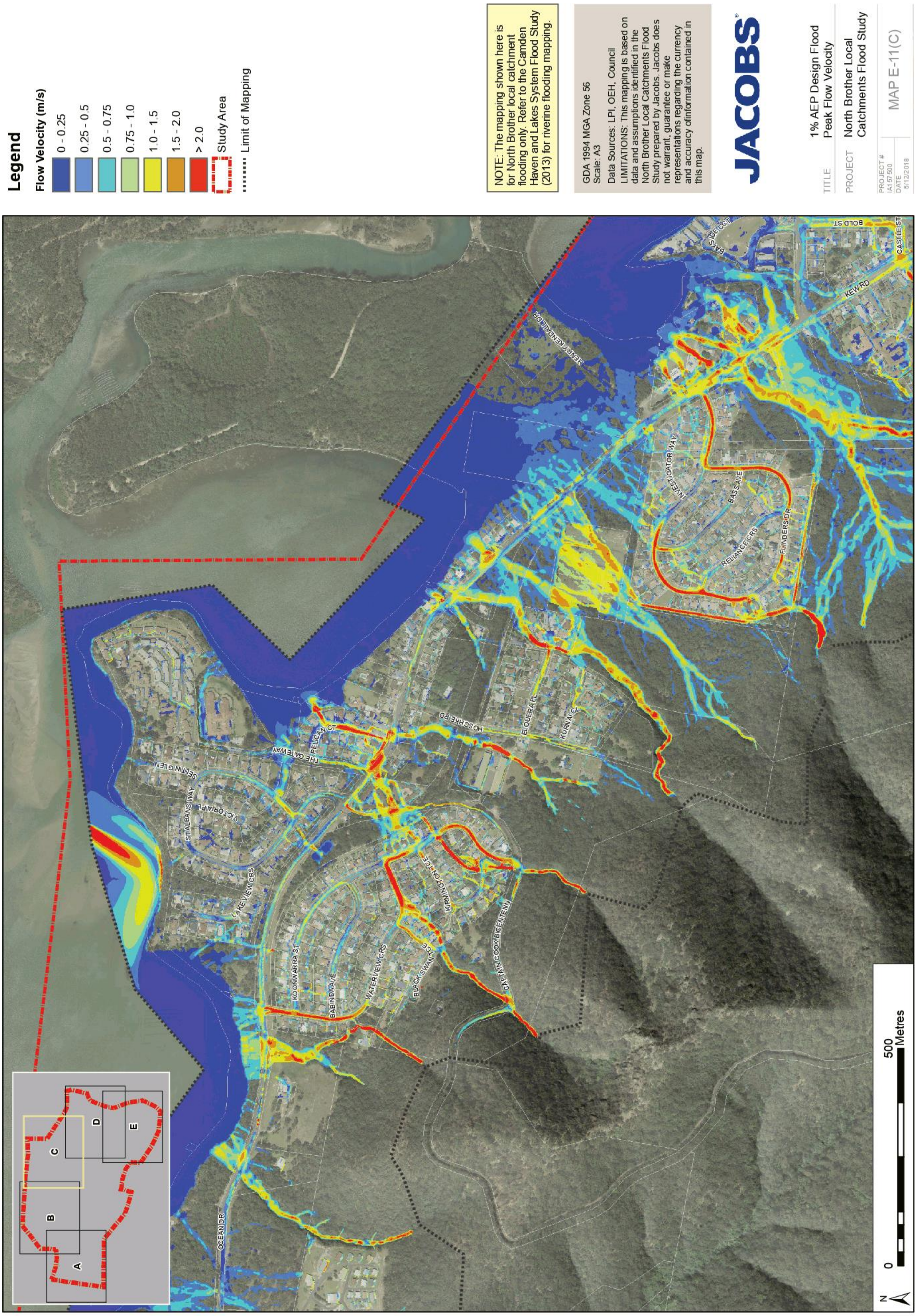

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 2% AEP Design Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-10(D)
0
500 Metres
N
A
B
C
D
E

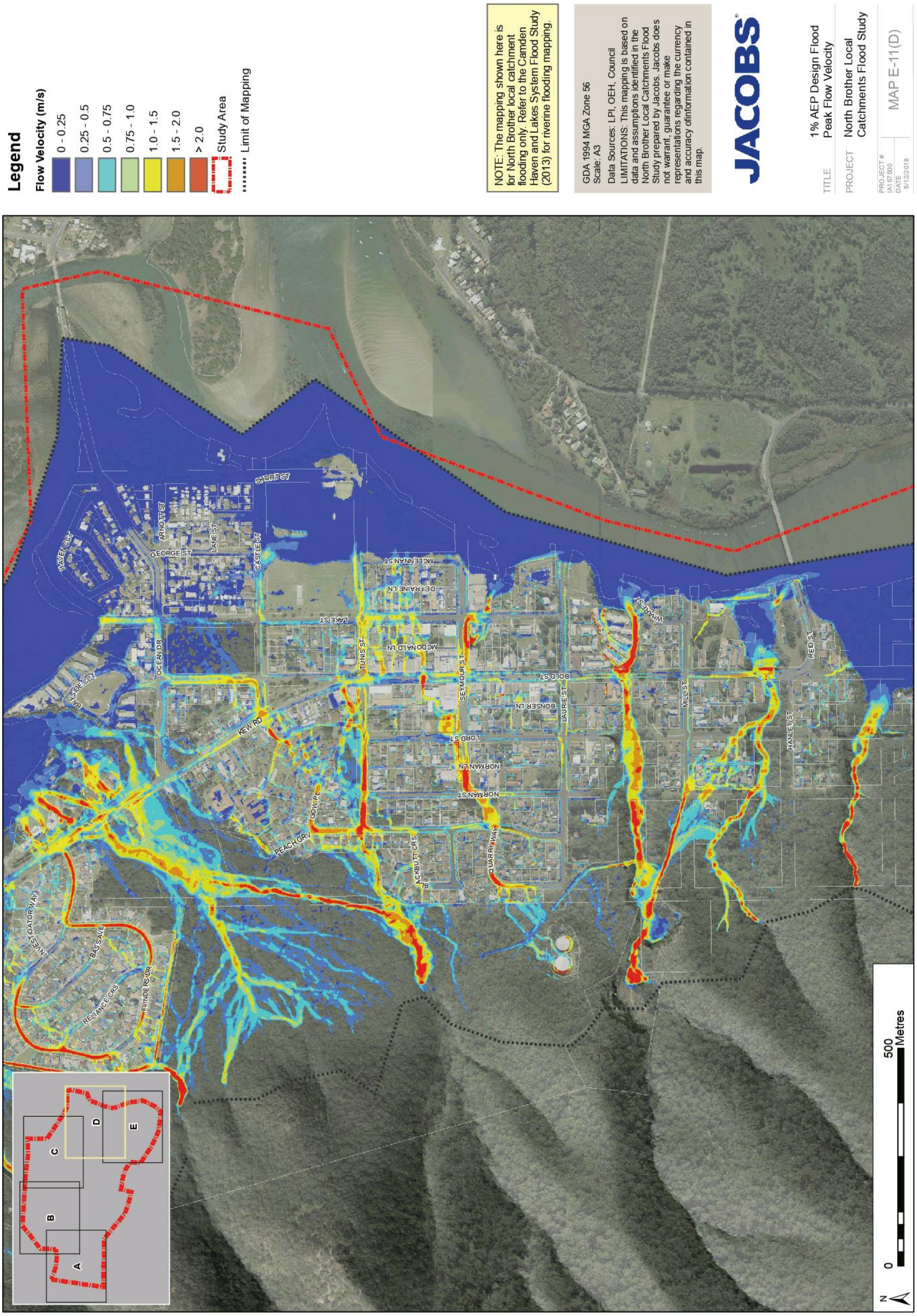

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 2% AEP Design Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-10(E)
BOLD ST
REID ST
MILL ST
HANLEY ST
NORMAN ST
A
B
C
D
E
0
500
Metres

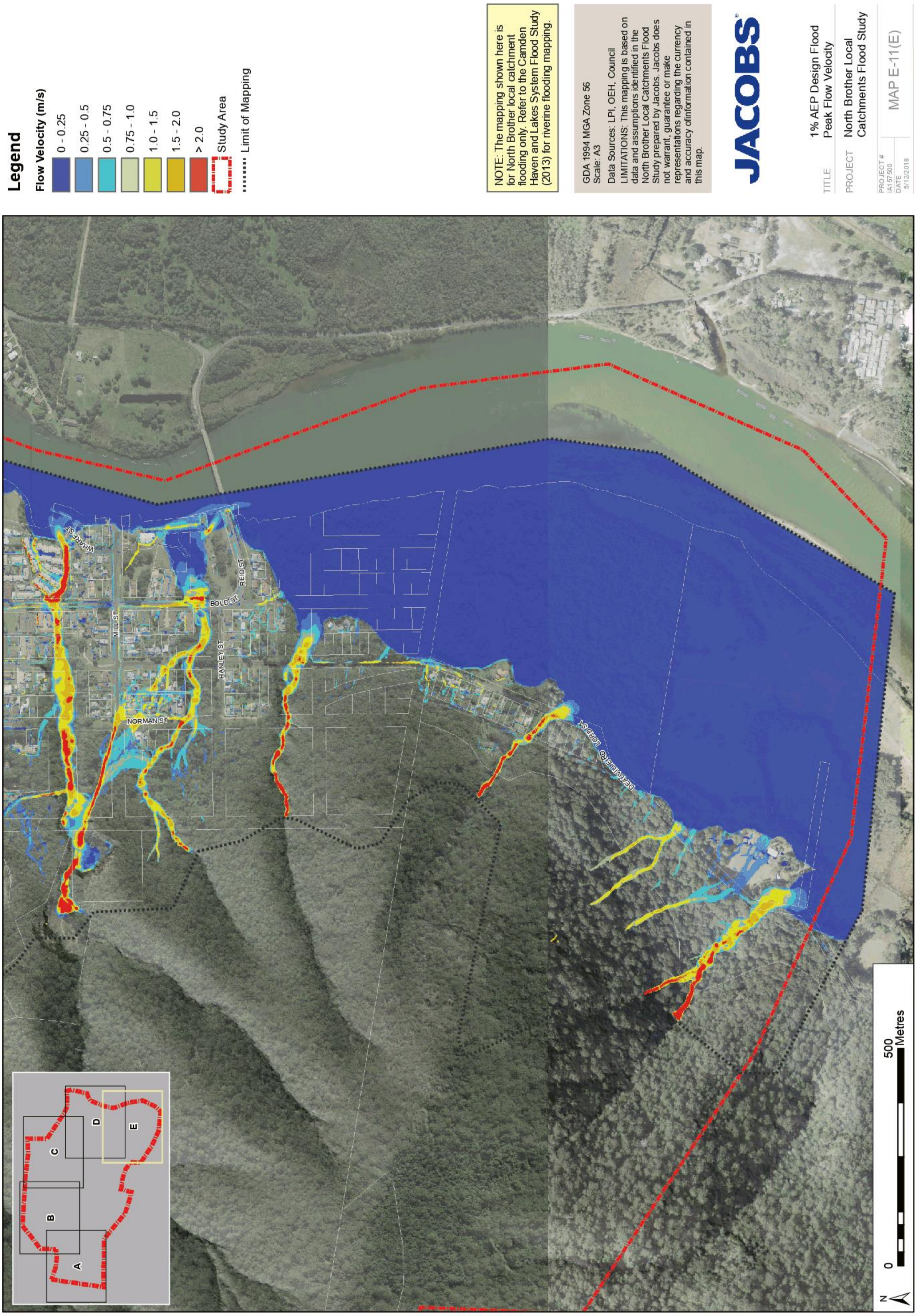


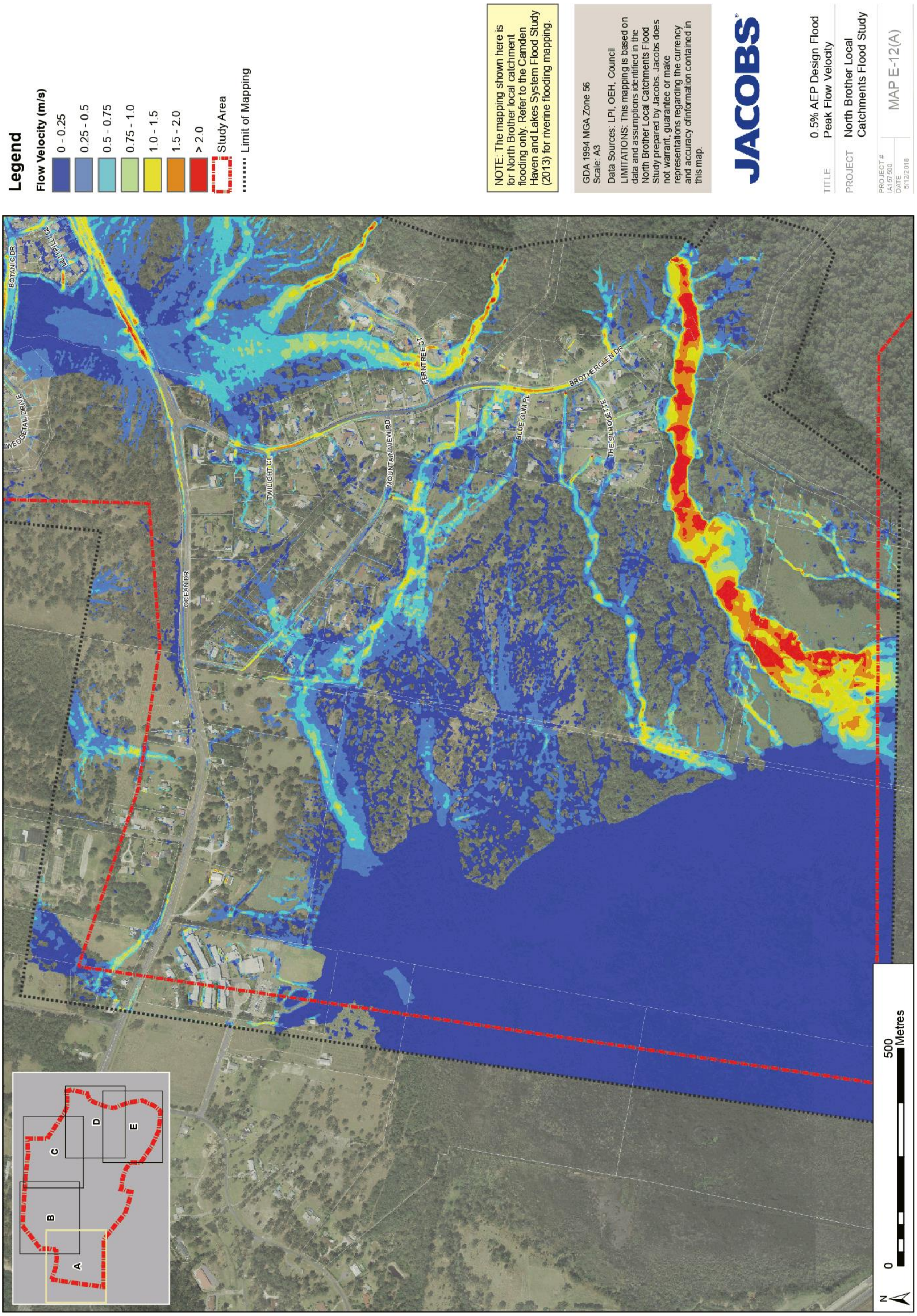
Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 1% AEP Design Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-11(A)
OCEAN DR
BROTHERGLEN DR
TWILIGHT CL
MOUNTAIN VIEW RD
FERNTREE CT
BLUE GUM PL
THE SILHOUETTE
BOTANIC DR
EDGETAL DRIVE
A
B
C
D
E
0
500
Metres
N

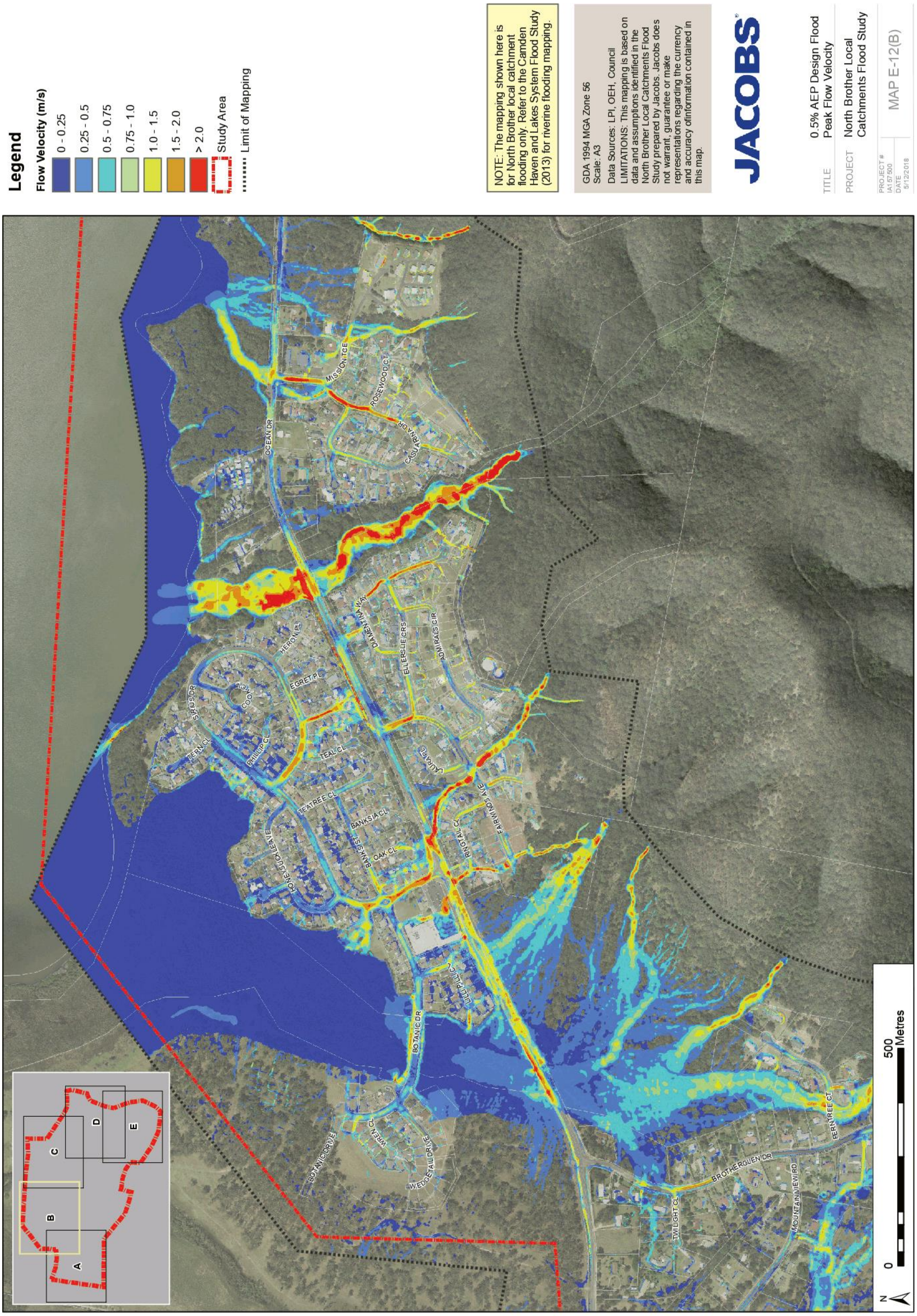

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 1% AEP Design Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-11(B)
0
500
Metres
N
OCEAN DR
MISSION TCE
ROSEWOOD CT
CASUARINA DR
DIAMENTINA WAY
ELLERSLIE CRS
ADMIRALS CIR
HERON PL
EGRET PL
CORMORANT CL
PHILLIP CL
TERN CL
TEAL CL
TEATREE CL
BANKSIA CL
BANKS ST
OAK CL
RINGTAIL CL
FAIRWINDS AVE
LILLIPILLI CL
BOTANIC DR
WREN CL
WEDGETAIL DRIVE
BROTHERGLEN DR
TWILIGHT CL
MOUNTAIN VIEW RD
FERNTREE CT
A
B
C
D
E

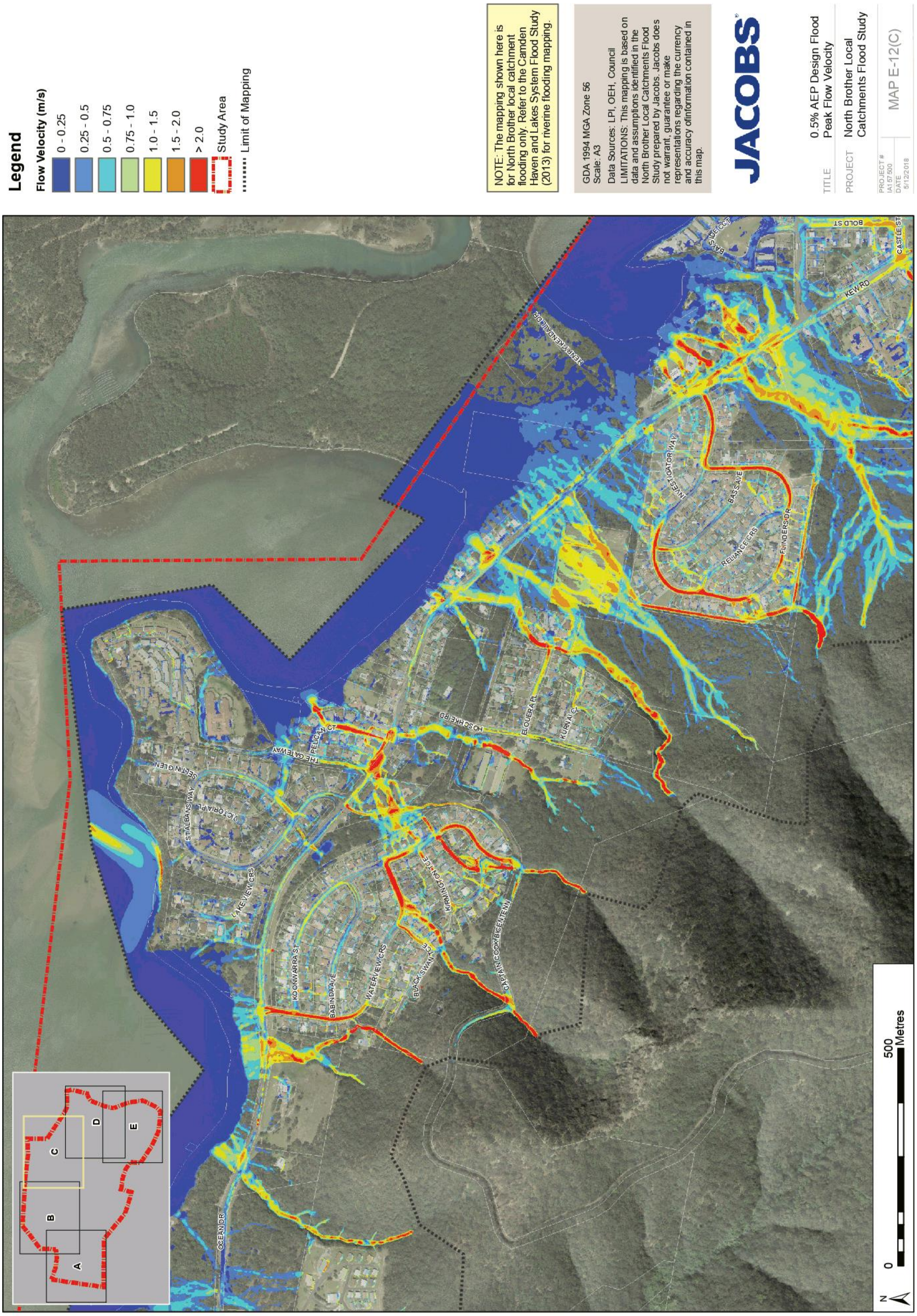

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 1% AEP Design Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-11(C)
0
500 Metres
N

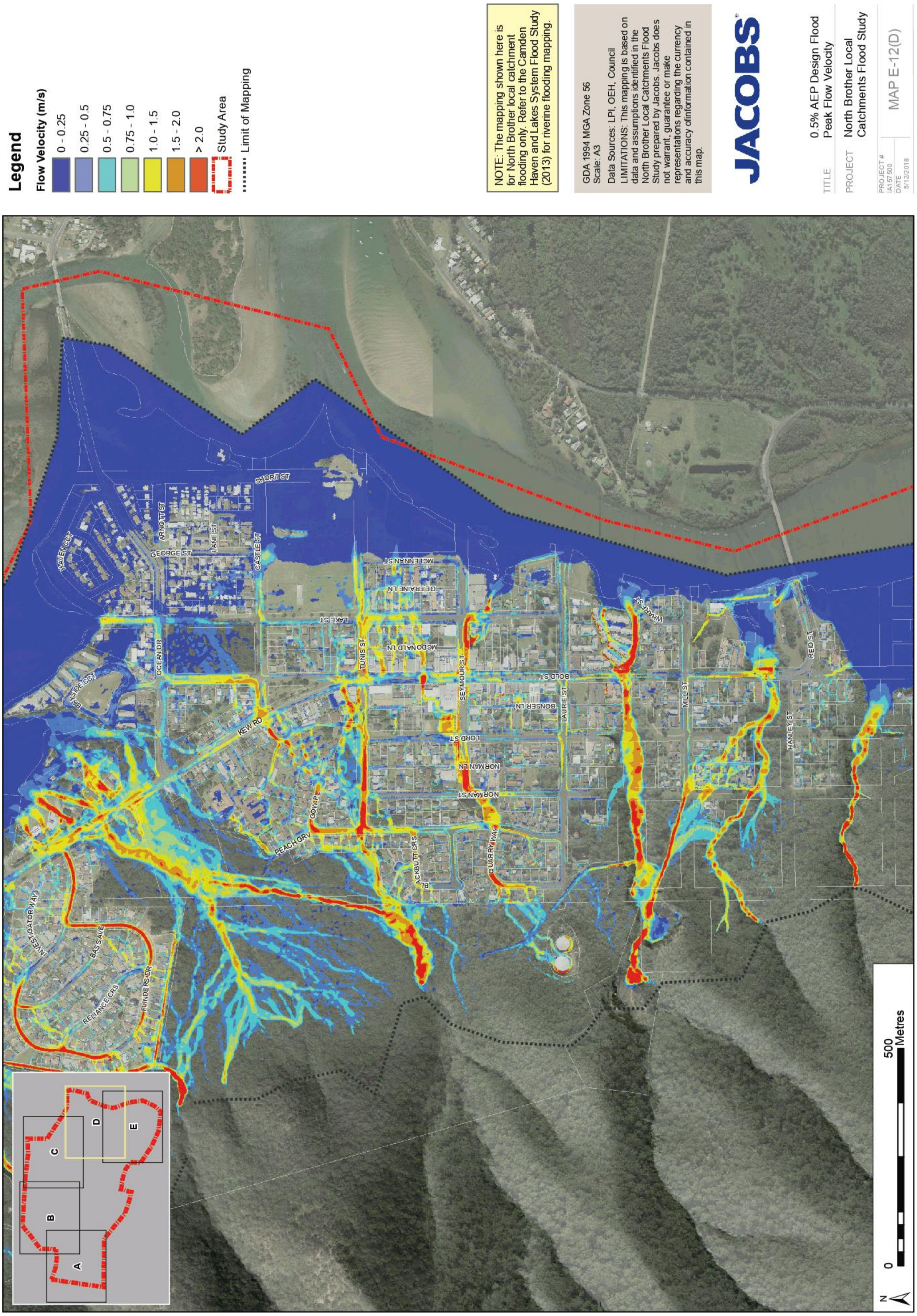

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE 1% AEP Design Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-11(D)
SHORT ST
GEORGE ST
ARNOTT ST
LAKE ST
CASTLE ST
HAVEN CCT
OCEAN DR
BAYSIDE CCT
KEW RD
TUNIS ST
MCLENNAN ST
DE FRAINE LN
MCDONALD LN
SEYMOUR ST
BOLD ST
BONSER LN
LORD ST
NORMAN LN
NORMAN ST
LAURIE ST
QUARRY WAY
PEACH GRV
WHARF ST
MILL ST
HANLEY ST
RED ST
INVESTIGATOR WAY
BASS AVE
RELIANCE CRS
FLINDERS DR
A
B
C
D
E
0
500
Metres
N

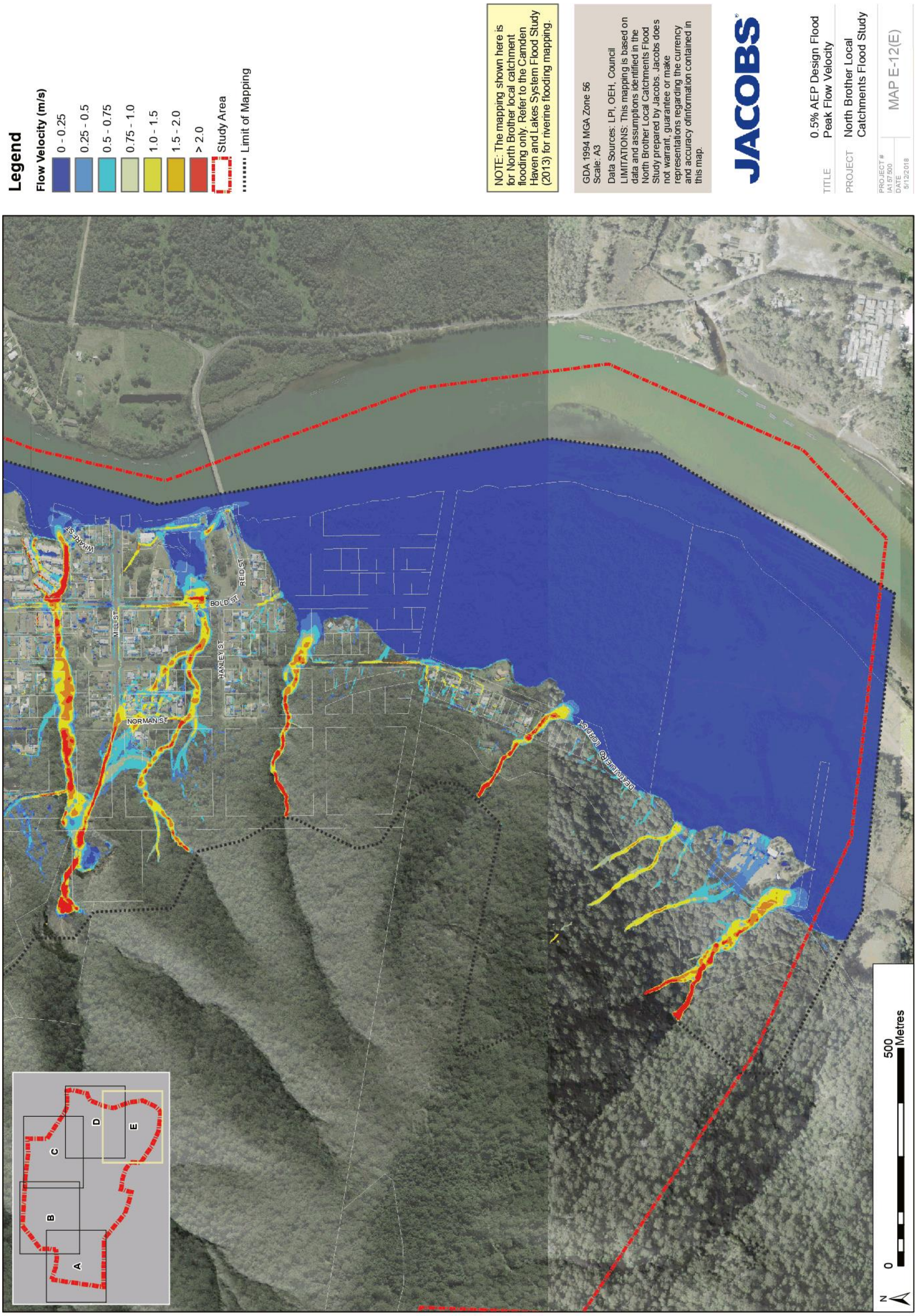

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 1% AEP Design Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-11(E)
BOLD ST
REID ST
MILL ST
HANLEY ST
NORMAN ST
0
500 Metres
N
A
B
C
D
E

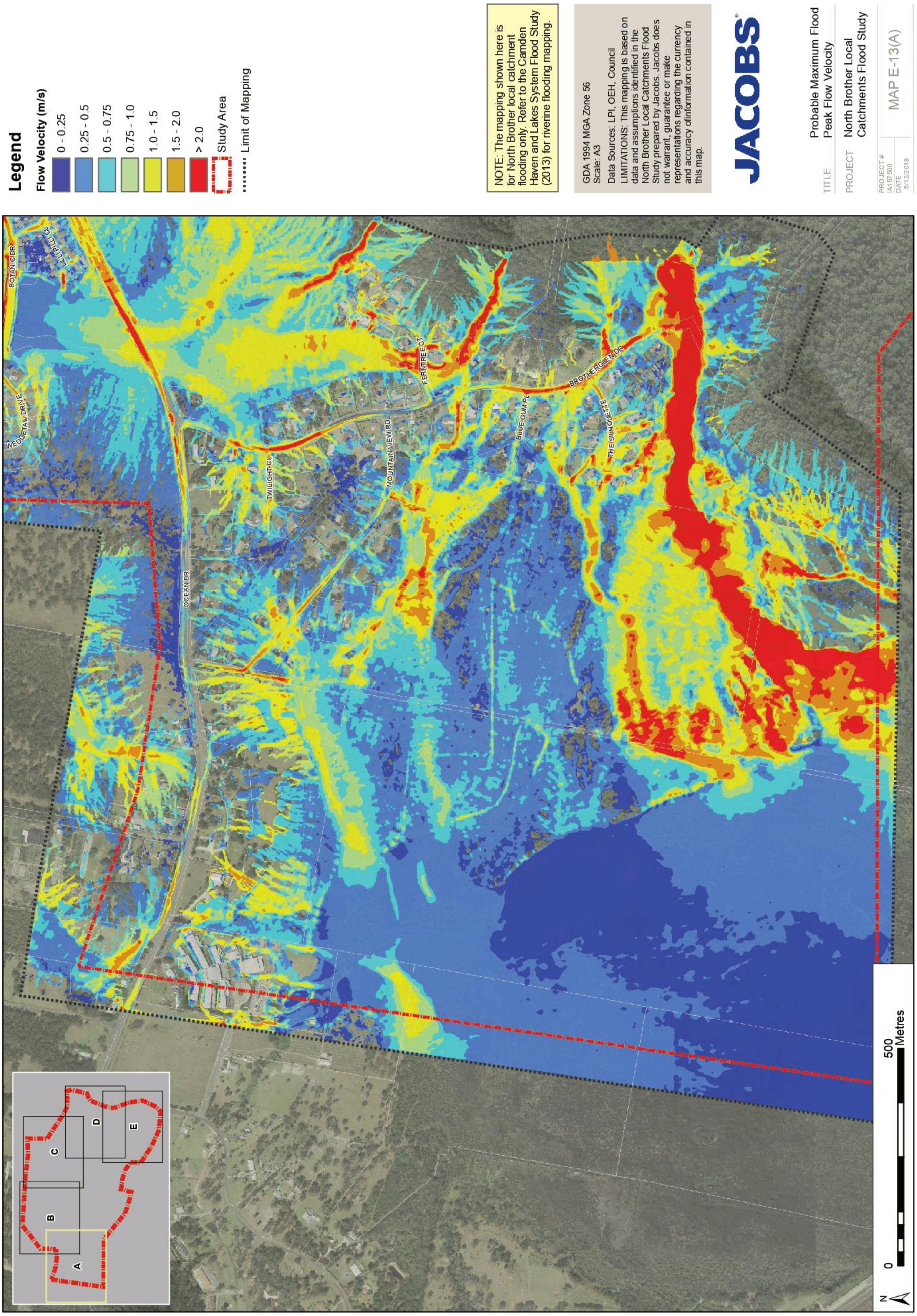

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE 0.5% AEP Design Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-12(A)
BOTANIC DR
OCEAN DR
TWILIGHT CL
MOUNTAIN VIEW RD
BLUE GUM PL
THE SILHOUETTE
BROTHERGLEN DR
FERNTREE CT
A
B
C
D
E
0
500
Metres

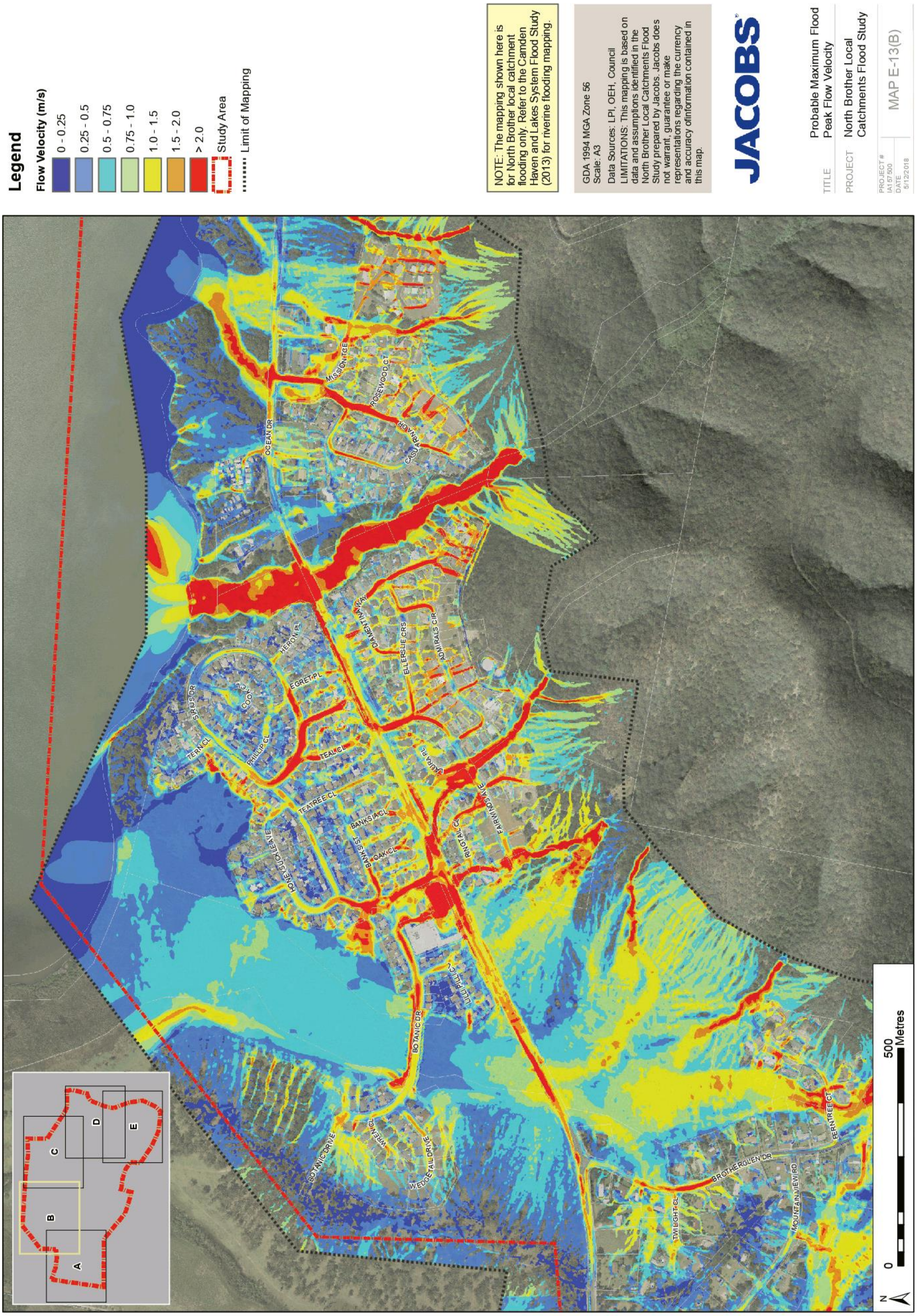

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE 0.5% AEP Design Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-12(B)
OCEAN DR
MISSION TCE
ROSEWOOD CT
CASUARINA DR
DIAMENTINA WAY
ELLERSLIE CRS
ADMIRALS CIR
HERON PL
EGRET PL
COOK CL
SIRIUS DR
FERN CL
PHILLIP CL
TEAL CL
CAUVARDEL
TEATREE CL
BANKSIA CL
OAK CL
RINGTAIL CL
FAIRWINDS AVE
HONEYSUCKLE AVE
LILLYPILLY CL
BOTANIC DR
WREN CL
WEDGETAIL DRIVE
BOTANIC DRIVE
TWILIGHT CL
BROTHERGLEN DR
MOUNTAINVIEW RD
FERNTREE CL
A
B
C
D
E
0
500
Metres
N

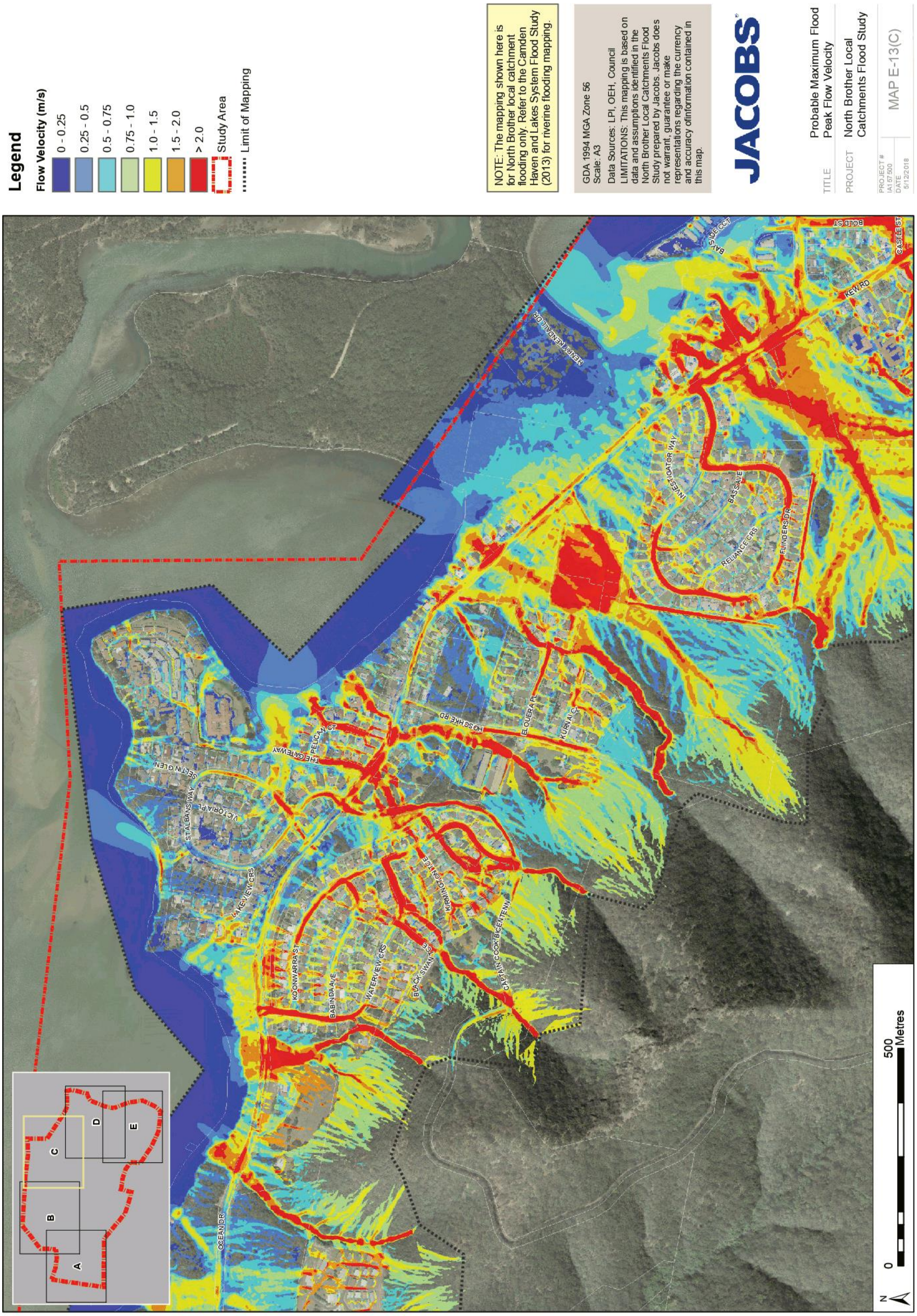

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 0.5% AEP Design Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-12(C)
0
500
Metres
N
A
B
C
D
E

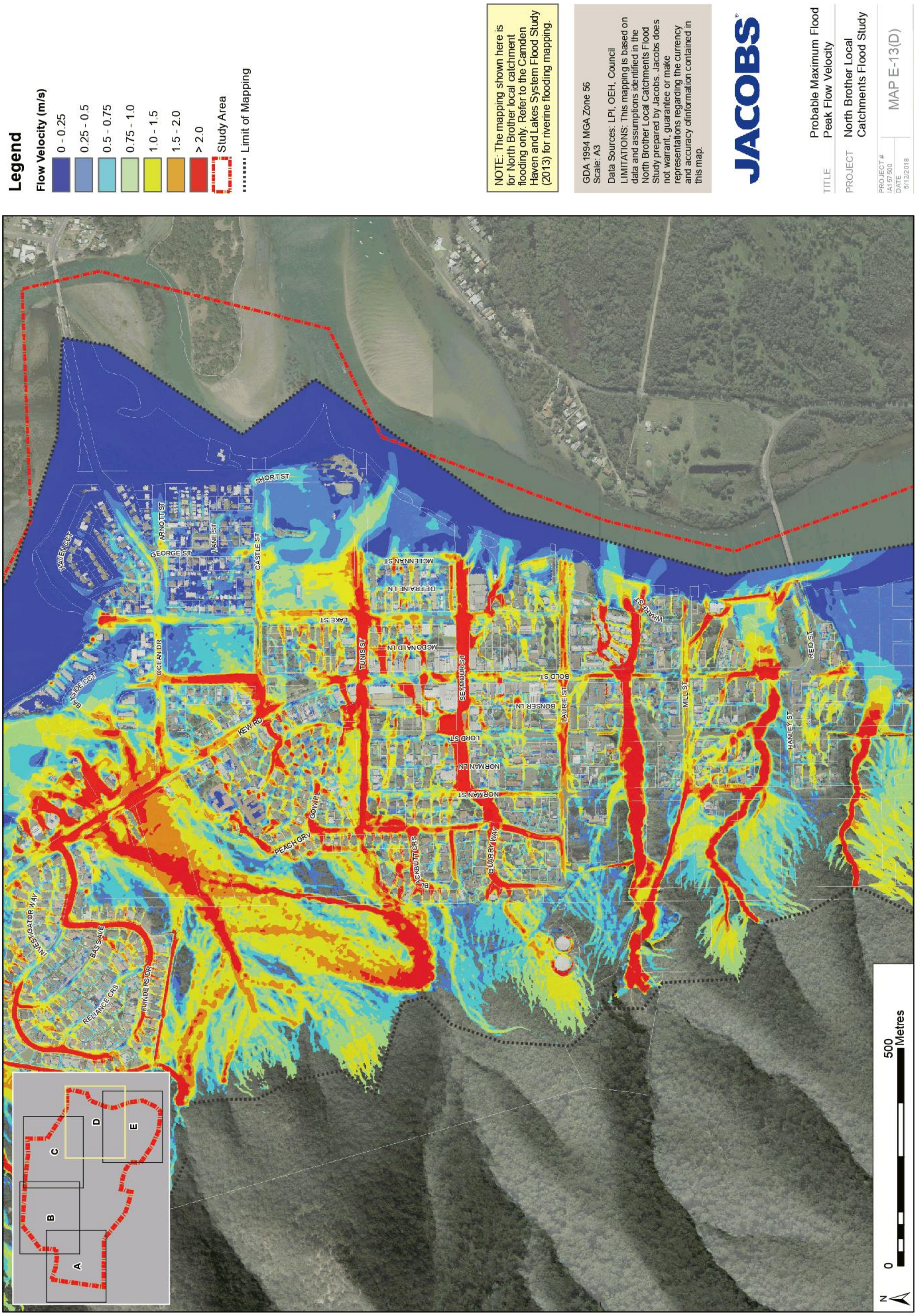

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 0.5% AEP Design Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-12(D)
SHORT ST
ARNOTT ST
GEORGE ST
LAKE ST
CASTLE ST
MCLENNAN ST
DE FRAINE LN
MCDONALD LN
OCEAN DR
TUNIS ST
BOLD ST
SEYMOUR ST
BONSER LN
LAURIE ST
MILL ST
WHARF ST
RED ST
HANLEY ST
LORD ST
NORMAN LN
NORMAN ST
KEW RD
PEACH GRV
QUARRY WAY
INVESTIGATOR WAY
BASS AVE
FLINDERS DR
RELIANCE CRS
A
B
C
D
E
0
500
Metres
N

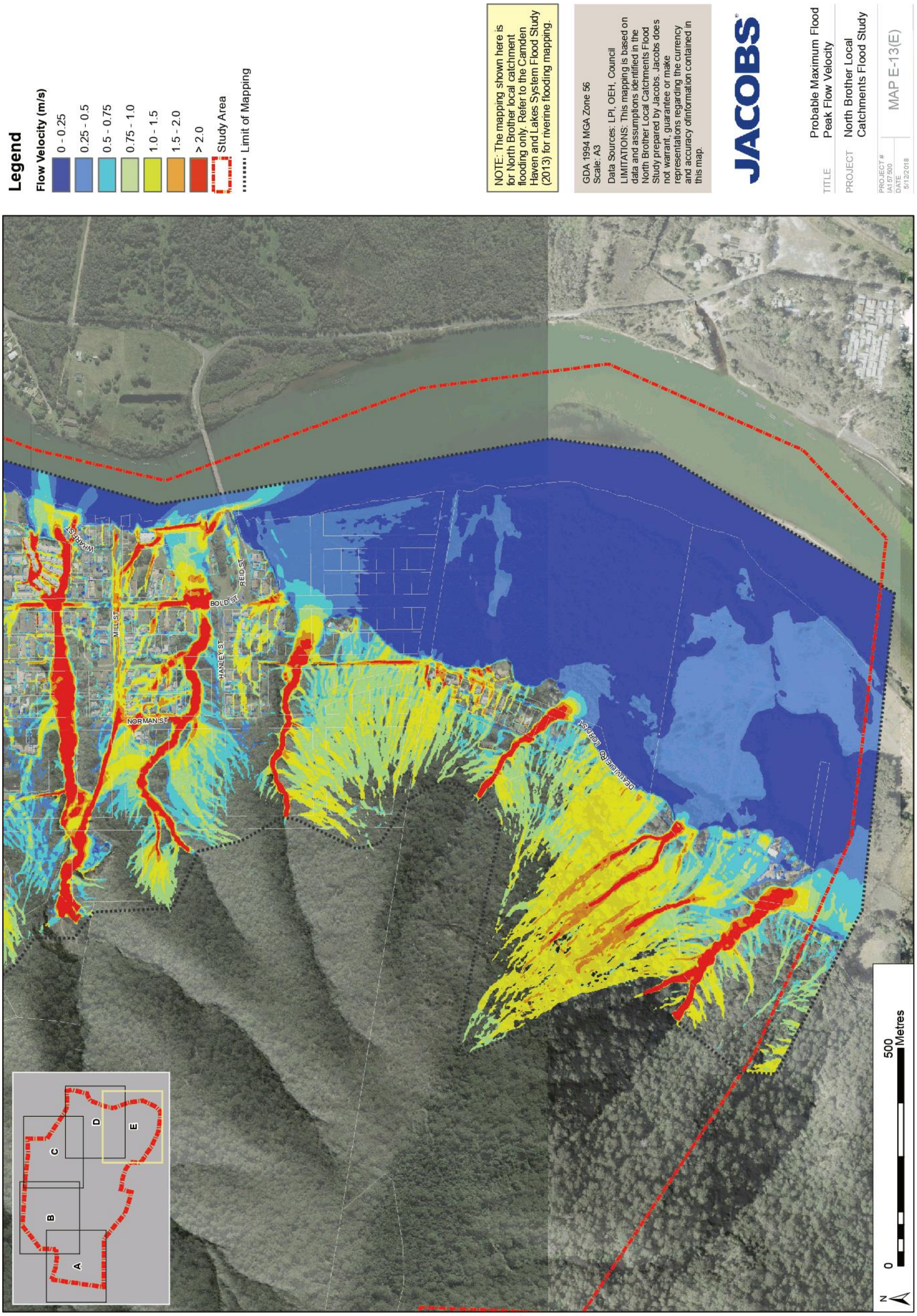

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE 0.5% AEP Design Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-12(E)
BOLD ST
REID ST
MILL ST
HANLEY ST
NORMAN ST
A
B
C
D
E
0
500 Metres
N

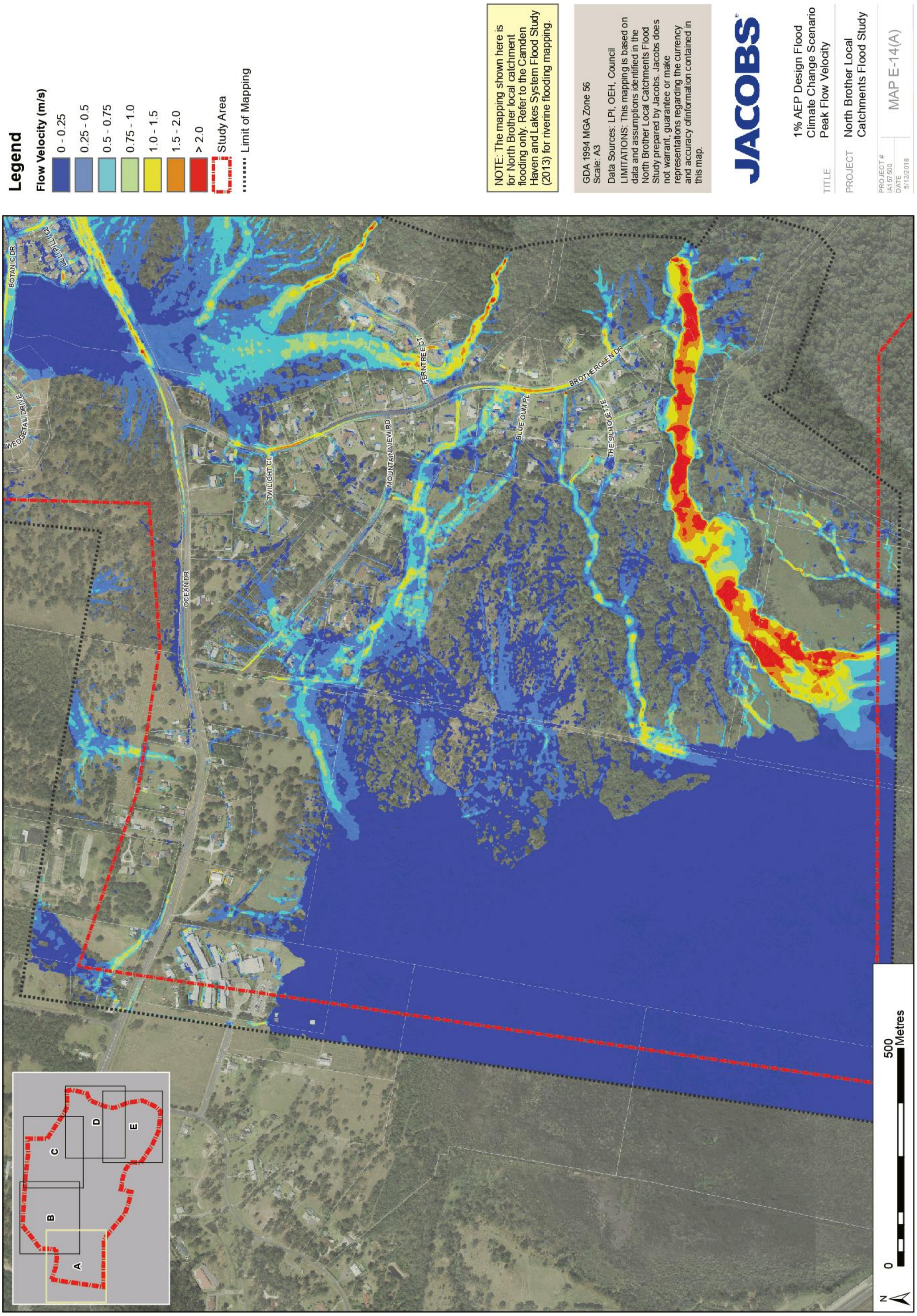

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE Probable Maximum Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-13(A)
BOTANIC DR
LILLIPILLI CL
EUCALYPTUS DRIVE
FERNTREE CT
BROTHERGLEN DR
MOUNTAIN VIEW RD
TWILIGHT CL
BLUE GUM PL
THE SILHOUETTE
OCEAN DR
A
B
C
D
E
0
500
Metres
N

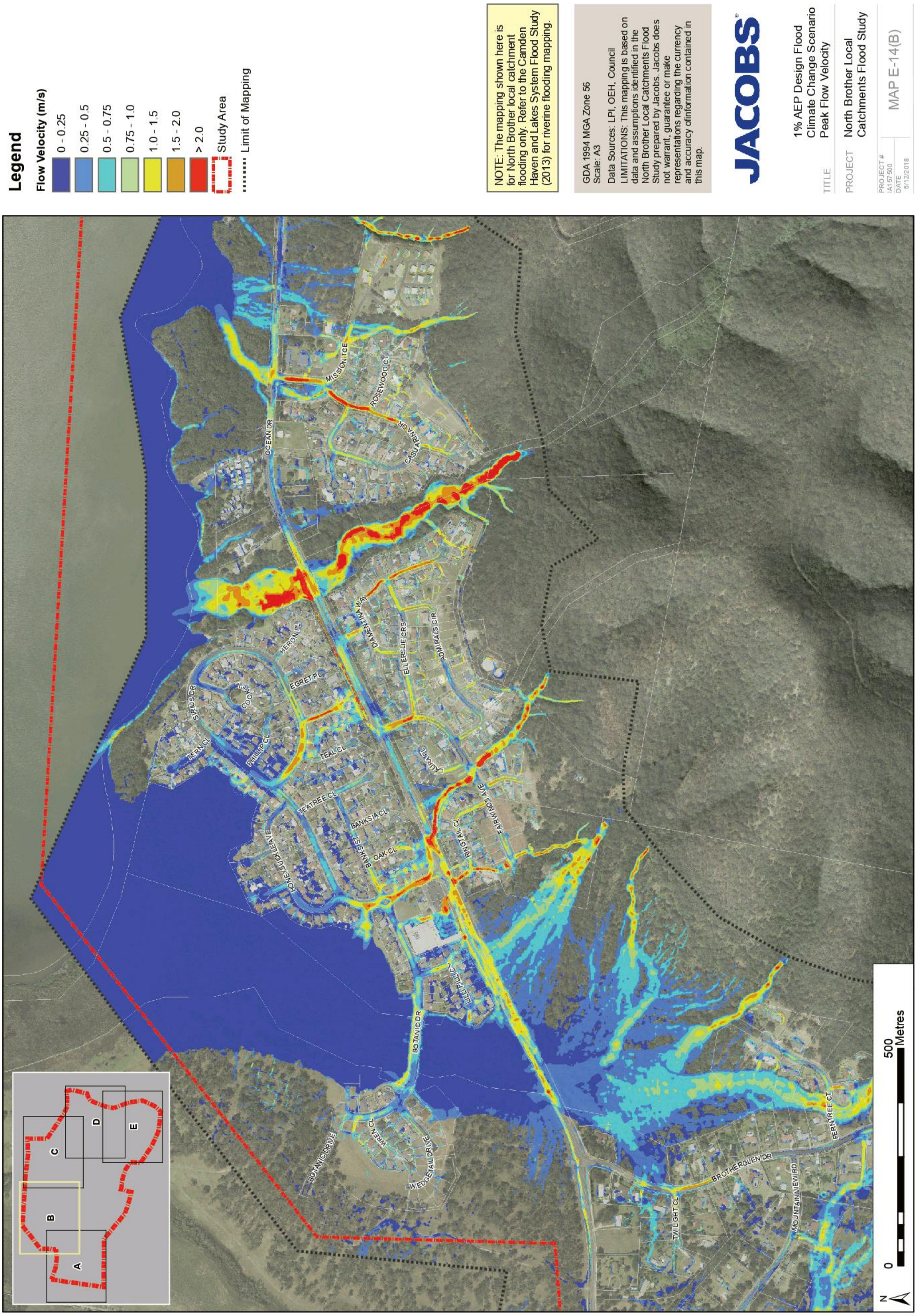

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE Probable Maximum Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-13(B)
OCEAN DR
BOTANIC DR
BOTANIC DRIVE
BROTHERGLEN DR
A
B
C
D
E
0
500
Metres
N

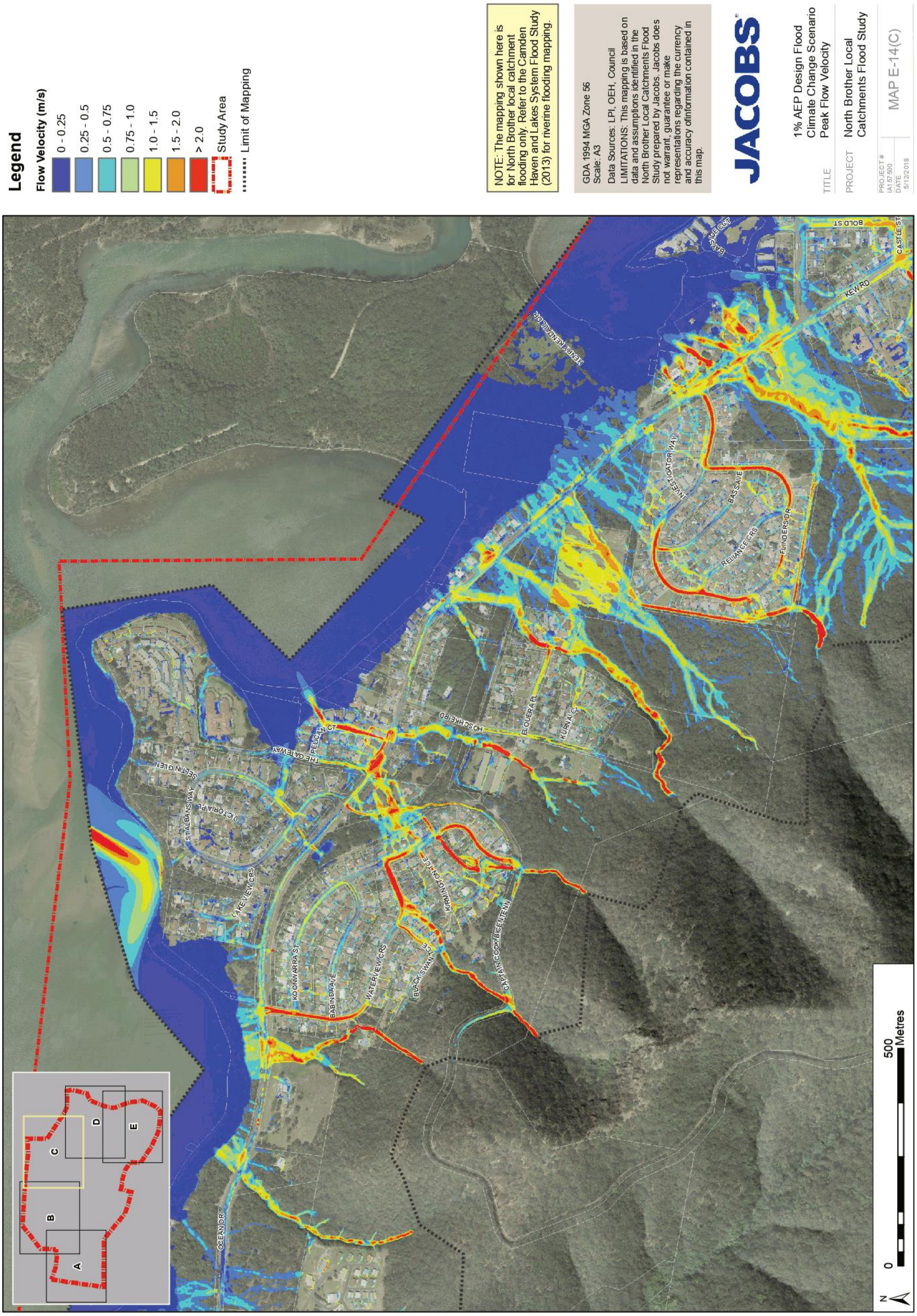

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE Probable Maximum Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-13(C)
0
500
Metres
N

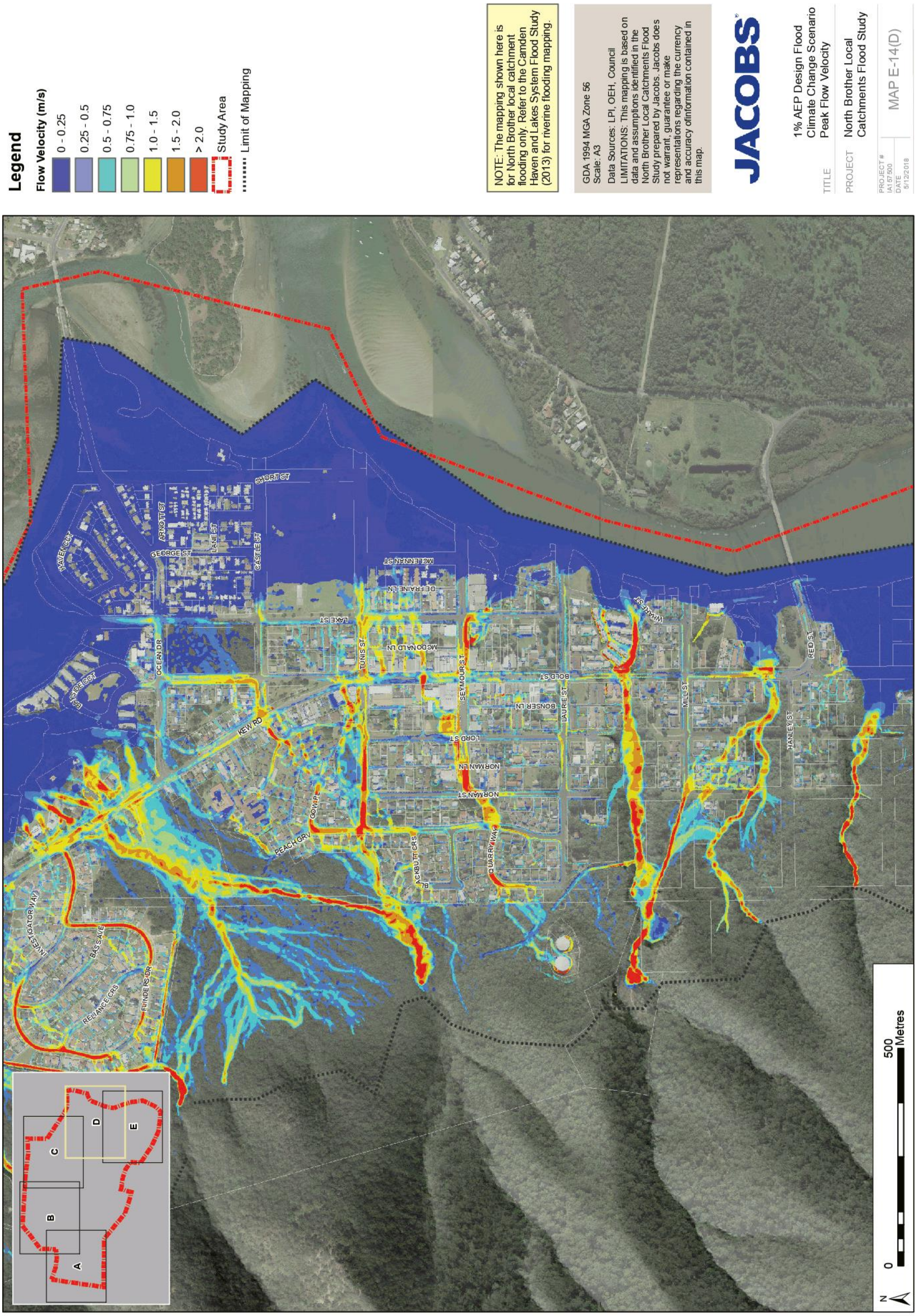

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE Probable Maximum Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-13(D)
SHORT ST
ARNOTT ST
GEORGE ST
LAKE ST
CASTLE ST
OCEAN DR
MCLENNAN ST
DE FRAINE LN
MCDONALD LN
TUNIS ST
SEYMOUR ST
BOLD ST
BONSER LN
LAURIE ST
LORD ST
NORMAN LN
NORMAN ST
QUARRY WAY
KEW RD
PEACH GRV
MILL ST
HANLEY ST
RED ST
FLINDERS DR
BASS AVE
RELIANCE CRS
INVESTIGATOR WAY
A
B
C
D
E
0
500
Metres
N

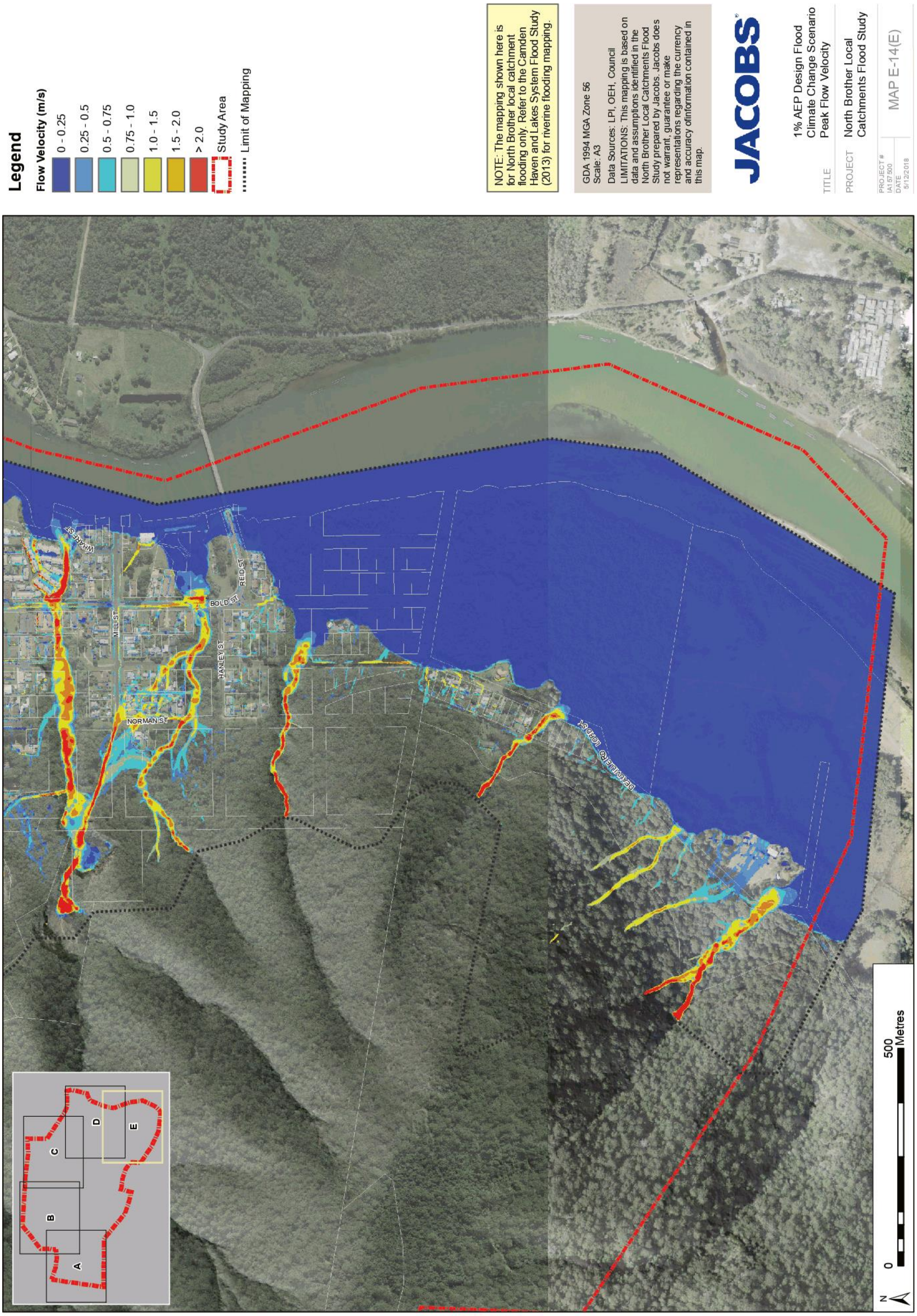

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE Probable Maximum Flood Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-13(E)
NORMAN ST
MILL ST
HANLEY ST
BOLD ST
REID ST
0
500
Metres
N
A
B
C
D
E

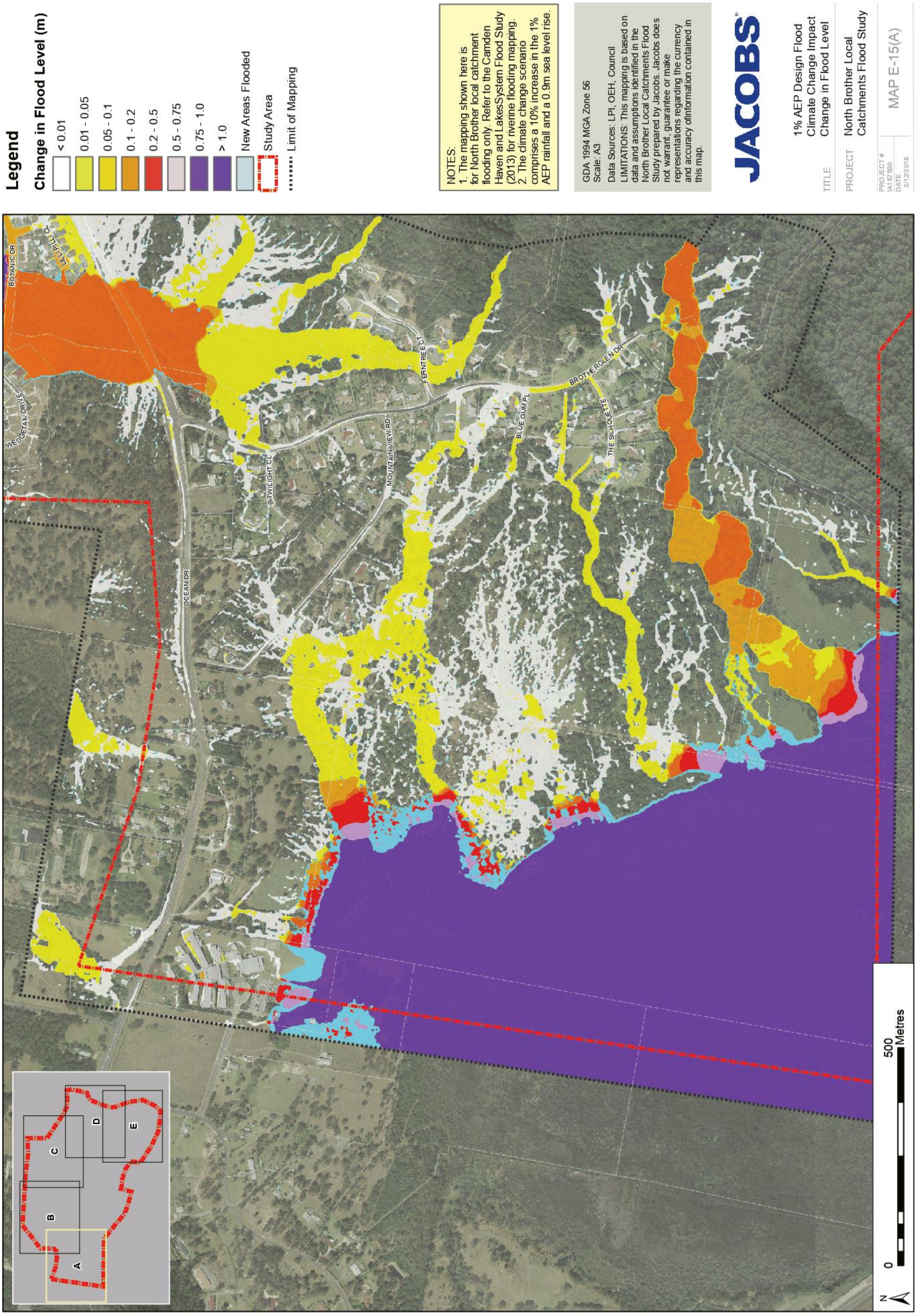

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE 1% AEP Design Flood Climate Change Scenario Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-14(A)
PROJECT # IA157500
DATE 5/12/2018
BOTANIC DR
DEGETAL DRIVE
TWILIGHT CL
MOUNTAIN VIEW RD
FERNTREE CT
BLUE GUM PL
THE SILHOUETTE
BROTHERGLEN DR
OCEAN DR
A
B
C
D
E
0
500
Metres
N

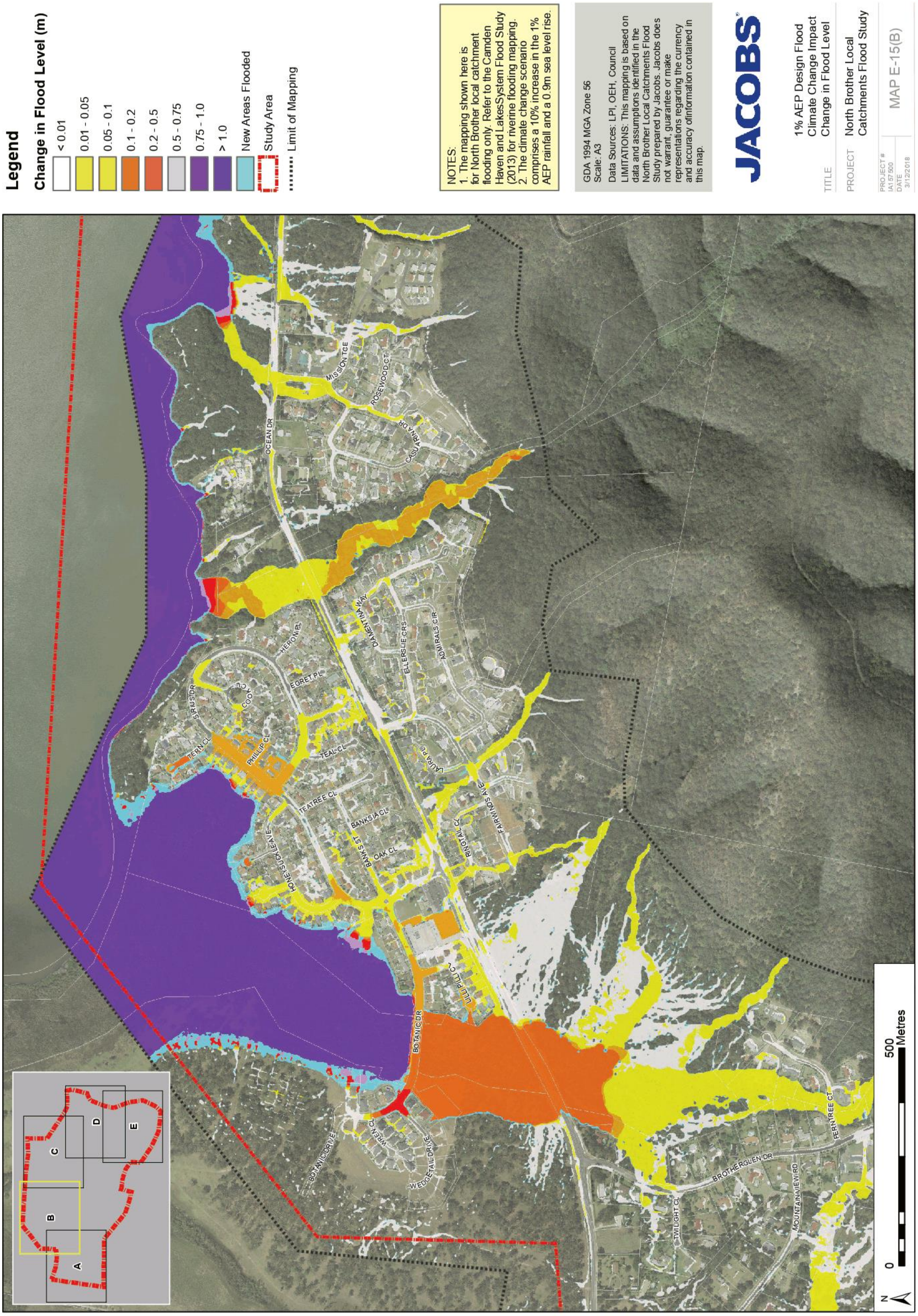

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE 1% AEP Design Flood Climate Change Scenario Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-14(B)
0
500 Metres
N
A
B
C
D
E

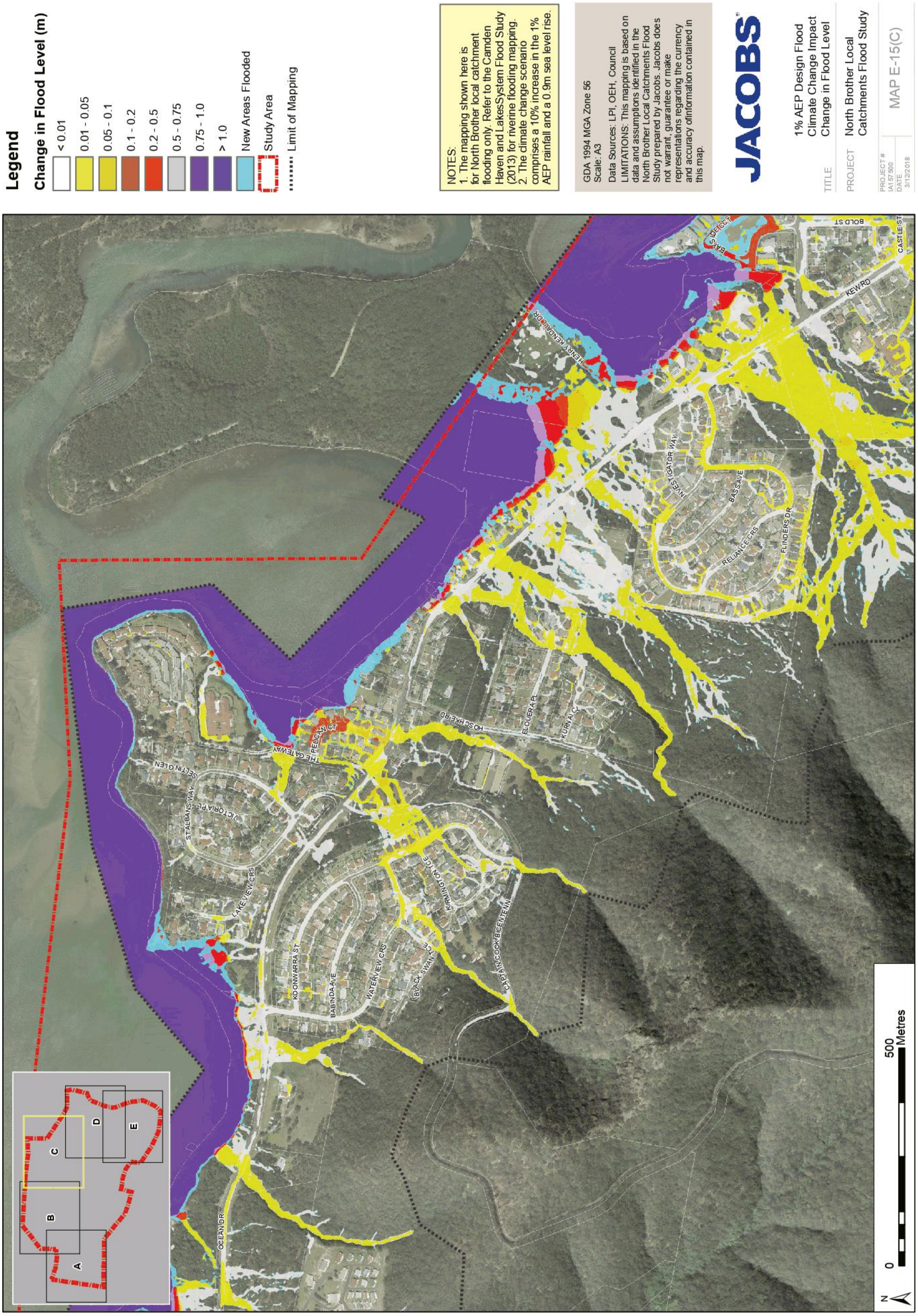

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 1% AEP Design Flood Climate Change Scenario Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-14(C)
0
500 Metres
N
A
B
C
D
E

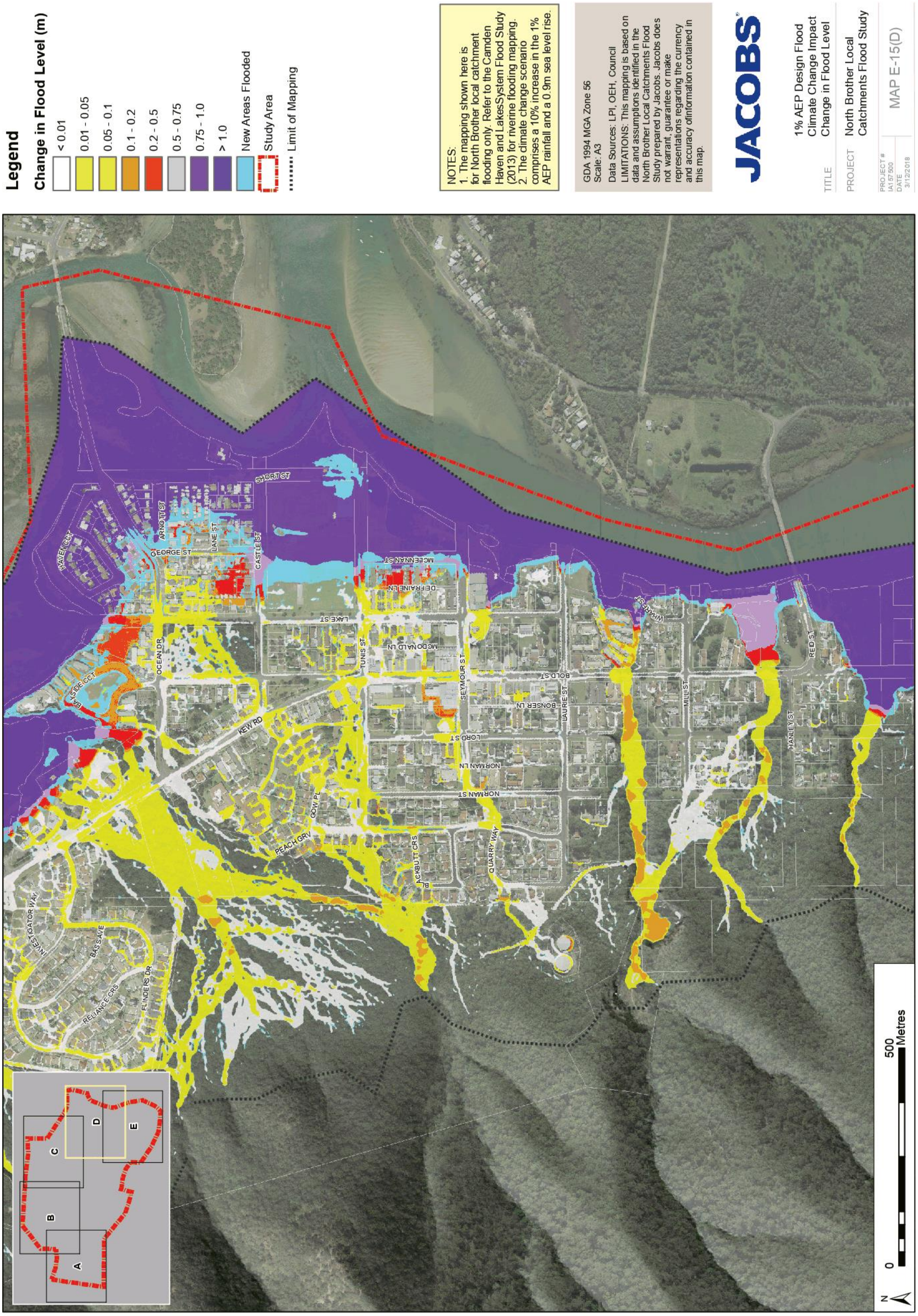

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE 1% AEP Design Flood Climate Change Scenario Peak Flow Velocity
PROJECT North Brother Local Catchments Flood Study
MAP E-14(D)
SHORT ST
HAVEN CCT
GEORGE ST
ARNOTT ST
LAKE ST
CASTLE ST
MCLENNAN ST
DEFRAINE LN
OCEAN DR
TUNIS ST
MCDONALD LN
SEYMOUR ST
BOLD ST
BONSER LN
LORD ST
NORMAN LN
NORMAN ST
LAURIE ST
MILL ST
WHARF ST
RED ST
HANLEY ST
BAYSIDE CCT
KEW RD
PEACH GRV
QUARRY WAY
FLINDERS DR
BASS AVE
RELIANCE CRS
INVESTIGATOR WAY
A
B
C
D
E
0
500
Metres
N

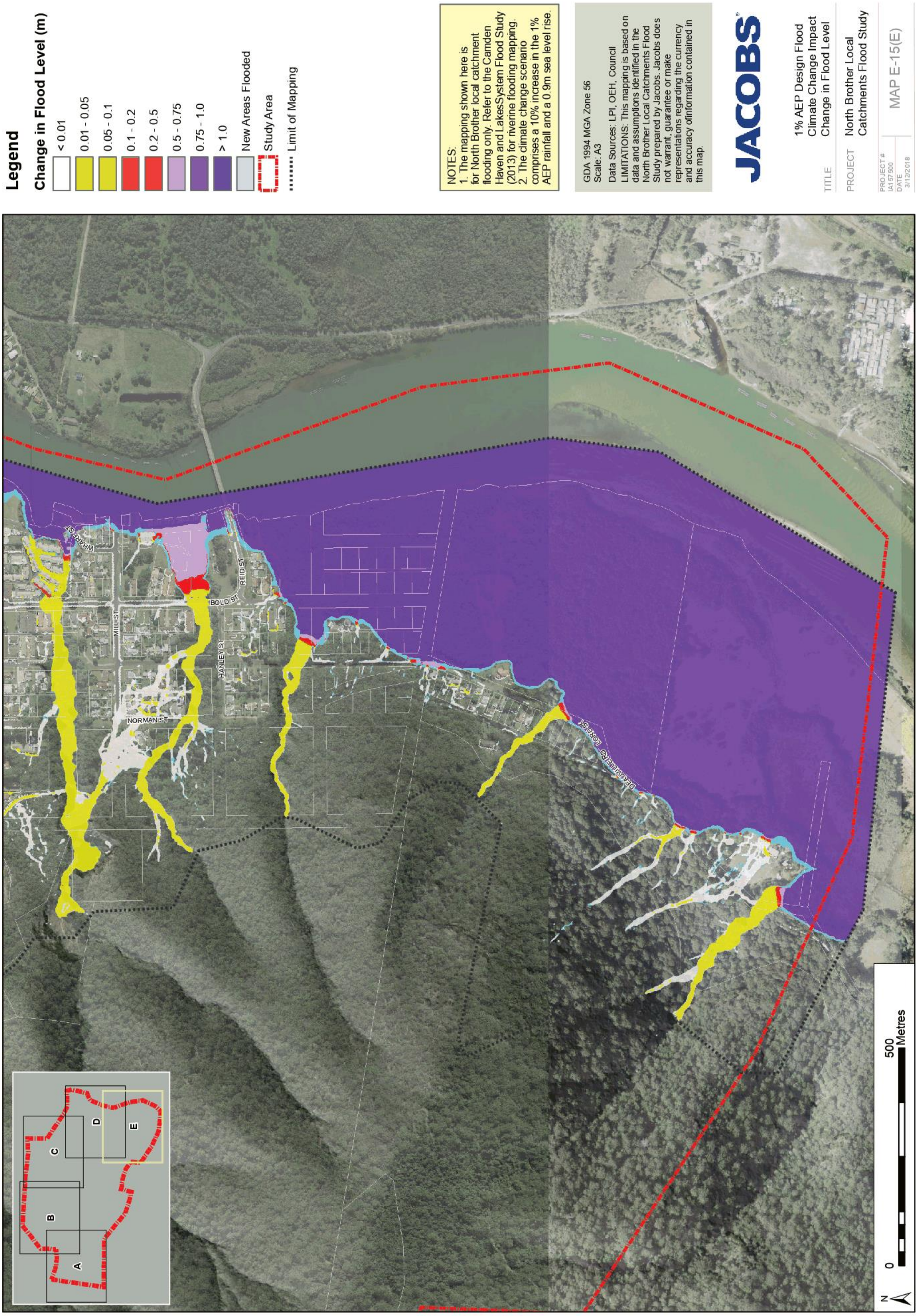

Legend
Flow Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE
1% AEP Design Flood
Climate Change Scenario
Peak Flow Velocity
PROJECT
North Brother Local
Catchments Flood Study
MAP E-14(E)
MILL ST
BOLD ST
REID ST
HANLEY ST
NORMAN ST
0
500
Metres
N
A
B
C
D
E


Legend
Change in Flood Level (m)
< 0.01
0.01 - 0.05
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 0.75
0.75 - 1.0
> 1.0
New Areas Flooded
Study Area
Limit of Mapping
NOTES:
1. The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and LakesSystem Flood Study (2013) for riverine flooding mapping.
2. The climate change scenario comprises a 10% increase in the 1% AEP rainfall and a 0.9m sea level rise.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE 1% AEP Design Flood Climate Change Impact Change in Flood Level
PROJECT North Brother Local Catchments Flood Study
MAP E-15(A)
BOTANIC DR
OCEAN DR
BROTHERGLEN DR
TWILIGHT CL
MOUNTAIN VIEW RD
BLUE GUM PL
THE SILHOUETTE
FERNTREE CT
A
B
C
D
E
0
500
Metres
N


Legend
Change in Flood Level (m)
< 0.01
0.01 - 0.05
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 0.75
0.75 - 1.0
> 1.0
New Areas Flooded
Study Area
Limit of Mapping
NOTES:
1. The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and LakesSystem Flood Study (2013) for riverine flooding mapping.
2. The climate change scenario comprises a 10% increase in the 1% AEP rainfall and a 0.9m sea level rise.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE 1% AEP Design Flood Climate Change Impact Change in Flood Level
PROJECT North Brother Local Catchments Flood Study
MAP E-15(B)
OCEAN DR
MISSION TCE
ROSEWOOD CT
CASUARINA DR
HEROWPL
EGRET PL
DIAMENTINA WAY
ELLERSLIE CRS
ADMIRALS CIR
COOK
TERN CL
PHILLIP CL
TEAL CL
TEATREE CL
BANKSIA CL
BANKS ST
OAK CL
HONEYSUCKLE AVE
FAIRWINDS AVE
BOTANIC DR
BOTANIC DRIVE
WEDGETAIL DRIVE
BROTHERGLEN DR
FERNTREE CT
TWILIGHT CL
MOUNTAIN VIEW RD
A
B
C
D
E
0
500
Metres
N


Legend
Change in Flood Level (m)
< 0.01
0.01 - 0.05
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 0.75
0.75 - 1.0
> 1.0
New Areas Flooded
Study Area
Limit of Mapping
NOTES:
1. The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and LakesSystem Flood Study (2013) for riverine flooding mapping.
2. The climate change scenario comprises a 10% increase in the 1% AEP rainfall and a 0.9m sea level rise.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE
1% AEP Design Flood Climate Change Impact Change in Flood Level
PROJECT
North Brother Local Catchments Flood Study
MAP E-15(C)
0
500 Metres
N

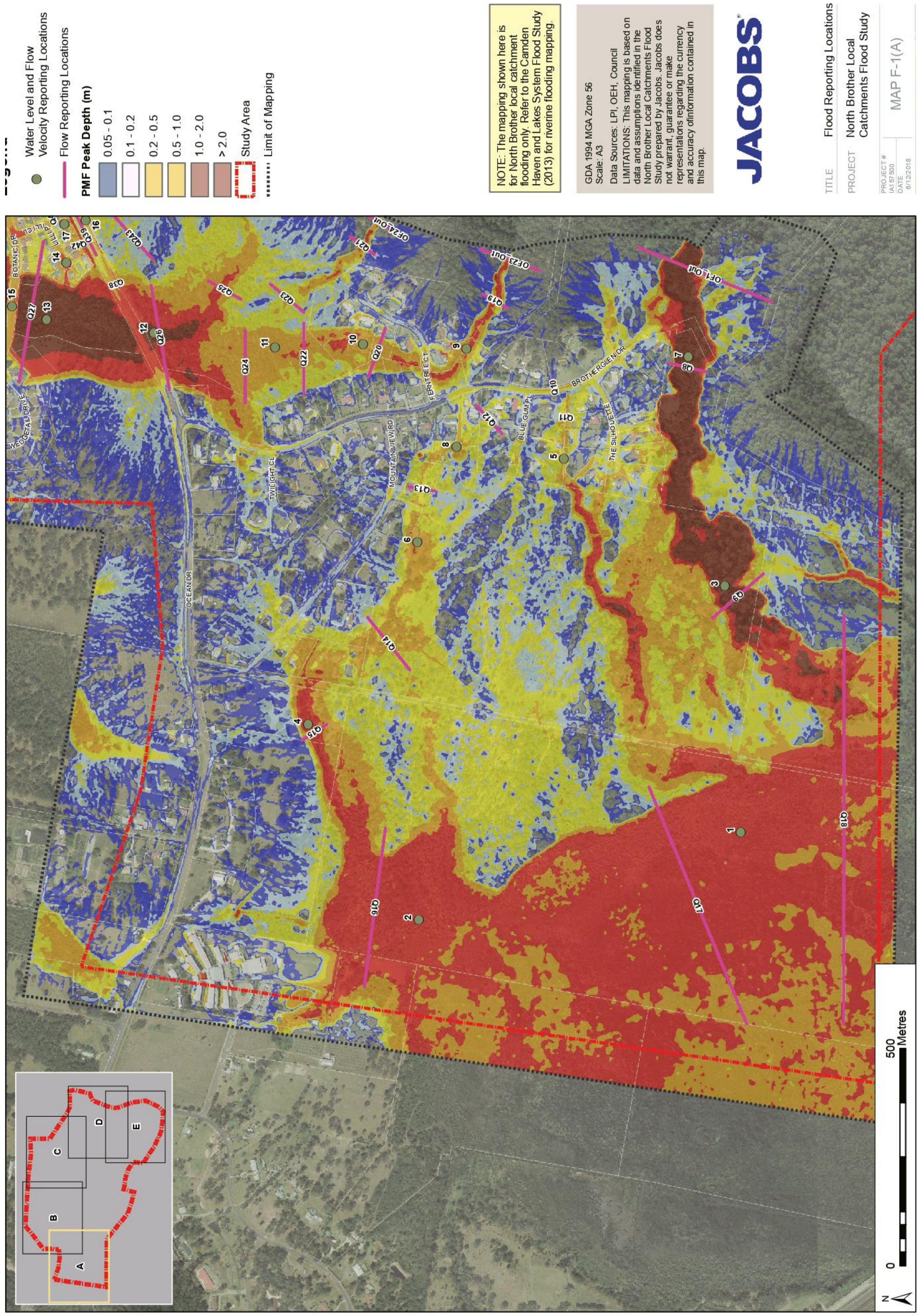

Legend
Change in Flood Level (m)
< 0.01
0.01 - 0.05
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 0.75
0.75 - 1.0
> 1.0
New Areas Flooded
Study Area
Limit of Mapping
NOTES:
1. The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and LakesSystem Flood Study (2013) for riverine flooding mapping.
2. The climate change scenario comprises a 10% increase in the 1% AEP rainfall and a 0.9m sea level rise.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE 1% AEP Design Flood Climate Change Impact Change in Flood Level
PROJECT North Brother Local Catchments Flood Study
MAP E-15(D)
0
500
Metres
N
A
B
C
D
E
SHORT ST
ARNOTT ST
GEORGE ST
LANE ST
CASTLE ST
HAVEN CCT
MCLENNAN ST
DEFRAINE LN
LAKE ST
TUNIS ST
MCDONALD LN
OCEAN DR
BAYSIDE CCT
KEW RD
SEYMOUR ST
BOLD ST
BONSER LN
LAURIE ST
LORD ST
NORMAN LN
NORMAN ST
MILL ST
HANLEY ST
RED ST
WHARF ST
QUARRY WAY
PEACH GRV
COW PL
ACKBUTT CRS
INVESTIGATOR WAY
BASS AVE
RELIANCE CRS
FLINDERS DR

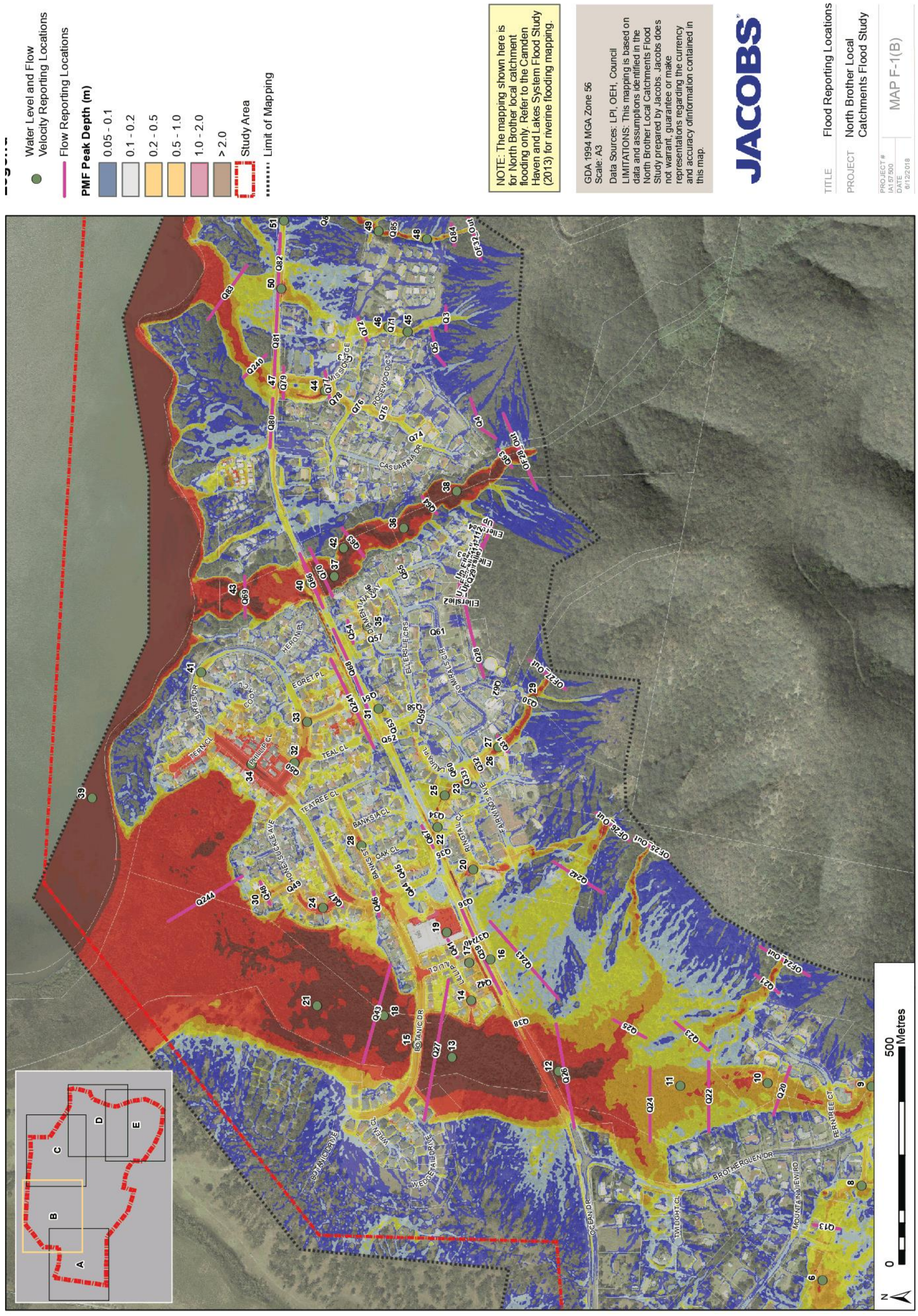

Legend
Change in Flood Level (m)
< 0.01
0.01 - 0.05
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 0.75
0.75 - 1.0
> 1.0
New Areas Flooded
Study Area
Limit of Mapping
NOTES:
1. The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and LakesSystem Flood Study (2013) for riverine flooding mapping.
2. The climate change scenario comprises a 10% increase in the 1% AEP rainfall and a 0.9m sea level rise.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE 1% AEP Design Flood Climate Change Impact Change in Flood Level
PROJECT North Brother Local Catchments Flood Study
PROJECT # IA157500
DATE 3/12/2018
MAP E-15(E)
BOLD ST
REID ST
MILL ST
HANLEY ST
NORMAN ST
0
500
Metres
N
A
B
C
D
E

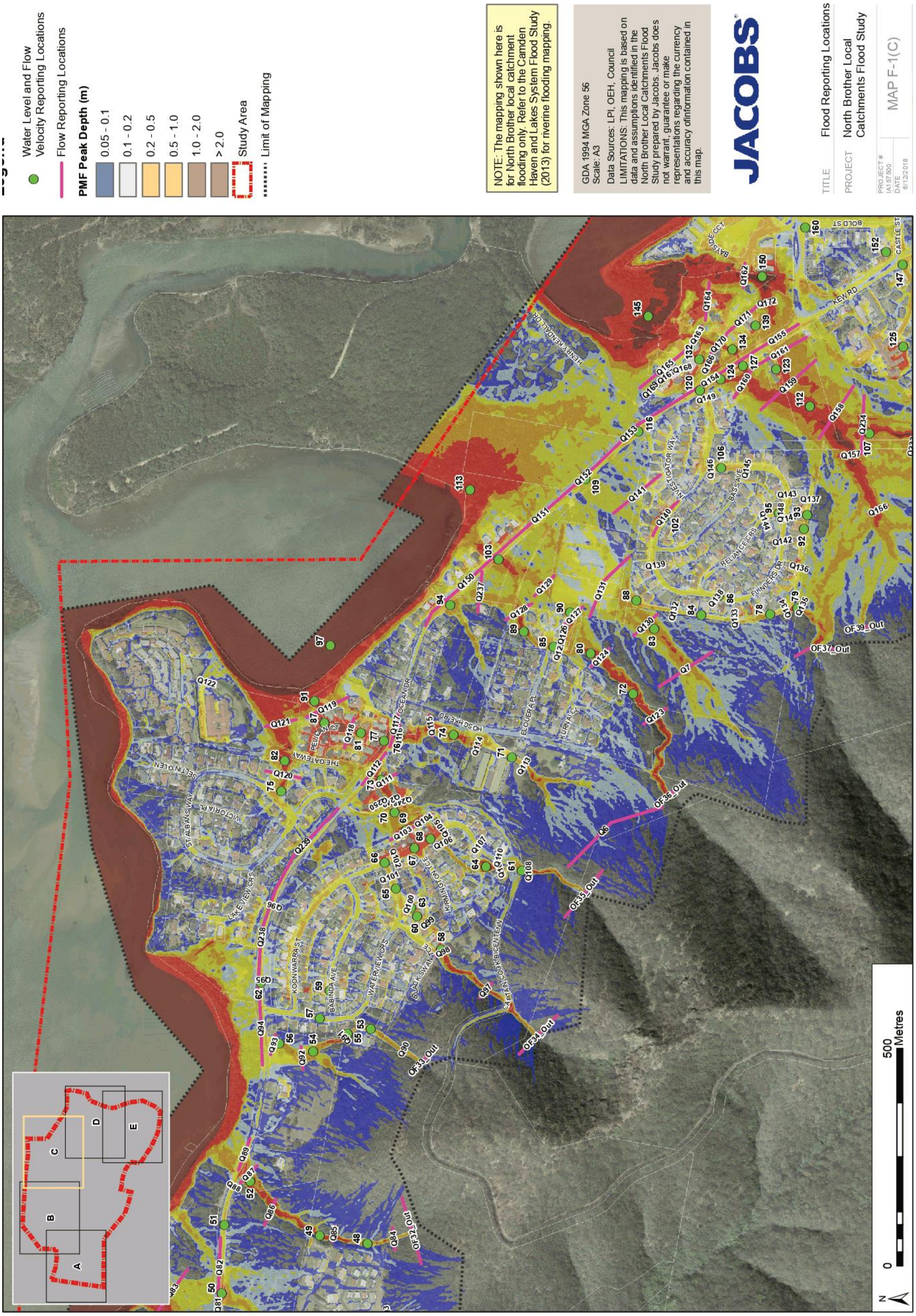
Appendix F. Summary of Flood Levels, Velocities and Flows at Specific Locations

Figure F-1 Flood Level, Velocity and Flow Reporting Locations

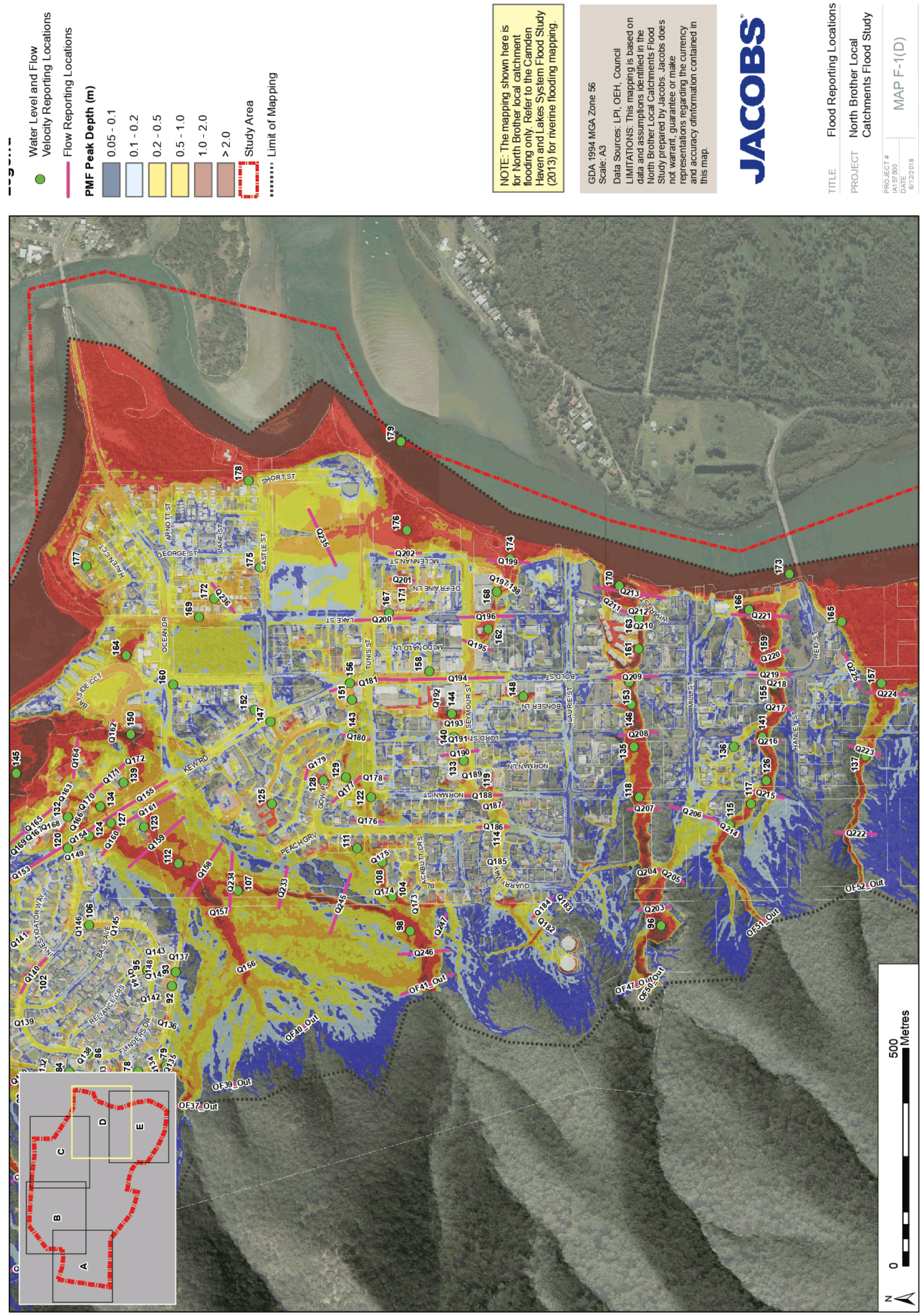
Table F-1 Summary of Peak Flood Level and Velocity at Selected Locations


Water Level and Flow Velocity Reporting Locations
Flow Reporting Locations
PMF Peak Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE Flood Reporting Locations
PROJECT North Brother Local Catchments Flood Study
MAP F-1(A)
0
500
Metres


Water Level and Flow Velocity Reporting Locations
Flow Reporting Locations
PMF Peak Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE Flood Reporting Locations
PROJECT North Brother Local Catchments Flood Study
MAP F-1(B)
0
500
Metres



Water Level and Flow Velocity Reporting Locations
Flow Reporting Locations
PMF Peak Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE Flood Reporting Locations
PROJECT North Brother Local Catchments Flood Study
MAP F-1(C)
0
500
Metres
N


Water Level and Flow Velocity Reporting Locations
Flow Reporting Locations
PMF Peak Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE Flood Reporting Locations
PROJECT North Brother Local Catchments Flood Study
MAP F-1(D)
0
500
Metres
N

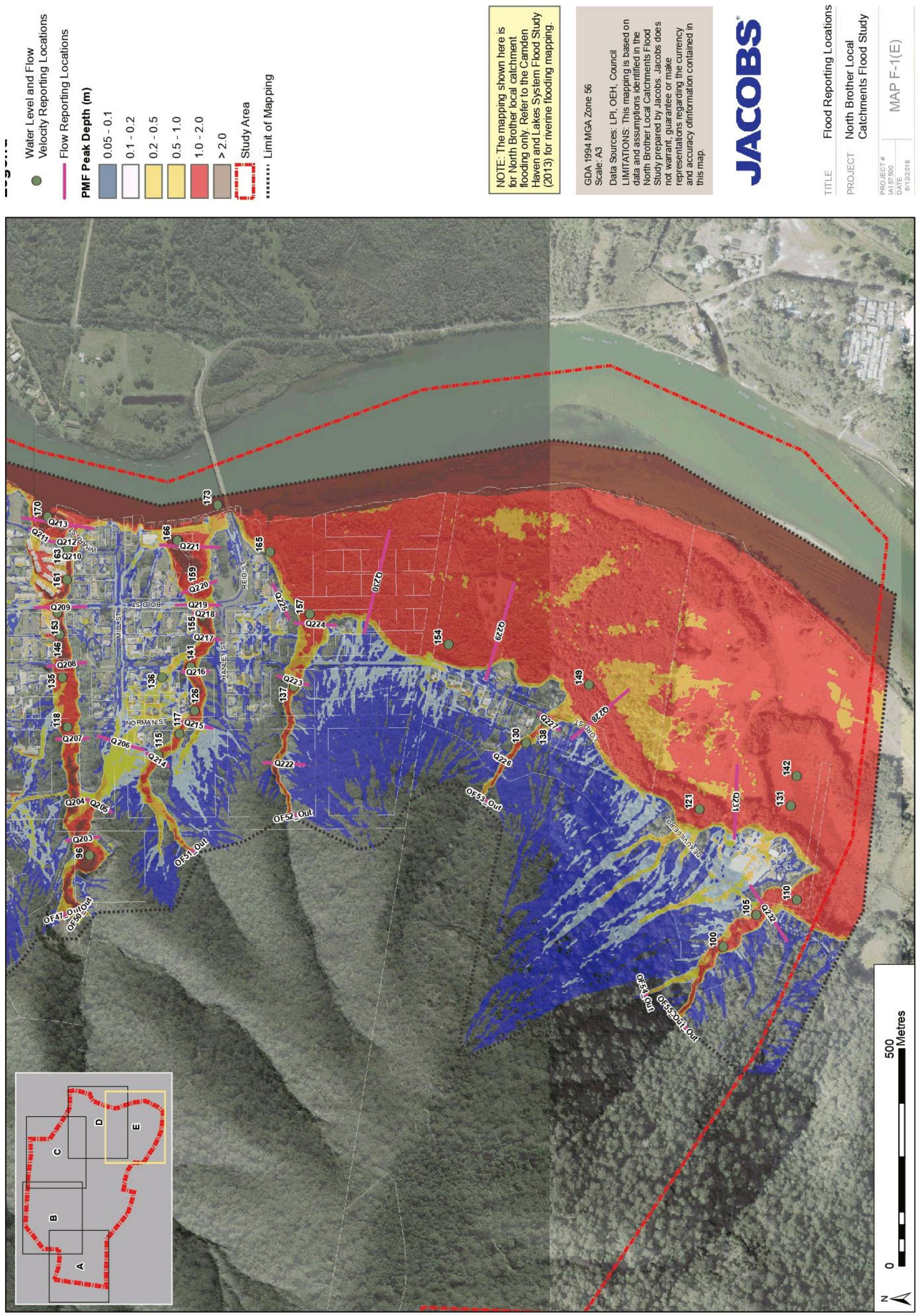

Water Level and Flow Velocity Reporting Locations
Flow Reporting Locations
PMF Peak Depth (m)
0.05 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
> 2.0
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
TITLE Flood Reporting Locations
PROJECT North Brother Local Catchments Flood Study
MAP F-1(E)
0
500 Metres
N

Table F-1 Summary of Peak Flood Level (m AHD) and Velocity (m/s) at Selected Locations

ID	0.2 EY		5% AEP		2% AEP		1% AEP		0.5% AEP		PMF		1%AEP + Climate Change	
	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity
1	1.39	0.1	1.43	0.1	2.01	0.0	2.11	0.0	2.11	0.0	2.39	0.4	3.02	0.0
2	1.52	0.1	1.58	0.1	2.01	0.1	2.11	0.1	2.12	0.1	2.48	0.4	3.02	0.0
3	9.71	1.5	9.96	1.7	10.11	1.8	10.23	1.9	10.32	2.0	11.47	2.9	10.33	2.0
4	4.17	0.4	4.29	0.5	4.35	0.5	4.40	0.5	4.44	0.6	5.12	1.0	4.44	0.6
5	15.67	0.5	15.69	0.5	15.71	0.5	15.70	0.5	15.72	0.5	16.13	1.1	15.72	0.5
6	9.78	0.3	9.84	0.4	9.90	0.4	9.90	0.4	9.92	0.4	10.38	0.9	9.91	0.5
7	19.33	1.1	19.60	1.3	19.78	1.4	19.92	1.5	20.02	1.6	22.39	2.8	20.02	1.6
8	13.99	0.5	14.06	0.6	14.11	0.7	14.10	0.7	14.12	0.7	14.49	1.2	14.12	0.7
9	19.68	1.2	19.74	1.4	19.79	1.5	19.80	1.6	19.82	1.6	20.25	2.7	19.82	1.6
10	11.01	0.6	11.07	0.7	11.11	0.8	11.12	0.8	11.14	0.8	11.55	1.4	11.15	0.8
11	6.82	0.5	6.88	0.6	6.94	0.7	6.96	0.7	6.98	0.7	7.48	1.2	6.98	0.7
12	3.47	0.2	3.53	0.3	3.62	0.4	3.69	0.4	3.76	0.4	4.54	1.2	3.85	0.4
13	2.83	0.8	3.42	0.7	3.61	0.2	3.68	0.2	3.74	0.2	4.39	0.5	3.82	0.2
14	3.64	0.4	3.73	0.5	3.81	0.6	3.84	0.4	3.87	0.4	4.41	0.7	3.89	0.3
15	3.28	0.0	3.38	0.1	3.54	0.3	3.59	0.4	3.64	0.5	4.14	1.3	3.71	0.6
16	5.62	1.1	5.65	1.2	5.68	1.2	5.69	1.2	5.70	1.2	5.86	1.4	5.70	1.2
17	4.44	0.2	4.51	0.2	4.58	0.2	4.60	0.2	4.62	0.2	5.21	0.5	4.62	0.2
18	1.40	0.1	1.47	0.2	2.04	0.2	2.11	0.2	2.19	0.2	3.15	0.7	3.03	0.2
19	-	-	4.44	0.2	4.77	0.3	4.81	0.2	4.89	0.2	5.97	0.7	4.90	0.2
20	10.87	0.5	10.91	0.6	10.98	0.9	10.98	0.9	11.01	1.0	11.67	2.9	11.00	1.0
21	1.35	0.1	1.40	0.1	2.03	0.1	2.11	0.1	2.16	0.1	2.98	0.5	3.02	0.1
22	11.55	1.3	11.57	2.0	11.60	2.3	11.61	2.3	11.62	2.4	11.87	3.4	11.62	2.4
23	17.21	0.9	17.30	1.0	17.40	1.0	17.41	1.0	17.44	1.0	18.18	2.2	17.44	1.1
24	3.05	0.2	3.19	0.2	3.28	0.3	3.31	0.3	3.34	0.3	3.95	1.4	3.36	0.3
25	14.79	1.6	14.87	1.8	14.93	1.8	14.93	1.8	14.95	1.9	15.32	2.5	14.96	1.9
26	19.01	1.3	19.20	1.3	19.33	2.0	19.34	1.3	19.38	1.3	20.01	3.3	19.38	1.4
27	23.19	1.2	23.25	1.4	23.31	1.5	23.31	1.5	23.33	1.6	23.85	2.7	23.36	1.6
28	5.00	0.1	5.04	0.1	5.09	0.1	5.09	0.1	5.11	0.2	5.76	0.5	5.11	0.2
29	31.26	0.6	31.37	0.7	31.45	0.7	31.47	0.8	31.51	0.8	32.29	1.5	31.51	0.8
30	2.64	0.2	3.08	0.3	3.17	0.3	3.20	0.3	3.22	0.3	3.65	0.8	3.24	0.2
31	9.70	0.2	9.73	0.1	9.75	0.1	9.74	0.1	9.75	0.1	9.95	0.5	9.75	0.1
32	3.54	1.1	3.62	1.5	3.69	1.7	3.69	1.7	3.72	1.8	4.64	3.6	3.72	1.8

ID	0.2 EY		5% AEP		2% AEP		1% AEP		0.5% AEP		PMF		1%AEP + Climate Change	
	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity
33	4.67	0.8	4.72	1.1	4.77	1.3	4.77	1.3	4.78	1.4	5.52	2.7	4.78	1.4
34	3.22	0.2	3.47	0.2	3.58	0.3	3.62	0.3	3.67	0.3	4.58	0.9	3.69	0.2
35	12.81	0.4	12.85	0.4	12.89	0.4	12.88	0.4	12.89	0.4	13.51	0.7	12.90	0.4
36	16.90	1.6	17.04	1.7	17.13	1.8	17.20	1.9	17.26	2.0	18.52	3.0	17.25	2.0
37	10.13	0.9	10.26	1.0	10.36	1.1	10.42	1.2	10.48	1.3	11.68	2.7	10.47	1.3
38	22.15	1.4	22.27	1.6	22.35	1.8	22.41	1.9	22.46	2.0	23.57	4.1	22.44	2.0
39	1.26	0.0	1.26	0.0	2.01	0.0	2.11	0.0	2.11	0.0	2.14	0.1	3.01	0.0
40	9.90	0.9	9.98	1.1	10.05	1.2	10.09	1.3	10.13	1.4	10.87	2.8	10.12	1.4
41	5.35	0.1	5.40	0.1	5.48	0.1	5.47	0.1	5.50	0.1	5.79	0.3	5.50	0.2
42	12.00	1.3	12.22	1.4	12.36	1.7	12.46	1.6	12.54	1.7	14.09	2.8	12.54	1.7
43	4.10	1.1	4.23	1.3	4.33	1.4	4.40	1.5	4.45	1.6	5.64	2.7	4.47	1.6
44	13.43	0.7	13.47	0.7	13.51	0.7	13.50	0.9	13.51	0.8	14.00	1.2	13.51	0.8
45	29.75	1.1	29.77	1.2	29.81	1.4	29.81	1.4	29.83	1.4	30.22	2.7	29.84	1.4
46	25.40	0.9	25.43	1.0	25.48	1.1	25.47	1.1	25.49	1.1	25.87	1.9	25.47	1.1
47	10.65	0.4	10.73	0.4	10.81	0.4	10.81	0.4	10.83	0.4	11.35	0.7	10.83	0.4
48	32.85	0.4	32.93	0.4	33.01	0.5	33.00	0.5	33.03	0.5	33.70	1.6	33.03	0.5
49	20.46	1.3	20.55	1.5	20.61	1.6	20.60	1.6	20.63	1.6	21.52	3.3	20.63	1.6
50	8.55	0.8	8.82	0.8	9.02	0.8	9.01	0.8	9.04	0.8	9.36	0.6	9.04	0.7
51	8.73	0.1	8.80	0.1	8.86	0.2	8.85	0.2	8.87	0.2	9.06	0.2	8.87	0.2
52	8.91	0.4	8.96	0.5	9.03	0.6	9.02	0.6	9.04	0.6	9.66	1.6	9.05	0.6
53	33.43	1.9	33.45	2.1	33.48	2.3	33.48	2.4	33.49	2.5	33.87	4.8	33.48	2.5
54	14.96	0.8	15.02	0.9	15.06	1.0	15.07	1.0	15.09	1.1	15.53	1.9	15.08	1.1
55	23.68	0.8	23.78	0.9	23.88	0.8	23.90	0.9	23.94	1.1	24.55	2.4	23.95	1.1
56	8.29	0.9	8.32	1.0	8.35	1.0	8.35	1.0	8.36	1.1	8.62	1.6	8.38	1.1
57	-	-	19.17	2.0	19.20	2.5	19.19	2.4	19.20	2.6	19.35	4.7	19.24	2.5
58	39.69	0.4	39.80	0.5	39.91	1.0	39.91	0.6	39.94	0.6	41.00	1.6	39.94	0.6
59	20.79	0.4	20.81	0.4	20.83	0.5	20.83	0.5	20.84	0.5	20.99	0.7	20.83	0.5
60	32.40	1.4	32.46	1.5	32.51	1.7	32.51	1.7	32.52	1.7	32.93	2.7	32.58	1.6
61	40.13	0.6	40.25	0.6	40.34	0.8	40.35	0.7	40.39	0.7	41.05	1.7	40.39	0.7
62	7.45	0.8	7.50	0.8	7.53	0.9	7.52	0.9	7.53	0.9	7.74	0.9	7.53	0.9
63	30.43	1.7	30.46	2.0	30.50	2.2	30.49	2.2	30.50	2.2	30.76	3.7	30.53	2.2
64	32.17	0.8	32.21	0.7	32.23	1.2	32.24	0.6	32.25	0.6	32.47	1.1	32.25	0.7
65	25.34	3.0	25.38	3.3	25.42	3.7	25.42	3.7	25.43	3.8	25.71	5.7	25.45	3.8

ID	0.2 EY		5% AEP		2% AEP		1% AEP		0.5% AEP		PMF		1%AEP + Climate Change	
	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity
66	20.15	1.2	20.22	1.5	20.29	2.0	20.29	1.9	20.31	2.1	20.54	5.4	20.30	2.1
67	18.81	0.7	18.89	0.7	18.94	0.8	18.94	0.7	18.96	0.7	20.05	1.8	18.96	0.7
68	18.81	0.7	18.87	0.7	18.91	0.7	18.92	0.7	18.94	0.5	19.91	1.2	18.94	0.6
69	16.71	0.7	16.78	0.9	16.84	1.0	16.84	1.0	16.87	1.1	17.32	2.2	16.91	1.1
70	13.79	1.4	13.83	1.6	13.87	1.7	13.87	1.7	13.88	1.7	14.24	2.5	13.87	1.7
71	21.66	0.8	21.71	0.9	21.77	1.1	21.77	1.0	21.79	1.1	22.33	3.4	21.79	1.1
72	28.98	1.5	29.05	1.7	29.10	1.8	29.13	1.9	29.15	1.9	29.63	3.0	29.14	2.0
73	9.53	0.9	9.68	1.0	9.79	1.1	9.80	1.1	9.85	1.1	10.84	1.8	9.85	1.1
74	13.80	0.4	13.86	0.4	13.92	0.5	13.91	0.5	13.94	0.6	14.54	1.7	13.94	0.5
75	3.97	0.9	4.07	0.9	4.15	0.9	4.14	0.9	4.16	0.9	4.72	1.1	4.16	0.9
76	7.77	0.9	7.85	0.9	7.91	1.0	7.90	1.0	7.92	1.0	8.38	3.0	7.92	1.0
77	6.03	1.3	6.27	1.3	6.46	1.3	6.46	1.3	6.53	1.3	8.16	1.2	6.55	1.3
78	37.51	2.3	37.56	2.5	37.60	2.6	37.62	2.7	37.64	2.7	37.82	3.2	37.63	2.7
79	39.08	0.7	39.17	0.8	39.22	1.0	39.26	1.0	39.28	1.1	39.55	2.4	39.28	1.1
80	21.40	1.2	21.51	1.4	21.58	1.5	21.62	1.6	21.65	1.7	22.32	2.6	21.66	1.6
81	4.16	1.8	4.36	2.1	4.50	2.3	4.50	2.3	4.55	2.4	5.37	3.8	4.56	2.3
82	3.11	0.4	3.16	0.5	3.20	0.6	3.20	0.6	3.21	0.6	3.93	1.1	3.21	0.6
83	23.85	0.7	23.89	0.8	23.94	0.9	23.93	0.9	23.95	1.0	24.34	1.8	23.94	1.0
84	28.44	2.4	28.47	2.6	28.48	2.7	28.49	2.7	28.50	2.7	28.74	3.5	28.49	2.7
85	16.16	0.9	16.23	1.1	16.29	1.0	16.30	1.2	16.32	0.9	16.67	4.0	16.30	1.1
86	28.63	1.9	28.69	2.2	28.72	2.4	28.73	2.5	28.75	2.6	28.93	3.6	28.74	2.5
87	3.30	1.5	3.59	1.5	3.80	1.6	3.80	1.6	3.89	1.6	5.12	2.5	3.91	1.4
88	19.93	0.8	20.00	0.9	20.05	1.0	20.06	1.0	20.08	1.0	20.57	1.6	20.09	1.0
89	12.78	0.8	12.84	1.0	12.88	1.2	12.89	1.2	12.90	1.3	13.26	2.3	12.89	1.3
90	14.98	0.6	15.04	0.8	15.08	0.9	15.10	0.9	15.12	1.0	15.53	1.7	15.16	0.9
91	1.69	0.5	1.78	0.7	2.04	0.8	2.11	0.8	2.12	0.9	2.41	2.3	3.01	0.6
92	28.37	0.8	28.42	1.0	28.46	1.1	28.48	1.1	28.50	1.2	28.94	1.9	28.51	1.3
93	27.50	0.9	27.54	1.0	27.57	1.2	27.58	1.2	27.60	1.3	27.99	2.5	27.61	1.3
94	3.85	0.8	3.90	0.8	3.95	0.9	3.96	0.8	3.97	0.8	4.28	1.1	3.97	0.7
95	24.51	0.3	24.55	0.3	24.58	0.2	24.58	0.3	24.59	0.2	24.76	0.2	24.59	0.2
96	40.96	0.3	41.10	0.3	41.17	0.3	41.24	0.3	41.29	0.3	42.44	1.3	41.29	0.3
97	1.26	0.0	1.26	0.0	2.01	0.0	2.11	0.0	2.11	0.0	2.11	0.1	3.01	0.0
98	37.78	1.3	37.88	1.4	37.95	1.5	38.00	1.6	38.04	1.6	38.59	2.3	38.04	1.6

ID	0.2 EY		5% AEP		2% AEP		1% AEP		0.5% AEP		PMF		1%AEP + Climate Change	
	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity
100	11.55	0.3	11.68	0.6	11.77	0.8	11.80	0.8	11.84	0.9	12.66	2.2	11.83	0.9
102	15.35	0.4	15.38	0.5	15.41	0.6	15.42	0.7	15.44	0.7	15.93	1.3	15.44	0.7
103	5.22	0.5	5.32	0.5	5.38	0.6	5.40	0.6	5.43	0.7	5.97	1.4	5.43	0.7
104	33.62	0.9	33.86	1.2	33.99	1.4	34.07	1.5	34.13	1.6	34.73	2.4	34.13	1.6
105	5.85	1.3	5.95	1.5	6.02	1.6	6.04	1.7	6.07	1.7	6.80	3.0	6.07	1.7
106	14.87	1.2	14.93	1.6	15.01	2.0	15.04	2.2	15.06	2.3	15.53	3.4	15.06	2.3
107	19.86	0.7	19.91	0.7	19.95	0.8	19.98	0.9	19.99	0.9	20.51	1.7	19.99	0.9
108	29.88	0.8	30.07	1.0	30.14	1.1	30.18	1.1	30.20	1.1	30.49	1.5	30.17	1.2
109	5.48	0.5	5.58	0.5	5.64	0.5	5.65	0.6	5.66	0.6	5.89	0.6	5.66	0.6
110	1.42	0.6	1.50	0.8	2.04	0.5	2.11	0.5	2.13	0.5	2.47	1.6	3.01	0.2
111	-	-	26.93	0.7	27.03	0.8	27.09	0.9	27.14	1.0	27.65	1.5	27.13	1.0
112	13.92	0.7	14.00	0.9	14.08	1.0	14.11	1.0	14.15	1.1	14.99	2.2	14.15	1.1
113	1.26	0.1	1.26	0.2	2.01	0.1	2.10	0.1	2.11	0.1	2.14	0.5	3.01	0.1
114	25.69	0.5	25.74	0.6	25.78	0.8	25.77	0.7	25.79	0.8	26.15	1.2	25.79	0.8
115	22.98	0.7	23.13	0.8	23.19	0.8	23.23	0.9	23.28	0.9	24.17	1.9	23.28	1.0
116	6.03	0.5	6.05	0.5	6.06	0.5	6.06	0.5	6.07	0.5	6.20	0.8	6.07	0.5
117	18.86	1.1	19.05	1.3	19.13	1.4	19.16	1.4	19.22	1.5	20.32	2.6	19.23	1.5
118	19.73	1.0	19.86	1.1	19.95	1.2	20.01	1.3	20.06	1.4	21.09	2.5	20.06	1.4
119	22.43	1.5	22.50	1.7	22.55	1.8	22.54	1.8	22.56	1.8	23.13	3.0	22.56	1.8
120	6.72	1.0	6.75	1.0	6.78	1.1	6.80	1.1	6.82	1.1	7.10	3.7	6.82	1.1
121	1.33	0.1	1.38	0.1	2.01	0.1	2.11	0.1	2.12	0.1	2.21	0.3	3.02	0.0
122	22.58	0.9	22.64	1.2	22.67	1.4	22.70	1.5	22.73	1.6	23.03	2.9	22.73	1.6
123	10.03	0.7	10.10	0.7	10.19	0.8	10.24	0.8	10.28	0.8	11.35	1.4	10.27	0.9
124	7.06	0.4	7.09	0.4	7.13	0.5	7.14	0.6	7.16	0.7	7.63	1.5	7.16	0.6
125	15.98	0.2	16.06	0.2	16.12	0.2	16.15	0.3	16.20	0.3	16.98	0.8	16.20	0.3
126	15.10	1.1	15.26	1.3	15.35	1.4	15.36	1.4	15.41	1.4	16.57	2.6	15.40	1.4
127	7.40	0.9	7.44	0.9	7.48	1.3	7.50	1.4	7.52	1.5	8.06	2.7	7.52	1.5
128	19.11	0.4	19.18	0.4	19.24	0.5	19.29	0.6	19.33	0.7	20.13	1.4	19.33	0.7
129	20.07	0.4	20.14	0.6	20.18	0.6	20.21	0.7	20.23	0.7	20.58	1.2	20.24	0.7
130	13.58	0.5	13.69	0.7	13.77	0.8	13.79	0.8	13.83	0.9	14.61	1.7	13.83	0.9
131	1.25	0.0	1.25	0.0	2.01	0.0	2.11	0.0	2.11	0.0	2.15	0.2	3.01	0.0

ID	0.2 EY		5% AEP		2% AEP		1% AEP		0.5% AEP		PMF		1%AEP + Climate Change	
	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity
132	3.80	1.7	3.86	1.8	3.93	2.0	3.96	2.0	3.98	2.1	4.55	3.9	3.98	2.1
133	18.15	1.1	18.25	1.3	18.34	1.5	18.32	1.5	18.36	1.6	19.20	3.8	18.37	1.5
134	5.91	1.0	5.95	1.1	5.99	1.2	6.01	1.2	6.03	1.3	6.50	2.1	6.03	1.3
135	14.14	0.6	14.23	0.8	14.30	0.9	14.34	1.0	14.38	1.1	15.22	2.0	14.38	1.1
136	17.44	0.8	17.46	0.9	17.49	0.9	17.50	0.9	17.51	0.9	17.69	1.2	17.51	0.9
137	9.89	1.0	9.98	1.2	10.05	1.3	10.06	1.3	10.09	1.4	10.79	2.8	10.09	1.4
138	6.61	1.4	6.69	1.6	6.76	1.8	6.77	1.8	6.80	1.9	7.35	3.3	6.77	1.9
139	5.85	0.6	5.91	0.7	5.97	0.7	6.00	0.8	6.03	0.8	6.79	1.5	6.03	0.8
140	16.29	0.3	16.34	0.4	16.37	0.5	16.37	0.5	16.38	0.5	16.64	0.9	16.38	0.5
141	10.78	0.7	10.92	0.9	11.00	1.0	11.03	1.0	11.07	1.1	12.10	2.6	11.07	1.0
142	1.25	0.0	1.25	0.0	2.01	0.0	2.11	0.0	2.11	0.0	2.15	0.2	3.01	0.0
143	15.48	0.4	15.59	0.4	15.65	0.4	15.70	0.4	15.73	0.5	16.27	1.2	15.73	0.5
144	13.16	0.3	13.41	0.4	13.65	0.7	13.59	0.6	13.70	0.7	15.18	1.6	13.70	0.7
145	1.28	0.1	1.30	0.2	2.01	0.1	2.11	0.2	2.11	0.2	2.41	0.8	3.01	0.1
146	10.36	1.6	10.52	1.7	10.65	1.9	10.73	2.0	10.80	2.0	12.68	3.1	10.81	2.0
147	11.24	0.8	11.27	1.0	11.30	1.2	11.31	1.3	11.32	1.3	11.48	2.8	11.31	1.3
148	13.98	0.7	14.08	0.7	14.13	0.7	14.14	0.8	14.17	0.9	15.14	1.3	14.17	0.9
149	1.33	0.1	1.38	0.2	2.02	0.1	2.12	0.1	2.12	0.1	2.23	0.3	3.03	0.0
150	2.41	0.4	2.55	0.4	2.72	0.4	2.79	0.4	2.85	0.5	4.33	1.2	3.11	0.4
151	11.64	1.0	11.71	1.3	11.76	1.5	11.79	1.6	11.82	1.7	12.40	2.4	11.82	1.7
152	9.59	0.2	9.72	0.2	9.79	0.3	9.82	0.3	9.85	0.3	10.30	0.3	9.85	0.3
153	10.17	1.5	10.29	1.8	10.39	2.2	10.43	1.5	10.48	1.5	11.30	4.4	10.47	1.5
154	1.28	0.0	1.30	0.0	2.02	0.0	2.11	0.0	2.12	0.0	2.19	0.2	3.02	0.0
155	6.40	0.2	6.49	0.2	6.57	0.2	6.60	0.2	6.63	0.2	7.56	1.2	6.63	0.3
156	11.19	0.5	11.28	0.7	11.32	0.8	11.35	0.9	11.36	1.0	11.70	2.0	11.36	1.0
157	1.37	0.3	1.44	0.4	2.02	0.2	2.11	0.2	2.12	0.2	2.38	0.9	3.01	0.1
158	10.73	0.7	10.83	0.9	10.94	1.0	10.92	1.0	10.97	1.0	11.51	1.5	10.96	1.0
159	2.30	0.4	2.48	0.4	2.58	0.4	2.61	0.4	2.65	0.4	3.52	1.2	3.03	0.3
160	4.25	0.4	4.29	0.3	4.29	0.3	4.31	0.3	4.32	0.4	4.49	0.7	4.32	0.4
161	4.40	2.8	4.55	3.2	4.66	3.4	4.72	3.6	4.77	3.8	5.81	6.2	4.78	3.8
162	4.18	0.7	4.27	0.7	4.31	0.8	4.31	0.8	4.33	0.8	5.04	1.3	4.33	0.8
163	1.93	1.7	2.04	2.1	2.22	2.1	2.27	2.2	2.33	2.3	3.30	4.5	3.05	1.5
164	2.16	0.1	2.54	0.1	2.84	0.0	2.90	0.0	2.93	0.0	3.37	0.3	3.03	0.0

ID	0.2 EY		5% AEP		2% AEP		1% AEP		0.5% AEP		PMF		1%AEP + Climate Change	
	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity	Water Level	Velocity
165	1.26	0.1	1.26	0.1	2.01	0.0	2.11	0.0	2.11	0.0	2.14	0.4	3.01	0.1
166	2.19	0.1	2.37	0.1	2.47	0.1	2.49	0.1	2.51	0.2	3.05	0.7	3.01	0.1
167	4.45	0.5	4.56	0.5	4.60	0.5	4.64	0.5	4.67	0.5	5.27	1.1	4.67	0.5
168	1.48	0.2	1.53	0.4	2.01	0.2	2.11	0.2	2.11	0.2	2.15	2.4	3.01	0.1
169	3.17	0.2	3.21	0.2	3.24	0.2	3.29	0.2	3.32	0.2	3.78	0.8	3.32	0.2
170	1.26	0.2	1.27	0.3	2.02	0.2	2.11	0.2	2.12	0.2	2.20	0.9	3.01	0.1
171	2.28	0.2	2.55	0.4	2.67	0.5	2.73	0.5	2.78	0.5	3.50	0.6	3.07	0.3
172	3.02	0.1	3.07	0.1	3.10	0.1	3.14	0.1	3.16	0.1	3.55	0.3	3.17	0.1
173	1.27	0.1	1.27	0.3	2.01	0.2	2.11	0.2	2.11	0.2	2.12	0.4	3.01	0.0
174	1.26	0.2	1.26	0.3	2.01	0.1	2.11	0.1	2.11	0.1	2.12	0.9	3.01	0.1
175	2.33	0.2	2.38	0.2	2.40	0.2	2.41	0.2	2.43	0.2	2.66	0.5	3.02	0.0
176	1.26	0.1	1.30	0.3	2.01	0.1	2.11	0.1	2.11	0.1	2.15	0.4	3.01	0.1
177	1.45	0.1	1.46	0.2	2.01	0.0	2.11	0.0	2.11	0.0	2.13	0.1	3.01	0.0
178	-	-	-	-	2.01	0.0	2.11	0.0	2.11	0.0	2.12	0.2	3.01	0.0
179	1.25	0.0	1.26	0.0	2.01	0.0	2.11	0.0	2.11	0.0	2.11	0.2	3.01	0.0

Table F-2 Summary of Peak Flow (m^3/s) at Selected Locations

ID	0.2 EY	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF	1%AEP + Climate Change	ID	0.2 EY	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF	1%AEP + Climate Change
Q2	0.1	0.1	0.1	0.1	0.1	0.4	0.1	Q33	6.0	8.7	10.9	11.4	12.5	31.8	12.5
Q3	0.8	1.0	1.4	1.4	1.6	6.2	1.6	Q34	6.0	8.1	10.2	10.4	11.1	21.1	11.1
Q4	0.2	0.2	0.3	0.3	0.3	1.2	0.3	Q35	3.7	4.8	5.7	5.7	6.1	10.6	6.1
Q5	0.3	0.4	0.5	0.5	0.6	2.3	0.6	Q36	2.6	3.6	4.5	4.5	4.8	8.4	4.8
Q6	1.2	1.6	2.2	2.2	2.5	9.7	2.5	Q37	2.2	2.6	2.8	2.9	2.9	4.7	2.9
Q7	2.9	4.1	5.5	5.4	6.1	25.3	6.1	Q38	5.2	5.9	6.4	6.6	6.7	10.4	6.7
Q8	73.8	106.3	131.0	151.4	169.8	521.8	169.8	Q39	1.2	3.4	5.5	6.1	7.1	26.4	7.1
Q9	70.5	102.9	125.6	147.2	164.1	437.7	164.1	Q40	1.2	1.3	1.5	1.5	1.6	2.3	1.6
Q10	1.6	2.4	3.2	3.2	3.5	7.1	3.5	Q41	1.8	2.1	2.5	2.5	2.7	7.2	2.7
Q11	0.9	1.0	1.1	1.1	1.2	8.7	1.2	Q42	1.1	2.1	3.0	3.3	3.7	12.3	3.7
Q12	1.1	1.8	2.5	2.5	2.8	7.3	2.8	Q43	8.6	12.2	25.5	34.3	44.9	249.4	56.0
Q13	1.9	3.0	4.4	4.3	4.7	15.4	4.7	Q44	1.6	2.8	4.1	4.3	4.8	13.6	4.8
Q14	3.6	5.9	8.4	8.8	9.8	40.8	9.8	Q45	0.4	1.0	1.6	1.8	2.0	6.8	2.0
Q15	5.9	9.6	11.6	14.1	15.5	61.0	15.5	Q46	2.0	4.1	6.7	7.2	8.5	46.1	8.7
Q16	8.3	12.4	17.1	23.1	26.1	117.0	21.9	Q47	0.9	1.8	3.1	3.5	4.3	27.8	4.6
Q17	1.5	1.9	2.8	3.2	2.9	7.6	5.2	Q48	0.2	0.8	1.6	2.0	2.3	11.0	2.4
Q18	62.1	94.5	124.5	143.6	160.6	540.7	158.6	Q49	0.1	0.9	1.7	2.0	2.3	13.0	2.6
Q19	5.6	7.9	10.3	11.1	12.2	32.4	12.2	Q50	1.6	3.9	6.2	6.0	7.2	37.3	7.5
Q20	6.3	9.5	13.3	13.8	15.2	47.7	15.2	Q51	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Q21	3.5	5.1	6.3	6.8	7.6	20.0	7.6	Q52	0.3	0.4	0.5	0.5	0.7	2.5	0.7
Q22	7.1	10.5	15.0	15.8	18.0	65.8	18.0	Q53	1.0	1.5	2.2	2.1	2.4	10.5	2.4
Q23	3.7	5.3	7.0	7.4	8.1	20.4	8.1	Q54	1.3	2.1	2.9	2.8	3.2	11.2	3.2
Q24	9.0	13.1	18.1	19.4	22.0	80.8	22.0	Q55	0.6	0.7	1.0	1.0	1.1	4.2	1.1
Q25	4.9	7.3	10.6	10.4	11.5	43.5	11.5	Q56	1.3	1.7	2.3	2.2	2.5	9.3	2.5
Q26	16.4	25.7	34.0	37.3	41.0	182.7	40.9	Q57	0.3	0.4	0.5	0.5	0.6	1.6	0.6
Q27	10.4	11.7	22.9	31.7	41.3	234.3	54.9	Q58	0.6	0.8	1.1	1.0	1.2	4.3	1.2
Q28	0.2	0.2	0.3	0.3	0.3	1.4	0.3	Q59	0.3	0.6	0.9	0.9	1.0	4.9	1.0
Q29	1.3	1.8	2.5	2.5	2.7	10.9	2.7	Q60	0.1	0.1	0.2	0.3	0.5	6.5	0.5
Q30	4.9	6.9	8.7	9.2	10.3	28.2	10.3	Q61	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q31	5.7	8.0	10.7	11.1	12.2	35.9	12.2	Q62	0.1	0.1	0.1	0.1	0.1	0.5	0.1
Q32	5.7	8.4	11.1	11.5	12.7	37.2	12.7	Q63	34.4	45.4	53.5	61.0	67.3	179.7	67.3

ID	0.2 EY	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF	1%AEP + Climate Change	ID	0.2 EY	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF	1%AEP + Climate Change
Q69	35.8	49.9	61.4	70.0	78.0	231.4	78.0	Q101	3.4	5.1	7.3	7.2	8.0	23.3	8.0
Q70	34.1	47.2	57.9	65.5	72.8	214.7	72.8	Q102	3.0	4.2	6.3	6.1	6.8	17.1	6.8
Q71	1.3	1.8	2.5	2.4	2.7	9.7	2.7	Q103	3.5	7.0	10.2	10.7	12.1	37.5	12.1
Q72	1.6	2.1	3.0	2.9	3.3	13.4	3.3	Q104	1.4	2.5	3.3	3.4	3.9	21.9	3.9
Q73	1.0	1.3	1.7	1.6	1.8	5.0	1.8	Q105	0.4	1.0	1.6	1.7	2.0	9.1	2.0
Q74	0.7	0.9	1.2	1.2	1.3	5.9	1.3	Q106	3.5	4.9	6.1	6.5	7.0	20.4	7.0
Q75	1.3	1.8	2.5	2.4	2.7	12.6	2.7	Q107	0.5	1.0	1.5	1.6	1.9	7.3	1.9
Q76	1.4	1.9	2.7	2.6	3.0	16.9	3.0	Q108	3.0	4.4	5.4	5.8	6.4	18.0	6.4
Q77	3.3	4.7	6.9	6.6	7.5	32.6	7.5	Q109	3.0	4.1	5.1	5.2	5.6	15.4	5.6
Q78	1.8	2.8	4.3	4.1	4.8	20.3	4.8	Q110	0.5	0.9	1.5	1.5	1.7	5.5	1.7
Q79	5.4	7.3	9.7	9.6	10.7	41.1	10.7	Q111	7.0	11.3	15.4	15.6	17.6	60.6	17.6
Q80	0.5	0.7	0.9	0.9	1.0	3.9	1.0	Q112	5.8	10.7	14.9	15.7	17.5	61.9	17.5
Q81	1.7	3.8	6.5	6.2	7.5	38.7	7.5	Q113	2.2	3.0	4.1	4.0	4.5	19.1	4.5
Q82	0.0	0.0	0.6	0.4	1.0	13.9	1.0	Q114	2.8	3.9	5.2	5.0	5.6	20.2	5.6
Q83	7.7	11.3	15.6	15.2	16.8	73.7	16.4	Q115	3.3	4.6	6.5	6.3	7.1	31.1	7.1
Q84	1.7	2.4	3.1	3.2	3.6	9.9	3.6	Q116	3.7	5.4	7.6	7.3	8.3	36.2	8.3
Q85	2.9	4.0	5.4	5.2	5.8	19.9	5.8	Q117	0.4	1.9	4.0	3.7	4.7	33.6	4.7
Q86	4.0	5.2	7.6	7.1	7.8	29.6	7.8	Q118	7.4	13.7	20.0	20.1	23.2	74.0	23.4
Q87	4.0	5.7	7.9	7.6	8.4	32.1	8.4	Q119	6.6	12.5	18.0	18.2	20.8	70.3	21.6
Q88	0.4	0.7	1.0	0.9	1.0	2.8	1.0	Q120	2.3	3.7	5.0	4.8	5.2	23.4	5.2
Q89	2.7	4.3	6.4	6.1	7.0	26.3	7.0	Q121	3.4	5.2	7.7	7.5	8.5	62.1	8.4
Q90	3.0	4.5	5.4	6.0	6.6	16.6	6.6	Q122	0.4	0.7	0.9	0.8	0.9	3.8	0.9
Q91	3.6	5.2	6.3	6.6	7.4	16.8	7.4	Q123	6.8	9.7	12.1	13.6	15.0	37.5	15.0
Q92	5.0	6.8	9.0	8.9	9.9	28.1	9.9	Q124	6.9	9.9	12.8	14.1	15.5	41.6	15.5
Q93	4.2	5.5	7.1	7.1	7.7	19.5	7.7	Q125	4.2	6.0	7.5	8.0	8.7	21.1	8.7
Q94	6.3	9.1	12.5	12.5	13.8	43.7	13.8	Q126	1.2	1.8	2.2	2.4	2.7	6.0	2.7
Q95	0.8	1.0	1.2	1.2	1.3	1.9	1.3	Q127	1.9	3.3	4.7	5.3	6.2	22.9	6.2
Q96	0.6	0.8	0.9	0.8	0.9	2.8	0.9	Q128	5.5	8.2	10.6	11.1	12.2	31.7	12.2
Q97	3.9	5.5	7.1	7.2	8.0	24.9	8.0	Q129	2.5	4.4	6.3	7.1	8.0	31.0	8.0
Q98	4.6	6.3	8.7	8.4	9.3	32.1	9.3	Q130	3.3	4.7	6.5	6.5	7.3	30.9	7.3
Q99	3.8	5.1	7.0	6.8	7.4	21.4	7.4	Q131	5.8	8.4	11.4	11.5	12.6	49.3	12.6
Q100	3.3	4.6	6.0	6.0	6.5	17.2	6.5	Q132	2.6	3.3	3.8	3.9	4.2	10.4	4.2

ID	0.2 EY	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF	1%AEP + Climate Change	ID	0.2 EY	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF	1%AEP + Climate Change
Q133	2.9	3.6	4.2	4.3	4.6	9.8	4.6	Q164	3.3	5.3	7.6	9.0	10.3	50.3	10.5
Q134	5.3	6.8	7.8	8.6	9.3	15.1	9.3	Q165	9.2	11.5	15.3	17.3	18.9	70.0	18.9
Q135	8.5	11.0	12.6	14.3	15.5	28.1	15.5	Q166	4.9	6.1	7.7	8.6	9.5	34.7	9.5
Q136	1.1	1.8	2.3	2.9	3.3	10.7	3.3	Q167	1.7	2.2	2.8	3.2	3.5	9.1	3.5
Q137	0.7	1.0	1.3	1.5	1.8	6.8	1.8	Q168	1.3	1.7	2.2	2.6	2.8	9.1	2.8
Q138	2.1	3.6	4.7	5.3	5.9	13.6	5.9	Q169	0.1	0.2	0.3	0.3	0.4	4.7	0.4
Q139	0.8	1.9	3.0	3.3	3.8	11.1	3.8	Q170	8.5	10.0	11.7	12.6	13.6	34.5	13.6
Q140	0.9	2.1	3.0	3.4	3.7	10.1	3.7	Q171	3.1	5.0	7.3	8.8	9.9	45.5	9.9
Q141	1.2	2.7	4.6	5.2	6.0	18.4	6.0	Q172	3.0	4.8	7.0	8.2	9.5	50.7	9.5
Q142	0.7	1.3	2.0	2.4	2.8	8.9	2.8	Q173	0.6	1.2	1.8	2.2	2.5	9.4	2.5
Q143	0.7	1.7	2.7	3.3	3.9	14.5	3.9	Q174	5.3	9.4	11.6	13.7	14.9	28.2	14.9
Q144	0.2	0.3	0.4	0.4	0.5	1.5	0.5	Q175	5.2	9.4	12.4	14.1	15.5	31.5	15.5
Q145	0.8	1.7	2.9	3.5	4.0	13.3	4.0	Q176	3.5	6.2	7.8	9.2	10.3	28.2	10.3
Q146	0.7	1.7	3.6	4.3	5.1	19.9	5.1	Q177	1.9	3.4	4.4	5.3	6.2	25.7	6.2
Q147	0.8	1.7	2.7	3.2	3.7	11.4	3.7	Q178	1.6	3.0	4.1	5.0	5.8	21.9	5.8
Q148	0.3	0.5	0.7	0.9	1.0	3.2	1.0	Q179	1.8	3.2	4.1	5.0	5.6	19.5	5.6
Q149	0.6	1.2	2.5	3.1	3.6	20.1	3.6	Q180	2.1	4.1	5.7	7.1	8.3	36.2	8.3
Q150	3.7	8.0	13.6	15.4	17.6	77.1	17.6	Q181	1.5	3.8	5.9	7.0	8.5	55.1	8.5
Q151	2.7	4.7	7.5	7.6	8.8	43.3	8.8	Q182	1.5	1.9	2.2	2.2	2.3	3.6	2.3
Q152	0.2	1.3	3.2	3.7	4.4	19.3	4.4	Q183	0.0	0.1	0.1	0.1	0.1	0.2	0.1
Q153	2.4	3.3	4.4	4.9	5.5	22.0	5.5	Q184	1.7	2.3	2.8	2.8	2.9	5.8	2.9
Q154	11.7	15.7	21.5	24.5	27.2	113.6	27.2	Q185	2.2	3.3	4.6	4.6	5.2	23.3	5.2
Q155	5.5	8.8	12.6	15.1	17.1	88.0	17.1	Q186	2.5	4.3	6.1	6.0	6.8	32.9	6.8
Q156	5.2	7.9	10.4	10.9	12.3	43.9	12.3	Q187	2.8	4.8	6.9	6.7	7.7	40.6	7.7
Q157	7.3	11.3	15.1	15.9	18.0	68.1	18.0	Q188	3.0	5.1	7.3	7.0	8.1	43.0	8.1
Q158	22.7	29.9	37.7	42.5	46.7	156.4	46.7	Q189	3.2	5.3	7.5	7.0	8.2	38.7	8.2
Q159	23.4	30.5	38.7	43.7	47.5	168.5	47.5	Q190	2.6	4.8	7.4	6.8	8.1	54.2	8.1
Q160	17.3	20.8	25.0	27.3	29.2	86.1	29.2	Q191	2.2	4.5	7.1	6.5	7.7	54.8	7.7
Q161	6.3	10.0	14.2	16.7	19.1	94.6	19.1	Q192	1.5	3.7	5.9	5.4	6.5	21.7	6.5
Q162	4.6	6.7	10.1	11.7	13.2	71.6	12.4	Q193	1.9	4.2	6.8	6.3	7.5	55.5	7.5
Q163	8.3	9.7	11.3	12.2	12.9	35.8	12.9	Q194	2.3	5.3	8.1	7.5	8.9	55.2	8.9

ID	0.2 EY	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF	1%AEP + Climate Change	ID	0.2 EY	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF	1%AEP + Climate Change
Q195	4.6	6.4	8.4	8.1	9.0	54.7	9.0	Q226	5.2	7.5	9.1	10.0	11.2	29.6	11.2
Q196	1.0	2.8	4.7	4.6	5.4	52.7	5.4	Q227	5.8	8.1	10.9	11.5	12.6	35.5	12.6
Q197	4.0	5.0	6.5	6.5	7.1	39.5	6.2	Q228	1.1	1.4	3.1	3.2	4.0	10.6	3.2
Q198	0.8	1.8	2.4	2.4	2.5	5.9	3.1	Q229	1.2	1.1	2.8	3.0	3.2	2.0	4.9
Q199	4.9	7.0	8.8	9.0	9.9	44.7	9.2	Q230	1.5	1.4	4.6	5.1	5.7	8.2	6.3
Q200	1.3	4.3	5.9	7.1	8.2	50.7	8.2	Q231	3.1	4.6	7.7	6.5	7.0	24.8	8.8
Q201	0.9	3.3	4.8	5.6	6.3	19.6	6.1	Q232	12.0	17.8	22.6	24.4	27.0	77.1	27.0
Q202	1.4	4.3	6.1	7.1	7.9	29.0	8.2	Q233	18.3	23.6	27.5	30.4	32.5	68.6	32.5
Q203	19.2	26.2	31.2	35.2	39.1	105.8	39.1	Q234	18.5	23.7	27.3	30.2	32.7	78.3	32.7
Q204	13.9	19.2	22.7	26.3	29.3	82.4	29.3	Q235	1.2	2.4	3.6	3.7	3.8	25.5	3.5
Q205	4.9	6.4	7.4	8.3	9.0	22.9	9.0	Q236	0.4	0.6	0.8	1.0	1.2	3.9	1.2
Q206	3.4	4.3	5.1	5.6	6.0	13.7	6.0	Q237	4.6	6.3	7.8	8.2	9.0	21.7	9.0
Q207	15.0	21.4	26.5	29.9	33.5	98.4	33.5	Q238	0.4	0.6	1.0	0.8	1.1	17.8	1.1
Q208	15.2	21.8	27.5	31.4	35.0	108.6	35.0	Q239	1.1	1.6	2.1	2.0	2.1	7.8	2.1
Q209	11.5	18.4	25.0	28.8	32.4	110.4	32.4	Q240	5.1	7.2	10.0	9.7	10.9	44.5	10.9
Q210	15.0	21.4	27.0	30.9	33.9	101.7	34.0	Q241	1.9	3.7	5.5	5.3	6.4	41.0	6.5
Q211	0.3	0.7	1.6	2.4	3.1	19.1	3.4	Q242	5.2	7.2	8.8	9.5	10.3	20.8	10.3
Q212	14.8	21.4	27.1	30.9	34.2	104.8	34.5	Q243	5.1	7.2	9.3	10.1	10.9	27.4	10.9
Q213	15.1	22.0	30.2	32.0	37.8	125.6	38.0	Q244	4.2	5.5	10.4	13.8	18.0	113.7	23.9
Q214	5.1	8.0	9.6	10.2	11.6	39.5	11.6	Q245	18.5	23.9	27.0	30.2	32.5	68.1	32.5
Q215	6.2	10.0	12.4	12.8	14.4	55.2	14.4	Q246	24.0	33.9	40.8	46.3	51.6	131.4	51.6
Q216	6.8	10.8	13.6	14.4	16.2	65.1	16.2	Q247	0.5	0.6	0.7	0.7	0.7	2.0	0.7
Q217	9.6	13.7	17.6	19.5	21.5	80.2	21.5	OF1_Out	55.7	96.5	117.5	132.8	146.1	446.6	146.1
Q218	9.6	13.7	17.6	19.6	21.7	81.5	21.7	OF23_Out	5.1	7.3	8.6	9.9	10.9	26.2	10.9
Q219	6.3	10.4	14.6	16.4	18.6	79.8	18.6	OF24_Out	0.8	1.4	1.8	2.1	2.4	8.6	2.4
Q220	10.1	14.3	18.7	20.5	22.9	87.5	22.9	OF25_Out	2.4	3.4	4.2	4.6	5.1	12.2	5.1
Q221	7.8	13.1	18.4	20.7	23.1	92.6	23.8	OF26_Out	1.9	2.3	2.7	3.3	3.6	6.7	3.6
Q222	6.0	8.7	10.8	11.6	12.9	34.8	12.9	OF27_Out	0.7	1.7	2.0	2.3	2.6	5.6	2.6
Q223	6.8	9.9	13.0	13.8	15.3	44.1	15.3	OF28_Out	3.0	5.3	7.1	8.8	10.2	6.7	10.2
Q224	7.4	10.7	14.7	15.2	16.9	52.4	17.5	OF32_Out	1.7	2.4	3.1	3.2	3.5	8.8	3.5
Q225	0.8	1.1	1.4	1.4	1.5	6.3	1.5	OF33_Out	0.2	0.5	0.8	0.9	1.0	4.0	1.0

ID	0.2 EY	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF	1%AEP + Climate Change	ID	0.2 EY	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF	1%AEP + Climate Change
OF34_Out	0.1	0.2	0.3	0.3	0.3	1.2	0.3	OF55_Out	0.1	0.1	0.2	0.2	0.2	0.8	0.2
OF35_Out	0.2	0.2	0.3	0.3	0.5	4.0	0.5	OF56_Out	1.1	1.8	2.2	2.6	2.9	7.7	2.9
OF36_Out	5.0	6.7	7.8	8.8	9.9	30.5	9.9	OF41_Out	24.1	34.2	40.0	46.9	52.1	137.2	52.1
OF37_Out	1.0	2.8	4.0	5.1	5.9	12.6	5.9	Up Ellerslie	0.7	0.9	1.3	1.3	1.4	5.5	1.4
OF39_Out	0.1	0.1	0.2	0.1	0.2	0.8	0.2	Up Ellerslie2	0.0	0.0	0.0	0.0	0.0	0.1	0.0
OF40_Out	0.1	0.2	0.3	0.4	0.4	1.9	0.4	Up Ellerslie3	0.0	0.0	0.0	0.0	0.0	0.2	0.0
OF47_Out	1.3	1.9	2.5	2.8	5.3	6.6	5.3	Up Ellerslie4	0.0	0.0	0.0	0.0	0.0	0.7	0.0
OF50_Out	1.5	2.4	3.1	3.3	3.2	10.4	3.2	Q248	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OF51_Out	1.6	1.6	1.9	2.4	2.6	4.8	2.6	Q249	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OF52_Out	1.1	2.3	2.9	3.7	4.4	15.9	4.4	Q250	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OF53_Out	0.4	1.1	1.5	1.8	2.0	8.1	2.0	Up Ellerslie111	0.8	1.1	1.5	1.5	1.6	6.6	1.6
OF54_Out	0.0	0.1	0.1	0.1	0.1	0.7	0.1	Up Ellerslie112	0.5	0.7	0.9	0.9	1.0	4.5	1.0

Appendix G. Provisional Hydraulic and Hazard Mapping

Legend

Flood Hazard Category

- H1 - Generally safe for vehicles, people and buildings.
- H2 - Unsafe for small vehicles.
- H3 - Unsafe for all vehicles, children and the elderly.
- H4 - Unsafe for all people and all vehicles.
- H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction.
- H6 - Unsafe for Vehicles and people. All building types considered vulnerable to failure.
- Study Area
- Limit of Mapping

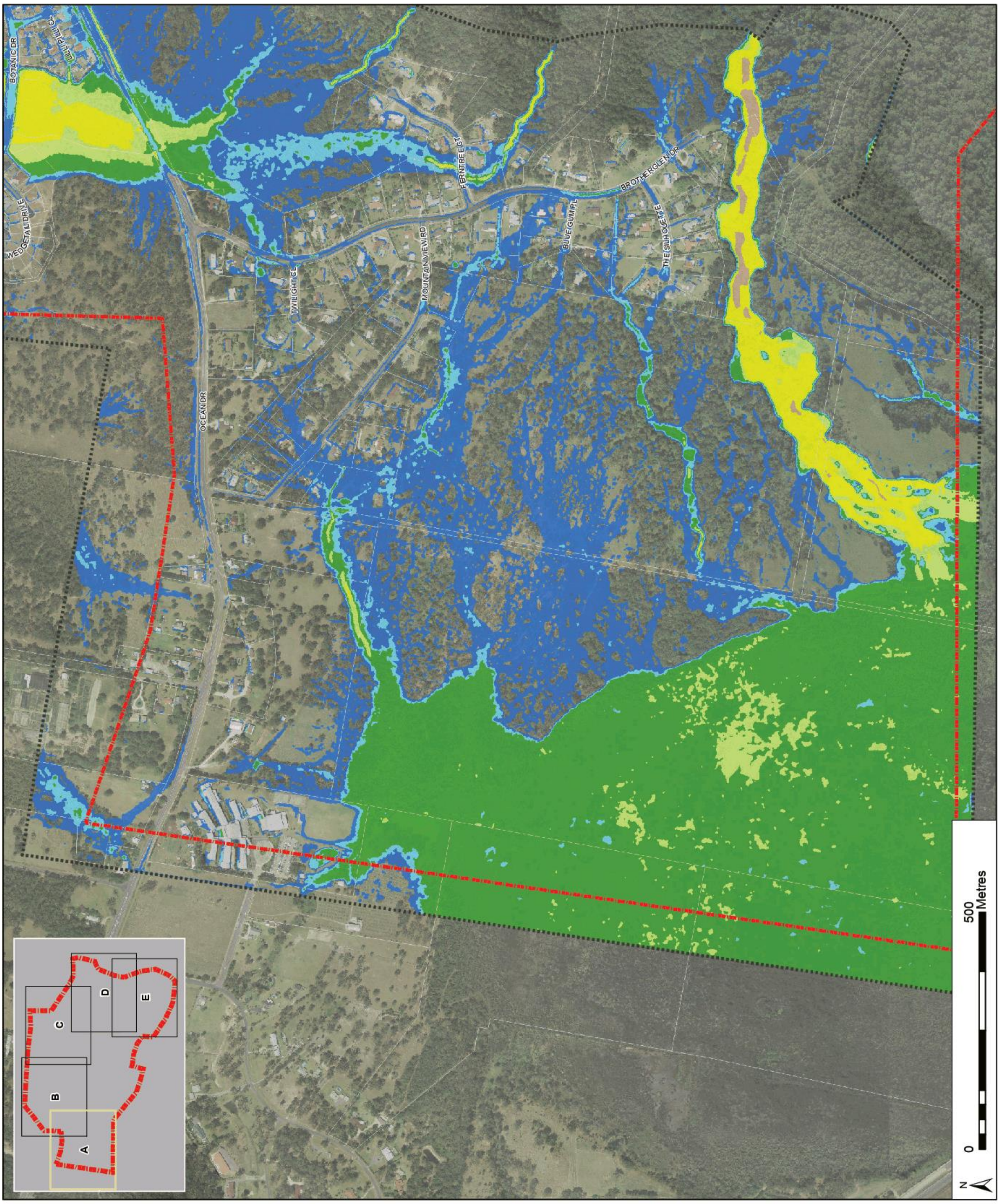
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.

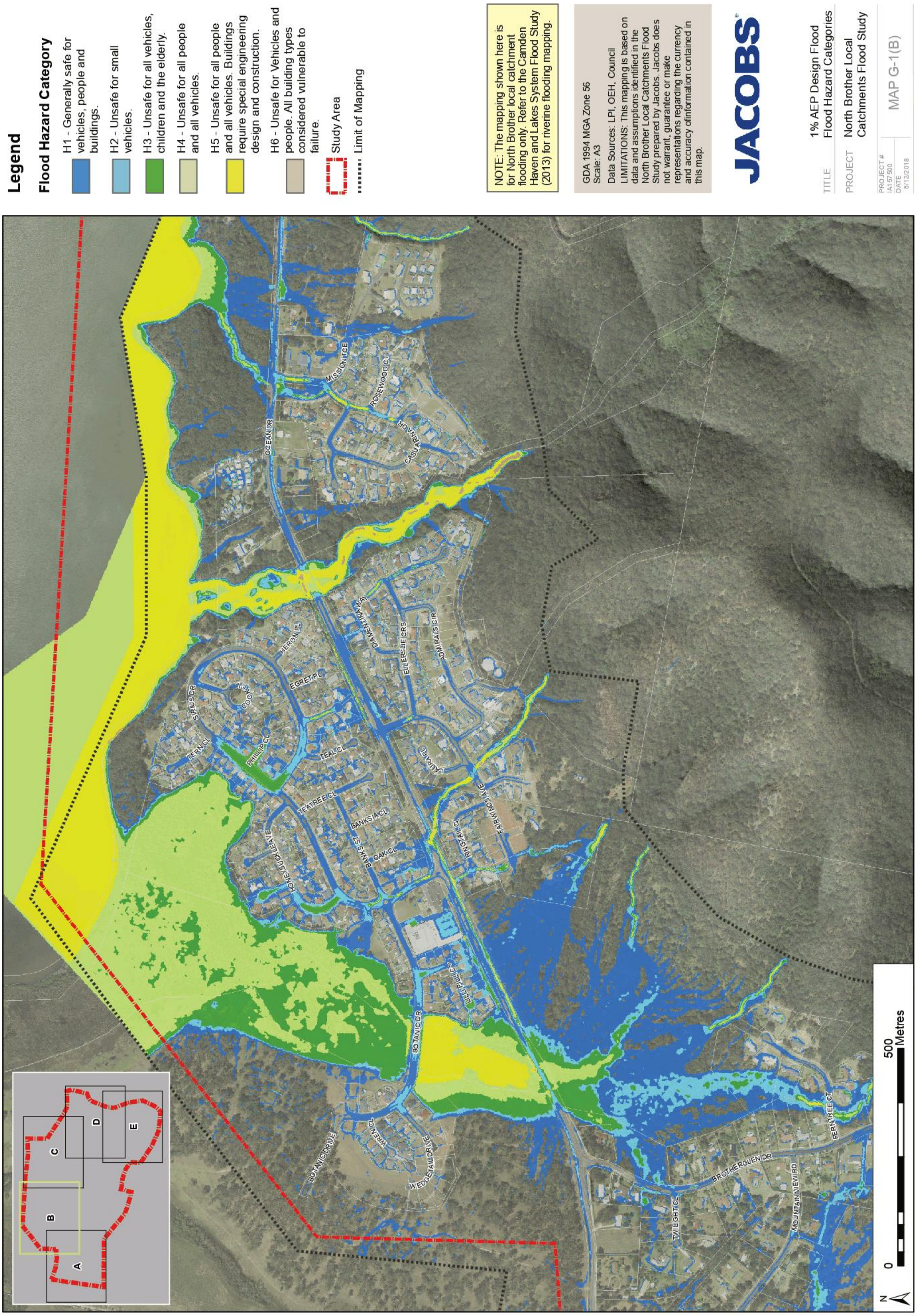
GDA 1994 MGA Zone 56
Scale: A3

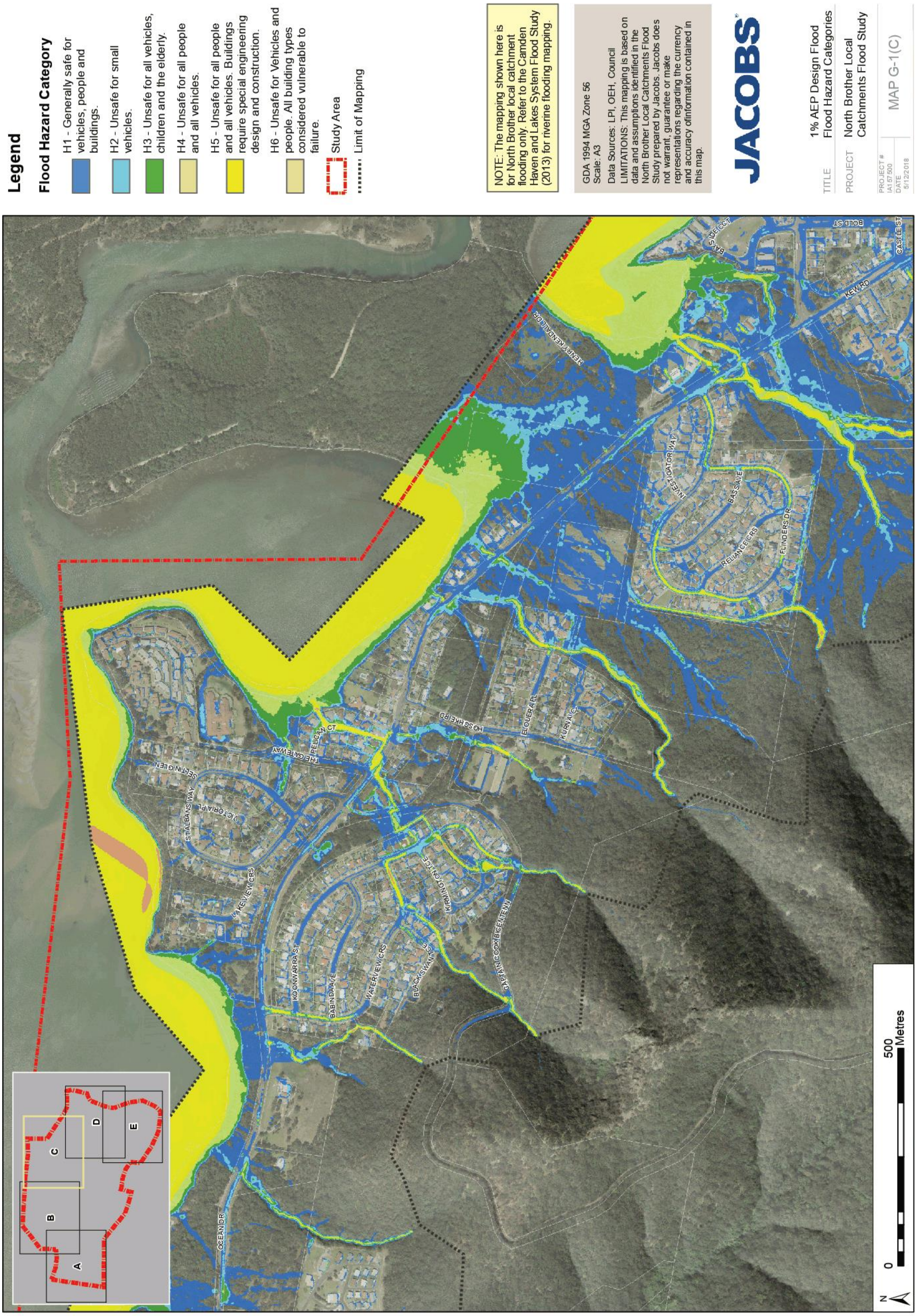
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.

JACOBS

TITLE	1% AEP Design Flood Flood Hazard Categories
PROJECT	North Brother Local Catchments Flood Study
PROJECT # IA157500 DATE 5/12/2018	MAP G-1(A)




Legend
Flood Hazard Category
H1 - Generally safe for vehicles, people and buildings.
H2 - Unsafe for small vehicles.
H3 - Unsafe for all vehicles, children and the elderly.
H4 - Unsafe for all people and all vehicles.
H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction.
H6 - Unsafe for Vehicles and people. All building types considered vulnerable to failure.
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE 1% AEP Design Flood Hazard Categories
PROJECT North Brother Local Catchments Flood Study
MAP G-1(B)
0
500 Metres
N


Legend
Flood Hazard Category
H1 - Generally safe for vehicles, people and buildings.
H2 - Unsafe for small vehicles.
H3 - Unsafe for all vehicles, children and the elderly.
H4 - Unsafe for all people and all vehicles.
H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction.
H6 - Unsafe for Vehicles and people. All building types considered vulnerable to failure.
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 1% AEP Design Flood Flood Hazard Categories
PROJECT North Brother Local Catchments Flood Study
MAP G-1(C)
0
500
Metres
N

Legend

Flood Hazard Category

- H1 - Generally safe for vehicles, people and buildings.
- H2 - Unsafe for small vehicles.
- H3 - Unsafe for all vehicles, children and the elderly.
- H4 - Unsafe for all people and all vehicles.
- H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction.
- H6 - Unsafe for Vehicles and people. All building types considered vulnerable to failure.
- Study Area
- Limit of Mapping

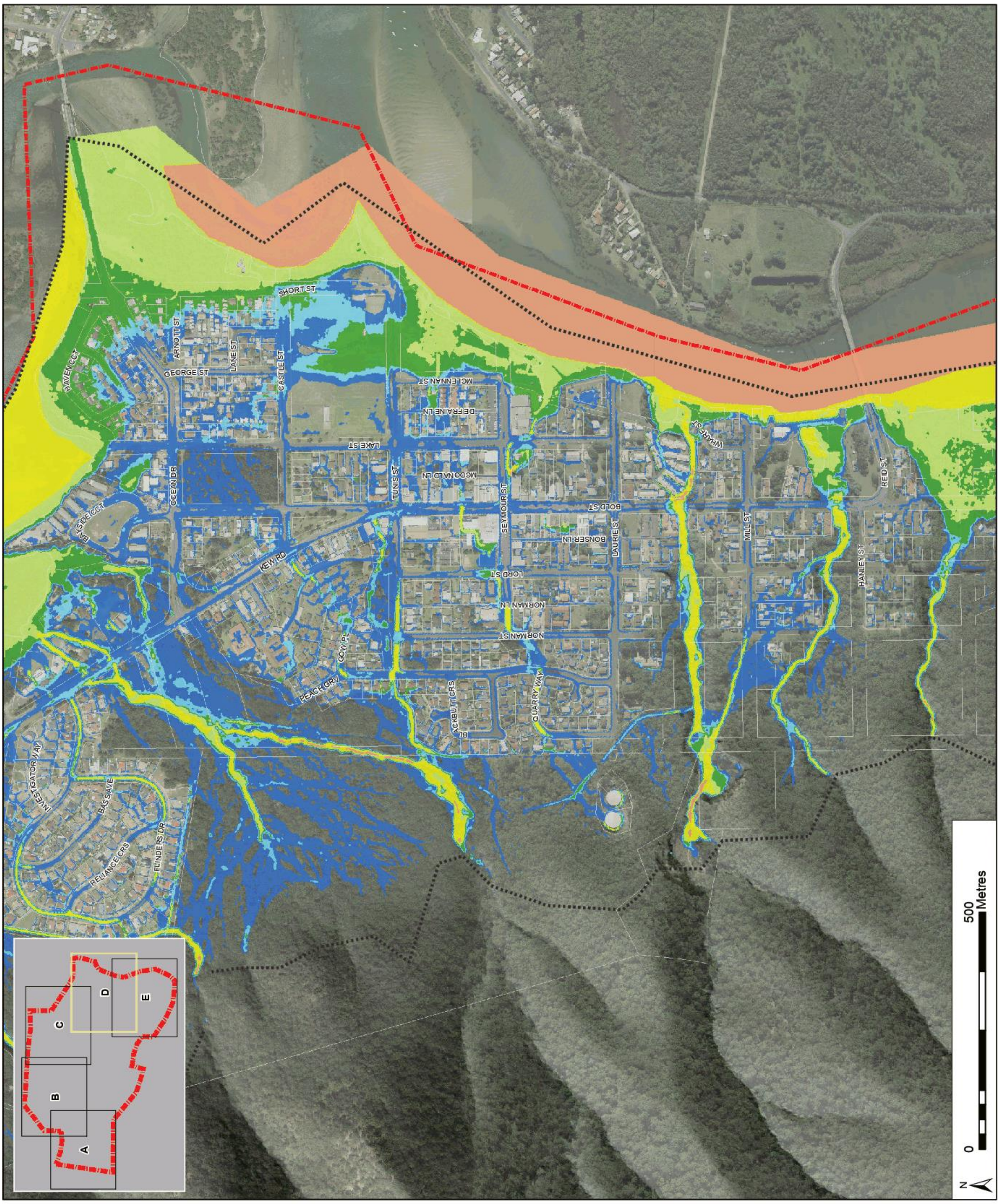
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.

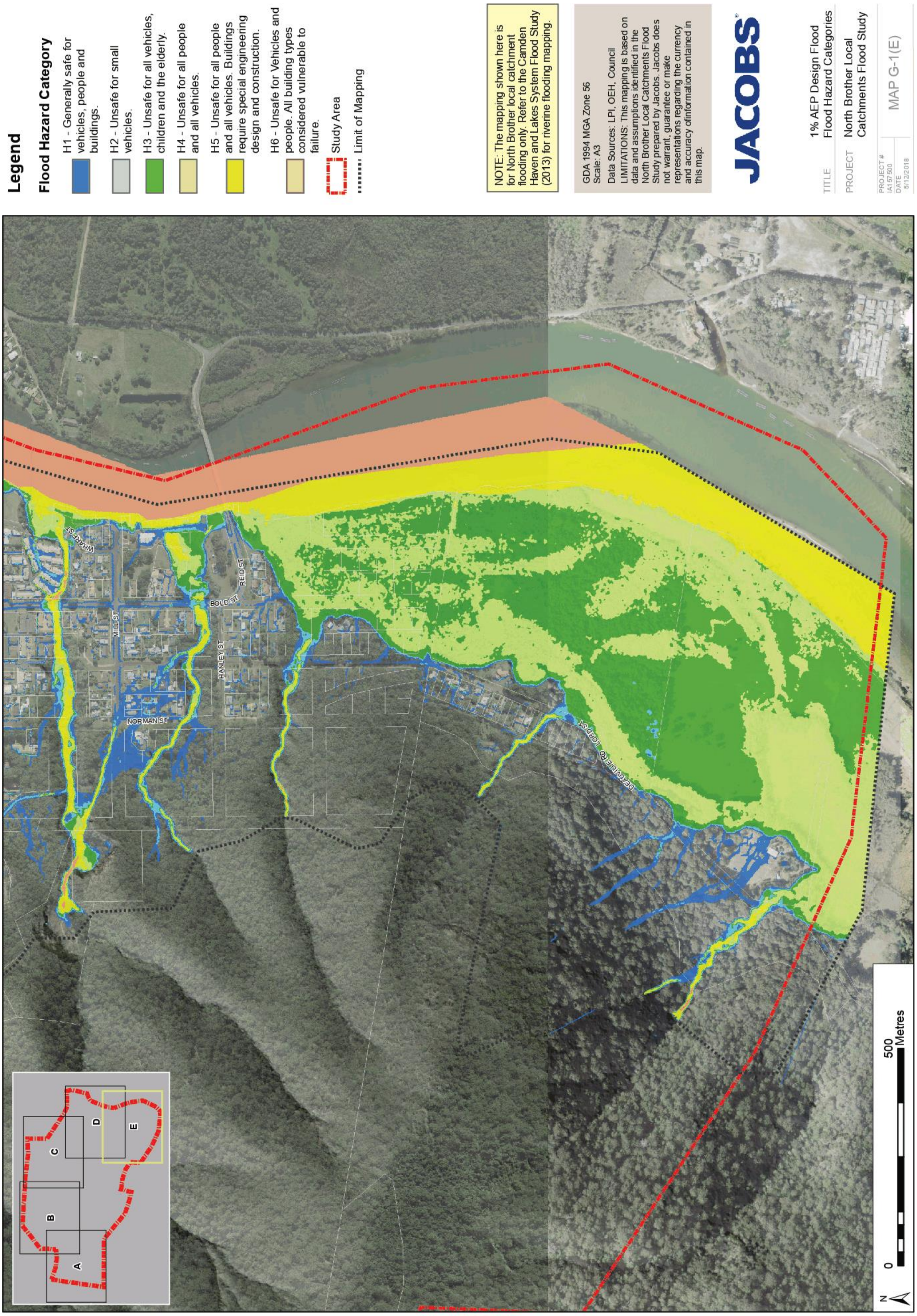
GDA 1994 MGA Zone 56
Scale: A3

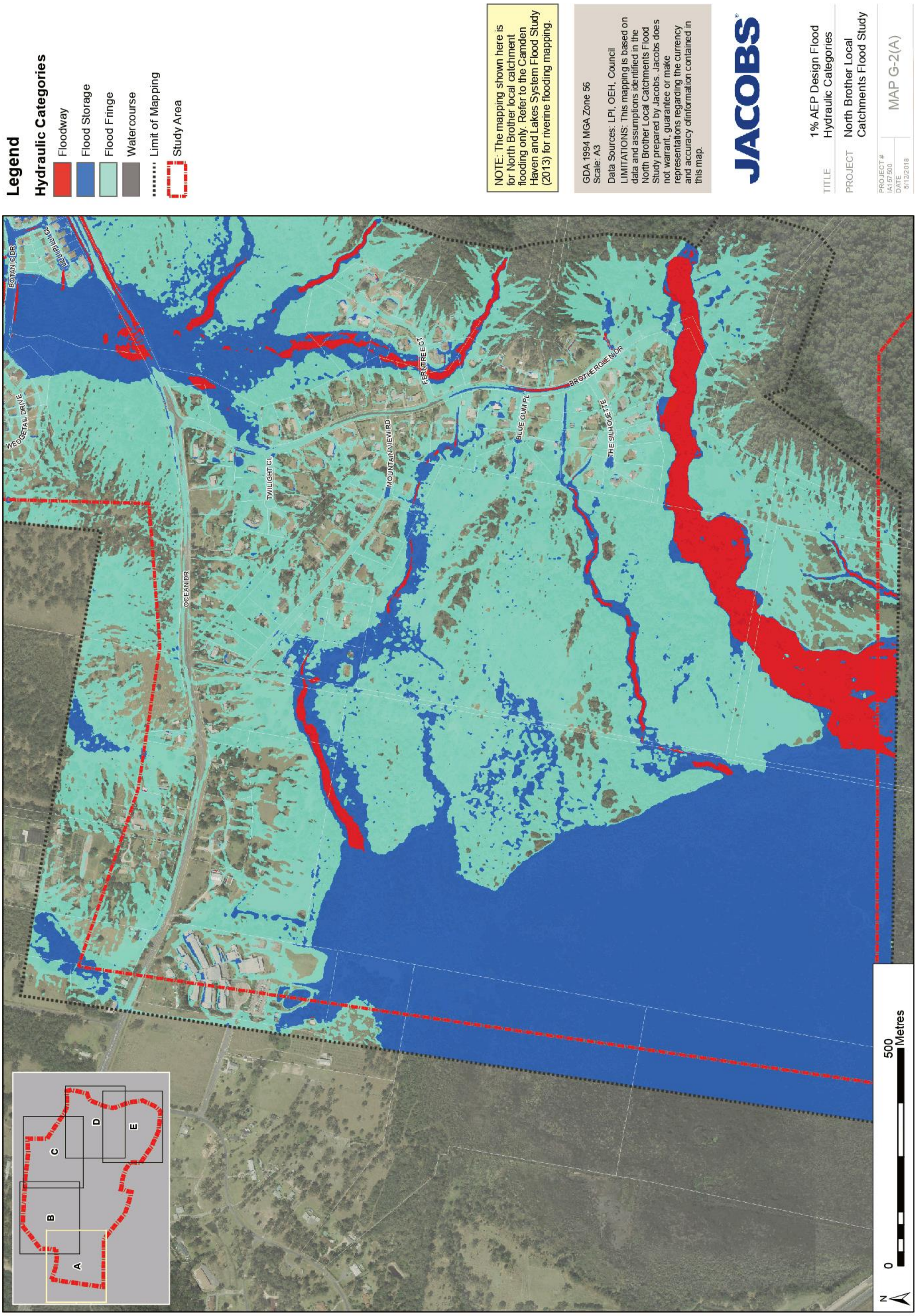
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

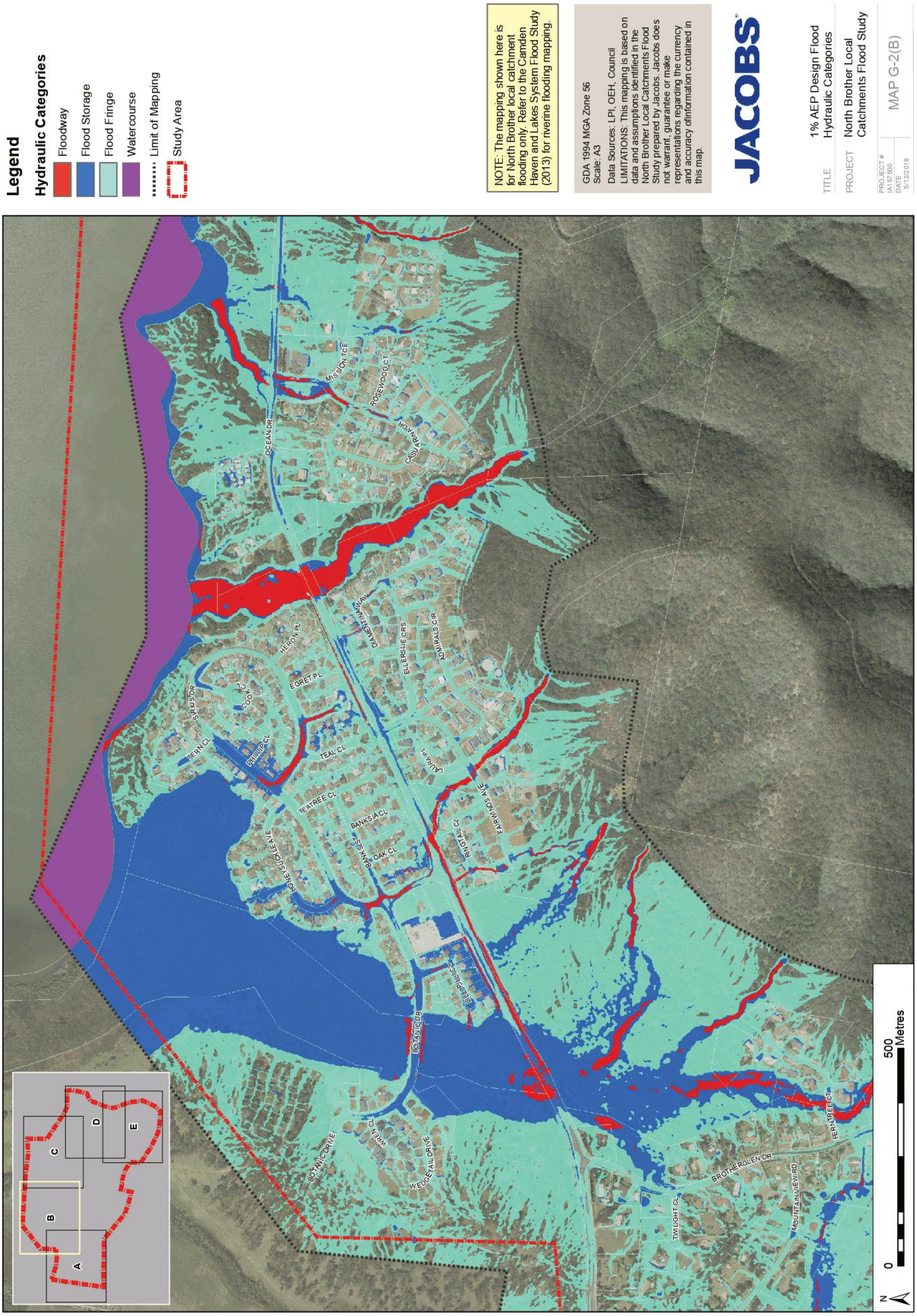
JACOBS

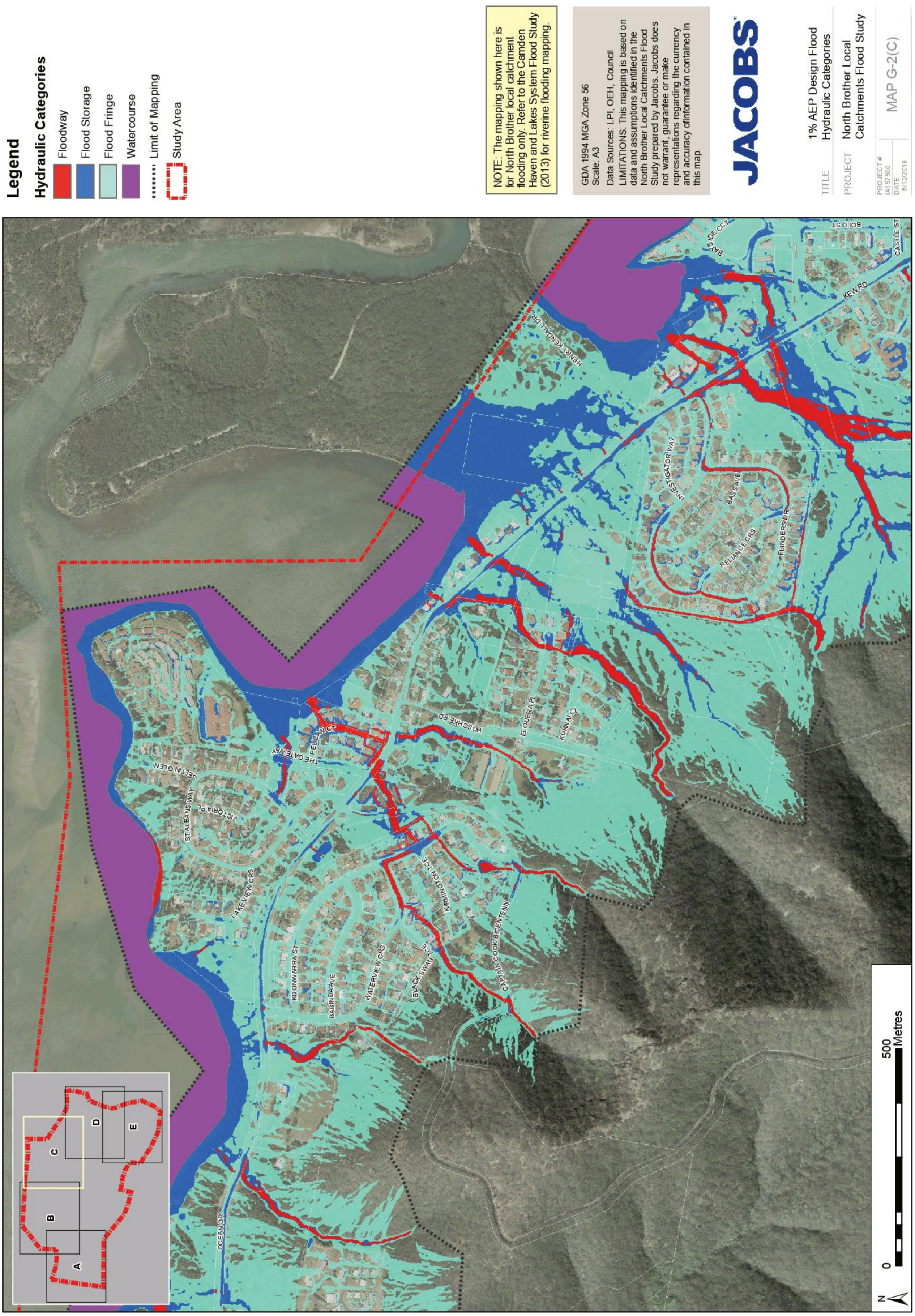
TITLE 1% AEP Design Flood Flood Hazard Categories
PROJECT North Brother Local Catchments Flood Study
PROJECT # IA157500
DATE 5/12/2018
MAP G-1(D)

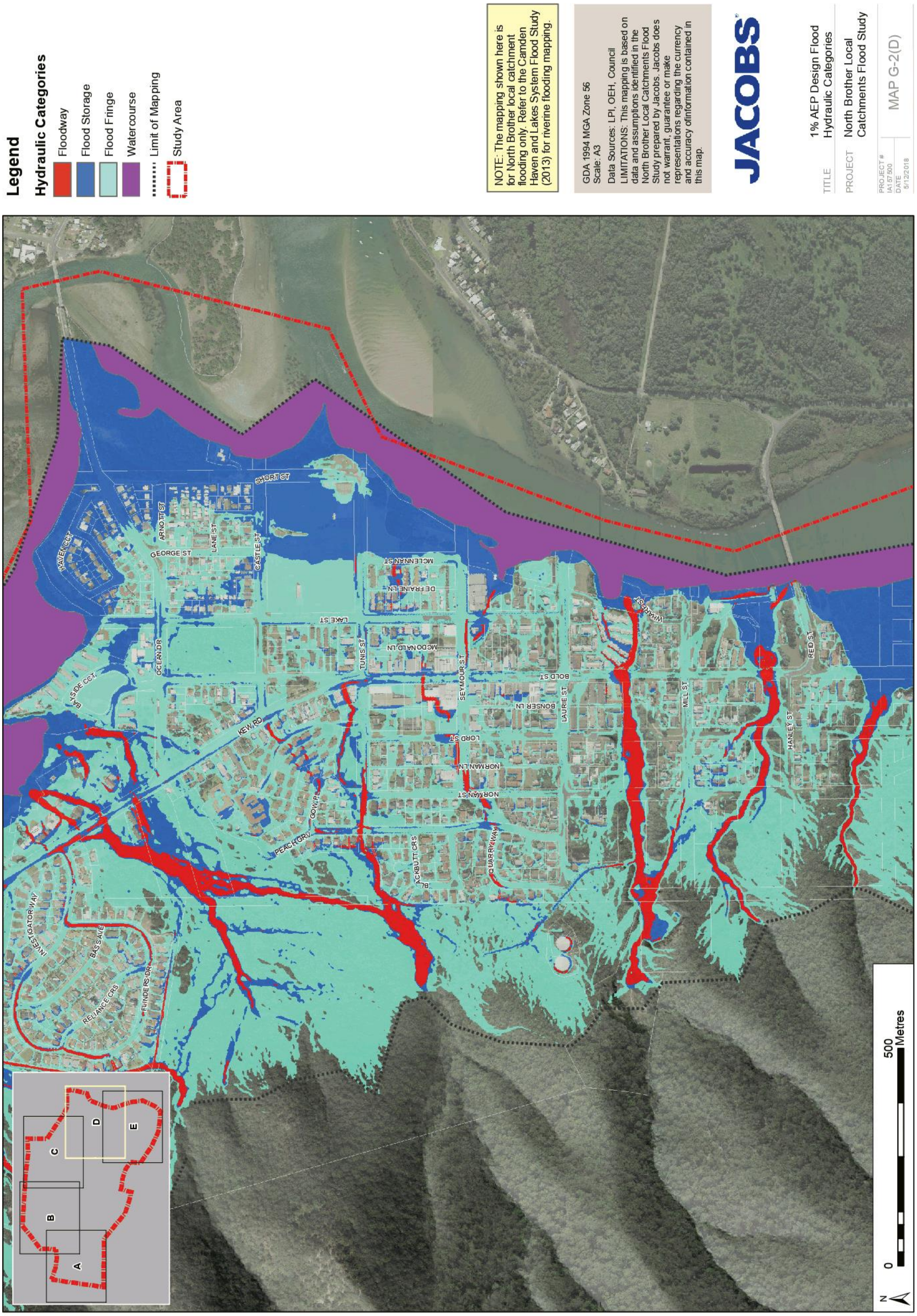


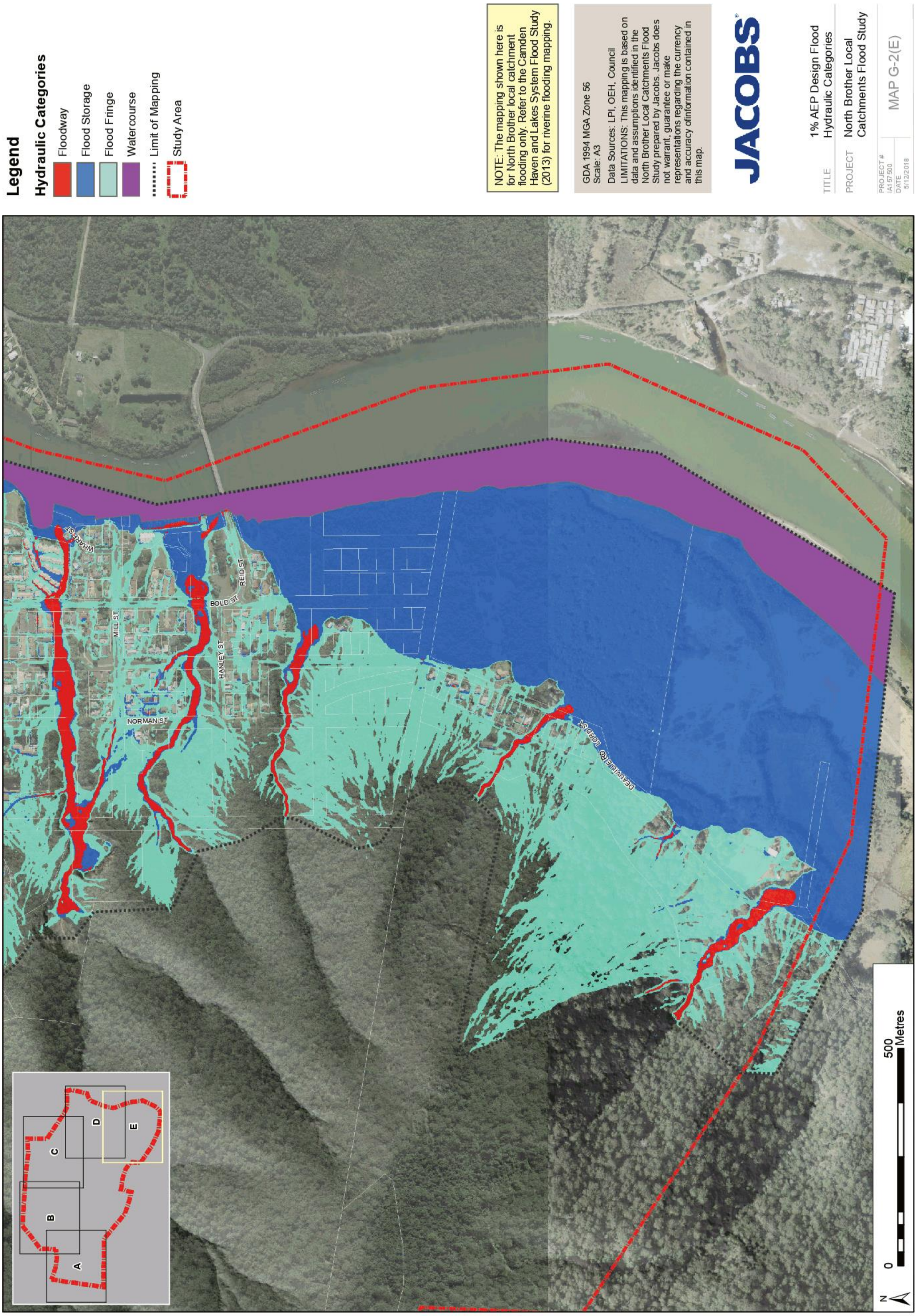

Legend
Flood Hazard Category
H1 - Generally safe for vehicles, people and buildings.
H2 - Unsafe for small vehicles.
H3 - Unsafe for all vehicles, children and the elderly.
H4 - Unsafe for all people and all vehicles.
H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction.
H6 - Unsafe for Vehicles and people. All building types considered vulnerable to failure.
Study Area
Limit of Mapping
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 1% AEP Design Flood Flood Hazard Categories
PROJECT North Brother Local Catchments Flood Study
MAP G-1(E)
MILL ST
BOLD ST
REID ST
HANLEY ST
NORMAN ST
A
B
C
D
E
0
500 Metres
N

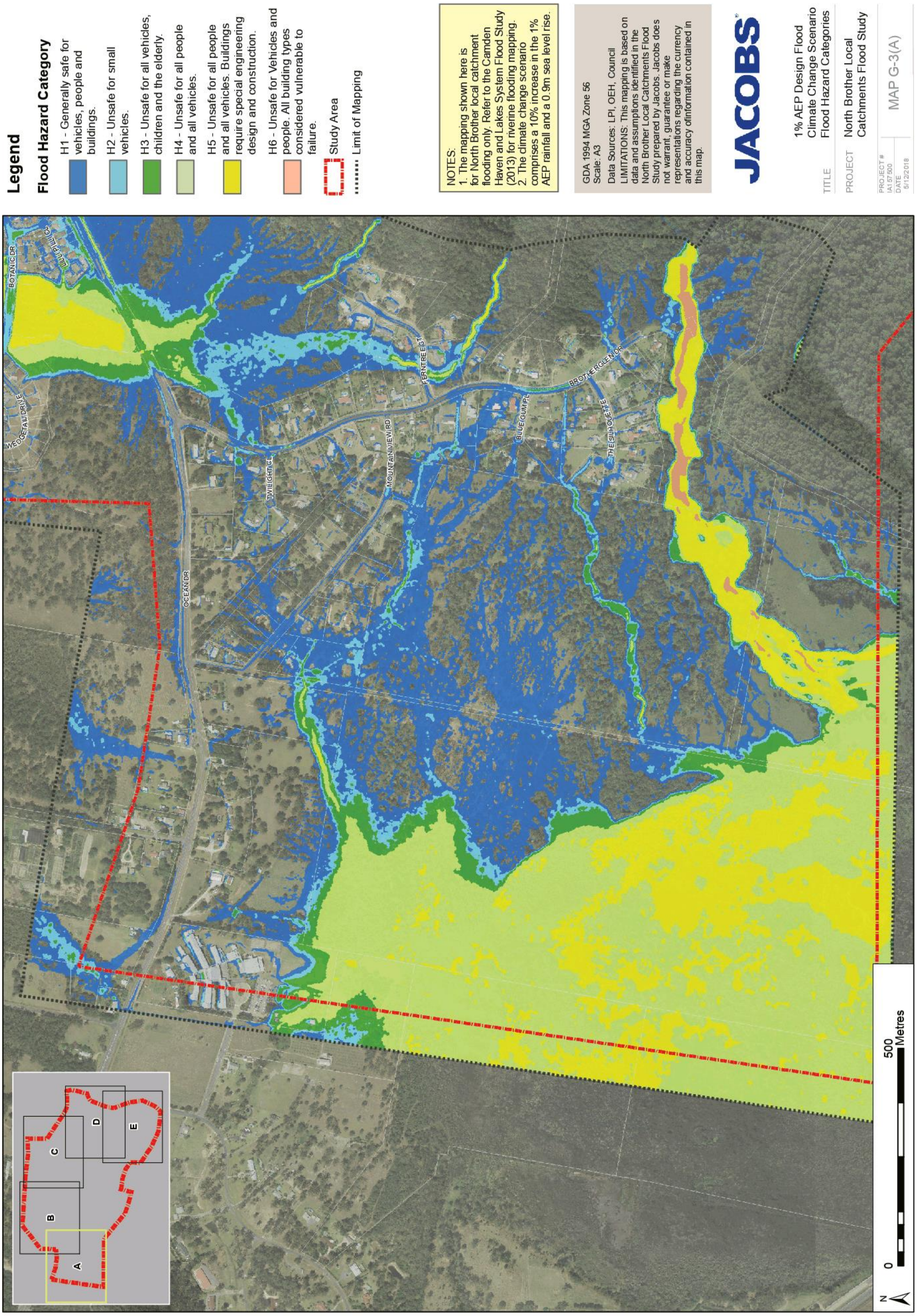

Legend
Hydraulic Categories
Floodway
Flood Storage
Flood Fringe
Watercourse
Limit of Mapping
Study Area
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 1% AEP Design Flood Hydraulic Categories
PROJECT North Brother Local Catchments Flood Study
MAP G-2(A)
OCEAN DR
TWILIGHT CL
MOUNTAIN VIEW RD
BLUE GUM PL
THE SILHOUETTE
BROTHERGLEN DR
FERNTREE CT
WEDGETAIL DRIVE
BOTANIC DR
A
B
C
D
E
0
500
Metres
N

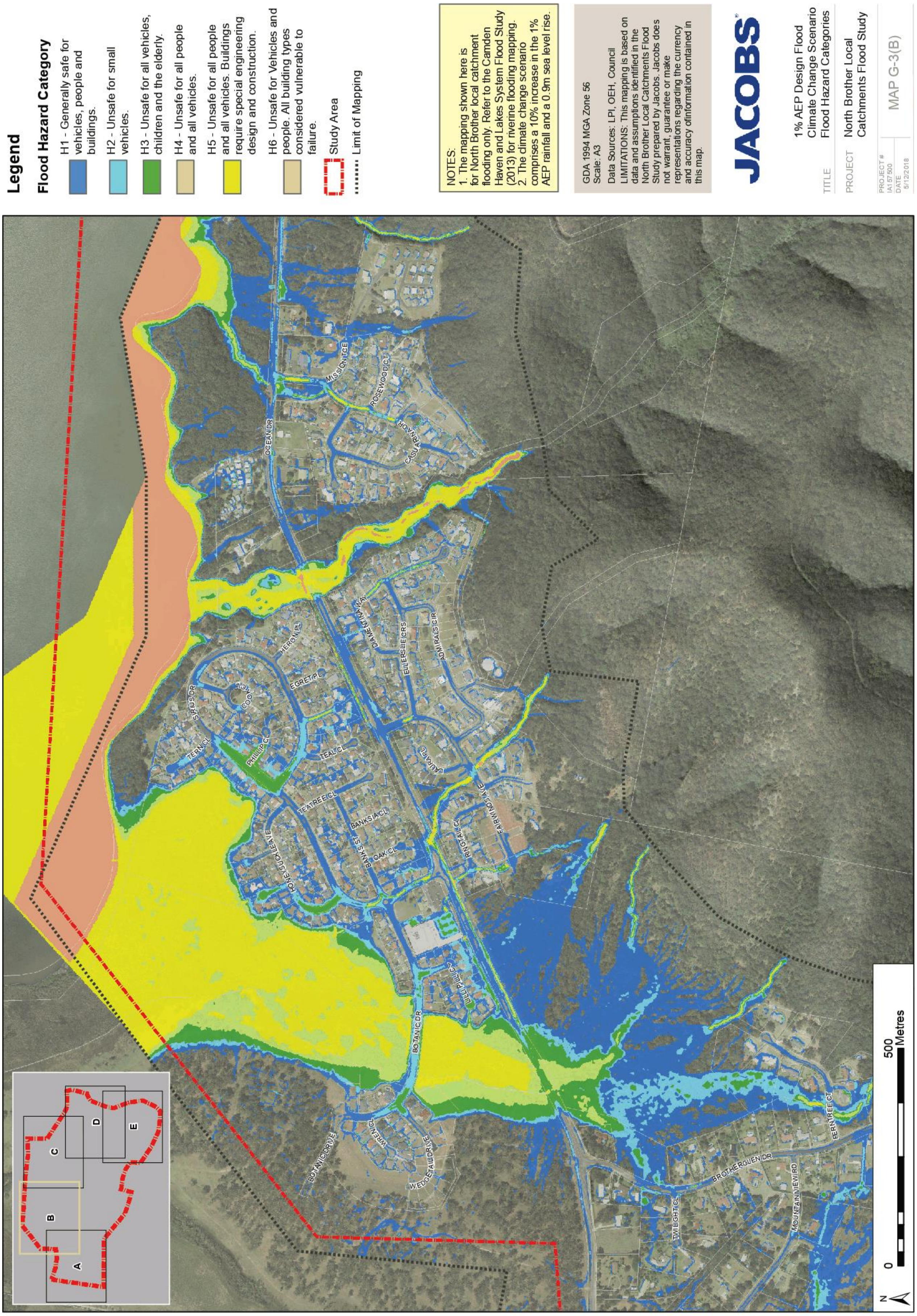

Legend
Hydraulic Categories
Floodway
Flood Storage
Flood Fringe
Watercourse
Limit of Mapping
Study Area
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 1% AEP Design Flood Hydraulic Categories
PROJECT North Brother Local Catchments Flood Study
MAP G-2(B)
0
500 Metres
N


Legend
Hydraulic Categories
Floodway
Flood Storage
Flood Fringe
Watercourse
Limit of Mapping
Study Area
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 1% AEP Design Flood Hydraulic Categories
PROJECT North Brother Local Catchments Flood Study
MAP G-2(C)
0
500 Metres
N


Legend
Hydraulic Categories
Floodway
Flood Storage
Flood Fringe
Watercourse
Limit of Mapping
Study Area
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 1% AEP Design Flood Hydraulic Categories
PROJECT North Brother Local Catchments Flood Study
MAP G-2(D)
0
500
Metres
N
SHORT ST
GEORGE ST
ARNOTT ST
LANE ST
CASTLE ST
HAVEN CCT
MCLENNAN ST
DE FRAINE LN
LAKE ST
MCDONALD LN
TUNIS ST
OCEAN DR
BAYSIDE CCT
KEW RD
SEYMOUR ST
BOLD ST
BONSER LN
LAURIE ST
LORD ST
NORMAN LN
NORMAN ST
MILL ST
HANLEY ST
RED ST
WHARF ST
PEACH GRV
QUARRY WAY
INVESTIGATOR WAY
BASS AVE
RELIANCE CRS
FLINDERS DR
A
B
C
D
E


Legend
Hydraulic Categories
Floodway
Flood Storage
Flood Fringe
Watercourse
Limit of Mapping
Study Area
NOTE: The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.
JACOBS
TITLE 1% AEP Design Flood Hydraulic Categories
PROJECT North Brother Local Catchments Flood Study
MAP G-2(E)
MILL ST
HANLEY ST
REID ST
BOLD ST
NORMAN ST
0
500 Metres
N
A
B
C
D
E


Legend
Flood Hazard Category
H1 - Generally safe for vehicles, people and buildings.
H2 - Unsafe for small vehicles.
H3 - Unsafe for all vehicles, children and the elderly.
H4 - Unsafe for all people and all vehicles.
H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction.
H6 - Unsafe for Vehicles and people. All building types considered vulnerable to failure.
Study Area
Limit of Mapping
NOTES:
1. The mapping shown here is for North Brother local catchment flooding only. Refer to the Camden Haven and Lakes System Flood Study (2013) for riverine flooding mapping.
2. The climate change scenario comprises a 10% increase in the 1% AEP rainfall and a 0.9m sea level rise.
GDA 1994 MGA Zone 56
Scale: A3
Data Sources: LPI, OEH, Council
LIMITATIONS: This mapping is based on data and assumptions identified in the North Brother Local Catchments Flood Study prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.
JACOBS
TITLE
1% AEP Design Flood
Climate Change Scenario
Flood Hazard Categories
PROJECT
North Brother Local
Catchments Flood Study
PROJECT # IA157500
DATE 5/12/2018
MAP G-3(A)
BOTANIC DR
LILLI PILLI CL
OCEAN DR
TWILIGHT CL
MOUNTAIN VIEW RD
FERNTREE CT
BROTHERGLEN DR
BLUE GUM PL
THE SILHOUETTE
A
B
C
D
E
0
500
Metres
N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Flood Hazard Category
H1 - Generally safe for vehicles, people and buildings.
H2 - Unsafe for small vehicles.
H3 - Unsafe for all vehicles, children and the elderly.
H4 - Unsafe for all people and all vehicles.
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Study Area
Limit of Mapping
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Scale: A3
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JACOBS
TITLE 1% AEP Design Flood Climate Change Scenario Flood Hazard Categories
PROJECT North Brother Local Catchments Flood Study
MAP G-3(B)
OCEAN DR
MISSION CT
ROSEWOOD CT
CASUARINA CR
HERON PL
EGRET PL
DIAMENTINA WAY
EUREKA CRS
ADMIRALS CIR
TERN CL
PHILLIP CL
TEAL CL
TEATREE CL
BANKSIA CL
BANKS ST
OAK CL
BOTANIC DR
BOTANIC DRIVE
WEDGETAIL DRIVE
BROTHERGLEN DR
TWILIGHT CL
MOUNTAINVIEW RD
FERNTREE CL
A
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Metres
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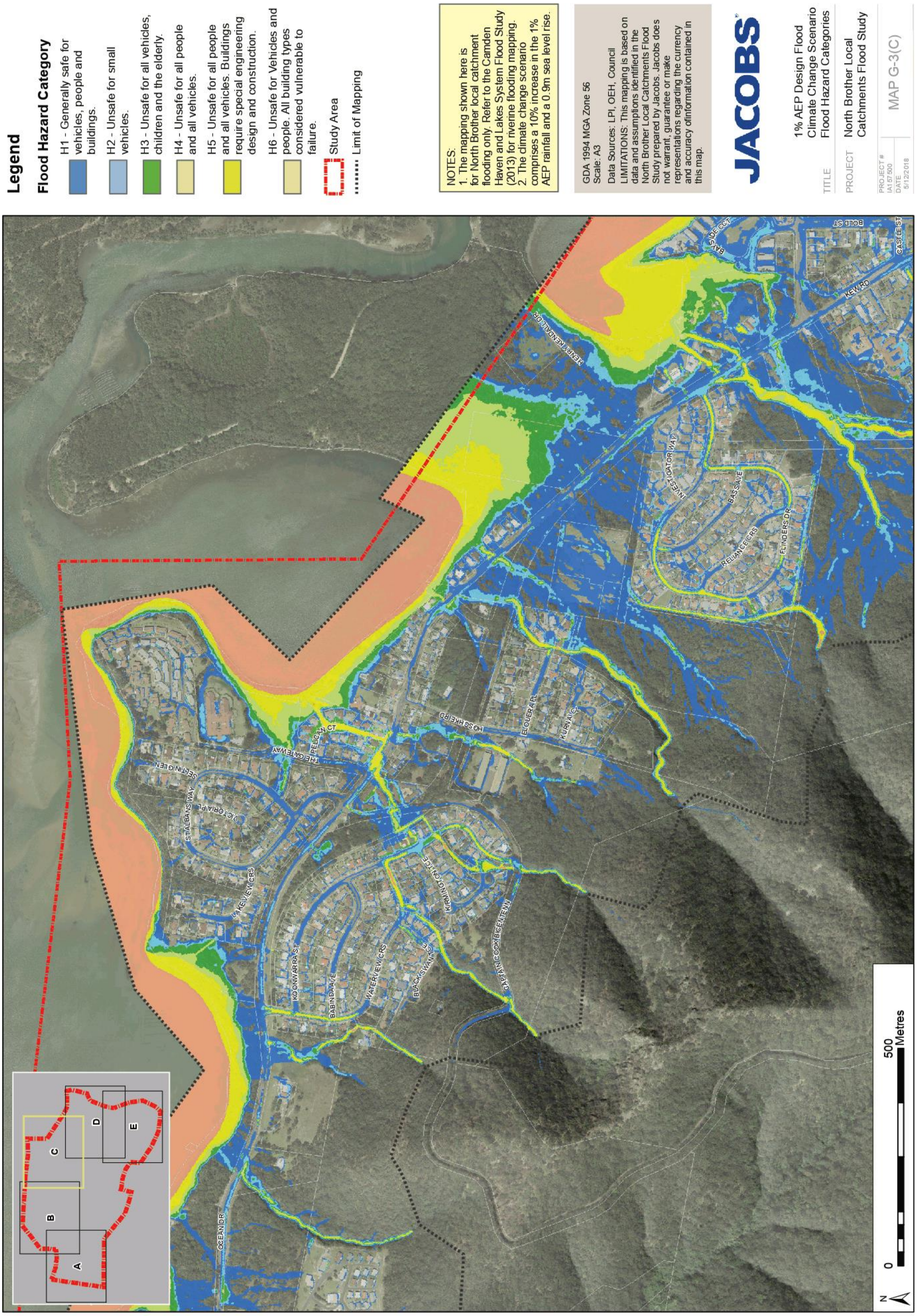
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TITLE 1% AEP Design Flood Climate Change Scenario Flood Hazard Categories
PROJECT North Brother Local Catchments Flood Study
MAP G-3(C)
0
500
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N
A
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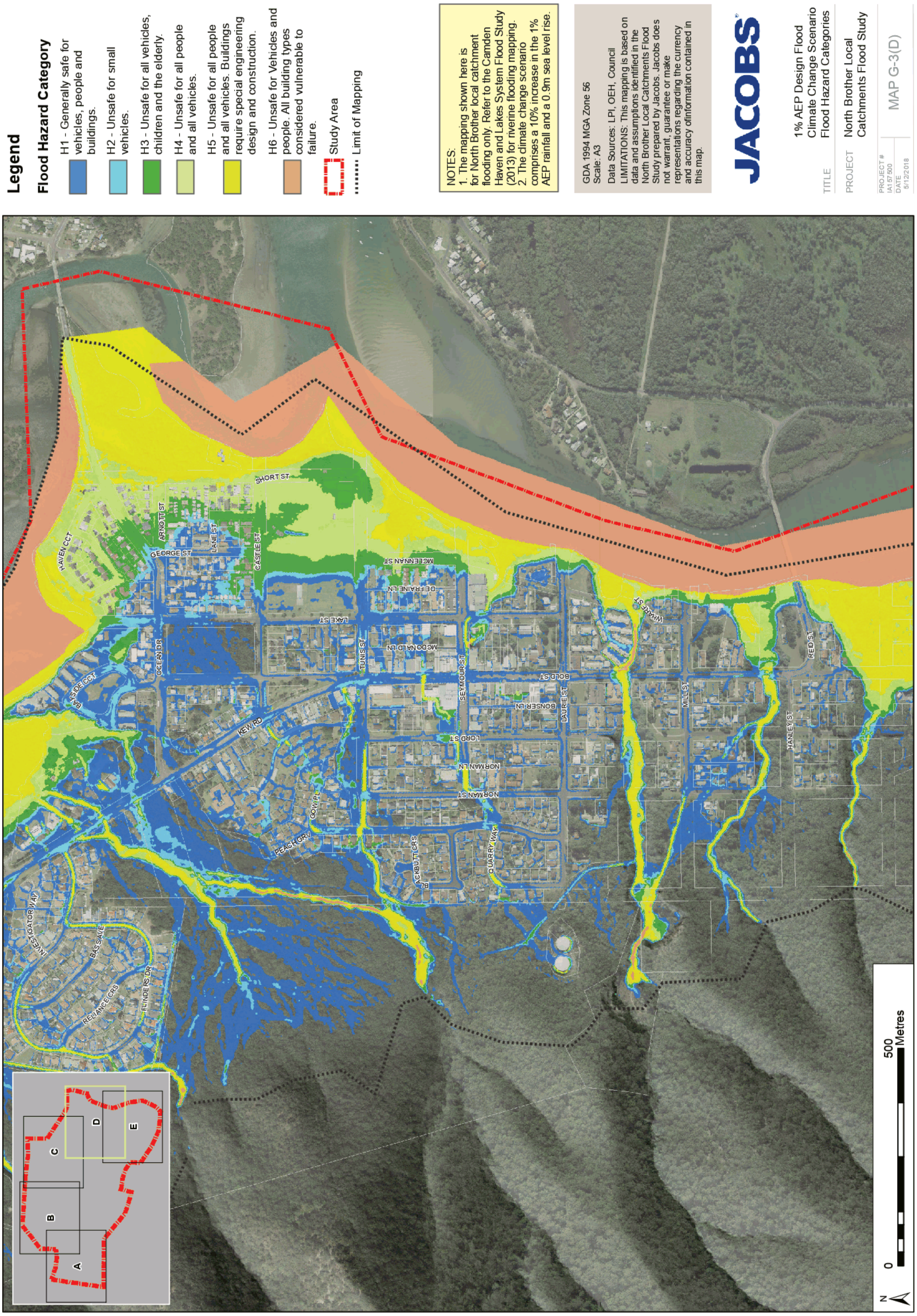
OCEAN DR
THE GATEWAY
PELICAN CT
FLINDERS DR
BASS AVE
INVESTIGATOR WAY
RELIANCE CRS
KEW RD
LAKEVIEW CRS
VICTORIA PL
ST ALBANS WAY
KOONWARRA ST
WATERVIEW CRS
CAPTAIN COOK BICENTENNIAL DR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JACOBS
TITLE 1% AEP Design Flood Climate Change Scenario Flood Hazard Categories
PROJECT North Brother Local Catchments Flood Study
MAP G-3(D)
SHORT ST
ARNOTT ST
GEORGE ST
LAKE ST
CASTLE ST
HAVEN CCT
MCLENNAN ST
DEFRAINE LN
OCEAN DR
TUNIS ST
MCDONALD LN
SEYMOUR ST
BOLD ST
BONSER LN
LAURIE ST
WHARF ST
MILL ST
RED ST
HANLEY ST
LORD ST
NORMAN LN
NORMAN ST
KEW RD
BAYSIDE CCT
PEACH GR
QUARRY WAY
INVESTIGATOR WAY
BASS AVE
FLINDERS DR
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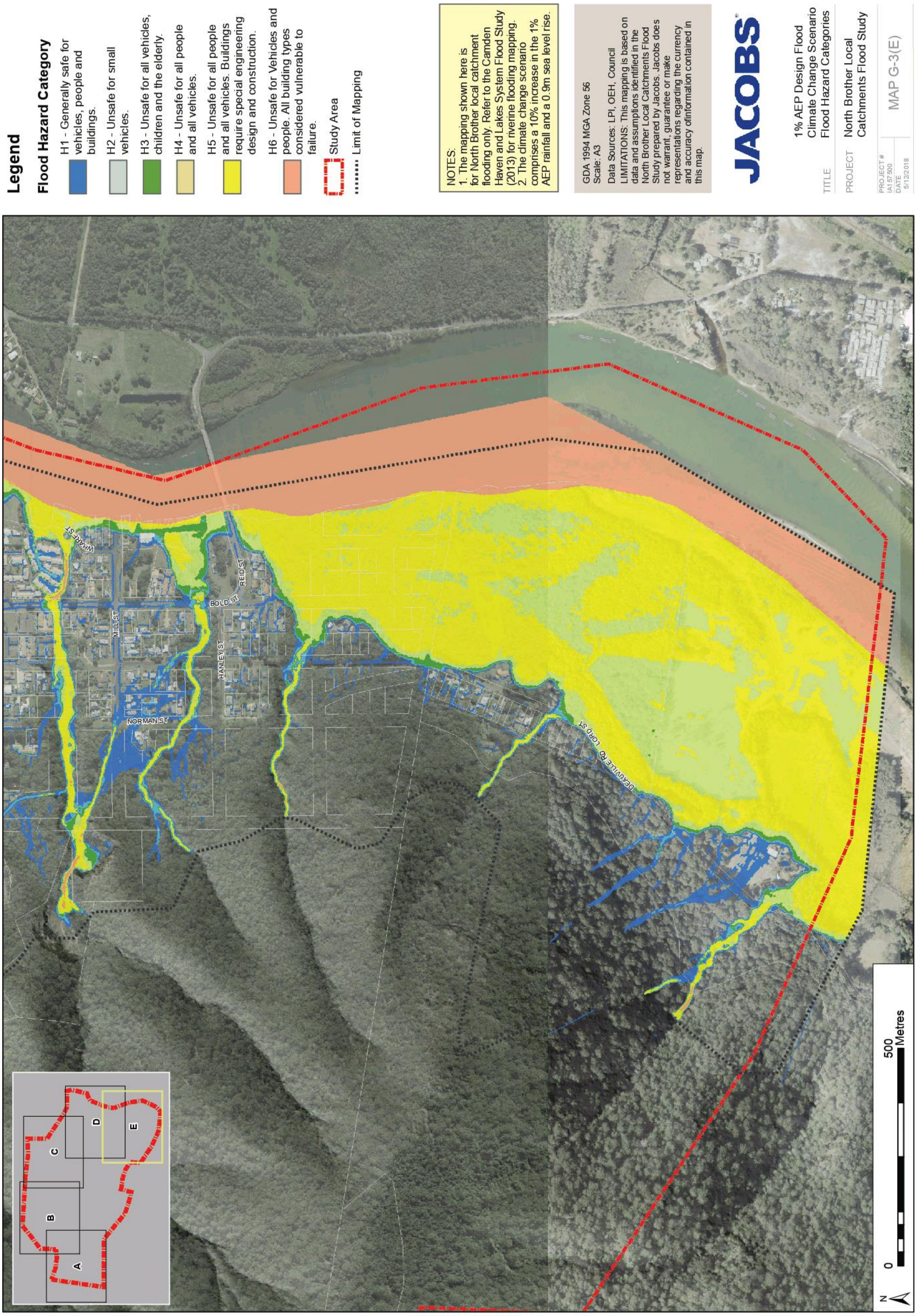
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JACOBS
TITLE
1% AEP Design Flood Climate Change Scenario Flood Hazard Categories
PROJECT
North Brother Local Catchments Flood Study
MAP G-3(E)
WHARF ST
MILL ST
BOLD ST
REID ST
HANLEY ST
NORMAN ST
LORD ST
DEAUVILLE RD
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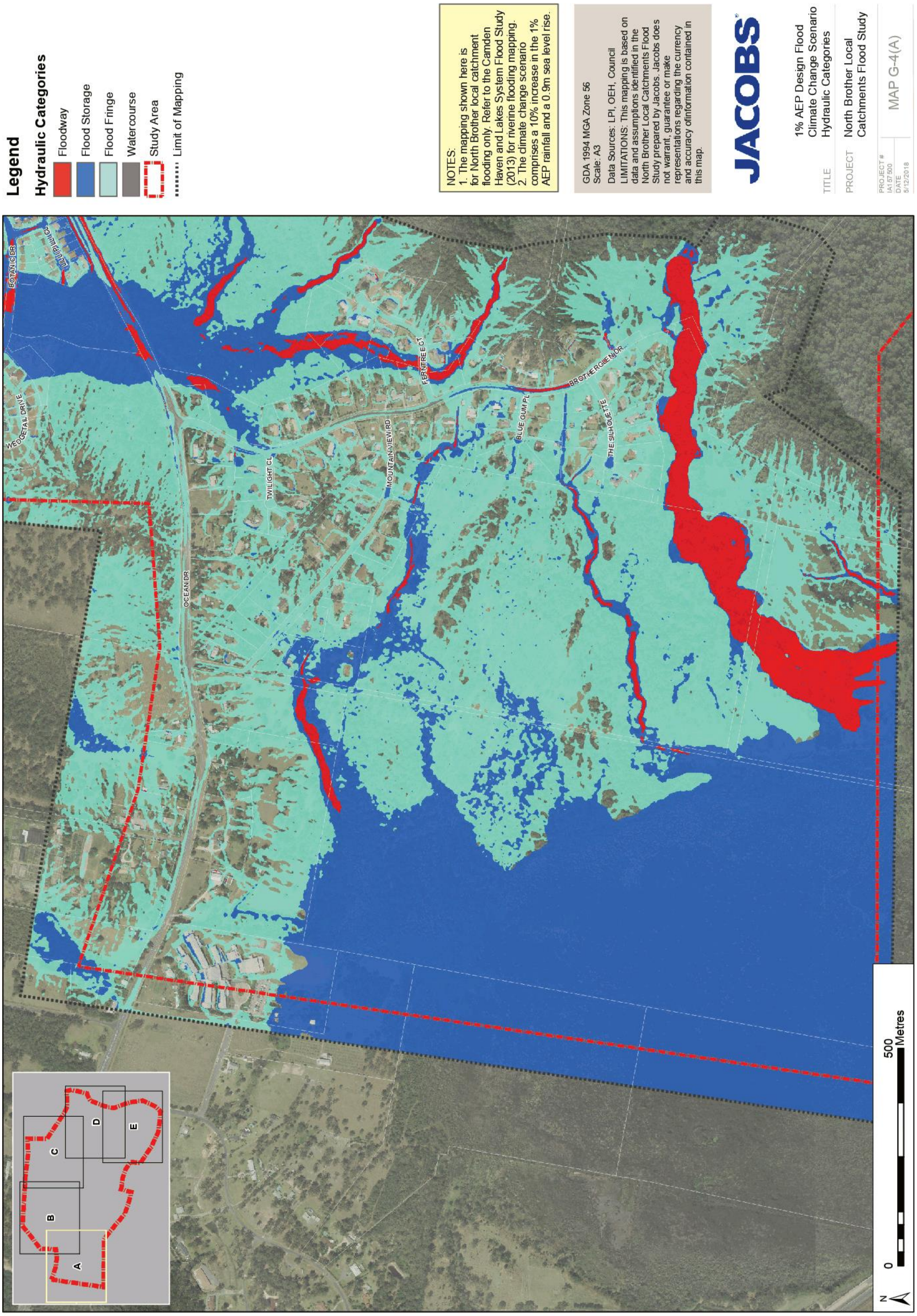
Legend
Hydraulic Categories
Floodway
Flood Storage
Flood Fringe
Watercourse
Study Area
Limit of Mapping
NOTES:
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JACOBS
TITLE
1% AEP Design Flood Climate Change Scenario Hydraulic Categories
PROJECT
North Brother Local Catchments Flood Study
MAP G-4(A)
BOTANIC DR
WEDGETAIL DRIVE
OCEAN DR
TWILIGHT CL
MOUNTAIN VIEW RD
FERNTREE CT
BROTHER GLEN DR
BLUE GUM PL
THE SILHOUETTE
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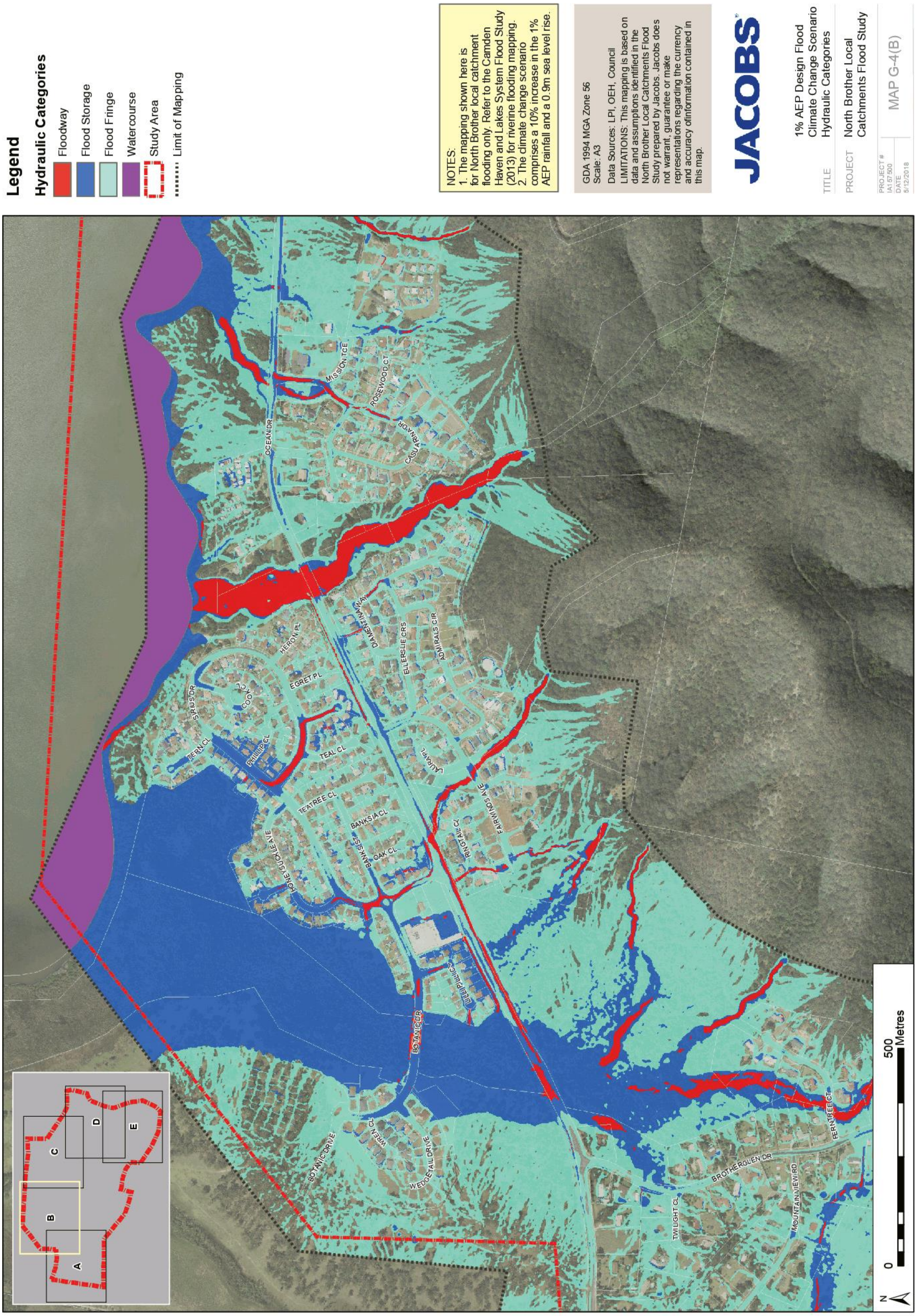
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1% AEP Design Flood
Climate Change Scenario
Hydraulic Categories
PROJECT
North Brother Local
Catchments Flood Study
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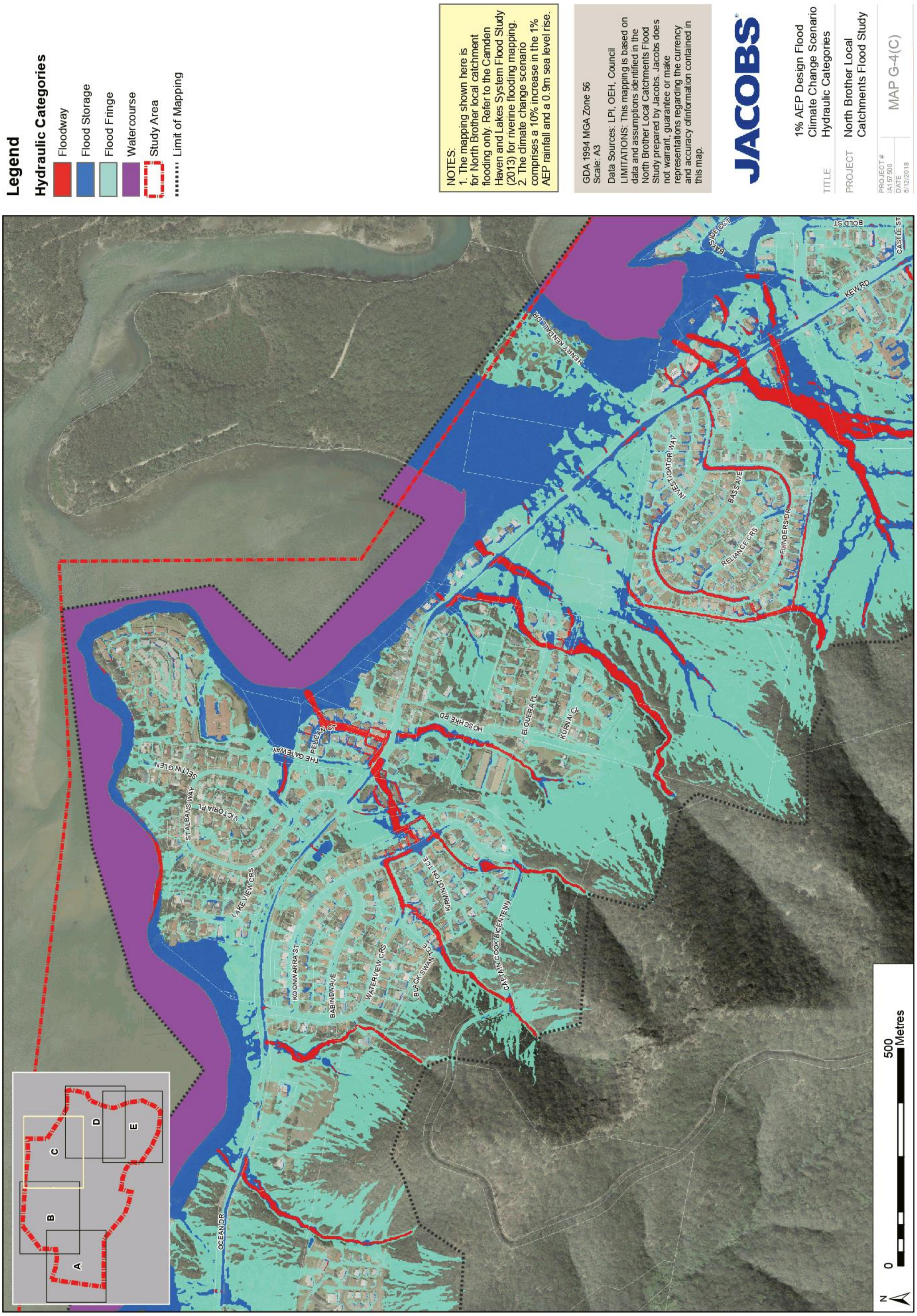
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PROJECT North Brother Local Catchments Flood Study
MAP G-4(C)
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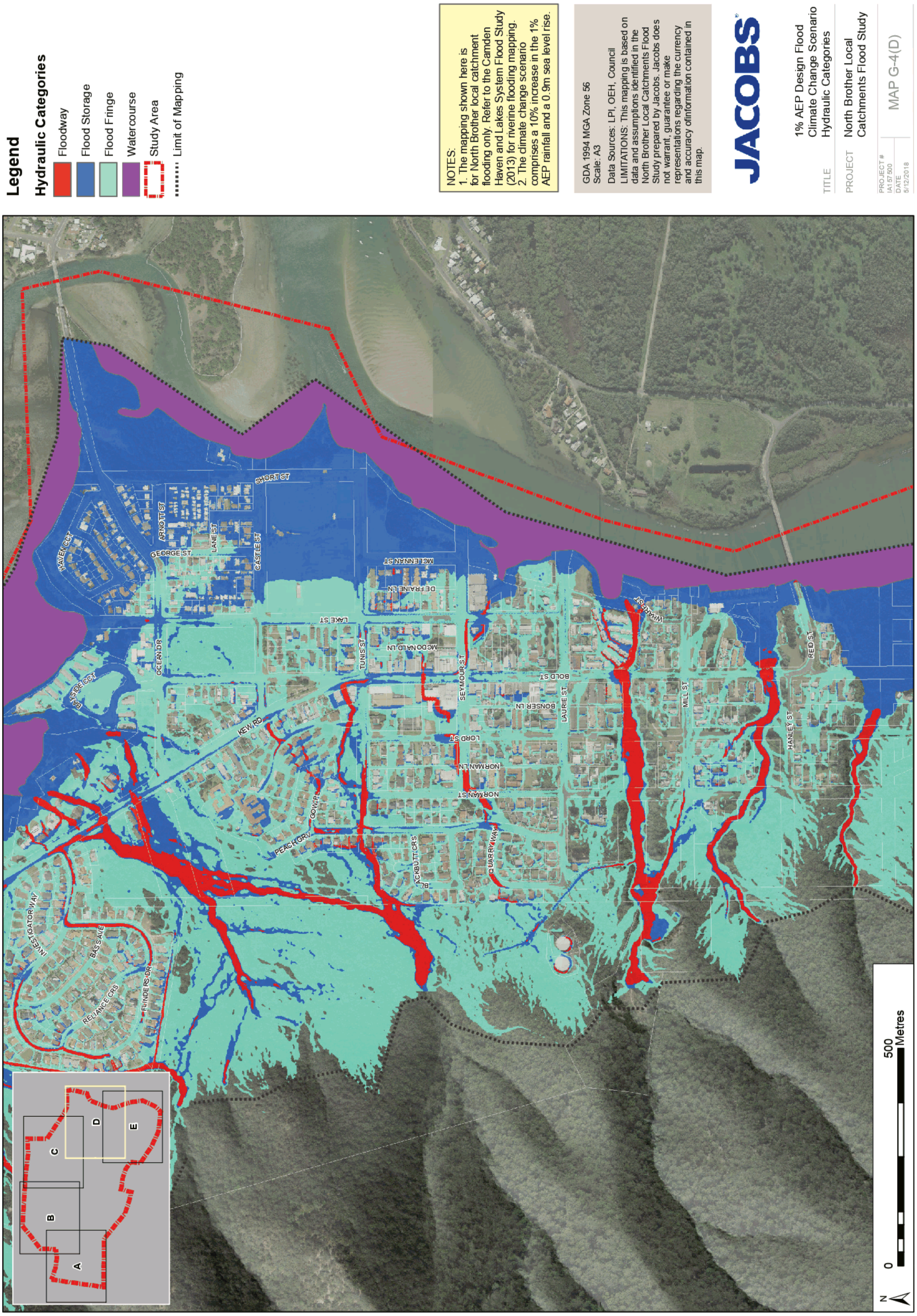
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CASTLE ST
MCLENNAN ST
DE FRAINE LN
LAKE ST
MCDONALD LN
TUNIS ST
SEYMOUR ST
BOLD ST
BONSER LN
LAURIE ST
MILL ST
WHARF ST
RED ST
HANLEY ST
LORD ST
NORMAN LN
NORMAN ST
KEW RD
OCEAN DR
PEACH GRV
QUARRY WAY
INVESTIGATOR WAY
BASS AVE
RELIANCE CRS
FLINDERS DR
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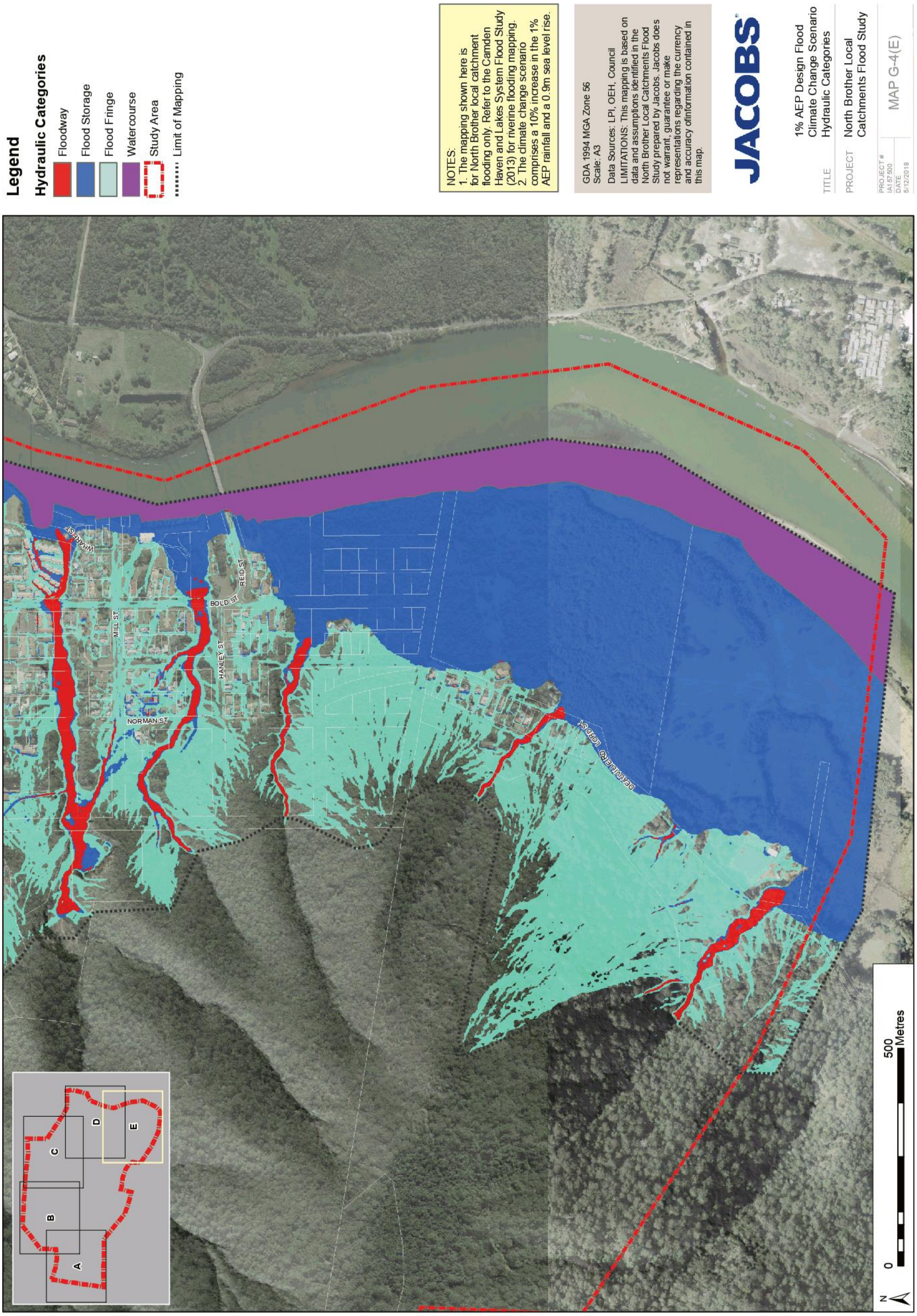
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MAP G-4(E)
BOLD ST
REID ST
MILL ST
HANLEY ST
NORMAN ST
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500 Metres
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Item: 08

Subject: LAKE CATHIE FISH KILL

Presented by: Development and Environment, Melissa Watkins

RECOMMENDATION

That the Committee note the report on the Lake Cathie Fish Kill.

Discussion

On Friday 11 January 2019, Port Macquarie Hastings Council (PMHC) received a report of a fish kill at Lake Cathie. Approximately 20 dead fish were found (species were Bream and Mullett). PMHC staff and DPI Fisheries inspected the site and PMHC's Environmental Laboratory conducted weekly water quality testing in the wake of this finding. The results received since this time shows that water quality indicators (eg. dissolved oxygen, pH etc) are generally good. However, temperature has been hovering around 30 degrees celsius and salinity has been at or above 40 parts per thousand (ppt).

On Thursday 24 January & Friday 1 March 2019, PMHC receive reports of more fish kills at Lake Cathie. PMHC staff inspected the lake and found evidence of dead fish, numbering in the hundreds (24 January) and thousands (1 March), all of which were very young (ie. less than 50 mm long). Refer to **Figures 1 to 4**. The condition and location of the fish suggests that those found on the 24 January and 1 March had been dead for some time and have 'washed up' on sand banks when the water levels drop through evaporation. Staff also spoke to a number of fishers whilst undertaking these inspections and they didn't report seeing any additional dead fish around the lake system.

As a result of the fish kills the PMHC Environmental Laboratory staff are continuing to conduct weekly monitoring and are now taking samples at three locations, these being the; Playground at Foreshore Reserve, Ocean Drive Bridge and the Perch Hole. The monitoring now includes algal analysis as a precaution.

The PMHC Environmental Laboratory will continue weekly monitoring until further notice. The monitoring will include both field and laboratory analysis for greater detail. The results of the weekly testing are being uploaded onto Council's website and the results can be found using the following link:

https://www.pmhc.nsw.gov.au/Services/Environment/Waterways-and-coastlines/Managing-our-coastline/Lake-Cathie-Management/Lake-Cathie-laboratory-testing-results

Lake Cathie Opening Strategy

The *Lake Cathie Opening Strategy* (2001) contains several opening triggers. The main trigger regularly used is when the water level reaches 1.6m AHD.

However, there is another opening trigger when the water level is; *less than 0.2m AHD **and** salinity is greater than 40 ppt.* Refer to **Figure 5** for the decision matrix flow chart from the opening strategy.

This trigger level is taken from the *Australian and New Zealand Environment and Conservation Council* (ANZECC) guidelines and is understood to reflect the fact that some fish species are sensitive to high salinity levels and this level of 40 ppt is set to accommodate most species. However ANZECC is based on overseas research and may not necessarily reflect the variety of waterway systems and fish species found in Australia. This is likely to be why the fish kills to date have been limited to small fish which appear to have been trapped in pools or within very localised areas of the lake system (i.e. around Kenwood Drive bridge) and that the majority of larger fish are tolerating the high salinity levels being recorded.

With the hot weather forecast to continue it is likely evaporation will lower water levels further and salinity concentration may increase. The BOM is predicting an 80% chance of exceeding median temperatures and only a 45% chance of exceeding median rainfall from February to April.

Since early January the water levels have dropped approx. 100 - 150mm per week, however in the past few weeks the water levels have stabilised due to seawater washing over the berm during high tides and intermittent rain showers.

At the time of writing this report the current water level is 0.0m AHD and salinity is greater than 40 ppt, therefore a lake opening is still triggered.

Options and risks

There are two management options available for Council.

I. Open Lake Cathie artificially, or
II. Do not open Lake Cathie and continue water quality monitoring.

<u>Opening the lake</u>
Even though a lake opening trigger has effectively been reached, there are significant risks with opening the lake at this time.

- If the lake is opened it is highly likely it will close quickly. With low water levels there will be insufficient hydraulic head to 'blow open' the channel that is excavated.
- There will likely be migration of sand into the lower estuary as a result of the opening bringing water into the system, rather than taking it out. This may infill the recently dredged area in front of foreshore reserve reducing longer term recreational amenity of this location.
- An opening may lower salinity levels and water temperatures in the short term but there is a risk if the lake closes quickly there may be insufficient flushing and salinity levels could increase.
- There is still evidence of 'red weed' in Port Macquarie coastal waters. 'Red weed' has caused fish kills in Crowdy Harbour & Killick Creek (ie. Dissolved oxygen is reduced due to decaying material) and there is a risk red weed will migrate in to the lake when open and be trapped when the lake closes.

<u>Not opening the lake</u>

Not opening the lake also comes with risks.

- There is a risk that PMHC will continue to be criticised in the media and by the community for not opening the lake when a lake opening trigger, within an adopted strategy, has been reached. Albeit opening the lake would be contrary to the caveat requiring "optimal conditions".
- If hot and dry conditions persist, and temperature and salinity levels remain high (creating hyper-saline conditions) deaths to fish and other marine species may occur. With the current media attention on fish kills in the Menindee Lakes and the Darling River this is a particularly sensitive issue.
- PMHC may open the lake in the near future and risk further criticism as to why the lake was not opened sooner.

Additional information

DPI Fisheries - specialist fish habitat section
PMHC have been in contact with the Port Stevens office of DPI Fisheries to discuss the situation with their fish habitat specialists. DPI Fisheries provided verbal advice that a 'limited impact approach' was appropriate (ie. Do nothing and continue to monitor is reasonable).

Statewide similarities
The situation at Lake Cathie is certainly not unique. Due to consistent high temperatures, continuing low rainfall and high evaporation rates many Intermittently Closed and Open Lakes and Lagoons (ICOLLs) have water levels that are at historically low levels. Smiths Lake, south of Tuncurry is currently experiencing record low water levels, which is a reflection of the current climatic conditions. Beyond ICOLLS, there have been fish kills recorded in the Kyogle & Richmond Rivers, Corindi River, Crowdy Head Harbour and Bellambi Lagoon (near Wollongong). Each incident had differing circumstances however high water temperatures, low water levels/flows and low dissolved oxygen (DO) content were all primary drivers. NB: DO at Lake Cathie is around 100% so is not relevant in our case.

Historical situation
In 2003 a similar situation occurred, where the water level and salinity trigger was reached, however council staff were concerned about negative impacts (same risks as above). A recommendation was put to Council on 24 March 2003 (through the estuary sub-committee – 26 February 2003) that the lake not be opened due to the high probability low water levels would not allow sufficient flushing and reduce salinity levels. This recommendation was adopted by Council.

Council staff's decision to keep the lake closed

Even though a lake opening trigger has effectively been reached, there are significant risks with opening the lake. Refer above.

If not for the Lake Cathie Opening Strategy, it appears there is limited science supporting an opening in the current circumstances; namely:

- There is no evidence of significant water quality issues,
- DPI Fisheries and local fishers are not seeing significant and ongoing fish deaths,

- Specialist DPI Fisheries staff have been comfortable with PMHC continuing to monitor and not open the lake.
- NP&WS staff have been comfortable with PMHC continuing to monitor and not open the lake.

The Lake Cathie Opening Strategy indicates that when opening triggers are reached the lake should be opened 'During Optimum Conditions'. Based on the above risks it is the view of staff that optimum conditions do not currently exist.

Figures

Figure 1 – Dead fish from 24 January 2019

Figure 2 – Dead fish from 1st February 2019

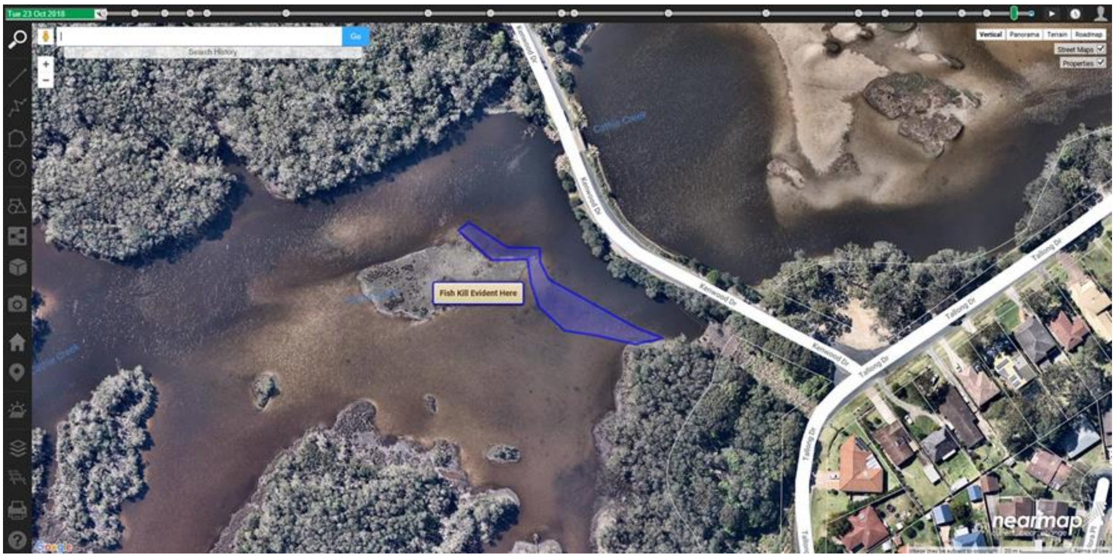

Figure 3 - Location of dead fish from 24 January 2019

Figure 4 - Location of dead fish from 1 March 2019

LAKE CATHIE
COMBINED ENTRANCE
OPENING STRATEGY
(Amended by Council Resolution 2 October 2001)

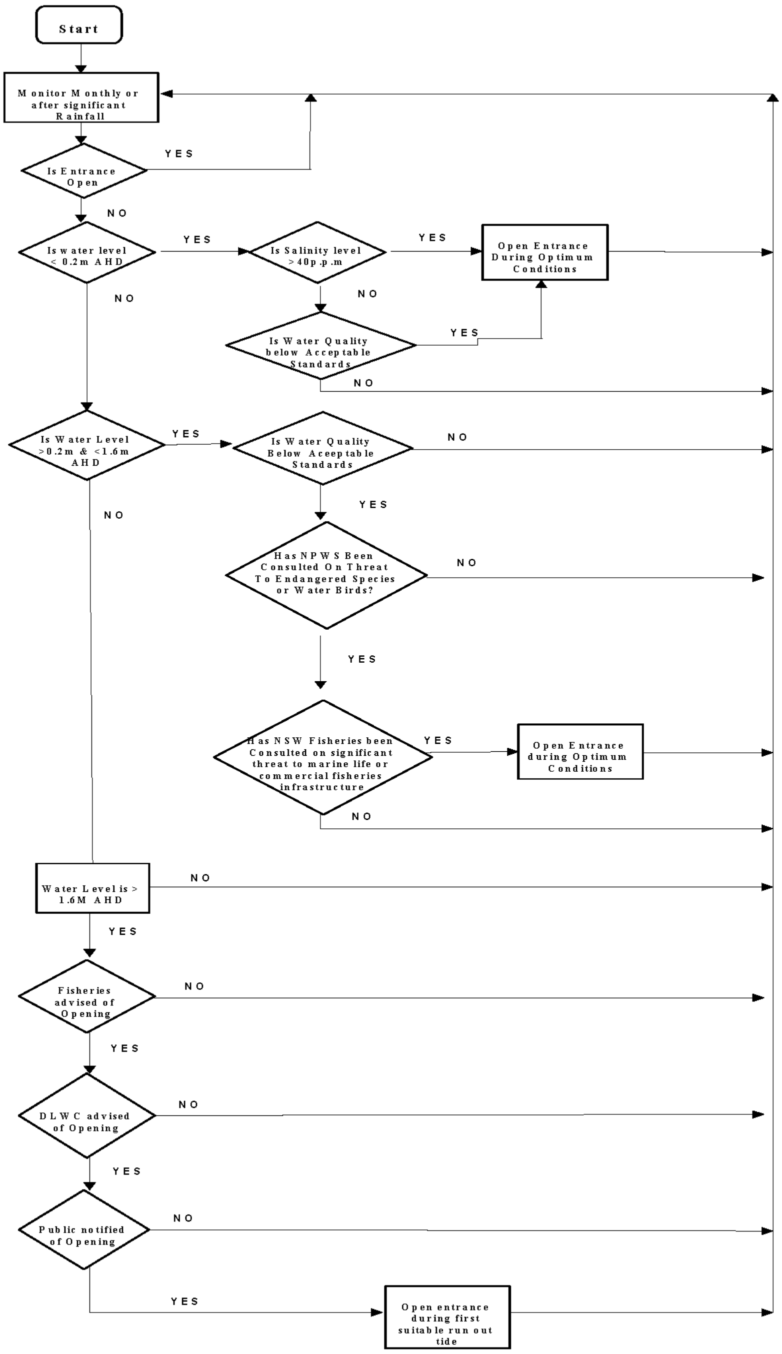

Figure 5 - Lake Cathie opening strategy flow chart

Attachments

Nil

Item: 09

Subject: **IMPACTS OF THE RECENT CLIMATE CHANGE DECISION OF COUNCIL ON FLOODPLAIN MANAGEMENT**

Presented by: Development and Environment, Melissa Watkins

RECOMMENDATION

That the Committee note the report.

Discussion

At the December 2018 meeting, Council made the decision to adopt climate change 'Scenario 3' (400mm SLR plus 10% increase in rainfall) for the basis of the Flood Planning Area (FPA) in the Hastings River & Wrights Creek Catchments rather than the recommended 'Scenario 1' (900mm SLR plus 10% increase in rainfall).

This decision represents a significant change in flood policy direction and is a departure from Port Macquarie-Hastings Council's (PMHC) historical approach to floodplain management. This policy change will have impacts on current and ongoing flood projects.

Staff are currently considering the implications of these changes and will advise the committee of the outcomes of this review upon its completion.

Attachments

Nil

Item: 10

Subject: ACTIVE COAST, ESTUARY & FLOODPLAIN PROJECTS STATUS UPDATE

Presented by: Development and Environment, Melissa Watkins

RECOMMENDATION

That the Committee note the status of the active Coast, Estuary and Floodplain projects.

Discussion

This report provides an update on active Port Macquarie Hastings Council Coast, Estuary and Floodplain projects. Where applicable, each project has been listed with the current project cost and corresponding grant amount provided by OEH or NSW DPI.

Floodplain Management

Hibbard Floodway Investigation
Current total project cost: $114,650.
Current OEH grant funding component: $76,433.33.
Successful grant application under 2015-16 Floodplain Management funding round.

Project is underway with the flood study component (Stage 1) nearing completion. Refer to separate report titled *'Hibbard Precinct Flood Study - Draft Report'* for further details. Refer also to separate report titled *'Impacts of the recent climate change decision on floodplain management'* for further details.

Hastings River Climate Change Modelling
Total project cost: $68,720.
OEH grant funding component: $42,533.33.
Successful grant application under 2015-16 Floodplain Management funding round.

This project was finalised with OEH in 2017. This project was reported to the December 2018 Council meeting. Refer to separate report titled *'Impacts of the recent climate change decision on floodplain management'* for further details.

Wrights Creek Flood Study Update, Climate Change Modelling & Floodplain Risk Management Study & Plan
Current total project cost: $110,310.
OEH grant funding component: $73,540.
Successful grant application under 2015-16 Floodplain Management funding round.

This project was reported to the December 2018 Council meeting. Refer to separate report titled *'Impacts of the recent climate change decision on floodplain management'* for further details.

North Brother Local Catchments Flood Study
Current total project cost: $125,612.
OEH grant funding component: $83,741.33.
Successful grant application under 2016-17 Floodplain Management funding round.

Project is underway with the flood study component (Stage 1) nearing completion. Refer to separate report titled *'North Brother Local Catchments Flood Study - Draft Report'* for further details. Refer also to separate report titled *'Impacts of the recent climate change decision on floodplain management'* for further details.

Hastings River Gauge Network Upgrades
Current total project cost: $50,000.
OEH grant funding component: $33,333.
Successful grant application under 2017-18 Floodplain Management funding round.

Project is underway with Manly Hydraulics Laboratory (MHL) directly engaged. This project has been delayed for a couple of reasons, primarily that the landowner initial support for PMHCs preferred gauge location at the end of Hacks Ferry road was ultimately not forthcoming. However an alternative location was found directly across the river at Mundays Lane, and a detailed environmental assessment was carried out on this new site. Crown Land licence is required and the application submitted. This is likely to take several months to be processed. Hence the installation of the gauge at Mundays Lane will not occur until late 2019.

Dunbogan Flood Access Road – Construction
Current total project cost: $1,500,000.
OEH grant funding component: $1,000,000.
Successful grant application under 2018-19 Floodplain Management funding round.

Council applied for grant funding in early 2018 and were placed on a 'reserve list'.

Coastal Management

Illaroo Road Stormwater Redirection – Construction
Current total project cost: $720,000.
OEH grant funding component: $360,000.
Successful grant application under 2017-18 Coastal Management funding round.

Council applied for grant funding in early 2018 and were notified of our successful grant application in late October. This project is now underway with Council's Works Crews poised to deliver the project.

However the recent discovery of dumped asbestos at the proposed outlet location has complicated matters, and PMHC have not yet finalised the approach that needs to be taken to resolve this issue. Council staff are working with Crown Lands and OEH to resolve funding arrangements and clean-up arrangements.

Middle Rock and Chepana Street Stormwater Outlet – Maintenance Works
Current total project cost: $114,000.
OEH grant funding component: $57,000.
Successful grant application under 2016-17 Coastal Management funding round.

Construction works have been completed on two southernmost outlets (i.e at the Middle Rock Carpark and at the southern end of Chepana Street). These works were completed in late 2018/early 2019. This project is virtually complete and the final grant funding claim forms will be submitted within coming weeks.

Lake Cathie CZMP – Funding Model
Current total project cost: $97,600.
OEH grant funding component: $58,800
Successful grant application under 2016-17 Coastal Management funding round.

Project is underway with Marsden Jacob Pty Ltd engaged. In addition to the Funding Model, this project now involves a review of the cost benefit analysis (CBA) previously completed by OEH in 2016. There have been delays in completing this project for numerous reasons. Primarily there was considerable time and effort involved in completing the detailed analysis of the impacts against each property that may be protected by the wall. Further to this we have been reliant on technical advice from OEH which has taken some time to produce. However the CBA is due imminently and will be a robust report. The project is anticipated to be completed mid-2019.

Flynns Beach Retaining Wall Replacement (Stage 1)
Current total project cost: $2,078,089.70.
OEH grant funding component: $1,035,448.50.
Successful grant application under 2015-16 Coastal Management funding round.

The procurement and tendering phase has been finalised with a 'Design and Construct' methodology being adopted by the successful contractor. The project is still being assessed by Council's Development Assessment team, however an approval appears imminent, with construction possibly commencing mid-2019.

Estuary Management

Estuarine Lake Linkages: Protecting the Islands & Foreshores of the Camden Haven
Current total project cost: $372,049
OEH grant funding component: $186,047.
Successful grant application under 2015-16 Estuary Management funding round.

Project is underway and is progressing well. The project officer position was filled and two years of management works completed. Six months of management works remain outstanding and will be carried out by contractors. This project is expected to be complete by mid-2019.

Attachments

Nil