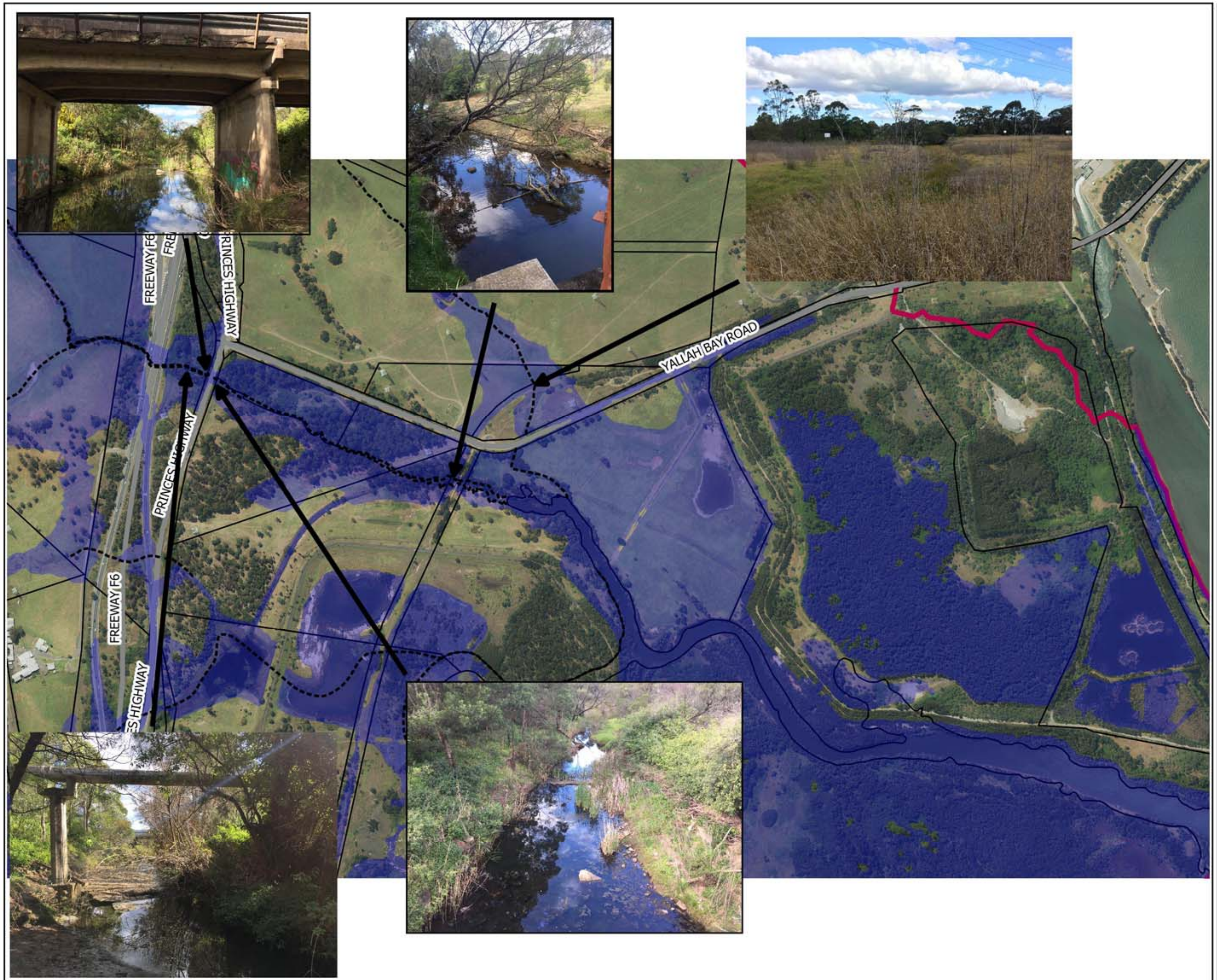
APPENDIX A

Site Inspection Details



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GA101 Site Inspection Photos Tile : A

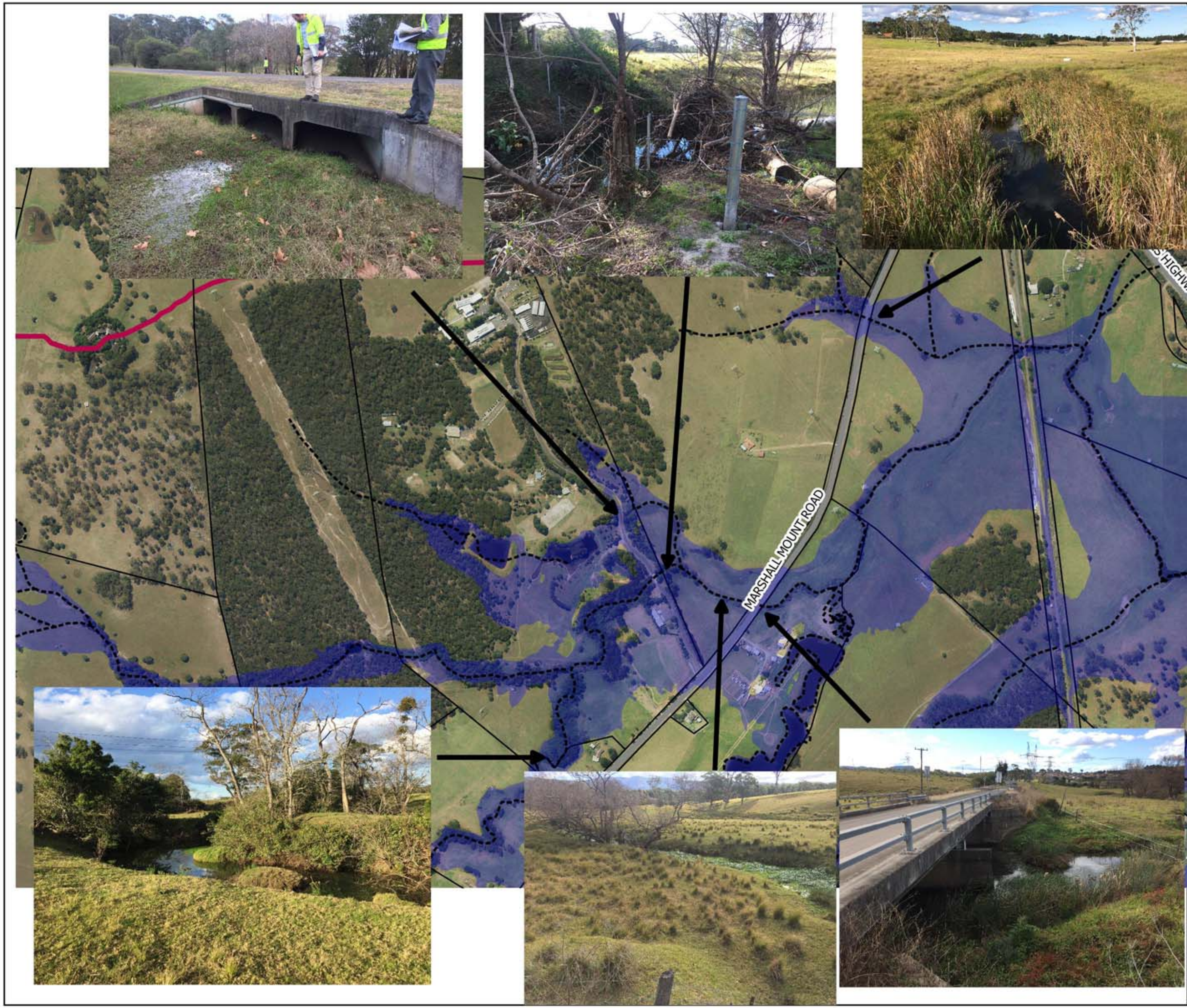
Legend

- RoadCentreLine
- Watercourse
- 1% AEP Extent (2012)
- Cadastre
- Catchment Boundary

100 0 100 200 300 m

Scale : 1:10,000@A4
Date : 6 September 2017
Revision : A
Created by : RST
Coordinate System : Map Grid of Australia 94

Rhelm



GA101
Site Inspection Photos
Tile : B

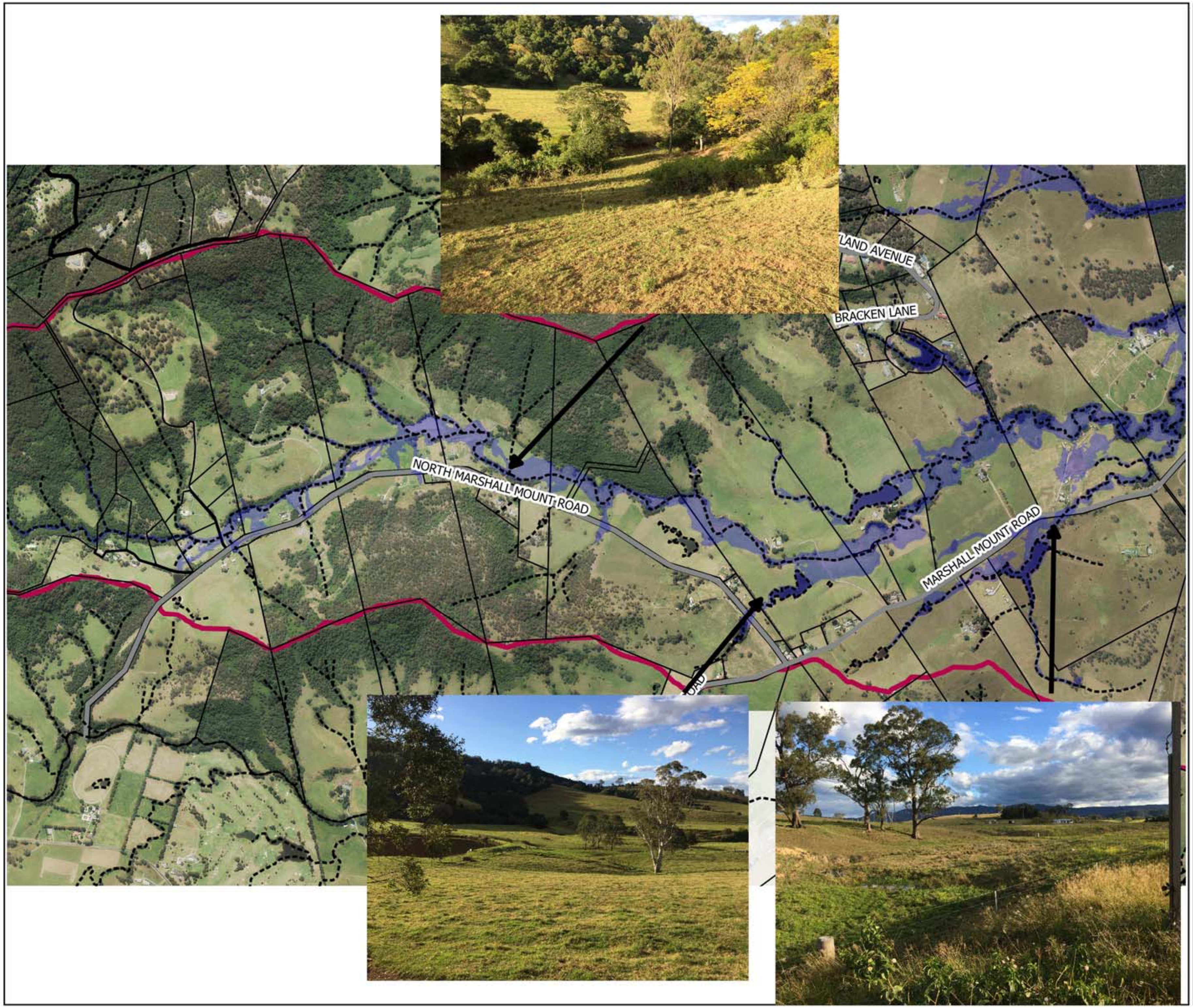
Legend

- 1% AEP Extent (2012)
- RoadCentreLine
- Watercourse
- Cadastre
- Catchment Boundary

100 0 100 200 300 m

Scale : 1:10,000@A4
Date : 6 September 2017
Revision : A
Created by : RST
Coordinate System : Map Grid of Australia 94

Rhelm



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GA101 Site Inspection Notes Tile : C

Legend

- 1% AEP Extent (2012)
- RoadCentreLine
- Watercourse
- Cadastre
- Catchment Boundary

200 0 200 400 600 m

Scale : 1:20,000@A4
Date : 6 September 2017
Revision : A
Created by : RST
Coordinate System : Map Grid of Australia 94

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APPENDIX B

LIDAR Comparison

ATTACHMENT 2 - LIDAR COMPARISON

Review of Duck Creek Flood Study

Reference: J1026 **Date : 10 September 2017 Rev: A**

1 Overview

There are two sets of LiDAR data that were investigated for use within the Duck Creek Flood Study, one dating from 2003-2005, and the other dating from 2011-2014. This summary report provides a comparison between the two data sets for the Duck Creek Catchment.

2 Methodology

The 2011-2014 data is a 1m DEM that was downloaded from the publicly available portals.

For the 2003 – 2005 data, point data sets that were provided by Council were combined, and a 1m DEM extracted.

Spatial data software (QGIS) was used to undertake a difference calculation between the two DEMs.

3 Summary Results

There are two attachments to this report:

- Map G006 showing the differences between the two LiDAR data sets (as noted above).
- A summary set of graphs and statistics for the two LiDAR 1m DEM sets. The summary statistics at the top of this summary is for the area only within the 1% AEP flood extent from the 2012 Flood Study, to ensure that this is representative of the floodplain.

4 Outcomes

Overall, the 2011-2014 data set shows ground levels at a higher elevation than the 2003 – 2005 data set. Focusing in on the floodplain, on average the 2011-2014 data set is 0.2m higher, although there are plenty of locations higher than that. Some key observations;

- Some of the larger differences are in the grass/ pasture land, and not in the denser vegetation locations in the floodplain. There is some anecdotal information that the 2011-2014 data set was collected under wetter conditions (and hence more vegetation) than the drier period represented by the 2003 – 2005 data set, and this outcome may align with that theory;
- Similar to above, in the pasture land areas generally there are larger differences in the floodplain, versus non-floodplain areas.

There are some large differences reported in the cross sections extracted from the DEMs (on the steep areas). This is expected because slight differences in LIDAR DEM point location or data that was flown can result in differences such as this. In these areas it is better to compare the overall shape of the cross section, to confirm the shape makes sense.

Comparison of 2011-2014 LiDAR with 2003-2005 LiDAR

Project Duck Creek Flood Study Review
Ref J1026
Date 12-Jul-17
Description

The following provides a summary comparison of cross sections extracted from the 2011-2014 and the 2003-2014 LiDAR sets. These were extracted from 1m DEMs that were created. The 2011-2014 1m DEM was downloaded through the public portal, while the 1m DEM for the 2003-2005 was generated based on the raw point data provided by Council

Summary Statistics

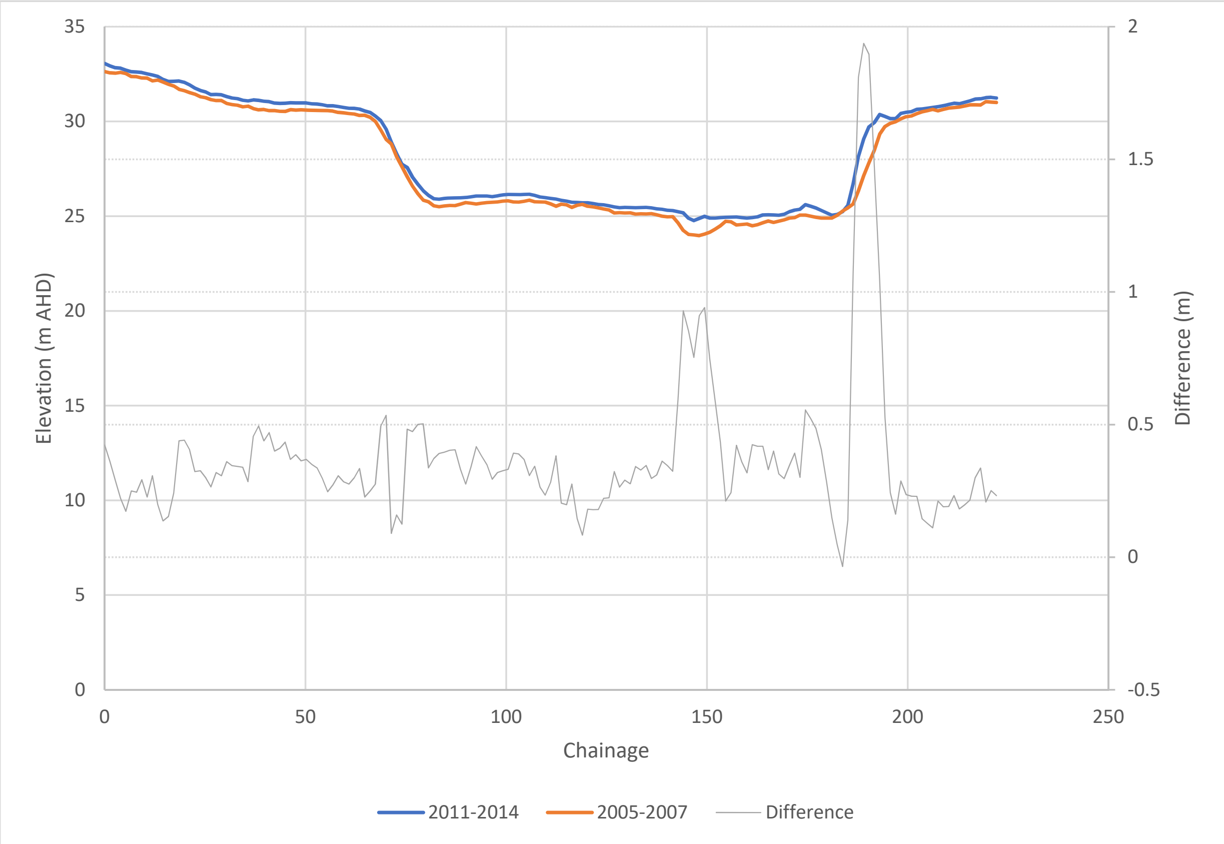
The following are summary stats within the 1% AEP Flood Extent from the 2012 study
These are a summary of the elevation difference between the two data sets
Positive values are where the 2011-2014 is higher than the 2003-2005

Mean	0.2
Median	0.19
Stdev	0.3
Min	-4.3
Max	8.4

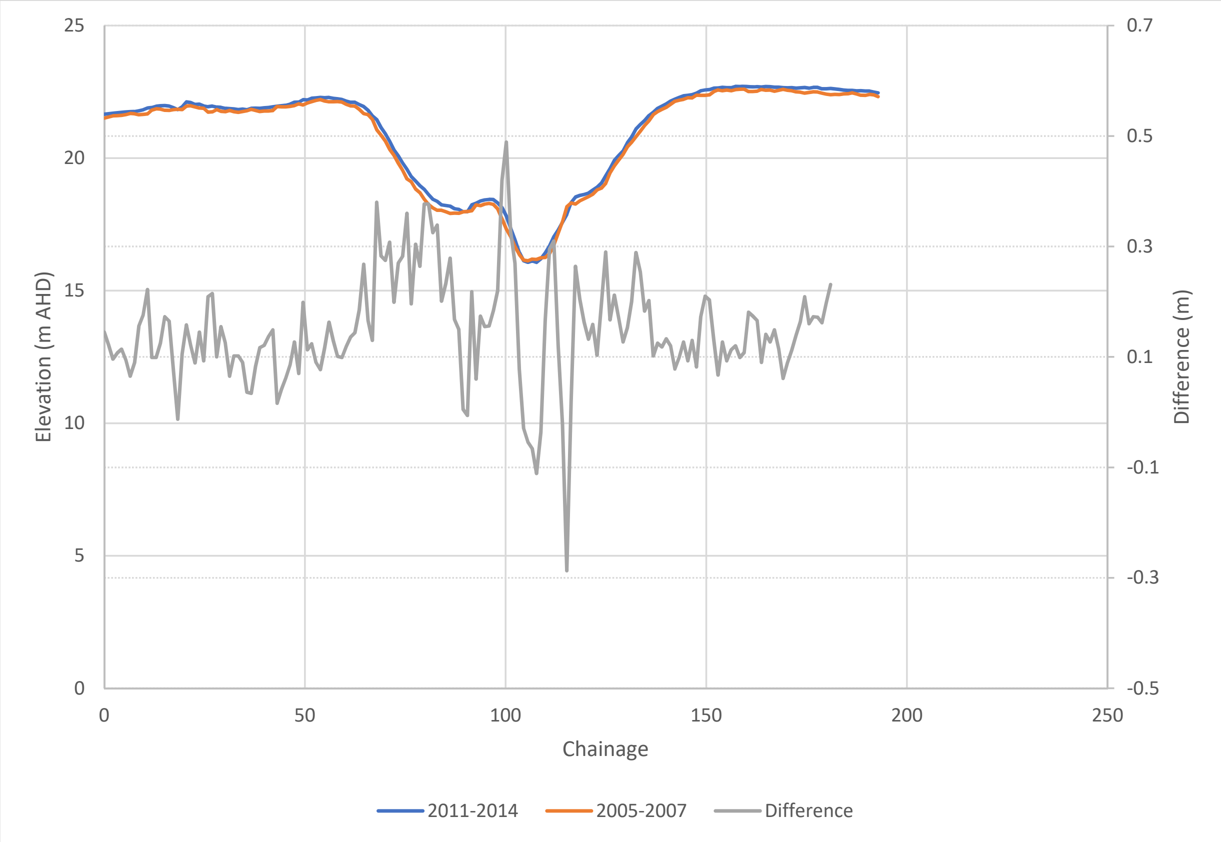
Cross Section Data

The following cross sections are based on the locations in Map G006

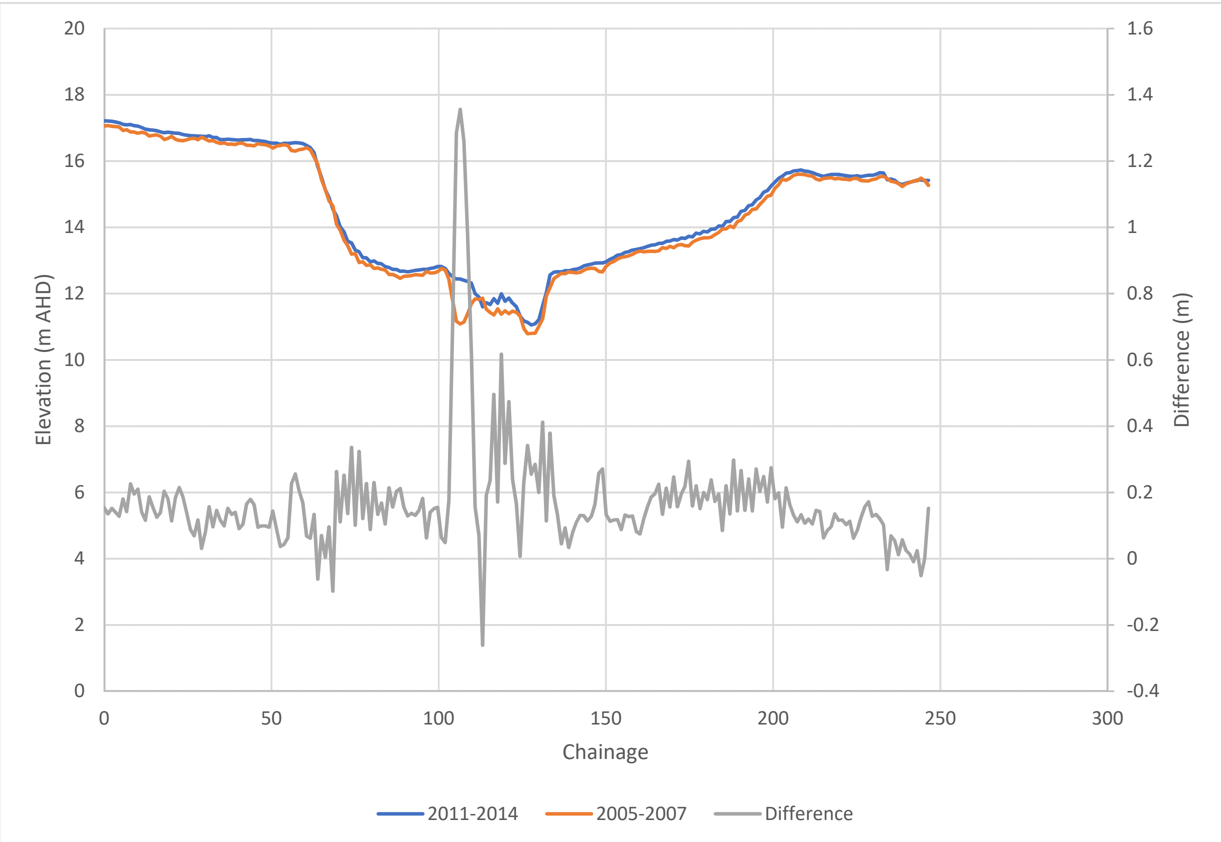
Section A



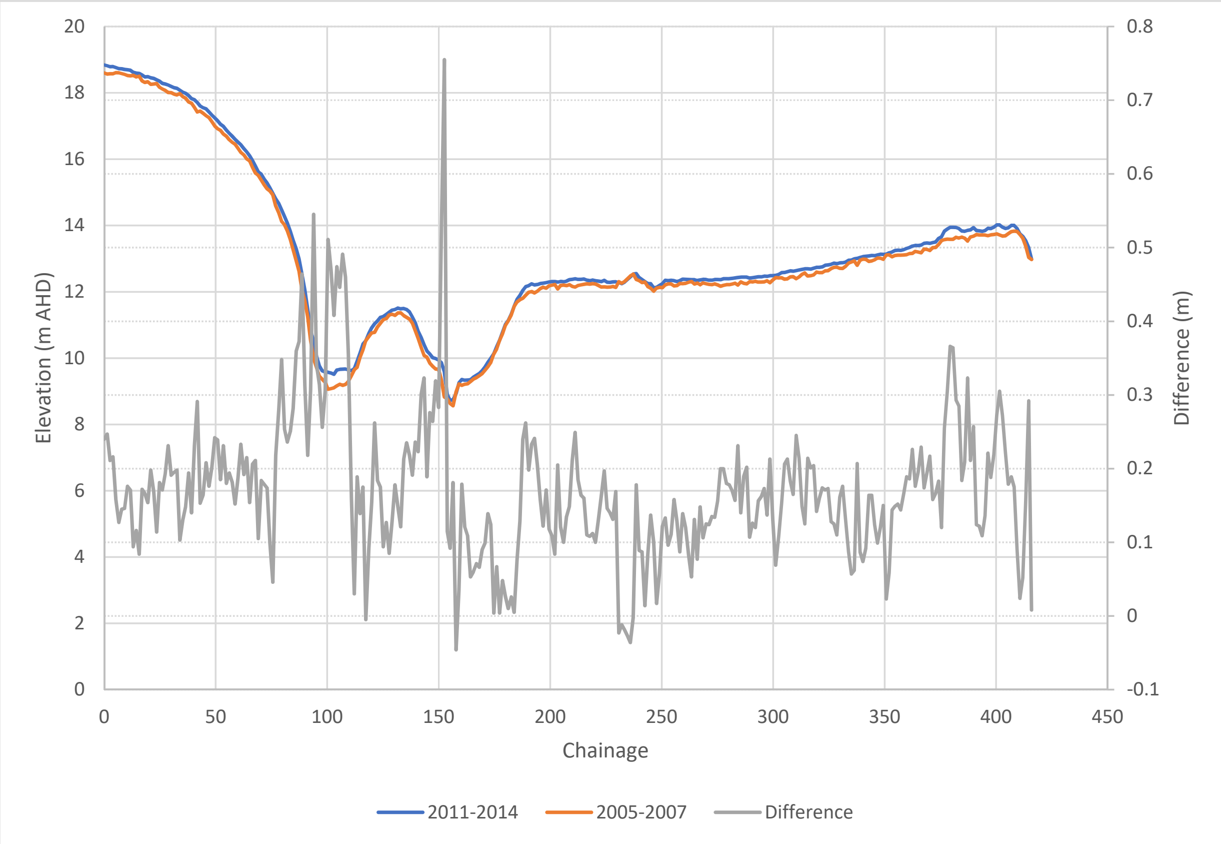
Section B



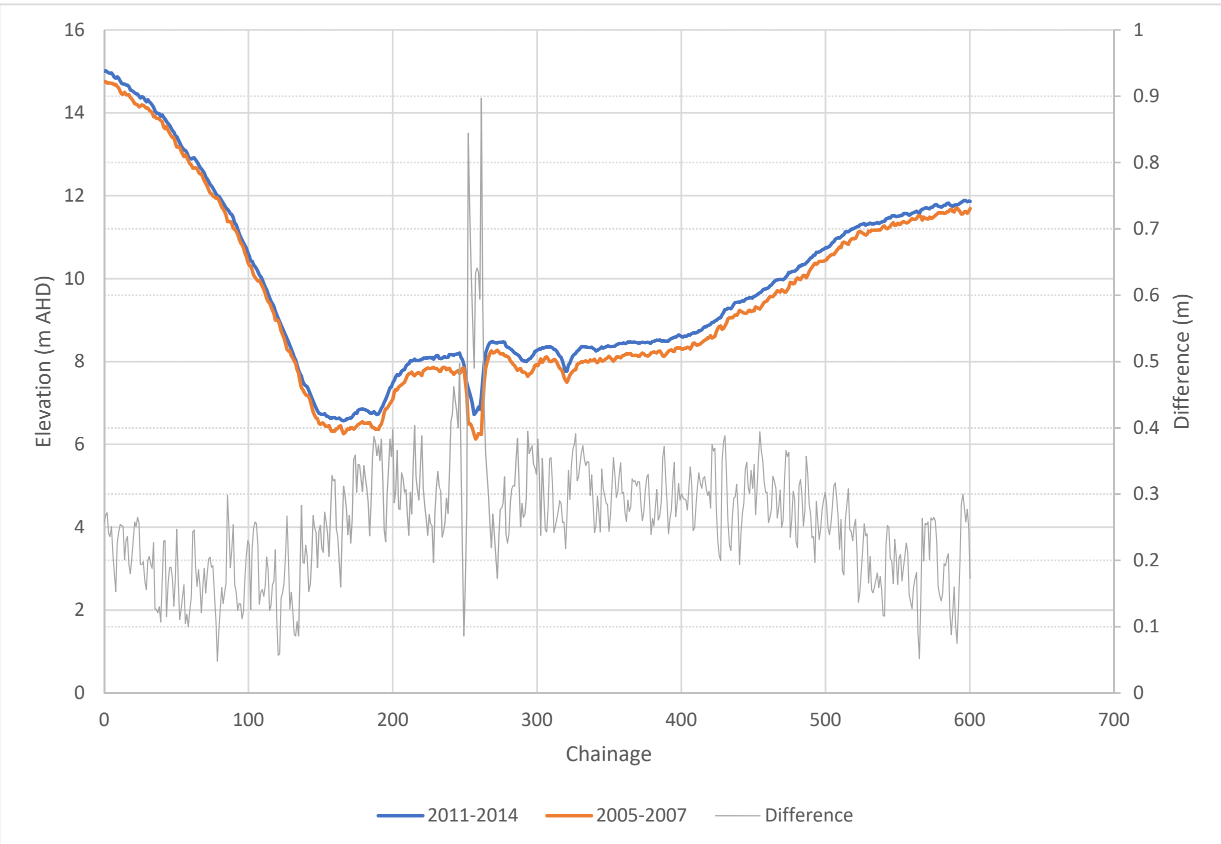
Section C



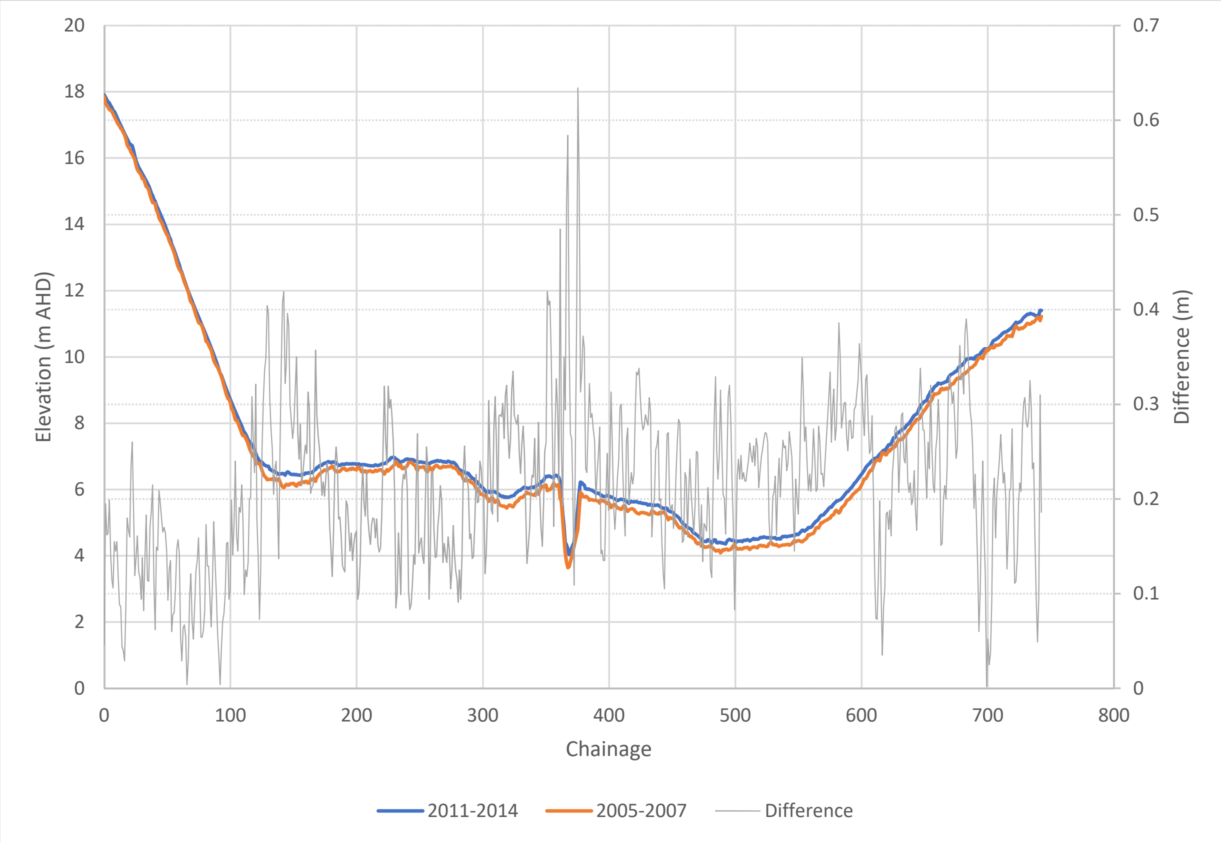
Section D



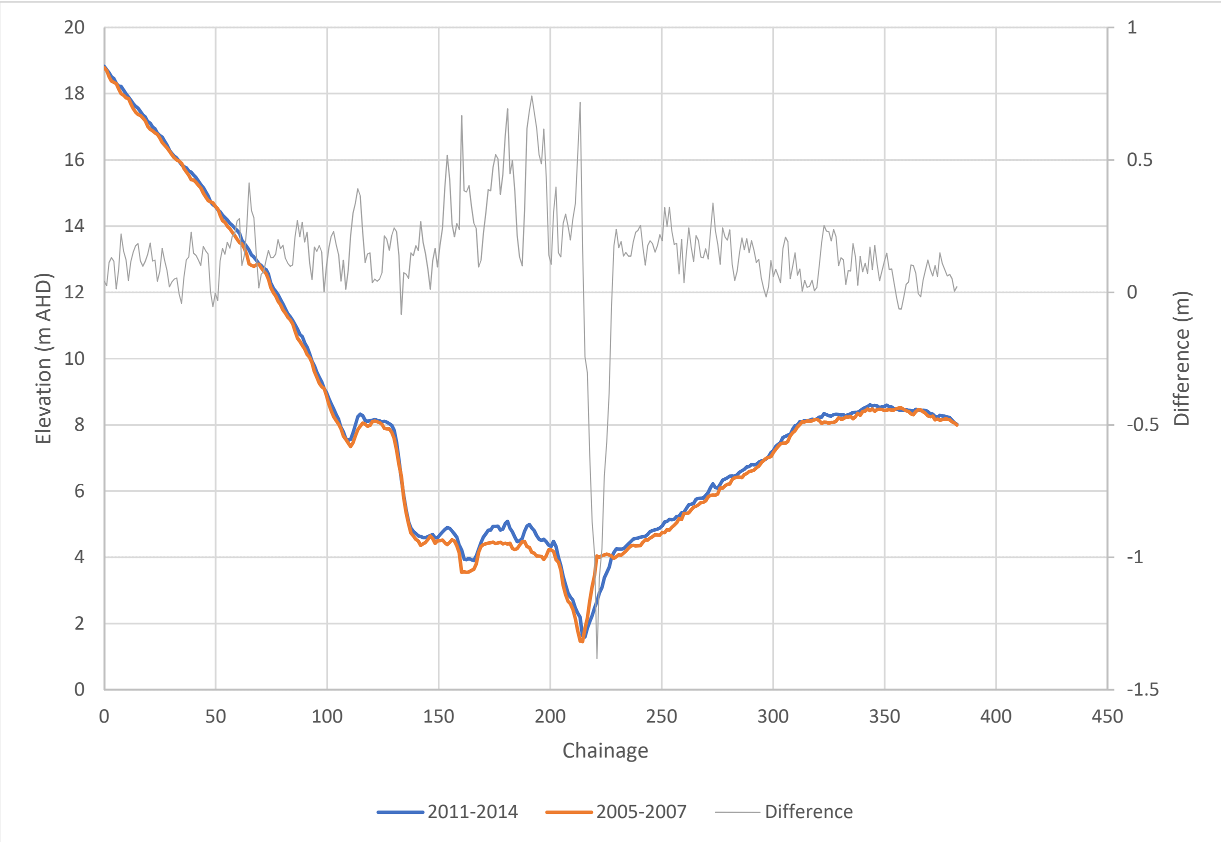
Section E



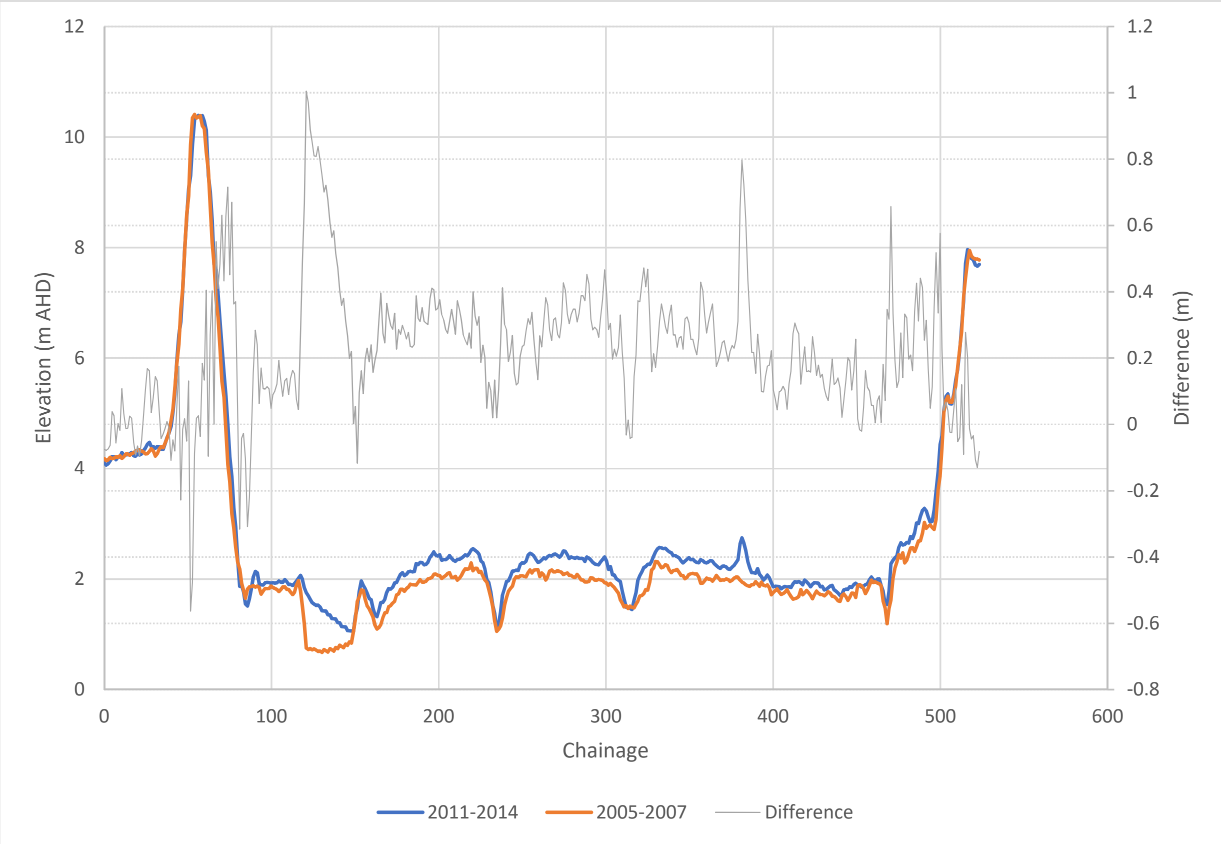
Section F



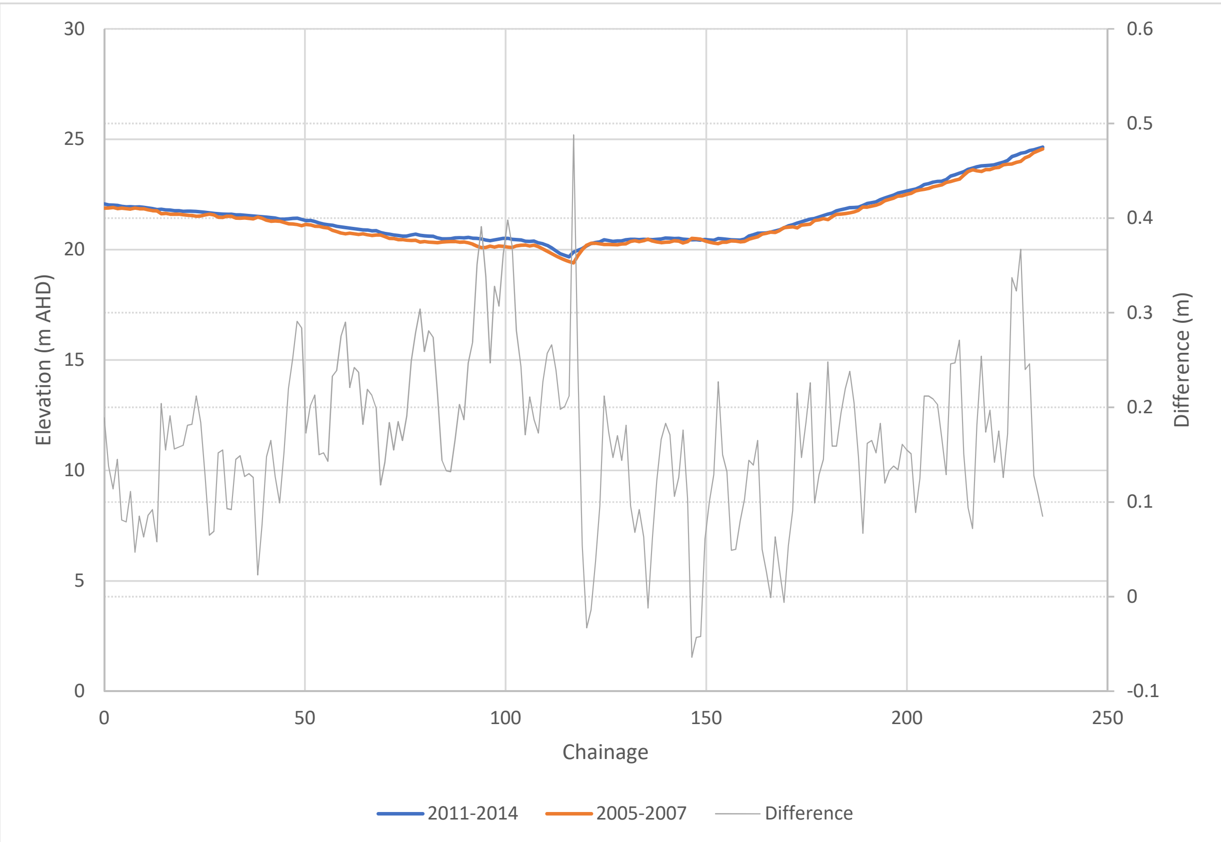
Section G



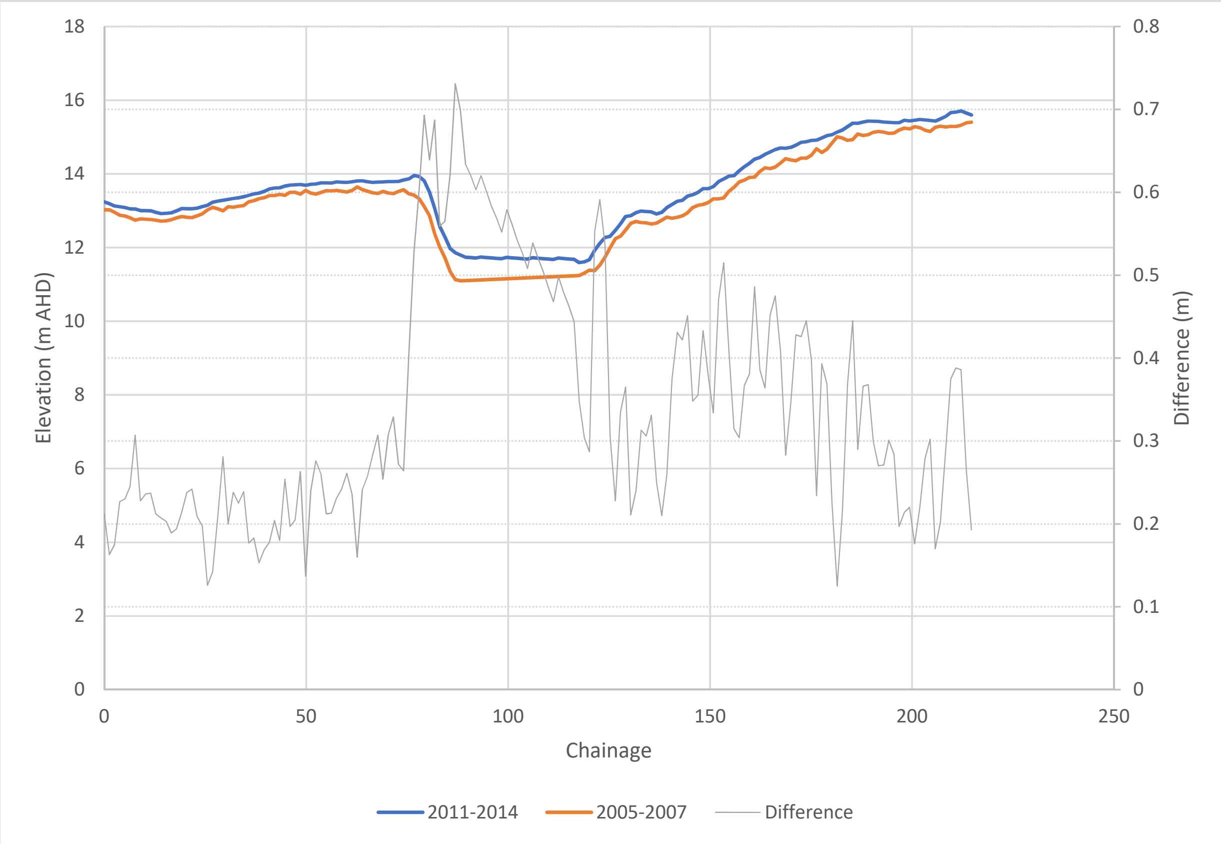
Section H



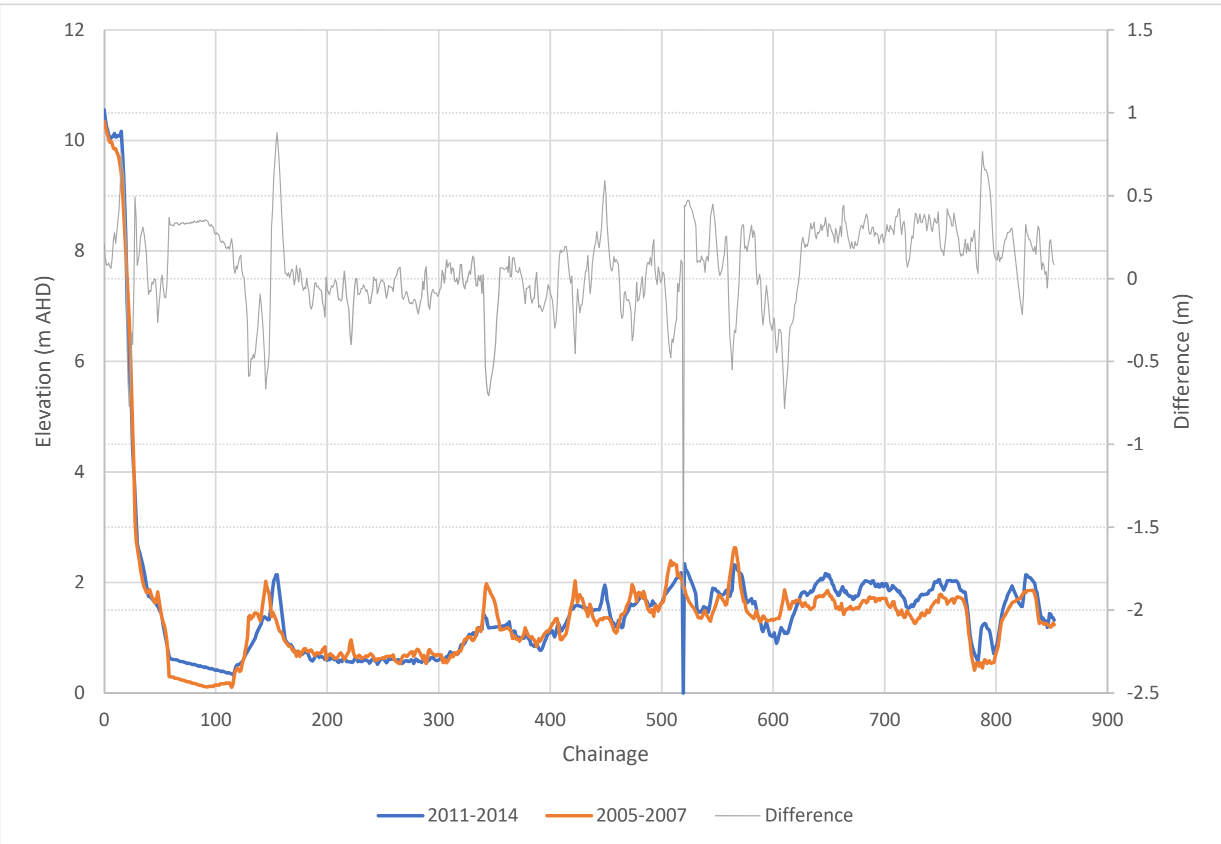
Section I

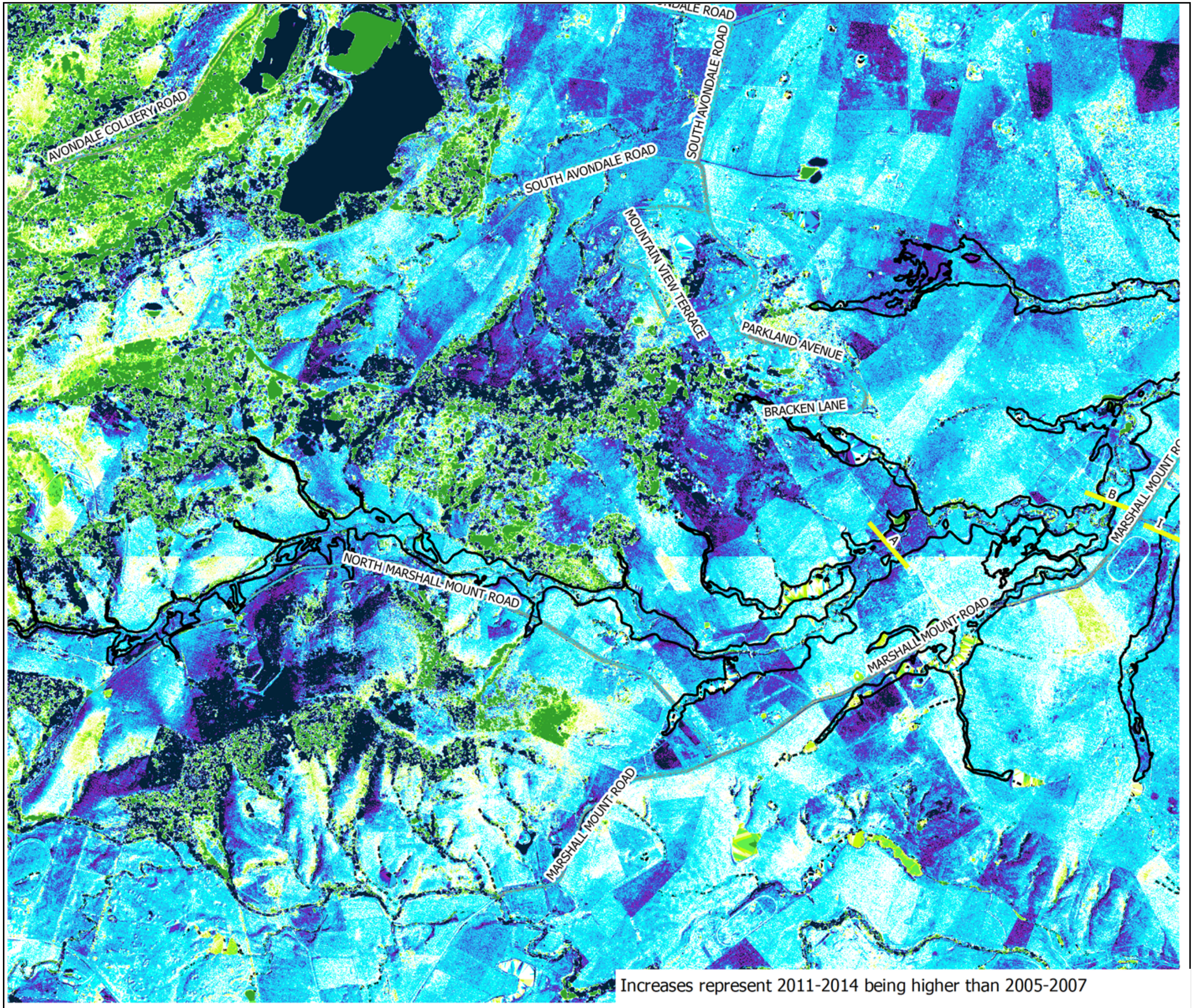


Section J



Section K





Map G006
LiDAR Comparison
2011-2014 vs 2005-2007
Tile : A

Legend

- Cadastre
- Cross Sections Extracted
- 1% AEP Flood Extent

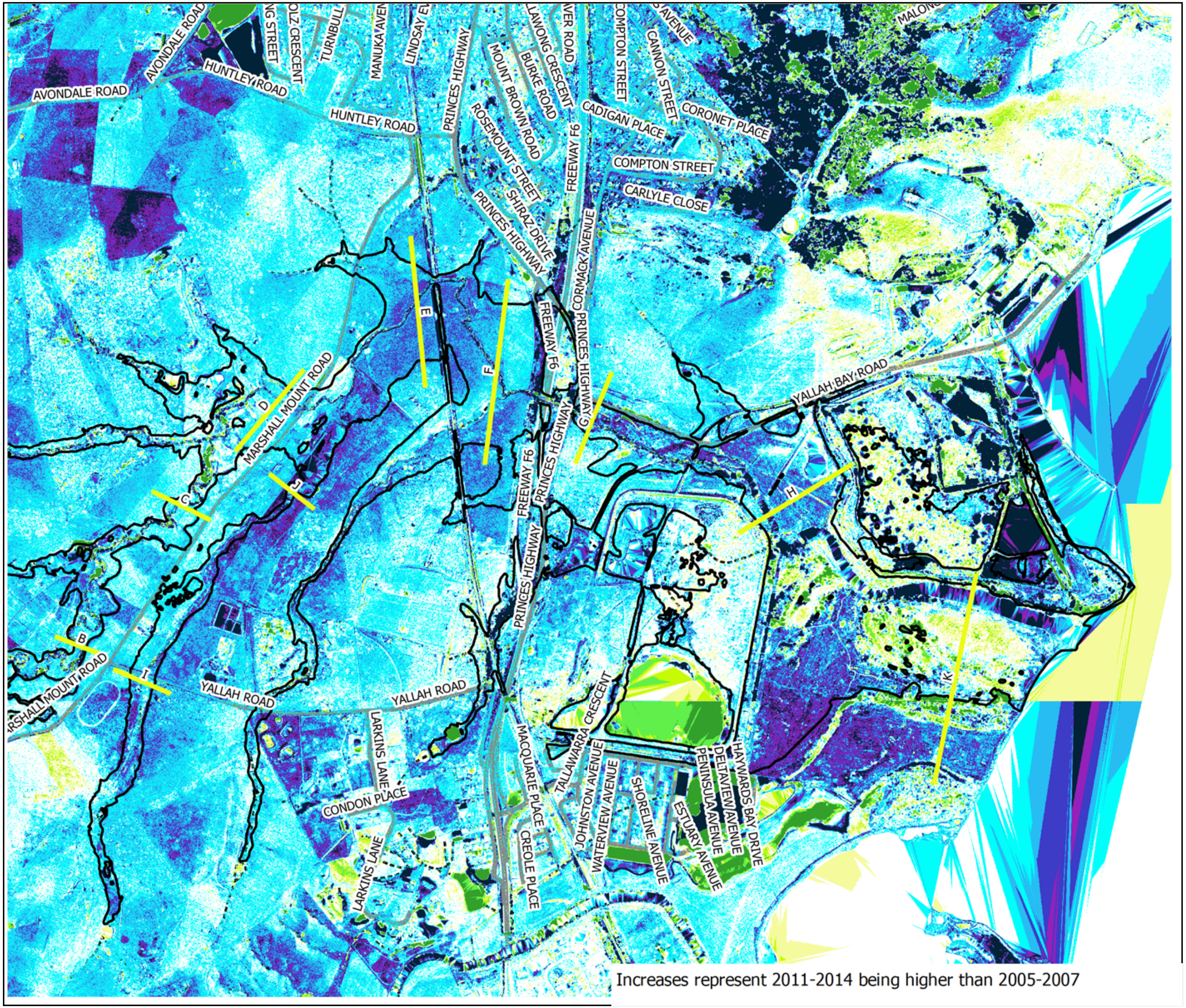
2011-2014 LIDAR less 2005-2007

- <= -0.5
- -0.5 - -0.3
- -0.3 - -0.2
- -0.2 - -0.1
- 0 - 0.01
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- > 0.5

150 0 150 300 450 m

Scale : 1:20000@A4
Date : 12 July 2017
Revision : A
Created by : RST
Coordinate System : Map Grid of Australia 94

Rhelm



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Map G006 LiDAR Comparison 2011-2014 vs 2005-2007

Tile : B

Legend

- Cadastre
- Cross Sections Extracted
- 1% AEP Flood Extent

2011-2014 LIDAR less 2005-2007

- <= -0.5
- -0.5 - -0.3
- -0.3 - -0.2
- -0.2 - -0.1
- 0 - 0.01
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- > 0.5

150 0 150 300 450 m

Scale : 1:20000@A4
Date : 12 July 2017
Revision : A
Created by : RST
Coordinate System : Map Grid of Australia 94

Rhelm

APPENDIX C

Community Engagement Materials

WOLLONGONG CITY COUNCIL | AUGUST 2017

DUCK CREEK CATCHMENT UPDATE OF FLOOD STUDY

What Is The Study About?

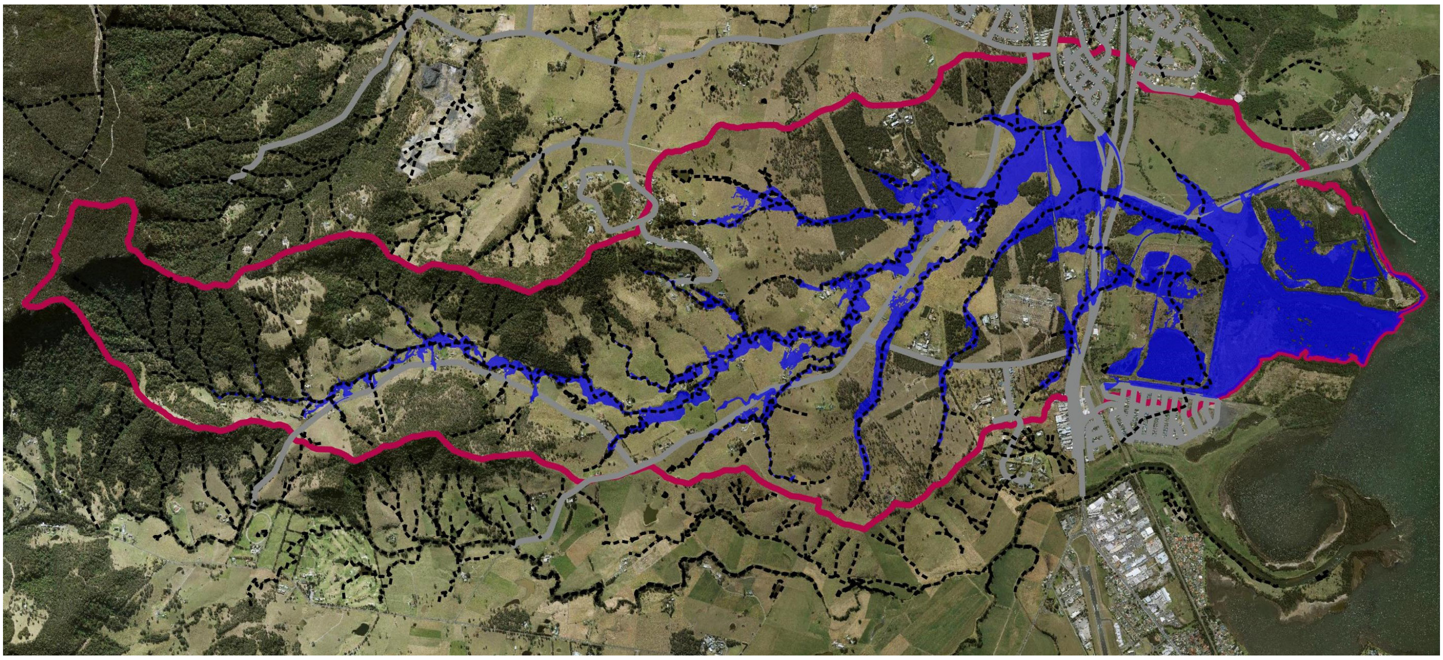
At Wollongong City Council we know some parts of the Local Government Area (LGA) are more prone to flooding than others, and we're committed to finding solutions to reduce the social and economic damages of flooding. Last year new national guidelines were released to better inform flood modelling with a particular focus on estimating rainfall data. In 2016 Council also updated our blockage policy, and the combination of our updated policy and the new guidelines saw Council resolve to review and update all of our flood studies. The Duck Creek Flood Study is one of ten under review.

The Duck Creek Flood Study was completed by Council in 2012. This study identified flood risk within the catchment. The map below shows the extent of flooding identified through these studies for the 1% annual exceedance probability (AEP) event.

The updated flood study will incorporate the revised national guidelines and blockage policy and updated ground survey to define the nature and extent of flooding in the catchment. It is also expected that data collected during recent rainfall events along with information from you will be used to verify the flood models used in this study.

As part of the review we want to draw on local knowledge of flooding in the Duck Creek Catchment. By filling in this short questionnaire you will help us understand the local flooding problems in more detail. Local knowledge and personal experiences of flooding are an invaluable source of data.

Duck Creek Catchment, Yallah and Marshall Mount, 1% AEP Flood Extent (BMT WBM, 2012)



DUCK CREEK CATCHMENT UPDATE OF FLOOD STUDY

The Floodplain Risk Management Process

This Flood Study update will be overseen by the Floodplain Risk Management Committee and informed by the community. The Committee itself is made up of local community representatives, along with Councillors, Council staff and State Government representatives. Below is an illustration of the review process. The opportunities where you can have your say are easy to identify, we've highlighted them in orange.

1. Data Collection

This is how we are bringing together existing and new data. A key part of this process will be the information provided by the community on past flooding. Have your say by filling in and returning the enclosed questionnaire.

2. Technical Review of Flood Study

The technical review is carried out by a professional consultant and overseen by a technical working group (including Council and State Government representatives). The review of the flood model will consider the updated policy, new guidelines and new data collected.

3. Draft Flood Study Report

The draft Flood Study compiles the process and findings of Stages 1 and 2. The report will provide information on the nature, extent and behaviour of flooding. The Committee is presented the Draft Flood Study Report to ensure due process and best practice has been applied.

4. Public Exhibition and Community Information Sessions

The draft Flood Study will be placed on public exhibition and everyone is encouraged to review the information and comment on it. As part of this phase, there will be community information sessions where the project team will be available to answer questions.

5. Finalisation and Adoption of Flood Study

Following the public exhibition, the Final Flood Study report, which will address any issues that may be raised by the community during the exhibition, will be presented to Council for adoption.

Study Progress

Right now, the Flood Study update is focused on initial community consultation and the collection of flood data. We will also be surveying waterways within the catchment.

Information from this stage will be used to update the computer models used to simulate flooding in the catchment.

Future Development Impacts on Flooding

Future planned development such as the West Dapto Urban Release Area and the Albion Park Bypass have the potential to impact flood behaviour within the Duck Creek Catchment. As part of this Flood Study Review we will be incorporating the master plans and designs of these developments into the flood model to evaluate any changes in flood behaviour and risk.

The results of this assessment will provide guidance to Council in future decision-making associated with development within the Duck Creek Catchment.

Why We Need Your Help

Community involvement is vital in the Floodplain Management Process. Your knowledge and experiences of flooding are an invaluable source of data and help to define the modelled nature and extent of flooding.

Right now we're seeking first hand information of any flooding problems that you may have experienced or are concerned about. As we work through the review, there will be other opportunities to provide further feedback including a community information session where we will present the draft Flood Study results.

Want More Information?

To provide flood information or for more details on the review, please contact us:

Duck Creek at Marshall Mount Road, March 2011 Flood
(Source: Unknown)

Duck Creek at Yallah Bay Road, March 2017 Flood
(Source: Sue Forner)

→WOLLONGONG CITY COUNCIL
Address 41 Burelli Street Wollongong NSW 2500
Phone (02) 4227 7111 **Email** council@wollongong.nsw.gov.au **Web** www.wollongong.nsw.gov.au

wollongong
city of innovation

→WOLLONGONG CITY COUNCIL
Address 41 Burelli Street Wollongong NSW 2500
Phone (02) 4227 7111 **Email** council@wollongong.nsw.gov.au **Web** www.wollongong.nsw.gov.au

Community Feedback Form

We know there is nothing like local knowledge. That is why we are calling upon you to help us collect flooding data for the Duck Creek Flood Study Review. We are particularly keen to collect information on flooding problems you may have experienced in significant flood events, possibly in 1978, 1984, 2011 and 2017. Any responses you can provide to the questions below would be greatly appreciated. Any additional comments, suggestions or information you would like to provide would also be welcome.

You can complete the survey online at www.haveyoursaywollongong.com.au or by completing the survey below and returning to Council by post (addressed envelope provided) or by email to council@wollongong.nsw.gov.au. All surveys should be returned no later than **Friday 25 August 2017.**

Contact and Property Details (all contact details will be kept confidential)

Name: ____________________

Address: ____________________

Phone or email: ____________________

Can we contact you for more information? ☐ YES ☐ NO

Previous Flood Experience

Have you experienced flooding in the Duck Creek Catchment?

☐ Flooding in or near a dwelling or business

☐ Rural property flooding (not near dwelling)

☐ Road flooding (but still trafficable)

☐ Road cut-off by flooding

☐ Other ____________________

Can you provide additional information on flooding you have experienced such as date(s), depth of flooding or other impacts of the flooding? Please attach additional pages.

Do you have any photographs or video of flooding that you are willing to share with Council? Photos and video can be mailed or emailed to the address on the previous page (all photos and videos will be returned).

Do you have any other concerns about flooding or flood related issues?

____

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wollongong
city of innovation

WOLLONGONG CITY COUNCIL

Address 41 Burelli Street Wollongong • **Post** Locked Bag 8821 Wollongong DC NSW 2500
Phone (02) 4227 7111 • **Fax** (02) 4227 7277 • **Email** council@wollongong.nsw.gov.au
Web www.wollongong.nsw.gov.au • ABN 63 139 525 939 - GST Registered

«PAFBSP»

«Owner»
«StreetNoandAddress»
«SuburbStatePostcode»

Your Ref	[Click HERE and type their reference]
Our Ref	Z19/63124
File	CCE-040.010.01.294
Date	[Type full date eg 2 June 2003]

Dear [Click HERE and type recipient's name]

DUCK CREEK FLOOD STUDY REVIEW (YALLAH REGION)

We're writing to let you know we've updated the 2012 Duck Creek Flood Study. As part of this work, we sent out a community survey, spoke to businesses and government agencies and contacted utility service providers to get their input. We gathered historical observations and were provided with information and photos of flooding in this catchment (see map of the catchment area overleaf).

We've made minor changes to the flood models to account for changes in the catchment since 2012, included additional survey data and modelled the March 2017 flood. The updated Study also uses Council's revised Blockage Policy, which was updated in 2016. This Policy helps us to determine how the potential blockage of bridges, culverts and other stormwater channels might affect flood behaviour. Although there have been some changes, the revised flood extent and behaviour is similar to the existing Study.

We've now finished our review, and would like to share the updated Study with the community and get feedback. Come along to a drop-in community information session for a chat with the floodplain engineers who are updating the Study. You can ask questions share information about your experiences of flooding in this area.

Where: Scribbly Gum Room at Dapto Ribbonwood Centre, 93-109 Princes Hwy, Dapto

When: Monday 8 April 2019, 4pm – 5:30pm

If you'd like to attend and have accessibility or mobility requirements, or need an interpreter, please contact me to let me know how we can support your attendance.

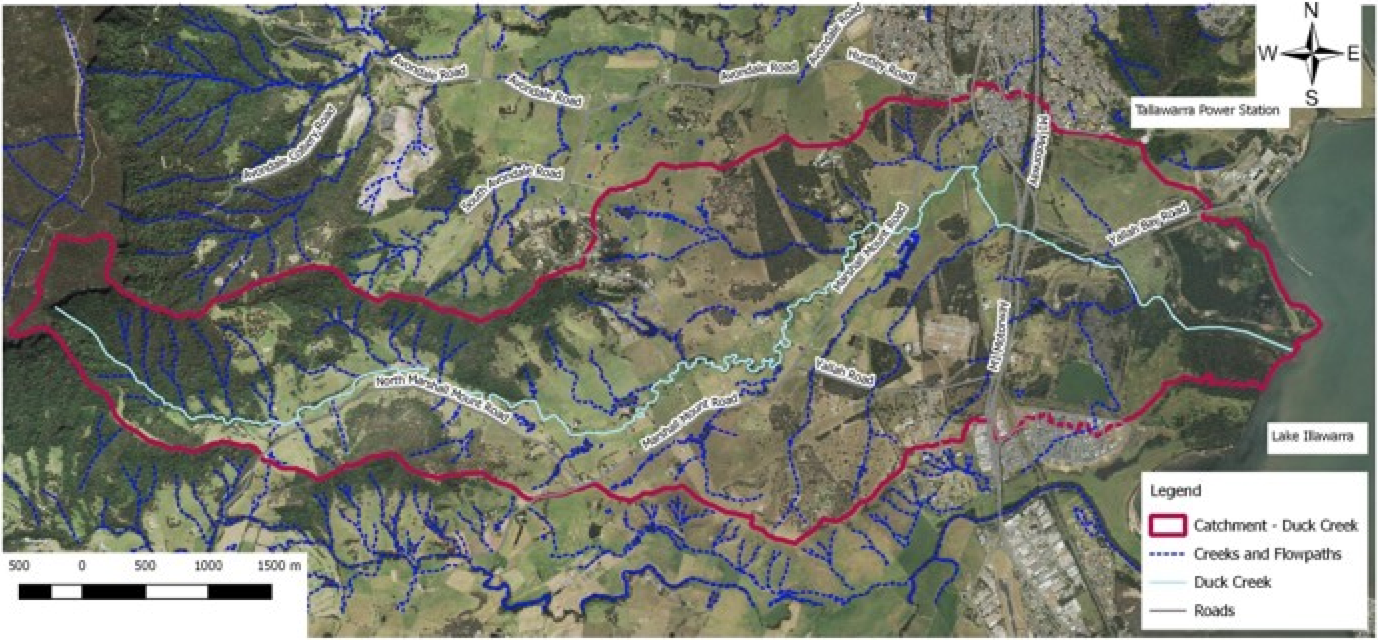
If you'd like to learn more but are unable to attend the session, information and a form to provide feedback online will be available on our website www.wollongong.nsw.gov.au until Monday 13 May 2019.

Please contact me should you require further information.

This letter is authorised by

Jen Lysle-van Dyk
Engagement Officer
Wollongong City Council
Telephone (02) 4227 7111

Map of the Duck Creek Catchment



Duck Creek Flood Study Review (Yallah)

As part of our commitment to managing flood and stormwater risks in our region, we've updated the 2012 Duck Creek Flood Study and would like your input.

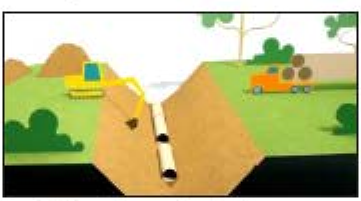
Please let us know your thoughts by 5pm Monday 13 May 2019

How does Council manage flood risk?

Each year, Council spends millions of dollars on stormwater and floodplain management. Our team of flood experts prepare flood studies and floodplain risk management studies that help us understand the flood behaviour for a particular catchment and see if there are any ways of reducing flooding risk in an area.

Floodplain risk management studies include a plan of potential solutions aimed at reducing the existing and future flood risk. Examples of these solutions include:

- emergency response plans based on detailed understanding of flood behaviour
- building new structures that collect and carry stormwater into drains or creeks, such as detention basins and swales, or improving existing ones to better manage stormwater and floods
- land zoning that says what can and can't be built on flood-prone land
- voluntary purchase of houses built in high flood risk areas



Installing a stormwater drain

What is a "1 in 100 year" flood?

A flood event that has the probability of occurring on average once every 100 years, i.e. there is a 1% chance of a flood of this size occurring at a particular location in any given year. This doesn't mean that if a location floods one year, that it won't flood again for the next 99 years. Nor, if it hasn't flooded for 99 years, that it will necessarily flood the next year. Some parts of Australia have experienced more than one "1 in 100 year" floods within a decade of each other. Within the Floodplain Risk Management Study and Plan, the "1 in 100 year" flood is called the **1% AEP flood event**.

What is the Flood Planning Area?

The area within which developments may be conditioned with flood-related development controls. The flood planning area is calculated as the area below the Flood Planning Level.

What is the Flood Planning Level?

The height used to set floor levels for property development in flood prone areas. It is generally the 1% AEP flood level plus an appropriate freeboard. This level may be higher for vulnerable land uses. Vulnerable land uses are those that are occupied by people that have less capacity to respond to flooding, which may pose evacuation challenges, e.g. hospitals or schools.

What is a Freeboard?

A height above the 1% AEP flood level that is included in the Flood Planning Level to account for factors such as wind, waves, unforeseen blockages, other localised hydraulic effects. Freeboard is usually 0.5m above a flood level.

Why do flood levels and information need to be reviewed over time?

There is a chance that floods of any size will occur in the future. As the size of a flood increases, the chances of it occurring becomes smaller. Because some rare types of floods have not occurred for over a century, the height of future floods is predicted using computer models. These models simulate different flood levels and velocities for a variety of different sized floods.

Given the importance of accurately predicting flood levels and information, Council engages experts to establish and operate these computer models. From time to time, computer models are reviewed, and predicted flood levels may change slightly. The reason why the models are revised can include:

- New floods occur, providing additional data to fine-tune the model

- Flood mitigation works undertaken may change flood levels
- More advanced computer models become available
- Development within the floodplain (which may be outside Council's control)

How are flood affected properties identified?

Council's flood modelling figures out the size of flooding throughout the catchment and which properties are partially or fully impacted by flooding.

Example of a flood modelling map

Where can I get information about flood levels on my property?

Council has historical flood level records and/or our completed flood studies for some properties, but not all. Please contact our Drainage Duty Officer on (02) 4227 7111 to find out what's available for your property.

What should I do in the event of a flood?

If the situation is life threatening, you should call 000. For other assistance during an emergency such as flood, storm or tsunami, please contact the NSW State Emergency Service (SES) on 132 500 or visit www.ses.nsw.gov.au It's best to be prepared for any flood. The SES provides advice on how to prepare at www.floodsafe.com.au

Be safe around floodwater. It's dangerous and full of nasty stuff like chemicals and sewerage, so don't play in or try to drive through it.

Why does Council study flooding?

Councils in NSW are responsible for managing flood risk and keeping the community informed. Councils follow the NSW Flood Prone Land Policy, which outlines how Councils should manage flooding to reduce the risk to people and properties.

What are Councils doing to manage flood risk?

Councils prepare flood studies and risk management plans according to the NSW Government's Floodplain Development Manual (2005). They carry out associated recommendations with the technical and financial assistance of NSW Government and other key people, groups or organisations that have an interest in this work.

What is the difference between a Flood Study and a Flood Risk Management Study and Plan?

A Flood Study looks at the flood behaviour for a particular catchment (which might be a river or creek). Council's flood studies help to understand existing flooding behaviour and see if there are any ways of minimising or reducing flooding risk in an area.

A floodplain risk management study and plan analyses flood behaviour, then details options that can help protect people and property through better planning, emergency management and infrastructure works.

What can I do around my yard to help keep watercourses clean?

- Be careful not to dispose of grass clippings and other garden cuttings in or near watercourses and remove any obstructions that may cause blockages or divert flood waters.
- Be aware of any drainage easements or overflow paths that affect your property. Seek Council approval before altering your driveway or footpath levels, as this may cause water to flow off the road and down your driveway.
- Take care when planting trees near drainage pipes. Certain species with aggressive root systems e.g. Jacaranda, Poplar, Willow, Fig, Camphor Laurel and Rubber Trees can cause pipes to become blocked or cracked.
- Don't lay any pipes, construct a bridge or divert a watercourse without first consulting Council. Unapproved work can increase flooding for both you and your neighbours.
- Don't fill low-lying areas of your yard without seeking Council approval, as this may cause water to pond and increase flooding potential on your and your neighbours' properties.
- Keep drainage inlets on your property clear of any rubbish or blockages. Remember, large paved areas will increase runoff, so you may need extra drainage.

How can I join the conversation?

There are a number of ways to ask questions or share your feedback with us:

⇒ **Complete an online feedback form on Council's website www.wollongong.nsw.gov.au**

⇒ **Phone (02) 4227 7111**

⇒ **Email engagement@wollongong.nsw.gov.au**

DUCK CREEK (YALLAH) FLOOD STUDY REVIEW

Community Feedback Form

As part of our commitment to managing flood and stormwater risks in our region, we've recently updated the 2012 Duck Creek Flood Study and would like your input.

All feedback must be received by Monday 13 May 2019.

Please share your comments about the revised Duck Creek Flood Study.

Please return completed form to:

More overleaf….

Wollongong City Council Community Engagement Unit
Locked Bag 8821
Wollongong NSW 2500
Telephone: 02 4427 7111
Facsimile: 02 4227 7580
Email: engagement@wollongong.nsw.gov.au

www.wollongong.nsw.gov.au

If there isn't enough room for your comments, please attach additional paper to this form.

If you'd like a reply to your submission and to be kept informed of progress, please fill in the section below:

Name:	
Address:	
Suburb:	Email:

Privacy Notification:
The purpose for seeking your submission on advertised matters is to better assist Council in its decision making processes.
The intended recipients of your submission are officers within Council and those granted lawful access to the information. Your submission may be exhibited on Council's website and included in publicly accessible registers. If you make an anonymous submission, Council will be unable to contact you further.
If your submission relates to a development proposal or other relevant planning application, Council is required to disclose on its website all relevant details of political donations or gifts made by you, including your name and address.
In limited circumstances, you may apply for suppression of your personal information from a publicly accessible register. Further information is available on Council's website at www.wollongong.nsw.gov.au/pages/privacy.aspx or by phoning Council on (02) 4227 7111

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APPENDIX D

Model Setup and Calibration

Appendix D – Model Development & Calibration

Review of Duck Creek Flood Study

Table of Contents

1 Model Development

1.1 Hydrologic Model

1.1.1 2012 Flood Study Hydrological Model Review

The 2012 Flood Study developed a hydrological model using WBNM software that provides for simulation of the rainfall-runoff process using the catchment characteristics of Duck Creek and historical and design rainfall data.

The previous model was found to be largely suitable for use in the current study. Some minor changes were made to imperviousness to ensure that the model was reflective of current catchment conditions.

The WBNM model was utilised in the 2012 study to generate sub-catchment flows, with routing being undertaken within the hydraulic (Tuflow) model. This means that the hydrological model could not be used to estimate flows other than those from the individual sub-catchments. This has been updated as a part of this study (see **Section 1.1.3**).

1.1.2 Catchment Delineation

The Duck Creek catchment drains an area of approximately 19km^2 to its point of discharge into Lake Illawarra. For the hydrologic model the catchment area has been delineated into 127 sub-catchments as shown in **Map 501**. The sub-catchment delineation provides for the generation of flow hydrographs at key confluences or inflow points to the hydraulic model.

1.1.3 Imperviousness

The percentage imperviousness adopted in the modelling was generally consistent with the 2012 Flood Study. Given the largely rural/ forested nature of the catchments, with limited directly connected impervious areas, a 1% imperviousness was adopted for most subcatchments. The exception to this was three subcatchments in the northern part of the study area, where there is a small portion of urban development.

Imperviousness for the urban area was estimated based on a detailed sample GIS mapping of impervious areas. This mapping suggested imperviousness of approximately 60% for the urban portions. Allowance was also made for the large road and motorway sections in these catchments. The urban area was also adjusted to account for the potential effective imperviousness of these areas (assumed to be 60% of the total impervious area). **Table 1-1** shows the estimated impervious percentages for the three urban catchments, incorporating the urban and non-urban portions.

Table 1-1 Imperviousness Adopted

Catchment ID	Total Area (ha)	Urban Area (ha)	Main Road (ha)	Impervious (%)
1	8.7	5.8	0.8	33
6	5.8	4.6	1.6	35
7	14.3	4.3	1.5	30

1.1.4 Flow Routing

Although WBNM has flow routing capabilities, the 2012 flood study instead adopted routing through the Tuflow model and the WBNM model essentially only needed to provide flows as inputs into the hydraulic model (TUFLOW).

There will be a need to utilise the WBNM model under the new ARR2016 in the future to assist in identifying the appropriate storm events for the modelling, rather than modelling all storm events through Tuflow. Therefore, a Stream Lag Factor was applied to route the flows between the subcatchments. A value of 1 was adopted for this modelling, to reflect the primarily natural channels throughout the catchment.

The application of the Stream Lag Factor and the catchment lag factor (**Section 1.1.5**) showed a reasonable comparison to the peak flows and hydrographs from the Tuflow model, suggesting that the routing is reasonable adopting a stream lag (see **Table 1-2** for the comparison at key locations within the catchment).

Table 1-2 Peak Flow Comparison - March 2017 Event

Location	Peak Flow m^3/s		
	Tuflow	WBNM	Variation
Duck Creek, 150m Downstream of Yallah Road	57.8	52.1	10%
Upstream of TAFE	71.2	60.0	16%
Upstream Marshall Mount Road	75.2	62.6	17%
Downstream of Rail Bridge	75.6	68.2	10%
Downstream of Princes Highway	80.7	76.5	5%

1.1.5 Lag Parameter

WBNM uses a Lag Parameter (also referred to as the C value) to calculate the catchment response time for runoff. The Lag Parameter is important in determining the timing of runoff from a catchment, and therefore the shape of the hydrograph. The general relationship is that a decrease in lag time results in an increase in flood peak discharges (Boyd et al., 2007).

Based on studies undertaken on ten catchments in eastern NSW, and an additional 54 catchments across Queensland, NSW, Victoria and South Australia, Boyd et al. (2007) recommends a Lag Parameter value near to 1.6.

It is beneficial to calibrate the WBNM model against recorded flood data in order to ensure that the adopted Lag Parameter is representative of the catchment being modelled. However, due to the limited flood data available for the current study, it was not possible to undertake a model calibration process to ascertain a calibrated C value for the Duck Creek catchment. Therefore, based on the recommendations in Boyd et al. (2007), a Lag Parameter value of 1.6 was adopted.

1.1.6 Losses

An initial and continuing loss model was utilised for this study. The initial loss is the depth (millimetres) of rainfall that is prevented from becoming runoff in the initial stages of the flood-producing rainfall event. It is a function of the initial “wetness” of a catchment (i.e. the wetter the catchment prior to flood-producing rainfall event, the lower the initial loss), as well as vegetation, soil infiltration, depression storages etc. Antecedent conditions can affect initial losses.

The continuing loss rate (millimetres per hour) is the rainfall that is continually (i.e. throughout the event) prevented from becoming runoff. Theoretically, this value is a constant function of the catchment. That is, the continuing loss rate is catchment specific rather than event specific and should therefore be kept the same across all rainfall events.

The initial loss and continuing loss rates for the hydrologic model are ideally determined during the model calibration process. A separate initial loss can be assigned to the pervious and impervious areas within the catchment. **Table 1-3** shows initial and continuing loss values adopted in the 2012 Flood Study.

Table 1-3 2012 Flood Study Rainfall Loss Rates

Rainfall Loss Type	Loss
Initial Loss – Pervious	20 mm
Initial Loss – Impervious	2 mm
Continuing Loss – Pervious	2.5 mm / hr
Continuing Loss – Impervious	0 mm / hr

1.1.7 Model Verification

There was no flow gauging available within the Duck Creek Catchment, and therefore a direct calibration of the hydrological model could not be undertaken. However, an indirect calibration was undertaken through the hydraulic model and comparison to observed flood levels within the catchment (**Section 6**).

As a check on the hydrological model, a verification was undertaken by comparing the flows derived in the current study with those of the 2010 Bewsher Study. The results of this verification are provided in **Table 1-4**.

As noted above, the 2012 hydrological model was setup so that flow routing occurs within the hydraulic model, rather than the hydrologic model. As such, the 2012 hydraulic model flows have been shown for verification purposes.

The model shows a reasonable agreement between the 2012 hydraulic model results and the 2010 Bewsher study, suggesting that the hydrological modelling approach adopted is comparable.

Table 1-4 Hydrological Model Verification

Location	100 Year ARI Peak Flow (m3/s)		
	Current Model	2012 Hydraulic Model (6 hour duration)	2010 Bewsher Study
F6 Freeway (downstream)	253	233	237.1
Duck Creek Outlet	290	NA	289.0

1.2 Hydraulic Model

1.2.1 Model Review

A TUFLOW model was developed by WBM as part of the 2012 Duck Creek Flood Study. The model developed was primarily a 2D model of the floodplain and channels. 1D components of the model were limited to hydraulic structures (culverts). Bridges were represented through the 2D component of TUFLOW.

The previous model was found to be largely suitable for use in the current study. Some minor changes were made to ensure that the model was reflective of current catchment conditions, namely:

- Update of culvert details based on new survey data;
- Update of previous survey based on field verification of current conditions;
- Update of bridge crossings based on new survey and field verification;
- Incorporation of additional cross sections to better define the creek areas; and
- Update of the roughness values to ensure they represent current conditions.

The details of the hydraulic model developed for the current study are provided in the following sections.

1.2.2 Digital Terrain Model

The digital terrain model was primarily based on the 2005-2007 LiDAR data (refer **Section 3 of the main report)** TUFLOW samples the terrain at both the cell centres and the cell edges, with the results that the grid was sampled every 2m, to generate the 4m grid for the TUFLOW model.

The LiDAR data was supplemented by cross sectional survey of the watercourses (**Sections 3.4.2 and 3.4.3**) to ensure that the necessary detail on channel shape and dimensions were captured in the hydraulic model.

Minor adjustments were made to the LiDAR data to ensure that creek inverts and road and embankment crest levels were captured accurately in the model.

The digital terrain model developed is shown in **Map G502**.

1.2.3 Structures

The 1D model network is limited to culverts within the study area, with the bridges being defined as 2D structures. Details of the culverts and bridges included in the model are presented below.

1.2.3.1 Culverts

The details of the culverts included in the model are provided in **Table 1-5**. The location of these elements is shown in Map **G503**.

Table 1-5 Details of 1D Model Elements

ID	Shape	Upstream Invert (mAHD)	Downstream Invert (mAHD)	Size (m)	Number of Cells	Length (m)
St8	Circular	11.62	12.22	1.35	3	7
St10	Rectangular	22.56	22.5	2.06 x 1.93	1	14
St11	Rectangular	19.11	19.04	1.8 x 0.77	2	21
St12	Rectangular	20.55	20.38	1.84 x 1.1	1	17

ID	Shape	Upstream Invert (mAHD)	Downstream Invert (mAHD)	Size (m)	Number of Cells	Length (m)
St13	Circular	11.13	10.81	1.2	1	21
St15	Irregular	8.01	8.09	-	1	23
St16	Rectangular	11.54	11.46	4.7 x 0.5	1	11
St17	Rectangular	4.72	4.55	3.05 x 2.4	1	24
St18	Circular	18.63	18.33	1.2	1	37
St20	Circular	6.9325	6.7	0.9	4	41
St21	Circular	9	8.7	0.9	4	33
St22	Circular	9.34	9.18	0.9	2	21
St23	Circular	4.18	3.69	0.9	6	47
St24	Circular	6.1	5.52	0.9	3	40
St25	Rectangular	1.49	1.41	1.15 x 3.9	1	29
St26	Rectangular	2.15	2.19	1.15 x 5.96	1	43
St27	Rectangular	1.64	2.77	1.15 x 5.86	1	39
St28	Rectangular	2.41	2.35	1.8 x 1.2	3	35
St29	Rectangular	9.08	9.03	2.4 x 1.35	1	17
ST31	Circular	20.4	19.8	1.2	1	42
ST32	Circular	19	18.4	2.05	1	37
ST37	Circular	3.6	3.3	0.75	2	22
ST38	Circular	2	1.9	0.9	1	30
ST101	Rectangular	11.02	10.97	1.6 x 0.74	3	19
ST102	Rectangular	1.86	1.8	1.8 x 1.2	3	13
St103	Rectangular	6.84	6.64	2.7 x 2.35	1	23
ST104	Circular	14.55	14.51	1.35	2	7
ST105	Circular	40.34	40.09	0.9	2	15
ST106	Rectangular	27.56	27.52	1.21 x 1.21	3	4
ST110	Circular	10.95	8.1	1.2	2	106

1.2.3.2 Bridges

The details of the bridges included in the model are provided in **Table 1-6**. The location of these elements is shown in **Map G503**.

The bridges have been incorporated into TUFLOW as layered flow constriction shapes. This methodology allows the bridges to be modelled in 2D. For each bridge, the height and width of the deck and any railings are inputted, as well as individual blockage rates for each. For example, it is possible to have a blockage of 10% under the bridge, 100% for the deck, and 50% for the railings. TUFLOW uses these values to dynamically adjust the conveyance of water through the bridge cells based as the water level height changes.

In the Duck Creek model, the blockage under the bridge will be adjusted based on historical observations and, for the design runs, Council's blockage policy.

Table 1-6 Details of Bridge Elements

Bridge	Width (m)	Invert (mAHD)	Soffit (mAHD) (Depth) (m)	Rail Level (mAHD)
South Freeway	40	3.08	8.70 (1.15)	10.70
Princes Highway	28	1.61	7.07 (1.10)	9.02
Princes Highway Overpass	15	12.81	19.14 (2.18)	22.17
Rail Overpass	25	12.65	19.65 (2.00)	22.45
Rail Bridge	25	5.32	12.29 (1.14)	14.43
TAFE Bridge	11	8.38	12.13 (0.20)	13.18
Marshall Mt North	6	8.93	11.11 (0.90)	12.86
Marshall Mt South	6	8.13	10.76 (0.80)	12.41

1.2.4 Model Roughness

The model roughness layer from the 2012 Flood Study was updated based on recent aerial imagery (2016) and field inspections (5-6 July 2017). The delineated roughness zones are shown in **Map G504**. The roughness values adopted are shown in **Table 1-7**.

Table 1-7 Roughness Parameters

Land Use Zone	Manning's 'n'
Pasture / Grass (Default)	0.05
Roads and Pavements	0.02
Heavy Vegetation	0.10
Ponds / Dams	0.03
Duck Creek Downstream (DS) – Mainstream, lower channel	0.05
Steep bushland	0.15
Duck Creek Channel	0.06
Riparian Vegetation	0.07
Median Vegetation	0.07
Fence Blockage	0.10

1.2.5 Boundary Conditions

Flows from WBNM are entered into the TUFLOW model via source-area (SA) polygons, which generally align with the sub-catchments from the WBNM model. This method applies the flow to the lowest cell within the SA polygon. As the flow increases, and the water level in the cell rises, adjacent cells become wet, and the inflow is then applied to these cells as well.

The exceptions to this were a few subcatchments (DC_11, DC11_1, DC11_2 and DC11_3) in the Tallawarra Lands area (immediately east of the M1), where it was necessary to use "streamlines" in Tuflow to ensure that flow applied along the length of the flowpath.

The model has a single downstream boundary. The boundary is located at the point where Duck Creek discharges into Lake Illawarra. A water level gauge (Koonawarra Bay) within the Lake was used to set the boundary conditions for the historical storm events.

2 Calibration

2.1 Selection of Calibration Event

The selection of suitable historical events for calibration of the computer models is largely dependent on available historical flood information. Based on the information collected from both the 2012 Flood Study and the data collection for this update of the flood study, there are five potential events that could be used for the calibration and validation of the model:

- March 1978
- February 1984
- February 2008
- March 2011
- March 2017

Of these events, March 2011 and March 2017 have the largest collection of observed flood levels for the calibration of the model.

March 1978, while a large event, did not have any nearby pluviometers (refer **Section 2.5**), which means that it is not possible to directly estimate the rainfall on the catchment.

The February 2008 event was a significantly smaller event than the others, and only had three observed levels (two of which were identified as being potentially uncertain due to steep grades in that area). Therefore, February 2008 was not included in the calibration and validation of the model.

A calibration and validation of the model has been undertaken for the March 2017, March 2011 and February 1984 events, discussed below. Given its magnitude, a review of the 1978 event is also undertaken, and this is provided in **Section 2.5**.

2.2 March 2017 Calibration Event

2.2.1 Rainfall Data

While there were no pluviometers within the Duck Creek Catchment during the March 2017 event, there were a number of pluviometer gauges in the surrounding catchments. In order to estimate the likely rainfall that occurred within the Duck Creek Catchment, an analysis was undertaken on these pluviometers based on 1 hour rainfall totals. These 1 hour rainfall totals and associated isohyets are shown in Figure 2-1.

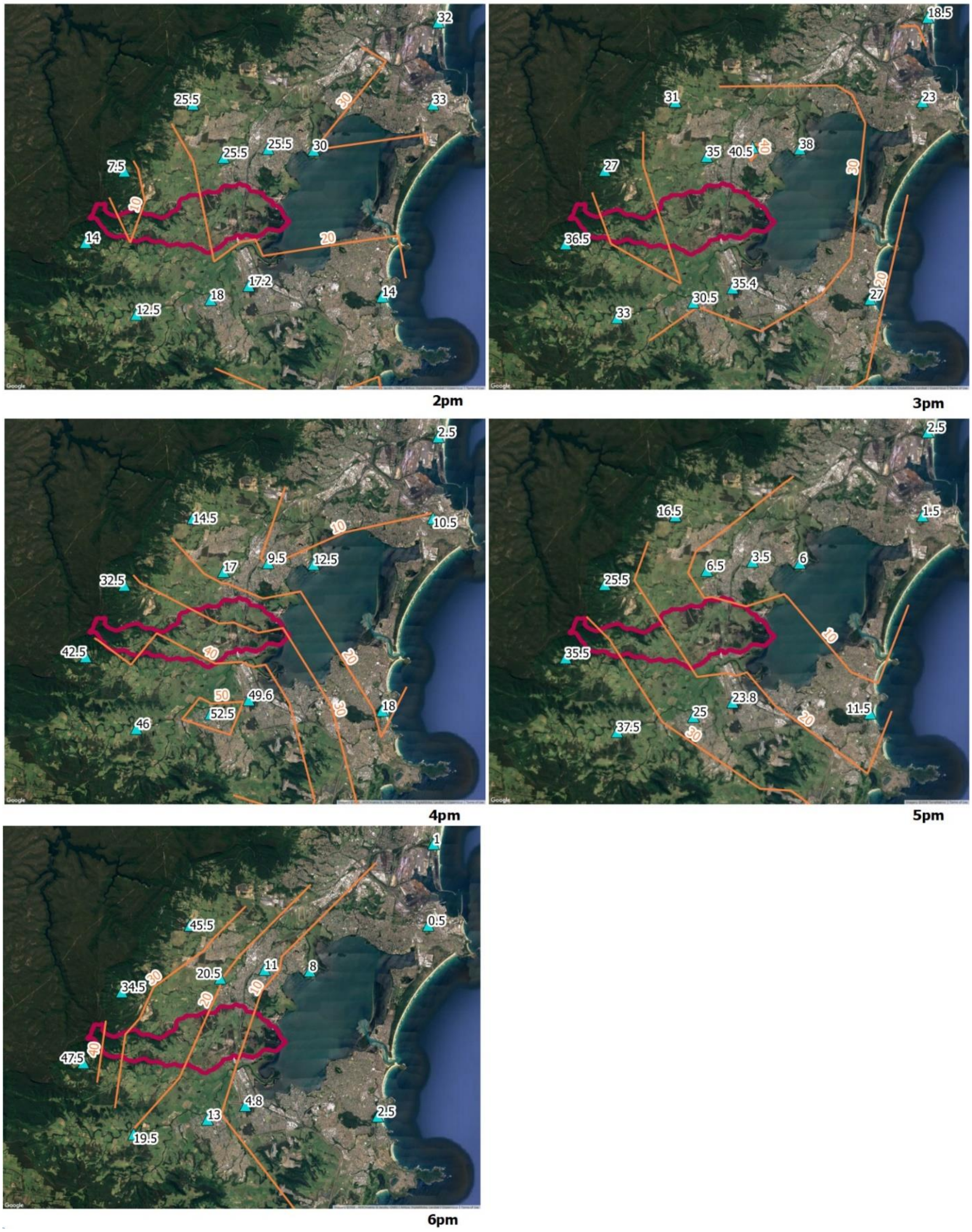


Figure 2-1. Rainfall Isohyets for March 2017 Event[1]

This analysis shows that the March 2017 event rainfall varied spatially across the catchment throughout the duration of the storm event. In order to estimate the rainfall pattern on the

[1] Hourly rainfall totals shown for rain gauges. Isohyets shown in 10mm increments

catchment, the catchment was split into three zones. These zones were estimated based on a review of the isohyets and rainfall data for March 2017 and based on the general topography of the catchment. These zones are shown in **Figure 2-2**.

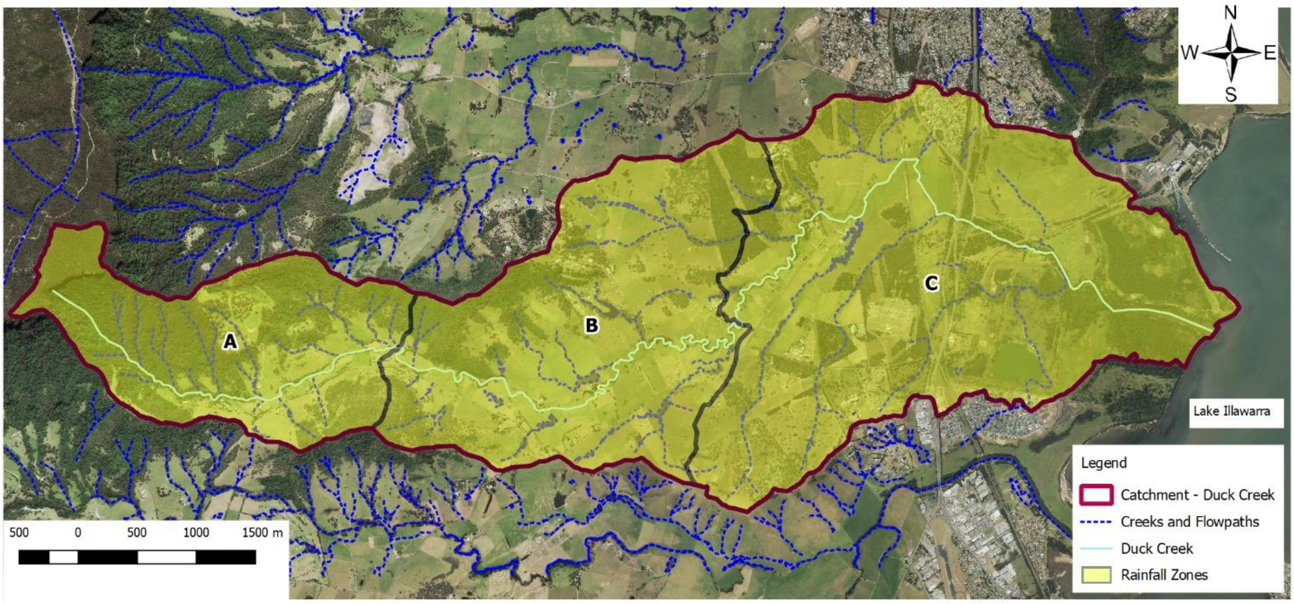


Figure 2-2. Rainfall Zones for March 2017 Event

For each of these rainfall zones, hourly rainfall was estimated through a review of both the isohyets, and engineering judgement based on the surrounding rainfall gauges hourly totals. These estimates are shown in **Table 2-1**. These hourly estimates were then used as a weighting to establish rainfall temporal patterns for each zone.

Given the variation in rainfall between the upper and lower catchment areas, Zone A (representing the upper catchment), was assumed to be more closely related to the Upper Calderwood Gauge, while Zone B and C assumed to be more closely related to Albion Park Bowling Club (refer to Map G305 for gauge locations). The temporal patterns from these two gauges were applied to the zones for the catchment. An overview of the three rainfall temporal patterns are shown in Figure 2-3.

Table 2-1 Hourly Rainfall Estimates for Catchment Zones (16 March 2017)

Zone	Hourly Rainfall Total (mm)				
	2pm	3pm	4pm	5pm	6pm
A	10	30	35	30	35
B	15	30	30	20	20
C	20	35	30	15	10
Upper Calderwood	14	36.5	42.5	35.5	47.5
Albion Park Bowling Club	18	30.5	52.5	25	13

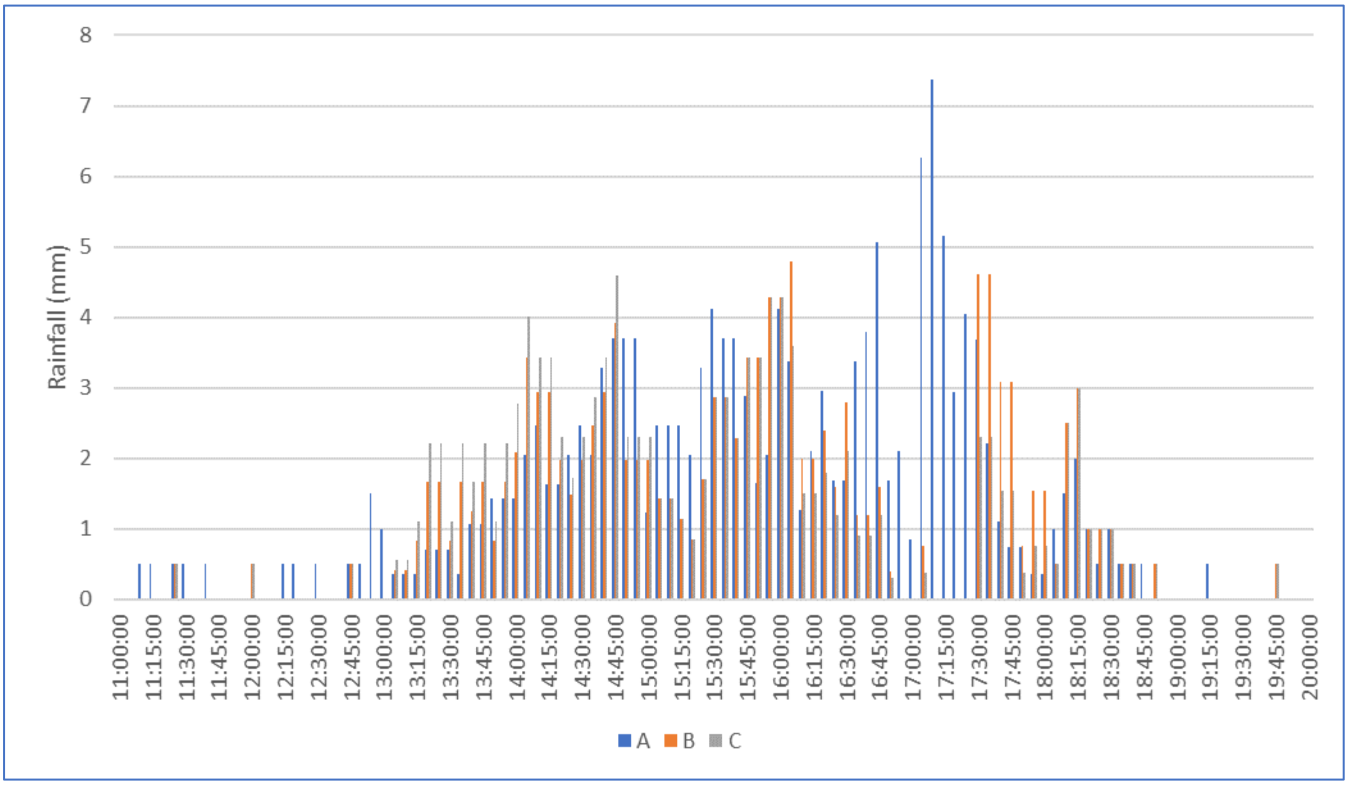


Figure 2-3. 16 March 2017 Rainfall for Model

2.2.2 Antecedent Conditions

The antecedent catchment condition reflecting the degree of wetness of the catchment prior to a major rainfall event directly influences the magnitude and rate of runoff. The 'initial loss - continuing loss' model has been adopted in the WBNM hydrologic model developed for the Duck Creek catchment. The initial loss component represents a depth of rainfall effectively lost from the system and not contributing to runoff and simulates the wetting up of the catchment to a saturated condition. The continuing loss represents the rainfall lost through soil infiltration and other factors once the catchment is saturated and is applied as a constant rate (mm/hr) for the duration of the runoff event.

An overview of the daily rainfall in the month prior to the event is provided in **Figure 2-4**. This shows relatively low rainfall in the month prior to the 16 March 2017 rainfall event, with some rainfall occurring in early March.

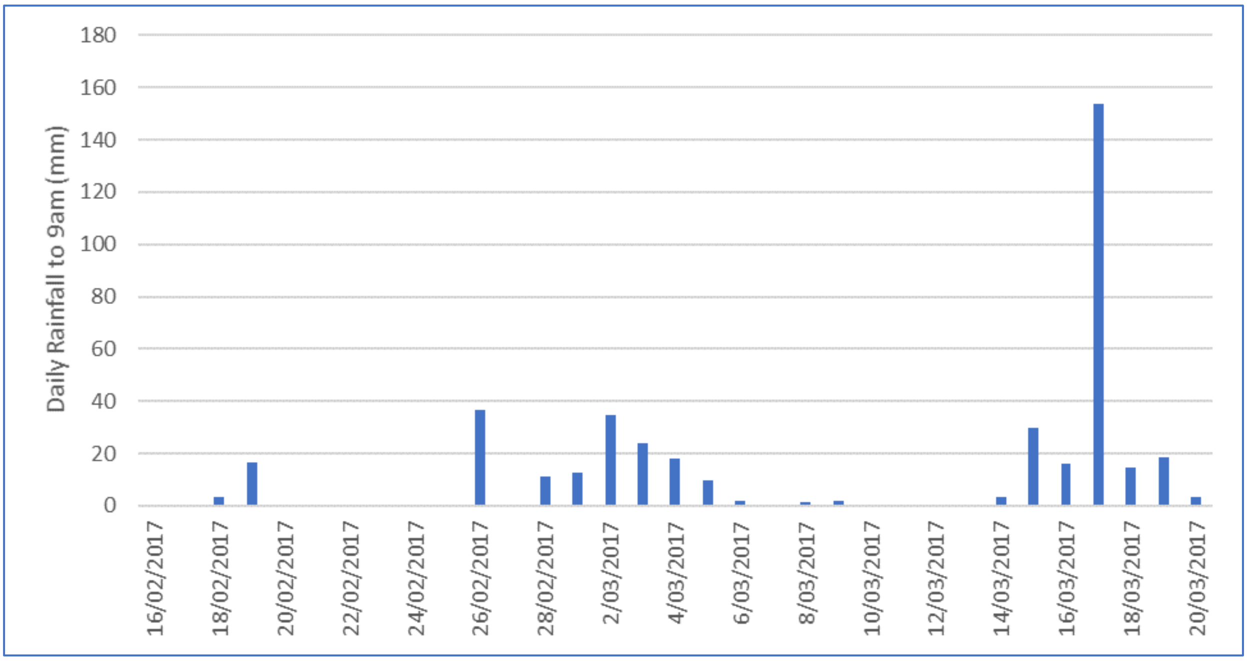


Figure 2-4. Antecedent Rainfall February to March 2017

The relative importance of the initial loss assumed in the model is dependent on the rainfall pattern and duration. A comparison of the impact of different initial loss assumption is provided in **Table 2-2**. An initial loss of 20mm was adopted for the purposes of the calibration, and consistent with assumptions on the other storm events that were made in the 2012 flood study.

Table 2-2 Peak Flows in WBNM from Different Initial Loss Assumptions

	Peak Flows (m^3/s)		
	Initial Loss = 0mm	Initial Loss = 20mm	Initial Loss = 40mm
Downstream of Princes Highway	86.4	76.5	70.5

2.2.3 Downstream Boundary Condition

Lake Illawarra water level data at Koonawarra was available for the March 2017 event from a continuous stage recorder maintained by MHL. This water level data is considered to be representative of the Lake Illawarra water levels at its confluence with Duck Creek. The relationship between recorded Lake Illawarra water levels and recorded rainfall at Albion Park Bowling Club is shown in **Figure 2-5**. It shows that the peak level in the Lake during this event occurred more than 6 hours after the peak of the rainfall.

It is important to note that the furthest downstream observed level in the 2017 event was near the Princes Highway at 4.21m AHD. This level is unlikely to be influenced by any assumptions made on the levels in Lake Illawarra.

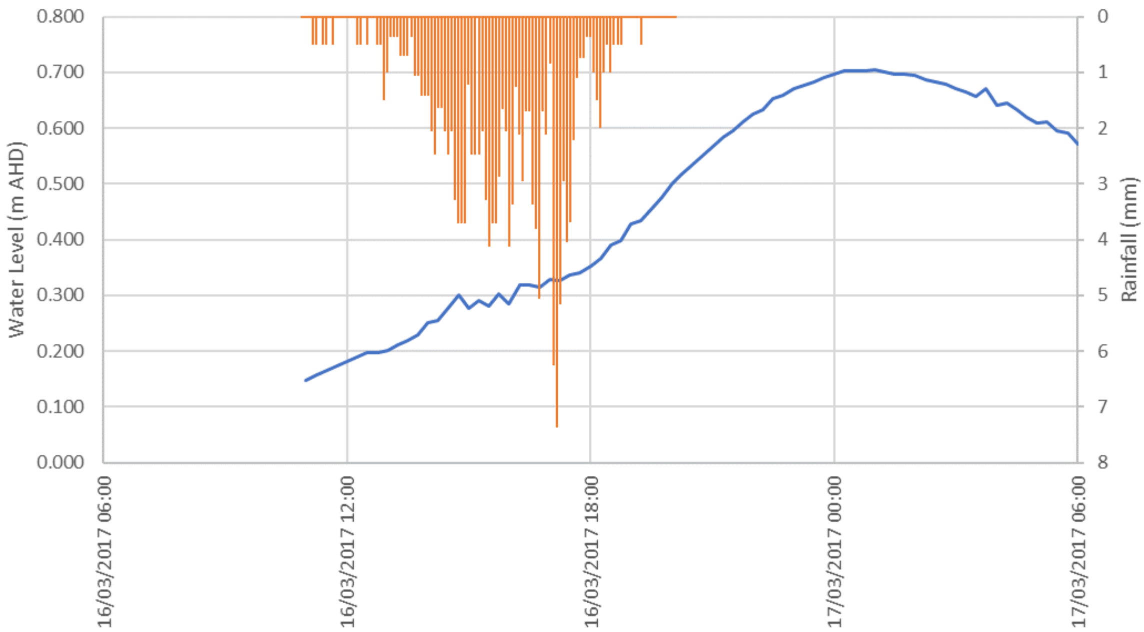


Figure 2-5. March 2017 Lake Illawarra Levels

2.2.4 Adopted Model Parameters

A summary of the adopted parameter values for the March 2017 event are shown in **Table 2-3**.

Table 2-3 Adopted Values for March 2017 Calibration

Parameter	Value	Comment
Initial Loss (mm)	20	Adopted consistent as per the 2012 flood study. Refer **Section 2.2.2**.
Continuing Loss (mm)	2.5	Adopted as per 2012 flood study
Roughness	Various	Unlikely to have been significant differences to roughness values in March 2017.
Terrain		Assumed no major catchment changes since March 2017.
WBNM Lag Parameter	1.6	

2.2.5 Model Results

The model results for the March 2017 flood event are shown in **Map G601**. A comparison of the observed and modelled levels is also provided in **Table 2-4**.

In the upper and middle catchment, the flows are generally contained within the macro channel for the creek. Downstream of the TAFE and Marshall Mount Road, where the macro channel is less defined, there floodwaters spread out across the farmland in this area. The model results indicate that neither Marshall Mount Road or the TAFE bridge overtopped during this event, which is consistent with anecdotal information.

The model generally aligns well with the observed levels from the event, with modelled levels typically within +/-0.2m of the observed levels. However, it is important to note that there is uncertainty in the observed levels. Some commentary of the comparisons, particularly where larger differences occur, are provided in **Table 2-4**.

Table 2-4 March 2017 Comparison with Observed Levels (m AHD)

ID	Observed	Modelled	Difference (m)	Comment
A	4.21	5.26	1.05	This is located downstream of the Princes Highway, based on debris observed by the project team 3 months after the event. Relative high uncertainty due to thick vegetation and steep creek banks.
B	5.14	5.55	0.41	Difficult to determine exact location of B. Location B, C and D are all in close proximity, and generally show reasonable agreement on observed levels.
C	5.81	5.72	-0.09	
D	5.57	5.74	0.17	
E	10.5	10.67	0.17	
F	9.91	10.07	0.16	
H	10.48	10.55	0.07	
G	10.6	10.63	0.03	
I	11.55	11.07	-0.48	Difficult to determine these locations
J	10.58	11.42	0.84	
K	12.96	11.01	-1.95[2]	This location not inundated in the model. Uncertain if location that was surveyed is in the correct location as the observation.
L	12.04	12.46	0.42	
Average			0.25	
Median of Differences (absolute values)			0.17	
Standard Deviation			0.42	

2.3 March 2011 Calibration Event

2.3.1 Rainfall Data

As with the March 2017 rainfall event, there were no pluviometers within the catchment in March 2011. A similar approach to the analysis was undertaken as per the March 2017 event. These 1 hour rainfall totals and associated isohyets are shown in **Figure 2-6**.

[2] Not included in statistical analysis, see comment.

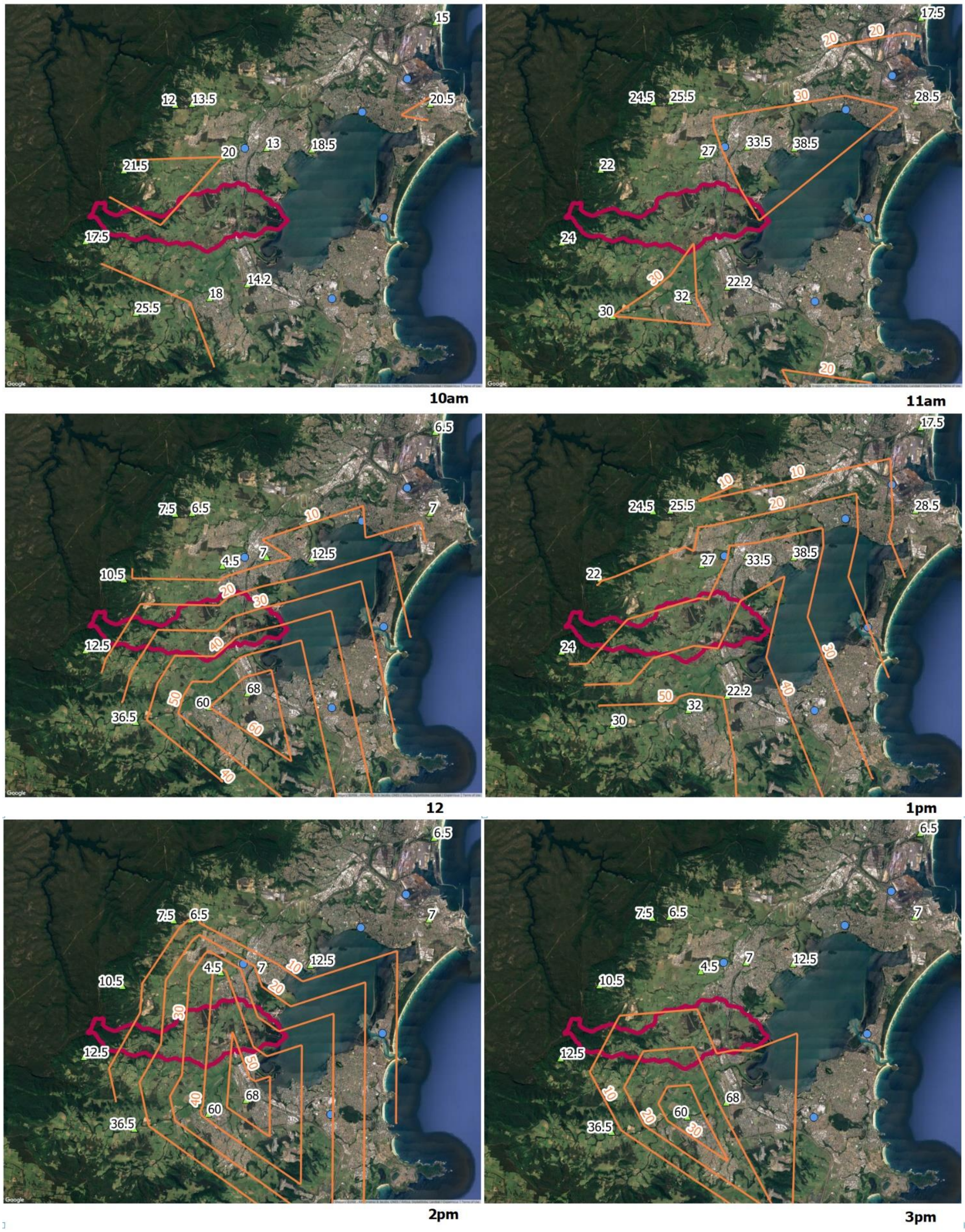


Figure 2-6. Hourly Rainfall Isohyets - March 2011[3]

Based on a review of the rainfall isohyets and rainfalls from the surrounding pluviometers, the catchment was divided into representative rainfall zones. The same zones were adopted as per the March 2017 Event (refer to **Figure 2-2**).

[3] Hourly rainfall totals shown for rain gauges. Isohyets shown in 10mm increments

The rainfall intensity for the March 2011 event varied across the catchment, with a reasonably high gradient between the gauges to the south and the gauges to the north (as well up to the escarpment). The highest rainfalls occurred to the south (Albion Park Bowling Club and Wollongong Airport). These relatively high gradients make estimation of rainfall on the catchment difficult, as the exact pattern of the storm on the catchment is unknown.

To represent this level of uncertainty, three different rainfalls were applied to the model, a lower estimate, likely estimate and an upper estimate, based on a review of the available rainfall data and the variation in rainfall across the catchment. These estimates are provided in **Table 2-5**, and attempt to reflect some of the uncertainty associated with the rainfall estimation for this event.

The calibration of a hydraulic model is intended to test that the chosen parameters for the model are appropriate in order to undertake design flood estimates. The estimation of historical rainfall is not part of the design flood estimate, and therefore the calibration is not intended to test the ability of the model to recreate historical rainfall. Therefore, representing the range in potential rainfall in this way allows for the uncertainty in the rainfall estimates to be reflected in the calibration of the model.

The temporal pattern for Zones A, B and C for the "Likely" estimate of rainfall is shown in **Figure 2-7**.

Table 2-5 Hourly Rainfall Estimates for Catchment Zones (21 March 2011) (mm)

Date/ Time	Albion Park Bowling Club	Upper Calderwood	Lower Estimate			Likely Estimate			Upper Estimate		
			A	B	C	A	B	C	A	B	C
21/03/2011 9:00	3.5	1.5	1.5	3.5	3.5	1.5	3.5	3.5	1.5	3.5	3.5
21/03/2011 10:00	18	17.5	19	20	15	19	20	15	19	20	15
21/03/2011 11:00	32	24	23	25	25	23	30	30	23	30	30
21/03/2011 12:00	60	12.5	11	20	20	11	30	30	25	35	40
21/03/2011 13:00	53.5	24	22	30	30	22	35	40	30	40	40
21/03/2011 14:00	42.5	2	2	20	35	2	30	40	15	35	45
21/03/2011 15:00	38.5	1.5	1.5	10	10	1.5	10	10	1.5	10	10

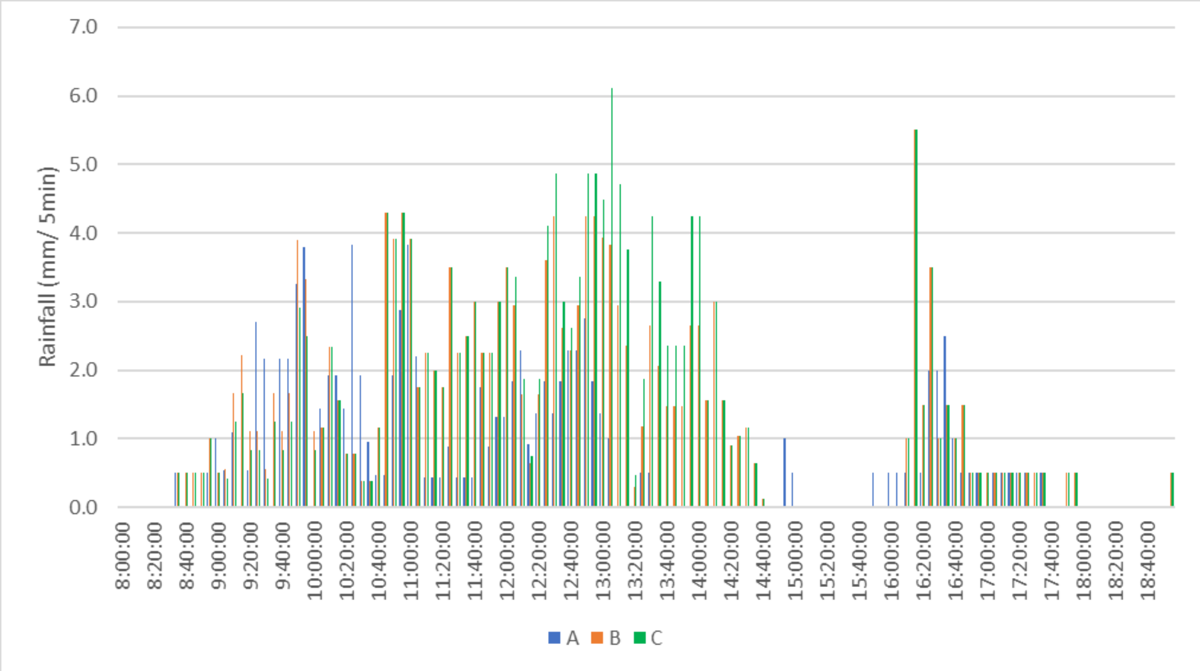


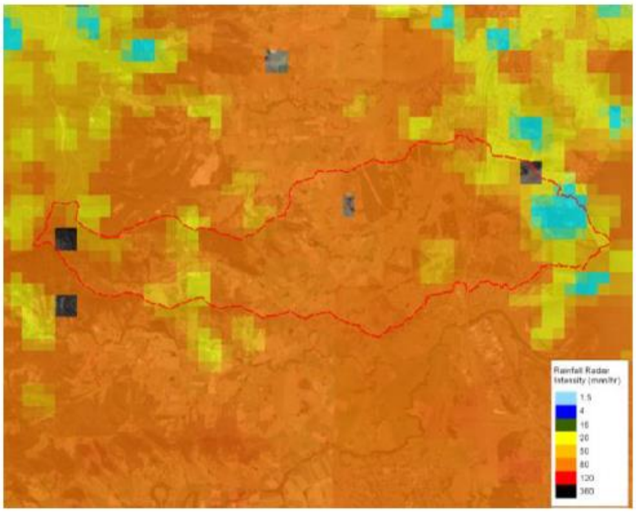
Figure 2-7. March 2011 Rainfall for Model

2012 Flood Study Methodology

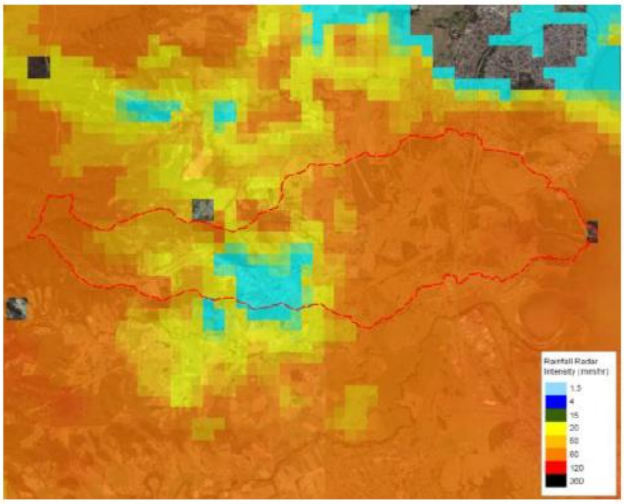
The 2012 Flood Study utilised radar data to directly estimate the rainfall for the catchment. This involved estimating the rainfall based on the reflectivity signal from the radar, and then adjusting this relative to the observed rainfall at Wollongong Airport. This scaling procedure compared 24 rainfall totals at the gauge versus those estimated with the radar at the same location.

The key challenge with this approach is that the radar can have a number of potential variances. While it can be used, it would ideally need to be scaled against more than one rainfall gauge in the surrounding area, and potentially on smaller increments than 24 hours.

The rainfall data can however be useful for understanding the movement and spread of the rainfall over the catchment during the storm. For comparison, the rainfall isohyets are compared below with the radar data. It is important to note though that the radar data is instantaneous for that period of time, while the isohyets represent the 1 hour rainfall for the preceding hour.

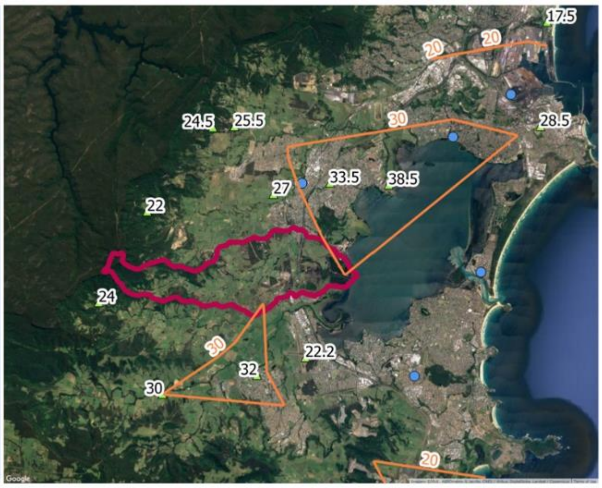


10am 21st March 2011



11am 21st March 2011

10am



11am

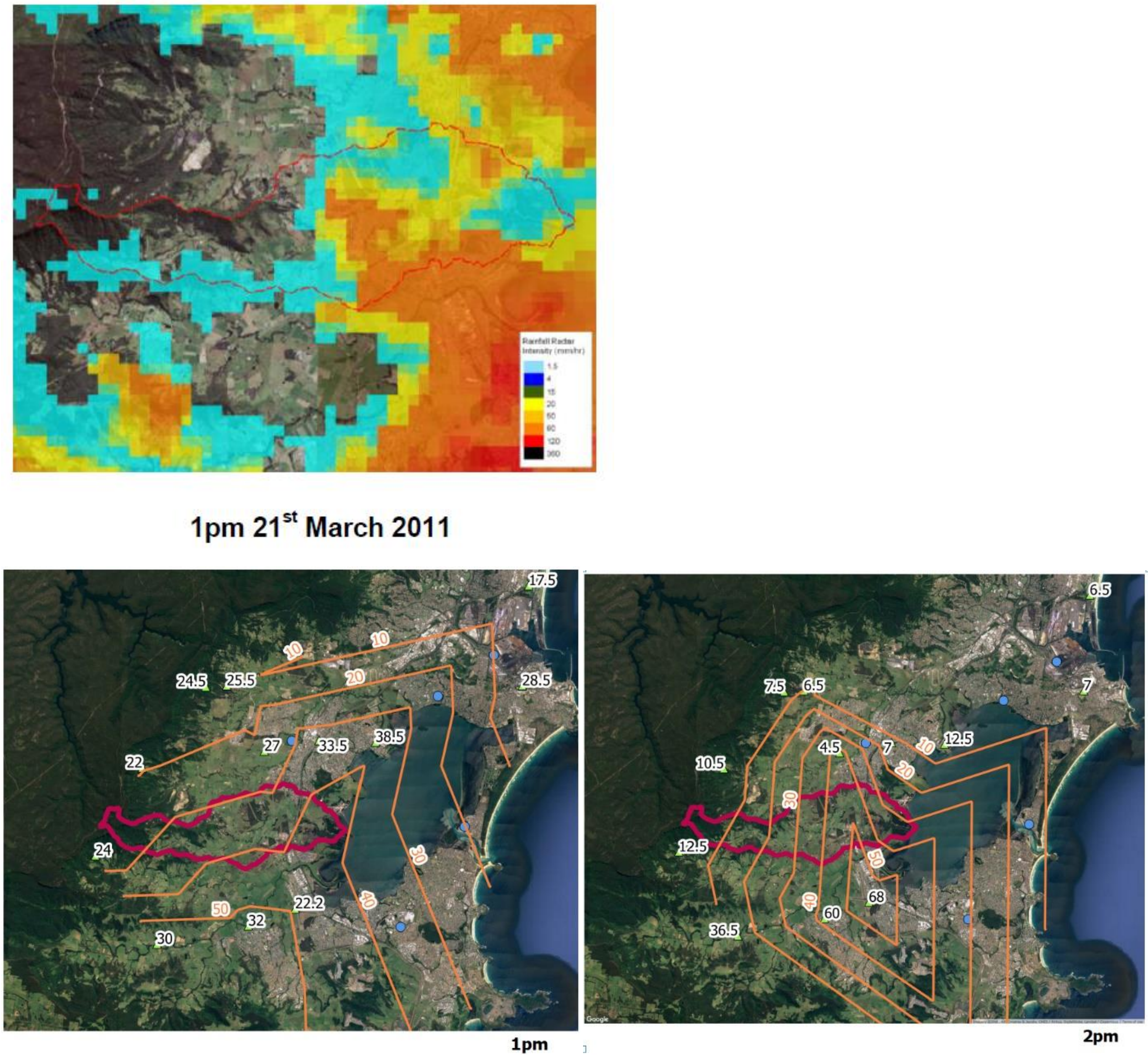


Figure 2-8. Comparison of Radar Data with Rainfall Isohyets for March 2011

2.3.2 Antecedent Conditions

Like the March 2017 event, a review was undertaken on the rainfall in the month prior to the March 2011 event. The daily rainfalls are shown in **Figure 2-9**. This shows a relatively dry period prior to the 21 March 2011 event. However, in the two days immediately prior to the event around 144mm of rainfall fell. As the rainfall in the model was initiated after this rainfall, there is the potential for a lower initial loss to be adopted for the rainfall event.

Consistent with the 2012 flood study, an initial loss of 20mm was adopted. However, to understand the potential influence of this high rainfall in the two days prior, a sensitivity analysis was undertaken on the flows with an initial loss (IL) of zero. The peak flows at the M1 in the WBNM model are shown below:

- Initial loss of 20mm – Peak flow at M1 = 121m^3/s
- Initial loss of 0mm – Peak flow at M1 = 123m^3/s

The relatively small difference in peak flows suggests that the initial loss assumptions for this particular storm are less significant.

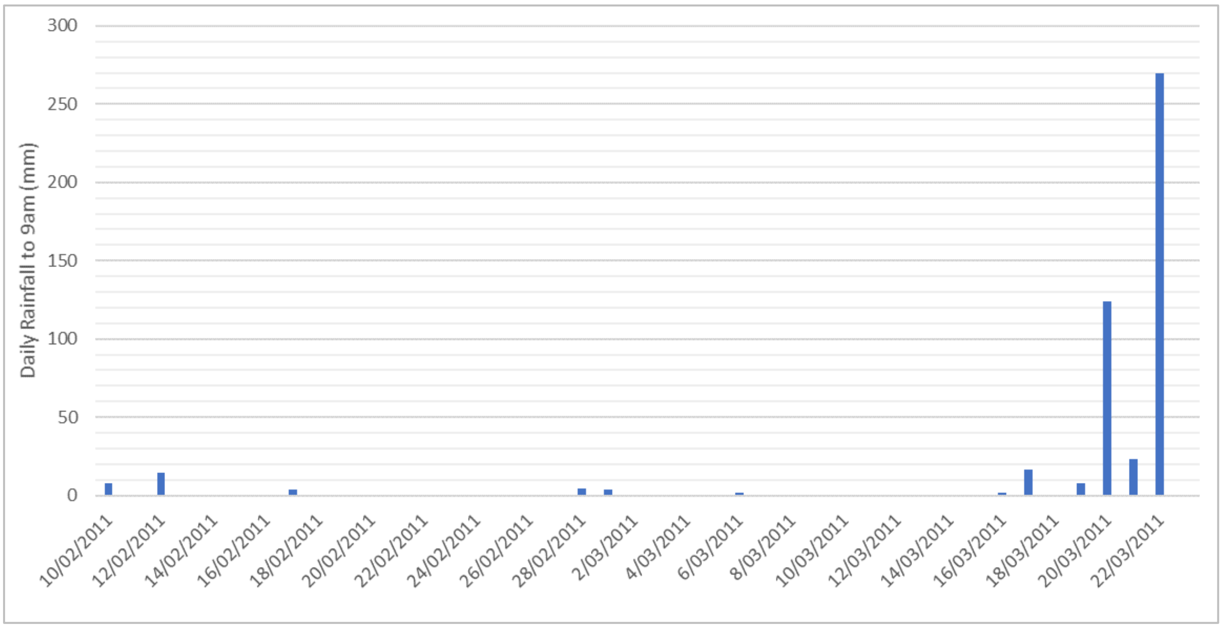


Figure 2-9. Antecedent Rainfall - March 2011

2.3.3 Downstream Boundary Condition

Lake Illawarra water level data at Koonawarra was available for the March 2017 event from a continuous stage recorder maintained by MHL. This water level data is considered to be representative of the Lake Illawarra water levels at its confluence with Duck Creek. The relationship between recorded Lake Illawarra water levels and recorded rainfall at Albion Park Bowling Club is shown in **Figure 2-10**. It shows that the peak level in the Lake during this event occurred more than 6 - 12 hours after the peak of the rainfall.

The lowest observed flood level for this event is at the Princes Highway, at a level of 4.5m AHD. It is unlikely that this would be significantly influenced by the levels in Lake Illawarra, and therefore the assumptions on downstream boundary for this calibration analysis are less important.

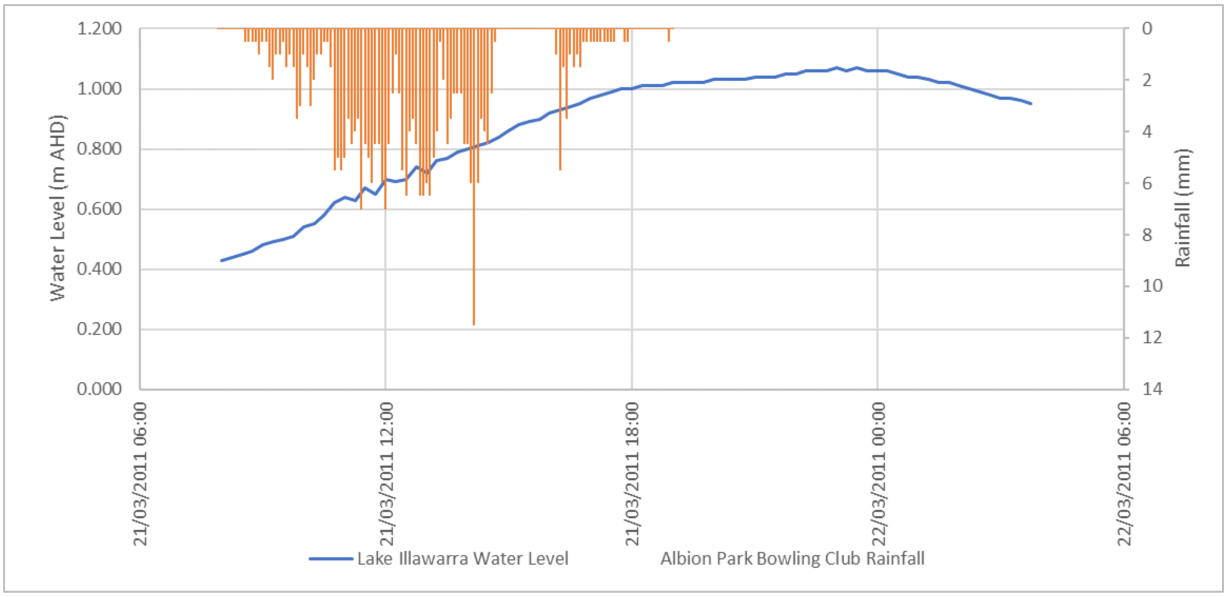


Figure 2-10. March 2011 Lake Illawarra Levels

2.3.4 Adopted Model Parameters

A summary of the adopted parameter values for the March 2011 event are shown in **Table 2-6**.

Table 2-6 Adopted Values for March 2011 Calibration

Parameter	Value	Comment
Initial Loss (mm)	20	Adopted consistent as per the 2012 flood study. Refer **Section 2.2.2**.
Continuing Loss (mm)	2.5	Adopted as per 2012 flood study
Roughness	Various	No changes undertaken to roughness.
Terrain		Assumed to be similar to existing conditions
WBNM Lag Parameter	1.6	

2.3.5 Model Results

The model results for the March 2011 flood event are shown in **Map G602**. A comparison of the observed and modelled levels is also provided in **Table 2-4**. This shows the modelled levels for low, high and likely rainfall estimates (refer **Section 2.3.1**). This table also includes the previous calibration results from the 2012 flood study for reference. **Figure 2-11** also provides a comparison of the relative differences between the model results and the observed results, as well as providing a comparison to the previous 2012 flood study calibration.

In general, the model provides a reasonable match to the observed flood levels from March 2011. The modelled levels are higher in the vicinity of the Freeway and Princes Highway, with the observed levels being closer to the lower estimate of rainfall. This may indicate that the lower estimate rainfall may be more appropriate for this area. However, these points are in very close proximity to the structures in this area, which may lead to localised effects that may affect the results.

There are also some larger differences in the upper part of the catchment. However, the terrain and water level gradient in this area is relatively steep. Therefore, any error in the horizontal location of an observed point in this area can lead to relatively large differences in vertical height.

Table 2-7 March 2011 Comparison with Observed Levels

ID	Observed Level (mAHD)	Peak Water Level (mAHD)			Difference (m)			2012 Flood Study	
		Low	Likely	High	Low	Likely	High	Level (mAHD)	Difference (m)
5	4.5	5.34	5.53	5.67	0.84	1.04	1.17	5.30	-0.23
6	5.5	5.84	6.02	6.14	0.34	0.52	0.64	5.80	-0.22
7	6.7	6.84	7.23	7.48	0.14	0.51	0.78	6.50	-0.73
8	8.4	8.17	8.35	8.48	-0.23	-0.02	0.08	8.20	-0.15
9	8.4	8.50	8.70	8.85	0.10	0.34	0.45	8.50	-0.20
10	10.7	10.43	10.57	10.68	-0.27	-0.09	-0.02	10.40	-0.17
11	10.9	10.52	10.69	10.83	-0.38	-0.18	-0.07	10.50	-0.19
12	10.3	10.38	10.55	10.71	0.07	0.33	0.41	10.30	-0.25
13	11	10.86	11.03	11.16	-0.14	0.08	0.16	10.90	-0.13
14	11.5	11.19	11.56	11.78	-0.31	0.15	0.28	11.90	0.34
15	11.1	11.13	11.19	11.29	0.03	0.13	0.19	11.20	0.01
16	17.8	17.63	17.79	17.93	-0.17	0.03	0.13	17.70	-0.09
17	17.7	17.41	17.61	17.77	-0.29	-0.03	0.07	17.50	-0.11
18	20.4	20.45	20.55	20.58	0.05	0.1	0.18	20.20	-0.35
19	20.5	20.44	20.52	20.54	-0.06	-0.01	0.04	20.50	-0.02
20	21.9	21.82	21.96	21.97	-0.08	0.02	0.07	21.90	-0.05
21	12.5	12.78	12.88	12.89	0.28	0.32	0.39	12.90	0.03
22	24	23.56	23.65	23.71	-0.44	-0.16	-0.29	23.70	0.05
23	25	24.19	24.49	24.70	-0.81	-0.48	-0.31	24.70	0.21
24	25.2	24.86	24.92	24.97	-0.34	-0.28	-0.23	25.00	0.08
25	36.5	36.70	36.96	37.07	0.20	0.48	0.57	36.90	-0.06
26	38	38.23	38.37	38.50	0.23	0.38	0.50	38.30	-0.07
Average					-0.06	0.14	0.24		-0.10
Median of Differences (absolute values)					0.23	0.17	0.26		0.14
Standard Deviation					0.34	0.33	0.36		0.21

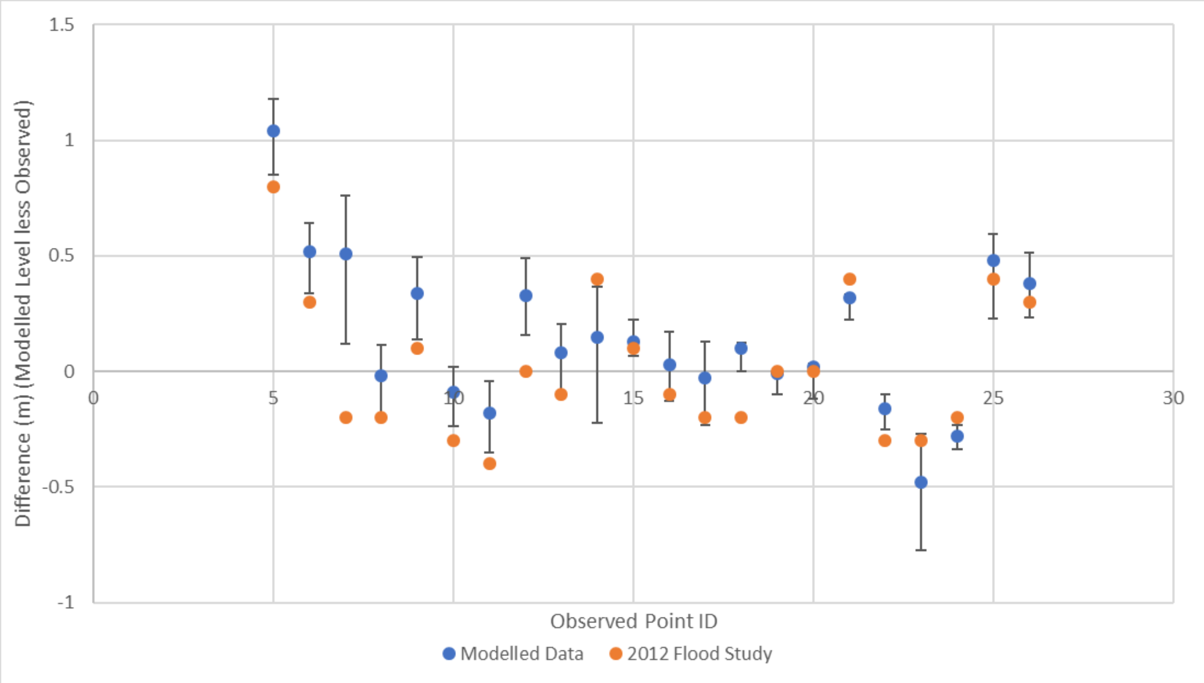


Figure 2-11. Modelled Versus Observed Data for March 2011

2.4 February 1984 Calibration Event

2.4.1 Rainfall Data

Unlike March 2017 and March 2011, there was not a large number of pluviometers in the surrounding catchments for the February 1984 event. Based on the daily rainfall measurements in the surrounding areas, a 48 hour rainfall totals were estimated and mapped as shown in **Figure 2-12**. As observed in the March 2017 and March 2011 event, the movement of the storm on an hourly basis can result in quite a different rainfall pattern than might be represented on a coarser 48 hour rainfall total.

There is a relatively steep gradient in the 48 rainfall totals across the catchment. The rainfall data suggests that the highest rainfalls occurred on the escarpment, with a relatively steep gradient in rainfall moving eastward toward Lake Illawarra and the coastline. In order to represent this variation in rainfall, four rainfall zones were applied to the catchment, as shown in **Figure 2-13**. The estimated 48 hour rainfall for each of these zones is shown in **Table 2-8**.

The assumed temporal pattern for the storm was based on the Calderwood gauge, which is shown in **Figure 2-14**.

Figure 2-12. 48 hour Rainfall Isohyets - February 1984 Event

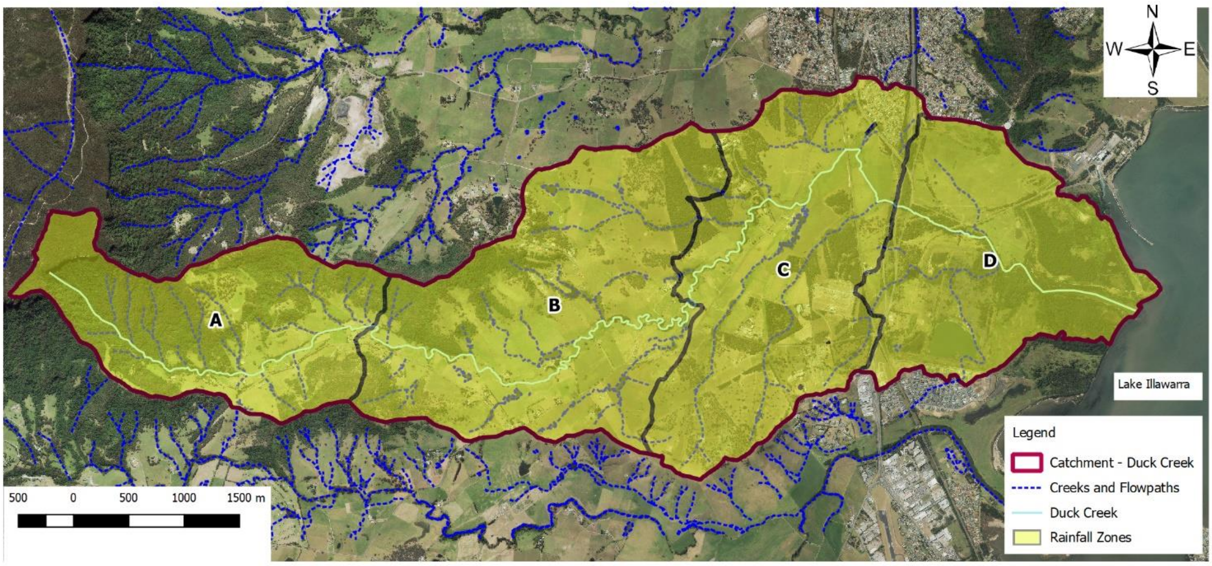


Figure 2-13. Rainfall Zones for Modelling - February 1984 Event

Table 2-8 February 1984 48 hour Rainfall Totals for Model (mm)

Gauge	48 Hour Rainfall Total (mm)
Calderwood Gauge	572
Rainfall Zone	
A	600
B	500
C	400
D	225

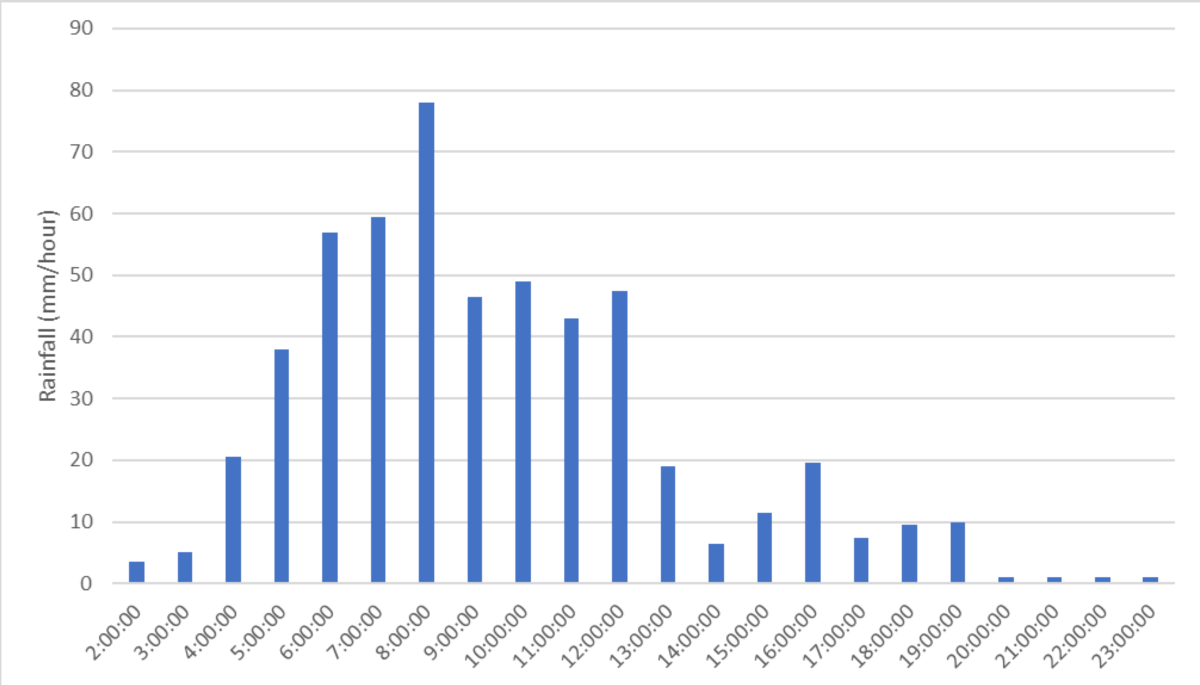


Figure 2-14. Calderwood Gauge Rainfall for 18 February 1984 (in mm per hour increment)

2.4.2 Antecedent Conditions

Similar to the March 2011 event, there was relatively low rainfall in the month leading up to event. In the evening prior to the rainfall event on 17 February 1984, there was around 20mm of rainfall. Consistent with the 2012 flood study, a 20mm initial loss was adopted.

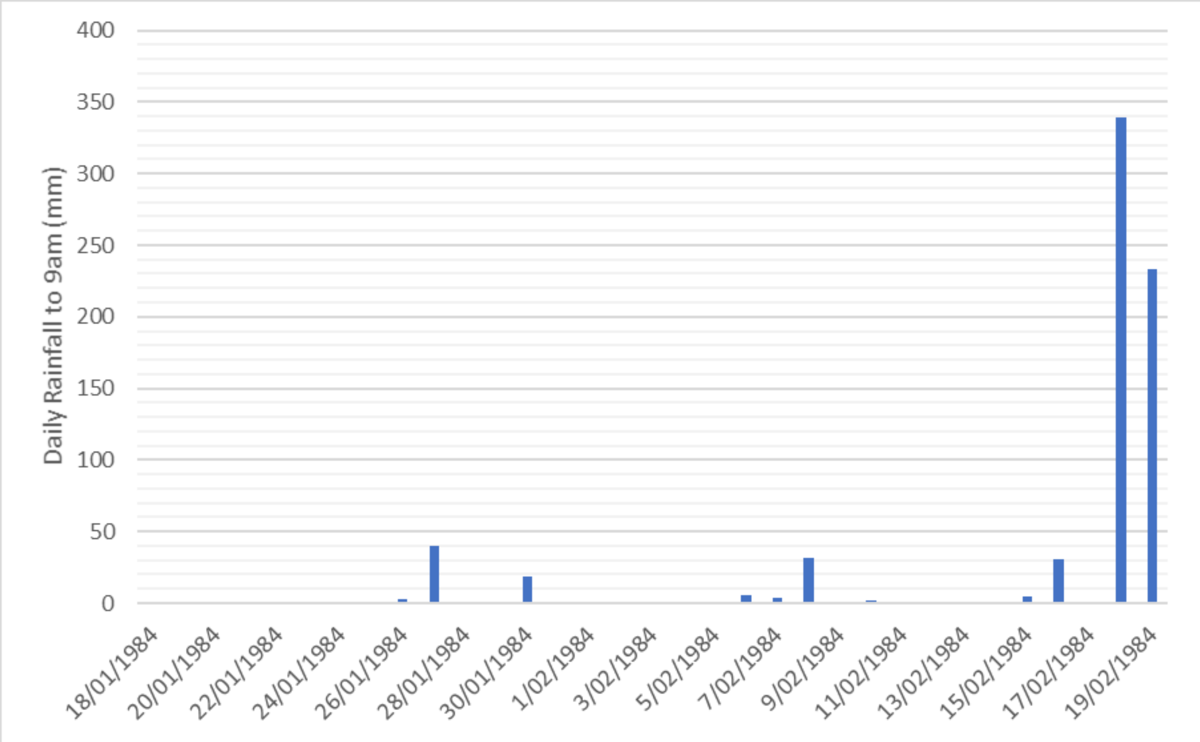


Figure 2-15. Antecedent Rainfall - February 1984 Event

2.4.3 Downstream Boundary Condition

There is limited historical data available for the time series of water levels in Lake Illawarra during significant rainfall events. The majority of data available is in the form of peak water levels only. A peak Lake Illawarra water level of 1.9m AHD was recorded during the February 1984 event (Cardno Lawson Treloar, 2001).

The 2012 flood study attempted to generate a synthesised lake level for this event. However, the one observed level from this event is upstream of where the TAFE access road is now located, at an elevation of 11.8m AHD, which would be well above any influence of the assumption on the downstream boundary conditions.

Therefore, instead of attempting to recreate a lake water level time series, a constant water level of 1.9m AHD was adopted for the modelling.

2.4.4 Adopted Model Parameters

The adopted model parameters for this calibration event were the same as those adopted for the 2011 March event. The only difference was that for this model event, the TAFE access road and bridge did not exist. Therefore, the model terrain was adjusted to remove these elements in an attempt to represent the catchment conditions at that time.

A review of aerial photography from around the 1984 period suggests that the riparian vegetation was significantly less before the TAFE access road, with the creek being more representative of downstream farmland areas. A comparison of the historical aerial imagery is provided in **Figure 2-16** to show the change that occurred once the TAFE road was constructed. Roughness mapping was therefore adjusted in this area to better represent the conditions in 1984.

	
1977 – 1978	2001
	
2006	2014

Figure 2-16. Historical Aerial Images near TAFE Road

2.4.5 Model Results

The location of the historical observed point for 1984 is provided in Map G603, along with the peak depths from the model. The model suggests a peak flood level at this location of 12.4m AHD, compared with the observed level of 11.8m AHD.

While the modelled level is higher in this location, there is a fair degree of uncertainty, related to:

- The rainfall pattern. The assessment as noted was based on the Calderwood Gauge, and weighted according to 48 hour rainfall. The analysis of the March 2011 and 2017 event suggests that there can be significant variation on hourly or less increments in this area;
- As demonstrated in the aerial imagery in **Figure 2-16**, there has been significant change in the area surrounding the observed point in vegetation. It is uncertain as to potential changes in terrain. While a representative terrain was included in the model by removing the road and the bridge, it is difficult to know what exactly was there at the time.

2.5 March 1978

The 1978 event was a large event in the catchment, with one observed level being available (refer to **Section 3 of the main report**). However, the key challenge for this event is that the closest pluviometer rainfall gauges are at Shellharbour STP (around 13km away from the catchment) and Wollongong STP (around 19km away from the catchment). Analysis of other events (2017, 2011 and 1984) suggests that there would be large differences in rainfall volume and pattern between these locations at Duck Creek.

This results in a difficulty in generating a local rainfall pattern for the Duck Creek catchment in order to undertake the calibration. The 2012 Flood Study utilised an artificial temporal pattern derived from ARR87 from the 72 hour duration storm. This approach leads to significant uncertainty, and in some part may explain the large difference in modelled level versus observed level from that report.

Given these uncertainties, the 1978 event has not been utilised for the calibration of the model. However, to understand the potential magnitude of this event relative to the other historical events, the single observed level has been compared with the other events to provide an indication of how large the event was. The observed levels from the different events in the vicinity of the Princes Highway are provided in **Table 2-9**. This suggests that the March 1978 event may have been similar in magnitude to the March 2011 event.

Table 2-9 Comparison of Observed Levels

Flood Event	Observed Level (m AHD)
March 1978	4.5
March 2011	4.5
March 2017	5.1 – 5.6

2.6 Comparison of Events

To provide a comparison of the relative magnitude of each of the calibration events, peak water levels were extracted at some key locations as shown in **Figure 2-17**. The results from each calibration run at these locations are shown in **Figure 2-18**, together with the estimated peak levels for the design events for the design blockage scenario.

Figure 2-18 shows that the 1984 event consistently had the highest levels across all sampling points. The 2017 event coincided generally with the lower estimate for the 2011 event.

The results also indicate that the 1984 event was between a 2% AEP and 1% AEP event near the M1 Motorway, and just below a 2% AEP event near the rail line and the TAFE bridge.

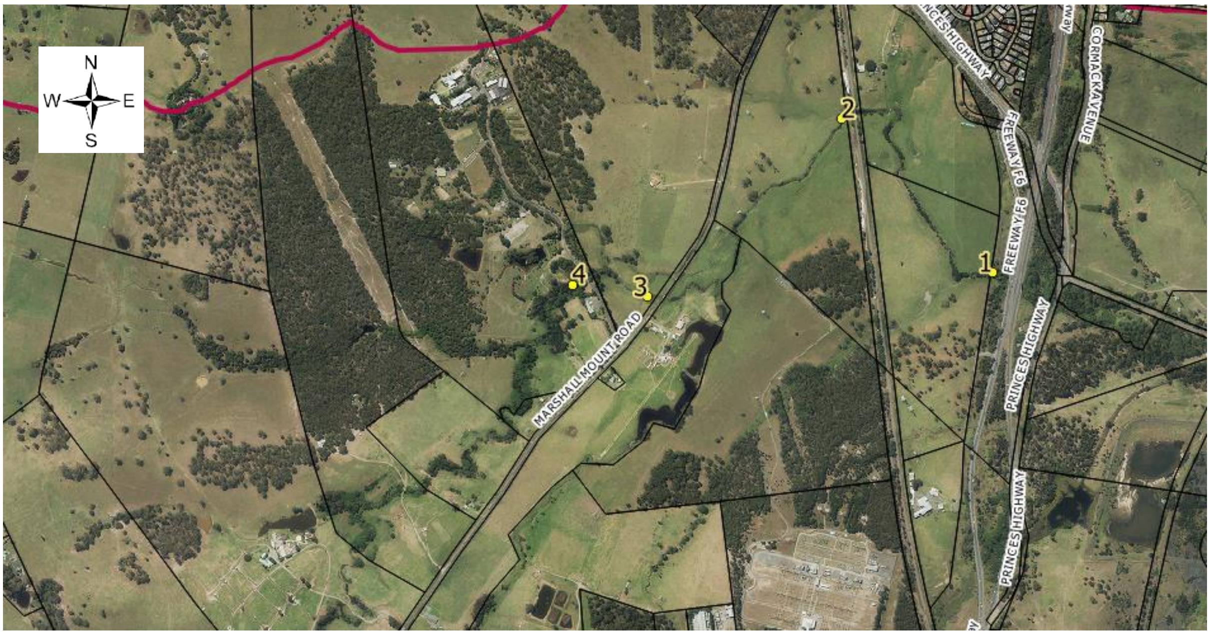


Figure 2-17. Location of Comparison Points

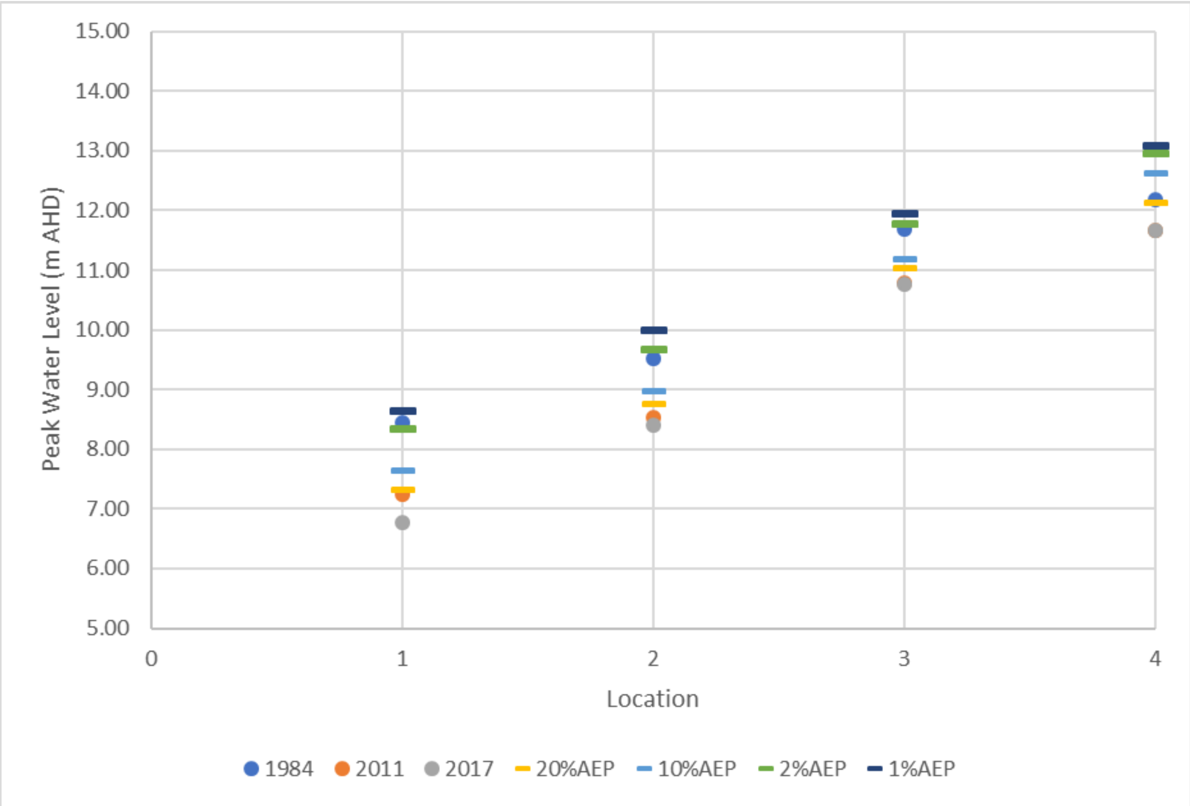


Figure 2-18. Comparison of Historical Flood Levels

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APPENDIX E

Design Flood Model Results

Peak Water Levels (mAHD) at Reporting Locations

Flood Event	Blockage Scenario (Envelope)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
20%	Design	1.82	3.34	3.57	1.97	5.75	7.21	7.88	9.48	11.09	12.92	7.44	12.25	8.72	9.45	10.99
	Risk	1.82	3.37	3.87	1.97	5.79	7.28	10.17	10.18	11.09	12.96	7.65	12.38	8.76	9.45	11.00
10%	Design	1.96	3.65	3.68	2.07	6.00	7.52	8.88	9.56	11.10	12.96	7.78	12.34	8.93	9.58	11.15
	Risk	1.96	3.70	4.04	2.07	6.04	7.60	10.26	10.26	11.10	12.99	8.06	12.45	8.99	9.58	11.17
2%	Design	2.31	4.46	3.95	2.32	6.54	8.26	9.97	9.98	11.42	13.06	8.67	12.55	9.63	10.01	11.75
	Risk	2.31	4.54	4.41	2.32	6.60	8.34	10.44	10.44	11.42	13.08	9.09	12.66	9.71	10.05	11.77
1%	Design	2.39	4.84	4.10	2.39	6.84	8.57	10.16	10.16	11.62	13.10	9.07	12.63	9.96	10.26	11.92
	Risk	2.39	4.90	4.48	2.39	6.89	8.64	10.48	10.48	11.62	13.11	9.53	12.71	10.04	10.31	11.94
0.50%	Design	2.74	5.09	4.26	2.72	7.11	8.86	10.30	10.30	11.83	13.12	9.46	12.69	10.25	10.51	12.06
	Risk	2.74	5.12	4.50	2.72	7.15	8.92	10.51	10.51	11.83	13.14	9.95	12.76	10.35	10.58	12.07
0.20%	Design	2.80	5.27	4.58	2.77	7.52	9.23	10.42	10.43	12.07	13.17	9.96	12.75	10.65	10.87	12.21
	Risk	2.80	5.29	4.62	2.77	7.58	9.30	10.54	10.55	12.07	13.18	10.46	12.81	10.75	10.95	12.23
PMF	Design	3.50	6.51	5.22	3.44	9.62	11.04	10.78	10.81	13.44	13.52	11.22	12.93	12.01	12.15	12.79
	Risk	3.50	6.53	5.24	3.44	9.64	11.08	10.82	10.85	13.44	13.52	11.25	12.95	12.02	12.17	12.81

Peak Water Levels (mAHD) at Reporting Locations

Flood Event	Blockage Scenario (Envelope)	16	17	18	19	20	21	22	23	24	25	26	27	28
20%	Design	11.07	12.39	11.93	13.55	14.82	20.60	15.66	20.21	25.18	29.04	43.17	42.07	79.72
	Risk	11.07	12.47	11.99	13.55	14.82	20.65	15.66	20.21	25.24	29.04	43.20	42.07	79.72
10%	Design	11.11	12.44	12.51	13.73	14.89	20.65	15.83	20.39	25.22	29.24	43.20	42.25	79.82
	Risk	11.11	12.49	12.55	13.73	14.89	20.69	15.83	20.39	25.28	29.24	43.23	42.25	79.82
2%	Design	11.22	12.50	12.87	14.19	15.10	20.74	16.28	20.92	25.32	29.72	43.27	42.62	80.08
	Risk	11.22	12.54	12.89	14.19	15.10	20.77	16.28	20.92	25.36	29.72	43.29	42.62	80.08
1%	Design	11.27	12.54	13.01	14.39	15.19	20.78	16.50	21.14	25.36	29.88	43.30	42.79	80.19
	Risk	11.27	12.57	13.03	14.39	15.19	20.81	16.50	21.14	25.41	29.88	43.32	42.79	80.19
0.50%	Design	11.32	12.58	13.12	14.59	15.24	20.82	16.71	21.37	25.41	30.04	43.32	42.91	80.31
	Risk	11.32	12.60	13.14	14.59	15.24	20.84	16.71	21.37	25.45	30.04	43.34	42.91	80.30
0.20%	Design	11.39	12.64	13.22	14.83	15.32	20.86	16.98	21.67	25.47	30.25	43.35	43.04	80.46
	Risk	11.39	12.65	13.25	14.83	15.32	20.88	16.98	21.67	25.51	30.25	43.37	43.05	80.46
PMF	Design	12.63	13.24	13.50	15.37	16.06	21.10	18.00	22.70	25.81	30.92	43.43	43.59	80.79
	Risk	12.64	13.25	13.53	15.37	16.06	21.12	18.00	22.70	25.84	30.92	43.45	43.59	80.79

Peak Model Flows (m3/s) at Reporting Locations

Flood Event	Blockage Scenario	Q 1	Q 2	Q 3	Q 4	Q 5	Q 6	Q 7	Q 8	Q 9	Q 10	Q 11	Q 12	Q 13	Q 14	Q 15	Q 16
20%	Design	79.2	9.9	88.8	10.5	9.3	106.4	11.7	118.8	114.5	119.6	101.1	88.9	8.4	4.5	112.8	106.8
	Risk	79.3	10.0	88.8	10.5	8.4	105.9	11.7	117.7	115.2	116.7	101.0	89.3	8.4	4.4	114.7	106.2
	Unblocked	79.2	9.9	88.8	10.2	10.1	106.5	11.5	119.3	116.3	121.9	101.4	88.3	8.3	4.3	108.2	107.0
10%	Design	99.3	12.8	110.5	12.8	10.9	125.1	14.4	139.3	135.1	141.1	120.5	111.0	10.4	5.7	132.5	125.7
	Risk	99.4	12.8	110.5	12.8	9.9	125.8	14.4	138.6	136.7	138.6	121.1	111.4	10.4	5.7	135.1	126.6
	Unblocked	99.5	12.3	110.7	12.7	12.2	128.3	14.2	143.0	138.2	144.9	122.9	110.5	10.4	5.7	129.9	128.7
2%	Design	162.4	21.4	178.9	20.6	15.2	195.1	22.9	203.4	194.0	201.0	191.2	178.4	16.8	9.3	194.2	197.9
	Risk	162.4	21.4	178.8	20.7	13.4	194.8	22.9	201.1	195.4	198.4	191.5	178.8	16.8	9.3	196.6	198.0
	Unblocked	162.4	21.3	178.9	20.5	18.2	195.7	22.8	207.4	197.7	207.1	191.2	177.8	16.7	9.4	189.4	197.9
1%	Design	194.7	25.5	213.4	24.8	17.9	231.4	27.3	237.8	224.5	230.6	229.6	212.8	19.9	11.5	228.5	235.7
	Risk	194.7	25.4	213.5	24.8	15.7	230.8	27.8	236.5	224.2	227.4	229.7	213.2	20.0	11.5	232.8	235.3
	Unblocked	194.8	25.2	213.5	24.7	21.1	232.6	27.3	241.2	226.9	236.9	229.6	212.2	19.9	11.5	220.9	235.7
0.50%	Design	226.1	30.0	250.7	28.6	19.8	268.4	35.3	271.1	255.5	263.5	266.5	247.5	23.5	13.6	259.4	276.2
	Risk	226.1	30.1	250.5	28.7	16.9	267.9	35.9	266.9	252.8	258.1	266.6	247.6	23.6	13.6	261.5	275.9
	Unblocked	226.1	29.9	250.6	28.6	23.5	270.1	34.2	276.8	258.5	270.5	266.8	246.7	23.5	13.6	253.9	277.0
0.20%	Design	272.8	36.4	299.8	34.5	22.9	318.0	53.1	315.9	291.3	303.0	309.9	296.9	28.3	16.1	301.6	328.2
	Risk	272.7	36.4	299.7	34.5	20.5	316.9	54.2	312.6	289.8	296.8	309.5	296.9	28.2	16.1	301.6	327.5
	Unblocked	272.7	36.0	299.6	34.5	27.8	319.8	51.1	322.6	299.3	313.3	310.7	296.6	28.3	16.1	296.5	329.2
PMF	Design	476.9	80.2	557.8	92.9	72.8	509.7	326.3	835.9	858.3	921.6	416.6	552.2	70.7	37.6	434.3	528.2
	Risk	476.6	80.2	557.7	92.9	74.4	507.1	328.5	837.4	859.7	922.0	415.8	552.2	70.7	37.6	418.7	525.2
	Unblocked	476.8	80.3	557.7	92.9	68.8	514.4	323.1	831.9	859.0	924.1	417.9	552.2	70.7	37.7	449.2	533.9

Peak Model Flows (m3/s) at Reporting Locations

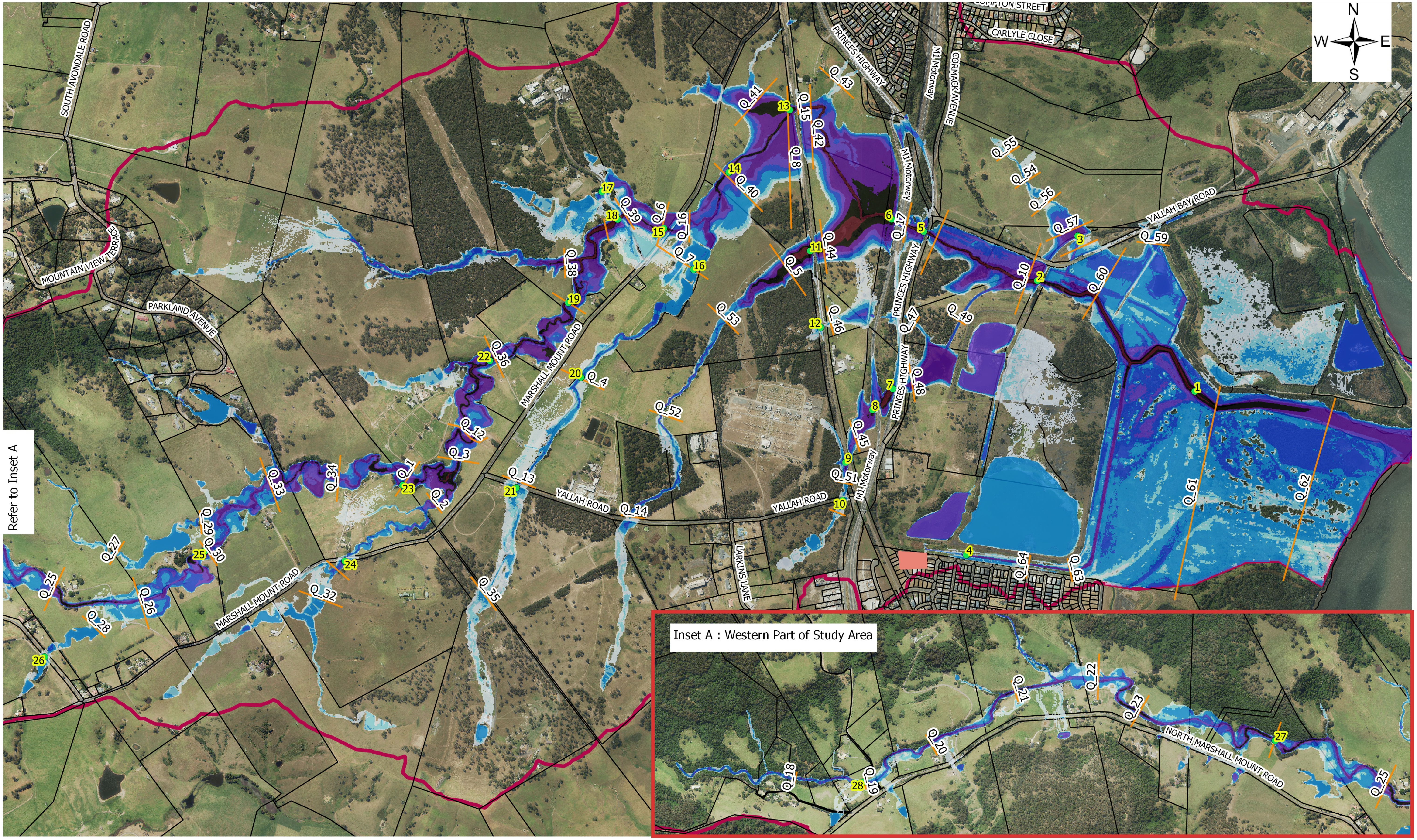
Flood Event	Blockage Scenario	Q 17	Q 18	Q 19	Q 20	Q 21	Q 22	Q 23	Q 24	Q 25	Q 26	Q 27	Q 28	Q 29	Q 30	Q 31	Q 32
20%	Design	114.2	20.1	24.4	28.8	33.3	46.5	48.4	55.0	59.6	63.8	4.1	3.2	7.1	65.1	7.9	5.9
	Risk	113.6	20.2	24.4	28.7	33.5	46.4	48.5	55.0	59.6	63.9	4.1	3.2	7.1	65.1	7.9	5.9
	Unblocked	116.0	20.2	24.4	28.8	33.2	46.5	48.4	55.0	59.6	63.7	4.3	3.2	7.1	64.9	7.8	5.9
10%	Design	134.7	24.2	30.1	36.8	43.5	61.2	64.6	72.6	78.4	83.2	5.3	4.0	7.7	84.2	9.9	7.6
	Risk	133.8	24.6	30.1	36.8	43.3	61.2	64.4	71.5	78.2	83.4	5.3	4.0	7.7	84.3	9.9	7.6
	Unblocked	137.8	24.3	30.4	36.8	43.3	61.1	64.5	72.9	78.1	83.6	5.3	4.0	7.7	84.5	9.8	7.6
2%	Design	193.5	38.7	50.5	60.1	71.7	102.2	105.7	120.4	129.9	137.5	8.8	6.6	12.7	138.5	16.8	12.7
	Risk	192.3	38.6	50.5	60.1	71.7	105.7	104.7	120.2	129.6	137.5	8.8	6.6	12.5	138.4	16.8	12.7
	Unblocked	197.7	38.6	50.5	60.1	71.6	102.5	105.0	120.1	129.2	137.5	8.8	6.6	12.8	138.4	16.4	12.7
1%	Design	221.9	47.3	60.9	72.4	85.2	122.1	126.9	143.6	153.0	164.2	10.4	8.4	15.1	165.8	20.3	15.4
	Risk	219.6	47.3	60.9	72.4	85.3	120.8	127.0	143.3	153.1	164.2	10.4	8.4	15.4	165.8	20.3	15.4
	Unblocked	225.5	47.4	60.8	72.6	85.2	121.2	127.1	143.6	153.1	164.2	10.4	8.3	15.2	165.8	20.2	15.4
0.50%	Design	252.0	55.6	71.8	86.5	98.0	141.7	147.7	167.1	178.1	192.3	12.1	10.3	18.0	193.4	23.8	18.0
	Risk	248.3	55.6	71.2	86.7	97.8	141.6	147.3	166.7	177.9	191.9	12.1	10.3	18.0	193.1	23.8	18.0
	Unblocked	257.1	55.6	71.2	86.8	97.9	141.5	147.3	166.8	178.0	192.1	12.1	10.3	18.1	193.3	23.7	18.0
0.20%	Design	287.7	67.5	86.4	105.1	114.9	172.1	179.3	201.3	212.5	227.8	14.5	12.7	22.2	229.8	28.9	22.3
	Risk	280.4	67.7	86.4	105.9	114.7	172.0	179.3	201.4	212.2	227.6	14.4	12.7	22.2	229.8	28.9	22.3
	Unblocked	297.1	67.6	86.8	104.5	115.4	171.9	179.2	201.2	212.2	227.7	14.4	12.7	22.2	229.7	28.6	22.3
PMF	Design	502.3	101.5	124.2	147.4	144.7	250.2	262.6	308.6	337.8	368.2	24.3	22.9	42.1	373.5	63.6	48.0
	Risk	486.2	102.0	124.8	147.5	144.5	250.1	262.3	307.8	337.5	367.7	24.3	22.9	42.1	372.9	63.6	48.0
	Unblocked	521.7	101.2	125.2	147.8	144.7	250.3	262.8	308.0	337.6	367.8	24.3	22.9	42.1	373.4	63.6	48.0

Peak Model Flows (m3/s) at Reporting Locations

Flood Event	Blockage Scenario	Q 33	Q 34	Q 35	Q 36	Q 37	Q 38	Q 39	Q 40	Q 41	Q 42	Q 43	Q 44	Q 45	Q 46	Q 47	Q 48
20%	Design	73.3	78.8	5.0	91.3	92.0	15.2	101.4	117.6	4.4	118.8	3.4	9.2	5.5	1.8	1.8	3.7
	Risk	73.1	78.8	5.0	91.2	92.0	15.2	101.3	117.2	5.0	117.9	3.0	7.9	5.2	1.8	0.3	0.6
	Unblocked	73.0	78.6	5.0	91.3	92.0	15.2	101.7	118.0	5.4	119.5	3.5	10.3	5.8	1.9	2.9	6.1
10%	Design	93.1	98.7	6.4	113.6	113.8	19.6	118.2	137.8	5.8	139.2	4.0	11.0	6.3	2.1	2.0	4.3
	Risk	93.1	98.7	6.4	113.6	113.8	19.6	118.5	138.8	6.3	138.4	3.9	8.5	6.2	1.9	0.5	0.7
	Unblocked	93.3	98.9	6.4	113.8	113.9	19.6	122.7	141.7	6.8	142.9	4.2	12.7	6.6	2.3	3.0	6.8
2%	Design	154.9	163.8	10.4	180.0	179.2	31.1	172.7	214.8	10.7	202.3	5.8	14.1	9.7	2.8	2.1	4.9
	Risk	154.9	163.8	10.4	180.0	179.2	31.1	167.2	214.5	11.4	199.7	5.3	10.7	9.6	2.2	1.1	3.6
	Unblocked	155.0	163.8	10.4	180.1	179.3	31.0	169.7	216.0	9.9	207.0	6.1	18.2	10.6	3.1	4.3	8.5
1%	Design	183.1	193.2	12.2	213.7	213.5	37.0	197.9	255.1	13.9	237.2	6.7	15.5	11.4	3.0	2.1	5.0
	Risk	183.1	193.2	12.2	213.8	213.5	37.0	203.0	254.4	13.8	233.7	6.0	11.6	11.5	2.6	1.2	5.2
	Unblocked	183.2	193.3	12.2	213.8	213.6	36.9	217.1	256.1	12.8	239.6	6.9	20.4	12.2	3.7	5.2	10.7
0.50%	Design	212.9	228.4	14.7	250.1	248.6	42.7	229.8	298.4	16.2	268.1	7.4	16.3	13.3	3.4	2.6	5.4
	Risk	212.6	228.2	14.7	250.1	248.5	42.7	227.0	297.7	16.4	263.8	6.6	12.8	13.4	3.0	1.3	6.7
	Unblocked	212.7	228.1	14.7	250.1	248.7	42.6	231.6	300.3	15.7	273.9	7.7	22.4	13.4	4.2	6.1	12.4
0.20%	Design	256.8	272.3	17.5	303.4	301.5	51.4	259.0	360.7	20.7	311.2	8.7	17.2	15.9	4.0	3.0	7.4
	Risk	256.6	272.2	17.5	303.4	301.5	51.4	256.5	358.3	20.3	306.5	7.1	14.5	16.0	3.8	1.3	8.5
	Unblocked	256.7	272.1	17.5	303.4	301.5	51.4	263.4	363.0	19.5	318.0	9.0	25.4	15.6	4.6	6.9	14.4
PMF	Design	431.4	472.7	41.4	581.2	458.5	99.5	352.4	820.8	37.4	590.4	12.4	102.3	37.7	9.3	46.9	33.7
	Risk	431.1	472.5	41.4	581.2	458.5	99.4	349.0	820.7	38.1	584.6	9.2	102.4	38.2	9.2	46.7	34.2
	Unblocked	431.3	472.7	41.4	581.3	458.5	100.0	358.1	819.5	37.9	605.1	13.3	95.8	38.1	9.3	48.3	34.1

Peak Model Flows (m3/s) at Reporting Locations

Flood Event	Blockage Scenario	Q 49	Q 50	Q 51	Q 52	Q 53	Q 54	Q 55	Q 56	Q 57	Q 58	Q 59	Q 60	Q 61	Q 62	Q 63	Q 64
20%	Design	4.9	2.3	2.6	8.3	9.3	5.2	2.1	5.8	5.8	4.6	2.7	120.4	107.0	103.5	1.3	1.2
	Risk	1.4	2.3	2.6	8.3	9.1	5.2	2.1	5.8	5.8	3.6	2.6	118.8	104.5	101.5	1.2	1.2
	Unblocked	7.0	2.3	2.6	8.1	9.1	5.4	2.1	5.8	5.9	5.2	2.7	122.7	108.5	104.4	1.6	1.5
10%	Design	5.7	3.0	3.4	11.5	11.5	6.5	2.7	7.6	6.6	5.4	3.0	144.0	130.4	125.5	1.8	1.6
	Risk	1.7	2.9	3.4	10.5	11.4	6.6	2.7	7.3	6.5	4.1	2.8	141.7	128.1	123.0	1.6	1.4
	Unblocked	8.4	3.0	3.4	10.0	11.3	6.3	2.7	7.6	6.6	6.0	3.4	147.9	132.7	127.6	2.2	2.0
2%	Design	7.9	5.3	6.1	16.7	18.3	9.9	4.3	11.3	8.9	7.3	4.1	206.1	202.7	201.4	2.8	2.5
	Risk	4.7	5.3	6.1	16.7	18.1	9.9	4.3	11.4	8.9	6.5	4.2	203.2	199.7	198.6	2.8	2.4
	Unblocked	11.2	5.3	6.0	16.7	18.4	10.1	4.3	11.4	9.0	8.7	4.2	211.1	207.8	206.6	3.2	2.9
1%	Design	8.3	6.2	7.3	19.7	22.0	11.6	5.1	13.3	9.7	8.2	4.9	236.7	233.3	232.6	3.6	3.2
	Risk	6.6	6.1	7.3	19.7	21.8	11.8	5.1	13.2	9.7	9.2	4.9	232.4	229.0	228.3	3.4	3.0
	Unblocked	12.8	6.1	7.3	19.5	22.2	11.8	5.1	13.2	9.9	10.2	5.1	241.4	239.3	238.6	3.8	3.5
0.50%	Design	9.2	7.4	8.2	23.2	25.4	13.6	6.0	15.0	10.7	9.0	5.6	266.8	271.5	272.9	3.5	3.2
	Risk	8.5	7.4	8.3	23.1	25.2	13.7	6.0	15.0	10.0	11.1	5.5	261.9	265.8	267.1	3.5	3.0
	Unblocked	14.7	7.4	8.2	23.1	25.7	13.6	6.0	15.0	11.5	11.6	6.0	273.9	278.8	280.2	4.3	4.0
0.20%	Design	11.5	9.2	10.3	28.2	30.6	16.0	6.9	17.9	11.4	20.4	6.8	308.2	313.9	315.7	4.2	3.7
	Risk	10.9	9.0	10.3	28.2	30.5	16.4	6.9	17.9	12.5	21.0	6.8	302.3	307.2	309.0	4.2	3.7
	Unblocked	16.9	9.2	10.2	28.3	30.9	16.5	6.9	17.9	13.6	16.5	7.0	314.6	321.3	323.1	4.9	4.5
PMF	Design	72.3	17.0	18.8	69.3	74.5	28.9	11.8	32.4	36.2	173.9	14.1	940.5	907.6	913.5	8.8	8.2
	Risk	72.2	17.0	18.8	69.3	74.2	28.9	11.9	32.4	36.6	177.8	14.2	940.9	907.4	913.7	9.2	8.2
	Unblocked	73.7	17.0	18.8	69.3	75.2	28.9	11.8	32.5	36.4	170.9	13.9	941.1	906.6	912.6	10.1	9.7



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Scale : 1:15000@A3
Date : 29 November 2018
Revision : A
Created by : RST
Coordinate System : Map Grid of Australia 94

0.25 0 0.25 0.5 0.75 km

Legend

Flow Lines (Q_1)

Peak Water Levels (1)

Recent Development Area

Hydraulic Model Extent

GA201
Key Reporting locations

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engineering | environmental | economics | engagement

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