TWEED
SHIRE COUNCIL

South Murwillumbah Floodplain Risk Management Study & Plan

Final Report

Volume 1 of 2: Report Text & Appendices

Revision 5
October 2019

Catchment Simulation Solutions

South Murwillumbah Floodplain Risk Management Study & Plan

REVISION / REVIEW HISTORY

Revision #	Description	Prepared by	Reviewed by
1	Draft report for Council/OEH review	D. Tetley & T. Steele	C. Ryan
2	Updated draft report incorporating changes to address Council/OEH comments	D. Tetley	C. Ryan
3	Final draft report	D. Tetley	L. Davis
4	Final draft report for public exhibition	D. Tetley	C. Ryan
5	Final report	D. Tetley	C. Ryan

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3	Tweed Shire Council	27/03/2019	PDF
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Overview

South Murwillumbah is located within the Tweed Shire Local Government Area (LGA) in northern New South Wales and forms part of the broader Murwillumbah urban area. As shown in **Figure ES1**, South Murwillumbah is located adjacent to the Tweed River.

Although South Murwillumbah is protected by a levee, the levee only affords protection during relatively small floods. As a result, there is potential for floodwaters to overtop the levee system and inundate South Murwillumbah following heavy rainfall in the catchment. Flooding has been experienced across South Murwillumbah on a number of occasions including 1954, 1974, 1989 and 2017. The 2017 flood resulted in many millions of dollars of damage across South Murwillumbah.

In recognition of the flooding problems confronting South Murwillumbah, Tweed Shire Council commisioned Catchment Simulation Solutions to prepare a Floodplain Risk Management Study and Plan for the area. The primary goal of the project was to quantify the nature and extent of the existing flooding problem and evaluate options that could be potentially implemented to better manage the flood risk.

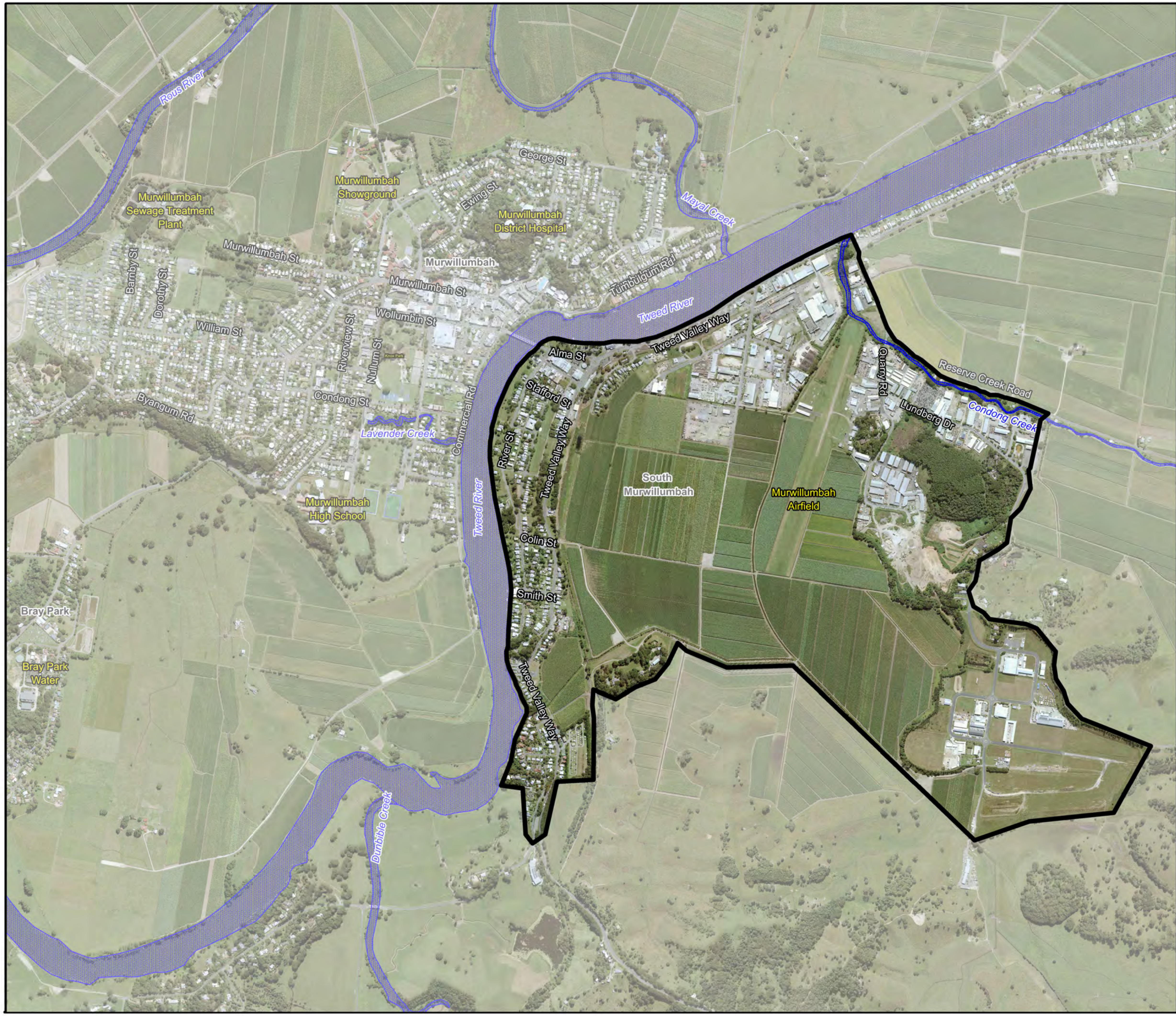
The Existing Flooding Problem

The nature and extent of the existing flooding problem was quantified using a computer flood model that extends along the Tweed River from Byangum downstream to Tumbulgum. The computer model was calibrated against historic flood information for three historic floods (including the 2017 flood) and was also used to simulate a range of design floods.

Peak floodwater depths were extracted from the results of the flood model for the 20% AEP (1 in 5 year) flood, 5% AEP (1 in 20 year) flood, 1% AEP (1 in 100 year) flood and 0.2% AEP flood (1 in 500 year) and are presented in **Figures ES2** to **ES5**.

The outputs from the design flood simulations were used to quantify the impact that flooding is likely to have on people and property across South Murwillumbah for a range of different floods. The outcomes of the flood modelling determined that:

- The existing South Murwillumbah levee is predicted to be overtopped in floods as frequent as the 20% AEP event. Inundation of South Murwillumbah first occurs across a low point in Alma Street (located approximately 50 metres west of Tweed Valley Way). The earthen section of the levee located west of River Street is predicted to be overtopped approximately 10 minutes after Alma Street first overtops.
- Alma Street would be overtopped and access to the main town would be lost approximately 30 hours after the initial start of rainfall during events up to and including the 1% AEP event. During the 0.2% AEP flood, considerably less warning time would be available (i.e., ~13 hours). Accordingly, there would be limited warning time available during particularly large floods.



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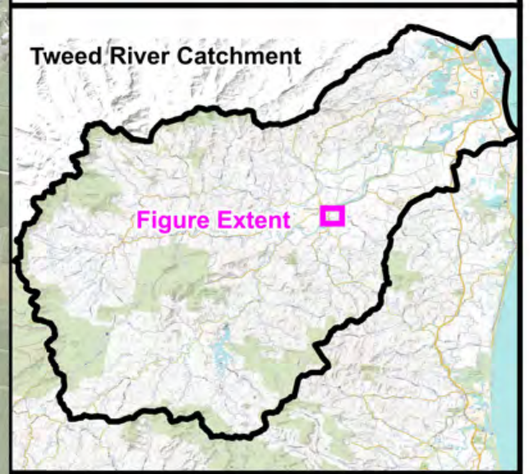

LEGEND

South Murwillumbah Study Area

Notes:

Aerial photograph date: 2016

N
W E
S

0 0.50 1.00
Km

Figure ES1: South Murwillumbah Study Area

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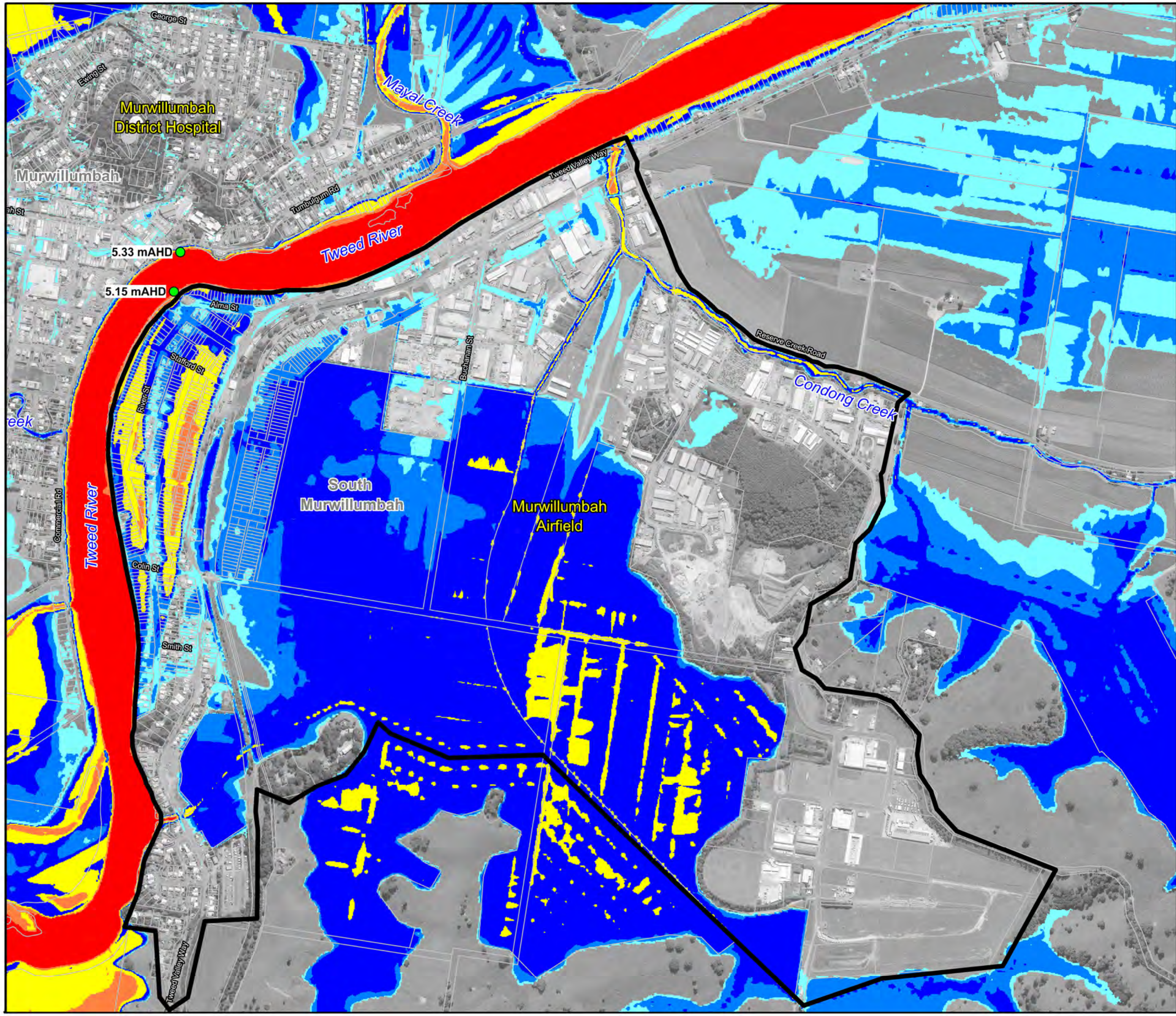
Suite 10.01, 70 Phillip St
Sydney, NSW 2000

File Name: Figure ES1 - South Murwillumbah Study Area.wor



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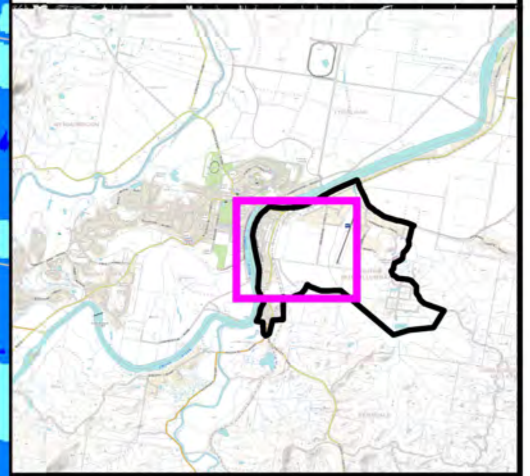

LEGEND

Depths (m)

- < 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- 2.0 - 4.0
- 4.0 - 6.0
- > 6.0

Peak Water Level at Gauge

Notes:

Aerial photograph date: 2016
Only areas exposed to depths of more than 0.15m are shown in the mapping

N W E S

0 0.35 0.70
Km

Figure ES2:
Floodwater Depths for the 20% AEP Flood

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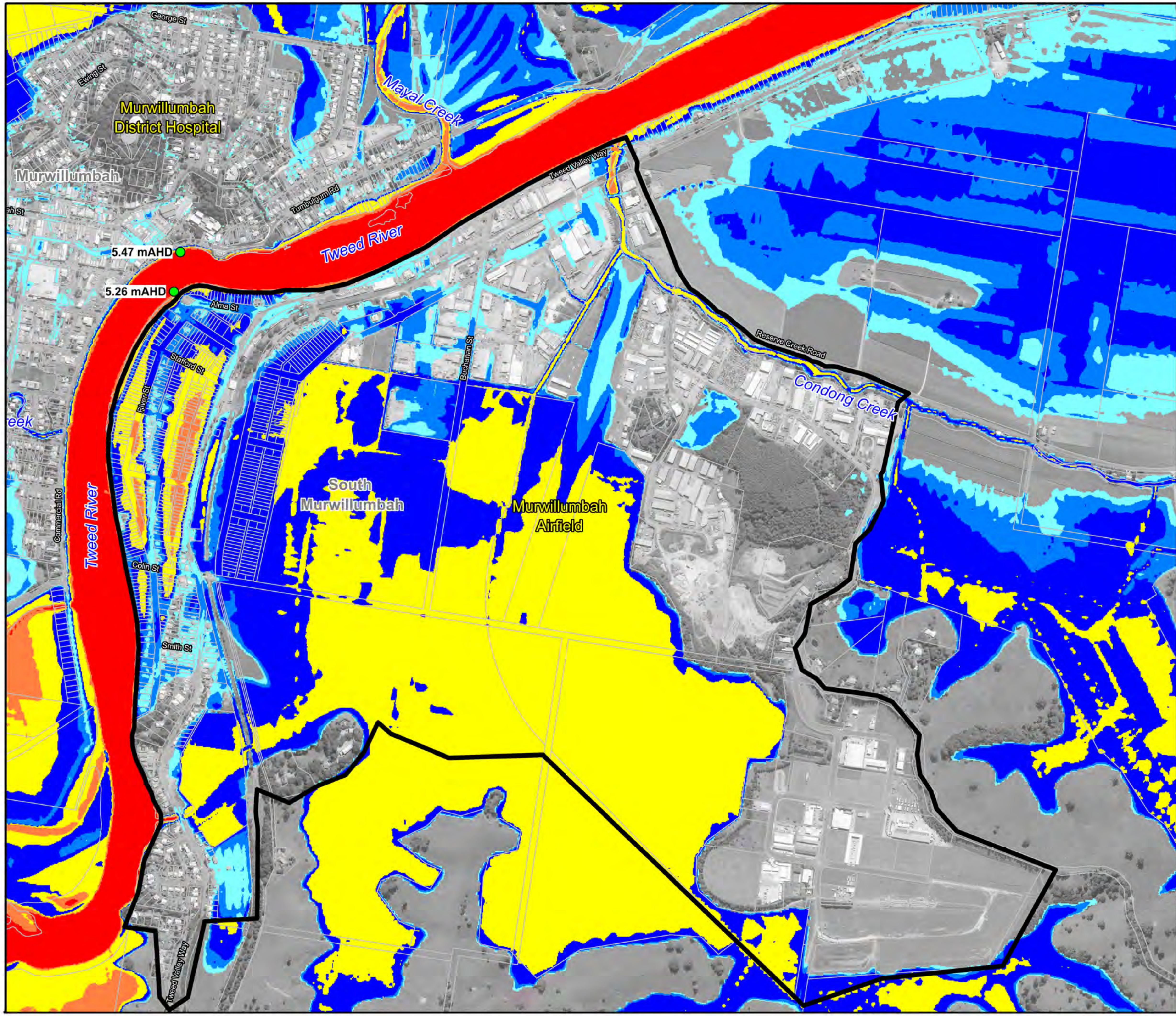
File Name: Figure ES2 - Floodwater Depths for the 20% AEP Flood.wor



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LEGEND

Depths (m)

- < 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- 2.0 - 4.0
- 4.0 - 6.0
- > 6.0

Peak Water Level at Gauge

Notes:

Aerial photograph date: 2016
Only areas exposed to depths of more than 0.15m are shown in the mapping

N W E S

0 0.35 0.70 Km

Figure ES3: Floodwater Depths for the 5% AEP Flood

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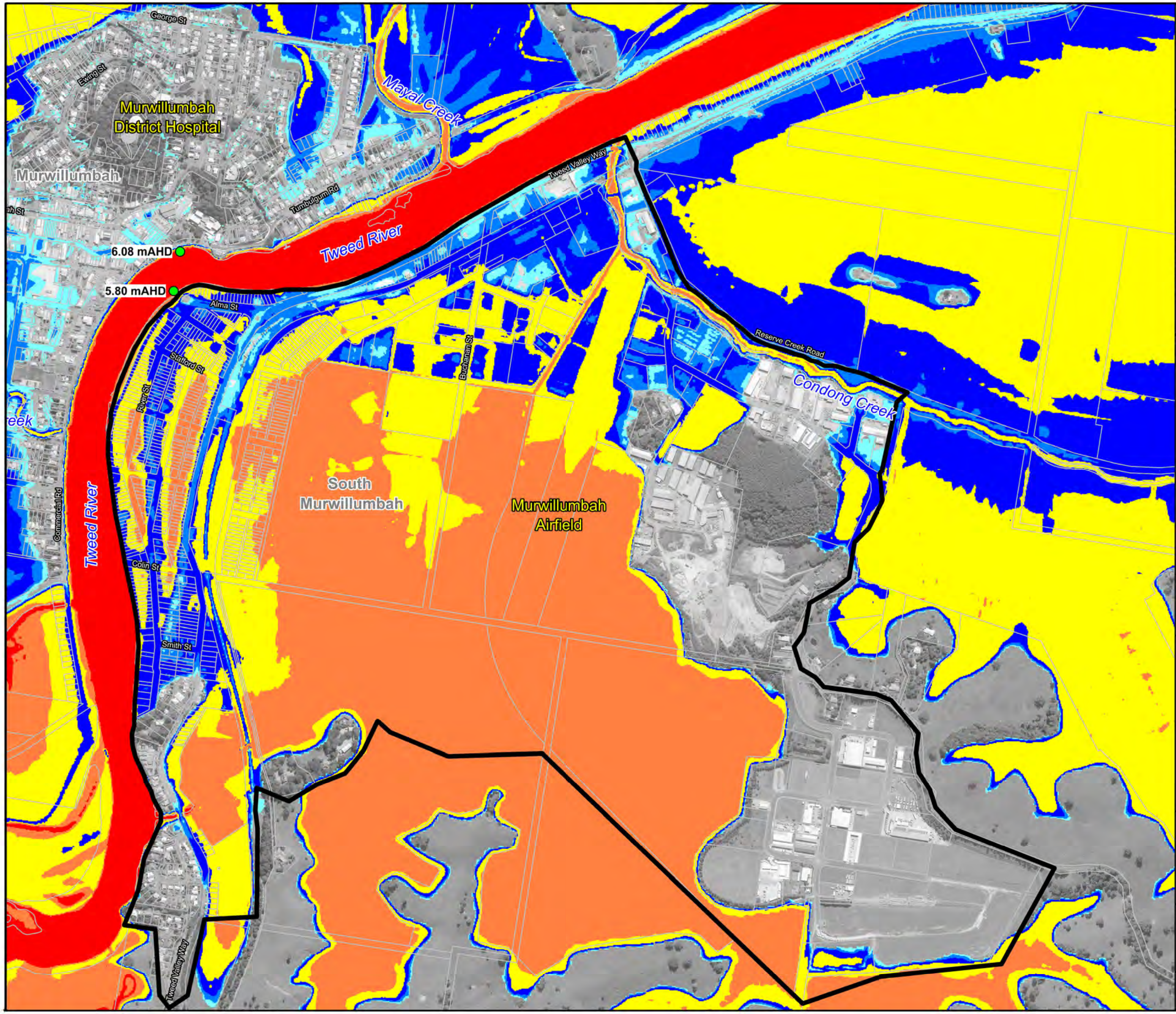
File Name: Figure ES3 - Floodwater Depths for the 5% AEP Flood.wor



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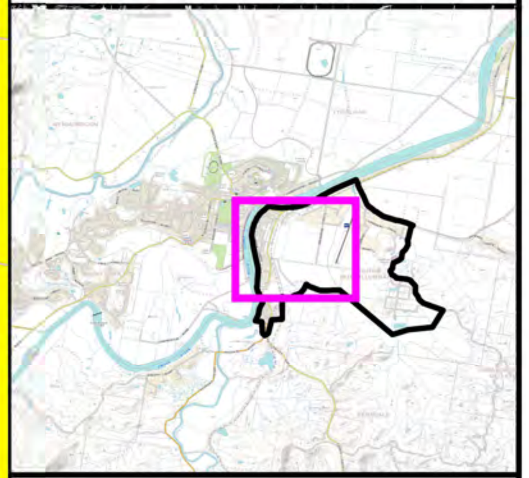

LEGEND

Depths (m)

- < 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- 2.0 - 4.0
- 4.0 - 6.0
- > 6.0

Peak Water Level at Gauge

Notes:

Aerial photograph date: 2016
Only areas exposed to depths of more than 0.15m are shown in the mapping

N W E S

0 0.35 0.70 Km

Figure ES4: Floodwater Depths for the 1% AEP Flood

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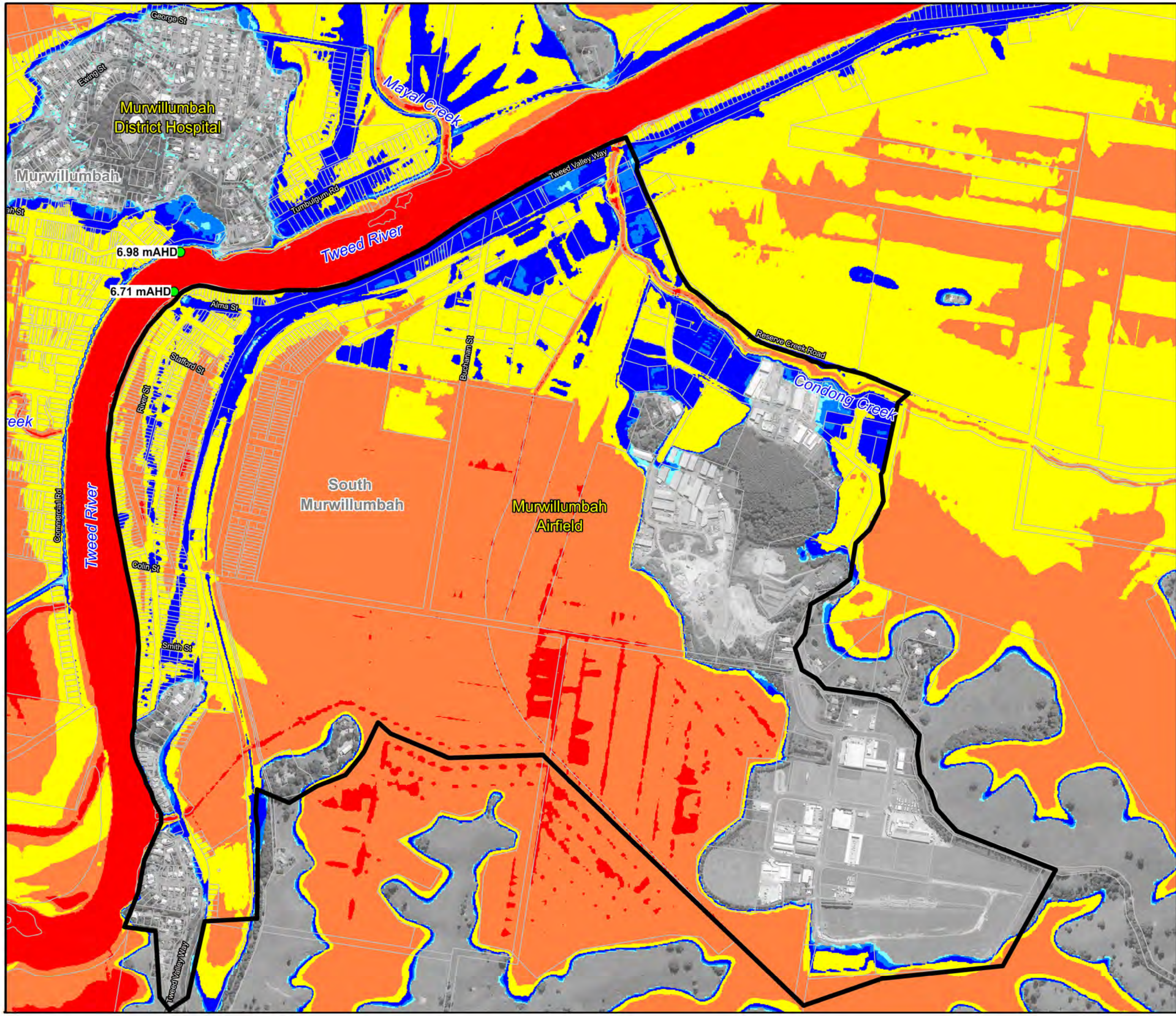
File Name: Figure ES4 - Floodwater Depths for the 1% AEP Flood.wor



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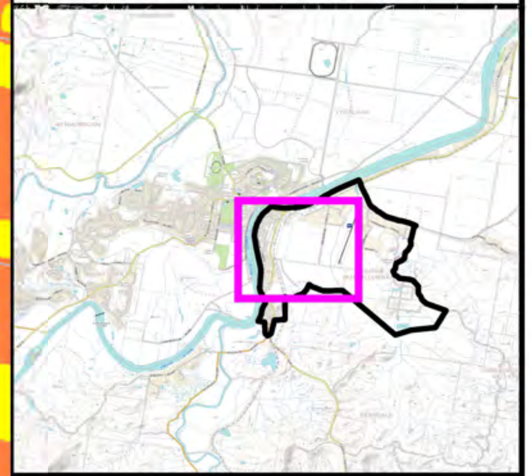

LEGEND

Depths (m)

- < 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- 2.0 - 4.0
- 4.0 - 6.0
- > 6.0

Peak Water Level at Gauge

Notes:

Aerial photograph date: 2016
Only areas exposed to depths of more than 0.15m are shown in the mapping

N
W E
S

0 0.35 0.70
Km

Figure ES5: Floodwater Depths for the 0.2% AEP Flood

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Catchment Simulation Solutions
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Sydney, NSW 2000

File Name: Figure ES5 - Floodwater Depths for the 0.2% AEP Flood.wor

- Once inundation of South Murwillumbah occurs it would be isolated for at least 12 hours (>40 hours during a 0.2% AEP flood).
- Once inundation of South Murwillumbah occurs, it would typically take at least 3 days for the floodwater to recede across most of the area. During the 0.2% AEP flood, it would take more than 4 days for floodwaters to recede.
- During a 1% AEP flood, 149 properties (out of a total of 415 buildings in the study area) are predicted to experience above floor inundation. This is predicted to increase to more than 260 properties if a 0.2% AEP flood was to occur.
- A flood damage bill of more than $45 million could be expected across South Murwillumbah should a 1% AEP (i.e., March 2017 type) flood occur. The average annual damage cost is predicted to be $5.1 million per annum.
- The current land zoning across most of South Murwillumbah appears to be largely incompatible with the flood risk. Accordingly, further development across most of the residential, commercial and industrial sections of South Murwillumbah is difficult to support. However, there are other areas adjacent to South Murwillumbah (most notably the "Industry Central" subdivision) where further development could be supported.

Impact of Climate Change

Climate change induced rainfall intensity and ocean level increases have the potential to further increase the existing flood risk across South Murwillumbah. More specifically:

- A 10% increase in rainfall coupled with a 0.4 m increase in ocean level is predicted to increase existing design flood levels by up to 1 metre in some locations. This is predicted to result in 31 additional properties being subject to above floor flooding during the 5% AEP event. Flood damage costs are predicted to increase by $5 million during the 5% AEP flood and over $12 million during the 1% AEP flood.
- A 20% increase in rainfall coupled with a 0.9 m increase in ocean level is predicted to result in 47 additional properties being subject to above floor inundation during a 5% AEP flood and 16 additional properties subject to above floor flooding during a 1% AEP flood. Flood damage costs are also predicted to increase by about $20 million during the 5% AEP flood and more than $23 million during a 1% AEP flood.

Community Consultation

Consultation with the community has been an important component of the study. Consultation was completed through a study website as well as the distribution of a community information sheet and two questionnaires. The consultation has provided a first-hand account of the community's experiences during past floods, how the community would likely respond during future floods and has also provided an opportunity for the community to provide feedback on the flood risk management options that were being considered as part of the study.

The responses to the questionnaire showed that:

- More than 80% of the questionnaire respondents have experienced some form of inundation or disruption as a result of flooding. Most of these reported flood impacts related to the 2017 flood.

- 43% of respondents indicated they would remain at home during a future flood and only 28% indicated they would evacuate. 12% of the respondents were unsure of how they would respond during a future flood.
- The primary reasons for people choosing to remain at home were concern for the security of their property and feeling that their house could not be flooded. However, it was determined that two thirds of those respondents would be flooded above floor level during the PMF event and the above floor flooding depths would typically exceed 4 m. This highlights that further education is necessary to reinforce that bigger floods than those that have been experienced could occur.

Options Considered for Better Managing the Flooding Problems

A total of 32 different flood risk management measures were investigated in detail as part of the current study to help better manage the existing flood risk. This included flood modification options, property modification options and response modification options. Each option was evaluated against a range of criteria to provide an appraisal of the potential feasibility of each option. The outcomes of the detailed assessment of each option are presented in the following chapters:

- Flood Modification Options (e.g., levee upgrades): Chapter 5.
- Property Modification Options (e.g., voluntary house purchase): Chapter 6.
- Response Modification Options (e.g., flood warning system upgrades): Chapter 7.

Floodplain Risk Management Plan

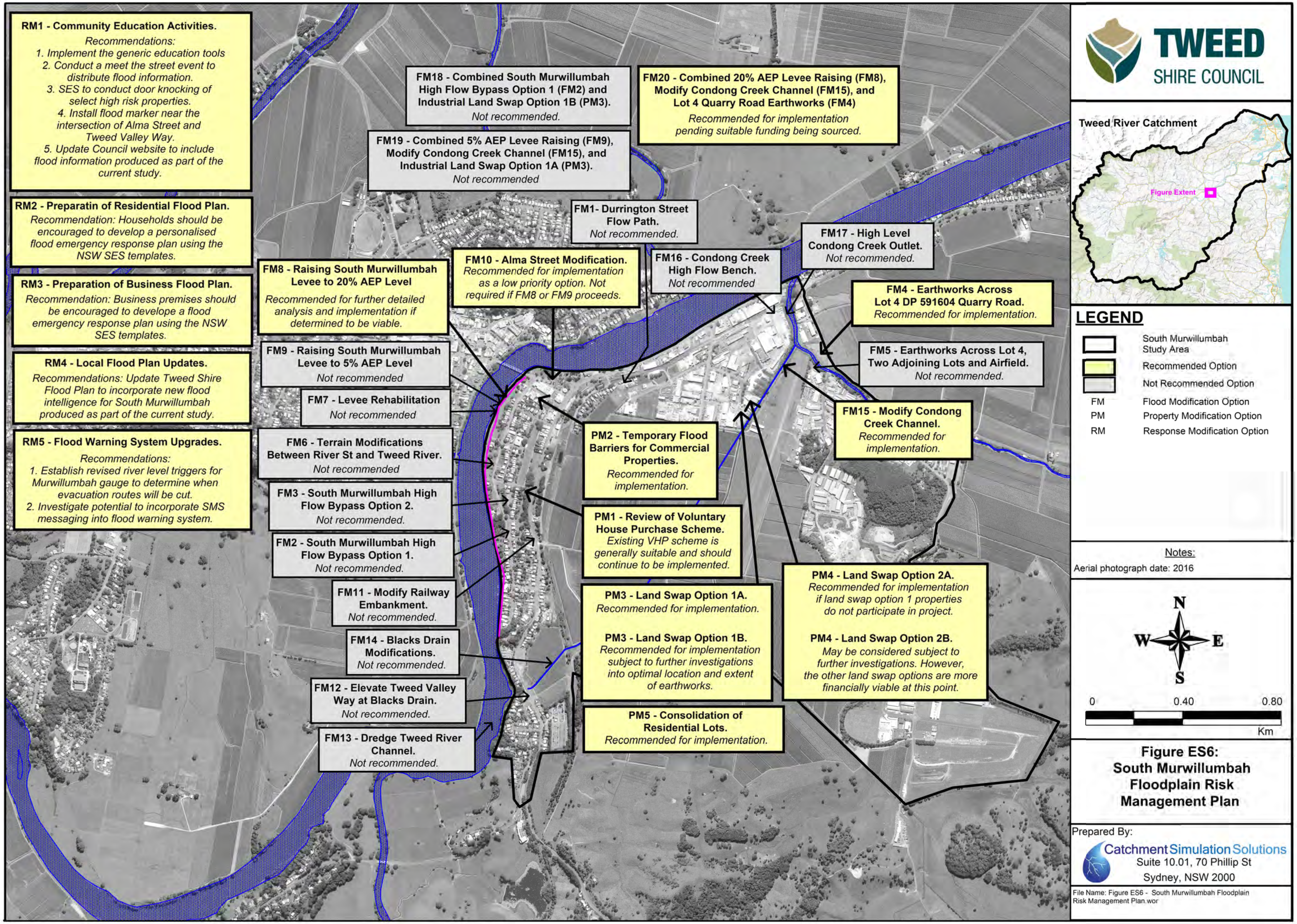
Based upon the outcomes of the detailed evaluation, the options outlined in **Table 1** are recommended for implementation as part of the Floodplain Risk Management Plan for South Murwillumbah. The recommended set of options are also shown on **Figure ES6**. **Figure ES6** also shows those options that were investigated but were not found to be viable.

Information on each option including costs, implementation schedules and funding opportunities is also included in **Table 1**. For more detailed information on each option including hydraulic benefits, community feedback and potential constraints, please refer to the report section referenced in **Table 1**.

It is expected that implementation of the plan will have a capital cost of approximately $7.8 million. The industrial land swap option is the biggest contributor to this total cost estimate (i.e., $6.6 million). This capital cost excludes the cost associated with implementation of Council's proposed voluntary house purchase scheme (this is likely to add $15 million to the implementation cost).

In addition to the capital costs, some options will incur ongoing maintenance costs. Many of the options will also require a significant investment in time from various agencies including Tweed Shire Council, the State Emergency Service and the Bureau of Meteorology which are not accounted for in the overall cost estimate.

Raising of the South Murwillumbah levee is predicted to afford some significant hydraulic and financial benefits across South Murwillumbah. However, there are several limitations that may limit the feasibility of this option. As a result, it is not recommended for implementation



RM1 - Community Education Activities.
Recommendations:
1. Implement the generic education tools
2. Conduct a meet the street event to distribute flood information.
3. SES to conduct door knocking of select high risk properties.
4. Install flood marker near the intersection of Alma Street and Tweed Valley Way.
5. Update Council website to include flood information produced as part of the current study.
RM2 - Preparatin of Residential Flood Plan.
Recommendation: Households should be encouraged to develop a personalised flood emergency response plan using the NSW SES templates.
RM3 - Preparation of Business Flood Plan.
Recommendation: Business premises should be encouraged to develope a flood emergency response plan using the NSW SES templates.
RM4 - Local Flood Plan Updates.
Recommendations: Update Tweed Shire Flood Plan to incorporate new flood intelligence for South Murwillumbah produced as part of the current study.
RM5 - Flood Warning System Upgrades.
Recommendations:
1. Establish revised river level triggers for Murwillumbah gauge to determine when evacuation routes will be cut.
2. Investigate potential to incorporate SMS messaging into flood warning system.
FM18 - Combined South Murwillumbah High Flow Bypass Option 1 (FM2) and Industrial Land Swap Option 1B (PM3).
Not recommended.
FM19 - Combined 5% AEP Levee Raising (FM9), Modify Condong Creek Channel (FM15), and Industrial Land Swap Option 1A (PM3).
Not recommended
FM20 - Combined 20% AEP Levee Raising (FM8), Modify Condong Creek Channel (FM15), and Lot 4 Quarry Road Earthworks (FM4)
Recommended for implementation pending suitable funding being sourced.
FM1- Durrington Street Flow Path.
Not recommended.
FM17 - High Level Condong Creek Outlet.
Not recommended.
FM16 - Condong Creek High Flow Bench.
Not recommended
FM10 - Alma Street Modification.
Recommended for implementation as a low priority option. Not required if FM8 or FM9 proceeds.
FM8 - Raising South Murwillumbah Levee to 20% AEP Level
Recommended for further detailed analysis and implementation if determined to be viable.
FM4 - Earthworks Across Lot 4 DP 591604 Quarry Road.
Recommended for implementation.
FM9 - Raising South Murwillumbah Levee to 5% AEP Level
Not recommended
FM5 - Earthworks Across Lot 4, Two Adjoining Lots and Airfield.
Not recommended.
FM7 - Levee Rehabilitation
Not recommended
FM15 - Modify Condong Creek Channel.
Recommended for implementation.
FM6 - Terrain Modifications Between River St and Tweed River.
Not recommended
PM2 - Temporary Flood Barriers for Commercial Properties.
Recommended for implementation.
FM3 - South Murwillumbah High Flow Bypass Option 2.
Not recommended.
PM1 - Review of Voluntary House Purchase Scheme.
Existing VHP scheme is generally suitable and should continue to be implemented.
FM2 - South Murwillumbah High Flow Bypass Option 1.
Not recommended.
PM4 - Land Swap Option 2A.
Recommended for implementation if land swap option 1 properties do not participate in project.
PM4 - Land Swap Option 2B.
May be considered subject to further investigations. However, the other land swap options are more financially viable at this point.
FM11 - Modify Railway Embankment.
Not recommended.
PM3 - Land Swap Option 1A.
Recommended for implementation.
PM3 - Land Swap Option 1B.
Recommended for implementation subject to further investigations into optimal location and extent of earthworks.
FM14 - Blacks Drain Modifications.
Not recommended.
FM12 - Elevate Tweed Valley Way at Blacks Drain.
Not recommended.
PM5 - Consolidation of Residential Lots.
Recommended for implementation.
FM13 - Dredge Tweed River Channel.
Not recommended.
TWEED SHIRE COUNCIL
Tweed River Catchment
Figure Extent
LEGEND
South Murwillumbah Study Area
Recommended Option
Not Recommended Option
FM Flood Modification Option
PM Property Modification Option
RM Response Modification Option
Notes:
Aerial photograph date: 2016
N
W
E
S
0
0.40
0.80
Km
Figure ES6: South Murwillumbah Floodplain Risk Management Plan
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Sydney, NSW 2000
File Name: Figure ES6 - South Murwillumbah Floodplain Risk Management Plan.wor

as part of the plan. However, there are sufficient benefits to warrant further investigations to determine if the identified limitations can be overcome. Preliminary cost estimates indicate that the levee raising would cost in the order of $14 million to implement but would afford over $20 million in reduced damage costs.

It needs to be recognised that implementation of the structural and industrial land swap options will not eliminate the potential for flooding of South Murwillumbah and some of the options may take a number of years before they are fully implemented. Therefore, implementation of the remaining, non-structural, options is considered essential for ensuring the existing flood risk is not increased in the future and the continuing flood risk is minimised during particularly severe floods.

FM	Flood modification option	PM	Property modification option	RM	Response modification option

Table 1 South Murwillumbah Floodplain Risk Management Plan

Option		Report Section	Implementation Responsibility	Total Cost	BCR	Priority	Timing	Recommendation/Comments
Flood Modification Options								
FM4	Earthworks across Lot 4 DP 591604 Quarry Road	5.2.4	Council	$0.4 million	1.2	High	3 years	Recommended for implementation
FM8	Raising South Murwillumbah Levee to 20%AEP Level + Raising Height of CBD Levee	5.3.2	Council	$50k for additional investigations	~1.6	Low	5 years	Additional investigations recommended. The capital cost of this option is likely to be in the order of $14 million
FM10	Alma Street Modification	5.4.1	Council	$0.4 million	0	Low	>5 years	This option may be considered for implementation as part of any future roadworks/stormwater modifications for the area. If the levee raising option is implemented (FM8), modification of Alma Street will occur as part of this and implementation of this option in isolation will not be necessary
FM15	Modify Condong Creek Channel	5.6.1	Council & Interested Parties	$0.3 million	0.3	Medium	2 years	Council to initiate discussions with interested parties to confirm their willingness to contribute to the implementation of this option.

Option		Report Section	Implementation Responsibility	Total Cost	BCR	Priority	Timing	Recommendation/Comments
Property Modification Options								
PM1	Proposed Voluntary House Purchase Scheme	6.2	Council	$15 million	0.2	Medium	10+ years	Proposed VHP scheme is generally suitable and should continue to be implemented. Council may consider purchasing and/or rezoning identified vacant residential lots. However, this may need to be completed under a separate scheme
PM2	Temporary Flood Barriers for Commercial Properties	6.3	Business owners	~$60,000 per property	1.3	Medium	2 years	Council to initiate discussions with identified commercial property owners. Property owners will likely be responsible for implementation costs
PM3	Land Swap Option 1	6.4.1	Council & business owners	$6.6 million	0.9	High	2 years	Earthworks could also be considered across land swap properties subject to funding availability and designing earthworks to minimise potential for adverse downstream impacts
PM4	Land Swap Option 2	6.4.2	Council & business owners	$13.2 million	0.7	High	2 years	Recommended for implementation if land swap option 1 properties do not participate in project
PM5	Consolidation of Residential Lots	6.5	Council & impacted residents	?	-	Medium	3 years	Implementation costs difficult to define. However, considered worthwhile pursuing if costs can be kept under $59,000 per property

Option		Report Section	Implementation Responsibility	Total Cost	BCR	Priority	Timing	Recommendation/Comments
Response Modification Options								
RM1	a) Implement the generic education tools recommended as part of the "Murwillumbah CBD Levee & Drainage Study"	7.2	Council & SES	Council & SES time	-	High	1-2 years	Recommended for implementation and to be repeated frequently (suggested annually)
	b) Conduct a meet the street event to distribute flood information		Council & SES	Council & SES time	-	Medium	1 year	Recommended for implementation and to be repeated frequently. Could be used as an opportunity to promote preparation of residential and business flood plans (RM2 & RM3)
	c) SES to conduct door knocking of select high risk properties		SES	SES time	-	High	1 year	Recommended for implementation and to be repeated frequently. Could be used as an opportunity to promote preparation of residential flood plans (RM2)
	d) Install flood marker near the intersection of Alma Street and Tweed Valley Way		Council	Council time	-	Medium	2 years	Recommended for implementation
	e) Update Council website to include flood information produced as part of the current study		Council	Council time	-	High	<1 year	Recommended for implementation

Option		Report Section	Implementation Responsibility	Total Cost	BCR	Priority	Timing	Recommendation/Comments
RM2	Preparation of Residential Flood Plan	7.3.1	Individual residents	Resident time	-	High	1 year	Council and SES could promote flood plan preparation as part of community education activities and provide additional flood information, as required to interested parties to assist with plan preparation
RM3	Preparation of Business Flood Plan	7.3.2	Individual businesses	Business owner time	-	High	1 year	
RM4	Local Flood Plan & Flood Intelligence Card Updates	7.3.3	SES	SES Time	-	High	2 years	Recommended for implementation
RM5	Flood Warning System Upgrades	7.4	SES, Council & BoM	SES, Council & BoM time	-	Medium	4 years	Recommendations: 1. Establish revised river level triggers for Murwillumbah gauge based on when evacuation routes will be cut, and when the South Murwillumbah levee will be overtopped (SES). 2. Investigate potential to incorporate SMS messaging into flood warning system (Council & BoM).

1 INTRODUCTION

1.1 Background

South Murwillumbah is located within the Tweed Shire Local Government Area (LGA) in northern New South Wales and forms part of the broader Murwillumbah urban area. As shown in **Figure 1**, South Murwillumbah is located adjacent to the Tweed River.

Although South Murwillumbah is protected by a levee, the levee only affords protection during relatively small floods. As a result, there is potential for floodwaters to overtop the banks of the Tweed River and inundate South Murwillumbah following heavy rainfall in the catchment. Flooding has been experienced across South Murwillumbah on a number of occasions including 1954, 1974, 1989 and 2017. The 2017 flood resulted in millions of dollars of damage across the residential, commercial and industrial sections of South Murwillumbah.

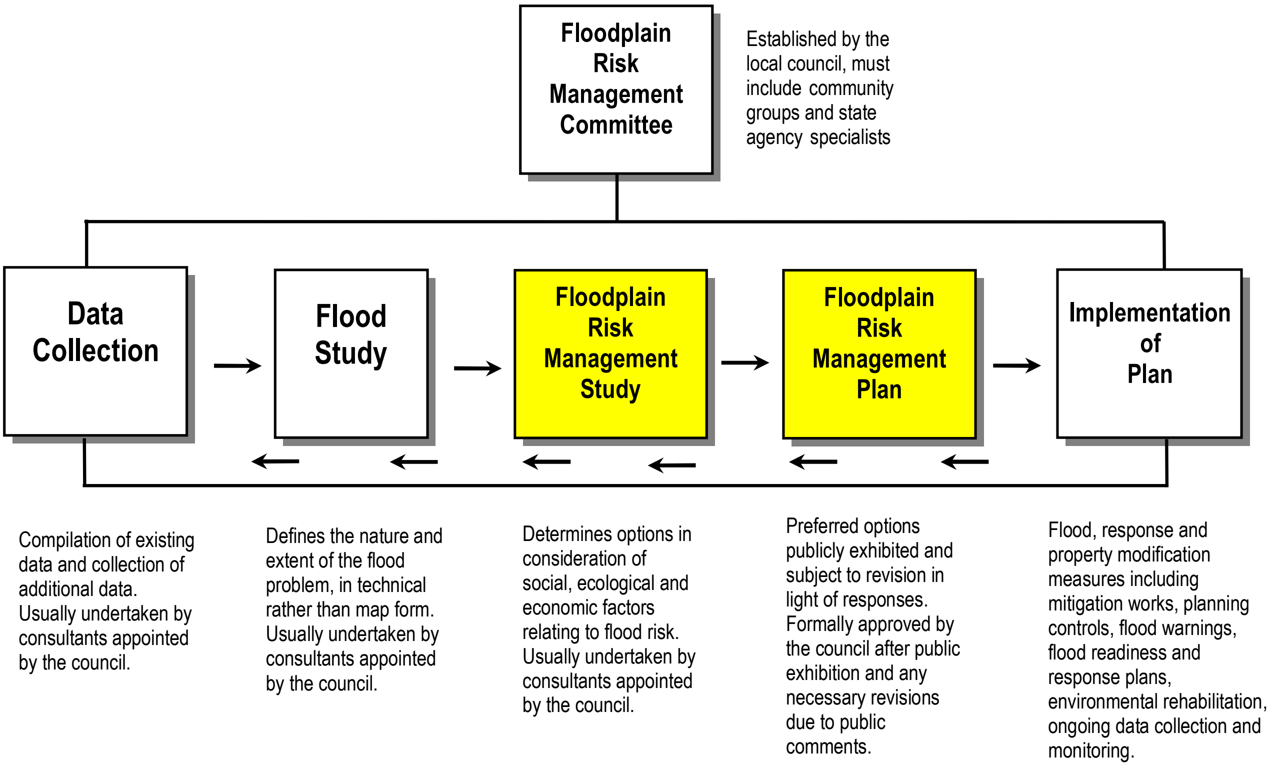
In recognition of the flooding problems confronting South Murwillumbah, Tweed Shire Council resolved to prepare a Floodplain Risk Management Study and Plan for the area.

1.2 The Floodplain Risk Management Process

The South Murwillumbah Floodplain Risk Management Study and Plan has been prepared in accordance with the requirements of the NSW Government's 'Floodplain Development Manual' (NSW Government, 2005). The 'Floodplain Development Manual' guides the implementation of the State Government's Flood Policy. The Flood Policy is directed towards providing solutions to existing flooding problems in developed areas and ensuring that new development is compatible with the flood hazard and does not create additional flooding problems in other areas. The Policy is defined in the NSW Government's 'Floodplain Development Manual' (NSW Government, 2005).

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

The Policy provides for technical and financial support by the State Government through the stages outlined on the following page. Tweed Shire Council engaged Catchment Simulation Solutions to prepare the South Murwillumbah Floodplain Risk Management Study and Plan, which represents stages 3 and 4 of the process. The aim of the Floodplain Risk Management Study is to identify, assess and compare various options for managing the flood risk across South Murwillumbah. The Floodplain Risk Management Plan draws on the outcomes of the Study and provides a set of recommended options that will outline how to best manage the existing, future and continuing flood risk across South Murwillumbah.



This floodplain risk management study and plan updates and expands upon the 'Tweed Valley Floodplain Risk Management Study' (WBM BMT, 2014) and the 'Tweed Valley Floodplain Risk Management Plan' (WBM BMT, 2014). Although these previous investigations did consider South Murwillumbah, the scale of the previous studies meant that a focussed assessment of flooding in the immediate vicinity of South Murwillumbah could not be undertaken.

1.3 Report Structure

The following report forms the Floodplain Risk Management Study and Plan for South Murwillumbah. It has been divided into the following sections:

- Section 2 - Background: Provides background information regarding the study area, flood history and previous flooding investigations.
- Section 3 – Defining the Existing Flood Problem: Describes the current impact of flooding on the community for a range of different floods. This includes an assessment of the impact of flooding on key facilities, the potential cost of flooding as well as the potential for floodwater to damage buildings and/or pose a danger to personal safety.
- Section 4 - Options for Managing the Flood Risk: Outlines options that could be potentially employed to manage the existing, future and continuing flood risk across the study area.
- Sections 5 to 7: discusses the merits of a range of flood, property and response modification measures that could be potentially employed to manage the existing, future and continuing flood risk across the catchment.
- Section 8 – Floodplain Risk Management Plan: provides a preferred list of options that are considered appropriate for implementation by Council to manage the flood risk across South Murwillumbah.

2 BACKGROUND INFORMATION

2.1 Overview

The following sections provide an overview of the catchment and study area and provide a description of the available datasets that were used as part of the project. It also provides a brief summary of past flooding investigations with a particular focus on South Murwillumbah including what options have previously been investigated to manage the flood risk.

2.2 Study Area Description

2.2.1 Catchment Description

The Tweed River is located in northern New South Wales and drains a 1,100 km^2 catchment into the Pacific Ocean at Tweed Heads. The Tweed River drains past Murwillumbah and South Murwillumbah, which are located approximately 28 km upstream of Tweed Heads.

In the vicinity of Murwillumbah, the main arm of the Tweed River is joined by the Oxley River (near Byangum), Dunbible Creek (joins upstream of Murwillumbah) as well as the Rous River (joins at Tumbulgum). Myall Creek, which is located near East Murwillumbah, also has the potential to carry flows from the Tweed River in north-westerly direction towards the Rous River.

Tweed Valley Way is the main roadway for the area and links Murwillumbah with the Pacific Motorway to the east and south-east. A railway line also extends through South Murwillumbah but is no longer in use.

The South Murwillumbah study area occupies an area of approximately 4 km^2 and incorporates the following land uses:

- Business/commercial area centred around Prospero Street. Commercial properties also front most of Tweed Valley Way extending north-west from Alma Street towards Condong Creek;
- Residential area extending south from Stafford Street. Residential properties also adjoin Railway Street on the eastern side of the railway line; and
- Industrial area located to the south of Tweed Valley Way and Quarry Road/Reserve Creek Road. An industrial subdivision known as “Industry Central” is also located on elevated land off Wardrop Valley Road.

In addition to the above land uses, low lying areas adjoining the “built up” sections of South Murwillumbah are also used for growing sugar cane. A school, aged care facility, caravan park and airfield are also located within the study area.

2.2.2 Major Hydraulic Controls

A number of natural and man-made topographic features and hydraulic controls influence the movement of floodwaters in the vicinity of South Murwillumbah. These include (refer to **Figure 2**).

- South Murwillumbah Levee: The levee extends from higher ground near Smith Street and extends along the river bank and ties into higher ground near the western end of Prospero Street. The crest of the levee varies between 4.8 mAHD and 5.25 mAHD and is considered to afford protection during events no larger than the 20% AEP event (BMT WBM, 2014). Further details of the South Murwillumbah Levee are provided in Section 2.5.1.
- Commercial Road and East Murwillumbah Levees: Commercial Road and East Murwillumbah Levees are located on the opposite bank of the river to South Murwillumbah and affords protection from inundation for the main township. The levees are located at an elevation of between 5.2 mAHD and 7.3 mAHD. Accordingly, the crest of the Commercial Road and East Murwillumbah levees are more elevated relative to the South Murwillumbah levee and afford protection during events up to approximately the 1% AEP flood (Catchment Simulation Solutions, 2018).
- Quarry Road Levee: Provides protection to a part section of the industrial area located west of Quarry Road. The levee crest is generally located above 4.8 mAHD. Further details of the Quarry Road levee are provided in Section 2.5.2.
- Tweed Valley Way: Is the main transportation link between Murwillumbah and the Pacific Motorway. The elevation of the roadway varies, but it is generally elevated above the adjoining floodplain. As a result, it can serve to impede the path of flows from the Tweed River. Flow can pass beneath the roadway at Blacks Drain (culvert protected by floodgates) and Condong Creek (bridge).
- Railway Line: The railway line is currently disused but previously formed part of a railway branch stretching between Casino and Murwillumbah. Much of the track is still intact and the embankment is typically elevated above the adjoining floodplain (most notably, near the residential areas of South Murwillumbah). As a result, it affords an impediment to flow from the Tweed River. Water can pass through the embankment at the Blacks Drain culvert as well as a viaduct located near Colin Street. The former bridge crossing at Condong Creek has been removed.
- Condong Creek Flood Gate (Gate 17L): Areas adjoining Condong Creek (e.g., Quarry Road and Reserve Creek Road properties) are protected by a gated flood barrier located approximately 120 metres (m) upstream of Tweed Valley Way. The top of the barrier is located at approximately 4.1 mAHD. Flow can pass through the barrier during non-flood times via eight 2.56 m wide x 1.85 m high box culverts with flood gates on their downstream faces (refer to **Plate 1**).

2.2.3 Flood History

Flooding across South Murwillumbah has been experienced on a number of occasions in the past. A selection of photos from past floods are included in **Appendix B**.

Plate 1 Flood Gate 17L (Condong Creek)

The most notable floods on record are included below. Only those floods that produced a peak flood level in excess of 5.0 m at the Murwillumbah Bridge gauge are included in this list (the peak flood elevations at the bridge are also included in parenthesis, where available, to give an indication of the relative magnitude of each flood) (BMT WBM, 2009).

- January 1887 (reported to be the largest flood on record at that time, although stream gauges were not established)
- February 1893 (said to be larger than the 1887 flood but, again, no gauge information is available to confirm)
- July 1921 (5.85 m)
- February 1931 (5.75 m)
- June 1945 (5.5m)
- February 1954 (6.07 m)
- March 1955 (5.11 m)
- February 1956 (5.82 m)
- May 1963 (5.21 m)
- June 1967 (5.01 m)
- January 1974 (5.42 m)
- March 1974 (5.9 m)
- February 1976 (5.01 m)

- March 1978 (5.2 m)
- May 1987 (5.26 m)
- April 1989 (5.6 m)
- March 2017 (6.35 m)

The peak flood levels listed above indicate that the March 2017 flood is the largest on record followed by the February 1954 flood. Floods in the late 1800s were also significant. However, the lack of stream gauges established at the time make it difficult to confirm how they rank compared to more recent floods.

The dates listed above also shows that major flooding within the Tweed River catchment most commonly occurs within the first quarter of the year. This is most commonly associated with tropical cyclones that originate in the warmer waters off the east coast of Australia. The two largest floods on record (i.e., 2017 and 1954) were a result of tropical cyclones.

Tweed Shire Council has also surveyed flood marks following past floods. A selection of surveyed flood marks is included on **Figure 3** and show the peak flood level reached by specific floods at various locations in the vicinity of South Murwillumbah.

2.3 Previous Reports

A summary of flood-related reports that have previously been prepared are provided in the following sections. It summarises the current understanding of flood behaviour in the vicinity of South Murwillumbah. The reports are listed in chronologic order.

2.3.1 Report of the Tweed River Valley Flood Mitigation Committee (1957)

The 'Report of the Tweed River Valley Flood Mitigation Committee' was prepared by the Tweed River Flood Mitigation Committee to determine if "…it is practicable to provide effective relief against damage and losses by floods in the Tweed River Valley and, if so, the nature of works required and the probable cost".

The report notes that:

- The largest flood on record at that point in time was the February 1954. This event remained the *'record flood'* until the March 2017 event;
- Most floods occur in the months of January to March;
- Soundings completed in 1883 and 1951 indicate that the river channel in the vicinity of Murwillumbah has deepened rather than shoaled over that period.
- South Murwillumbah is flooded approximately once every 1.5 years.
- The February 1954 flood breached the railway embankment. The breached area was subsequently replaced by a viaduct which is still in place today.
- Flood damage costs during the 1954 flood were estimated to be about £700,000;

The report investigated a number of options for reducing the flood risk throughout the Tweed River Valley. Those options that targeted flooding in the vicinity of South Murwillumbah that were recommended for implementation included:

- Construction of a higher levee (this was expected to reduce inundation from once every 1.5 years to one every 3 years;
- Improvements to the local drainage system;
- Removal of rock outcrop referred to as 'The Bluff' located downstream of the Murwillumbah bridge;
- Dredging of the river channel was generally not recommended. However, the report notes that dredging in the vicinity of Murwillumbah may be beneficial;
- Raising existing floor levels;
- Further development on low-lying ground should be restricted;
- Early and accurate flood warnings;
- Education to promote residents and business owners to elevate stock/belongings prior to a flood arriving.

The following options were found not to be feasible:

- Bypass floodway through South Murwillumbah from the Tweed River to the South Murwillumbah Basin (very high cost and relatively low hydraulic benefits).
- Flood storage dams (very high cost).

Although this study has since been superseded by subsequent studies, it highlights the evolution of some of the first flood mitigation options in the vicinity of South Murwillumbah as well as the broader Tweed River Valley.

2.3.2 Murwillumbah Flooding Investigation (1981, 1982, 1986 & 1990)

The 'Murwillumbah Flooding Investigation' (referred to as the 'Stage I' study) was prepared by Oceanics Australia for Tweed Shire Council. The primary goal of the study was to investigate existing (at that time) flood behaviour in and around Murwillumbah and evaluate options for mitigating the flood risk across Murwillumbah and South Murwillumbah. The study was completed using the 1-dimensional ESTRY hydraulic software.

Four flood mitigation options were evaluated as part of the Stage I study to reduce the severity of flooding in the vicinity of Murwillumbah. This included:

- <u>Removal of South Murwillumbah levee</u>: Removal of South Murwillumbah levee was determined to produce only minor reductions in flood levels along the river and through the town (~0.05 m).
- <u>Flood diversion channel through the cutting into Blacks Drain</u>: Three different floodway sizes were assessed, with each option producing significant flood level reductions through the town (i.e., >0.3 m in all cases). However, the size of the opening is restricted by existing buildings on either side of the cutting and increases in flood level were predicted across the South Murwillumbah basin.
- <u>Raising Murwillumbah town levees</u>: This option afforded a greater level of protection for the town. However, it was also predicted to generate increases in water levels (0.05-0.10 m) upstream of the town as well as through South Murwillumbah.

- Raising Murwillumbah town levees and South Murwillumbah levees: This option would block the existing flow path through the Colin Street railway viaduct generating significant increases in water levels within the river (i.e., 0.5 m).

The 'Murwillumbah Flooding Investigation Stage II' report was subsequently prepared by Oceanics Australia in 1982. It aimed to provide a more detailed assessment of the town levee raising and Blacks Drain diversion options that were originally assessed as part of the 1981 study. This determined that increasing the available flow width of the Blacks Drain diversion from the existing 27 m to 140 m would reduce the average return period of levee overtopping by only 50%. More significant improvements in the frequency of overtopping would be afforded by undertaking the diversion in conjunction with increasing the height of the town levee to above the 1% AEP flood level.

The 'Murwillumbah Flooding Investigation Stage III' report was prepared by Oceanics Australia in 1986 and focused on flood behaviour and the impact of potential flood mitigation options across South Murwillumbah. The study determined that almost all South Murwillumbah would be inundated during the 1% AEP flood, with water depths exceeding 2 m across most of the area between the river and Tweed Valley way and north of Smith Street. Peak flow velocities across Alma Street were predicted to exceed 2.5 m/s.

The primary mitigation option that was investigated as part of the Stage III report was raising of the main town levee (as investigated in the Stage I and II studies). However, multiple different floodway/flow path options were also investigated to offset the predicted flood level increases in the river associated with the levee raising. This determined that an excavated channel from the river channel to the Colin St railway viaduct would suitably reduce the elevated water levels in the river. However, hydraulic analysis of this channel indicated very high velocities were predicted in the channel itself as well as through parts of South Murwillumbah. It would also reduce the level of protection afforded by the existing levee system. Therefore, additional floodway options were investigated involving no excavation, but with clearing of flow obstructions. This showed only minor changes in flood level across South Murwillumbah and an increase in flood levels across the South Murwillumbah basin/Condong Creek area.

The 'Murwillumbah Flooding Investigation Stage IV' report was prepared by Oceanics Australia in 1990 and further expanded on the Stage I to III investigations. The study used the same ESTRY hydraulic model as the previous investigations but took advantage of updated hydrologic information developed for the 'Murwillumbah Floodplain Risk Management Plan' (NSW Public Works Department, 1989) (discussed in more detail below), which included revised information from the 1987 version of 'Australian Rainfall & Runoff' (Engineers Australia).

The Stage IV investigation quantified the flood impacts associated with three different levee options in the vicinity of Murwillumbah. This included:

- Raising the main town levee to above the 1% AEP flood level: This option would afford protection for the main township during Tweed River floods up to and including the 1% AEP events (although local stormwater inundation could still occur behind the levee). This option was predicted to increase peak 1% AEP flood levels by up to 0.22 m (in the vicinity of Bray Park), although increases in the vicinity of South Murwillumbah were typically about 0.08 m. This option has since been implemented;

- Raising the South Murwillumbah levee to exclude floods prior to Alma Street being overtopped: This option was predicted to afford a slightly higher level of protection for South Murwillumbah and would result in only relatively minor increases in flood levels along the Tweed River during smaller floods (i.e., 0.03 m). However, the levee would be "drowned out" during larger Tweed River floods. This option has since been implemented.
- Construction of a levee adjacent to Commercial Road to prevent floodwaters from entering Bray Park during minor events: This option was investigated to offset the predicted flood level increases associated with elevating the main town levee (as described above). This option was predicted to cause minor increases in flood levels during small Tweed River floods (i.e., 0.02 m). During large Tweed River floods, the levee would be "drowned out" resulting in negligible flood impacts along the Tweed River.

2.3.3 Murwillumbah Floodplain Management Plan (1989)

The 'Murwillumbah Floodplain Risk Management Plan' was prepared by the Tweed River Flood Mitigation Committee with assistance from the NSW Public Works Department.

The Plan recommended that the South Murwillumbah levee be raised by 600 mm to afford protection during events up to and including the 20% AEP event. The raising of the South Murwillumbah levee has since been completed.

The Plan also recommended voluntary purchase of high risk properties in River Street between Greville and Collin Street. Most of these properties have since been purchased and Council continues to explore opportunities to purchase the final four properties in the near future.

Voluntary house raising was also recommended for properties located upstream of Colin Street. Again, most of the eligible properties have since been raised.

Other options that were investigated but were not found to be feasible include:

- River Improvements: Looked at removing the rock outcrop located downstream of the Murwillumbah bridge. However, this was found to afford negligible hydraulic benefits so was not pursued.
- Flood Bypass Channel: looked at constructing flood bypass channels near Colin Street and Colin/Alma Street as well as enlarging Blacks drain. Each floodway option produced reductions in flood level along the main river channel. However, they also increased flood levels in the South Murwillumbah basin impacting on >40 properties. The high cost of property acquisitions also hampered the financial feasibility of the Colin Street and Colin/Alma Street options.

The implementation of the raised levee as well as the voluntary house raising and purchase schemes that were recommended in the Plan has reduced the flood exposure for South Murwillumbah. However, the report notes that protection during floods up to and including the 1% AEP event cannot be provided for South Murwillumbah (e.g., by elevating the levee further) as it would generate unacceptable flood impacts across the main township of Murwillumbah. Accordingly, a significant flood risk remains.

2.3.4 Tweed Valley Flood Study (2005)

In 2005, the first edition of the 'Tweed Valley Flood Study' was prepared by BMT WBM Pty Ltd for Tweed Shire Council. The Flood Study was undertaken to define flood behaviour across the lower Tweed River floodplain. This included the floodplain of the Tweed River downstream of Byangum, the Rous River downstream from Boat Harbour, and the lower reaches of the Broadwater tributaries and covered approximately 230 km^2 of the Tweed River catchment. South Murwillumbah formed part of this study area.

Hydrology was defined as part of the study using a RORB model developed as part of the 'Murwillumbah Floodplain Risk Management Plan' (1989). However, a new hydraulic model of the lower Tweed River valley was developed using the TUFLOW software. Flows across the floodplain and in the wider, lower reaches of the Tweed River were modelled in 2D based on a 40 m x 40 m grid size. Hydraulic flows through large culverts and bridges were also modelled in 2D and included the effects of bridge decks and submerged culvert flow. The narrower reaches of watercourses and smaller hydraulic structures such as pipes, were embedded as 1D elements dynamically linked to the 2D domain.

Calibration of the hydrologic model and hydraulic model was completed based on recorded flows and flood level information for the March 1974 flood. The models were also verified against recorded data for the March 1978 and April 1989 floods. In general, the models were found to provide a reasonable reproduction of the historic flood information.

The calibrated models were used to simulate the 20% AEP, 5% AEP, 1% AEP and 0.2% AEP design floods, as well as an 'extreme' flood and PMF flood. The study determined the critical storm duration for the Tweed River at Murwillumbah to be 36 hours.

Key findings from the study regarding flood behaviour in the vicinity of South Murwillumbah includes:

- South Murwillumbah is impacted by flooding in events as frequent as the 20% AEP event;
- South Murwillumbah is predicted to be completely inundated during a 1% AEP flood with depths of up to 5 m;
- The airfield acts as a major flow path during floods;

It is noted that the relatively large grid size (i.e., 40 m) employed in the hydraulic modelling means that a detailed understanding of the local movement of floodwaters in the vicinity of South Murwillumbah is not provided by the TUFLOW model and a more detailed model is necessary to reliably reflect the movement of water along roadways and around buildings. Nevertheless, the information contained in the TUFLOW model developed for the flood study served as a suitable basis for the development of a new and more detailed TUFLOW model for the 'Murwillumbah CBD Levee and Drainage Study' (2018) (discussed in Section 2.3.7).

2.3.5 Tweed Valley Flood Study Update, Climate Change (2009)

BMT WBM Pty Ltd also prepared an updated flood study in 2009 for the Tweed Valley that built upon the 2005 flood study (referred to as the '*Tweed Valley Flood Study (2009 Update)*'. This report included revised design flood information as well as the outcomes of additional climate change investigations. Both the hydrologic and hydraulic models were updated as part of this study to take advantage of improvements in modelling technology and new datasets in the intervening four-year period.

More specifically, the 2009 update included the development of a new WBNM hydrologic model to define the hydrology across the catchment under existing conditions. This TUFLOW model was also updated to incorporate a Digital Terrain Model (DTM) developed from aerial laser survey data that was gathered for the Tweed River floodplain in 2007.

The updated models were used to re-simulate each of the 'base' design floods. Two climate change scenarios were also selected for assessment based on the 1% AEP flood:

- Medium level climate change impacts: A 20% increase in rainfall intensity and a 55 cm increase in sea level; and
- High level climate change impacts: A 30% increase in rainfall intensity and a 91 cm increase in sea level.

The results of the climate change simulations were compared against the 'existing' 1% AEP design flood levels. For the high impact climate change scenario, it was determined that design 1% AEP flood levels would be:

- 0.5 to 1 m higher along the Tweed River from Murwillumbah to the river mouth;
- More than 2.5 m higher in the vicinity of Murwillumbah;
- 1 to 1.5 m higher along the Tweed River from Byangum to Murwillumbah.

The report explained that the higher flood levels around Murwillumbah were the result of a natural constriction in the floodplain at Murwillumbah formed by the Reservoir Hill to the north and the ridgelines following Tweed Valley Way and Wardrop Valley Road heading south. In addition, flow in the Tweed River is further constrained in Murwillumbah by levees on both river banks. Therefore, the effect of the increase in rainfall intensity on 1% AEP flood levels is more pronounced around and immediately upstream of Murwillumbah.

Subsequent to these initial climate change simulations being completed, an additional 1% AEP climate change simulation was completed based upon a 10% increase in rainfall and a 91 cm increase in ocean level. This was referred to as the "adopted" climate change scenario.

2.3.6 Tweed Valley Floodplain Risk Management Study (2014)

The 'Tweed Valley Floodplain Risk Management Study' was prepared by BMT WBM Pty Ltd for Tweed Shire Council. It assesses the existing and future flood risk to people and property across the Tweed River floodplain. The study also makes recommendations for a range of flood, response and property modification measures to reduce the community's flood risk exposure. These measures were evaluated based on consideration of social, ecological and economic factors, as well as hydraulic behaviour. The information from this document was subsequently used to inform the 'Tweed Valley Floodplain Risk Management Plan' (WBM BMT, 2014).

The flood risk within the Tweed Valley was assessed based on the WBNM and TUFLOW models developed for the 'Tweed Valley Flood Study (2009 Update)'. Across the Tweed River floodplain, the study estimated that 41,500 people are potentially located within flood prone land and the Average Annual Damage (AAD) estimate was $22.5 million.

The study determined that there are a number of significant flooding and drainage issues in the vicinity of South Murwillumbah, most notably:

- The South Murwillumbah levee is overtopped under existing conditions during the 20% AEP flood.
- The majority of land within South Murwillumbah is considered flood storage
- Most of South Murwillumbah is subject to high depth hazard (i.e. depths exceeding 1 m across most of the area) in a 1% AEP flood.
- As Murwillumbah is located mid-catchment, there is less time to predict and prepare for flooding before the peak of the flood hits relative to the lower catchment areas.
- There are no identified evacuation centres in South Murwillumbah and the evacuation routes to the main township are cut before warnings can be issued in a PMF event.

The following measures were recommended and included within the Floodplain Risk Management Plan for South Murwillumbah:

- Preserve South Murwillumbah Condong Flowpath, particularly Lot 4 DP 591604 Quarry Road. There are three potential options associated with the measure:
  - Introduce specific planning controls for the lot;
  - Acquire and lower the lot
  - Acquire and lower the lot with a new hydraulic structure at Quarry Road.

    It is our understanding that Lot 4 DP 591604 has been subsequently acquired by Council. However, no topographic modifications have been completed across the site.
- Establish a new voluntary house purchase scheme, which included two options:
  - High hazard and depths greater than 2.5 m - would include 23 properties within South Murwillumbah.
  - High hazard and depths greater than 3 m - has a greater benefit cost ratio and would include 4 houses within South Murwillumbah.
- Establish a new voluntary house raising scheme. This includes the following options:
  - Above floor flooding but not eligible for voluntary house purchase in prior scheme (i.e. High hazard and depths greater than 2.5 m) - 1 property; and,
  - Above floor flooding but not eligible for voluntary house purchase in prior scheme (i.e. High hazard and depths greater than 3 m) - 6 properties in South Murwillumbah.
- Further development in South Murwillumbah and the industrial area was not supported due to the high hazard and potential impacts of filling flood storage areas.

- Preservation of the river front precinct as a continuous river front park.
- Any future development would need to be supported by detailed consideration of the hydraulic constraints and evacuation risk.
- Additional measures not specifically related to South Murwillumbah including response modification measures such as improved flood education, emergency planning, development planning as well as specific detailed evacuation plans.

Options that were considered but not recommended as part of the study include:

- A bypass floodway through South Murwillumbah – Condong Flowpath (Blacks Drain to the airfield), this would have beneficial impacts for the main town, however this would lead to higher flood levels in the South Murwillumbah basin and was considered to be a non-viable option.
- A number of catchment scale flood modifications such as dams and floodways were considered but none were identified as both effective and feasible.
- Other engineering options such as dredging, additional levees, development of a new river mouth were also revisited but found not to be viable.

2.3.7 Murwillumbah CBD Levee & Drainage Study (2018)

The 'Murwillumbah CBD Levee & Drainage Study' was prepared by Catchment Simulation Solutions for Tweed Shire Council. The study was commissioned after the 'Tweed Valley Floodplain Risk Management Plan' (WBM BMT, 2014) recommended that a detailed local drainage and levee overtopping study be commissioned for Murwillumbah. The study focussed on the main township of Murwillumbah (i.e., South Murwillumbah was not included as part of this study). In addition to providing an improved understanding of local flood and drainage behaviour across Murwillumbah, the study also outlines a range of options that could be potentially implemented to better manage the flood risk.

The study was completed using the same WBNM hydrologic model that was developed for the 'Tweed Valley Flood Study (2009 Update)' (BMT WBM, 2009). A new TUFLOW model was developed as part of the study based upon the TUFLOW model used for the 'Tweed Valley Flood Study (2009 Update)'. However, the model extent was reduced to only cover the area immediately surrounding Murwillumbah to allow a more detailed 5 m grid size to be adopted and a full representation of the local stormwater drainage system to be included. The "truncated" model extends along the Tweed River from Bray Park to Condong.

The models were used to re-evaluate the existing flooding and drainage problems across the Murwillumbah CBD with a particular emphasis on defining the flood risk associated with levee overtopping. This determined that inundation for the area contained behind the CBD levee system (comprising three separate levees) can occur in events are frequent as the 20% AEP event because of local stormwater runoff. However, overtopping of the Commercial Road and East Murwillumbah levees typically does not occur until roughly the 1% AEP event. The Dorothy Street levee is predicted to overtop during the 0.2% AEP event.

The models were also used to evaluate the potential hydraulic benefits of a range of structural flood risk mitigation measures. This included upgrades to existing levees, pumps and stormwater pits/pipes as well as installation of additional stormwater infrastructure and pump systems. A range of non-structural options were also evaluated. The following options were ultimately recommended for implementation/further investigation:

- Remediation of Commercial Road levee;
- Installation of new pump system behind the Dorothy Street levee;
- Temporary flood barriers for commercial properties;
- Modifications to existing planning documents;
- Local flood plan updates;
- Flood warning system upgrades; and,
- Community education.

Each of the recommended options were reviewed to ensure that it did not adversely impact on flood behaviour across other areas (this included South Murwillumbah). This confirmed that each of the recommended option across the Murwillumbah CBD would not produce a significant adverse impact on flood behaviour across other areas.

Overall, the WBNM and TUFLOW models used as part of the study are considered to represent the best available tools for defining design flood behaviour in the vicinity of Murwillumbah. Therefore, they are considered appropriate to adopt for the current study. However, some modifications to the model were considered necessary to ensure that the best possible representation of flood behaviour was being provided across the full study area. Further information on the updates that were completed to the TUFLOW model are provided in **Appendix C**.

2.3.8 Condong Creek Drainage Management Plan (Draft, 2018)

The draft 'Condong Creek Drainage Management Plan' was prepared by Australian Wetlands Consulting Pty Ltd for Tweed Shire Council. Condong Creek drains most of the industrial area of South Murwillumbah as well as the adjoining sugar cane fields (refer to **Figure 1**).

The goals of the drainage management plan were to:

- Highlight areas of the creek requiring improvements to bank stability;
- Develop a strategy to provide adequate access for creek maintenance;
- Assess and manage Acid Sulphate Soils; and,
- Provide a revegetation and maintenance plan for the creek banks.

The report recommended the follow stages of work be completed to achieve the stated goals:

- Stage 1: Provision of a maintenance access track, revegetation and batter stabilisation;
- Stage 2a: Undertake hydraulic and business case investigation to support channel widening and re-profiling; and,
- Stage 2b: Re-profile the channel to increase hydraulic capacity from the Condong Creek weir (i.e., flood gates) upstream to the airfield and Quarry Road Bridge.

Design plans for Stage 1 and Stage 2b of the proposed works were provided by Council but are yet to be implemented. It is also noted that Stage 2b of the project is subject to the outcomes of Stage 2a

Although the proposed works are yet to be implemented, it was considered important to gain an understanding of the potential for the works to impact on flood behaviour across South Murwillumbah in addition to the potential benefits of channel widening. Further discussion on the impacts of the Condong Creek modifications is provided in Section 5.6.1.

2.4 Topographic Information

2.4.1 LiDAR

LiDAR data was collected across the Tweed River Valley in March and April 2013 by the NSW Government's Land and Property Information Department. This included the full extent of the South Murwillumbah study area. The LiDAR has a stated absolute horizontal accuracy of better than 0.8 m and an absolute vertical accuracy of better than 0.3 m and provides a stated minimum point density of one laser pulse per square metre. Accordingly, it is considered to provide a reliable description of the variation in terrain across the study area.

2.4.2 Hydrographic Survey

Hydrographic survey of the Tweed River channel was completed by the Office of Environment & Heritage between the 7th and 10th of August 2018. The hydrographic survey provided cross-sections of the Tweed River at 25 to 50 m intervals. The survey extends from Barneys Point along the Tweed River upstream to Bray Park and included the lower section of the Rous River (extending approximately 1.5 km upstream from the Tweed River confluence).

2.4.3 Digital Elevation Model

The LiDAR and hydrographic survey were combined to develop a Digital Elevation Model (DEM) of South Murwillumbah and the surrounding area. The DEM is shown in **Figure 4**.

Figure 4 shows that the terrain across the residential and commercial areas of South Murwillumbah (i.e., those areas typically contained between the Tweed River and the railway line) comprise a number of topographic "bands" (troughs and ridges running in a north-south orientation). In general, the elevated bands/ridges are located above 4.5 mAHD and coincide with where most residential and commercial buildings are located. The lower lying sections of land are typically located below 1.5 mAHD and most often coincide with areas of open space or front/back yards. The highest sections of land in this area are located south of River Street and are typically located above 9 mAHD (with the exception of Blacks Drain).

The Greenhills Caravan Park, which is located south of Blacks Drain and between Tweed Valley Way and the railway line, is generally located at about 3.2 mAHD.

The elevations across the industrial sections of South Murwillumbah (located to the south of Tweed Valley Way and south-west of Quarry Road/Reserve Creek Road) vary considerably. With the exception of roadways adjoining Tweed Valley Way, most of the roadways in the area are located below 4 mAHD. The elevations across the industrial lots are located anywhere from 2.5 mAHD to over 5 mAHD. In general, the pre-European ground surface elevations across this area were likely well below 3 mAHD. Therefore, the industrial area has largely been established through the introduction of imported fill.

The sugar cane fields located in the vicinity of South Murwillumbah are typically located on land below 3 mAHD and, in most cases, below 2 mAHD. The cane fields are also serviced by a network of drainage channels that are designed to collect excess runoff and carry that runoff into the Tweed River. The drainage channels are generally trapezoidal in shape and no greater than 5 m in width. The majority of the drainage channels in the area drain into either Condong Creek or Blacks Drain. Both Condong Creek and Blacks Drain are fitted with flood gates that prevent water from "backing up" along the drainage channels and inundating the sugar cane fields during small Tweed River floods. The location of the floodgates is shown in **Figure 2**.

Tweed Valley Way as well as the railway line form notable man-made embankments that are typically elevated above the adjoining topography. Tweed Valley Way is generally located above 5 mAHD, although drops down to 4.2 mAHD near Colin Street. The top of the railway embankment is typically located around 5.5 mAHD in the vicinity of the residential area of South Murwillumbah but drops in elevation as it approaches the industrial areas. Through the industrial areas, the railway is typically located below 4.5 mAHD, although it rises up above 5 mAHD as it approaches Condong Creek.

2.5 Levee Information

2.5.1 South Murwillumbah Levee

South Murwillumbah is protected by a low-level levee that extends along the eastern bank of the Tweed River. The alignment of the levee is shown in **Figure 2**.

The levee comprises a grass-lined earthen embankment along its full length with some sections of rock protection at the toe. The levee extends from higher ground near Smith Street and extends along the river bank and ties into higher ground near the western end of Prospero Street. The northern end of River Street as well as Alma Street (between the bridge and Tweed Valley Way) also forms part of the levee system protecting South Murwillumbah. Anecdotal evidence suggests that overtopping of the South Murwillumbah levee system first occurs across Alma Street.

The crest of the earthen section of the levee varies between 4.8 mAHD near Prospero Street and 5.25 mAHD near Smith Street. The low point in Alma Street is located at an elevation of about 4.4 mAHD. As noted in Section 2.3.6, previous modelling indicates that the levee would be overtopped in events as frequent as the 20% AEP flood.

2.5.2 Quarry Road Levee

A part section of the South Murwillumbah industrial area located west of Quarry Road is protected by a levee. The alignment of the levee is shown in **Figure 2**.

The levee is a grass lined earthen embankment and extends in a northerly direction from elevated ground near Airfield Avenue along the eastern edge of the Murwillumbah Airfield. The levee then "turns" east near Condong Creek and meets up with the higher ground formed by Quarry Road before continuing east along the southern edge of Condong Creek for an additional 350 m where it joins higher ground.

The elevation of the levee crest varies along its length:

- Near Airfield Avenue: approximately 4.5 mAHD (although adjoining terrain is typically located >5 mAHD)
- Between Airfield and Quarry Road: 4.8 and 5.1 mAHD
- East of Quarry Road: 5.1 to 5.3 mAHD

It is noted that the ground surface elevations near Airfield Avenue are generally no greater than 4.7 mAHD. Accordingly, the southern end of the levee affords a lower level of protection relative to the northern end of the levee and is the likely location where overtopping would first occur.

2.6 Local Environment

2.6.1 Vegetation

South Murwillumbah has been largely cleared of native vegetation since European settlement. Nevertheless, there are isolated vegetation communities (largely introduced species) scattered across the study area, which are shown in **Figure 5**. The vegetation types include eucalyptus, paperbark, sclerophyll and melaleuca.

2.6.2 Acid Sulphate Soils

The Office of Environment and Heritage has mapped the occurrence of Acid Sulphate Soils (ASS) along the coast of NSW, including the area around Murwillumbah. The acid sulphate soil mapping is provided is provided in **Figure 5**.

When exposed to oxygen, ASS oxidise and sulphuric acid is released, reducing soil fertility, killing vegetation and reducing fish population. Therefore, the presence of ASS can impact on the feasibility of structural flood mitigation works where excavation is required.

The ASS mapping is grouped into one of five classes ranging from Class 1 (ASS likely to be found at or immediately below ground level) to Class 5 (ASS not typically found). The ASS mapping in **Figure 5** indicates a large variation in ASS soil potential across the area. This includes:

- <u>Tweed River channel</u>: ASS at or immediately below ground surface (ASS Class 1);
- <u>Industrial areas of South Murwillumbah and cane growing areas</u>: ASS likely to be found >1 m below ground surface (ASS Class 3)
- Lower lying residential and commercial areas of South Murwillumbah and areas adjoining Tweed Valley Way: ASS likely to be found >2 m below ground surface (ASS Class 4)

Accordingly, ASS are not likely to be a problem across most sections of South Murwillumbah assuming that significant excavation depths are not required.

2.6.3 Heritage

Two sites within the South Murwillumbah study area are currently protected through heritage listing under the Tweed Local Environmental Plan 2014. The location of the heritage items is shown in **Figure 5** as grey polygons and includes:

- Murwillumbah Railway Station and Yard Group (State significance)
- Remains of the Condong Sugar Mill Rail Line (Local significance)

One Aboriginal heritage site also falls within the study area (Greenhills Tweed ACH Artefact). The location of the Aboriginal heritage site is also shown in **Figure 5**.

2.7 Demographics

Having an understanding of the characteristics of the population living and working within the catchment is an important component of developing and assessing potential flood risk management measures. For example, the availability of internet, the primary language spoken at home and the availability of a motor vehicle can have a strong bearing on the feasibility of different education, flood warning and evacuation strategies.

In this regard, the Australian Bureau of Statistics (ABS) provides a range of information for the various communities that are contained within the study area that was collected as part of the 2016 census. A summary of pertinent information extracted from the ABS website (http://www.abs.gov.au/) is provided in **Table 2.**

The information presented in **Table 2** shows that:

- Just over 1,100 people reside in and around South Murwillumbah (this includes adjoining farm land and villages such as Kielvale).
- Approximately 39% of the population would be considered more vulnerable to the impacts of flooding (i.e., people under the age of 15 or over the age of 65). The median age of residents within the area is 47.
- English is the only language spoken at home in 89% of households.
- 80% of households have an internet connection.
- Most households have access to at least one car (94%)

2.8 Community Consultation

2.8.1 Stage 1 Consultation

A community questionnaire was prepared and distributed to approximately 800 residential and business properties within the study area during the early stages of the project. A copy of the questionnaire is included in **Appendix A**.

The questionnaire sought information from the community regarding whether they had experienced flooding, their level of flood awareness and how they would respond in a future major flood. A total of 93 questionnaire responses were received and a summary of all questionnaire responses is provided in **Appendix A** in **Tables A1** to **A3**.

Table 2 Summary of Demographics for South Murwillumbah

Statistic				Numbers
Population Statistics	Total Population			1,114
	Age	Median Age		47
		<15 years of age		187
		>65 years of age		251
	Education	Year 12 or equivalent		256
		Year 10 or equivalent		323
		Did not Complete Year 10		151
Dwelling Statistics	Motor Vehicles	Dwellings with no vehicles		21
		Dwellings with ≥ 1 vehicle		351
		Average persons per dwelling		2.4
		Number of unpaid volunteers		158
	Language spoken at home	Speaks English only		982 (89%)
		Other	French	6 (0.5%)
			Punjabi	6 (0.5%)
			Tagalog	4 (0.4%)
			Nepali	3 (0.3%)
	Home Ownership	Rented		128 (32%)
		Home owned outright		121 (30%)
		Home owned with mortgage		133 (33%)
	Dwelling Type	Separate house		346
		Semi-detached, row or terrace house, townhouse		0
		Flat, unit or apartment:		23
		Other dwelling (cabin, caravan):		29
Income		Median total household income ($/weekly)		$1,042
		Median Rent ($/weekly)		$320
Internet Statistics		No Internet connection		68 (17%)
		Access to Internet connection		318 (80%)
		Not Stated		14 (3%)

Most of the responses included addresses enabling spatial interpretation of the questionnaire responses. **Figure A1** in **Appendix A** shows the spatial distribution of reported flood impacts (the 2017 flood extent is also superimposed as the flood that most respondents reported on). **Figure A2** in **Appendix A** shows the spatial distribution of how people will respond during future floods (the PMF extent is superimposed to gain an initial understanding of the suitability of the flood response across different sections of the floodplain).

The responses to the questionnaire indicate that:

- 82 of the 93 respondents (88%) have experienced some form of inundation or disruption as a result of flooding (refer to **Table A1**). Most of the responses related to the 2017 flood. The location and types of flood impacts that were reported are shown in **Figure A1.**
- It was found that 43% of respondents indicated they would remain at home and only 28% indicated they would evacuate (refer to **Table A2**). 8% of the respondents said they would evacuate to an official evacuation centre while the other 20% said they would evacuate elsewhere (e.g., friend/family). 12% of the respondents were unsure of how they would respond during a future flood.
- The primary reasons for people choosing to remain at home were concern for the security of their property and feeling that their house could not be flooded. However, it was determined that two thirds of those respondents would be flooded above floor level during the PMF event and the above floor flooding depths would typically exceed 4 m. This highlights that further education is necessary to reinforce that bigger floods than those that have been experienced could occur.
- For those intending to evacuate, safety of their family was the overriding concern followed by the discomfort/inconvenience of being isolated by floodwater.

The questionnaire also sought initial feedback on potential options for better managing the flood risk. In general, most of the generic options that were suggested as part of the questionnaire were supported by the community. However, the following options were ranked highest by the community:

- SES Local Flood Plan updates
- Updates to flood warning system
- Community education
- Flood evacuation upgrades
- Updated development/planning controls
- Bypass floodways
- Dredging of river/creeks
- New/upgraded flood gates

As discussed, most of the suggested options were supported by the community. However, the following options were the least favoured by the community:

- New levees
- Raising existing levees
- Voluntary flood proofing
- Voluntary house raising

2.8.2 Stage 2 Consultation

A second questionnaire was also distributed to households and businesses once a short list of specific flood risk management measures was developed (refer Section 4.3). The questionnaire provided the community with the list of flood risk management options that were being considered as part of the study and sought feedback from the community regarding each of these options (i.e., whether they opposed or supported the option).

A total of 60 responses were received. The questionnaire responses are summarised in **Table A4** in **Appendix A** and showed that the most favoured flood risk reduction measures included:

- Raising of Alma Street;
- Raising of Tweed Valley Way;
- Providing additional openings in the railway embankment;
- Enlarging the Blacks Drain channel;
- Dredging of the Tweed River channel; and
- Upgrading/updating the flood warning system.

Although each of the flood risk management measures were broadly supported by the community, the following options were the last favoured:

- Reshaping of land to create an additional flow path from the Tweed River to the South Murwillumbah basin;
- Creating a high flow bench adjacent to Condong Creek channel;
- Lowering of Lot 4 DP 591604 Quarry Road; and
- Temporary flood barriers for commercial properties.

The feedback provided via the questionnaire formed one of the criteria that was used to evaluate each of the flood risk management measures that were considered for implementation as part of the study. The outcomes of the options evaluation are presented in Sections 5, 6 and 7.

2.8.3 Public Exhibition

The final draft 'South Murwillumbah Floodplain Risk Management Study & Plan' was placed on public exhibition at Tweed Shire Council's Murwillumbah offices from 21 August 2019 until 2 October 2019. A digital version of the final draft report was also available on Council's website as well as Council's "Your Say, Tweed" website during the exhibition period. The public exhibition provided the opportunity for the community and key stakeholders to review the final draft report and provide feedback on the report content.

A community drop-in session was also held on 12 September 2019 and allowed the community to ask questions and raise any concerns that they may have. A total of 25 people officially signed in at the workshop although there were a significant number of people that attended and did not sign in at the door.

A total of five submissions were received during the exhibition period. A summary of the submissions that were received is provided in **Appendix K**. Also included in **Appendix K** are the responses/actions that were taken to address each submission when preparing the final report.

3 Defining the Existing Flooding Problem

3.1 Overview

In order to identify and evaluate potential options for managing the flood risk, it is first important to have an understanding of the nature and extent of the existing flood risk. This is typically achieved by using the computer flood model to simulate a range of "design" floods. Design floods are hypothetical floods that are commonly used for planning and floodplain management investigations. Design floods are based on statistical analysis of rainfall and flood records and are typically defined by their probability of exceedance. This is typically expressed as an Annual Exceedance Probability (AEP). For example, a 1% AEP flood has a 1% chance in any year of being equalled or exceeded.

The TUFLOW model that was developed as part of the 'Murwillumbah CBD Levee & Drainage Study' (Catchment Simulation Solutions, 2018) was used as the basis for undertaking the design flood simulations. However, the model was updated and expanded to improve the representation of flood behaviour across South Murwillumbah. A summary of the updates that were completed to the model are provided in **Appendix C**. The updated model was also calibrated using recorded flood information for three historic floods before proceeding with the design flood simulations. The outcomes of the model calibration are also summarised in **Appendix C**.

3.2 Existing Flood Behaviour

The calibrated TUFLOW model was used to simulate design flood behaviour in the vicinity of Murwillumbah for existing topographic and development conditions for the design 20%, 5%, 1% and 0.2% AEP events. Hydrology was defined based upon the WBNM model also used as part of the 'Murwillumbah CBD Levee & Drainage Study' with the 1987 version of Australian Rainfall and Runoff (Engineers Australia).

3.2.1 Flood Frequency Analysis

A revised flood frequency analysis (FFA) was completed as part of the current study for the Murwillumbah and Tumbulgum gauges. The outcomes of this assessment are presented in **Appendix D**.

Overall, it was determined that the Log Pearson III probability distribution provided the best "fit" Peak discharges and are summarised in **Table 3** for the Murwillumbah Gauge. Peak FFA discharges that were determined as part of the FFA completed for the *'Tweed Valley Flood Study'* (BMT WBM, 2005) are also included in **Table 3** for comparison. Peak FFA discharges for the Tumbulgum Gauge are also summarised in **Table 4** (no FFA has previously been completed for the Tumbulgum gauges, so a discharge comparison cannot be provided).

The comparison provided in **Table 3** shows that the updated FFA completed for the current study produces peak discharges that are slightly higher than the 2005 flood study for events up to and including the 5% AEP event. The peak 1% AEP discharge is slightly lower than the corresponding peak discharge calculated for the 2005 study and the peak 0.2% AEP discharge for the current study is considerably lower than that 2005 study. As noted in **Appendix D**, this is considered to be associated with censoring of the gauge data, which provides a better "fit" between the probability distribution and the recorded gauge data.

Table 3 Peak flood frequency design discharges for Murwillumbah Gauge

AEP	Peak Discharge (m^3/s)	
	2005 Flood Study	**Current Study**
20%	1,700	1,728
5%	2,430	2,683
1%	3,240	3,357
0.2%	4,070	3,739

Table 4 Peak flood frequency design discharges for Tumbulgum Gauge

AEP	Peak Discharge (m^3/s)
	Current Study
20%	1,196
5%	1,678
1%	2,238
0.2%	2,824

A comparison between the peak discharges provided in **Table 3** and **Table 4** shows that there is a notable reduction in peak discharge between Murwillumbah and Tumbulgum despite the Rous River including additional inflows to the Tweed River at Tumbulgum. This is considered to be associated with the significant storage that is afforded across the floodplain between Murwillumbah and Tumbulgum which serves to attenuate flood flows.

It should be noted that the flood frequency results do have some limitations. This includes uncertainties with the adopted rating curves. In addition, the flow estimates at the Murwillumbah gauge would fail to account for any flow that bypasses the bridge via Blacks Drain or South Murwillumbah (i.e., the FFA discharge estimates are unlikely to provide a reliable representation of the "total" flow at Murwillumbah).

3.2.2 Floodwater Depths, Levels and Velocities

Peak floodwater depths were extracted from the results of each design flood simulation and are presented in **Figures 6** to **9**. Peak flood levels and peak flow velocities were also extracted from the results of the modelling and are presented in **Figures 10** to **13** and **Figures 14** to **17** respectively. The velocity maps also include velocity vectors which illustrate the direction of movement of floodwaters.

Peak floodwater survey profiles were also extracted along the edge of the Tweed River immediately adjacent to South Murwillumbah and are provided on **Figure 18**. The profile of the South Murwillumbah levee is also included.

The flood maps and floodwater surface profiles indicate that:

- The South Murwillumbah levee is predicted to be overtopped during each of the simulated design floods. Accordingly, the levee provides less than a 20% AEP level of protection. During the 20% AEP event, the levee would be overtopped to a depth of at least 0.2 metres.
- Most of the residential area of South Murwillumbah contained between the river and Tweed Valley Way would be inundated during each of the simulated design floods. Peak water depths are predicted to exceed 1 metre during the 1% AEP flood. During the 0.2% AEP flood, peak water depths are predicted to exceed 2 metres at most locations.
- Most of the industrial sections of South Murwillumbah are predicted to be remain "dry" during the 20% AEP flood. However, inundation depths of at least 1 metre are anticipated across most of this area during the 1% AEP flood. During the 0.2% AEP flood, peak depths are predicted to exceed 2 metres at most locations.
- Peak flow velocities are predicted to vary considerably, particularly across the residential area located between the river and Tweed Valley Way. More specifically, peak flow velocities generally do not exceed 0.5 m/s in areas immediately west of Tweed Valley Way. However, areas immediately adjoining the river as well as some roadways are exposed to local velocities that are predicted to exceed 3 m/s. During the 1% AEP and 0.2% AEP floods a significant proportion of the residential and commercial sections of South Murwillumbah would be exposed to peak velocities that exceed 1 m/s.
- Peak velocities across the industrial areas are typically much lower than the residential/commercial sections of South Murwillumbah. With the exception of Condong Creek and the area around the airfield, peak velocities generally do not exceed 1 m/s during events up to and including the 1% AEP flood. However, during the 0.2% AEP event some more notable, continuous higher velocity (i.e., >1 m/s) flow paths start to develop around buildings/fill pads and down roadways (e.g., Buchanan Street). Localised high velocities are also predicted around the BP service station that fronts Tweed Valley Way.

3.2.3 Flood Hazard Categories

Flood hazard defines the potential impact that flooding will have on buildings, vehicles and people across different sections of the floodplain. More specifically, it describes the potential for floodwaters to cause damage to property and/or loss of life and injury (Australian Government, 2014).

For this study, the variation in flood hazard across Murwillumbah was defined using flood hazard vulnerability curves presented in the Australian Government's "Technical Flood Risk Management Guideline: Flood Hazard" (2014). The hazard curves are reproduced in **Plate 2**. As shown in **Plate 2**, the hazard curves assess the potential vulnerability of people, cars and structures based upon the depth and velocity of floodwaters at a particular location.

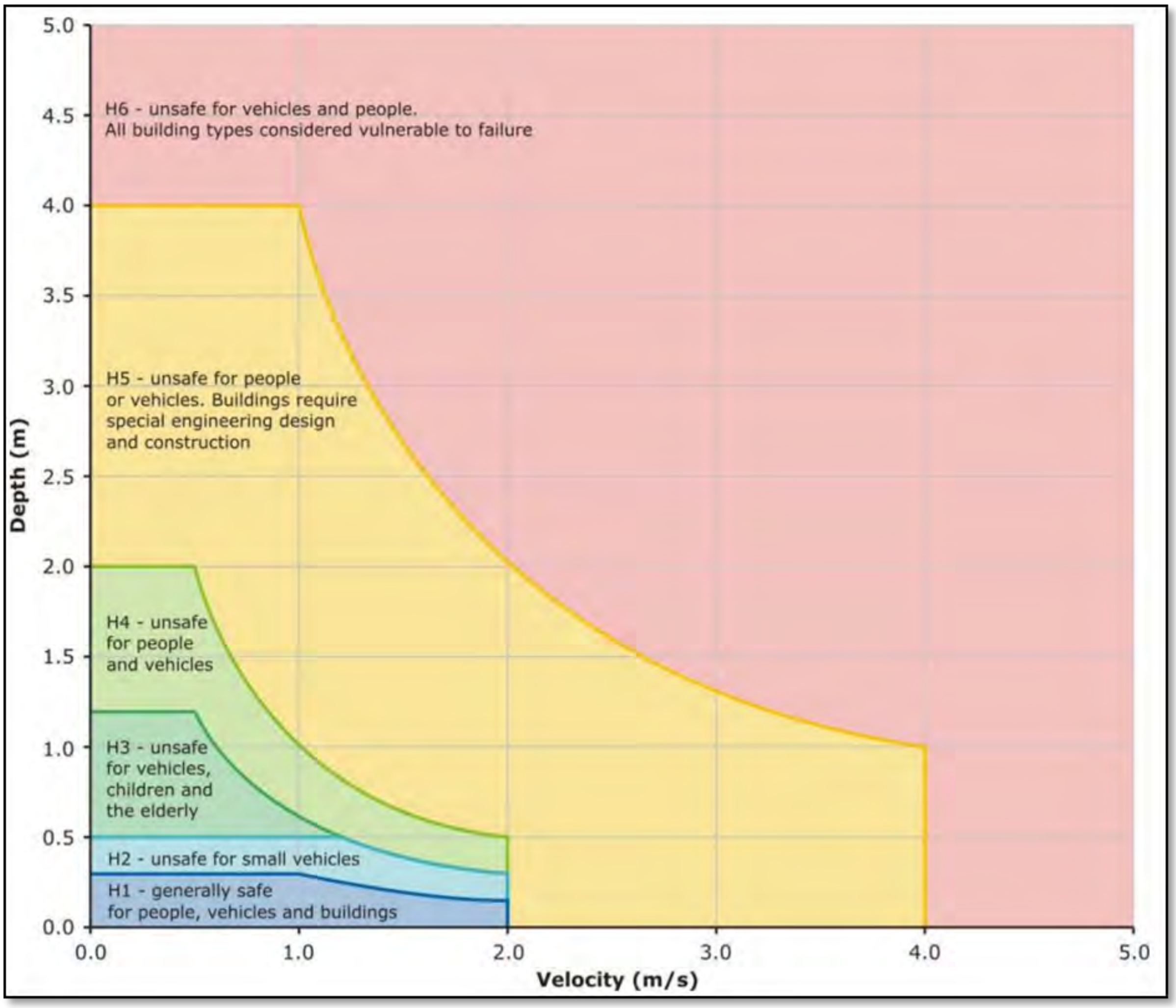


Plate 2 Flood hazard vulnerability curves (Australian Government, 2014)

Peak depth, velocity and velocity-depth product outputs generated by the TUFLOW model were used to map the variation in flood hazard across South Murwillumbah based on the hazard criteria shown in **Plate 2** for the 1% and 0.2% AEP floods. The resulting hazard category maps are shown in **Figure 19** and **Figure 20**.

Figure 19 shows that a significant proportion of the South Murwillumbah study area would be exposed to a hazard classification of at least H5, although some more elevated areas would only be subject to H3 or H4 hazard.

Figure 20 shows that if a 0.2% AEP flood was to occur most of the floodplain would fall under the H5 or H6 hazard categories. Accordingly, there is potential for structural failure of some buildings should an event of this magnitude occur.

3.2.4 Hydraulic Categories

The NSW Government's 'Floodplain Development Manual' (NSW Government, 2005) recommends subdividing flood prone areas into three separate hydraulic categories (refer to **Table 5**). The hydraulic categories provide an indication of areas that should be retained for the conveyance of floodwaters (i.e., floodways) and also highlights areas that are important for providing temporary storage volume during floods (i.e., flood storage areas) and, therefore, where filling may adversely impact on existing flood behaviour.

Table 5 Qualitative and Quantitative Criteria for Hydraulic Categories

Hydraulic Category	Definition	Adopted Criteria
Floodway	• Those areas where a significant volume of water flows during floods • Often aligned with obvious natural channels and drainage depressions • They are areas that, even if only partially blocked, would have a significant impact on upstream water levels and/or would divert water from existing flowpaths resulting in the development of new flowpaths. • They are often, but not necessarily, areas with deeper flow or areas where higher velocities occur.	Velocity x Depth >= 1 m^2/s
Flood Storage	• Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood • If the capacity of a flood storage area is substantially reduced by, for example, the construction of levees or by landfill, flood levels in nearby areas may rise and the peak discharge downstream may be increased. • Substantial reduction of the capacity of a flood storage area can also cause a significant redistribution of flood flows.	Depths > 0.15 m and not Floodway
Flood Fringe	• The remaining area of land affected by flooding, after floodway and flood storage areas have been defined. • Development (e.g., filling) in flood fringe areas would not have any significant effect on the pattern of flood flows and/or flood levels.	Areas that are not floodway or flood storage

The 'Floodplain Development Manual' (NSW Government, 2005) does not provide quantitative criteria for defining hydraulic categories. This is because the extent of floodway, flood storage and flood fringe areas are typically specific to a particular catchment. However, criteria for defining hydraulic categories was previously prepared as part of the Tweed Valley Flood Study' (WBM BMT, 2009). These criteria are summarised in **Table 5** and were retained as part of the current study.

The hydraulic category maps that were developed based upon the criteria listed in **Table 5** for the 1% and 0.2% AEP floods are shown in **Figure 21** and **Figure 22**.

Figure 21 shows that during the 1% AEP flood, the majority of the South Murwillumbah study area would fall with a flood storage area. However, some areas, particularly those contained on the western side of Tweed Valley Way would be classified as a floodway. **Figure 22** shows that during the 0.2% AEP flood much more of the developed sections of South Murwillumbah would fall within floodways.

Accordingly, the hydraulic category mapping indicates that the study area would generally be classified as flood storage or floodway during the 1% AEP and 0.2% AEP events. This indicates that any further development in the study area is likely to generate adverse flood impacts across other areas.

3.2.5 Emergency Response Precinct Classifications

In an effort to understand the potential emergency response requirements across different sections of South Murwillumbah, flood emergency response precinct (ERP) classifications were prepared in accordance with the flow chart shown in **Plate 3** (Australian Emergency Management Institute, 2014). The ERP classifications can be used to provide an indication of areas which may be inundated or may be isolated during floods. This information, in turn, can be used to quantify the type of emergency response that may be required across different sections of the floodplain during future floods. This information can be useful in emergency response planning.

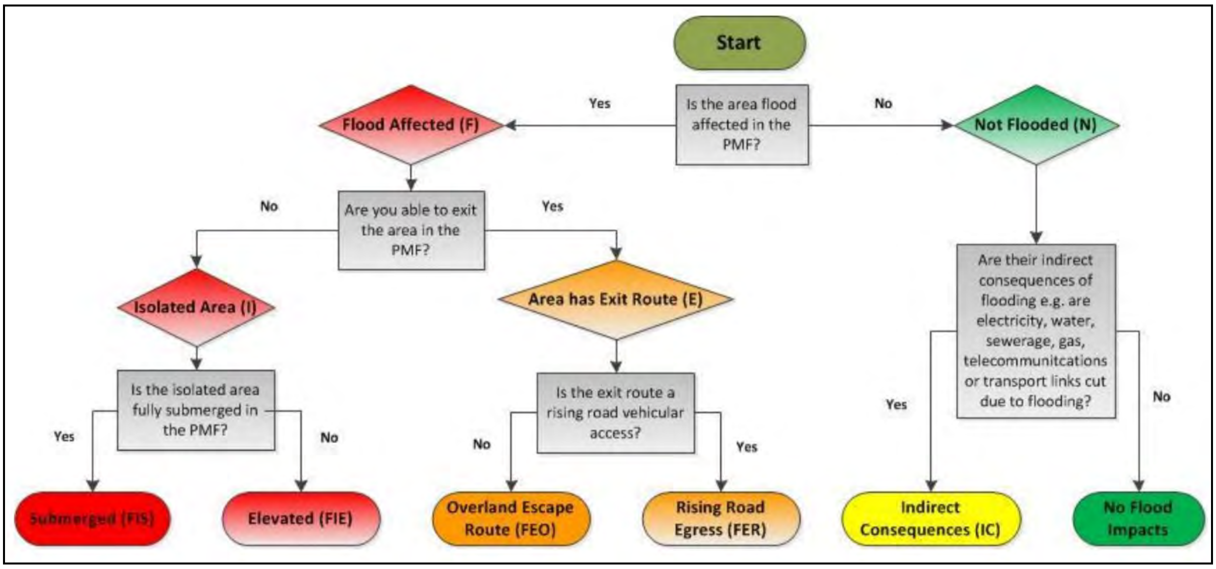


Plate 3 Flow Chart for Determining Emergency Response Planning Classifications (AEMI, 2014).

Each allotment within the South Murwillumbah study area was classified based upon the ERP flow chart shown above for the 1% and 0.2% AEP floods. This was completed using the TUFLOW model results, digital elevation model and a road network GIS layer in conjunction with proprietary software that considered the following factors:

- Whether evacuation routes/roadways get “cut off” by the depth of inundation (a 0.2 m depth threshold was used to define a “cut” road).
- Whether evacuation routes continuously rise out of the floodplain.
- Whether properties become inundated.

The resulting ERP classifications for the 1% and 0.2% AEP floods are provided in **Figure 23** and **Figure 24**. A range of other datasets were also generated as part of the classification process to assist Council and the SES. This includes the locations where roadways are first cut by floodwaters, which are discussed in more detail in Section 3.4.2.

Figure 23 and **Figure 24** show that the majority of the South Murwillumbah study area would be classified as “flooded, isolated, submerged” during both the 1% AEP and 0.2% AEP floods. This classification indicates that the lots become isolated and completely inundated during the 1% AEP and 0.2% AEP floods.

There are also small areas of “flooded, isolated, elevated” areas where evacuation access is also lost, but the majority of the lot area remains elevated above the peak flood levels. In these instances, it should be safe to seek refuge-in-place, however, it may still be necessary for emergency services to resupply the area if floodwaters remain for an extended period.

Figure 23 shows that during a 1% AEP flood, most roadways across the residential and commercial areas of South Murwillumbah would be cut about 30 hours after the initial onset of rainfall. Once inundated, they would typically remain cut for at least 12 hours although some areas would not be trafficable for more than 40 hours. Across the industrial areas, access would also be lost after about 30 hours of rainfall but, owing to the flat topography, the area would typically take longer to drain (i.e., >20 hours).

Figure 24 shows that during a 0.2% AEP flood, most roadways across the residential and commercial areas of South Murwillumbah would be cut 15 hours after the initial onset of rainfall. Once inundated, they would typically remain cut for at least 30 hours. However, some of the lower lying roadway areas would remain underwater for over 80 hours. Inundation of roadways across the industrial sections of South Murwillumbah would generally occur 16 hours after the onset of rainfall and the roads would remain cut for more than 60 hours across much of the area.

3.2.6 Duration of Inundation

A key consideration when quantifying the potential flood risk across South Murwillumbah is how much warning time would be available before levee overtopping and roadway inundation commences. The time that it takes for water to drain is also an important consideration as it dictates when recovery efforts can commence and can also quantify the potential for floodwaters to impact on the health of crops, most notably sugar cane. In this regard, overtopping times for the South Murwillumbah levee were extracted from the results of the modelling and are presented in **Table 6**. As noted in Section 3.2.2, inundation of South Murwillumbah first begins at the low point in Alma St. All times are measured relative to the start of rainfall.

The total duration of inundation during each flood was also extracted from the results of the modelling and are presented in **Figures 25** to **28**.

The information contained in **Table 6** shows that during events up to and including the 1% AEP flood, Alma Street would be overtopped approximately 30 hours after the initial onset of rainfall. Once overtopped, access would remain cut for at least 12 hours.

Table 6 Inundation Times for South Murwillumbah

Flood	Alma Street Overtopping Details (hours)		
	Time of First Overtopping	Time of Last Overtopping	Duration of Overtopping
20% AEP	32	44	12
5% AEP	31	44	13
1% AEP	29	46	17
0.2% AEP	15	57	42

Table 6 also shows that during the 0.2% AEP flood, the amount of warning time would decrease significantly, with Alma Street being overtopped approximately 15 hours after the onset of rainfall. The total duration of inundation also increases significantly during the 0.2% AEP event (i.e., Alma Street would remain cut for >40 hours). Accordingly, there is significant reduction in the amount of warning time and a significant increase in the time that South Murwillumbah would be isolated once the flood severity exceeds that of a 1% AEP flood.

Figures 25 to **27** shows that during floods up to and including the 1% AEP event, with the exception of the sugar cane fields located south of the airfield, most sections of South Murwillumbah would drain in less than 3 days. However, **Figure 28** shows that during the 0.2% AEP flood, many more areas would be subject to extended periods of inundation (i.e., 3 days or greater). This includes a significant section of the industrial area and the lower lying residential and commercial areas of South Murwillumbah. This outcome echoes the Alma Street overtopping analysis and suggests and notable increase in inundation times for floods in excess of the 1% AEP event.

It should be noted that the inundation times presented in this section are based upon design floods and cannot be relied upon to provide a reliable estimate of warning times during future floods.

3.2.7 High Flow Areas

Section A3.2.5 of the Tweed Shire Council Development Control Plan (DCP) 2011 outlines the concept of "high flow areas". High flow areas attempt to identify sections of the floodplain where the majority of flow is conveyed during a flood and the DCP provides restrictions on the extent of development that is permitted in these areas. Accordingly, the high flow mapping forms an important part of Council's DCP.

As the model developed for this study provides a more detailed description of flow velocities and depths in the vicinity of South Murwillumbah, revised high flow mapping was prepared. The DCP defines high flow areas as sections of the floodplain that are exposed to a velocity depth product that exceeds 0.3 m^2/s during the 1% AEP flood. Accordingly, the velocity depth product results were extracted from the 1% AEP flood simulation and were used as the basis for preparing the high flow velocity map shown in **Figure 29**.

3.3 Levee Overtopping Analysis

The results of the design flood modelling show that the South Murwillumbah levee is initially overtopped at three different locations. The locations of overtopping are shown in **Plate 4** and are also described below:

- Location 1: Alma Street approximately 60 metres west of Tweed Valley Way
- Location 2: Near southern end of levee (60 metres west of the intersection of River Street and Smith Street
- Location 3: On the Tweed Riverbank 50 metres south west of the southern-most tip of River Street

Key overtopping statistics/times for each overtopping locations are also provided in **Table 7** and floodwater depths and velocity vectors immediately after overtopping are provided for each location in **Plate 5**, **Plate 6** and **Plate 7**.

Table 7 Levee overtopping statistics

Flood	Location (refer Plate 4)	Time Since Start of Rainfall (hours:minutes)		
		First Overtops	Last Overtops	Duration of Overtopping
20% AEP	1	32:30	43:20	10:40
	2	32:40	40:40	8:00
	3	32:40	40:40	8:00
5% AEP	1	31:20	44:00	12:40
	2	32:00	41:20	9:20
	3	32:00	41:20	9:20
1% AEP	1	29:10	46:40	17:00
	2	29:20	42:40	13:00
	3	29:20	42:40	13:00
0.2% AEP	1	14:00	56:40	42:40
	2	14:00	45:20	31:20
	3	14:00	45:20	31:20
PMF	1	8:00	>70:00	>60:00
	2	8:00	>70:00	>60:00
	3	8:00	>70:00	>60:00

As noted in **Table 7**, the levee system is predicted to be first overtopped at the low point in Alma Street (Location 1). Overtopping is predicted to commence approximately 30 hours after the onset of rainfall for floods up to and including the 1% AEP event. However, during the 0.2% AEP flood and PMF, a significant reduction in warning time is anticipated (i.e., Alma St would be overtopped in as little as 8 hours after the onset of rainfall). Once overtopped, Alma Street would remain cut for a minimum of 10 hours during smaller floods and in excess of 40 hours in larger floods.

Plate 4 Levee overtopping locations

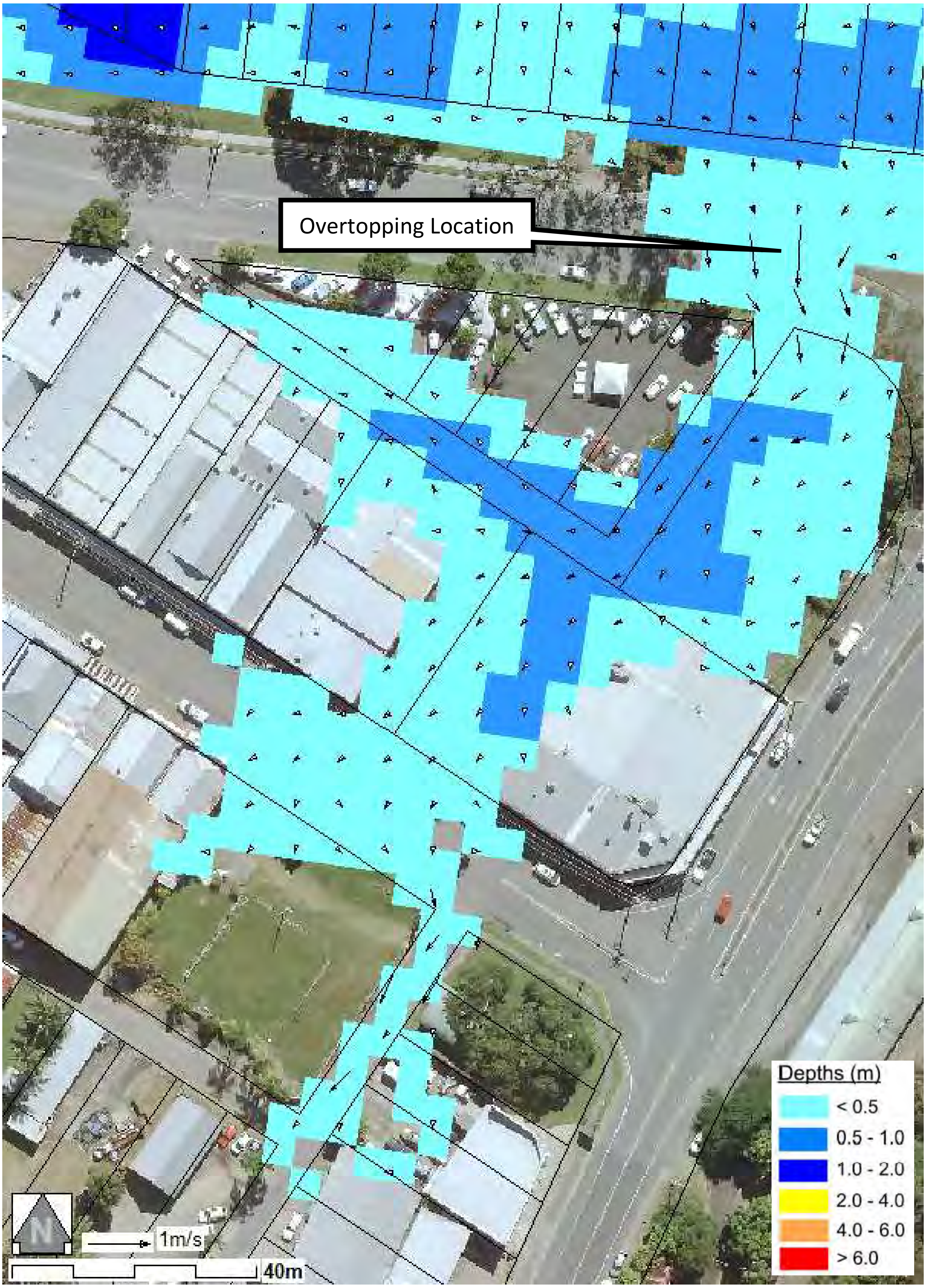


Plate 5 Floodwater depths and velocity vectors after overtopping commences at Location 1

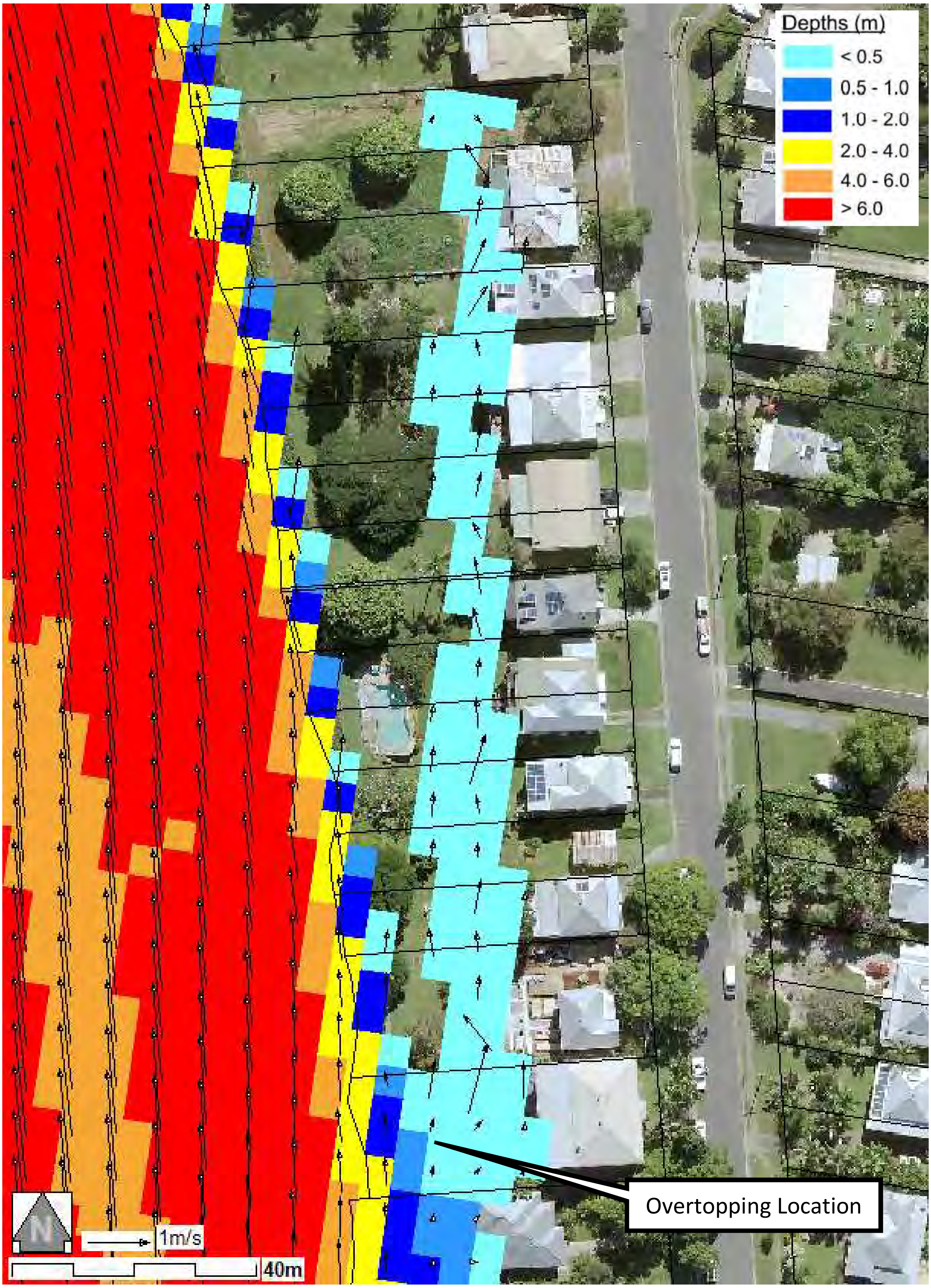


Plate 6 Floodwater depths and velocity vectors after overtopping commences at Location 2

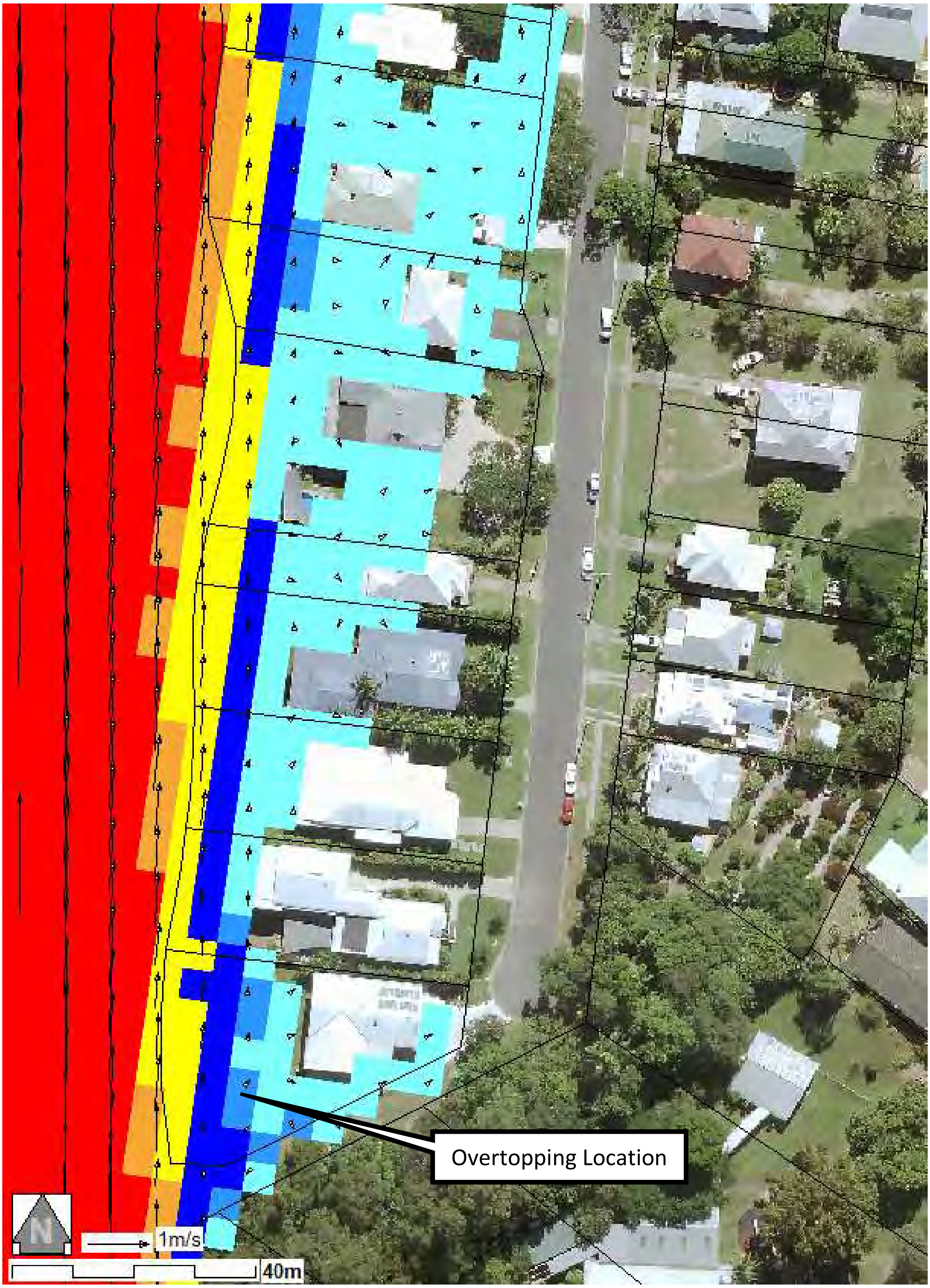


Plate 7 Floodwater depths and velocity vectors after overtopping commences at Location 3

As shown in **Plate 5**, once overtopping of Alma Street commences, floodwaters move slowly southwards towards Prospero Street and Cliffords Lane. Floodwaters continue south inundating low lying land between Wardop Street and Tweed Valley Way. At the peak of larger floods, the low point in Alma Street allows floodwaters to escape from the commercial and residential areas of South Murwillumbah back into the Tweed River.

Approximately 10 minutes after Alma Street overtops, the levee is predicted to be overtopped west of the intersection of River Street and Smith Street (Location 2). Floodwaters are predicted to move quickly (i.e., ~1 m/s) and fill the rear yards of properties located between 105 and 127 River Road before spilling onto River Street near Colin Street (refer **Plate 6**). Water travels north along River Street towards Prospero Street at speeds exceeding 1 m/s during larger floods. The rear yards of the River Street properties are predicted to be exposed to peak velocities approaching 2 m/s at the peak of larger floods.

At roughly the same times as Location 2 overtops, existing high ground located near the southern end of River Street (Location 3) is also predicted to be overtopped (refer **Plate 7**). This area is not part of the official levee system but comprises natural high ground. Inundation in this area is characterised by relatively slow-moving water initially. However, after water builds up sufficiently and "spills" into River Street, localised areas (most notably between buildings) are exposed to velocities of around 1 m/s.

Once overtopping of the levee commences, the "basin" located behind the levee is predicted to fill very quickly. The results of the design flood simulations indicate that all potentially flood liable properties located behind the levee would be inundated approximately X hours after the levee first overtops. In addition, River Street (one of the major evacuation routes), would be exposed to velocities of over 1.5 m/s. Accordingly, there would be minimal opportunities to evacuate if residents were to wait for levee overtopping to commence.

During smaller floods (e.g., 20% AEP), floodwaters would typically take a minimum of 1 day to recede from the more elevated areas of South Murwillumbah. However, lower lying areas may take more than 4 days to drain. During larger floods (e.g., 0.2% AEP), most areas would remain inundated for a period of at least 2 days, with lower lying areas subject to inundation for at least 5 days.

3.4 Impacts of Flooding

3.4.1 Impact of Flooding on Key Facilities

South Murwillumbah is home to a range of property types and infrastructure. This includes facilities where the occupants may be particularly vulnerable during floods, such as schools, child care centres and aged care facilities. In addition, some facilities will play important roles for emergency response and evacuation purposes during future floods (e.g., hospitals & evacuation centres). Therefore, it is important to have an understanding of the potential vulnerability of these facilities during a range of floods.

Critical and vulnerable facilities located within the South Murwillumbah study area are summarised below. A discussion on the impacts of flooding on each facility is provided below and is also summarised in **Table 8**.

Table 8 Impact of Flooding on Key Facilities

Facility		5% AEP Flood		1% AEP Flood		0.2% AEP Flood	
		Max Hazard	Access Cut?	Max Hazard	Access Cut?	Max Hazard	Access Cut?
Evacuation Centres	TAFE NSW Murwillumbah and Sacred Heart Catholic Hall *146 Murwillumbah St, Murwillumbah*	-	☑	-	☑	-	☑
Fire Stations	Tweed Fire Control Centre – NSW RFS *Lot 2 Lundberg Dr*	-	*	-	*	-	*
Schools	St Josephs Catholic Primary School *3 Greville St*	H5 (D > 2 m)	☑	H5 (D > 2 m)	☑	H5 (D > 2 m)	☑
	Murwillumbah South Infants School (closed) *427 Tweed Valley Way*	-	☑	-	☑	-	☑
Aged Care Facilities	Greenhills Lodge *437 Tweed Valley Way*	-	☑	-	☑	-	☑
Caravan Parks	Greenhills Caravan Park *488 Tweed Valley Way*	H5 (D > 2 m)	☑	H5 (D > 2 m)	☑	H5 (D > 2 m)	☑

NOTE: *Access is cut from Murwillumbah but regional access maintained via Wardrop Valley Rd

- Evacuation Centres:
  - ***TAFE NSW Murwillumbah and Sacred Heart Catholic Hall*** (Murwillumbah St, Murwillumbah): The TAFE buildings are predicted to remain flood free during all design flood events. The Sacred Heart Catholic Hall is located opposite the TAFE and is also predicted to remain flood free in all design events. However, access between the evacuation centre and South Murwillumbah is predicted to be cut at Alma Street in floods as frequent as the 20% AEP flood. Accordingly, early evacuation from South Murwillumbah would need to be completed.
- Fire Stations:
  - ***Tweed Fire Control Centre – NSW RFS*** (94 Wardrop Valley Way, South Murwillumbah): The Tweed Fire Control Centre is located in an industrial centre off Wardrop Valley Rd. The site is not affected by flooding, however it is cut from Murwillumbah along Quarry Road in events as often as the 5% AEP.
- Schools:
  - ***St Josephs Catholic Primary School*** (3 Greville St, South Murwillumbah): is located well within the floodplain and is affected by high hazard flooding as often as the 5% AEP event. Flood depths are relatively high (greater than 2 m) even in smaller floods

while flood velocities remain relatively low (less than 0.5 m /s) even in extreme events.

- ***Murwillumbah South Infants School*** (427 Tweed Valley Way, South Murwillumbah): is located on the top of a hill in South Murwillumbah. The school is currently closed and not in use. The school is largely unaffected by flooding, however access is cut relatively frequently, in events as often as the 5% AEP.

- Aged Care Facilities:
  - ***Greenhills Lodge*** (437 Tweed Valley Way, South Murwillumbah): is located on an elevated position along the river bank. The facility is generally flood free, however access is cut in floods as frequent as the 5% AEP.
- Caravan Parks:
  - ***Greenhills Caravan Park*** (488 Tweed Valley Way, South Murwillumbah): is located in a depression between Tweed Valley Way and the railway line. The flood conditions are high depths, greater than 2 m and up to around 3 m, in floods as frequent as the 5% AEP and depths up to around 3.8 m in the 0.2% AEP. Velocities vary from around 0.5 m/s in the 20% AEP event to around 1 m /s in some located of the site in the 0.2% AEP event.

3.4.2 Transportation Impacts

There are a number of major roadways across South Murwillumbah which may be required for evacuation or emergency services access during floods. It is important to have an understanding of the impacts of flooding on these transportation links so that appropriate emergency response planning can occur.

The location where roads are first overtopped was established by comparing peak design water levels against road centreline elevations as part of the emergency response precinct classifications. The location where roadways are predicted to be first cut by floodwater during the 1% AEP and 0.2% AEP flood is shown in **Figure 23** and **Figure 24**. Also included on **Figure 23** and **Figure 24** are labels for each roadway overtopping location that provides the following information:

- The time at which each roadway is first inundated (relative to the start of rainfall); and,
- The duration of inundation.

The flood level at the Murwillumbah and Murwillumbah Bridge gauges at the time each roadway is overtopped was also extracted and are presented in **Appendix I**. The location where each road first overtops is also shown in **Figure I1** in **Appendix I**. The overtopping data is provided as three separate tables (all with the same overall content). The first is sorted alphabetically according to the road name, the second is sorted numerically based upon the gauge heights at which overtopping occurs and the third is listed accordingly to the road overtopping ID number.

The roadway inundation information indicates that:

- The residential and commercial sections of South Murwillumbah are first inundated as a result of floodwaters overtopping a low point in Alma Street (approximately 50 metres west of Tweed Valley Way). This is predicted to occur about 30 hours after the onset of rainfall during floods up to and including the 1% AEP flood. Once overtopping of Alma Street commences, the low points of many of the roadways located south of Alma Street would be quickly inundated. During a 0.2% AEP flood, overtopping and inundation would first occur after about 15 hours.

- Multiple roadways across the industrial section of South Murwillumbah would be cut approximately 16 hours after the onset of rainfall during a 0.2% AEP event. This includes Tweed Valley Way, Buchanan Street, Durrington Street and Mayfield Street. Quarry Road would be cut about 23 hours after rainfall commences during a 0.2% AEP flood.

It should be noted that the roadway inundation information is based on "design" flood information. No two floods are the same and future floods will likely exhibit different characteristics. Nevertheless, the information provides a good indication of the relative susceptibility of roadways in different parts of the study area to inundation and can assist emergency services in evacuation planning.

3.4.3 Above Floor Flooding

In an effort to quantify the impact that flooding has across South Murwillumbah, the number of residential, commercial and industrial buildings expected to be subject to above floor flooding during each design floods was calculated. This was completed by comparing peak design flood level information with surveyed floor levels that were collected as part of the *'Tweed Valley Floodplain Risk Management Study'* (*WBM BMT, 2014*).

The number of properties expected to be subject to above floor flooding during each design flood across South Murwillumbah was extracted and is summarised in **Table 9**. The design flood at which above floor flooding first occurs was extracted from the results of the analysis and is presented in **Figure 30**.

Table 9 Number of Properties Subject to Above Floor Inundation

Flood	Number of buildings with above floor flooding			
	Residential	Commercial	Industrial	Total Number
20% AEP	5	18	3	26
5% AEP	8	22	5	35
1% AEP	51	62	45	158
0.2% AEP	144	75	56	275

Table 9 shows that only a relatively small number of residential properties are predicted to be exposed to above floor flooding during 20% and 5% AEP flood events. However, the numbers of residential properties subject to above floor inundation is predicted to increase significantly during the 1% AEP and 0.2% AEP floods. **Table 9** also shows that a significant number of commercial properties would be subject to inundation during floods as frequent as the 20% AEP event.

It is expected that over 150 properties would be subject to above floor flooding during a 1% AEP flood. During a 0.2% AEP flood, more than 270 properties are predicted to experience above floor inundation.

3.4.4 The Cost of Flooding

To assist in quantifying the financial impacts of flooding on the community, a flood damage assessment was also completed. The flood damage assessment aimed to quantify the potential flood damage costs incurred during a range of design floods across South Murwillumbah. A detailed description of the approach used to establish the flood damage cost estimates is provided in **Appendix E**.

As outlined in **Appendix E**, flood damage estimates were prepared using flood damage curves in conjunction with design flood level estimates and building floor levels for each of the following property/asset types:

- Residential properties
- Commercial properties
- Industrial properties
- Infrastructure

The final flood damage estimates for each design flood for South Murwillumbah are summarised in **Table 10** for existing topographic and development conditions. It indicates that if a 1% AEP flood was to occur, over $45 million worth of damage could be expected across South Murwillumbah (note that this damage estimate does not include any areas outside of the study, including the Murwillumbah CBD). It should also be noted that the damage estimates do not account for agricultural damage costs. Although agricultural impacts are an important consideration, the economic assessment is based on urban damages only, which is consistent with the approach adopted for the *'Tweed Valley Floodplain Risk Management Study'* (*WBM BMT, 2014*).

Table 10 Summary of South Murwillumbah Flood Damage Costs for Existing Conditions

Flood	**Flood Damages** ($ millions)				
	Residential	**Commercial**	**Industrial**	**Infrastructure**	**Total Damages**
20% AEP	2.66	3.44	0.25	0.55	6.90
5% AEP	3.31	3.88	0.80	0.70	8.69
1% AEP	6.98	16.3	16.8	4.97	45.1
0.2% AEP	12.8	27.1	37.1	9.63	86.6

Table 10 shows that during the 1% AEP and 0.2% AEP floods, the majority of the flood damage cost is predicted to occur across commercial and, in particular, industrial properties. During more frequent events, residential properties are predicted to contribute a more substantial proportion of the overall damage costs.

Table 10 also shows a significant increase in flood damage costs between the 5% AEP and 1% AEP floods as well as the 1% AEP and 0.2% AEP floods. Accordingly, once significant overtopping of the levee occurs, flood damage costs can be expected to increase significantly.

The damage estimates were also used to prepare an Average Annual Damage (AAD) estimate for each property. The AAD takes into consideration the frequency of a particular event occurring and the damage incurred during that event to estimate the average damage that is likely to occur each year, on average.

The AAD for South Murwillumbah was determined to be **$5.1 million**. Accordingly, if the “status quo” was maintained, residents and business owners within the study area as well as infrastructure providers, such as Council, would likely be subject to flood damage costs of approximately $5.1 million per annum (on average).

3.5 Critical Flood Zone

As part of the current study, Tweed Shire Council requested that a “critical flood zone” be defined to assist in identifying land that would benefit as part of the industrial land swap project. No criteria were provided to define how the critical flood zone would be established. Therefore, it was necessary to establish criteria as part of the project.

It was noted that a single set of criteria may not adequately define all potential flood exposures / flood risk. As a result, a range of criteria were interrogated to assist in identifying the critical flood zone. These criteria included:

- The flood hazard a property was exposed to;
- Whether the property was located in a floodway or flood storage area;
- Whether the property was located in a high flow area;
- The frequency of above floor inundation; and,
- Emergency response classifications.

A “score” was assigned to each of the above criteria to reflect the severity of the flood exposure. The scores that were adopted are summarised in **Table 11**. A higher score indicates a more significant flood risk/exposure.

Table 11 Critical Flood Zone Criteria

1% AEP Flood Hazard		1% AEP Hydraulic Category		1% AEP High Flow Area		Frequency of above Floor Flooding		1% AEP Emergency Response Classification	
Hazard	**Score**	**Hyd. Cat**	**Score**	**HFA?**	**Score**	**Freq.**	**Score**	**ERC**	**Score**
H6	5	Floodway	5	Yes	4	20% AEP	4	FIS	4
H5	4	Flood Storage	2	No	0	5% AEP	3	FIE	3
H4	3	Flood Fringe	0			1% AEP	2	FEO	2
H3	2					0.5% AEP	1	FER	1
H2	1							IC or No Impacts	0
H1	0								0

Each parcel of land within the study area was interrogated against each of the criteria and a "score" was assigned to each parcel based on the information presented in **Table 11** (a score of 0 up to 5 could be assigned to each parcel for each of the five criterion). The individual scores were subsequently summed to provide an overall "critical flood zone" score for each parcel. The resulting overall scores are thematically mapped in **Figure 31**. It should be noted that only parcels of land containing a industrial buildings were included in the analysis.

Any area that is not mapped in **Figure 31** is considered to fall outside of the "critical flood zone" for one of the following reasons:

- It is located outside of the study area;
- It falls outside of the 1% AEP flood extent;
- It does not contain an industrial building; or,
- It does not satisfy any of the criteria in **Table 11**.

Those parcels that are mapped in **Figure 31** do fall within the "critical flood zone" and the different colours indicate the severity of the flood exposure/level of flood criticality.

Figure 31 shows that a significant number of properties across the industrial sections of South Murwillumbah comprise a critical flood zone score of more than 15. This score indicates that these lots are significantly impacted by flooding, with high levels of exposure across most of the criteria considered. It is considered that any lot with a score above 15 is likely to benefit as part of the industrial land swap.

3.6 Sensitivity Assessment

3.6.1 Overview

The previous sections have outlined the potential flood risk that residents and business owners in South Murwillumbah may be exposed to. This assessment was based upon the outcomes of design flood modelling.

However, the design flood modelling does include some parameters that are not known with absolute certainty. Furthermore, failure of the South Murwillumbah levee or flood gates could occur during future floods, which may alter the flood risk previously described.

Therefore, to gain an understanding of how some of these "unknowns" may impact on the existing flood risk, a range of sensitivity simulations were completed. This included:

- Failure of South Murwillumbah levee
- Failure of Critical Flood Gates
- Bridge/Culvert Blockage
- 2016 version of Australian Rainfall & Runoff

The outcomes of each sensitivity assessment are presented below.

3.6.2 South Murwillumbah Levee Failure

It was assumed that the South Murwillumbah levee remained intact as part of each design flood simulation. However, there is the potential that the levee could fail during a future flood. This failure may result in an increase in flood risk for those properties located behind the levee system.

Therefore, additional 20% AEP and 1% AEP simulations were completed incorporating a failure of the levee. The levee was assumed to breach along a 40 metres segment of the levee immediately north of Colin Street. The failure was assumed to occur immediately prior to the peak of each design flood and the breach was assumed to take place progressively over a 15-minute timeframe.

The levee breach parameters were included in the TUFLOW model as a variable "z shape". This allowed the levee breach in the TUFLOW model to be varied with respect to time. The updated TUFLOW model was used to re-simulate the 20% AEP and 1% AEP floods with the levee break.

Flood level difference mapping was prepared for the 20% AEP and 1% AEP levee failure scenarios and is presented in **Plates F1** and **F2** in **Appendix F**.

Plates F1 and **F2** shows that failure of the levee is predicted to have a small impact on peak 20% AEP and 1% AEP flood levels. During the 1% AEP flood, the differences are not predicted to exceed 0.02 metres and the differences are contained to the immediate vicinity of the breach. This lack of impact is associated with the levee already being submerged to a depth of at least 1 metre during the 1% AEP flood. Accordingly, the area behind the levee is already subject to significant inundation and failure of the levee is not predicted to significantly alter this outcome.

Flood level impacts are slightly more significant during the 20% AEP flood with flood level increases exceeding 0.05 metres at some locations. The flood level increases are also predicted to extend across a larger area, impacting flood levels as far east as the railway line.

Although the sensitivity assessment has shown that a breach of the South Murwillumbah levee would generate some localised flood level increases, the magnitude of the increases is small and indicates that the base modelling results are not particularly sensitive to a failure of the levee.

3.6.3 Critical Flood Gate Failure

As outlined in Section 2.2.2, floodgates are installed at the Tweed Valley Way crossing of Blacks Drain as well as upstream of the Tweed Valley Way crossing of Condong Creek (referred to as "floodgate 17L"). The floodgates serve to prevent floodwater from "backing up" along each watercourse and inundating areas behind the flood gates. To assess the potential impacts that failure of each flood gate would have on flood behaviour in the area, additional 20% AEP and 1% AEP simulations were completed with no flood gates in place.

Flood level difference mapping was prepared for the 20% AEP and 1% AEP flood gates failure scenarios and is presented in **Plates F3** and **F4** in **Appendix F**.

Plate F3 shows that failure of the floodgates would have a significant impact on flood levels across the South Murwillumbah industrial areas as well as the airfield and sugar cane fields south of the industrial area during the 20% AEP flood. 20% AEP flood levels are predicted to increase by more than 1 metre across most of the area. There is predicted to be a commensurate reduction in flood levels along the Tweed River and across the residential and commercial sections of South Murwillumbah. However, the reductions in flood level are modest (i.e., <0.1 metres during the 20% AEP flood).

Plate F4 shows that flood gate failure is predicted to have less of an impact during larger floods, with failure of the gates altering 1% AEP flood levels by less than 0.15 metres across the industrial areas and typically less than 0.10 metres across the residential and commercial areas of South Murwillumbah. The reduced sensitivity during larger events is considered to be associated with floodwaters already overtopping each of the flood gates at the peak of larger floods.

Therefore, the results of the flood gate failure simulations illustrate that the flood gates play an important role in reducing the severity of flooding across the industrial areas of South Murwillumbah during frequent floods. The impact is less significant during larger events, but the gates still afford some benefit indicating that the continuing maintenance and use of the flood gates is an important component of managing the existing flood risk across South Murwillumbah.

3.6.4 Bridge/Culvert Blockage

The design simulations included a representation of all hydraulic structures (i.e., bridges and culverts) located within and adjacent to the study area. It was assumed that each of these structures was not subject to any blockage during the simulated design floods. However, there is potential for debris to be mobilised from the upstream catchment and lead to blockage of the hydraulic structures. Accordingly, additional 1% AEP simulations were completed incorporating 75% blockage of hydraulic structures to gain an understanding of the potential impacts that blockage of these structures would have on design flood behaviour.

Initial simulation results showed that blockage of the Murwillumbah Bridge dominated all other structure in the area. Therefore, the blockage simulations were broken up into two separate scenarios:

- Blockage of the Murwillumbah Bridge in isolation; and,
- Blockage of all structures except the Murwillumbah Bridge.

Flood level difference mapping was prepared for the 1% AEP flood for both blockage scenarios scenarios and is presented in **Plates F5** and **F6** in **Appendix F**.

Plate F5 shows that blockage of all structures other than the Murwillumbah bridge is predicted to produce small localised changes in 1% AEP flood levels. Flood levels are typically predicted to increase upstream of the structure and decrease downstream of the structures. However, the flood level differences are predicted to be less than 0.05 metres indicating that blockage of these minor structures is not predicted to have a significant impact on flood behaviour.

However, **Plate F5** shows blockage of the Murwillumbah Bridge would have a more significant impact on flood behaviour. More specifically, peak 1% AEP flood levels are predicted to increase by well over 1 metre across the residential and commercial sections of South Murwillumbah and by more than 0.7 metres across most of the industrial land. The maximum flood level increase is predicted to be about 1.8 metres and occurs immediately upstream of the bridge.

Therefore, although blockage of each of the smaller hydraulic structures is not predicted to have a big impact on flood behaviour across South Murwillumbah, blockage of the main bridge is predicted to significantly increase the flood exposure/risk across South Murwillumbah.

3.6.5 Australian Rainfall & Runoff 2016

The *'Tweed Valley Flood Study'* (BMT WMB, 2009) derived design flood estimates based upon hydrologic procedures outlined in *'Australian Rainfall and Runoff – A Guide to Flood Estimation'* (Engineers Australia, 1987) (referred to herein as ARR1987). Since publication of this study, a revised version of Australian Rainfall and Runoff was released (Geoscience Australia, 2016) (referred to herein as ARR2016). Therefore, an additional sensitivity assessment was completed to confirm the impact that the revised hydrologic procedures may have on design flood behaviour in the vicinity of South Murwillumbah. The outcome of this assessment is provided in **Appendix G**.

The outcomes of this sensitivity assessment has determined that ARR2016 will typically produce higher peak 1% AEP flood level estimates relative to ARR1987 (refer difference mapping included in **Appendix G**). In general, ARR2016 1% AEP flood levels are between 0.15 to 0.2 metres higher than ARR1987 flood levels across most of the study area.

It is also noted that the critical ARR2016 storm duration was determined to be 12-hours, which is significantly shorter than then 36-hour duration determined under ARR1987. Accordingly, the use of ARR1987 hydrology may be overstating the amount of warning time that may be available for South Murwillumbah. However, in order to maintain continuity with the *'Tweed Valley Flood Study'* (BMT WMB, 2009) and *'Murwillumbah CBD Levee & Drainage Study'* (Catchment Simulation Solutions, 2018), the ARR1987 hydrology was retained for the current study. However, further consideration of the ARR2016 should be completed as part of future investigations that may come out of the current study.

3.7 Climate Change Assessment

3.7.1 Overview

Climate change refers to a significant and lasting change in weather patterns arising from both natural and human induced processes. The Office of Environment and Heritage's *'Practical Consideration of Climate Change'* states that climate change is expected to have adverse impacts on sea levels and rainfall intensities in the future.

Increases in rainfall intensities would produce increases in runoff volumes across the catchment. This, in turn, would likely produce an increase in the depth, extent and velocity of floodwaters. Furthermore, increases in ocean levels may increase flood levels along the tidally influenced sections of the Tweed River which extends upstream of Murwillumbah. This may also increase the severity of flooding across South Murwillumbah.

Although there is uncertainty associated with how climate change may impact on future rainfall and ocean levels, it was considered important to provide an assessment of the potential impact that climate change may have on the current description of flood risk across South Murwillumbah.

Therefore, additional 20% AEP, 5% AEP 1% AEP simulations were completed to reflect the following potential future climate change scenarios:

- 10% increases in rainfall and 0.4 m increase in ocean level (2050 conditions)
- 20% increases in rainfall and 0.9 m increase in ocean level (2100 conditions)

3.7.2 10% Increase in Rainfall with 0.4 metre Increase in Sea Level

The first climate change simulation investigated the potential impacts of a 10% increase in current 1% AEP rainfall depths as well as a 0.4 m increase in ocean levels. This is intended to provide an indication of climate change impacts for the year 2050.

It is noted that the downstream boundary of the TUFLOW model is located at Tumbulgum and the impact of an ocean level increase at Tweed Heads will be "dampened" moving upstream from the coast (i.e., a 0.4 m ocean level increase will not necessary produce a 0.4 m increase in water levels at Tumbulgum). A review of the climate change simulation results produced as part of the 'Tweed Valley Flood Study Update, Climate Change' (BMT WBM, 2009) shows that a 0.4 m increase in ocean level at Tweed Heads would produce a 0.1 m increase in water level at Tumbulgum. Accordingly, the "base" 1% AEP tailwater levels at Tumbulgum were elevated by 0.1 m as part of this simulation to reflect the ocean level increase.

The WBNM model was updated to reflect the 10% increase in rainfall. The results from this simulation show that a 10% increase in rainfall would produce the following changes to peak design discharges for the Tweed River at Murwillumbah:

- 20% AEP: increases from 3,110 m^3/s to 3,520 m^3/s (13% increase)
- 5% AEP: increases from 3,650 m^3/s to 4,130 m^3/s (13% increase)
- 1% AEP: increases from 5,160 m^3/s to 5,790 m^3/s (12% increase)

The revised discharge hydrographs were applied to the TUFLOW model and were used to simulate each design flood with a 10% increase in rainfall and 0.4 m increase in ocean level as the result of climate change. The peak flood level results from the climate change simulations were extracted and were subtracted from 'existing' design flood levels to create flood level difference mapping. The difference mapping shows the location and magnitude of flood level and inundation extent changes associated with climate change for each design flood. The difference mapping is presented in **Plates H1** to **H3** in **Appendix H**.

The number of buildings exposed to above floor inundation as well as the total flood damages were also extracted from the results of each climate change simulation and are presented in **Table 12**, **Table 13** and **Table 14**. The results are subdivided into "Study Area West" reflecting the residential and commercial areas concentrated west of the Tweed Valley Way/Railway Street intersection and "Study Area East" reflecting the industrial areas located east of the Tweed Valley Way/Railway Street intersection. There is a total of 415 buildings within the study area.

Table 12 Predicted Climate Change Impacts for 20% AEP event

Metric	Existing		Climate Change			
			10% increases in rainfall and 0.4 m increase in ocean level		20% increases in rainfall and 0.9 m increase in ocean level	
	Study Area West	Study Area East	Study Area West	Study Area East	Study Area West	Study Area East
Buildings Flooded Above Floor Level	26	1	**30**	**2**	**41**	**8**
Flood Damage ($ millions)	6.8	0.2	**7.8**	**0.5**	**9.3**	**1.3**

Table 13 Predicted Climate Change Impacts for 5% AEP event

Metric	Existing		Climate Change			
			10% increases in rainfall and 0.4 m increase in ocean level		20% increases in rainfall and 0.9 m increase in ocean level	
	Study Area West	Study Area East	Study Area West	Study Area East	Study Area West	Study Area East
Buildings Flooded Above Floor Level	32	3	**43**	**23**	**68**	**60**
Flood Damage ($ millions)	8.1	0.8	**10.1**	**3.8**	**12.8**	**16.3**

Table 14 Predicted Climate Change Impacts for 1% AEP event

Metric	Existing		Climate Change			
			10% increases in rainfall and 0.4 m increase in ocean level		20% increases in rainfall and 0.9 m increase in ocean level	
	Study Area West	Study Area East	Study Area West	Study Area East	Study Area West	Study Area East
Buildings Flooded Above Floor Level	83	77	**108**	**90**	**145**	**92**
Flood Damage ($ millions)	15.6	28.9	**19.5**	**37.5**	**23.1**	**44.9**

The difference mapping in **Appendix H** shows that climate change has the potential to cause increases in flood levels and extents across all simulated design events. Along the Tweed River and across the residential/commercial areas of South Murwillumbah, the flood level increases are predicted to vary between 0.1 metres during the 20% AEP flood and 0.3 metres during the 1% AEP flood.

Across the industrial areas, the biggest flood level differences are predicted to occur during the 5% AEP flood, with 5% AEP climate change flood levels being around 1 metre higher than existing 5% AEP flood levels. This significant difference appears to be associated with the 5% AEP climate change simulation overtopping Tweed Valley Way at Blacks Drain (the existing 5% AEP flood is not predicted to overtop Tweed Valley Way at this location). The flood level differences during the 20% AEP and 1% AEP events are not as substantial (typically 0.4 metres and 0.3 metres higher respectively).

The increases in design flood levels are predicted to increase the number of buildings predicted to be exposed to above floor inundation during each design flood. Although the number of additional buildings exposed to above floor flooding during the 20% AEP is modest (i.e., 5 additional buildings), the number of buildings exposed to above floor flooding during the 5% AEP flood is predicted to increase by 31, with most of the additional above floor flooding occurring across the industrial areas.

The additional above floor inundation is predicted to generate a commensurate increase in flood damages. More specifically, flood damage costs are predicted to increase by $5 million during the 5% AEP flood and over $12 million during the 1% AEP flood.

3.7.3 20% Increase in Rainfall with 0.9 metre Increase in Sea Level

The second climate change simulation investigated the potential impacts of a 20% increase in current 1% AEP rainfall depths as well as a 0.9 m increase in ocean levels. This is intended to provide an indication of climate change impacts for the year 2100.

As for the first climate change simulation, the climate change simulation results from the 'Tweed Valley Flood Study Update, Climate Change' (BMT WBM, 2009) were reviewed to determine the impact that a 0.9 metre ocean level increase would have on flood levels at Tumbulgum. This showed that a 0.9 m increase in ocean level at Tweed Heads would produce a 0.27 m increase in water level at Tumbulgum. Accordingly, the "base" 1% AEP tailwater levels at Tumbulgum were elevated by 0.27 m as part of this simulation to reflect the ocean level increase.

The WBNM model was updated to reflect the 20% increase in rainfall. The results from this simulation show that a 20% increase in rainfall would produce the following changes to peak design discharges for the Tweed River at Murwillumbah:

- 20% AEP: increases from 3,110 m^3/s to 3,930 m^3/s (26% increase)
- 5% AEP: increases from 3,650 m^3/s to 4,600 m^3/s (26% increase)
- 1% AEP: increases from 5,160 m^3/s to 6,420 m^3/s (24% increase)

The revised discharge hydrographs were applied to the TUFLOW model and were used to simulate each design flood with a 20% increase in rainfall and 0.9 m increase in ocean level as the result of climate change. The peak flood level results from the climate change simulations were extracted and were subtracted from 'existing' design flood levels to create flood level difference mapping. The difference mapping shows the location and magnitude of flood level and inundation extent changes associated with climate change for each design flood. The difference mapping is presented in **Plates H4** to **H6** in **Appendix H**.

The total area exposed to inundation, the number of buildings exposed to above floor inundation as well as the total flood damages were also extracted from the results of each climate change simulation and are presented in **Table 12**, **Table 13** and **Table 14**.

The difference mapping in **Appendix H** shows that along the Tweed River and across the residential/commercial areas of South Murwillumbah, the flood level increases are predicted to vary between 0.25 metres during the 20% AEP flood and 0.6 metres during the 1% AEP flood.

As for the 2050 climate changes simulations, the largest flood level increases are predicted to occur across the industrial areas of South Murwillumbah during the 5% AEP event. Under the 2100 climate change scenario, peak 5% AEP flood levels are predicted to increase by about 1.8 metres. Peak 20% AEP and 1% AEP flood level are predicted to increase by 1.2m and 0.6 metres respectively.

A 20% increase in rainfall coupled with a 0.9 metre increase in ocean level is predicted to produce a significant increase to the number of properties exposed to above floor flooding as well as a significant increase in flood damages. More than 90 additional properties are predicted to be inundated above floor during the 5% AEP flood. This is predicted to increase damages during the 5% AEP flood by around $20 million. Flood damages during the 1% AEP flood are predicted to increase by more than $23 million.

3.8 Flood Planning Considerations

3.8.1 Flood Planning Constraint Categories

Appropriate land use planning is one of the most effective measures available to floodplain managers, especially to control future risk but also to reduce existing flood risks as redevelopment occurs.

A review of existing planning legislation and policies that affect the development of land within the Tweed Shire Council LGA was completed as part of the *'Tweed Valley Floodplain Risk Management Study'* (*WBM BMT, 2014*). This study put forward the following planning recommendations which relate directly to South Murwillumbah:

- Further development in the residential, commercial and industrial areas of South Murwillumbah was not supported due to the high hazard and impact of filling.
- Preservation of the river front precinct as a continuous river front park.
- Any future development would need to be supported by detailed consideration of the hydraulic constraints and evacuation risk.

The outcomes of the flood assessment presented in this chapter have highlighted that much of South Murwillumbah would be classified as either flood storage or floodway during the 1% AEP flood. This tends to reinforce the conclusions from the *'Tweed Valley Floodplain Risk Management Study'* which suggests any further development across South Murwillumbah would likely adversely impact on existing flood behaviour.

However, to further assist in identifying the compatibility of the current land zoning with the existing flood risk and identify if future development could be supported in other areas, flood planning constraint category mapping was prepared based on guidance provided in the *'Australian Disaster Resilience Guideline 7-5: Flood Information to Support Land-use Planning'* (AIDR 2017). This guideline delineates flood liable land into one of four major "constraint" categories (with several subcategories) based upon key flooding considerations such as flood hazard, flood function and emergency response. The resulting categories can serve to inform land use planning activities. The guideline notes that the categorisation is intended to support community/precinct scale decisions where flow paths and flood extents can be readily defined and was not developed to support change of land use or development at the lot/site scale.

The flood planning constraint categories (FPCC) are summarised in **Table 15**. **Table 15** also summarises how the categories are defined along with the associated planning implication/considerations. In general, a FPCC categorisation of "1" implies a more flood constrained section of land relative to FPCC category "2", and so on.

The categories use a "Defined Flood Event" (DFE), which is analogous to the "planning flood" (i.e., 1% AEP event). It also requires consideration of flood impacts in events rarer than the DFE. The 0.2% AEP event was selected for this purpose.

The information contained in **Table 15** was used with the flood modelling outputs (most notably the flood hazard, hydraulic category and emergency response mapping) to prepare the FPCC map shown in **Figure 32**. Also included on **Figure 32** are the current land use zones to gain an appreciation for how the current zoning aligns with the FPCC. The proportion of each land zone that fall within each FPCC was also extracted and is presented in **Table 16**.

The FPCC categories presented in **Figure 32** shows that category 1A dominates the South Murwillumbah study area. Category 1A extends across areas of open space, but also covers most of the area currently zoned residential, commercial and industrial. This includes 96% of the commercial "B5" zoning, 68% of the residential "R2" zoning and 43% of the industrial "IN1" zoning. This categorisation indicates that any development in this area has the potential to adversely impact on existing flood behaviour. This outcome indicates that the current land use is largely incompatible with the flooding constraints and further supports the findings of the *'Tweed Valley Floodplain Risk Management Study'* (*WBM BMT, 2014*) which discouraged further development across South Murwillumbah.

Table 15 Flood Planning Constraint Categories (AIDR, 2017)

FPCC	Sub-Category	Constraint	Implications	Consideration
1	A	Flow conveyance and storage areas in the DFE	Development or changes to topography within flow conveyance areas and flood storages areas affect flood behaviour, which will alter flow depth or velocity in other areas of the floodplain. Changes can negatively affect the existing community and other property	The majority of developments and uses have adverse impacts on flood behaviour. Consider limiting uses and development to those compatible with maintaining flood function
	B	H6 hazard in the DFE	Hazardous conditions considered unsafe for vehicles and people. All building types are considered vulnerable to structural failure	The majority of developments and uses are vulnerable to failure in this flood hazard category. Consider limiting developments and uses to those that are compatible with flood hazard H6
2	A	Flow conveyance area in events larger than the DFE	Flow conveyance areas may develop during an event larger than the DFE. People and buildings in these areas may be affected by flowing and dangerous floodwaters	Consider compatibility of developments and users with rare flood flows in this area
	B	H5 hazard in the DFE	Hazardous conditions are considered unsafe for vehicles and people, and all buildings are vulnerable to structural damage	Many uses and developments will be vulnerable to flood hazard. Consider limiting new uses to those compatible with flood hazard H5. Consider treatments such as filling (where this will not affect flood behaviour) to reduce the hazard to a level that allows standard development conditions to be applied. Alternatively, consider a requirement for special development conditions
	C	Isolated and submerged areas (low flood island or low trapped perimeter in 1%AEP event)	Area becomes isolated by floodwater or impassable terrain, with loss of evacuation route to the community evacuation location. The area will become fully submerged with no flood-free land in an extreme event, with ramifications for those who have not evacuated and are unable to be rescued	Consequences of isolation and inundation can be severe. Consider the consequences of: • evacuation difficulty or inundation of the area on the development and its users, which may include limitations on land use, or on land use that has occupants who are more vulnerable to disruption and loss • the development on emergency management planning for the existing community, including the need for additional treatments • the development on community flood recovery • disruption or loss of the development on the users and wider community
	D	Isolated but not submerged areas (high flood island or high trapped perimeter in 1%AEP event)	Area becomes isolated by floodwater or impassable terrain, with loss of an evacuation route to a community evacuation location. The area has some land elevated above the extreme flood level. Those not evacuated may be isolated with limited or no services, and will need rescue or resupply until floods recede and roads are passable	Some developments and their users may be vulnerable to disruption or loss. Consider: • the consequences of disruption or loss of the development on the users and the wider community • limiting land use, or land use that has occupants who are more vulnerable to disruption and loss • additional emergency management treatment requirements • issues associated with the level of support required during a flood, particularly for long-duration flood events
	E	H6 hazard in events rarer than the DFE	Hazardous conditions may develop in an event rarer than the DFE, which may have implications for the development and its occupants	Consider the need for additional development conditions to reduce the effect of flooding on the development and its occupants

FPCC	Sub-Category	Constraint	Implications	Consideration
3	-	Outside FPCC 2 but generally below the DFE plus freeboard	Hazardous conditions may exist creating issues for vehicles and people. Structural damage to buildings that meet building standards unlikely because of flooding	Standard land-use and development controls aimed at reducing damage and the exposure of the development to flooding in the DFE are likely to be suitable. Consider the need for additional conditions for emergency response facilities, key community infrastructure and vulnerable users
4	-	Outside of FPCC 3 but within the PMF extent	Emergency response may rely on key community facilities such as emergency hospitals, emergency management headquarters and evacuation centres operating during an event. Recovery may rely on key utility services being able to be readily re-established after an event	Consider the need for conditions for emergency response facilities, key community infrastructure and land uses with vulnerable users

Table 16 Land use zones falling within each Flood Planning Constraint Category

Zone	Flood Planning Constraint Category									
	1		2					3	4	Not Impacted
	A	B	A	B	C	D	E			
B5	96%	0%	0%	0%	0%	4%	0%	0%	0%	0%
DM	36%	0%	0%	0%	0%	64%	0%	0%	0%	0%
IN1	43%	0%	0%	0%	0%	17%	0%	0%	1%	40%
R2	68%	0%	0%	0%	0%	9%	0%	0%	2%	20%
RE1	47%	0%	0%	0%	0%	52%	0%	0%	1%	0%
RU1	99%	0%	0%	0%	0%	1%	0%	0%	0%	0%
RU2	88%	0%	0%	0%	0%	9%	0%	0%	1%	2%
SP2	99%	0%	0%	0%	0%	1%	0%	0%	0%	0%
W1	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
W2	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%

The next most significant FPCC category that impacts the study area is category 2D. This indicates areas that are elevated above the peak flood level but become isolated during the flood. These areas are significantly less constrained relative to the 1A and commercial, industrial and residential land uses are generally suitable. However, sensitive land uses where occupants may require access during a flood are discouraged (e.g., aged care where medical access may be required).

It is noted that most of the "Industry Central" subdivision does not fall within any FPCC category indicating that this land is generally not subject to flood constraints. The only identified flood constraint was the potential for this area to lose direct access to the main town during large floods. However, alternate access may be available in an easterly direction along Wardrop Valley Road & Fernvale Road.

3.8.2 Minimum Floor Level Requirements

As shown in **Figures 21** and **29**, most industrial and commercial areas of South Murwillumbah fall within high flow areas and/or floodway/flood storage areas. It is noted that no specific floor level controls are specified for industrial and business/commercial areas in the Tweed

Development Control Plan 2015 (Tweed DCP 2015). Discussions with Council indicate that Council will provide the business owner with flood information and it is up to the owner to determine what level of flood exposure they are willing to accept and determine their preferred floor level based upon this. Although this strategy may have afforded an acceptable compromise with historic industrial properties (i.e., generally comprising low value/flood resilient internal components where inundation is unlikely to cause significant damage), many industrial properties now include extensive computer systems/electronics. As a result, the flood damage cost associated with inundation of modern industrial buildings is likely to be significant. As a result, it is considered that a minimum floor level standard may be necessary to reduce the frequency and severity of above floor inundation and associated damage costs.

The major downside of imposing a minimum floor level of, say, the 1% AEP flood + 0.5 m freeboard is the need to provide on-grade access to many of these industrial properties. To facilitate this, filling up to the FPL will generally be required, which is contrary to outcomes of the FPCC analysis and the recommendations in the 'Tweed Valley Floodplain Risk Management Study' (2014), which discouraged further industrial development due to the potential adverse impacts of filling. Furthermore, the Tweed DCP 2015 does not permit filling across the industrial areas to a height greater than the 20-year ARI (i.e., 5% AEP) level due to the potential for filling to adversely impact on existing flood behaviour. This may limit the practicality of implementing floor levels any greater than the 5% AEP flood level as most industrial properties will require "on grade" access from external areas to buildings.

If filling to the 5% AEP flood level was completed across all industrial zoned land, this would afford a significant flow obstruction to the Condong flow path during most large floods, which would likely cause existing flood levels to significantly increase across the residential and business areas of South Murwillumbah. Accordingly, reducing the flood exposure across the industrial areas of South Murwillumbah is unlikely to occur without increasing the flood exposure across other areas. Therefore, the long-term sustainability of siting high-value industrial properties in South Murwillumbah is questionable. As discussed in the preceding section, the existing industrial zoning does not appear to be compatible with the existing flood constraints across a large section of the industrial land. Therefore, the recommendation from the 'Tweed Valley Floodplain Risk Management Study' (2014) to not support further development in the South Murwillumbah industrial area is reinforced as part of the current study.

It is considered that one of the only feasible long-term strategies for the area will involve relocating high risk/value industrial properties from the floodplain. The implementation of such a strategy has commenced and is referred to as the 'South Murwillumbah Industrial Land Swap Project. In the interim, it is suggested that an additional control could be placed on industrial properties in high flow areas to ensure that all critical electrical equipment is located above the 1% AEP flood level to reduce the potential flood damage costs and commercial "down time" immediately following a flood.

3.9 Summary

The information presented in this section indicates that the residential, commercial and industrial areas of South Murwillumbah face some notable flooding problems. More specifically:

- The existing South Murwillumbah levee is predicted to be overtopped in floods as frequent as the 20% AEP event. Inundation of South Murwillumbah first occurs across a low point in Alma Street (located approximately 50 metres west of Tweed Valley Way).
- Alma Street would be overtopped and access to the main town would be lost approximately 30 hours after the initial start of rainfall during events up to and including the 1% AEP event. During the 0.2% AEP flood, considerably less warning time would be available (i.e., ~13 hours). Accordingly, there would be limited warning time available during particularly large floods.
- Once inundation of South Murwillumbah occurs it would be isolated for at least 12 hours (>40 hours during a 0.2% AEP flood).
- Once inundation of South Murwillumbah occurs, it would typically take at least 3 days for the floodwater to recede across most of the study area. During the 0.2% AEP flood, it would take more than 4 days for floodwaters to fully recede.
- During a 1% AEP flood, 149 properties are predicted to experience above floor inundation. This is predicted to increase to more than 260 properties if a 0.2% AEP flood was to occur.
- A flood damage bill of more than $45 million could be expected across South Murwillumbah should a 1% AEP (i.e., March 2017 type) flood occur. The average annual damage cost is predicted to be $1.4 million per annum.
- The current land zoning across most of South Murwillumbah appears to be largely incompatible with the flood risk. Accordingly, further development across the residential, commercial and industrial sections of South Murwillumbah is difficult to support. However, there are other areas adjacent to South Murwillumbah (most notably the “Industry Central” subdivision) where further development could be supported.

Climate change induced rainfall intensity and ocean level increases have the potential to further increase the flood risk across these areas. More specifically:

- A 10% increase in rainfall coupled with a 0.4 m increase in ocean level is predicted to increase existing design flood levels by up to 1 metre in some locations. This is predicted to result in 31 additional properties being subject to above floor flooding during the 5% AEP event. Flood damage costs are predicted to increase by $5 million during the 5% AEP flood and over $12 million during the 1% AEP flood.
- A 20% increase in rainfall with a 0.9 m increase in ocean level is predicted to result in 47 additional properties being subject to above floor inundation during a 5% AEP flood and 16 additional properties subject to above floor flooding during a 1% AEP flood. Flood damage costs are also predicted to increase by about $20 million during the 5% AEP flood and more than $23 million during a 1% AEP flood.

4 OPTIONS FOR MANAGING THE FLOOD RISK

4.1 General

As outlined in Section 3, a number of existing properties within the South Murwillumbah area are predicted to be exposed to a significant flood risk and/or significant financial impacts during floods as frequent as the 20% AEP event. The following chapters outline options that could be potentially implemented to build upon current emergency response protocols to better manage this flood risk.

4.2 Potential Options for Managing the Flooding Risk

4.2.1 Types of Options

Options for managing the flood risk can be broadly grouped into one of the following categories:

- **Flood Modification Options**: are measures that aim to modify existing flood behaviour, thereby, reducing the extent, depth and velocity of floodwater across flood liable areas. Flood modification measures will generally benefit a number of properties and are primarily aimed at reducing the existing flood risk. Flood Modification Options are discussed in Section 5.
- **Property Modification Options**: refers to modifications to planning controls and/or modifications to individual properties to reduce the potential for inundation in the first instance or improve the resilience of properties should inundation occur. Modifications to individual properties is typically used to manage existing flood risk while planning measures (e.g., land use/development controls) are employed to manage future flood risk. Property Modification Options are discussed in Section 6.
- **Response Modification Options**: are measures that can be implemented to change the way in which emergency services as well as the public responds before, during and after a flood. Response modification measures are the key measures employed to manage the continuing flood risk. Response Modification Options are discussed in Section 7.

4.2.2 Options Considered as Part of Current Study

An initial list of potential flood risk management options was prepared for consideration by Council and the Floodplain Risk Management Committee. The initial list of risk management measures was developed based upon consideration of the following factors:

- Location of high flood risk/high flood damage properties
- Recommendations in previous reports
- Council recommendations
- Community feedback

A total of 35 options were initially identified and these options are summarised in **Table 17** (flood modification options), **Table 18** (property modification options) and **Table 19** (response modification options).

Table 17 Preliminary List of Flood Modification Options Considered for Managing the Flood Risk

Potential Flood Modification Options	Description of Option
Topographic Modifications/Auxiliary Flow Paths	
Remove Airfield fill	Remove existing hangers and fill across Murwillumbah Airfield to allow water to drain more readily through industrial area
Railway Street flow path	Lower ground elevations between Railway Street and Durrington St to provide additional flow path towards Tweed River
Earthworks across Lot 4 DP 591604 Quarry Road	Lower ground elevations across Lot 4 DP 591604 Quarry Road to a similar elevation as Quarry Road to provide a flow path for floodwaters to more readily "escape" from the South Murwillumbah Basin across Quarry Road and into the Condong Basin
Earthworks across Lot 4 DP 591604 Quarry Road and inclusion of additional culvert across Quarry Road	Lowering terrain across Lot 4 to lower than Quarry Road, elevation of Quarry Road and providing of additional culverts beneath Quarry Road.
Earthworks across Lot 4 DP 591604, two adjoining lots on Quarry Road and Airfield	Lower ground elevations across Lot 4 DP 591604 Quarry Road as well as adjoining lots located north and south of Lot 4 as well as airfield to provide a flow path for floodwaters to more readily "escape" from the South Murwillumbah Basin across Quarry Road and into the Condong Basin
Durrington Street flow path	Lower ground elevations near the western end of Durrington Street to provide additional flow path towards Tweed River
Earthworks at The Bluff	Topographic modifications to reduce flow "constriction" in the vicinity The Bluff
Modify terrain between River Street and Tweed River	Purchase existing properties and lower existing ground surface elevations between River Street and the Tweed River to provide additional flow carrying capacity
South Murwillumbah high flow bypass	Purchase of existing properties in vicinity of Colin St between River St and Tweed Valley Way and reshaping of terrain to create additional flow path between Tweed River and railway line
Levee Modifications	
Levee Rehabilitation	Elevate sections of the South Murwillumbah levee that have "settled" over time to original design elevations and construct dedicated spillway to allow for controlled levee overtopping
Raising South Murwillumbah Levee to 20%AEP Level	Raise existing South Murwillumbah levee to provide protection during the 20% AEP flood
Raising South Murwillumbah Levee to 5%AEP Level	Raise existing South Murwillumbah levee to provide protection during the 5% AEP flood
Road, Railway & Bridge Modifications	
Alma Street modification	Elevate low point in Alma St to reduce frequency of overtopping and provide additional evacuation time from South Murwillumbah into town
Modify railway embankment	Remove elevated section of railway line to allow floodwaters to more readily move from the residential area of South Murwillumbah
Additional railway culvert/bridge	Provide additional culvert/bridge opening in existing railway embankment to allow floodwaters to more readily move from the residential areas of Murwillumbah
Additional Murwillumbah bridge opening	Provide additional "opening" in eastern approach to Murwillumbah bridge to provide additional conveyance through bridge.
Elevate Tweed Valley Way at Blacks Drain	Elevate Tweed Valley Way at Blacks Drain to reduce frequency of overtopping and provide additional evacuation time

Potential Flood Modification Options	Description of Option
Elevate Tweed Valley Way north of Condong	Elevate Tweed Valley Way north of Condong (this is the location where Tweed Valley Way is first predicted to overtop) to reduce frequency of overtopping, provide additional evacuation time and reduce the volume of water entering the Condong Basin.
Elevate Tweed Valley Way downstream of Condong	Elevate the existing low point in Tweed Valley Way downstream of Condong to reduce frequency of roadway inundation and provide additional flood storage capacity in sugar cane fields by reducing the volume of water spilling across the road
Channel Modifications	
Dredge Tweed River channel	Lower bed elevation of Tweed River channel adjacent to South Murwillumbah to provide additional flow carrying capacity.
Blacks Drain modification	Widening of Blacks Drain between Tweed River and Condong Creek
Condong Creek Modifications	
Modify Condong Creek channel	Modify Condong Creek channel to include maintenance bench as outlined in 'Condong Creek Drainage Management Plan' (2018)
Condong Creek High Flow bench	Create high flow bench across eastern section of Boral site to carry additional flows into Tweed River when capacity of Condong Creek channel is exceeded
High level Condong Creek Outlet	Provision of additional set of high-level floodgate-protected outlets at flood gate 17L to allow area behind flood gates to begin draining sooner
Pump Systems	
Pump system behind Floodgate 17L	Provision of pump system behind floodgate 17L to assist in more rapidly draining floodwater from industrial area
Pump system behind Blacks Drain floodgate	Provision of pump system behind Tweed Valley Way crossing of Blacks Drain to assist in more rapidly draining floodwater from industrial area

Table 18 Preliminary List of Property Modification Options Considered for Managing the Flood Risk

Potential Property Modification Options	Description of Option
Residential Property Modifications	
Voluntary house purchase program	Review of Council's existing voluntary house purchase program
Voluntary house raising program	Review of Council's existing voluntary house raising program
Voluntary flood proofing	Flood proofing of select residential properties
Consolidation of residential lots	Consolidate (i.e., combine) select residential lots in South Murwillumbah to prevent intensification of development
Industrial and Commercial Property Modifications	
Temporary flood barriers	Temporary flood barriers that will reduce the potential for ingress of floodwaters into commercial properties
Minimum floor level requirement	Update of Council DCP to impose minimum floor level requirement for industrial properties

Potential Property Modification Options	Description of Option
Industrial Land Swap	
Land swap option 1	Relocation of industrial properties and/or lowering of ground elevations across all critical flood zone lots with a total "score" of between 1 and 15 (15 lots total)
Land swap option 2	Relocation of industrial properties and/or lowering of ground elevations across all critical flood zone lots with a total "score" of above 16 (30 lots total)

Table 19 Preliminary List of Response Modification Options Considered for Managing the Flood Risk

Potential Response Modification Options	Description of Option
Education	
Community education activities	Various community education activities to increase flood awareness and allow residents and business owners to be more self-sufficient during future floods
Private Flood Plans	
Preparation of residential flood plans	Preparation of flood plans by residential property occupiers to identify actions to be taken before during and after a flood
Preparation of business flood plans	Preparation of flood plans by business owners to identify actions to be taken before during and after a flood
Miscellaneous	
Local flood plan updates	Update SES local flood plan to take advantage of updated flood information generated as part of the current study
Flood warning system upgrades	Updates to existing flood warning system to improve the dissemination of flood information
Install automated flood gates	Install automatic flood gates at known roadway overtopping points to prevent the community driving through floodwater

A preliminary assessment of each option was completed to provide an initial assessment of the potential feasibility of each option and to determine which measures showed merit for the detailed feasibility assessment. The adopted evaluation criteria/scoring system is summarised in **Table 20** and the outcomes of the assessment are provided in **Table 21**, **Table 22** and **Table 23**.

As shown in **Table 20** each measure was evaluated against six criteria. The expected performance of each measure against each criterion was scored between -2 (significant negative impact) and +2 (significant positive impact).

Table 20 Adopted Evaluation Criteria and Scoring System for Qualitative Assessment of Flood Risk Management Options

Score:	Change in Flood Levels/Extents	Emergency Response	Technical Feasibility	Environmental Impacts	Economic Feasibility	Community Acceptance
-2	Significant increases in levels/extents	Significant disbenefit to emergency services	Significant technical challenges	Significant impacts	Costs significantly outweigh benefits	Majority of community opposed
-1	Minor increases in levels/extents	Slight disbenefit to emergency services	Some technical challenges	Minor impacts	Costs outweigh benefits	Some opposed
0	Negligible changes in levels/extents	No impact on emergency services	Minor technical challenges	No impacts	Benefits and costs approximately equal	Neutral
+1	Minor decreases in levels/extents	Slight benefit to emergency services	Negligible technical challenges	Some benefits	Benefits outweigh costs	Some support
+2	Significant decreases in levels/extents	Significant benefit to emergency services	No technical challenges	Significant benefits	Benefits significantly outweigh costs	Majority of community support

Table 21 Qualitative Assessment of Preliminary List of Flood Modification Options

Potential Flood Modification Options	Evaluation Criteria/Score						
	Change in Flood Levels / Extents	Emergency Response	Technical Feasibility	Environmenta l Impacts	Economic Feasibility	Community Acceptance	Overall Score
Topographic Modifications							
Remove airfield fill	+1	0	0	0	-1	-1	**-1**
Railway Street flow path	+1	0	0	-1	1	-2	**-1**
Earthworks across Lot 4 DP 591604 Quarry Road	+1	0	+1	0	0	+1	**3**
Earthworks across Lot 4 DP 591604 Quarry Road and inclusion of additional culvert across Quarry Road	+1	+1	-1	-1	-1	0	**-1**
Earthworks across Lot 4 DP 591604, two adjoining lots on Quarry Road and Airfield	+1	0	+1	0	0	+1	**3**
Durrington Street flow path	+1	0	0	-1	+1	0	**1**
Earthworks at The Bluff	+1	0	-2	-1	-1	+1	**-2**

Potential Flood Modification Options	Evaluation Criteria/Score						
	Change in Flood Levels / Extents	Emergency Response	Technical Feasibility	Environmental Impacts	Economic Feasibility	Community Acceptance	Overall Score
Modify terrain between River Street and Tweed River	+1	0	0	1	-1	0	**1**
South Murwillumbah high flow bypass	+1	1	-2	1	-1	+1	**1**
Levee Modifications							
Levee Rehabilitation	0	+1	0	0	-1	0	**0**
Raising South Murwillumbah Levee to 20%AEP Level	+1	+1	-1	0	+1	-1	**1**
Raising South Murwillumbah Levee to 5%AEP Level	+2	+1	-1	0	0	-1	**1**
Road, Railway & Bridge Modifications							
Elevate Alma Street	+1	+1	-1	0	-1	+1	**1**
Additional Railway Bridge/Culvert	+1	0	-1	0	0	-1	**-1**
Modifications to railway embankment	+1	0	-1	0	-1	+1	**0**
Additional Murwillumbah bridge opening	+1	0	-2	0	-2	0	**-3**
Alma Street modification	+1	+1	-1	0	-1	+1	**1**
Elevate Tweed Valley Way downstream of Condong	0	+1	-1	0	-1	0	**-1**
Channel Modifications							
Dredge Tweed River channel	+2	0	0	-2	-2	+2	**0**
Blacks Drain modification	+2	0	-1	-1	-1	+1	**0**
Condong Creek Modifications							
Modify Condong Creek channel	0	0	0	+1	0	+1	**2**
Condong Creek High Flow bench	+1	0	0	0	-1	+1	**1**

Potential Flood Modification Options	Evaluation Criteria/Score						
	Change in Flood Levels / Extents	Emergency Response	Technical Feasibility	Environmental Impacts	Economic Feasibility	Community Acceptance	Overall Score
High level Condong Creek Outlet	+1	0	-1	0	-1	+1	**0**
Pump Systems							
Pump system behind Floodgate 17L	0	+1	-1	0	-1	0	**-1**
Pump system behind Blacks Drain floodgate	0	+1	-1	0	-1	0	**-1**

Table 22 Qualitative Assessment of Preliminary List of Property Modification Options

Potential Property Modification Options	Evaluation Criteria/Score						
	Change in Flood Levels / Extents	Emergency Response	Technical Feasibility	Environmental Impacts	Economic Feasibility	Community Acceptance	Overall Score
Residential Property Modifications							
Voluntary house purchase program	0	+2	0	+1	-2	0	**1**
Voluntary house raising program	0	-1	-1	0	0	-1	**-3**
Voluntary flood proofing	0	-1	0	0	-1	-2	**-4**
Consolidation of existing residential lots	0	+2	0	0	-1	-1	**0**
Industrial and Commercial Property Modifications							
Temporary flood barriers	0	0	0	0	+1	+1	**2**
Minimum floor level requirement	-2	0	-1	0	+1	0	**-2**
Industrial Land Swap							
Land swap option 1	+1	+1	-1	+1	0	+1	**3**
Land swap option 2	+1	+2	-1	+1	0	+1	**4**

Table 23 Qualitative Assessment of Preliminary List of Response Modification Options

Potential Response Modification Options	Evaluation Criteria/Score						
	Change in Flood Levels / Extents	Emergency Response	Technical Feasibility	Environmental Impacts	Economic Feasibility	Community Acceptance	Overall Score
Education							
Community education activities	0	+2	+1	0	+1	+1	5
Private Flood Plans							
Preparation of residential flood plans	0	+2	+1	0	+1	+1	**5**
Preparation of business flood plans	0	+1	+1	0	+1	+1	**4**
Miscellaneous							
Local flood plan updates	0	+2	+1	0	+1	+1	**5**
Flood warning system upgrades	0	+2	-1	0	-1	+1	**1**
Install automated flood gates	0	+1	-1	0	-1	-1	**-2**

The scores were summed to provide an overall score for each option and enable a means of comparing the different options as well as provide an initial assessment of whether specific options would provide a net positive outcome. Those options where the assessment yielded an overall score of equal to or greater than 0 are highlighted and were carried forward into the detailed assessment.

4.3 Flood Risk Management Options Assessed in Detail

Based upon the qualitative assessment presented in the previous section, the options listed in **Table 24** were selected for detailed assessment. In addition to the individual options listed in **Table 24**, a selection of combined options were also assessed.

4.4 Options Assessment Approach

Each flood risk management option will generally be a compromise as it is unlikely that an option will provide only benefits (e.g., there may be an adverse environmental impact or significant costs associated with the implementation of the option). In general, if the advantages associated with implementing the option outweigh the disadvantages, it will afford a net positive outcome and may be considered viable for future implementation. Therefore, each option in **Table 24** was evaluated in more detail against a range of criteria to provide an appraisal of the potential feasibility of each option.

Each flood and property modification option was evaluated against the following criteria, where sufficient information was available:

- Hydraulic impacts
- Change in number of buildings inundated above floor level
- Financial feasibility
- Community acceptance
- Environmental impacts
- Emergency responses impacts
- Technical feasibility

Further details on each of these evaluation criteria is presented below.

The response modification options were generally not evaluated against these criteria as they will generally have negligible hydraulic and environmental impacts, are difficult to quantify in monetary benefits (i.e., response modification options will generally not reduce flood damages) and will generally improve emergency response.

4.4.1 Hydraulic Impacts

Flood modification options and some property modification options will alter the distribution of floodwaters. Although this aims to reduce the extent and depth of inundation across populated areas, it may divert floodwaters elsewhere, thereby increasing the flooding risk across other areas. Therefore, it is important that the potential flood impacts associated with implementing each option is understood.

Table 24 Options Adopted for Detailed Investigations

Flood Modification Options		Property Modification Options		Response Modification Options	
FM1	Durrington Street flow path	PM1	Voluntary house purchase program	RM1	Community education activities
FM2	South Murwillumbah high flow bypass Option 1	PM2	Temporary flood barriers	RM2	Preparation of residential flood plans
FM3	South Murwillumbah high flow bypass Option 2	PM3	Land swap option A	RM3	Preparation of business flood plans
FM4	Earthworks across Lot 4 DP591604 Quarry Road	PM4	Land swap option B	RM4	Local flood plan updates
FM5	Earthworks across Lot 4 DP591604 Quarry Road, Two Adjoining Lots and Airfield	PM5	Consolidation of residential lots	RM5	Flood warning system upgrades
FM6	Modify terrain between River Street and Tweed River				
FM7	Levee Rehabilitation				
FM8	Raising South Murwillumbah Levee to 20%AEP Level + Raising Height of CBD Levee				
FM9	Raising South Murwillumbah Levee to 5%AEP Level + Raising Height of CBD Levee				
FM10	Elevating Alma Street				
FM11	Modify railway embankment				
FM12	Elevate Tweed Valley Way at Blacks Drain				
FM13	Dredge Tweed River channel				
FM14	Blacks Drain modification				
FM15	Modify Condong Creek channel				
FM16	Condong Creek high flow bench				
FM17	High level Condong Creek outlet				
FM18	South Murwillumbah High Flow Bypass Option 1 and Industrial Land Swap Option 1B				
FM19	Raising South Murwillumbah Levee to 5% AEP Level, Condong Creek Modifications and Industrial Land Swap Option 1A				
FM20	Raising South Murwillumbah Levee to 20%AEP Level, Raising CBD Levee, Condong Creek Modifications and Lot 4 Quarry Road Earthworks				

To assess the hydraulic impact of each flood modification option and select property modification options, the TUFLOW hydraulic model that was used to define existing flood behaviour was updated to include each flood modification option. The updated TUFLOW models were then used to re-simulate each of the design floods. The flood level and extent results from the revised simulations were compared against the flood level and inundation extent results from the existing conditions/do nothing scenario to prepare "difference mapping". The difference mapping shows the magnitude and location of changes in flood levels and inundation extents associated with implementation of the option.

4.4.2 Financial Feasibility

A preliminary economic assessment of each flood modification and selected property modification options was completed to assist in determining the financial viability of each option. The assessment was completed by estimating the 'costs' and 'benefits' that could be expected if the option was implemented. This enabled a benefit cost ratio (BCR) to be prepared for each option.

From a flooding perspective, economic 'benefits' were quantified as the reduction in flood damage costs that could be expected if the option is implemented. The benefit of each option was quantified by preparing damage estimates for each design flood event with the option in place and using this information to prepare a revised average annual damage (AAD) estimate. In order for a BCR to be estimated, it is necessary to modify the 'base' AAD estimates (which reflect the average damage that is likely to be incurred in a single year) to a total damage that could be expected to occur over the life of each flood risk management option. Accordingly, the AAD estimates were accumulated over a 50-year period and then discounted to a present-day value by applying a discount rate of 7%.

Cost estimates have also been prepared for each option. The cost estimate includes capital costs as well as ongoing costs (e.g., maintenance) to provide a total life cycle cost for each option. It was assumed that each option has a design life of 50 years for the purposes of establishing the life cycle cost.

The cost estimates were prepared using the best available information. However, the designs presented in this report are concept designs only. Precise cost estimates can only be prepared following detailed investigations and once design plans have been prepared. Therefore, the cost estimates presented in this report should be considered approximate only. Nevertheless, they are considered suitable for providing an initial appraisal of the financial viability of each option. Prior to any option proceeding to implementation, it is recommended that detailed concept design plans are prepared for the option to allow for a revised cost estimate to be prepared.

The BCR provides the following economic insights:

- BCR > 1: The economic benefits are predicted to be greater than the cost to implement the option.
- 0 < BCR < 1: There is still an economic benefit (i.e., reduction in flood damage costs). However, the cost of implementing the option is greater than the economic benefit.
- BCR = 0: There is no economic benefit (i.e., no reduction in flood damage costs) associated with implementing the option.

- BCR < 0 (i.e., negative): Implementing the option is predicted to generate a negative economic impact (i.e., increase flood damage costs).

4.4.3 Community Acceptance

Floodplain risk management options do have the potential to impact on the broader community in both beneficial and adverse ways. For example, a levee may reduce the potential for inundation of a property but may also remove water views. Therefore, the community's attitudes towards each option can have a significant impact on the viability of an option.

A community questionnaire was distributed to approximately 800 residents and business owners within the study area. The questionnaire provided the community with the list of flood risk management options that were being considered as part of the study and sought feedback from the community regarding each of these options (i.e., whether they opposed or supported the option). A summary of the responses to the questionnaire are included in the discussion on each option to gain an understanding of the community's attitudes towards each option.

4.4.4 Environmental Impacts

Any flood risk management option that involves structural works on the floodplain has the potential to impact on local flora and/or fauna. At the same time, some options may provide an opportunity to improve the local environment. Therefore, the potential environmental impact was considered as part of the evaluation of each structural option.

4.4.5 Emergency Response Impacts

Emergency response is arguably one of the most important measures for managing the continuing flood risk across any catchment, particularly during very large floods where flood modification options may not be effective. Therefore, the potential for each option to impact on current emergency response processes was considered as part of the assessment of each option.

4.4.6 Technical Feasibility

If a structural option is proposed, it needs to be physically possible to construct the option considering the option itself as well as any local constraints. Therefore, an assessment of any technical impediments was completed for each option to determine if there would be any "show stoppers" that may render the option impractical.

4.5 Summary

The options that were considered for managing the existing, future and residual flood risk (refer **Table 24**) are discussed in detail in the following chapters:

- Flood Modification Options: Chapter 5.
- Property Modification Options: Chapter 6.
- Response Modification Options: Chapter 7.

5 Flood Modification Options

5.1 Introduction

Flood modification options are measures that aim to modify existing flood behaviour, thereby, reducing the extent, depth and velocity of floodwater across developed/populated areas. Flood modification measures will generally benefit multiple properties and are primarily aimed at reducing the existing flood risk.

Flood modification options considered as part of the study included:

Topographic Modification/Auxiliary Flow Paths:

- FM1 - Durrington Street flow path;
- FM2 - South Murwillumbah high flow bypass option 1;
- FM3 - South Murwillumbah high flow bypass option 2;
- FM4 - Earthworks across Lot 4 DP 591604 Quarry Road
- FM5 - Earthworks across Lot 4 DP 591604 Quarry Road, Two Adjoining Lots and Airfield
- FM6 - Modify terrain between River Street and Tweed River

Levee Modifications:

- FM7 - Levee Rehabilitation
- FM8 - Raising South Murwillumbah Levee to 20%AEP Level + Raising Height of CBD Levee
- FM9 - Raising South Murwillumbah Levee to 5%AEP Level + Raising Height of CBD Levee

Road, Railway and Bridge Modifications:

- FM10 - Elevating Alma Street;
- FM11 - Modify railway embankment;
- FM12 - Elevate Tweed Valley Way at Blacks Drain;

Channel Modifications:

- FM13 - Dredge Tweed River channel;
- FM14 - Blacks Drain modification;

Condong Creek Modifications:

- FM15 - Modify Condong Creek channel;
- FM16 - Condong Creek high flow bench; and,
- FM17 - High level Condong Creek outlet.

Combined Options:

- FM18 - South Murwillumbah High Flow Bypass Option 1 and Industrial Land Swap Option 1A
- FM19 - Raising South Murwillumbah Levee to 5% AEP Level, Raising CBD Levee, Condong Creek Modifications and Industrial Land Swap Option 1A
- FM20 - Raising South Murwillumbah Levee to 20%AEP Level, Raising CBD Levee, Condong Creek Modifications and Lot 4 Quarry Road Earthworks

Table 25 Summary of Economic Assessment for Flood Modification Options

Option		$ Millions				
		Cost	Existing Flood Damage	Total Damage with Option in Place	Reduction in Damage with Option in Place	Benefit-Cost Ratio
FM1	Durrington Street Flow Path	13.7	60.5	59.9	0.6	0
FM2	South Murwillumbah high flow bypass Option 1	17.6		63.7	-3.2	-0.2
FM3	South Murwillumbah high flow bypass Option 2	5.5		59.6	0.9	0.2
FM4	Earthworks across Lot 4 DP 591604 Quarry Road	0.4		60	0.5	1.2
FM5	Earthworks across Lot 4 DP 591604 Quarry Road, two adjoining lots and Airfield	4.1		58.8	1.7	0.4
FM6	Modify terrain between River Street and Tweed River	20.7		59.2	1.3	<0.1
FM7	Levee Rehabilitation	1.2		60.4	0.1	<0.1
FM8	Raising South Murwillumbah Levee to 20%AEP Level + Raising Height of CBD Levee	14.0		39.9	20.6	1.5
FM9	Raising South Murwillumbah Levee to 5%AEP Level + Raising Height of CBD Levee	18.6		37.7	22.8	1.2
FM10	Elevating Alma Street	0.4		60.5	0	0
FM11	Modify railway embankment	0.8		60.3	0.2	0.25
FM12	Elevate Tweed Valley Way at Blacks Drain	1.3		60.4	0.1	<0.1
FM13	Dredge Tweed River channel	7.8		58.8	1.7	0.2
FM14	Blacks Drain modification	4.0		60.8	-0.3	-0.1
FM15	Modify Condong Creek channel	0.3		60.4	0.1	0.3
FM16	Condong Creek high flow bench	5.5		59.4	1.1	0.2
FM17	High level Condong Creek outlet	1.2		60.5	0	0
FM18	South Murwillumbah High Flow Bypass Option 1 and Industrial Land Swap Option 1B	28.9		55.1	5.4	0.2
FM19	Raising South Murwillumbah Levee to 5% AEP Level, Condong Creek Modifications and Industrial Land Swap Option 1A	25.6		33.0	27.5	1.1
FM20	Raising South Murwillumbah Levee to 20%AEP Level, Raising CBD Levee, Condong Creek Modifications and Lot 4 Quarry Road Earthworks	14.8		39.4	21.1	1.4

As discussed in Section 5.4.1, the hydraulic benefits of each flood modification option was assessed by including the option in the flood model and using the updated model to re-simulate each design flood. The hydraulic benefits were then quantified by preparing flood level difference mapping for each option.

Cost estimates for each option were also prepared and are summarised in **Table 25**. **Table 25** also summarises the predicted reduction in flood damage costs if the option was implemented along with the associated benefit-cost ratio.

Further detailed discussion on each flood modification option investigated to assist in managing the flood risk is presented in the following sections.

5.2 Topographic Modifications/Auxiliary Flow Paths

5.2.1 FM1 - Durrington Street Flow Path

Recommendation: Not recommended for implementation

A concept plan for the Durrington Street Flow Path is included in **Figure 33**. As shown in **Figure 33** this option will involve lowering existing ground surface elevations near the western end of Durrington Street to provide an additional flow path from the South Murwillumbah Basin back into the Tweed River. This will involve the removal of more than 3 metres depth of fill at some locations (refer to **Figure 33.2**). A large culvert or bridge structure will also need to be provided to allow water from the flow path to pass beneath Tweed Valley Way and into the Tweed River.

The concept design for the Durrington Street flow path was included in the TUFLOW model and the updated model was used to re-simulate each design flood. Peak flood level difference mapping for the 20% and 1% AEP events with this option in place were prepared and are presented in **Plate 8** and **Plate 9**.

Plate 8 and **Plate 9** shows that this option is predicted to generate localised increases and decreases in existing flood levels. More specifically, the following changes in flood levels are anticipated:

- 20% AEP flood: minor reductions (i.e., <0.02m) are predicted across the South Murwillumbah basin with slightly greater reductions between the railway line and Tweed Valley Way (0.05m) and much greater reductions across the western end of Durrington St (>0.2m). No significant increases in flood levels are predicted at any location.
- 1% AEP flood: 0.03 metre reductions are predicted across industrial properties located south of Durrington Street and 0.02 metres reductions are predicted east of Quarry Road. Increases of between 0.02m and 0.03m are predicted within the Tweed River downstream of the bridge.

The flood level reductions are not predicted to alter the number of properties exposed to above floor inundation during any design flood.

Plate 8 20% AEP Flood Level Difference Map for Durrington Street Flow Path (FM1)

Plate 9 1% AEP Flood Level Difference Map for Durrington Street Flow Path (FM1)

The cost to implement the Durrington Street is estimated to be about $13.7 million. A significant contributor to the cost is the acquisition of five properties and the construction of a new bridge/culvert across Tweed Valley Way. A breakdown of costs is provided in **Appendix J**.

The potential financial benefit associated with implementation of the flow path was quantified by preparing revised flood damage calculations based upon the hydraulic modelling results with the flow path in place. The outcomes of the revised damage assessment determined that a reduction in total flood damage costs of around $0.6 million was predicted over the next 50-years. This yielded a preliminary benefit-cost ratio of less than 0.1. Accordingly, the financial cost of implementing this option outweighs the financial benefits.

This option was generally supported by the community with 56% of questionnaire respondents either supporting or strongly supporting the option. Only 7% of respondents did not support the option.

Overall, this option affords some localised reductions in flood levels and flood damages. However, these benefits are not sufficient enough to outweigh the significant capital costs. In addition, the construction works would provide a significant disruption to local traffic, particularly along Tweed Valley Way. Therefore, this option is not recommended for implementation as it currently stands.

5.2.2 FM2 - South Murwillumbah High Flow Bypass Option 1

Recommendation: Not recommended for implementation

Two different options were investigated for the South Murwillumbah High Flow Bypass. The concept plan for option 1 is provided in **Figure 34** (Option 2 is discussed in Section 5.2.3). As shown in **Figure 34** this option will involve constructing an auxiliary flow path from the Tweed River through a section of the residential area of South Murwillumbah. The implantation of this option would incorporate the following works:

- Purchase of 8 existing residential properties located between Colin Street and Orme Street (it is noted that 4 of the properties that would need to be acquired as part of this option are identified under Tweed Shire Council's draft Voluntary Purchase Scheme, which is discussed further in Section 6.2).
- Regrading land between the Tweed River and the railway line (including removal of a section of the railway embankment).
- Extension of existing levees along Orme Street and Colin Street to ensure the level of protection provided by the existing levee is not compromised.
- Construction of a new bridge or culvert system across the new bypass channel for Tweed Valley Way.

It is noted that extension of the levee system along Colin Street will create a flow obstruction for the existing south-north flow path that runs adjacent to Wardrop Street. Therefore, it will also be necessary to implement new drainage infrastructure (i.e., new culverts) to allow water to drain from behind the new levee embankments towards the South Murwillumbah Basin.

The location where new pipes/culverts will be required as part of this option is shown in **Figure 34.**

The concept design for the Option 1 High Flow Bypass was included in the TUFLOW model and the updated model was used to re-simulate each design flood. Peak floodwater level difference mapping for the 20% AEP flood with this option in place is presented in **Plate 10** and **Plate 11** and the difference mapping for the 1% AEP flood is provided in **Plate 12** and **Plate 13**.

Plate 10 and **Plate 11** shows that this option is predicted to produce some notable changes to existing 20% AEP flood levels. More specifically, flood level reductions of up to 0.15 metres are predicted across the residential areas of South Murwillumbah. Flood level reductions of around 0.1 metres are predicted along the Tweed River channel and these reductions are predicted to extend upstream to Bray Park and almost downstream to Condong. Accordingly, the high flow bypass affords some significant benefits during smaller design floods. However, it is noted that flood levels across the South Murwillumbah basin are predicted to increase by around 0.5 metres, which is predicted to extend across multiple industrial properties. This significant increase in flood level is associated with the bypass directing additional flow into the South Murwillumbah basin during the 20% AEP flood.

Plate 12 and **Plate 13** shows that the high flow bypass is predicted to reduce 1% AEP flood levels along the Tweed River by around 0.04 metres. These reductions are predicted to extend across some of the residential areas of South Murwillumbah as well as a significant area upstream of Murwillumbah and South Murwillumbah (including Bray Park). However, **Plate 12** also shows that the bypass is predicted to increase flood levels across the South Murwillumbah basin and these flood level increases are predicted to extend across multiple industrial properties as well as some of the residential and commercial areas of South Murwillumbah. The flood level increases across these areas is typically between 0.02 and 0.1 metres. Flood level increases are predicted to extend as far downstream as Condong (although most of the increases are predicted to occur across sugar cane fields and are less than 0.05 metres).

Overall, the difference maps do show that the bypass would produce reductions in flood levels along the Tweed River and across parts of the residential sections of South Murwillumbah during each design flood. However, the bypass also directs more water into the South Murwillumbah basin, which consumes a significant flood storage volume by the time the peak of each design flood arrives. This is predicted to adversely impact on a significant number of industrial properties across South Murwillumbah during each design flood as well as some residential properties during large floods. Therefore, the hydraulic results indicate that this option is difficult to support from a flood impact perspective. Nevertheless, the hydraulic viability of this option could be improved if it was coupled with an option that served to reduce flood levels across the South Murwillumbah basin, such as the industrial land swap option.

The cost to implement the high flow bypass is estimated to be about $17.6 million. Accordingly, the cost of this option is predicted to be significant. A breakdown of costs is provided in **Appendix J**.

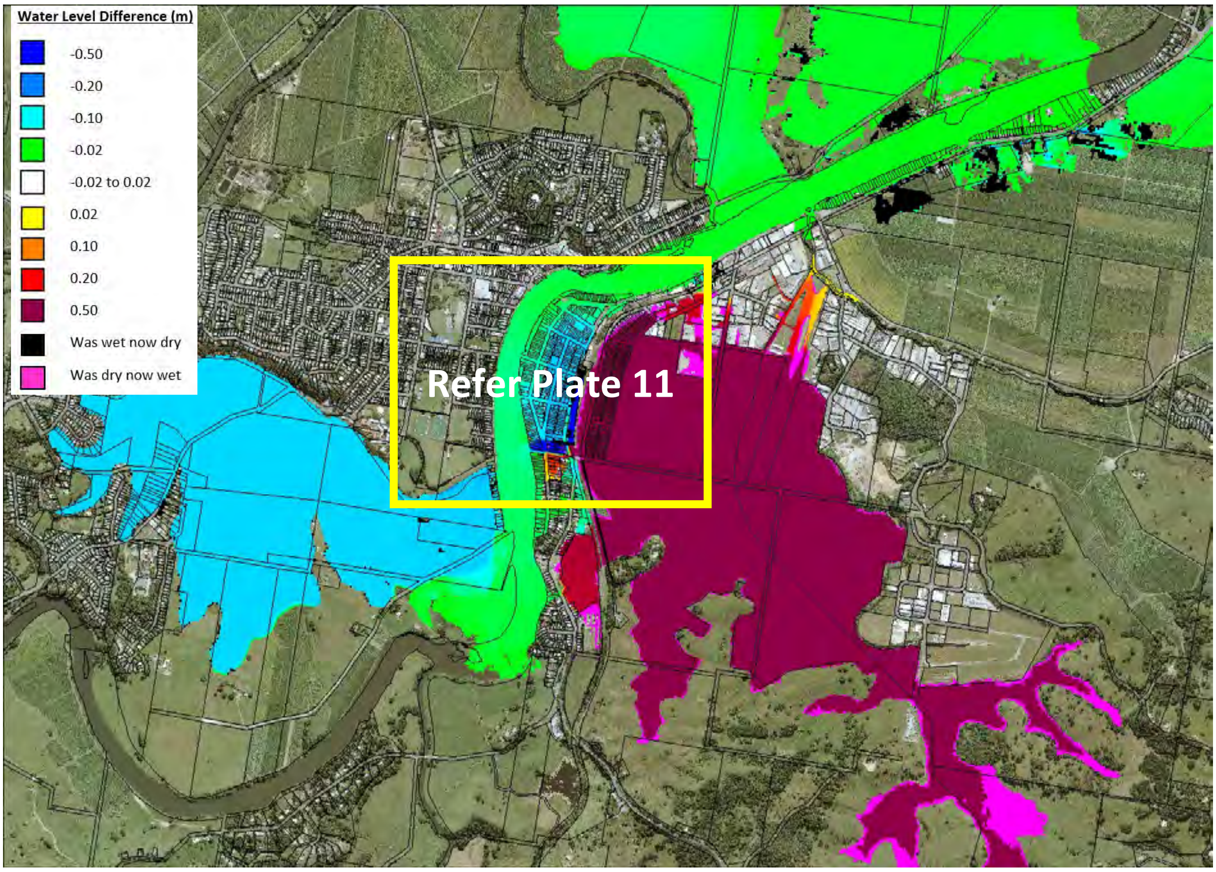


Plate 10 20% AEP Flood Level Difference Map for South Murwillumbah High Flow Bypass Option 1 (FM2)

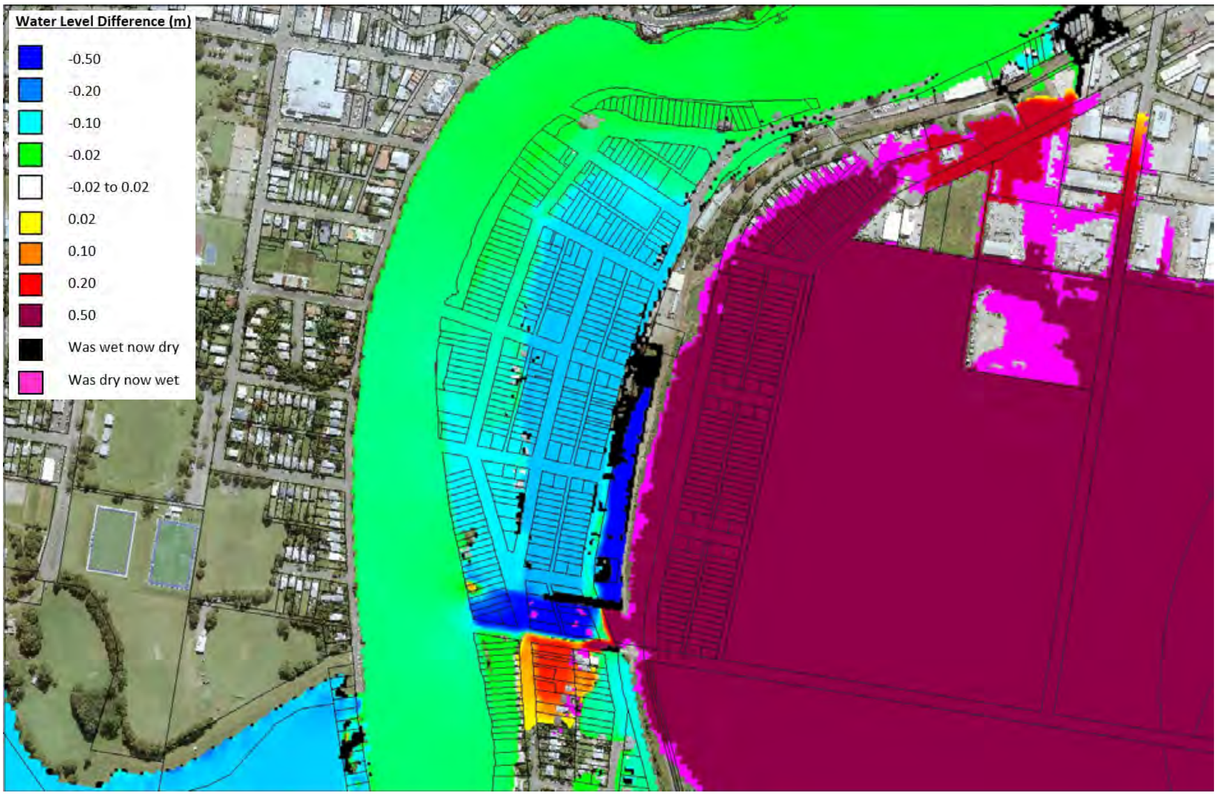


Plate 11 20% AEP Flood Level Difference Map for South Murwillumbah High Flow Bypass Option 1 (Detailed)

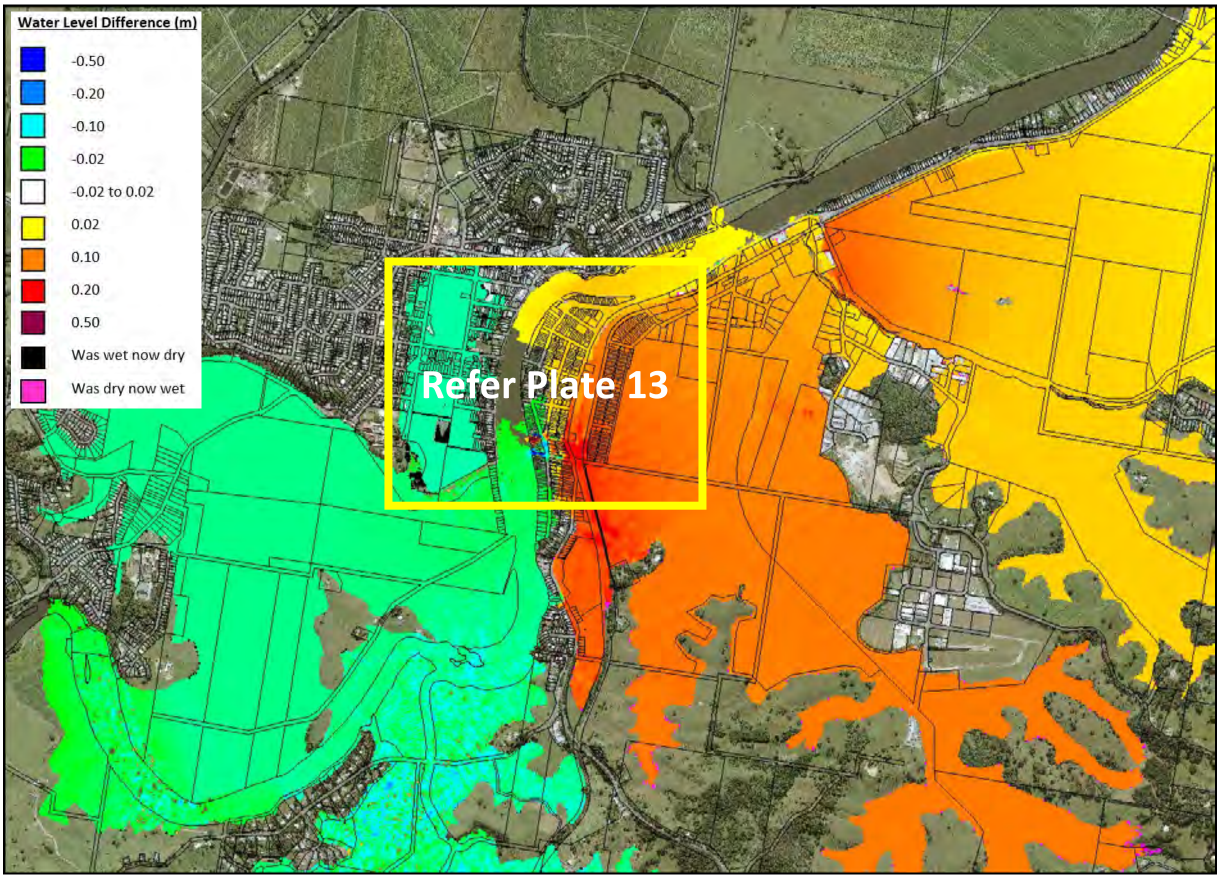


Plate 12 1% AEP Flood Level Difference Map for South Murwillumbah High Flow Bypass Option 1 (FM2)

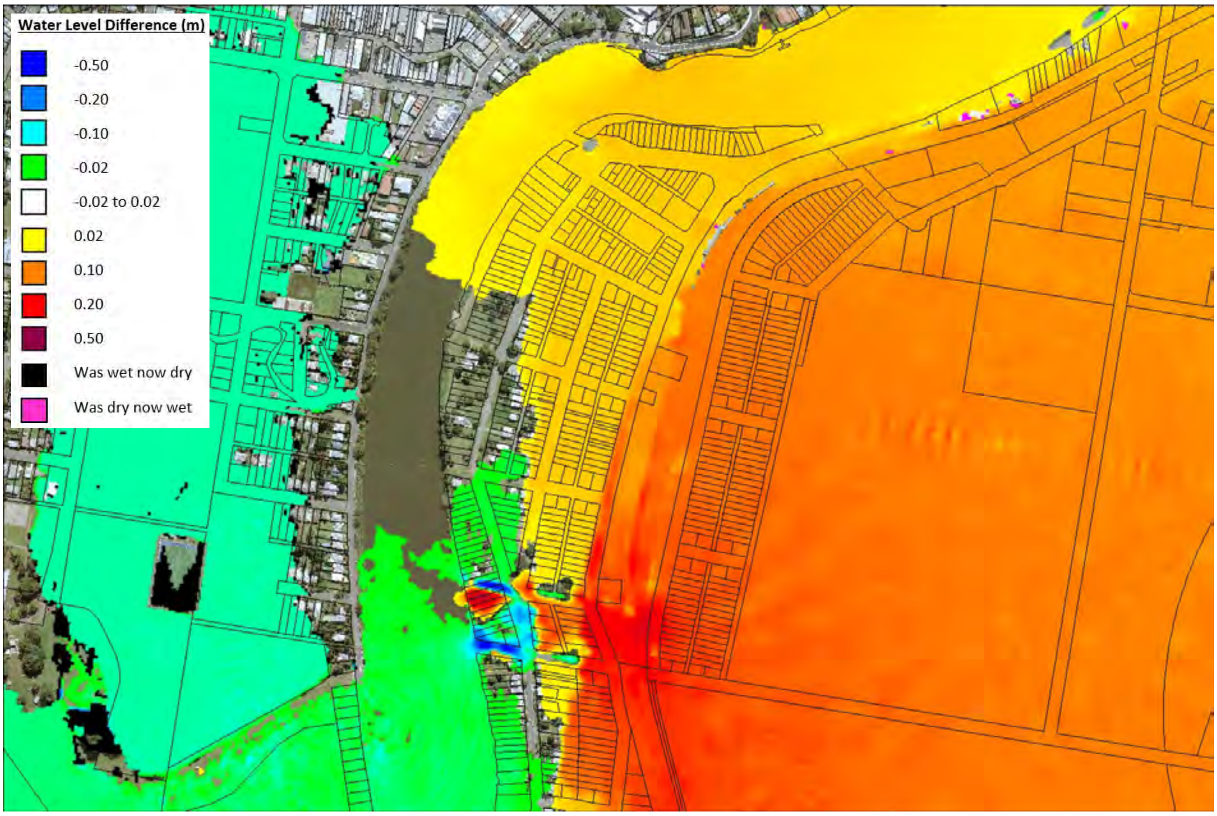


Plate 13 1% AEP Flood Level Difference Map for South Murwillumbah High Flow Bypass Option 1 (Detailed)

The potential financial benefit associated with implementation of the bypass was quantified by preparing revised flood damage calculations based upon the hydraulic modelling results with the bypass in place. The outcomes of the revised damage assessment determined that the total flood damage costs were predicted to increase by $3.2 million as a result of this option. Accordingly, this provides a negative benefit cost ratio.

Although this option was generally supported by the community with (57% of respondents either supporting or strongly supporting the option), around 15% did not support the option. Therefore, it was one of the options that garnered the most negative feedback relative to other options.

This option, when considered in isolation, cannot be supported owing to its significant capital costs and the fact that flood damages are predicted to increase as a result of its implementation. Nevertheless, it is predicted to reduce flood levels along the Tweed River as well as parts of the residential sections of South Murwillumbah. Therefore, if this option was combined with an option that can offset the flood level increases across the South Murwillumbah basin, it may improve the viability of this option. In this regard, the bypass was assessed in combination the industrial land swap option. This outcomes of the assessment of this combined option is discussed in Section 5.7.1.

5.2.3 FM3 - South Murwillumbah High Flow Bypass Option 2

Recommendation: Not recommended for implementation

As discussed, two different options were investigated for the South Murwillumbah High Flow Bypass. The concept plan for Option 2 is provided in **Figure 35**. As shown in **Figure 35** this option will involve constructing an auxiliary flow path from River Street through a part section of the residential area of South Murwillumbah and into the South Murwillumbah basin. The implantation of this option would incorporate the following works:

- Purchase of 3 existing residential properties located between Colin Street and Orme Street (it is noted that each of these properties is identified under Tweed Shire Council's draft Voluntary House Purchase Scheme, which is discussed further in Section 6.2).
- Acquisition of an additional 3 vacant residential allotments. 3 "RE1" allotments adjoining Tweed Valley Way" would also be used as part of this option.
- Lowering existing "high" terrain between River Street and the railway line to a maximum elevation of 2.5 mAHD (including removal of a part section of the railway embankment).
- Construction of a new bridge or culvert system across the new channel for Tweed Valley Way.

Unlike Option 1, Option 2 would not modify the existing South Murwillumbah levee. That is, Option 2 would only be "activated" once the existing levee is overtopped and would provide an auxiliary flow path for water to "escape" from the residential and commercial areas of South Murwillumbah.

The concept design for the Option 2 High Flow Bypass was included in the TUFLOW model and the updated model was used to re-simulate each design flood. Peak floodwater level difference mapping for the 20% AEP flood with this option in place is presented in **Plate 14** and the difference mapping for the 1% AEP flood is provided in **Plate 15.**

Plate 14 shows that this option is predicted to produce some notable changes to existing 20% AEP flood levels. More specifically, flood level reductions of up to 0.5 metres are predicted across the residential areas of South Murwillumbah. Flood level reductions of around 0.15 metres are predicted along the Tweed River channel and these reductions are predicted to extend upstream to Bray Park and downstream of Condong. However, flood levels across the South Murwillumbah basin are predicted to increase by more than 0.8 metres, which is predicted to extend across multiple industrial properties and several residential properties. Therefore, relative to FM2, FM3 is predicted to afford greater flood level reductions across the residential and commercial areas of South Murwillumbah but larger increases across the industrial areas during the 20% AEP flood.

Plate 15 shows that the high flow bypass is predicted to reduce 1% AEP flood levels along the Tweed River by around 0.02 metres. These reductions are predicted to extend across some of the residential areas of South Murwillumbah as well as a significant area upstream of Murwillumbah and South Murwillumbah (including the Murwillumbah CBD and Bray Park). However, **Plate 15** shows that, like FM2, the bypass is predicted to increase flood levels across the South Murwillumbah basin and these flood level increases are predicted to extend across multiple industrial properties as well as some of the residential and commercial areas of South Murwillumbah. The flood level increases across these areas are typically 0.03 metres. Therefore, the magnitude of the flood level increases for FM3 are not as substantial as FM2.

The cost to implement the Option 2 high flow bypass is estimated to be about $5.5 million. A breakdown of costs is provided in **Appendix J**.

The potential financial benefit associated with implementation of the Option 2 bypass was quantified by preparing revised flood damage calculations based upon the hydraulic modelling results with the bypass in place. The outcomes of the revised damage assessment determined that total flood damage costs are predicted to reduce by $0.9 million over the next 50 years if this option was implemented. This provided a benefit cost ratio of 0.2. Therefore, FM3 provides a better economic performance relative the FM2, however, the benefit cost ratio is still well below 1.

The low benefit cost ratio makes this option difficult to support. Like FM2, the viability of this option could be potentially improved by combining it with an option that reduces flood levels across the South Murwillumbah, such as FM4 or the industrial land swap option (PM3 and PM4). However, as it currently stands, this option is not recommended for implementation.

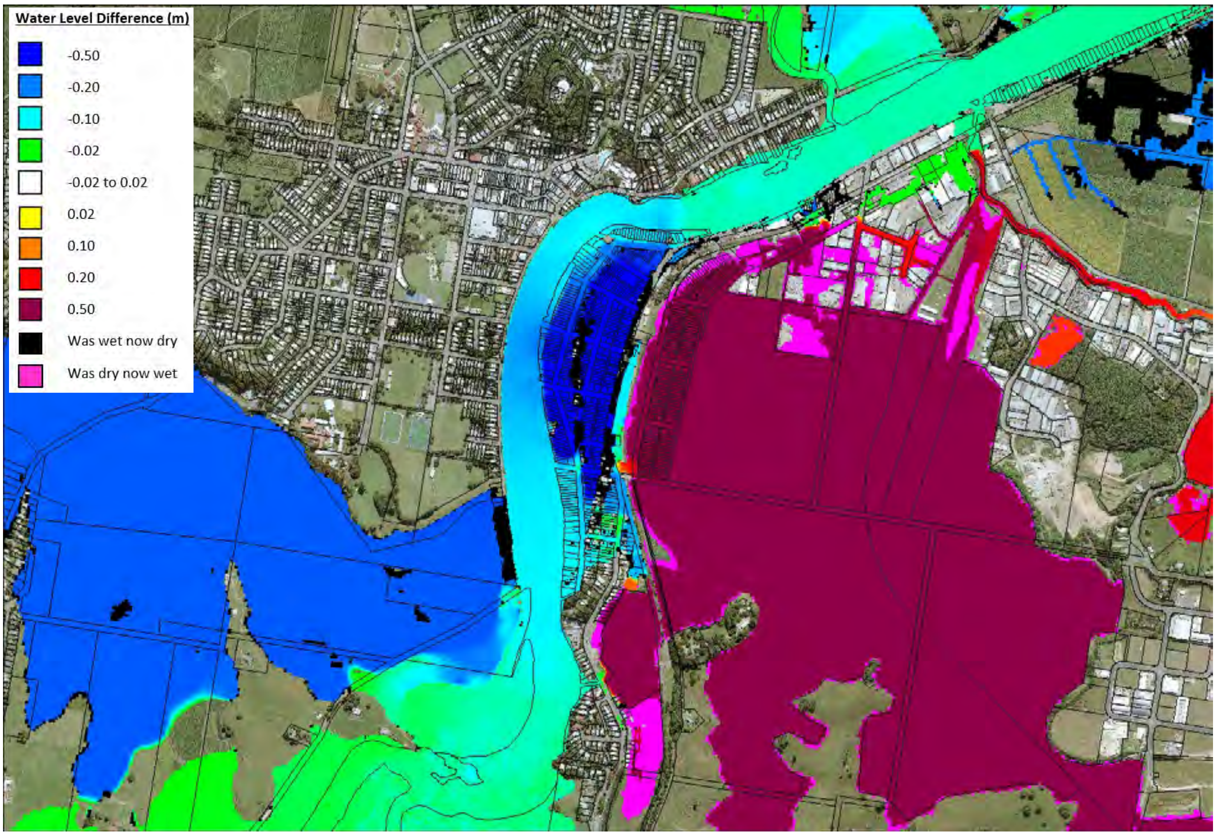


Plate 14 20% AEP Flood Level Difference Map for South Murwillumbah High Flow Bypass Option 2 (FM3)

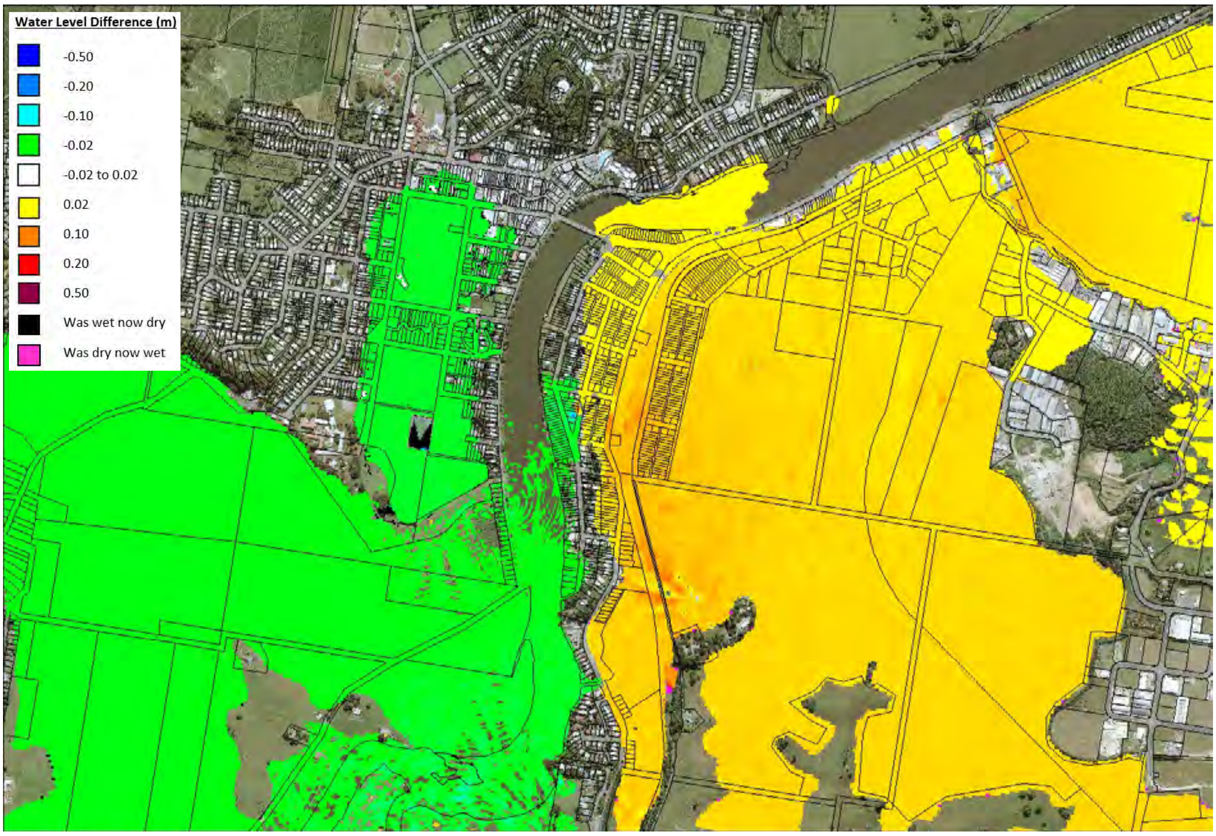


Plate 15 1% AEP Flood Level Difference Map for South Murwillumbah High Flow Bypass Option 2 (FM3)

5.2.4 FM4 – Earthworks across Lot 4 DP 591604 Quarry Road

Recommendation: Recommended for implementation

As discussed in Section 2.3.6, a key recommendation of the *'Tweed Valley Floodplain Risk Management Plan'* (WBM BMT, 2014) was the preservation of the South Murwillumbah Condong Flowpath, particularly Lot 4 DP 591604 Quarry Road. Following on from this recommendation, Council subsequently purchased Lot 4.

The *'Tweed Valley Floodplain Risk Management Plan'* also suggested that there may be opportunities to improve the conveyance capacity of the South Murwillumbah Condong Flowpath by lowering the existing ground surface elevations across Lot 4. Therefore, this option investigated the potential benefits associated with lowering the ground surface elevation across Lot 4 to approximately the same elevation as the adjoining Quarry Road. As shown in **Figure 36**, this will typically require the existing ground surface elevations across Lot 4 to be lowered by more than 1 metre.

The earthworks across Lot 4 were included in the TUFLOW model and the updated model was used to re-simulate each design flood. Peak floodwater level difference mapping was prepared and is shown in **Plate 16** for the 1% AEP flood. Difference mapping was also prepared for the 20% AEP flood, but it demonstrated negligible changes in 20% AEP flood level. The lack of hydraulic benefits during the smaller floods is associated with water not being sufficiently elevated to spill across Lot 4 during these events.

Plate 16 shows that the earthworks across Lot 4 is predicted to reduce 1% AEP flood levels across the South Murwillumbah basin (including the South Murwillumbah industrial area). The reductions are typically around 0.05 metres. The reductions are also predicted to extend into some of the residential and commercial areas of South Murwillumbah.

Plate 16 also shows that the additional water that is directed across Lot 4 is predicted to increase existing flood levels north-east of Quarry Road. The flood level increases are typically predicted to be less than 0.06 metres and are primarily contained to sugar cane fields. Flood level increases in the vicinity of Condong are predicted to be less than 0.03 metres.

It should be noted that although flood level increases are predicted, the magnitude of the increases is small relative to the overall depths of inundation. For example, during the 1% AEP flood, more than 3 metres of water is predicted across the sugar cane fields. Therefore, a flood level increase of 0.06 metres reflects a depth change of ~2%. Furthermore, the magnitude of the increases is not sufficient to expose any additional buildings to above floor inundation during any of the simulated floods.

Nevertheless, there is potential for the additional water directed into the sugar cane fields to increase the duration of inundation during large floods which may increase the potential for crop damage. Therefore, to quantify the potential impacts of the Lot 4 earthworks on the duration of flooding, "duration of inundation" difference mapping was prepared for the 1% AEP flood. The difference map is shown in **Plate 17** and shows the predicted change in the duration of inundation associated with the Lot 4 earthworks relative to the "existing" inundation durations shown in **Figure 27**.

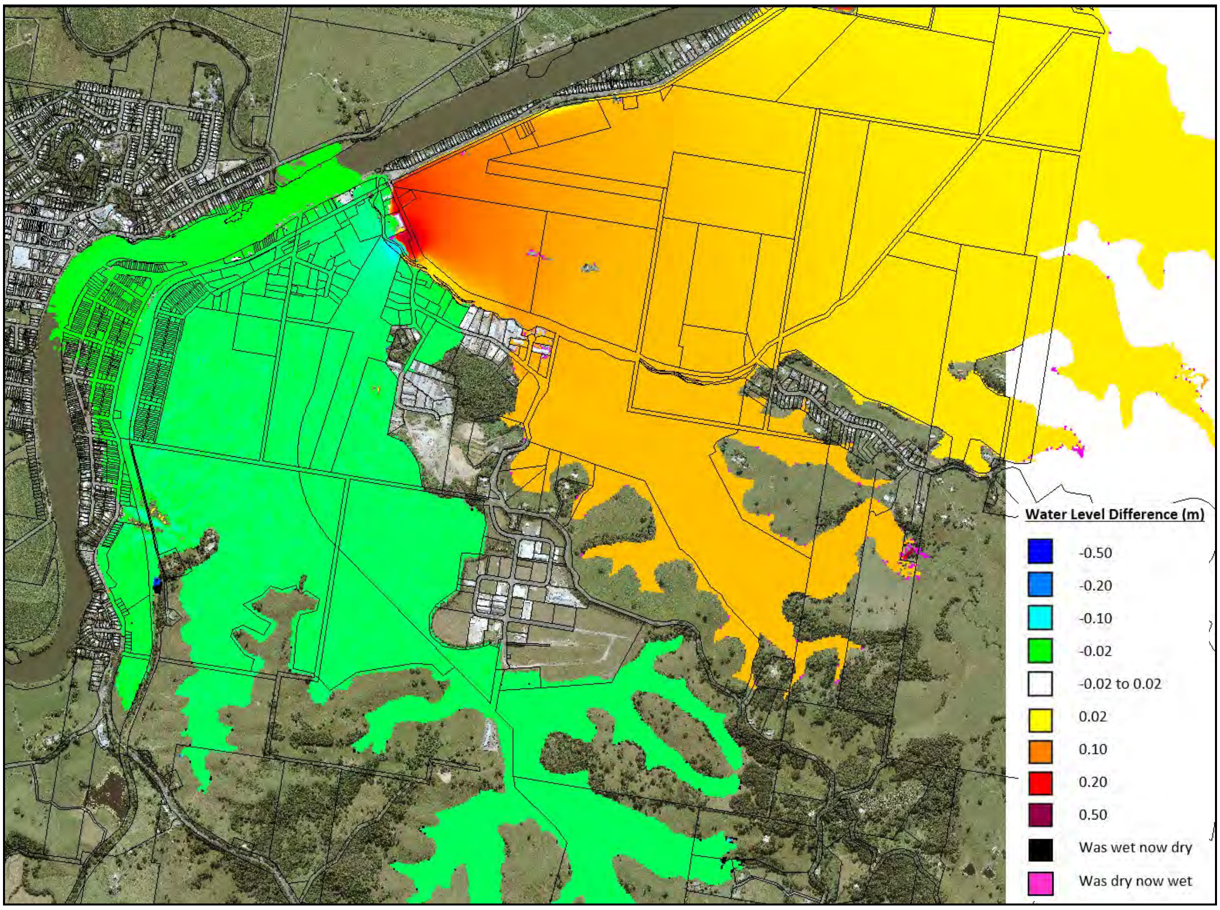


Plate 16 1% AEP Flood Level Difference Map for Lot 4, Quarry Road Earthworks (FM4)

Plate 17 1% AEP Duration of Inundation Difference Map for Lot 4, Quarry Road Earthworks (FM4)

Plate 17 shows that the Lot 4 earthworks are predicted to increase the duration of inundation immediately east of Quarry Road during the 1% AEP flood. However, the increase is only expected to be in the order of 1 hour and extend over a small, localised area (elsewhere across the sugar cane fields, the changes in inundation duration are predicted to be less than 30 minutes). This increase is not considered to be sufficient to increase the potential for crop damage across the sugar cane fields during large floods. Furthermore, the more elevated sections of the industrial area of South Murwillumbah would drain around 1 hour quicker (only Lot 4 itself would be subject to additional inundation times of more than 4 hours).

The cost to implement the earthworks is estimated to be about $0.4 million. A breakdown of costs is provided in **Appendix J**.

A revised flood damages assessment was completed with the Lot 4 earthworks in place and this determined that the earthworks are predicted to reduce flood damage costs by about $0.5 million over the next 50 years. Therefore, the benefit cost ratio associated with this option is predicted to be 1.2 indicating a positive financial outcome.

This option was generally supported by the community with 58% of questionnaire respondents either supporting or strongly supporting the option. 9% of respondents did not support the option.

Overall, this option is predicted to afford reductions in flood levels during larger floods across most of South Murwillumbah. Although the hydraulic benefits during more frequent events is minimal, this option is still predicted to provide a benefit cost ratio of more than 1. Therefore, this option is recommended for implementation.

5.2.5 FM5 – Earthworks across Lot 4 DP 591604 Quarry Road, Two Adjoining Lots and Airfield

Recommendation: Not recommended for implementation

FM5 expands on the earthworks proposed as part of FM4 (i.e., across Lot 4 DP 591604 Quarry Road) to also include the lots located immediately north and south of Lot 4 as well as the adjoining airfield. The goal of the additional earthworks is to further improve the conveyance capacity along the South Murwillumbah Condong Flowpath. The extent of the potential earthworks associated with this option are shown in **Figure 37.2**. As shown in **Figure 37.1**, it was assumed that the existing ground surface elevations would be modified to:

- Lot 4 DP 591604 Quarry Road: No higher than 3.5 mAHD
- Lot on northern side of Lot 4 DP 591604 Quarry Road: No higher than 3.5 mAHD
- Airfield and lot on southern side of Lot 4 DP 591604 Quarry Road (including section of Quarry Road levee running along lot boundaries): No higher than 2.5 mAHD

In addition to the earthworks shown in **Figure 37**, FM5 would require acquisition of the two lots adjoining Lot 4 or inclusion of these lots as part of the industrial land swap discussed in Section 6.4.

The earthworks shown in **Figure 37** were included in the TUFLOW model and the updated model was used to re-simulate each design flood. Peak floodwater level difference mapping for the 20% AEP flood with this option in place are presented in **Plate 18** and the difference mapping for the 1% AEP flood is provided in **Plate 19**.

Plate 19 shows that the earthworks are predicted to reduce 1% AEP flood levels across the South Murwillumbah basin (including the South Murwillumbah industrial area). The reductions are typically around 0.1 metres. The reductions are also predicted to extend into some of the residential and commercial areas of South Murwillumbah. **Plate 19** also shows that the additional water that is directed across Quarry Road is predicted to increase existing 1% AEP flood levels north-east of Quarry Road. The flood level increases are predicted to be less than 0.1 metres and are typically contained to sugar cane fields. Flood level increases in the vicinity of Condong are predicted to be less than 0.05 metres.

Plate 18 shows that this option is also predicted to produce reductions in existing 20% AEP flood levels along the main Condong Creek channel, across the airfield and across lower lying areas adjoining Wardop Valley Road. Flood level reductions of up to 0.2 metres are anticipated across these areas. However, minimal flood level reductions are anticipated across existing industrial properties. **Plate 18** also shows that this option is predicted to generate small (0.03m) increases in flood level across the South Murwillumbah basin. This increase is associated with the reduced elevations across the airfield allowing local catchment runoff to more readily "backup" from the 17L floodgates and begin to fill the basin earlier during smaller floods. Accordingly, the overall hydraulic benefits afforded by this option during more frequent floods is considered to be minimal. Nevertheless, further refinement of the ground surface elevation across the airfield could be completed to potentially offset the flood level increases during more frequent events while retaining the overall hydraulic benefits during larger floods.

The cost to implement FM5 is estimated to be about $4.1 million. A breakdown of costs is provided in **Appendix J**. The major cost associated with implementation of this option is the purchase of the properties adjoining Lot 4. If these properties are included in the industrial land swap (refer Section 6.4), the costs associated with implementation of this option would reduce considerably.

A revised flood damages assessment was completed, and this determined that the earthworks are predicted to reduce flood damage costs by about $1.7 million over the next 50 years. Therefore, the benefit cost ratio associated with this option is predicted to be 0.4. Therefore, including earthworks across the airfield and two lots adjoining Lot 4, reduces the financial viability of this option relative to FM4. However, as discussed, if the identified lots are included in the industrial land swap, the financial viability of this option would improve.

Overall, this option is predicted to afford reductions in flood levels during larger floods across most of South Murwillumbah. However, FM4 appears to provide better economic and hydraulic performance during smaller floods and should be pursued in preference to FM5. Therefore, FM5 is not recommended for implementation. However, it could be revisited after the industrial land swap is initiated.

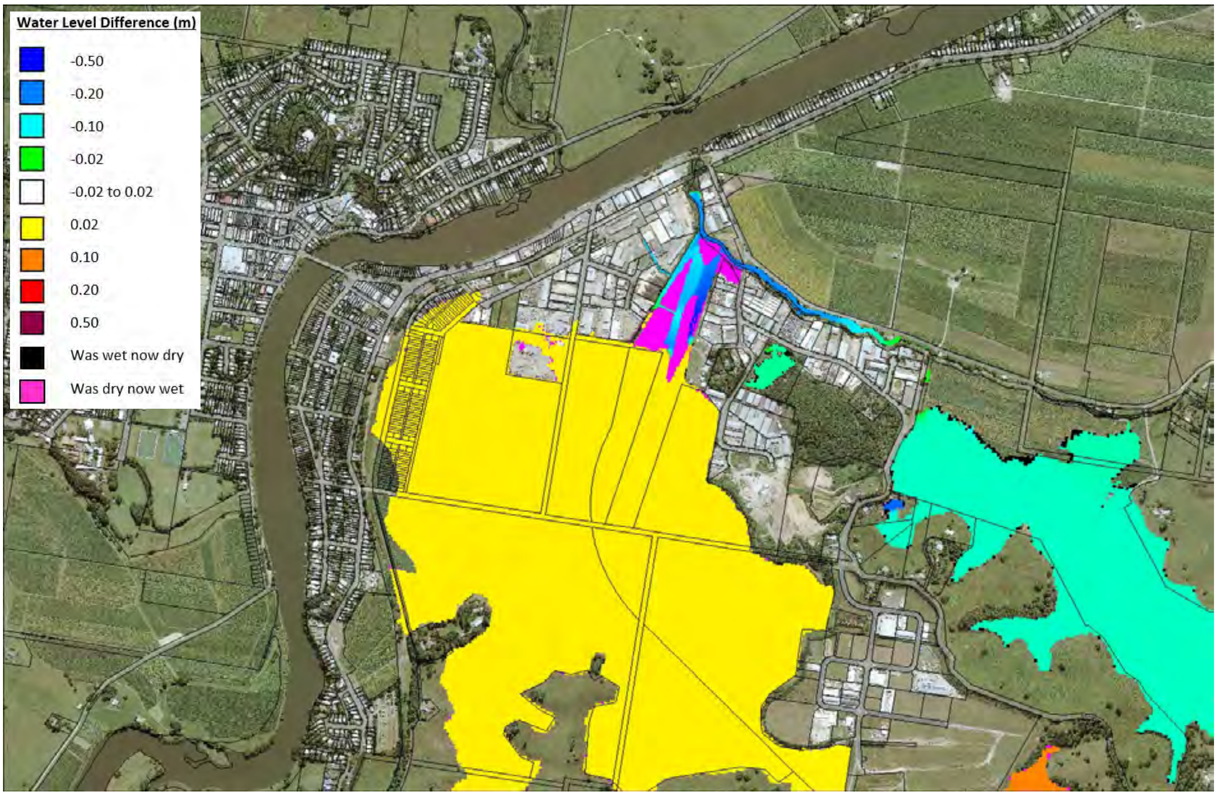


Plate 18 20% AEP Flood Level Difference Map for Earthworks across Lot 4 Quarry Road, Adjoining Lots and Airfield (FM5)

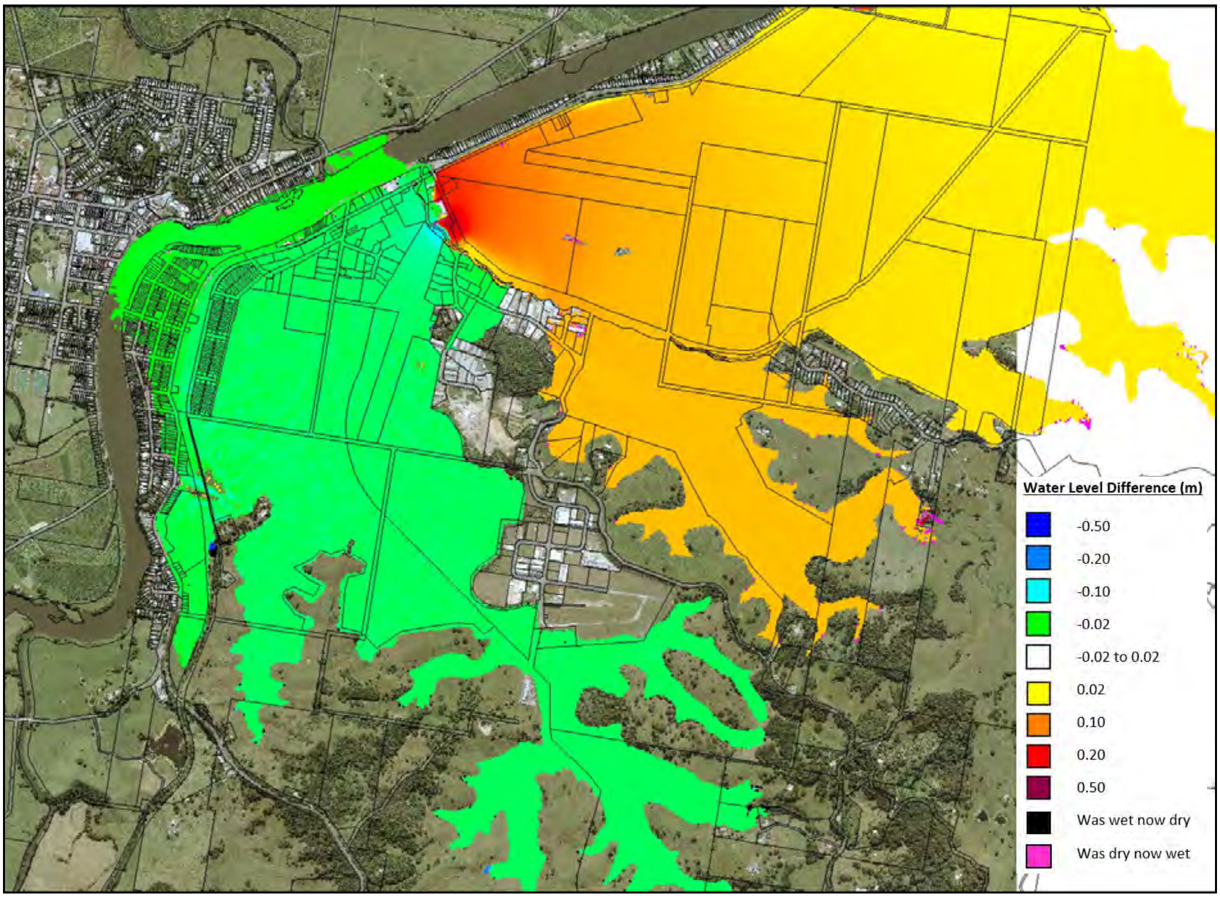


Plate 19 1% AEP Flood Level Difference Map for Earthworks across Lot 4 Quarry Road, Adjoining Lots and Airfield (FM5)

5.2.6 FM6 – Modify Terrain Between River Street and Tweed River

Recommendation: Not recommended

Tweed Shire Council plans to proceed with implementation of a draft Voluntary House Purchase (VHP) program. Further details on the VHP program is provided in Section 6.2 of this report.

The VHP scheme includes the purchase of existing residential properties located between the Tweed River and River Street as high priorities. This will ultimately remove all existing buildings between the Tweed River and River Street and provide an area of "open space". FM6 explored the potential benefits associated with lowering the existing terrain across this area of open space to provide additional out-of-bank flow carrying capacity.

Details of the suggested terrain modifications are provided in **Figure 38**. As shown in **Figure 38**, the proposed works would include lowering the ground surface elevations (including the existing South Murwillumbah levee) to approximately 1.5 mAHD. Accordingly, the area will be sufficiently elevated to remain "dry" during non-flood times, providing a passive recreation area.

To help ensure the remaining properties in South Murwillumbah are not adversely impacted as a result of the levee removal, some land (i.e., sections of River Street, Stafford Street and Wardrop Street) would also need to be raised by approximately 0.4 metres. Some modifications to the existing stormwater system would also be necessary (e.g., removing the stormwater system from the lowered sections of land and installing new flood gates).

The TUFLOW model was updated to include a representation of FM6 and the updated model was used to re-simulate each design flood. Peak floodwater level difference mapping for the 20% AEP flood with this option in place are presented in **Plate 20** and the difference mapping for the 1% AEP flood is provided in **Plate 21**.

Plate 20 and **Plate 21** shows that the earthworks are predicted to reduce 1% AEP flood levels along the Tweed River south of Colin Street and the flood level reductions are predicted to extend as far upstream as Bray Park. The flood level reductions across the residential areas of South Murwillumbah are predicted to be around 0.05 metres during the 20% AEP flood and between 0.1 and 0.15 metres during the 1% AP flood. Flood level reductions of up to 0.16 metres during the 20% AEP flood and 0.05 metres during the 1% AEP flood are also expected south of the Murwillumbah CBD and Bray Park.

However, **Plate 20** and **Plate 21** also shows that FM6 is also predicted to generate increases in peak 20% AEP and 1% AEP flood levels between Alma Street and Colin Street. The magnitude of the flood increases across the commercial and residential areas of South Murwillumbah is typically between 0.05 and 0.1 metres during the 20% AEP flood and 0.1 and 0.2 metres during the 1% AEP flood.

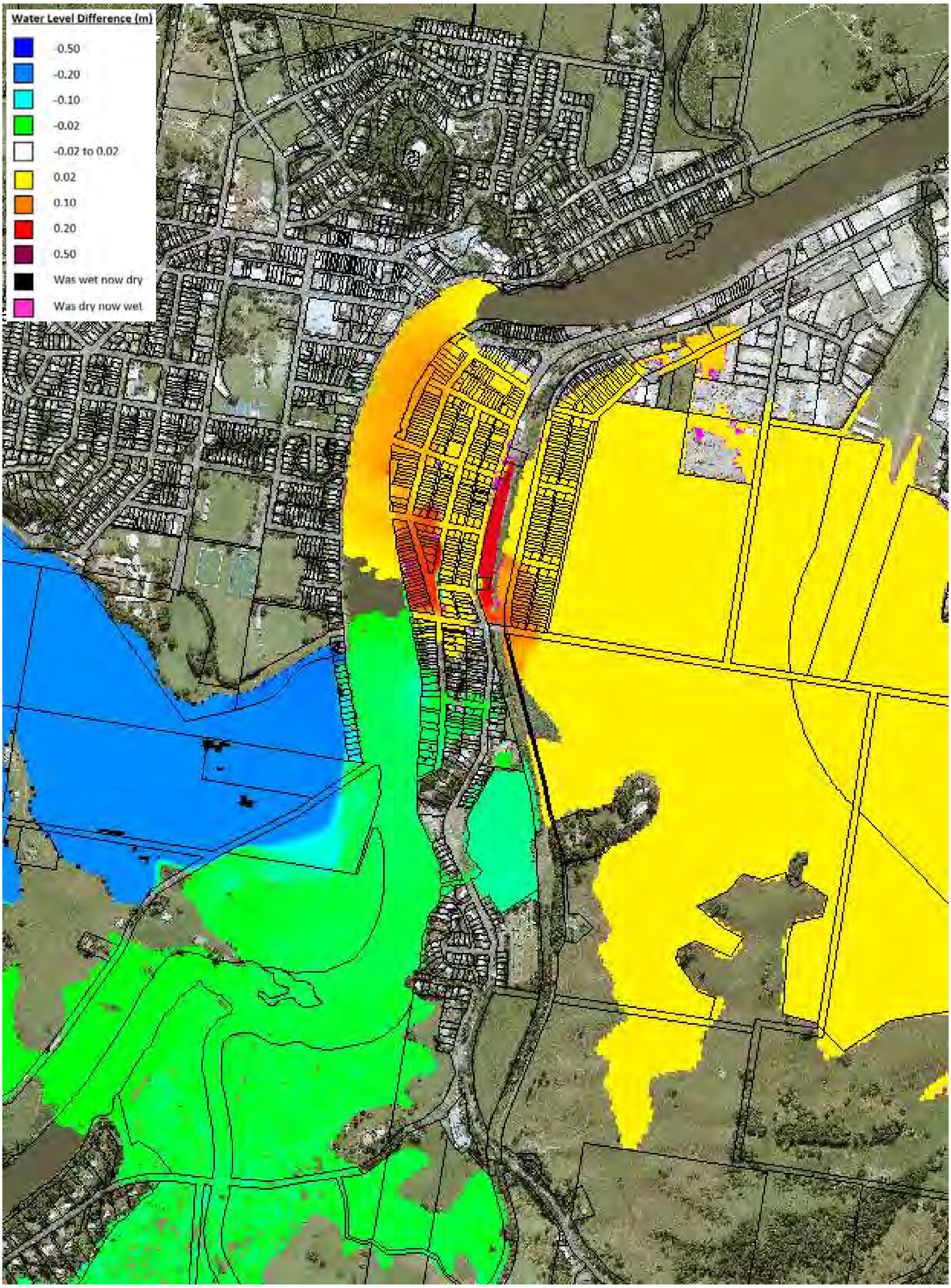


Plate 20 20% AEP Flood Level Difference Map for Terrain Modifications between River Street and Tweed River (FM6)

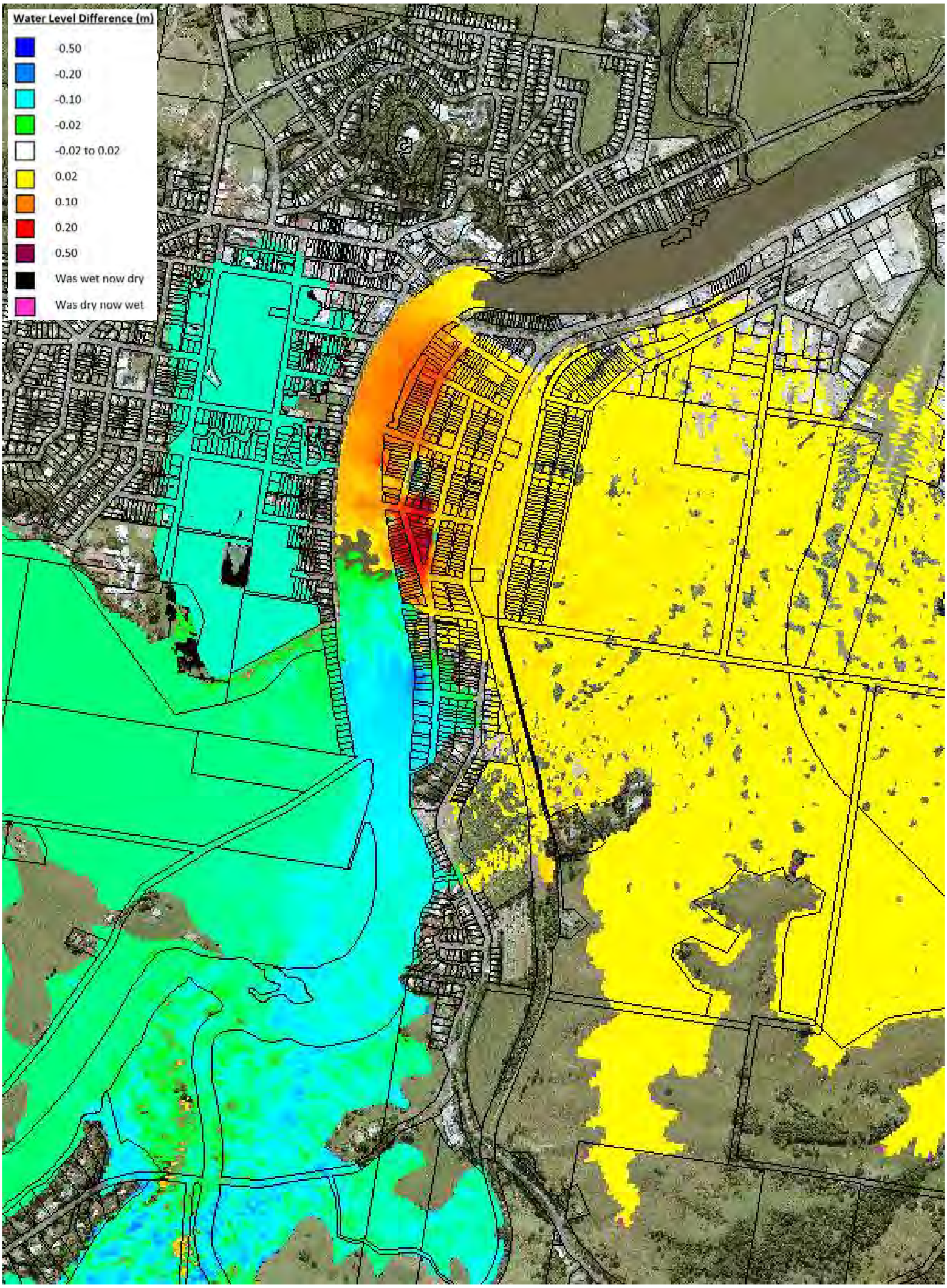


Plate 21 1% AEP Flood Level Difference Map for Terrain Modifications between River Street and Tweed River (FM6)

Flood level increases are also predicted to extend into the South Murwillumbah basin and impacts on some industrial properties (however, the magnitude of the increases is typically less than 0.03 metres). A review of the modelling results indicates that these flood level increases are primarily a result of the Murwillumbah Bridge approach. More specifically, the additional conveyance afforded by the earthworks directs additional, high-velocity water towards the bridge approach which serves to impede this additional flow (resulting in additional water "building up" behind the approach embankment and spilling into South Murwillumbah).

The cost to implement FM6 is estimated to be about $21 million. A breakdown of costs is provided in **Appendix J**. This cost includes an allowance for the purchase of 26 properties between River Street and the Tweed River, which is the major cost component for this option. If property acquisition costs are excluded (e.g., the properties where purchased under Council's VHP), it would likely reduce the implementation costs to around $5 million.

A revised flood damages assessment was completed, and this determined that the earthworks are predicted to reduce flood damage costs by about $1.3 million over the next 50 years. Therefore, the benefit cost ratio associated with this option is predicted to be less than 0.1 (assuming VHP costs are included) or 0.25 (assuming VHP are excluded). Accordingly, there appears to be little financial incentive to implement this option.

The hydraulic performance of this option could likely be improved by upgrading the Murwillumbah Bridge to incorporate an additional approach span to provide additional flow carrying capacity beneath the bridge. However, this will add significantly to the implementation cost and is unlikely to yield a sufficiently high BCR. Nevertheless, it may be possible to revisit this option in the future once the VHP scheme is implemented and if bridge replacement is being considered.

The lack of significant financial benefits coupled with adverse flood level impacts across parts of South Murwillumbah means that this option is not recommended for implementation.

5.3 Levee Modifications

5.3.1 FM7 – Levee Rehabilitation

Recommendation: Not recommended for implementation. However, use of the Murwillumbah stream gauge to provide additional flood intelligence for South Murwillumbah should be explored.

A review of the levee and water surface profiles in **Figure 18** shows that the existing levee crest does not provide a consistent "freeboard" along its length. This is most likely associated with differential settlement since the levee was constructed. As a result, it does not afford a consistent level of protection along its length nor does it provide the same level of protection now relative to when it was first constructed. Accordingly, "remediation" of the existing levee could be completed to elevate these areas back to their original "design" levels. The suggested extent of the levee modifications is shown in **Figure 39**. As shown in **Figure 39**, the rehabilitation would involve elevating part sections of the existing levee crest by up to 0.3 m (with elevation changes of around 0.1 metres being most common).

Although this remediation would slightly improve the current level of protection afforded by the levee, it would not prevent the levee from overtopping. The 'International Levee Handbook' (CIRIA, 2013) states that when levee overtopping occurs, it should take place in a way that produces the lowest possible hazard conditions. As discussed in Section 3.2.6, inundation of South Murwillumbah first occurs at Alma Street. However, this is quickly followed by overtopping along multiple sections of the levee located adjacent to River Street. During large floods, this overtopping can result in significant velocities and depths (i.e., high flood hazard) through parts of South Murwillumbah. Accordingly, there may be benefits in providing a designated spillway/overtopping location as part of the levee rehabilitation to reduce the existing flood hazard when overtopping does occur. **Figure 39** shows the potential location of a spillway. The spillway was located in an attempt to direct flows initially into vacant land near the western end of Holland Street rather than across existing residential properties.

The suggested levee modifications shown in **Figure 39** were included in the TUFLOW model and the updated model was used to re-simulate each design flood. Peak floodwater level difference mapping for the 20% AEP flood with this option in place are presented in **Plate 22** and the difference mapping for the 1% AEP flood is provided in **Plate 23**.

Plate 22 shows that this option is predicted to produce very small, localised changes in flood level across some parts of South Murwillumbah. This includes localised reductions of up to 0.03 metres across properties on the western side of River Street and reductions of around 0.02 metres between Tweed Valley Way and the railway.

Plate 23 shows that the levee rehabilitation is also predicted to generate small changes in 1% AEP flood levels across South Murwillumbah. However, the changes are very localised and do not exceed 0.05 metres. Accordingly, the levee rehabilitation is not predicted to afford any significant hydraulic benefits during large Tweed River floods.

The cost to implement the levee rehabilitation is estimated to be about $1.2 million. A breakdown of costs is provided in **Appendix J**.

A revised flood damages assessment was completed, and this determined that the levee rehabilitation is predicted to reduce flood damage costs by about $0.1 million over the next 50 years. Therefore, the benefit cost ratio associated with this option is predicted to be less than 0.1. That is, there does not appear to be a significant financial incentive to implement this option.

However, it should be noted that a key goal of the levee rehabilitation is not necessarily to provide a significant reduction in peak flood level/extents across South Murwillumbah but to better manage the flood hazard when levee overtopping does occur. In this regard, additional investigations were completed to determine if the levee rehabilitation would afford any significant reduction in the depth and velocity of floodwaters and/or any additional evacuation time.

Plate 22 20% AEP Flood Level Difference Map for Levee Rehabilitation (FM7)

Plate 23 1% AEP Flood Level Difference Map for Levee Rehabilitation (FM7)

A velocity difference map was prepared for the 20% AEP flood and is provided in **Plate 24**. The velocity shows the potential for the rehabilitation to reduce peak velocities (and, therefore, hazard) across South Murwillumbah.

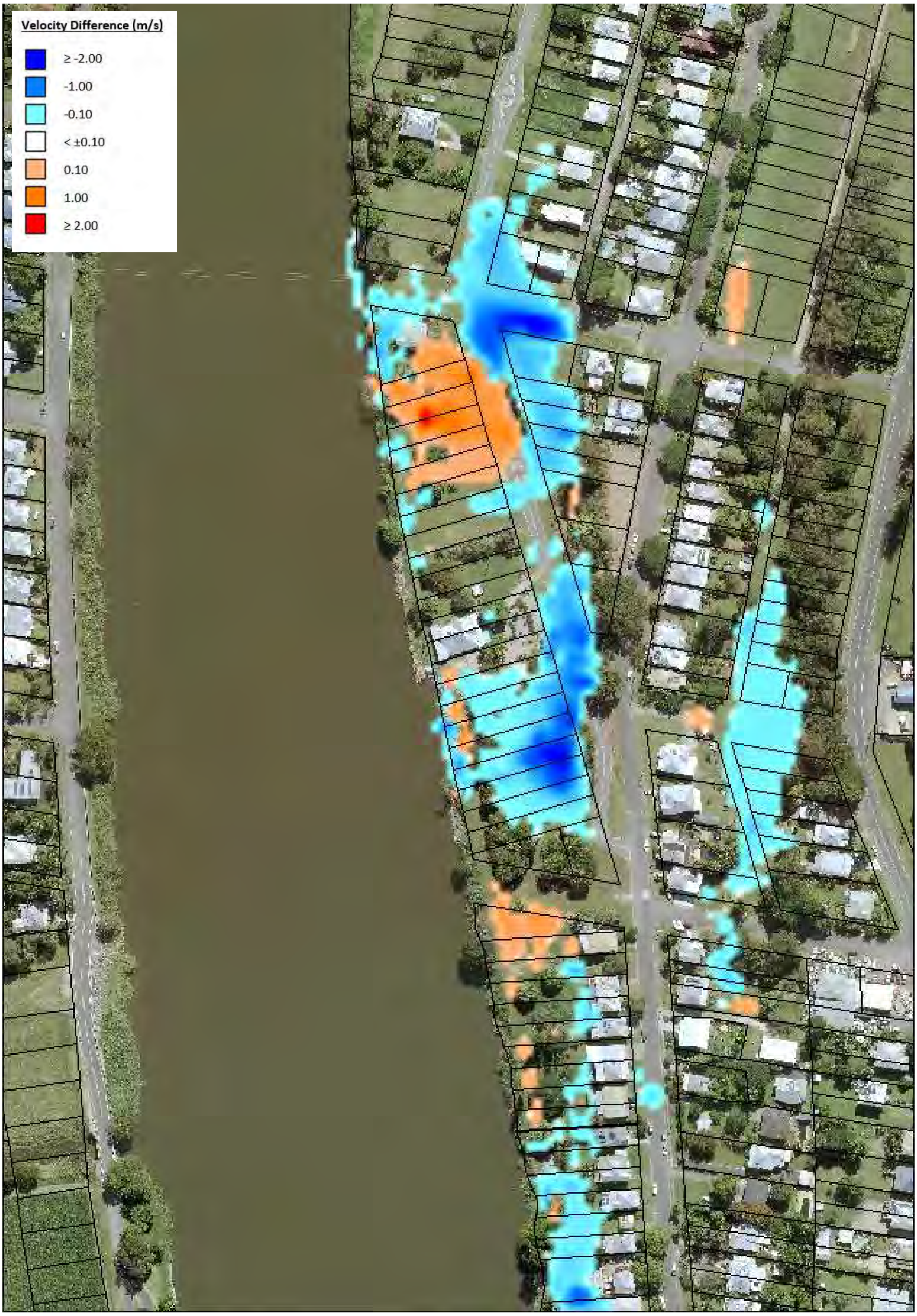


Plate 24 Change in 20% AEP flow velocity

The velocity difference map in **Plate 24** shows that the levee rehabilitation is predicted to increase flow velocities in the vicinity of the proposed spillway but reduce peak velocities by more than 1 m/s along parts of River Street (i.e., between Colin Street and Holland Street) as well as across some properties adjoining River Street. Accordingly, if residents adjoining River Street (south of Holland Street) were to wait until overtopping of the levee commences before commencing evacuation, the levee rehabilitation would likely result in a lower level of flood exposure during the rising limb of the flood hydrograph should they choose to evacuate along River Street. Unfortunately, there are very few properties that adjoin the section of River Street that would likely benefit from the velocity reductions resulting in a relatively small improvement to the overall flood hazard / evacuation potential. Furthermore, it is likely that Wardrop Street would be the preferred evacuation route (as it is located a higher elevation relative to River Street) and the rehabilitation is not predicted to afford any significant reductions in flow velocity along this stretch of roadway.

The time variation in 20% AEP velocities were also extracted along River Street (near the Orme Street road reserve) to confirm if the rehabilitation would alter the time variation in velocities (most notably just after levee overtopping commences). This information is presented in **Plate 25** for existing conditions as well with the levee rehabilitation in place.

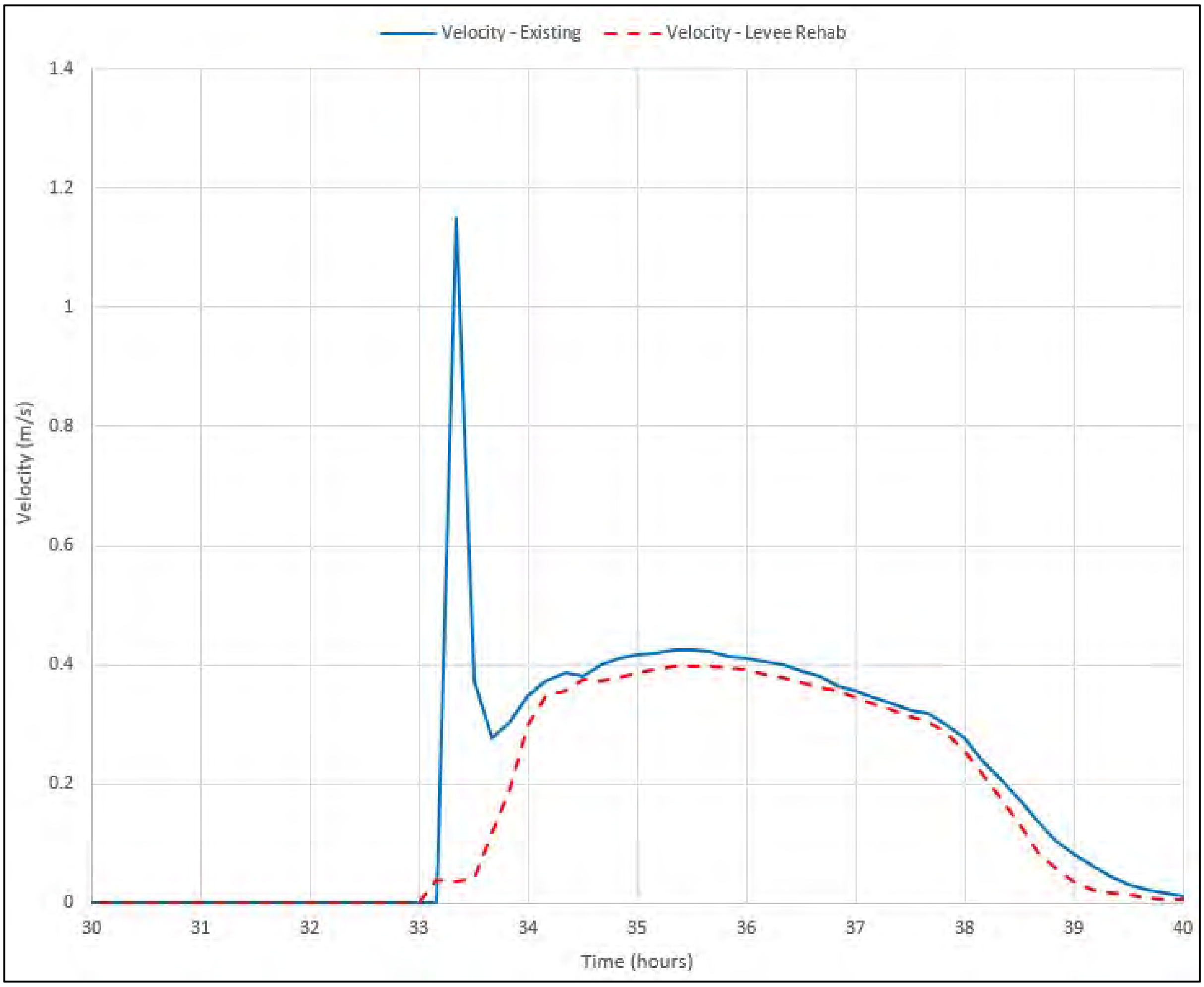


Plate 25 20% AEP floodwater depth and velocity time series for River Street near Orme Street road reserve

Plate 25 shows there is a notable “spike” in existing 20% AEP velocities at the time the levee is first overtopped. The levee rehabilitation eliminates the “spike” and also reduces velocities throughout the remainder of the flood. Accordingly, the levee rehabilitation affords a notable reduction in flood hazard at the time the levee first overtops. However, **Plate 25** shows that there is minimal change in the time at which overtopping first occurs or the overall duration of inundation. Accordingly, the rehabilitation is unlikely to afford any significant improvements to available evacuation time.

Although the potential emergency response benefits of the levee rehabilitation appear to be limited to a small area of South Murwillumbah, there may be opportunities to provide wider reaching benefits by introducing additional features into the levee rehabilitation, such as telemetered water level gauges or remote cameras at the Alma Street overtopping location and/or proposed spillway. These devices could be potentially setup to issue automated warnings to emergency services, Council and/or local residents when the levee is about to be overtopped.

If it is not possible to employ a new gauge, the Murwillumbah or Murwillumbah bridge gauges (shown in **Figure 39**) could be used to achieve a similar outcome (with or without the levee rehabilitation). More specifically, the roadway overtopping information presented in **Appendix I** could be used in conjunction with projected peak water levels to determine which roadways are likely to be cut during a flood and, therefore, which areas would benefit from early evacuation. It is suggested that the Murwillumbah bridge gauge may be the better of the two gauges to use in this regard due to its closer proximity to South Murwillumbah and the fact it is less impacted by superelevated water levels around the outside bend of the river.

The analysis presented in this section also highlights the importance of emergency management planning and associated education activities with the community. For example, the SES could use the information contained in this report to identify preferred evacuation routes (e.g., using Wardrop Street rather than River Street) and this information could be subsequently passed on to local residents and business owners to assist in optimising flood plan preparation (flood plans are discussed further in Section 7.3).

Overall, FM7 is predicted to provide only small, localised reductions in flood levels and flood damages. As a result, it is not predicted to afford any significant hydraulic or financial benefits. The option is predicted to afford emergency response and flood hazard improvements; however, these improvements would only benefit a small section of South Murwillumbah. As a result, this option is not recommended for implementation. Nevertheless, it is recommended that the potential for the Murwillumbah bridge gauge to be used to provide additional flood intelligence be explored to assist in maximising available flood warning time for emergency services, Council as well as local residents and business owners.

5.3.2 FM8 – Raising South Murwillumbah Levee to 20%AEP Level + Raising Height of CBD Levee

Recommendation: Recommended for further detailed analysis

As discussed, the outcomes of the flood modelling for existing conditions demonstrates that the existing South Murwillumbah levee affords less than a 20% AEP level of protection for the residential and commercial areas of South Murwillumbah. FM8 would look to elevate and extend the existing levee to afford at least a 20% AEP level of protection.

A concept plan for the levee modifications is included in **Figure 40**. Key features of the levee modifications include:

- The existing earthen embankment section of the levee would need to be raised by between 0.4 and 0.8 metres between Colin Street and Alma Street (this would provide a levee crest elevation very slightly above the peak 20% AEP flood level with no allowance for freeboard).
- A new spillway will be included near Holland Street to allow for floodwaters to be initially directed into vacant land when the levee is first overtopped.
- The earthen embankment would need to be extended further to the south. This would require constructing a new levee wall/embankment across the rear of properties fronting River Street (south of Colin Street towards Smith Street). The embankment/wall would need to be up to 1.4 metres high through this area.
- The portion of the levee formed by Alma Street would typically need to be raised by 0.2 metres. However, the low point in Alma Street (located ~50 metres west of Tweed Valley Way) would need to be elevated by approximately 0.4 metres. The low point in Alma Street would be retained as the "location of first overtopping" for the following reasons:
  - Floodwaters entering South Murwillumbah at this location are characterised by low velocities providing the lowest hazard scenario relative to an overtopping occurring further upstream
  - Floodwaters in South Murwillumbah naturally want to drain to this location (i.e., elevating this location further may reduce the potential for water to freely drain from behind the levee system back into the Tweed River)

Initial TUFLOW model simulations showed that the levee raising was predicted to increase existing flood levels upstream of South Murwillumbah. This included flood level increases south of the Murwillumbah CBD, resulting in more water spilling across the Commercial Road levee (also referred to as the "CBD levee") during the 1% AEP flood. Consequently, the levee raising was predicted to generate flood level increases of just over 0.1m across the Murwillumbah CBD. Therefore, elevating the Commercial Road levee was subsequently included in the assessment of this option to mitigate the predicted flood level increases across the CBD.

The elevated South Murwillumbah and Commercial Road levee were included in the TUFLOW model and the updated model was used to re-simulate each design flood. Peak floodwater level difference mapping for the 20% and 1% AEP events with this option in place are presented in **Plate 26** and **Plate 27.**

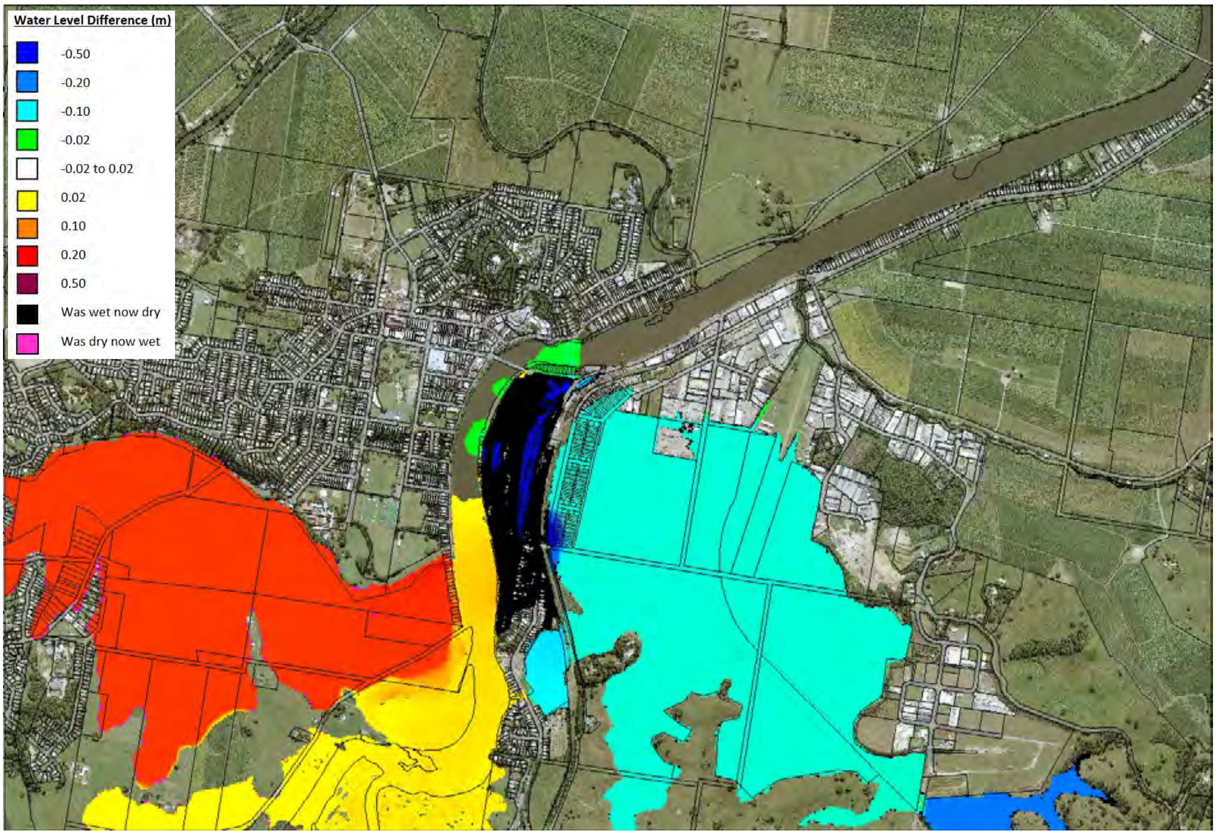


Plate 26 20% AEP Flood Level Difference Map for Raising South Murwillumbah Levee to 20%AEP Level (FM8)

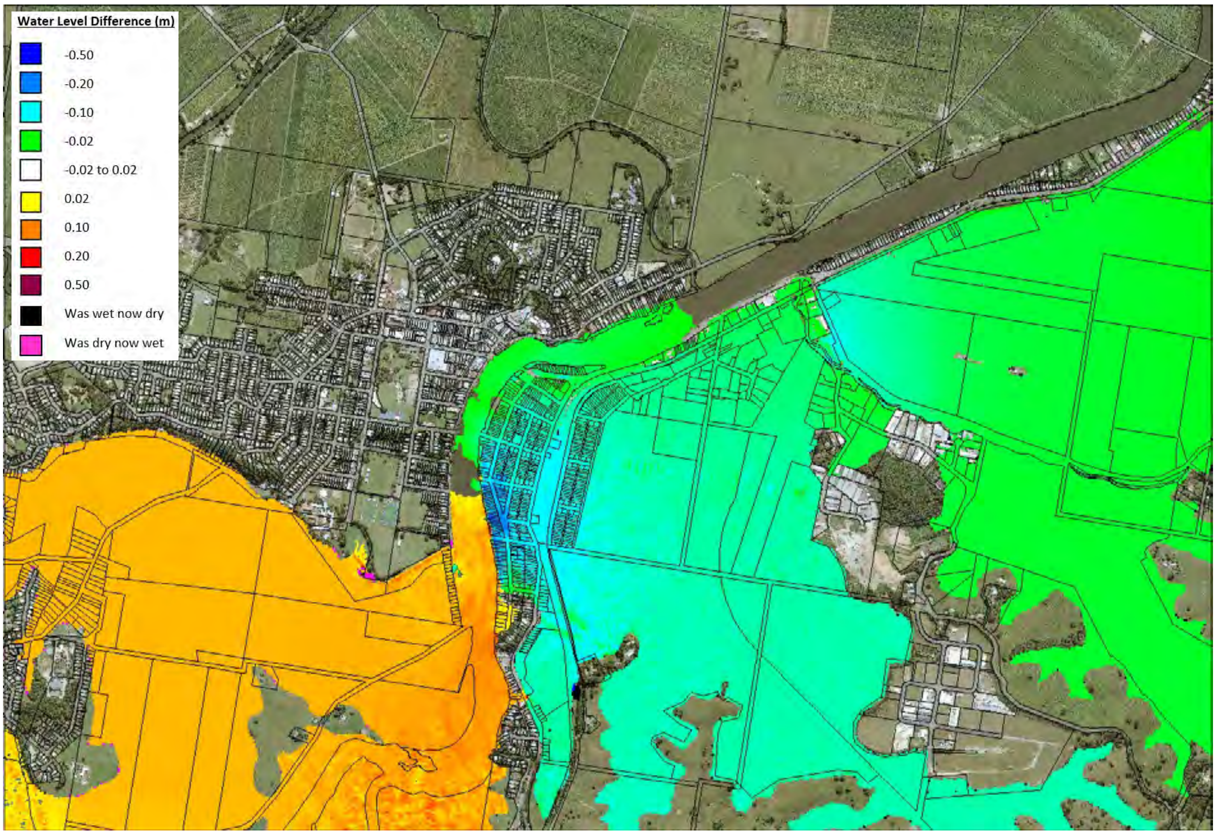


Plate 27 1% AEP Flood Level Difference Map for Raising South Murwillumbah Levee to 20%AEP Level (FM8)

Plate 26 shows significant reductions in flood levels and inundation extents across the residential and commercial areas of South Murwillumbah during the 20% AEP flood (refer black areas in **Plate 26**). Some localised inundation is still predicted across some of the lower lying residential/commercial areas, which is associated with local catchment runoff and the elevated water levels in the Tweed River preventing these areas from draining under gravity. Flood level reductions of 0.09 metres are also predicted to extend into the South Murwillumbah basin. There are predicted to be increases in flood level of around 0.05 metres in the Tweed River with flood level increases of around 0.16 metres immediately south of the Commercial Road levee. The flood level increases are predicted to extend upstream to Bray Park.

During the 1% AEP flood, **Plate 27** shows typical flood level reductions of between 0.1 and 0.2 metres across most of South Murwillumbah. Flood level reductions of around 0.07 metres are also predicted to extend across most of the South Murwillumbah industrial area. Flood levels within the Tweed River and south of the Commercial Road levee are predicted to increase by 0.05 to 0.1 metres. However, the Commercial Road levee modifications are sufficient to prevent these increases from impacting on the CBD. Nevertheless, flood level increases of 0.07 metres are predicted to extend upstream to Bray Park.

The changes in peak design flood levels are sufficient to result in the number of properties exposed to above floor flooding (AFF) changing during each design flood:

- <u>20% AEP flood</u>: 25 fewer properties with AFF and no new properties exposed to AFF
- <u>5% AEP flood</u>: 26 fewer properties with AFF and no new properties exposed to AFF
- <u>1% AEP flood</u>: 5 fewer properties with AFF and 3 new properties exposed to AFF
- <u>0.2% AEP flood</u>: 6 fewer properties with AFF and no new properties exposed to AFF

Accordingly, the levee raising is predicted to result in significantly less above floor flooding across South Murwillumbah during more frequent floods (e.g., 5% AEP and 20% AEP floods). The improvements during larger floods (e.g., ≥1% AEP flood) are more modest but still notable.

However, the flood level increases that are predicted across Bray Park are sufficient to result in 3 properties being newly exposed to above floor flooding in the 1% AEP flood. A review of these properties indicates that they are isolated from each other (refer **Plate 28**), which limits the potential to cost effectively implement any additional flood modifications options to mitigate the adverse impacts (i.e., individual property modification options may be the only cost-effective alternative). A review of the individual properties indicates that none are identified under Council's draft Voluntary House Purchase (VHP) program and none are likely to be suitable for house raising. At this stage, the most straight-forward approach for mitigating the AFF impacts may be to include all three properties in the draft VHP scheme. Although this will add to the overall implementation cost, it is not predicted to adversely impact on the overall financial feasibility of this option (discussed in more detail below).

The cost to implement the South Murwillumbah and CBD levee raising is estimated to be about $14 million. A breakdown of costs is provided in **Appendix J**. The cost includes an allowance for the voluntary purchase of the three properties in Bray Park that are adversely impacted as a result of the option.

Plate 28 Location of properties newly exposed to above floor flooding as a result of FM8

The potential financial benefit associated with implementation of the levee raising was quantified by preparing revised flood damage calculations based upon the hydraulic modelling results with the elevated levees in place. The outcomes of the revised damage assessment determined that a reduction in total flood damage costs of just under $21 million was predicted over the next 50-years. This yielded a preliminary benefit-cost ratio of 1.5. Accordingly, this option is predicted to afford a significant financial benefit for South Murwillumbah even with the cost contribution associated with the voluntary purchase of 3 properties in Bray Park.

This option was generally supported by the community with 50% of questionnaire respondents either supporting or strongly supporting levee raising. However, it was noted that nearly 20% of respondents did not support levee raising. The main reason cited for not supporting this option was that it may lead to an increased "false sense of security" resulting in complacency for those located behind the levee (e.g., reduced desire to evacuate early). Accordingly, any levee raising would need to be coupled with appropriate education (refer Section 7.2) to ensure that all residents and business owners are aware that overtopping of the elevated levee system can and will still occur and that evacuation procedures would not change as a result of the works (i.e., levees around existing properties are designed to reduce financial losses and are not intended to facilitate shelter in place or reduce the risk to life as a result of overtopping of the levee or evacuation routes).

Elevating the levee is likely to provide emergency response benefits. More specifically, if Alma Street is raised as part of the works, it would provide an additional 3 hours of time to evacuate from South Murwillumbah into the CBD during the 1% AEP flood. During the 0.2% AEP flood, an additional 4.5 hours of evacuation time will be afforded. Given the relatively limited amount of warning time that is currently available during the 0.2% AEP (i.e., 15 hours), this is considered to be a significant improvement.

Further detailed investigation of the levee extension south of Colin Street will need to be completed to confirm the preferred alignment and preferred construction technique (e.g., permanent earth embankment / concrete wall or temporary levee system). Consultation with landowners in this area will also need to be completed to confirm their willingness to participate in the levee extension, which will also help inform the potential levee alignment, construction technique and overall feasibility of this option.

The potential to offset the adverse flood level impacts across Bray Park should also be explored. As discussed, as only 3 additional properties are impacted from an above floor flooding perspective, it may be possible to incorporate these properties into Councils VHP scheme. Alternatively, other options could be explored to offset the water level increases across a broader area (e.g., providing additional storage volume or conveyance capacity within the Bray Park floodway).

As noted above, there are several limitations that may impact on the feasibility of this option including adverse flood impacts across Bray Park, the potential need to extend the levee across private property as well as the high implementation costs. However, this option affords some significant reductions in flood levels and flood damages across South Murwillumbah. As a result, it considered that this option warrants further detailed investigations to refine the levee design, look at opportunities to offset the Bray Park flood impacts and refine the cost estimates. If these additional investigations yield a positive outcome and assuming that sufficient funding can be sourced, this option may be considered for implementation.

5.3.3 FM9 – Raising South Murwillumbah Levee to 5%AEP Level + Raising Height of CBD Levee

Recommendation: Not recommended for implementation

As discussed, the existing South Murwillumbah levee affords less than a 20% AEP level of protection for the residential and commercial areas of South Murwillumbah. Option FM8 (discussed in Section 5.3.2), assessed the potential benefits associated with elevating the existing levee to afford protection during events up to and including the 20% AEP flood. FM9 would involve elevating the levee further to afford protection during floods up to and including the 5% AEP. Like FM8, FM9 would also include raising of the existing Commercial Road/CBD levee to offset predicted flood level increases south of the Murwillumbah CBD.

A concept design for the FM9 levee modification is included in **Figure 41**. It will generally involve a similar scope of work to FM8. However, the levee crest elevations would need to be further elevated by around 0.2 metres to afford protection during the 5% AEP flood (this assumes that no freeboard is provided).

The elevated levee was included in the TUFLOW model and the updated model was used to re-simulate each design flood. Peak floodwater level difference mapping for the 20% and 1% AEP events with this option in place are presented in **Plate 29** and **Plate 30**.

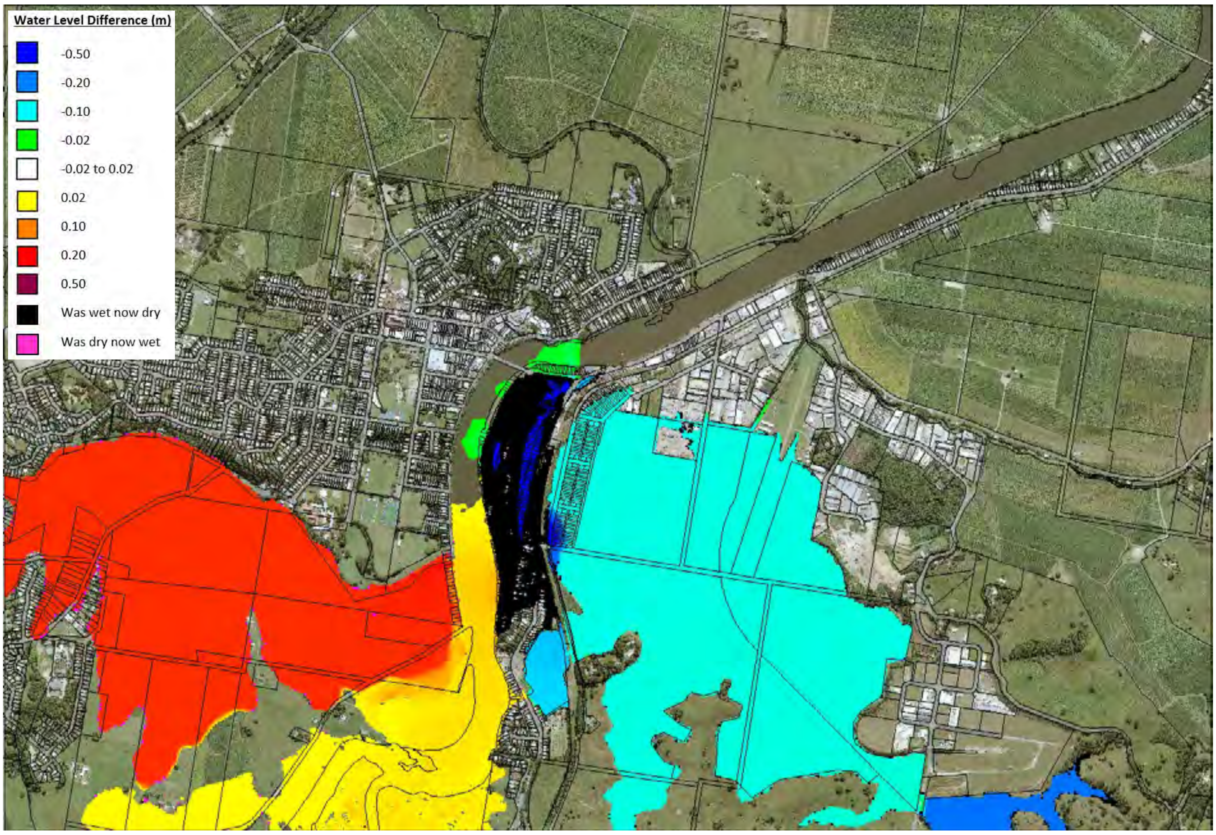


Plate 29 20% AEP Flood Level Difference Map for Raising South Murwillumbah Levee to 5%AEP Level (FM9)

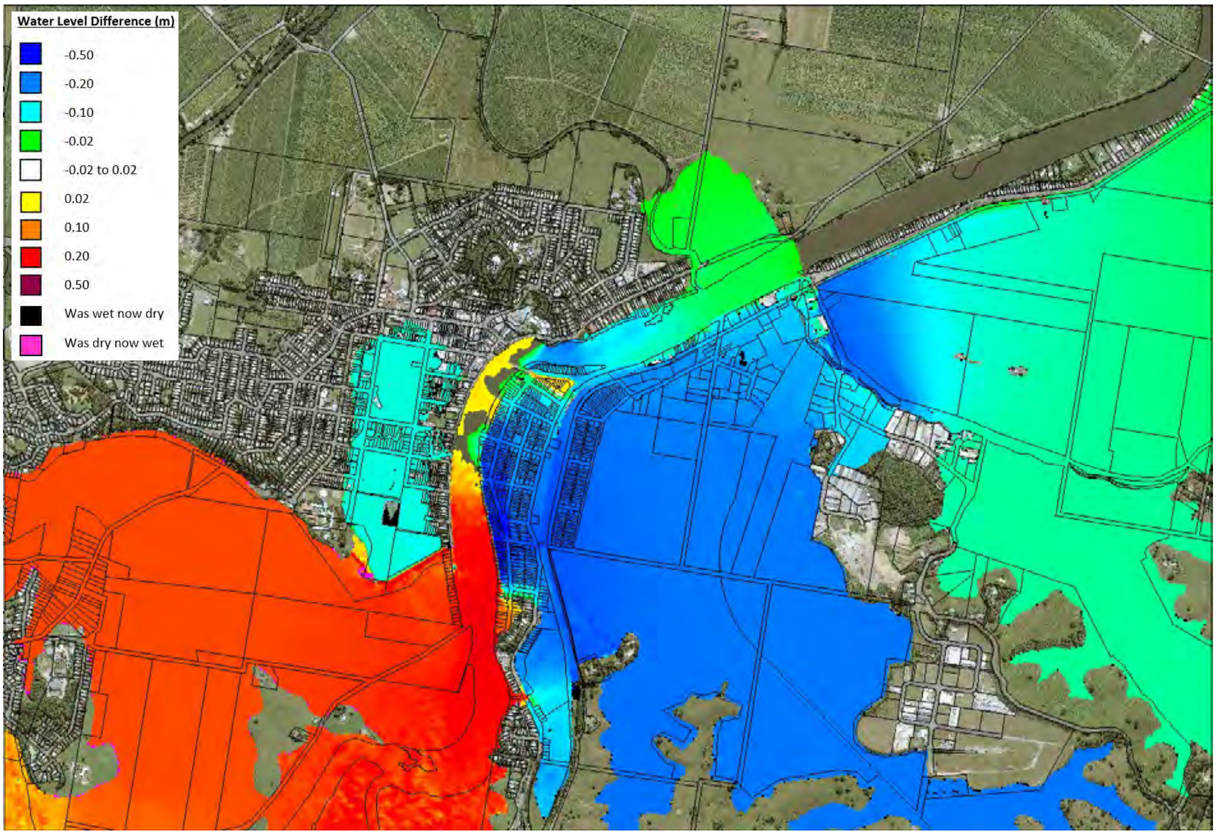


Plate 30 1% AEP Flood Level Difference Map for Raising South Murwillumbah Levee to 5%AEP Level (FM9)

Plate 29 shows the flood level impacts associated with FM9 are essentially identical to FM8 during the 20% AEP flood. That is, flood levels and extents across South Murwillumbah are predicted to be significantly reduced. Although some inundation is still predicted across lower lying area, flood levels are predicted to reduce by over 1.5 metres. There are predicted to be increases in flood level of between 0.05 and 0.15m extending upstream to Bray Park.

During the 1% AEP flood, **Plate 30** shows typical flood level reductions of around 0.2 metres across most of South Murwillumbah. Accordingly, FM9 is predicted to afford greater flood level reductions across South Murwillumbah relative to FM8 (FM9 1% AEP flood levels are typically 0.1 metres lower than FM8 flood levels). Although FM9 is predicted to afford larger flood level reductions across South Murwillumbah, it is also predicted to produce more significant flood level increases upstream of Murwillumbah. This includes flood level increases of around 0.15 metres south of the CBD (FM8 flood level increases across this area are typically around 0.07 metres). Therefore, the Commercial Road levee would need to be elevated more under FM9 relative to FM8 to offset these flood level increases. In addition, FM9 is predicted to produce more significant adverse impacts across Bray Park relative to FM8.

The changes in peak design flood levels are predicted to change the number of properties subject to above floor flooding (AFF) during each design flood:

- 20% AEP flood: 25 fewer properties with AFF and no new properties exposed to AFF
- 5% AEP flood: 31 fewer properties with AFF and no new properties exposed to AFF
- 1% AEP flood: 18 fewer properties with AFF and 3 new properties exposed to AFF
- 0.2% AEP flood: 18 fewer properties with AFF and 2 new properties exposed to AFF

Therefore, FM9 is predicted to afford greater AFF benefits during larger Tweed River floods relative to FM8. However, this is partly offset by more significant adverse AFF impacts across Bray Park (5 additional properties are newly flooded above floor during the 1% AEP and 0.2% AEP floods for FM9 relative to 3 additional properties newly exposed to AFF for FM8). As discussed in Section 5.3.2, it may be possible to offset the predicted AFF impacts across Bray Park by incorporating the impacted properties (refer **Plate 31**) in Council's Voluntary House Purchase (VHP) program. A review of the VHP program shows that one of the impacted properties is already incorporated in the VHP program. Therefore, four additional properties would need to be included in the program to offset the AFF impacts.

The cost to implement the South Murwillumbah levee raising to the 5% AEP design flood level is estimated to be about $18.6 million. Therefore, the total cost of this option is significant. A breakdown of costs is provided in **Appendix J**. The cost estimate includes an allowance for the voluntary purchase of the 5 Bray Park properties that are adversely impacted as a result of this option.

Revised flood damage calculations were completed based upon the hydraulic modelling results with the elevated levees in place. The outcomes of the revised damage assessment determined that a reduction in total flood damage costs of just under $23 million was predicted over the next 50-years. This yielded a preliminary benefit-cost ratio of 1.2. Accordingly, this option is predicted to afford a financial benefit for South Murwillumbah.

Plate 31 Location of properties newly exposed to above floor flooding as a result of FM9

Elevating the levee is likely to afford emergency response benefits for South Murwillumbah. More specifically, if Alma Street is raised as part of the works, it would provide an additional 4 hours of time to evacuate from South Murwillumbah into the CBD during the 1% AEP flood. During the 0.2% AEP flood, more than 6 hours of additional evacuation time will be provided.

As discussed in Section 5.3.2, the intent of a levee raising project is to reduce losses to existing property, not to facilitate shelter in place or eliminate the flood risk, as a levee will always be overtopped and, therefore, there is always a residual flood risk associated with these options. Therefore, any levee raising will need to be supplemented with appropriate education materials to highlight that evacuation protocols will not change, and that early evacuation is the preferred emergency response strategy for best managing this residual risk.

Overall, this option affords some significant reductions in flood levels and flood damages across South Murwillumbah. However, FM8 will provide a cheaper levee raising alternative, will result in less significant adverse impacts across Bray Park and will also provide a higher benefit cost ratio. As a result, FM8 is recommended for further detailed investigation in preference to FM9.

5.4 Road, Railway & Bridge Modifications

5.4.1 FM10 – Elevating Alma Street

Recommendation: Recommended for implementation as a low priority option. Not required if FM8 proceeds

A concept plan for the Alma Street modifications is included in **Figure 42**. As shown in **Figure 42** this option would involve elevating the low point in Alma Street from ~4.35 mAHD to 4.65 mAHD. The goal of this option is to provide additional time for people from South Murwillumbah to evacuate into the Murwillumbah CBD and, potentially, reduce the volume of water entering the commercial and residential areas of South Murwillumbah (floodwater first enters this area via the low point in Alma Street).

The elevated Alma Street was included in the TUFLOW model and the updated model was used to re-simulate each design flood. Peak floodwater level difference mapping was prepared for the 20% and 1% AEP events. However, the difference map showed no changes in 1% AEP flood levels and only small changes in 20% and 5% AEP flood levels with this option in place (refer to **Plate 32**).

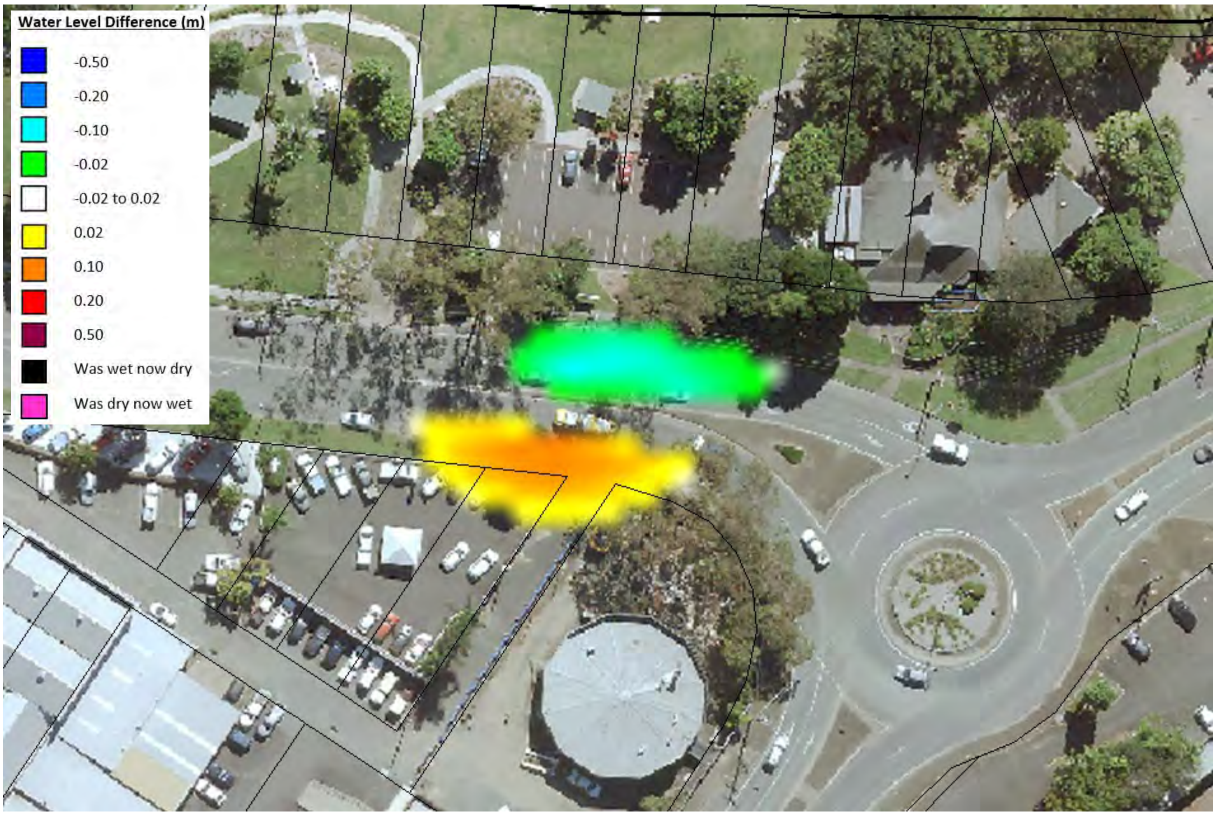


Plate 32 20% AEP Flood Level Difference Map for Alma Street Modification (FM10)

Overall, elevating Alma St to 4.65 mAHD is not predicted to generate any significant beneficial flood impacts. It is also not predicted to alter existing flood damage or change the number of properties exposed to above floor inundation.

It is noted that alternate Alma Street elevations were trialled as part of the option assessment. This determined that elevating Alma Street any higher than 4.65 mAHD would generate adverse flood impacts that would extend across existing commercial properties south of Alma Street (the low point in Alma St controls the ability of water to drain from South Murwillumbah back into the Tweed River).

The cost to implement the Alma Street modifications is estimated to be about $0.4 million. A breakdown of costs is provided in **Appendix J**.

As discussed, no reduction in flood damages is predicted with this option. Therefore, the benefit-cost ratio is predicted to be zero.

Despite the lack of significant hydraulic and economic benefits, this option is predicted to afford a minimum of 1 hour of additional time for people to evacuate from South Murwillumbah into the Murwillumbah CBD. Given the relatively limited amount of evacuation time currently available (particularly during particularly large floods), this is considered to be a beneficial outcome.

It should also be noted that elevating Alma Street does restrict the ability for floodwaters across the commercial and residential areas of Murwillumbah to freely drain in a northerly direction back into the Tweed River. The results of the modelling determined that floodwaters would take approximately 1 hour longer to drain from South Murwillumbah with the elevated roadway in place.

This option was one of the more strongly supported options by the community with nearly 80% of respondents either supporting or strongly supporting the option. Only 8% of respondents did not support the option.

Overall, this option does not afford any significant hydraulic or financial benefits. However, it is predicted to afford additional evacuation time for South Murwillumbah residents and business owners. Although implementation of this option is not considered to be a high priority option, it may be considered for implementation as part of any future roadworks/stormwater modifications for the area. If Option FM8 or FM9 (i.e., levee raising) is implemented, this option would not be required as the levee raising options also incorporate raising of Alma Street.

5.4.2 FM11 – Modify Railway Embankment

Recommendation: Not recommended for implementation

A concept plan for the railway embankment modifications is included in **Figure 43**. As shown in **Figure 43** this option will involve removing a 100m length of the existing railway embankment located east of Tweed Valley Way. This would aim to provide an additional opportunity for water from the residential/commercial sections of South Murwillumbah to drain into the South Murwillumbah basin located on the eastern side of the railway (currently the majority of flow must pass through the 30m wide viaduct near Colin St).

The railway embankment modifications were included in the TUFLOW model and the updated model was used to re-simulate each design flood. Peak floodwater level difference mapping was prepared for the 20% and 1% AEP events. However, the difference map showed no significant changes in 1% AEP flood levels.

More significant reductions in flood levels are predicted during the 20% AEP flood (refer to **Plate 33**). However, the flood level reductions are only predicted to extend across a small area contained to the east of Tweed Valley Way. Although 20% AEP flood levels are predicted to reduce by over 0.5 metres across some areas, the reductions mostly occur across vacant land. Nevertheless, 3 existing buildings located on the eastern side of Tweed Valley Way are predicted to benefit.

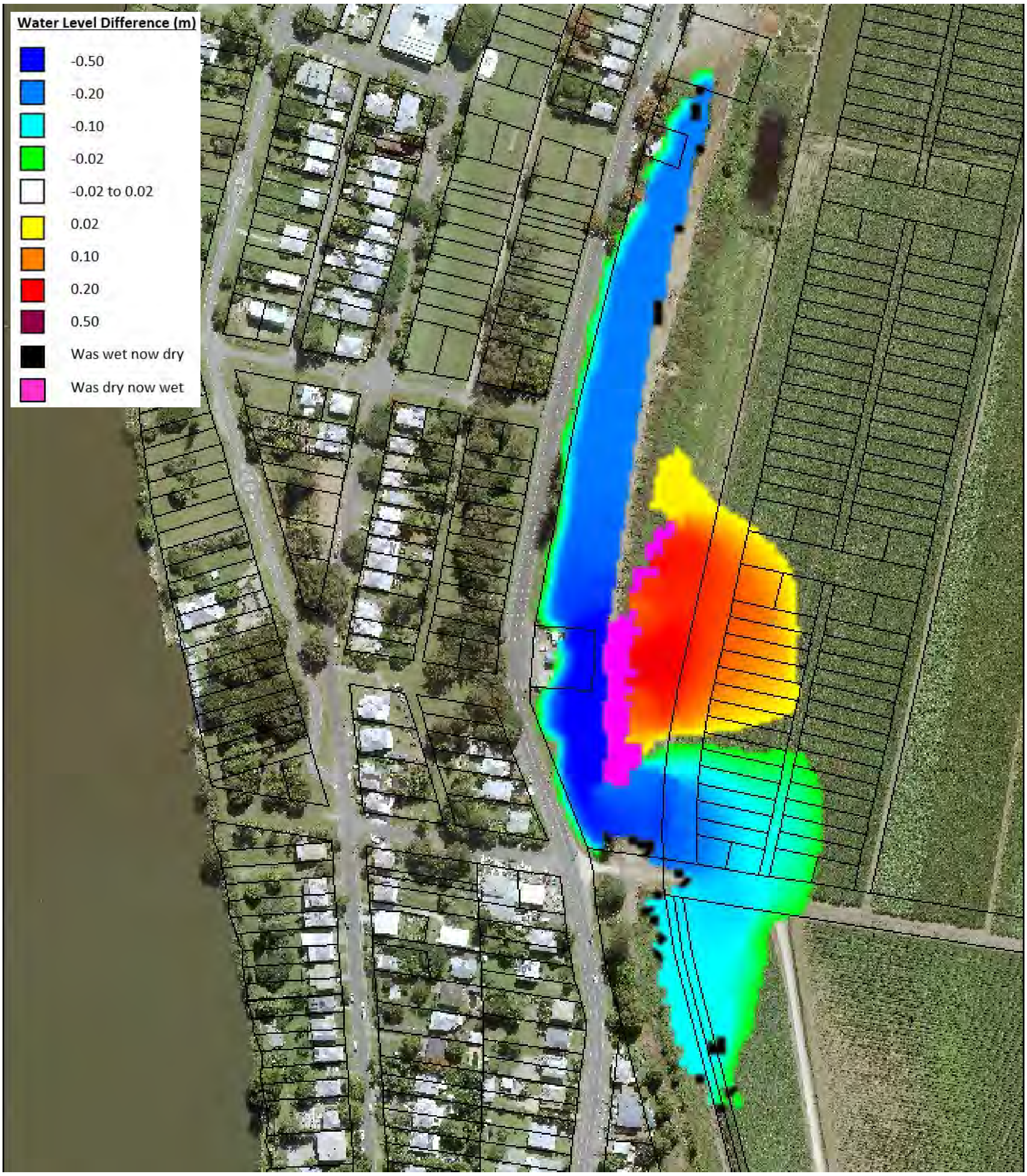


Plate 33 20% AEP Flood Level Difference Map for Railway Embankment Modification (FM11)

Therefore, the results of the hydraulic modelling show that enlarging the railway embankment opening only provides a localised flood benefit during smaller events. This is most likely a result of the fact that the primary flow paths through the residential areas of South Murwillumbah are contained on the western side of Tweed Valley Way. Therefore, enlarging the existing railway opening is not anticipated to have a significant impact on broadscale flood behaviour, particularly during larger floods.

The cost to implement the railway modifications is estimated to be about $0.8 million. A breakdown of costs is provided in **Appendix J**.

A revised flood damages assessment was completed, and this determined that the railway embankment modifications are predicted to reduce flood damage costs by about $0.2 million over the next 50 years. Therefore, although the hydraulic benefits are quite localised, the reduction in flood damage costs are not insignificant. Nevertheless, the benefit cost ratio associated with this option is predicted to be less than 1 (i.e., 0.25).

This option was generally supported by the community with 72% of questionnaire respondents either supporting or strongly supporting the option. 12% of respondents did not support the option.

Overall, this option only affords benefits across a fairly localised area during smaller floods. It is likely that a better financial return would be provided by some of the other options being considered as part of this study. Therefore, this option is not recommended for implementation.

5.4.3 FM12 – Elevate Tweed Valley Way at Blacks Drain

Recommendation: Not recommended for implementation

A concept plan for the Tweed Valley modifications is included in **Figure 44**. As shown in **Figure 44** this option will involve elevating Tweed Valley Way to an elevation of between 5.85 and 6.1 mAHD near the Blacks Drain crossing. The goal of this option is to provide additional time for people from South Murwillumbah to evacuate into the Murwillumbah CBD or to higher ground to the south. At the same time, this additional embankment height will potentially reduce the amount of water pilling across Tweed Valley Way during large floods, thereby reducing flood levels within the South Murwillumbah Basin.

The elevated Tweed Valley Way was included in the TUFLOW model and the updated model was used to re-simulate each design flood. Peak floodwater level difference mapping was prepared for the 20% and 1% AEP events and is presented in **Plate 34** and **Plate 35**.

Plate 35 shows that flood level reductions are predicted on the eastern side of Tweed Valley Way during the 1% AEP flood. This includes reductions of around 0.06 metres across the Greenhills Caravan Park. However, the reductions across the balance of the South Murwillumbah basin are only predicted to be around 0.02 metres.

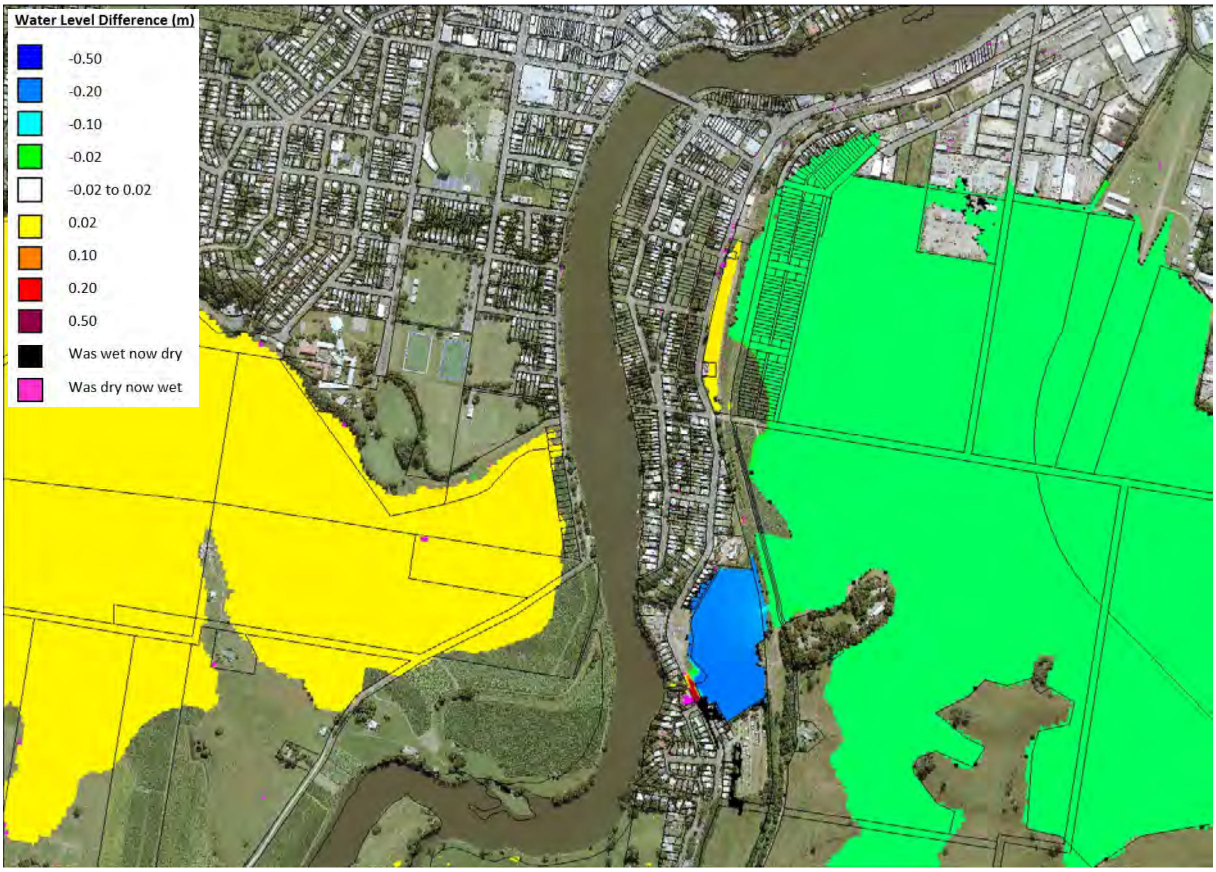


Plate 34 20% AEP Flood Level Difference Map for Tweed Valley Way Modification (FM12)

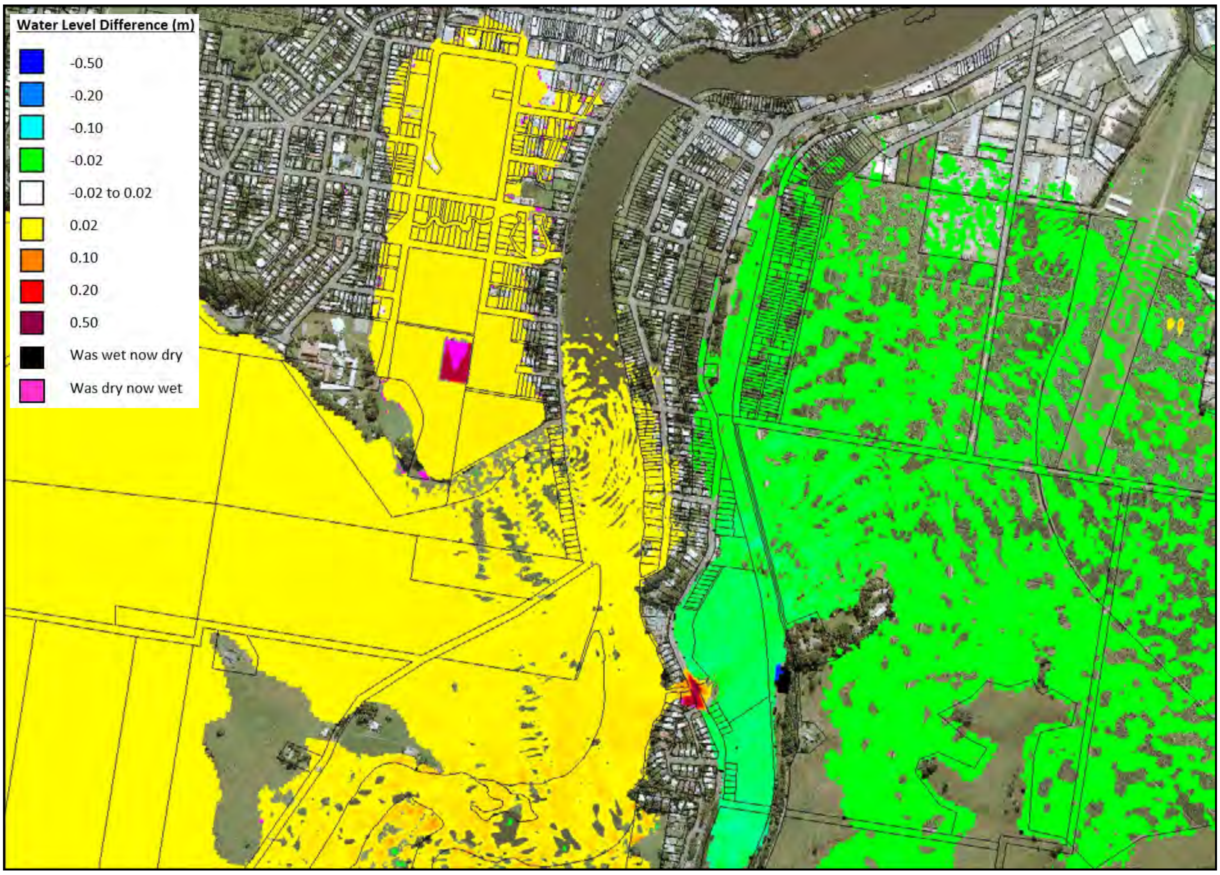


Plate 35 1% AEP Flood Level Difference Map for Tweed Valley Way Modification (FM12)

Plate 35 also shows that this option is likely to generate some flood level increases within the Tweed River near the Blacks Drain confluence. The flood level increases at this location are predicted to be about 0.02 metres and are not predicted to significantly impact on adjoining properties. However, the flood level increases are predicted to extend towards the Commercial Road levee. Although the increases at this location are only predicted to be about 0.02 metres, it does increase the amount of time and, consequently, the volume of water that spills across the levee and into the Murwillumbah CBD during the 1% AEP flood. Flood level increases of around 0.03 metres are predicted across lower lying sections of the Murwillumbah CBD.

Plate 34 shows similar changes in flood behaviour during the 20% AEP flood. That is, flood levels are predicted to increase by around 0.02 metres upstream of Blacks Drain and reduce by around 0.05 metres on the eastern side of Tweed Valley Way. The flood level reductions are largely restricted to undeveloped sections of the South Murwillumbah basin. However, a handful of residential properties adjoining Railway Street are predicted to benefit.

The cost to implement the Tweed Valley Way modifications is estimated to be about $1.3 million. A breakdown of costs is provided in **Appendix J**.

Revised flood damage calculation with this option in place indicate that it will likely reduce flood damage costs by around $0.1 million over the next 50 years. This provides a benefit-cost ratio of less than 0.1. Accordingly, there appears to minimal financial incentive to implement this option.

However, this option is predicted to afford about 1 hour of additional time for people to evacuate across Blacks Drain during large floods. Given the relatively limited amount of evacuation time that is available for South Murwillumbah residents, this is considered to be a beneficial outcome. However, it should be noted that Tweed Valley Way is also predicted to be overtopped further to the north (just south of Colin Street). Therefore, it is likely that any works to elevate Tweed Valley Way at Blacks Drain would not afford any improvements in evacuation time unless this additional low point was also elevated.

This option was generally supported by the community with 77% of questionnaire respondents either supporting or strongly supporting the option. It was noted that 15% of respondents did not support the option, which makes it one of the least supported of the options considered as part of study.

Overall, this option provides only relatively small hydraulic and financial benefits. In addition, it is unlikely to afford any significant improvement to evacuation potential unless other low-lying sections of Tweed Valley Way are also elevated. The lack of significant financial and evacuation benefits coupled with small increases in flood levels across the Murwillumbah CBD make this option difficult to support.

5.5 Channel Modifications

5.5.1 FM13 – Dredge Tweed River Channel

Recommendation: Not recommended for implementation.

Initial Dredging Option

The Tweed River bed shallows significantly adjacent to the residential areas of South Murwillumbah. Therefore, dredging of the Tweed River was investigated as a potential option for increasing the flow carrying capacity of the river.

Initially, an option involving dredging the invert of the riverbed down to -10 mAHD was investigated. This elevation was selected to "tie in" with existing deeper sections of the Tweed River channel upstream (near Blacks Drain confluence) and downstream (near "the bluff") of South Murwillumbah.

The hydraulic impacts associated with this dredging option was quantified by updating the channel geometry in the hydraulic model to reflect the channel dredging down to -10 mAHD. The updated TUFLOW model was then used to re-simulate each design flood. Peak floodwater level difference mapping for the 20% and 1% AEP events with this option in place are presented in **Plate 36** and **Plate 37**.

Plate 36 and **Plate 37** shows that this dredging option is predicted to generate some significant reductions in flood levels. Reductions of between 0.2 and 0.4 metres are predicted across the residential and commercial areas of South Murwillumbah during the 1% AEP flood and reduction of 0.3 metres are typical across the industrial areas. This option is also predicted to afford reductions in 1% AEP flood levels across the Murwillumbah CBD (0.25 metres) as well as upstream to Bray Park (>0.4 metres).

However, **Plate 36** and **Plate 37** also shows that there are predicted to be commensurate increases in flood level across areas downstream of Murwillumbah. Although the flood level increases are typically less than 0.1 metres, they do extend across numerous properties that adjoin Tweed Valley Way between South Murwillumbah and Condong as well as a number of rural properties located north of Murwillumbah.

Furthermore, a review of the Murwillumbah bridge plans indicate that it may not be possible to dredge down to a depth of -10 mAHD as it would likely undermine the bridge footings which is highly undesirable.

As a result of the adverse flood impacts predicted across downstream properties as well as the potential adverse impacts in the vicinity of the bridge, a revised dredge option was investigated.

Revised Dredging Option

As discussed, the initial dredging option investigated the potential impacts associated with dredging the Tweed River channel down to a level of -10 mAHD. However, this was predicted to generate adverse flood impacts downstream of Murwillumbah and may impact on the integrity of the Murwillumbah bridge.

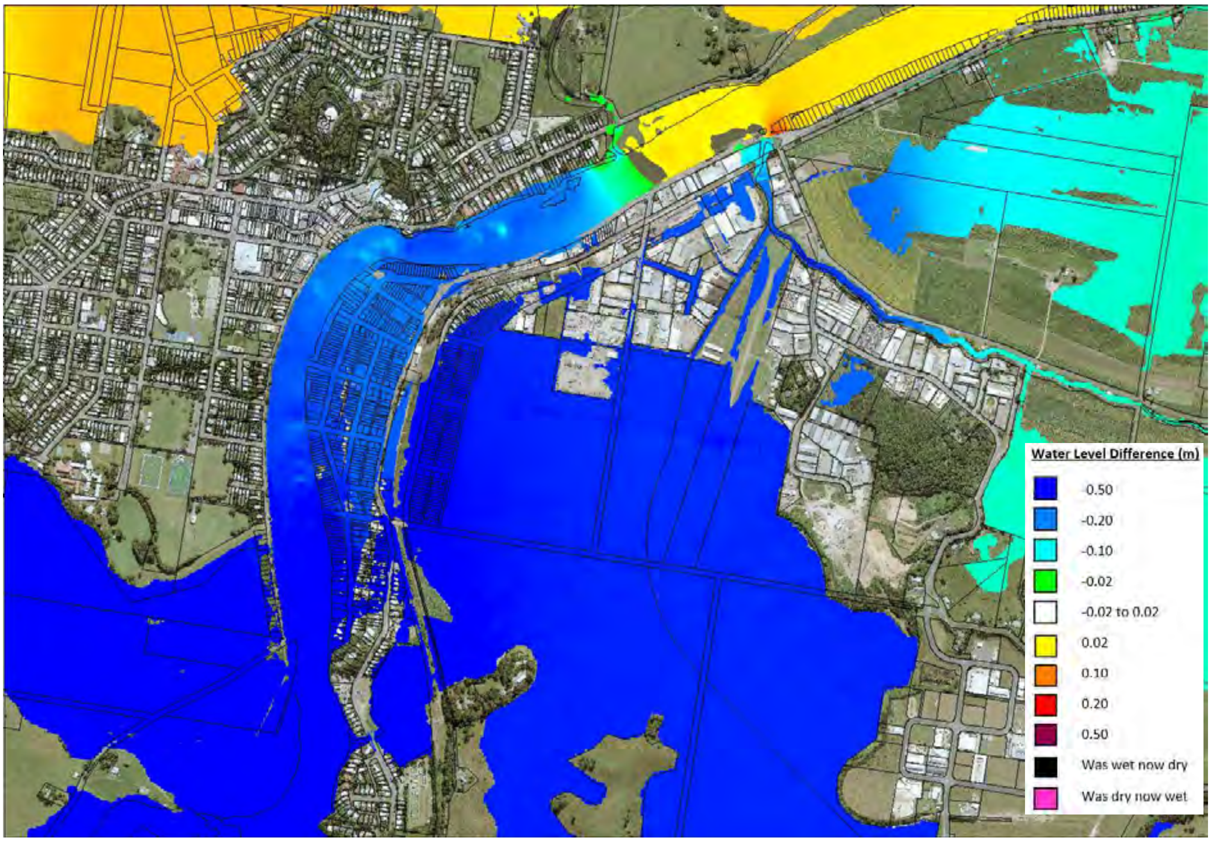


Plate 36 20% AEP Flood Level Difference Map for Tweed River dredging (-10mAHD Option) (FM13)

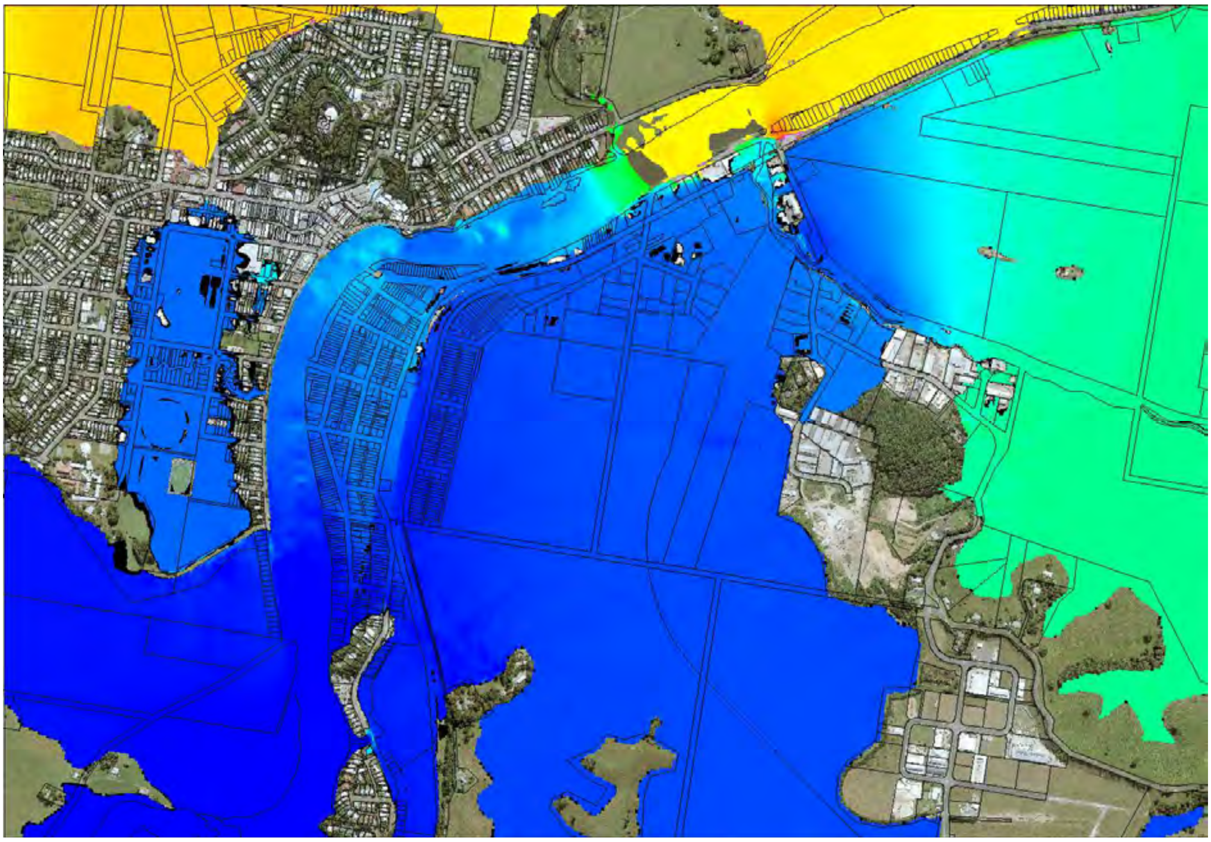


Plate 37 1% AEP Flood Level Difference Map for Tweed River dredging (-10mAHD Option) (FM13)

Therefore, a revised dredging option was investigated involving a reduced dredge depth of -5 mAHD. This dredging depth was selected as geotechnical information indicates it is unlikely to encounter any bedrock and it will also require minimal dredging in the vicinity of the bridge. As shown in **Figure 45**, this will require lowering the current riverbed levels by up to 4 metres and will involve the removal of around 230,000 m^3 of bed material.

The hydraulic impacts associated with the revised dredging option was quantified by updating the channel geometry in the hydraulic model to reflect the channel dredging. The updated TUFLOW model was then used to re-simulate each design flood. Peak floodwater level difference mapping for the 20% and 1% AEP events with this option in place are presented in **Plate 38** and **Plate 39**.

Plate 38 and **Plate 39** shows that this option is predicted to generate reductions in flood levels across South Murwillumbah in addition to areas upstream of South Murwillumbah. Reductions of around 0.1 metres are predicted across most of the residential and commercial areas of South Murwillumbah during the 1% AEP flood and reductions of just under 0.1 metres are typical across the industrial areas. This option is also predicted to afford reductions in 1% AEP flood levels across the Murwillumbah CBD (0.1 metres) as well as upstream to Bray Park (<0.1 metres). **Plate 38** also shows more significant flood level reductions are anticipated across the South Murwillumbah basin during the 20% AEP flood (~0.3 metres). The more significant reductions during this smaller event are associated with the lower water levels in the Tweed River reducing the amount of water overtopping Tweed Valley Way at Blacks Drain and entering the South Murwillumbah basin.

Plate 38 also shows that there are predicted to be increases in flood level across some areas downstream of Murwillumbah during the 20% AEP flood. Although the flood level increases are typically less than 0.05 metres, they do extend across a number of properties that adjoin Tweed Valley Way between South Murwillumbah and Condong.

It should be noted that the potential environmental impacts associated with dredging are significant. The environmental impacts are associated with dredging sediment (and associated contaminants) which causes turbidity of the water (i.e., reduced water quality) and potentially covers any in-stream vegetation (i.e., loss of vegetation and habitat for aquatic life). Any nutrients released during dredging, particularly nitrogen and phosphorus, risks triggering algal blooms which can have adverse health impacts.

The potential environmental impacts are reflected in the large range of statutory requirements that would need to be satisfied before proceeding with any dredging activities. This may include:

- Commonwealth Environment Protection and Biodiversity Act 1999;
- Environmental Planning & Assessment Act 1979;
- Crown Lands Act 1989;
- Protection of the Environment Operations Act 1997;
- Threatened Species Conservations Act 1995;
- Fisheries Management Act 1994; and,
- Water Management Act 2000.

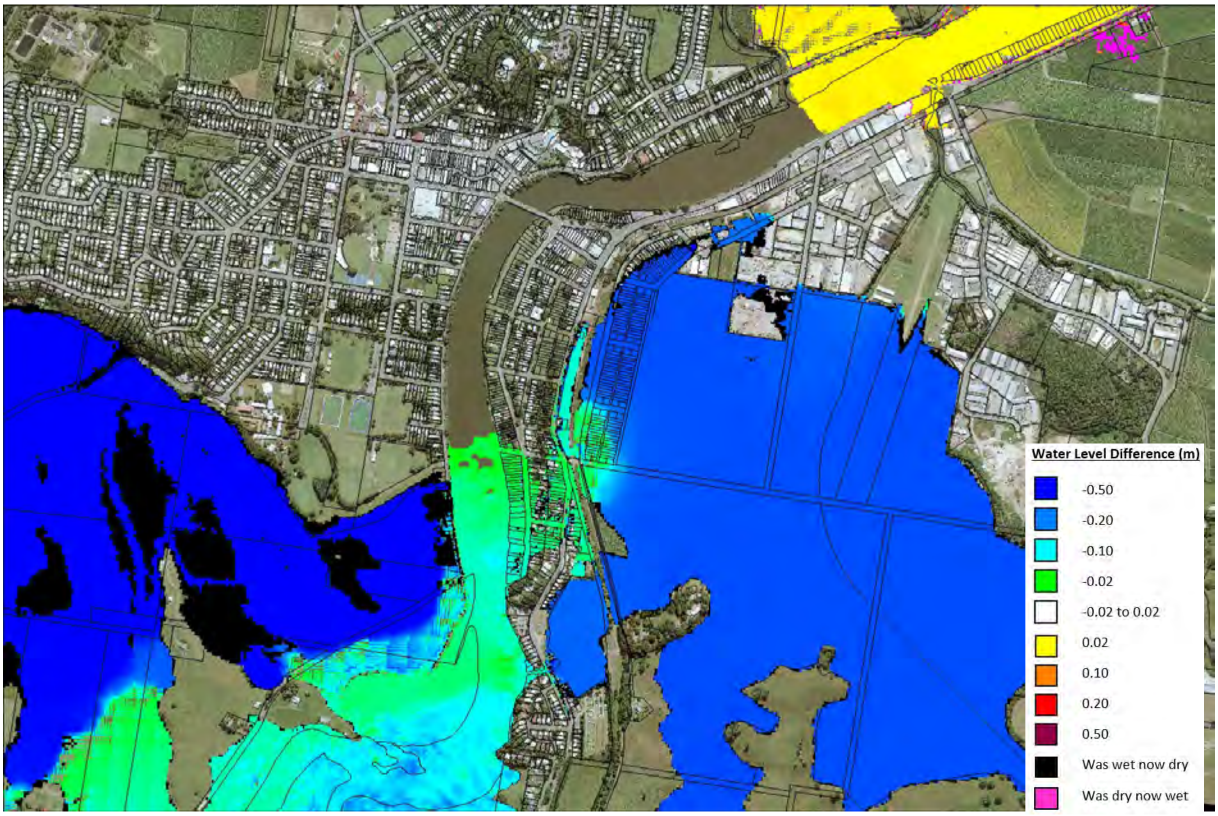


Plate 38 20% AEP Flood Level Difference Map for Tweed River dredging (-5mAHD Option) (FM13)

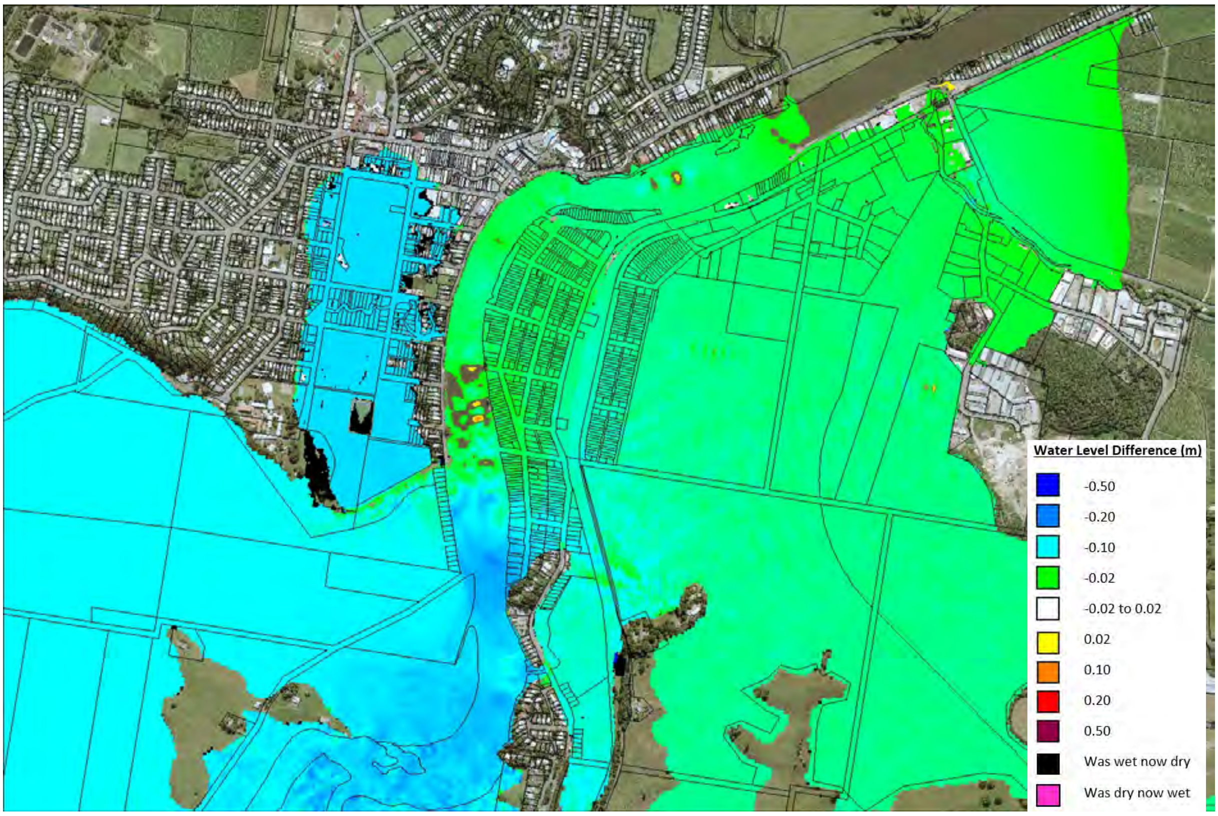


Plate 39 1% AEP Flood Level Difference Map for Tweed River dredging (-5mAHD Option) (FM13)

Geotechnical information that was compiled as part of the South Murwillumbah Levee Restoration project also confirmed that Potential Acid Sulfate Soils are present below the water table along the Tweed River bank at South Murwillumbah. If these soils are exposed to oxygen as part of the dredging process (which is likely), they would likely convert to Actual Acid Sulfate Soils and would potentially release acid and heavy metals into the surrounding environmental. Therefore, an Acid Sulfate Soil Management Plan would need to be prepared to demonstrate how the dredged material will be managed.

It will also be necessary to appropriately dispose of the dredged material. This is also an involved process including storage, dewatering, transportation as well as disposal of the material in a land fill. The cost associated with this process is significant. Moreover, existing landfills have a limited capacity, which may ultimately limit the volume of material that can be dredged over the long term. Any contamination of the dredged material (e.g., organic materials, heavy metals) would require special treatment before disposal which would add to the overall cost of implementation.

The up front and ongoing costs of dredging are likely to be significant. The exact cost of ongoing dredging is difficult to estimate without detailed sediment transportation modelling to gain an understanding of the volume of sediment that is likely to be regularly deposited in the channel. As outlined previously, it is estimated that around 230,000 cubic metres of sediment would need to be initially removed and, for the purposes of providing an indicative cost estimate, that an additional 20% of this volume would need to be removed by the dredge on an annual basis to maintain the dredged channel. These assumptions yielded a total implementation cost over 50 years of over $7.8 million (refer to **Appendix J** for a detailed cost breakdown). Accordingly, the life cycle cost of this option is significant and funding for the up front and ongoing costs associated with the option will be challenging to secure.

Revised damage estimates were also prepared based on the revised simulation results and determined that the dredging would potentially reduce flood damage costs by $1.7 million. This provides a benefit cost ratio of 0.2. Therefore, although the anticipated damage reductions are significant, the high capital and ongoing costs are likely to outweigh the financial benefits.

However, this option was strongly supported by the community with 84% of respondents either supporting or strongly supporting the option and only 5% opposed.

The financial viability of this option could be potentially improved if the dredging was completed by a commercial entity. For example, there may be opportunities for private operators to undertake the dredging and use the dredged material for aggregate in concrete. However, this is highly dependent on the dredged material being suitable for commercial application (e.g. appropriate particle size distribution, grading, particle shape etc). Any extraction activity would likely require payment of a royalties to the State Government, particularly if the extraction works are for sale or profit, which may reduce the commercial viability. Overall, the potential for the dredging to be undertaken by a commercial entity cannot be guaranteed at this point in time. However, it could be explored if this option is investigated in more detail in the future.

Overall, the significant capital and ongoing costs coupled with the potential for significant environmental impacts make this option difficult to support.

It should also be noted that during floods, high velocity flows have the potential to carry sediment and naturally scour the river channel. A review of the computer model outputs indicates that flow velocities in the main river channel are predicted to exceed 2 m/s as the 1% AEP flood approaches its peak. This velocity is sufficient to carry course sand/fine gravel. Accordingly, there is a high probability that some natural scouring of the channel will occur during large Tweed River floods. Therefore, some of hydraulic benefits identified as part of the dredging assessment will likely be afforded through natural scouring of the river channel.

5.5.2 FM14 – Blacks Drain Modifications

Recommendation: Not recommended for implementation

The modifications to Black Drain will involve enlarging the existing Blacks Drain "opening" between the Tweed River and Tweed Valley Way as well as enlarging and realigning the Blacks Drain channel between Tweed Valley Way and Condong Creek. This option would aim to direct a greater proportion of flow from the Tweed River into the South Murwillumbah basin, thereby reducing flows and flood levels along the Tweed River near the residential areas of South Murwillumbah. A concept design for the Blacks Drain modifications is provided in **Figure 46**.

The Blacks Drain modifications were included in the TUFLOW model and the updated model was used to re-simulate each design flood. Peak floodwater level difference mapping for the 20% and 1% AEP events with this option in place are presented in **Plate 40** and **Plate 41.**

Plate 40 and **Plate 41** shows that this option is predicted to reduce peak 20% AEP and 1% AEP flood levels along part sections of the Tweed River as well as south of the Murwillumbah CBD. However, the flood level reductions are typically less than 0.05 metres and do not extend across the residential or commercial areas of South Murwillumbah. **Plate 40** and **Plate 41** also show that flood levels within the South Murwillumbah Basin are predicted to increase by around 0.04 metres. These increases are predicted to extend across parts of the South Murwillumbah industrial areas as well as residential properties adjoining Railway Street.

It appears that the additional conveyance capacity afforded by the Blacks Drain modifications are relatively minor relative to the overall storage volume afforded by the South Murwillumbah basin. The relatively flat grades available across the South Murwillumbah basin also reduce the conveyance potential afforded by the new channel. It is also apparent that the Blacks Drain "opening" would need to be significantly larger to afford any significant reduction in flood levels along the Tweed River.

The cost to implement the Blacks Drain modifications is estimated to be about $4 million. A significant contributor to the cost is the enlargement of the channel on the western side of Tweed Valley Way which will require the purchase of 3 existing properties. A breakdown of costs is provided in **Appendix J**.

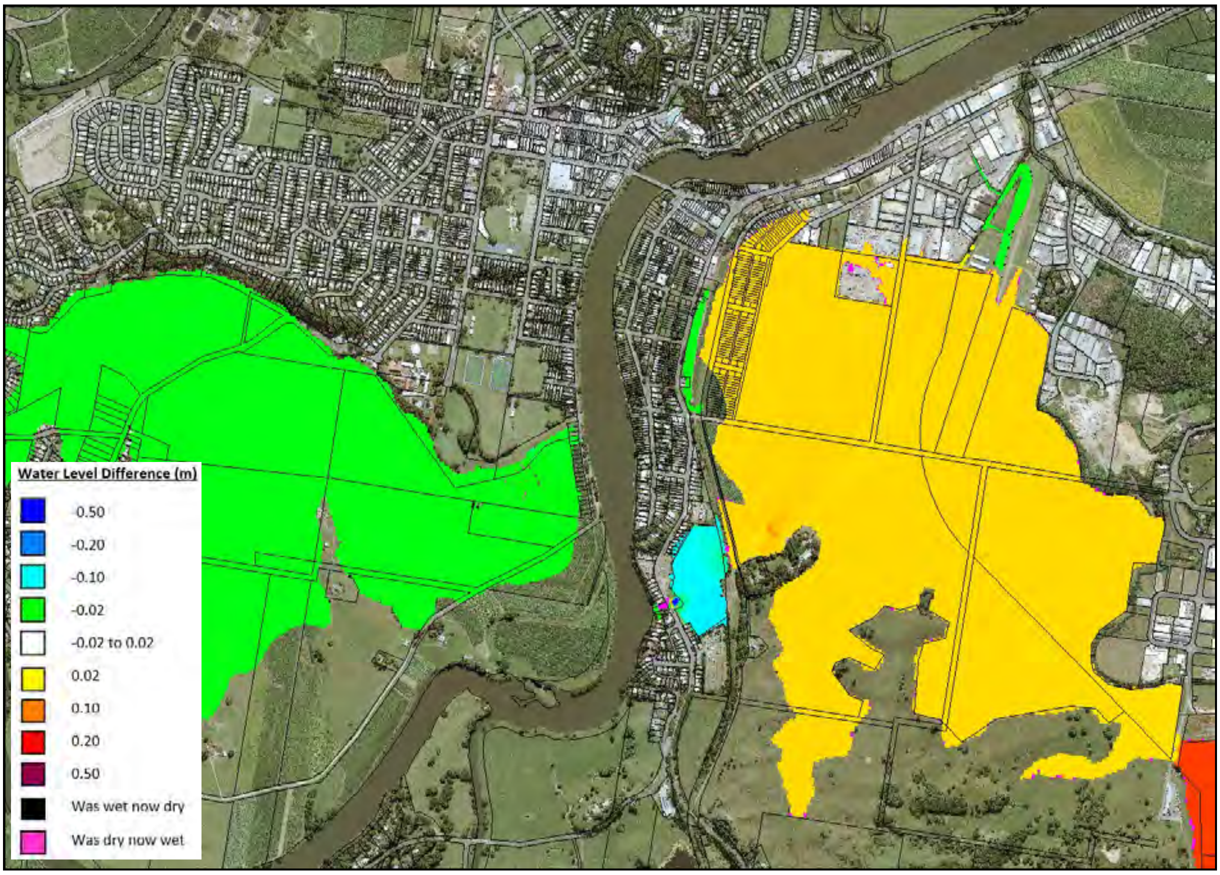


Plate 40 20% AEP Flood Level Difference Map for Blacks Drain Modifications (FM14)

Plate 41 1% AEP Flood Level Difference Map for Blacks Drain Modifications (FM14)

The potential financial benefit associated with this option was quantified by preparing revised flood damage calculations based upon the hydraulic modelling results with the Blacks Drain modifications in place. The outcomes of the revised damage assessment determined implementation of this option would like increase flood damages by $0.3 million over the next 50-years. This yielded a negative benefit cost ratio.

This option was generally supported by the community with 69% of questionnaire respondents either supporting or strongly supporting the option. Over 16% of respondents did not support this option making it the option with the most opposition.

Much of the area where earthworks will be required to construct the new channel and expand the existing channel is located within a “class 3” acid sulphate soil (ASS) area (i.e., acid sulphate soils are likely to be found >1 m below ground surface). Treatment of ASS could add significantly to the cost of implementation of this option.

Overall, this option is predicted to afford some localised reductions in flood levels. However, the lack of significant financial and hydraulic benefits coupled with lack of community support indicates that this option is unlikely to be viable.

5.6 Condong Creek Modifications

5.6.1 FM15 - Modify Condong Creek Channel

Recommendation: Recommended in implementation

As discussed in Section 2.3.8, a draft ‘Condong Creek Drainage Management Plan’ was prepared by Australian Wetlands Consulting Pty Ltd for Tweed Shire Council. The primary goals of the management plan were to improve maintenance access, improve bank stability and allow better vegetation management along the creek. This was to be largely achieved by modifying the geometry of the creek channel. This will involve enlarging part sections of the existing Condong Creek channel (refer **Figure 47**), which may also afford hydraulic benefits.

To quantify the potential flood benefits of the Condong Creek channel modifications, the modifications were included in an updated version of the TUFLOW model and the updated model was used to re-simulate each design flood. Peak floodwater level difference mapping for the 20% event with this option in place is presented in **Plate 42**. The difference mapping for the 1% AEP flood is not included as it showed negligible changes in 1% AEP flood levels.

Plate 42 shows that this option is predicted to generate very minor reductions in peak 20% AEP flood level (typically between 0.03 and 0.06 metres). However, the reductions are typically contained to the Condong Creek channel and do not extend across adjoining industrial properties.

As discussed, negligible changes in flood level are anticipated at the peak of the 1% AEP flood. Therefore, it is evident that the relatively small changes in channel geometry are not sufficient to produce significant changes in levels during large floods.

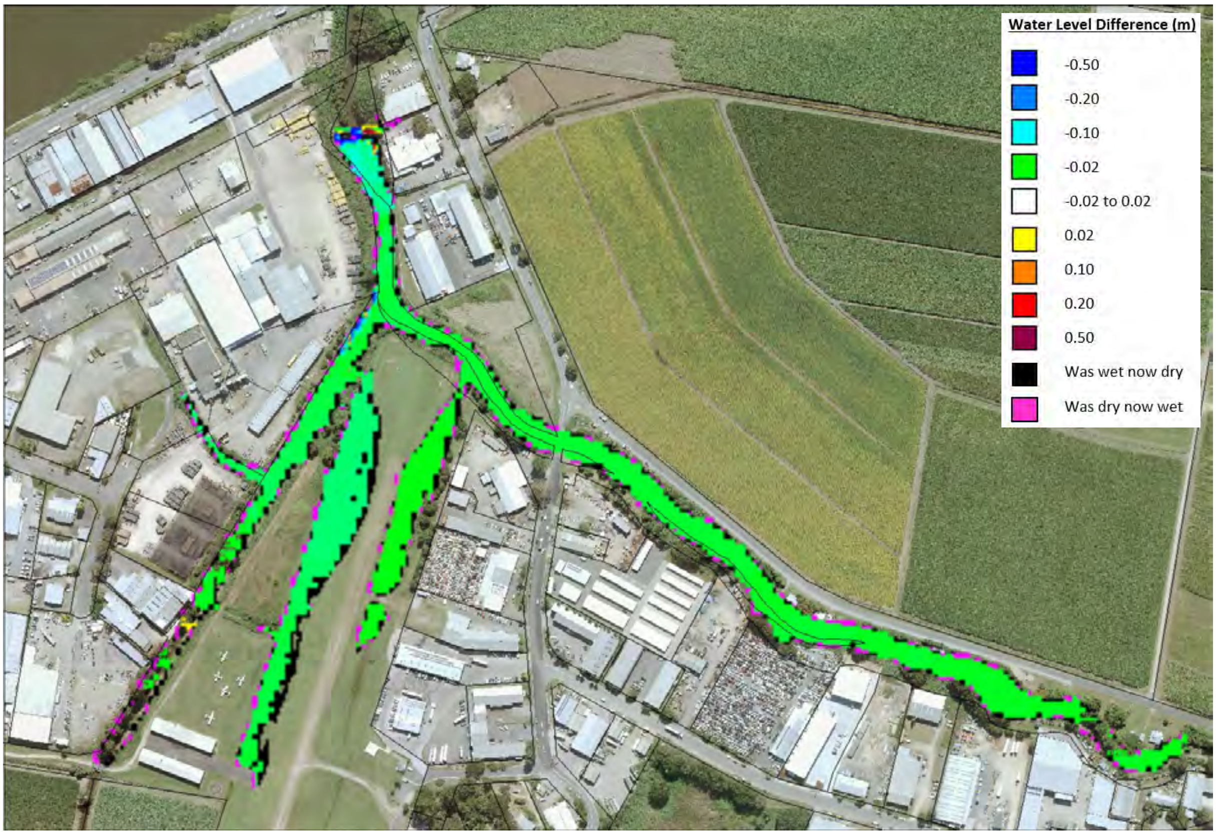


Plate 42 20% AEP Flood Level Difference Map for Condong Creek Modifications (FM15)

Accordingly, the results of the hydraulic analysis show that the channel modifications are only likely to afford hydraulic benefits during small floods where the majority of the flow is contained to the Condong Creek channel.

It is also evident that Floodgate 17L is a key control on the hydraulic performance of the Condong Creek channel. More specifically, the flood gates will remain closed and prevent flow from draining along Condong Creek whenever the water level in the Tweed River is higher than the water level upstream of the flood gates. As noted in Section 3.6.3, removal of this flood gate is predicted to significantly increase flood levels across the South Murwillumbah industrial area, so removal of the floodgates is not a viable option for improving the performance of this option. However, it may be possible to augment the existing flood gates to further improve the performance of this option (e.g., installation of a high-level outlet, as discussed in Section 5.6.3).

The cost to implement the Condong Creek modifications is estimated to be about $0.3 million. A breakdown of costs is provided in **Appendix J**.

The potential financial benefit associated with this option was quantified by preparing revised flood damage calculations based upon the hydraulic modelling results with the Condong Creek modifications in place. The outcomes of the revised damage assessment determined that a reduction in total flood damage costs of around $0.1 million could be expected over the next 50-years if this option was implemented. This yielded a preliminary benefit-cost ratio of 0.3.

However, discussions with representative of Council's floodplain risk management committee indicated that some parties in the area have verbally offered to complete the channel modification works at their own cost. If a formal agreement can be reached between Council and the parties, it would significantly reduce the implementation costs for this option and would improve the overall viability of this option (from an economic as well as implementation point of view). It is recommended that Council initiate discussions with the parties to confirm their willingness to contribute to the implementation of this option.

This option was well supported by the community with 80% of questionnaire respondents supporting the option and less than 2% of respondents not supporting the option.

It should be recognised that the primary objective of the channel modifications is to improve maintenance access, improve bank stability and allow better vegetation management along the creek. In this regard, any hydraulic benefits afforded by this option are considered to be a bonus.

Overall, this option affords small hydraulic benefits along Condong Creek during more frequent floods. Although the costs to implement this option are likely to be higher than the reduction in damage costs, this could be potentially offset by interested parties contributing to the implementation of the option. Therefore, it is recommended that Council continue to pursue the implementation of this option.

5.6.2 FM16 - Condong Creek High Flow Bench

Recommendation: Not recommended for implementation

The Condong Creek High Flow Bench option attempts to expand on the Condong Creek modifications option (FM15) by providing an additional conveyance area on the western side of the creek to carry additional flows towards the Tweed River during floods. The location and geometry of the high flow bench is shown on **Figure 48**.

To quantify the potential hydraulic benefits of the high flow bench, the option was included in an updated version of the TUFLOW model and the updated model was used to re-simulate each design flood. Peak floodwater level difference mapping was prepared for the 20% and 1% AEP events. This showed no significant reductions in 20% AEP flood levels. This is associated with the high flow bench not being "activated" during smaller floods (i.e., water levels are contained to the main channel and do not make use of the additional conveyance provided by the bench).

However, as shown in **Plate 9**, the high flow bench is predicted to afford some reductions in existing flood levels during the 1% AEP flood. In general, the reductions are predicted to be less than 0.05 metres. **Plate 9** also shows that flood level increases of up to 0.02 metres are predicted within the Tweed River channel.

The cost to implement the Condong Creek high flow bench is estimated to be about $5.5 million. A breakdown of costs is provided in **Appendix J**. The most significant component of this overall cost is the installation of culverts across Tweed Valley Way.

Plate 43 1% AEP Flood Level Difference Map for Condong Creek High Flow Bench (FM16)

The potential financial benefit associated with this option was quantified by preparing revised flood damage calculations with the high flow bench in place. The outcomes of the revised damage assessment determined that a reduction in total flood damage costs of around $1.1 million could be expected over the next 50-years if this option was implemented. This yielded a preliminary benefit-cost ratio of about 0.2. Accordingly, the financial cost of implementing this option far outweighs the benefits (i.e., reduction in damage costs).

This option was supported by the community, but not as strongly as some of the other options (66% of respondents either supported or strongly supported the option). However, it is noted that less than 2% did not support the option. So, although the option isn't necessarily strongly supported there is not a significant amount of opposition.

Overall, this option is predicted to afford some small benefits across parts of the industrial areas of South Murwillumbah during large floods. However, the hydraulic and financial benefits are not considered to be sufficient to support the relatively high capital investment. Therefore, this option is not recommended for implementation.

5.6.3 FM17 - High Level Condong Creek Outlet

Recommendation: Not recommended for implementation

The High Level Condong Creek Outlet option involves modifying the existing Condong Creek outlet (flood gate 17L) to include an additional set of gated outlets on top of the current low level outlets. The design concept for the high-level outlet is shown on **Figure 49**.

To quantify the potential hydraulic benefits of the high-level outlet, the option was included in an updated version of the TUFLOW model and the updated model was used to re-simulate each design flood. Peak floodwater level difference mapping for the 20% and 1% AEP events with this option in place are presented in **Plate 44** and **Plate 45**.

The difference mapping shows that only very small, localised changes in flood level are predicted in the immediate vicinity of the flood gate. That is, this option is predicted to afford minimal change in broadscale flood behaviour. This outcome is associated with the flood levels on the downstream side of the gate generally always being higher than on the upstream side. Therefore, at the peak of the flood, water is still predicted to be "trapped" on the upstream side of the gate even with the high-level outlets in place.

A review of the time variation in water levels was also completed to determine if the high-level flood gates would afford any reductions in flood levels at other times during the flood. The outcomes of this assessment are presented in the stage hydrograph presented in **Plate 46.**

Plate 46 confirms the high-level outlet is not predicted to reduce peak stages. However, it will afford small reductions in flood levels during the rising and falling limb of the hydrograph. A maximum reduction in flood level of 0.1 metres is anticipated. As flood levels will not rise as rapidly, it may afford additional evacuation time for some industrial properties. In addition, as water levels are predicted to drop more rapidly after the peak of the flood, it will allow recovery/clean up efforts to commence sooner. It is expected that implementation of the high-level outlets will allow the area behind the flood gate to drain approximately 5 hours quicker during a 1% AEP flood.

The cost to implement the Condong Creek high level outlet is estimated to be about $1.2 million. A breakdown of costs is provided in **Appendix J**.

The potential financial benefit associated with this option was quantified by preparing revised flood damage calculations based upon the hydraulic modelling results with the high flow bench in place. The outcomes of the revised damage assessment determined that the high level outlet is not predicted to alter existing flood damage costs. This yielded a preliminary benefit-cost ratio of 0.

This option was generally supported by the community with 79% of questionnaire respondents either supporting or strongly supporting the option. Interestingly, none of the respondents opposed this option (i.e., this was the only one of the options that did not receive any opposition).

Overall, this option is predicted to provide some small beneficial hydraulic impacts during the early stages of each flood. This option will also assist in more rapidly draining the South Murwillumbah basin. However, there are predicted to be negligible beneficial hydraulic impacts at the peak of each flood. As a result, this option is not recommended for implementation.

Plate 44 20% AEP Flood Level Difference Map for High Level Condong Creek Outlet (FM17)

Plate 45 1% AEP Flood Level Difference Map for High Level Condong Creek Outlet (FM17)

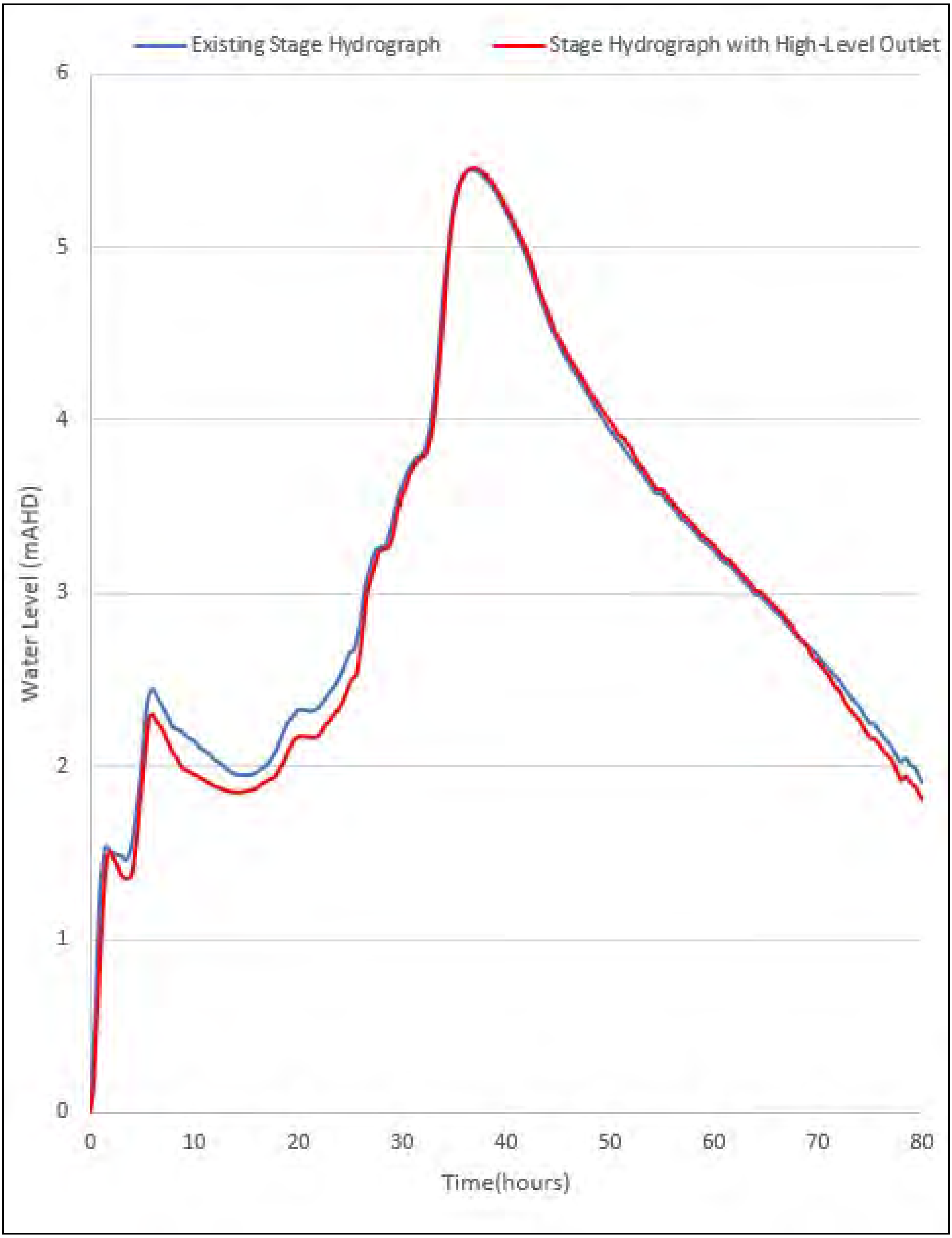


Plate 46 1% AEP Stage hydrograph upstream of flood gate 17L with high level outlet

5.7 Combined Options

5.7.1 FM18 – South Murwillumbah High Flow Bypass Option 1 and Industrial Land Swap Option 1B

Recommendation: Not recommended for implementation

As discussed in Section 5.2.2, the South Murwillumbah High Flow Bypass (Option 1) (FM2) is predicted to afford some significant reductions in flood levels across the residential and commercial areas of South Murwillumbah during frequent floods. However, the water that is directed into the South Murwillumbah basin as part of this option is predicted to increase flood levels within the basin, which is predicted to extend into the industrial areas of South Murwillumbah. During larger floods the flood level increases are sufficient to "back up" and also impact on the residential and commercial areas of South Murwillumbah. Accordingly, this option looked to combine the South Murwillumbah High Flow Bypass with the Industrial Land Swap Option 1B (discussed in detail in Section 6.4.1) to assist in reducing the predicted flood level increases within the South Murwillumbah Basin.

To quantify the potential hydraulic benefits of the combined options, the bypass and land swap modifications were included in an updated version of the TUFLOW model and the updated model was used to re-simulate each design flood. Peak floodwater level difference mapping for the 20% and 1% AEP events with this option in place are presented in **Plate 47** and **Plate 48**.

Plate 48 shows that this combined option is predicted to generate notable reductions in 1% AEP flood levels across most of the residential, commercial and industrial areas of South Murwillumbah. The flood level reductions are generally predicted to be around 0.05 to 0.1 metres although localised areas are predicted to experience reductions of over 0.3 metres. Flood level reductions are also predicted to extend well upstream of South Murwillumbah, including the Murwillumbah CBD.

Plate 48 also shows that the combined option is predicted to increase 1% AEP flood levels north-east of Quarry Road. Although the flood level increases do extend mostly across sugar cane fields, several existing properties adjoining Tweed Valley Way are predicted to experience flood level increases of more than 0.05 metres. Accordingly, the adverse flood impacts that are predicted with the land swap option 1B implemented in isolation (refer Section 6.4.1) are exacerbated with the inclusion of the bypass floodway which directs additional flow into the South Murwillumbah basin.

Plate 47 shows the combined option is predicted to generated reductions in 20% AEP flood level of more than 0.1 metres across most of the residential and commercial areas of South Murwillumbah. The flood level reductions are also predicted to extend a significant distance upstream of South Murwillumbah. However, **Plate 47** also shows that inclusion of the industrial land swap is not predicted to produce a significant reduction in 20% AEP flood levels across the South Murwillumbah basin relative to the high flow bypass in isolation. A review of results indicates that this is associated with the 20% AEP flood levels within the South Murwillumbah basin not being sufficiently elevated to overtop Quarry Road and fully activate the South Murwillumbah Condong Flowpath (i.e., the improved conveyance afforded by the industrial land swap is not fully realised during smaller floods).

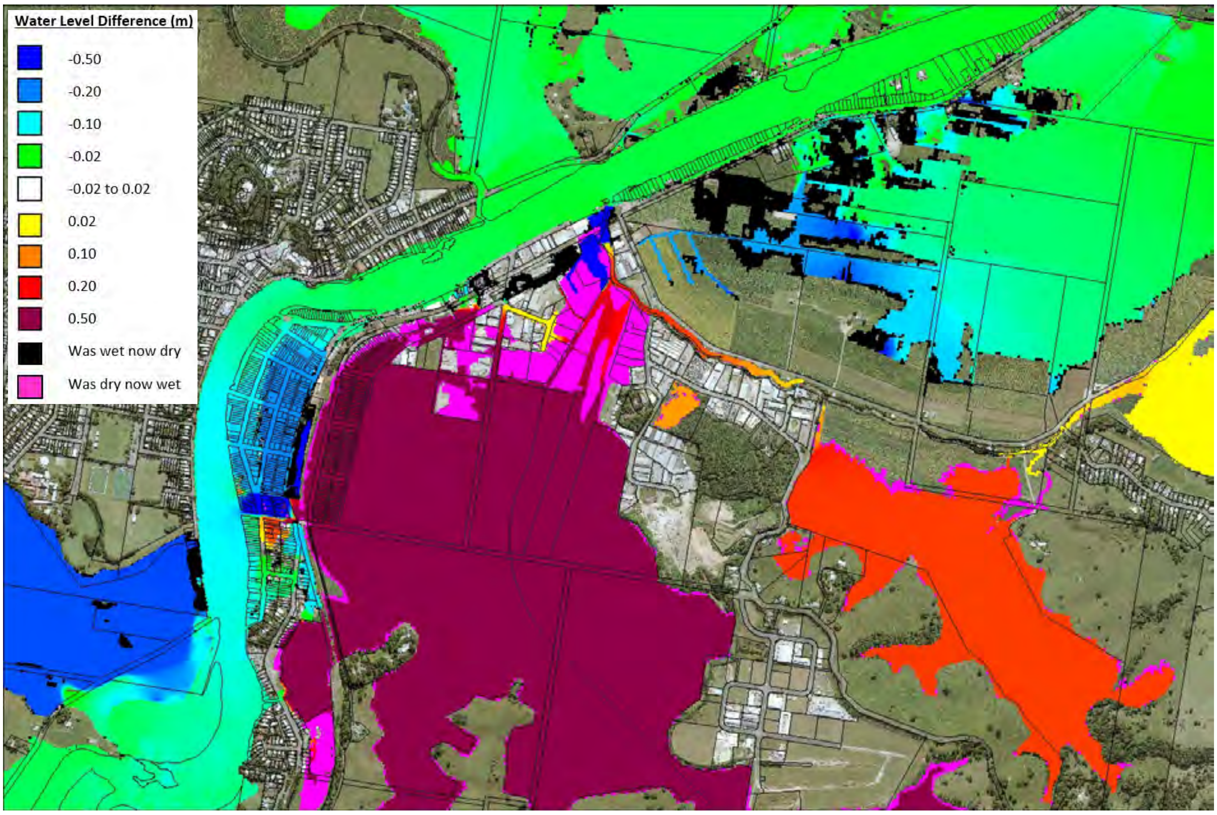


Plate 47 20% AEP Flood Level Difference Map for South Murwillumbah High Flow Bypass and Industrial Land Swap (FM18)

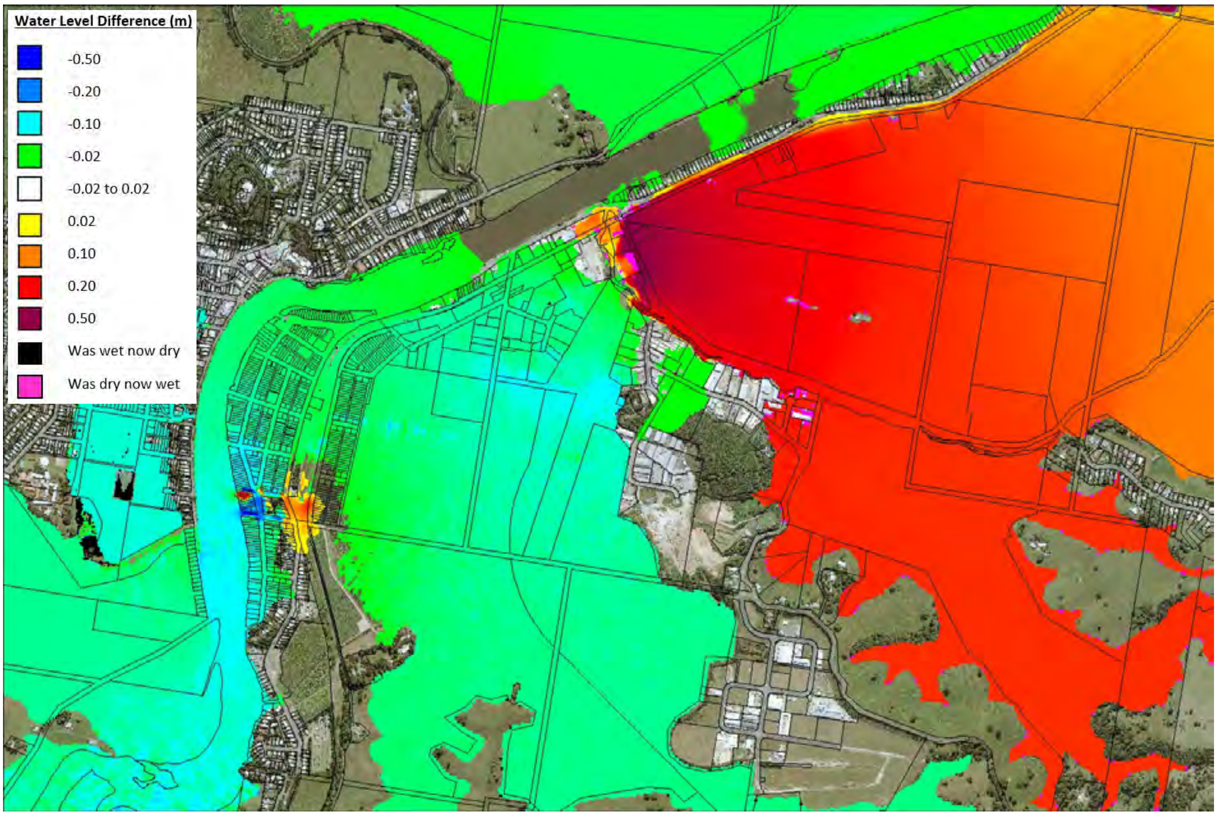


Plate 48 1% AEP Flood Level Difference Map for South Murwillumbah High Flow Bypass and Industrial Land Swap (FM18)

The cost to implement the high flow bypass and industrial land swap is estimated to be about $29 million. Accordingly, the total cost to implement this combined option is significant.

The potential financial benefit associated with this option was quantified by preparing revised flood damage calculations based upon the hydraulic modelling results with the Condong Creek modifications in place. The outcomes of the revised damage assessment determined that a reduction in total flood damage costs of around $5.4 million could be expected over the next 50-years if this option was implemented. This yielded a preliminary benefit-cost ratio of 0.2. Accordingly, the implementation costs are predicted to significantly outweigh the benefits

Overall, this combined option is predicted to provide some significant reductions in flood levels across the residential and commercial areas of South Murwillumbah during smaller and larger floods. However, the high implementation cost, low benefit cost ratio and flood level increases that are predicted elsewhere make this combined option difficult to support for implementation.

5.7.2 FM19 – Raising South Murwillumbah Levee to 5% AEP Level, Raising CBD Levee, Condong Creek Modifications and Industrial Land Swap Option 1A

Recommendation: Not recommended for implementation

This option investigated the potential benefits associated with combining the following flood risk management options:

- FM9: Raising South Murwillumbah levee to 5% AEP level & raising CBD levee;
- FM15: Condong Creek modifications; and,
- PM3: Industrial Land Swap Option 1A.

The combined options were included in an updated version of the TUFLOW model and the updated model was used to re-simulate each design flood. Peak floodwater level difference mapping for the 20% and 1% AEP events with this option in place are presented in **Plate 49** and **Plate 50**.

Plate 49 shows significant reductions in inundation extents across the residential and commercial areas of South Murwillumbah during the 20% AEP flood. Reductions in flood level are also predicted across the South Murwillumbah Basin and the reductions are predicted to extend across some of the industrial area. The flood level reductions across the South Murwillumbah Basin are predicted to be around 0.08 metres (a small improvement of 0.01 metres relative to FM9).

Plate 49 also shows that flood levels in the Tweed River are predicted to increase by around 0.05 metres. Flood level increases of around 0.15 metres are predicted immediately south of the Commercial Road levee (a reduction of 0.01 metres relative to FM9). However, the flood level increases are still predicted to extend upstream to Bray Park.

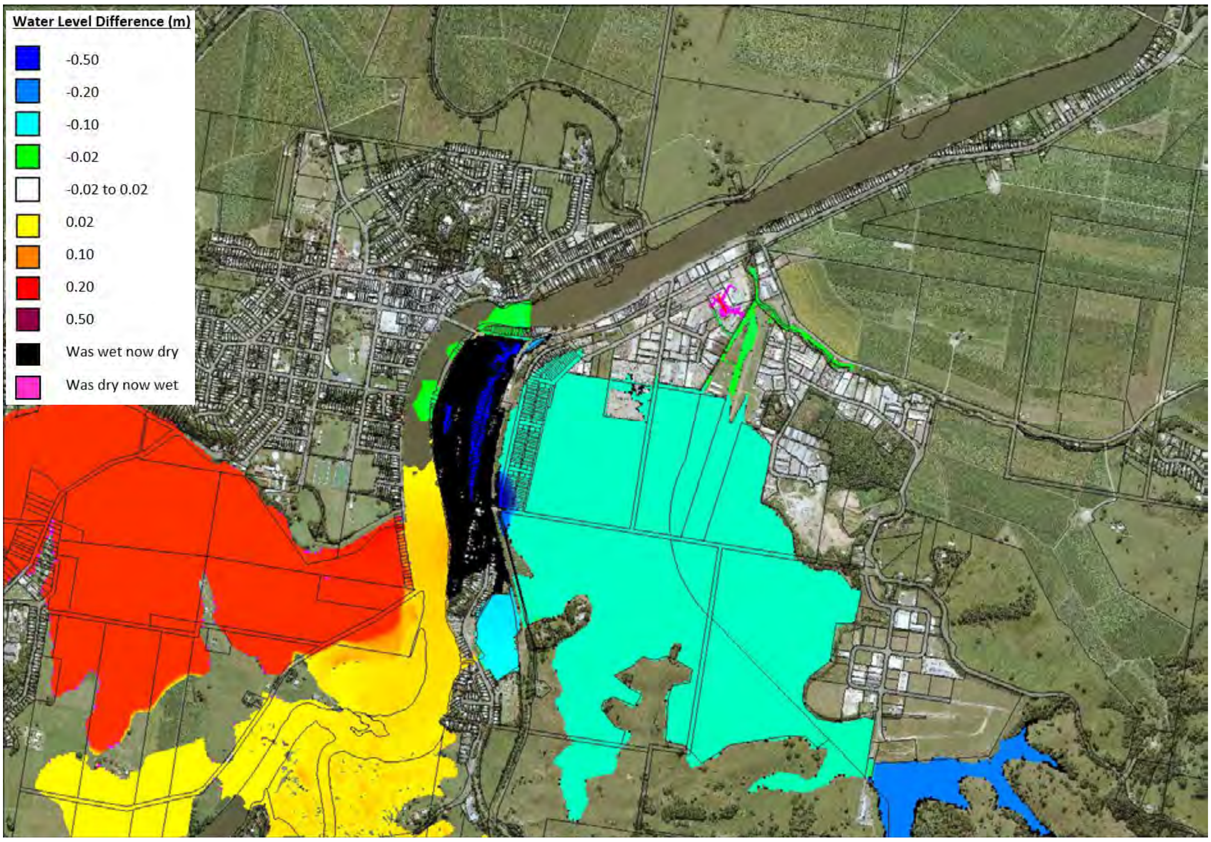


Plate 49 20% AEP Flood Level Difference Map for combined FM9, FM15 and PM3 (FM19)

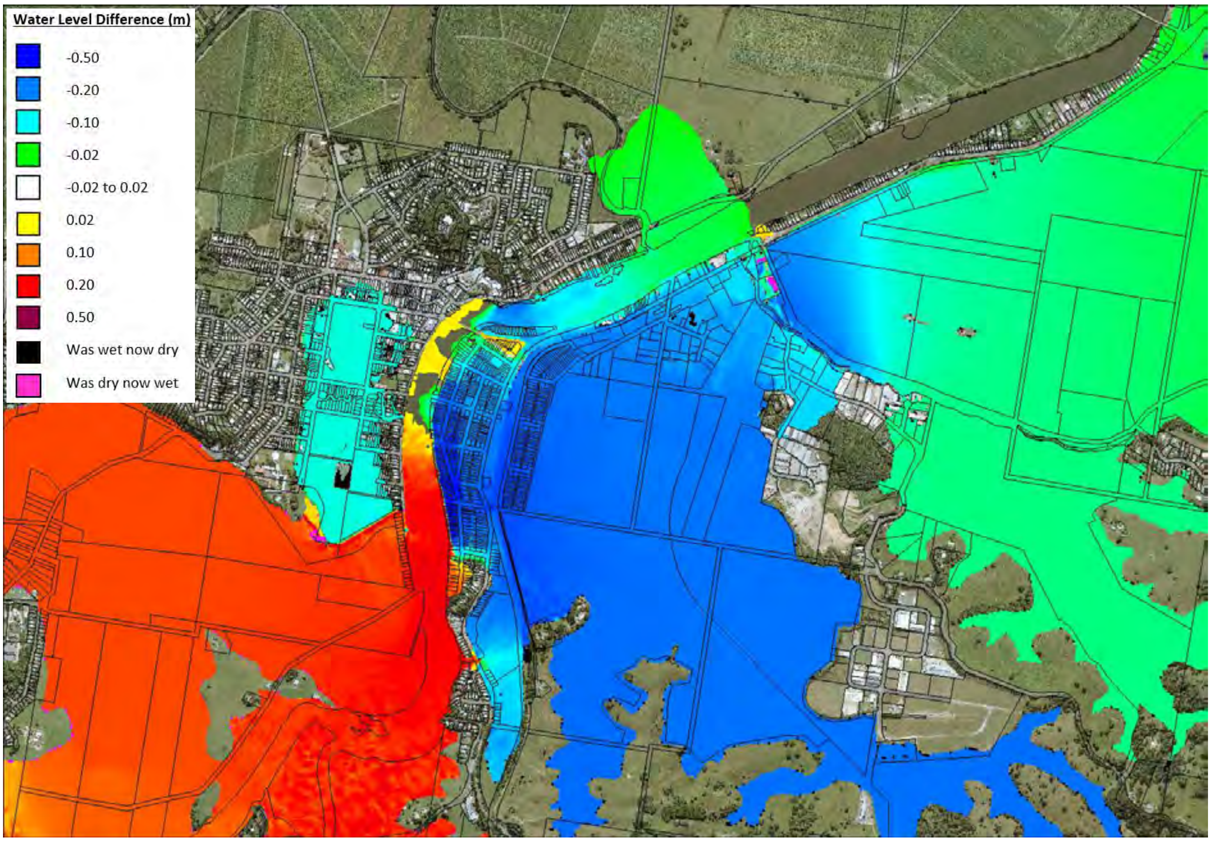


Plate 50 1% AEP Flood Level Difference Map for combined FM9, FM15 and PM3 (FM19)

Plate 50 shows that during the 1% AEP flood, flood level reductions of at least 0.2 metres are predicted across most of the residential and commercial sections of South Murwillumbah. Across the industrial areas, the combined option is predicted to reduce flood levels by around 0.2 metres. Therefore, inclusion of FM15 and PM3 affords additional hydraulic performance relative to FM9 in isolation (although not substantially so).

Flood levels within the Tweed River and south of the Commercial Road levee are predicted to increase by between 0.08 and 0.13 metres (i.e., ~0.02 metres lower than FM9). Despite the improved hydraulic performance south of the Commercial Road levee, the flood level increases are still sufficient to allow more water to spill into the CBD. Therefore, inclusion of the additional options is unlikely to be sufficient to offset the predicted flood level increases across the CBD associated with the levee raising. Therefore, raising of the Commercial Road levee will still likely need to be pursued as part of this combined option to ensure CBD properties are not adversely impacted.

Flood level increases during the 1% AEP flood of around 0.14 metres are predicted to extend upstream to Bray Park. The flood level increases are sufficient to result in 3 additional properties being exposed to above floor flooding during the 1% AEP flood and 2 additional properties being exposed to above floor flooding during the 0.2% AEP flood (no changes in above floor flooding during the 20% AEP or 5% AEP flood). As discussed in Section 5.3.3, it may be possible to offset these impacts by including the five impacted properties in Council's voluntary house purchase program.

The cost to implement the South Murwillumbah levee raising, the CBD levee raising, Condong Creek modifications and industrial land swap is estimated to be about $25.6 million (this includes an allowance for the voluntary purchase of 5 properties in Bray Park). Therefore, the total cost to implement this combined option is significant.

The potential financial benefit associated with this option was quantified by preparing revised flood damage calculations based upon the hydraulic modelling results with the combined option in place. The outcomes of the revised damage assessment determined that a reduction in total flood damage costs of around $27.5 million could be expected over the next 50-years if this option was implemented. This yielded a preliminary benefit-cost ratio of 1.1. Therefore, despite the significant capital cost, the reduction in flood damages is predicted to be sufficient to offset the cost.

FM19 would also afford evacuation improvements, with a minimum of 4 hours of additional evacuation time being available from South Murwillumbah into the CBD during large Tweed River floods.

Overall, this combined option is predicted to provide some significant hydraulic benefits and flood damage reductions across South Murwillumbah. However, the capital required to implement this combined option is significant. FM20 involves a significantly lower capital investment and affords an improved benefit cost ratio. As a result, FM20 is recommended for implementation in preference to FM19.

5.7.3 FM20 – Raising South Murwillumbah Levee to 20% AEP Level, Raising CBD Levee, Condong Creek Modifications and Lot 4 Quarry Road Earthworks

Recommendation: Recommended for implementation pending further detailed investigations into feasibility of levee raising and sufficient funding being available

This option investigated the potential benefits associated with combining the following flood risk management options, which are all recommended for implementation individually:

- FM4: Earthworks across Lot 4 DP 591604 Quarry Road;
- FM8: Raising South Murwillumbah levee to 20% AEP level & raising CBD levee; and
- FM15: Condong Creek modifications.

The combined options were included in an updated version of the TUFLOW model and the updated model was used to re-simulate each design flood. Peak floodwater level difference mapping for the 20% and 1% AEP events with this option in place were prepared and are presented in **Plate 51** and **Plate 52**.

Plate 51 shows FM20 is predicted to produce significant reductions in flood levels and inundation extents across the residential and commercial areas of South Murwillumbah during the 20% AEP flood. Reductions in flood level are also predicted across the South Murwillumbah basin and the reductions are predicted to extend across some of the industrial area. The flood level reductions across the South Murwillumbah basin are predicted to be around 0.08 metres.

Plate 52 shows that during the 1% AEP flood, flood level reductions of more than 0.1 metres are predicted across most of the residential, commercial and industrial sections of South Murwillumbah. Flood levels south of the Commercial Road levee are predicted to increase by 0.07 metres (i.e., ~0.09 metres lower than FM8 in isolation). Despite the improved hydraulic performance, the elevated 1% AEP flood levels are still sufficient to produce additional overtopping of the Commercial Road levee. Therefore, raising of the Commercial Road levee will still likely need to be pursued as part of this combined option to ensure CBD properties are not adversely impacted. However, the magnitude of the CBD levee modifications is less significant relative to FM8 in isolation.

The flood level increases in the vicinity of Bray Park are predicted to alter the number of properties predicted to be exposed to above floor flooding. More specifically, three additional properties are predicted to be flooded above floor during the 1% AEP flood (no increases in above floor flooding are predicted during the other simulated design floods). As discussed in Section 5.3.2, it may be possible to offset these impacts by incorporating the impacted properties in Council's voluntary purchase scheme.

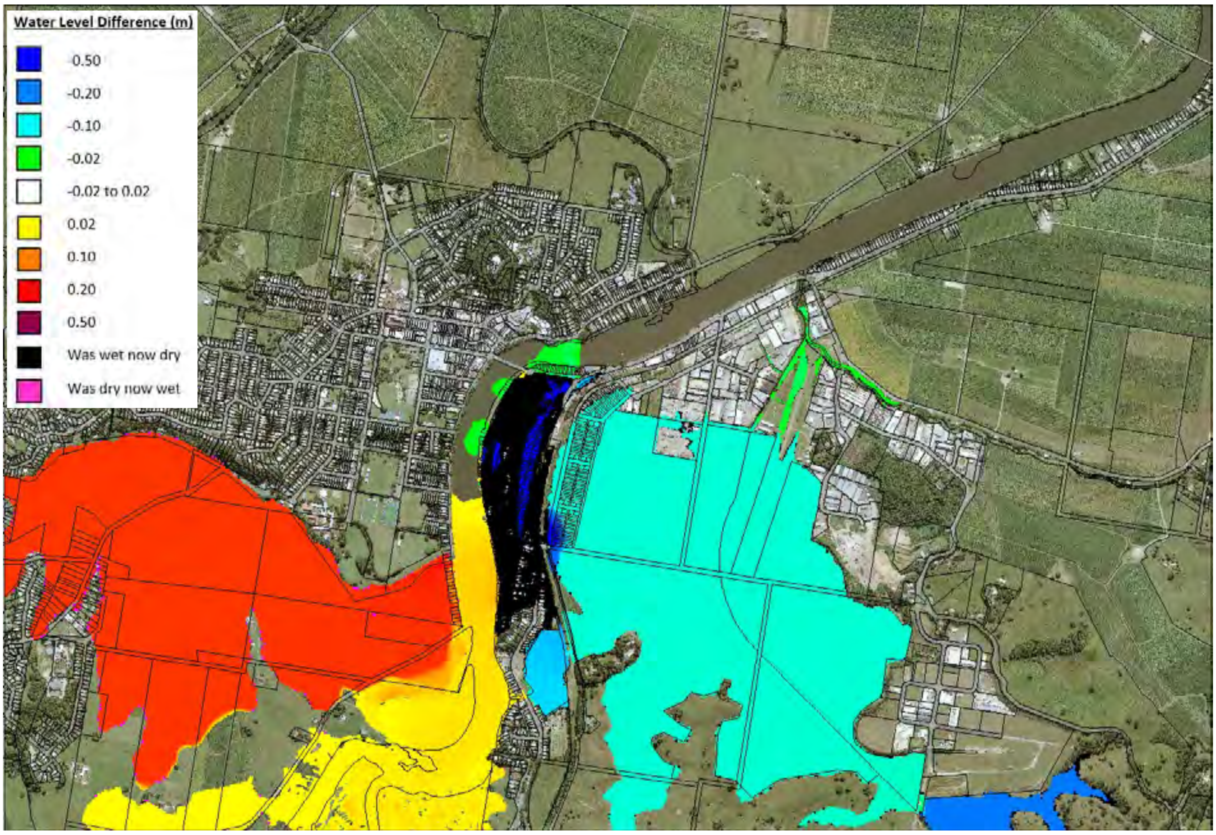


Plate 51 20% AEP Flood Level Difference Map for combined FM4, FM8 and FM15 (FM20)

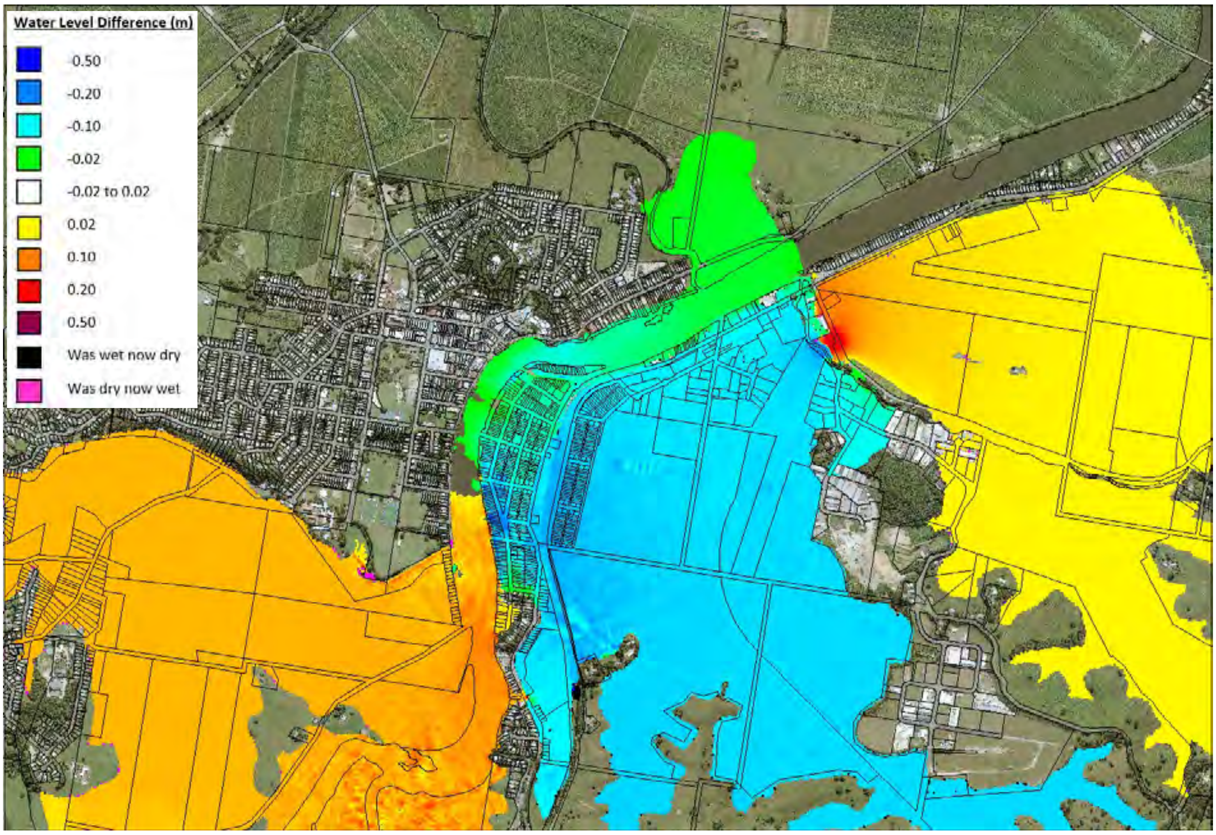


Plate 52 1% AEP Flood Level Difference Map for combined FM4, FM8 and FM15 (FM20)

Although an increase in above floor flooding is predicted across Bray Park during the 1% AEP event, a significant reduction in the number of properties exposed to above floor flooding is predicted across South Murwillumbah. This includes:

- 20% AEP flood: 25 fewer properties with above floor flooding
- 5% AEP flood: 26 fewer properties with above floor flooding
- 1% AEP flood: 5 fewer properties with above floor flooding
- 0.2% AEP flood: 6 fewer properties with above floor flooding

Accordingly, the overall reduction in flood impacts associated with this combined option is significant.

The cost to implement the levee raising, Condong Creek modifications and Lot 4 Quarry Road earthworks is estimated to be about $14.8 million. This cost includes an allowance for the voluntary purchase of three Bray Park properties. Although the total cost to implement this combined option is significant, it is lower than the implementation cost for FM19.

The potential financial benefit associated with this option was quantified by preparing revised flood damage calculations based upon the hydraulic modelling results with the combined option in place. The outcomes of the revised damage assessment determined that a reduction in total flood damage costs of around $21 million could be expected over the next 50-years if this combined option was implemented. This provides a preliminary benefit-cost ratio of 1.4.

Overall, this combined option is predicted to provide some significant hydraulic benefits and flood damage reductions across South Murwillumbah. The capital cost is significant, which will reduce the potential to implement all components in the short term. In addition, some adverse flood impacts are predicted across Bray Park. Nevertheless, the financial benefits are predicted to be significant if all components are ultimately implemented. Therefore, it is recommended that each of the individual components of this option are progressively investigated in detail and implemented if/when funding can be secured. It is suggested that the Lot 4 Quarry Road topographic modifications and Condong Creek modifications proceed first with the levee raising to be implemented at a later stage if this individual option is determined to be feasible and suitable funding can be secured. If each component of this option is to be constructed individually, then the detail design of each option is to ensure that all flooding impacts are carefully assessed, and adverse flood impacts as a result of the construction of one particular construction are mitigated at that stage.

6 PROPERTY MODIFICATION OPTIONS

6.1 Introduction

Property modification options refer to modifications to planning controls and/or modifications to individual properties to reduce the potential for inundation in the first instance or improve the resilience of properties should inundation occur. Modifications to individual properties are typically used to manage existing flood risk while planning measures are employed to manage future flood risk.

The following property modifications were investigated as part of the study:

- PM1 – Review of Council's current voluntary house purchase program
- PM2 – Temporary flood barriers for commercial properties
- PM3 – Industrial land swap option 1
- PM4 – Industrial land swap option 2
- PM5 – Consolidation of existing residential lots

In general, modifications to individual properties will not have a significant impact on broad-scale flood behaviour. Therefore, the impacts of the voluntary house purchase, flood barrier and lot consolidation options were not assessed in the hydraulic model. However, as the industrial land swap option involves more significant changes, this option was assessed in the model.

Where possible, cost estimates for each option were prepared and are included in **Table 26. Table 26** also summarises the predicted reduction in flood damage costs if the option was implemented along with the associated benefit-cost ratio.

Table 26 Economic Assessment for Property Modification Options

Option		$ Millions				
		Cost	Existing Damage	Total Damage with Option in Place	Reduction in Damage with Option in Place	Benefit-Cost Ratio
PM2	Temporary flood Barriers for high priority commercial buildings	1.08	60.5	48.5	12.1	11.2
	Temporary flood Barriers for high and medium priority commercial buildings	1.3		48.2	12.3	9.5
PM3	Land Swap Option 1A	6.6		55.4	6.1	0.9
	Land Swap Option 1B	11.2		54.4	7.1	0.6
PM4	Land Swap Option 2A	13.2		52.9	8.6	0.7
	Land Swap Option 2B	20.0		52.1	9.4	0.5

6.2 PM1 – Review of Proposed Voluntary House Purchase Scheme

Recommendation: Proposed VHP scheme is generally suitable and should continue to be implemented.

Voluntary house purchase (VHP) refers to the voluntary purchase of an existing property. The purchased property is typically demolished, and the land is retained as open space or an equivalent land use that is more compatible with the flood risk. Due to the high capital cost, VHP is typically restricted to high risk properties (i.e., properties located in high hazard, floodways) where no other risk management measures are considered feasible.

VHP across South Murwillumbah dates back to the 'Murwillumbah Floodplain Risk Management Plan' (NSW Public Works, 1989) where eleven properties in River Street (between Greville Street and Colin Street) were identified as being suitable for VHP. Since this time, seven of these properties have been purchased. Four properties from this original VHP scheme remain to be purchased and there are plans to do this as part of the next phase of the scheme.

The most recent VHP scheme for South Murwillumbah was originally documented in the 'Tweed Valley Floodplain Risk Management Study' and was subsequently endorsed by Tweed Shire Council in 2014. Council has subsequently refined the VHP as additional information became available such as updated modelling completed for the 'Murwillumbah CBD Levee & Drainage Study' (CSS, 2018).

As discussed in Section 3.2, the current study included further refinement of the flood model across South Murwillumbah. The results from this updated modelling were made available to Council to further confirm the suitability of the proposed VHP scheme. The proposed VHP scheme for South Murwillumbah is documented in the draft 'South Murwillumbah & Bray Park Voluntary House Purchase Scheme: Scoping Study & Implementation Plan' (Version 1.2, November 2018). Given the significant cost associated with VHP, Council requested that an independent review of the draft VHP scheme be completed as part of the current study.

The proposed VHP scheme includes a total of 39 properties that are identified as either high, medium or low priority. The properties were selected and prioritised based upon a range of criteria including flood hazard, potential for isolation, evacuation difficulties as well as above floor flooding depth in the 1% AEP event, which are all considered appropriate. The location of each of the 39 properties identified under the proposed VHP scheme is shown on **Figure 50**. The "highest scoring" VHP properties are typically located adjacent to River Street and Wardrop Street.

The proposed VHP scheme also identifies a "future, expanded VHP" scheme which is also included on **Figure 50**.

An independent review of the proposed VHP properties shown in **Figure 50** was completed as part of the current study based upon the results from the updated modelling. This incorporated flood hazard, hydraulic categories and flood depth outputs. The outcomes of this review were generally consistent with the properties identified in Council's proposed VHP. That is, the properties identified under Council's proposed VHP scheme were consistent with those identified as part of the current study.

The only location that was identified as part of the current study where there is a significant flood risk that was excluded from Council's proposed VHP scheme is 6 Holland Street where the entire lot falls within a H5 or H6 hazard area during 1% AEP flood. However, subsequent discussions with Council determined that this property was recently purchased and is, therefore, excluded from the proposed VHP program.

Council may like to consider purchasing and/or rezoning land located east of Wardop Street (between Stafford Street and Greville Street) which is currently zoned for residential land uses (refer green lots identified in **Figure 50**). This area serves as a significant flow path during major floods and most of the area would be classified as a H6 hazard area during the 1% AEP flood. As a result, future residential development in this area is considered incompatible with the hazard. As these lots currently serve as a school sports field (which are considered to be a compatible land use), rezoning of the land is the most likely outcome.

It was noted that there are also five lots located at 45 Wardop Street that are identified in Council's VHP. These lots do not currently include any residential buildings so the ability to secure funding under the State Government's VHP program is considered to be limited. However, like the properties identified above, purchasing and rezoning of this land is considered to be a worthwhile pursuit for ensuring the existing flood risk is not increased. A review of the flood modelling outputs confirms that approximately half of each lot would be exposed to H6 hazard conditions at the peak of the 1% AEP flood with the balance of each lot exposed to H5 hazard conditions. Accordingly, the structural integrity of any residential buildings that may be constructed on these lots in the future cannot be guaranteed even when they are specially engineered. It is recommended that Council continue to pursue the purchase of these properties.

An economic assessment was also completed to quantify the potential economic impacts of the proposed VHP scheme. The assessment was completed for both the "immediate" VHP scheme as well as the future expanded VHP. The assessment was restricted to those properties currently containing residential buildings. The cost was estimated based upon the current median house price in South Murwillumbah of $390,000. The reduction in damages was estimated by assuming that all residential buildings identified in the VHP scheme would be removed (i.e., the damage contributed by each of the VHP properties was removed from the overall damage calculations).

The total cost to purchase all 39 residential properties identified in the proposed VHP scheme is estimated to be just over $15 million. Purchasing and removing these buildings from the floodplain is predicted to reduce flood damage costs by over $2.8 million. This provides a benefit cost ratio of 0.2.

The total cost to purchase all 85 residential properties identified in the expanded VHP scheme is estimated to be just over $33 million. This cost incorporates the 39 properties included in the proposed VHP scheme (i.e., the additional cost of the expanded VHP would be about $18 million). Flood damage costs are predicted to reduce by over $6.8 million if all properties in the proposed and expanded VHP are purchased. This provides a benefit cost ratio of 0.2.

Therefore, the economic performance of the proposed and expanded VHP scheme is predicted to be similar. It is noted that the implementation cost is significant, and this option yields a benefit cost ratio of well below 1. However, this is not uncommon for VHP schemes as the VHP is targeted towards removing people from high hazard sections of the floodplain (i.e., economics is not the main priority). If the reduction in flood exposure and potential reduction in loss of life is taken into consideration, this option is still considered worthwhile pursuing.

This option was generally supported by the community with 68% of respondents supporting the option and only 7% not supporting the option.

It is recommended that Council implement the proposed VHP as it is considered the best long-term option for addressing the significant flood risk across the residential areas of South Murwillumbah. In general, the draft 'South Murwillumbah & Bray Park Voluntary House Purchase Scheme: Scoping Study & Implementation Plan' appropriately identifies the properties that would most benefit from VHP and no significant modifications are considered necessary. It is recommended that Council continue to pursue the purchase of 45 Wardop Street and may like to consider purchasing or rezoning the existing vacant lots east of Wardop Street (shown in **Figure 50**). However, this may need to be completed under a separate scheme (i.e., not part of the VHP scheme).

6.3 PM2 - Temporary Flood Barriers for Commercial Properties

Recommendation: Recommended for implementation

South Murwillumbah is home to a range of residential, commercial and industrial buildings. Although the majority of flood damage costs is predicted to occur across residential properties, commercial property damage makes up a considerable proportion of the overall damage bill despite it only occupying a small proportion of the study area.

Commercial properties typically aren't well suited or eligible for traditional residential property modification options such as voluntary purchase. However, it is possible to install temporary flood barriers in commercial properties as a means of reducing flood damages and disruption to commercial businesses.

Examples of temporary flood barriers are provided in **Plate 46**. As shown in **Plate 46**, the barrier arrangement would typically include a bracket permanently attached to the front (and potentially back) of the commercial buildings. 0.3m high planks can then be lowered into the brackets to provide protection from inundation depths up to 1.5 metres high.

Unfortunately, floodwater depths across much of the commercial area of South Murwillumbah (e.g., Hayes Lane, Prospero Street and Holstons Lane) during large events (e.g., 1% AEP and 0.2% AEP floods) are predicted to exceed 2 metres. Therefore, the barriers would only likely afford protection across most commercial properties during smaller floods such as the 20% AEP and 5% AEP events.

Plate 53 Examples of temporary flood barriers (provided courtesy of Flood Control International)

An assessment of the potential economic impact that temporary flood barriers would have was completed by undertaking a revised flood damage assessment. Commercial properties that are subject to relatively frequent above floor inundation were initially identified as candidates for temporary flood barriers. Those properties where above floor inundation is predicted in the 20% AEP flood were identified as high priority properties and those subject to above floor inundation during a 5% AEP flood were selected as medium priority properties. The location of each of these properties is shown in **Figure 51**. A total of 18 properties were identified as high priority and a further 4 properties were identified as medium priority properties.

As discussed, most of the commercial properties identified in **Figure 51** are subject to significant inundation depths. Therefore, it was assumed that 1.5 metres high barriers would be provided. The capital cost of a temporary flood barrier that is 1.5 metres high is in the order of $4,500 per metre. On top of this capital cost, the barrier seals need to be replaced every 10 years. Based upon the average width of each commercial building frontage (i.e., 10m), the life cycle cost of the flood barriers would be approximately $60,000 per property. Therefore, to protect all of the 18 high priority properties identified in **Figure 51** would cost about $1.08 million and to protect all of the high and medium priority properties would cost about $1.3 million.

A revised flood damage assessment was completed by updating the commercial flood damage curves to reflect the identified properties being protected by 1.5m high barriers. This involved removing all flood damage costs for over floor flooding depths of less than 1.5 metres. Once inundation depths exceeded 1.5m it was assumed that the barriers would be overtopped, and damage would occur as if the barriers were not present.

The revised flood damage calculations determined that:

- Inclusion of flood barriers on high priority properties is predicted to reduce flood damages costs by $12.1 million. This yields a preliminary BCR of more than 11.
- Inclusion of flood barriers on high and medium priority properties is predicted to reduce flood damages costs by $12.3 million. This yields a preliminary BCR of more than 9.

Therefore, the outcomes of the economic assessment show that installation of temporary flood barriers is likely to have a significant positive economic impact for the identified commercial properties.

However, it should be noted that mitigation measures for commercial properties are typically not subsidised by state government funding. Therefore, it is likely that the flood barriers would need to be purchased by the individual commercial property owners.

The temporary flood barriers were generally supported by the community with 60% of the community “supporting” the option. It is noted that 15% of the respondents did not support the option making it one of the least favoured options from a community support perspective.

As discussed, the barriers will likely only afford benefits during events up to and including the 5% AEP event. During particularly large floods (e.g.,1% AEP and 0.2% AEP flood), over 2 metres depth of water is predicted across the commercial areas of South Murwillumbah and temporary flood barriers of this height are not available.

In particularly severe floods, the temporary barriers may provide additional time for shop owners to relocate stock to a higher level, thereby reducing flood damage costs should the barriers overtop. However, should store owners be relocating stock and not be aware of the rising water levels outside of their property, they may become isolated, increasing the burden on SES (although this is unlikely to occur if commercial property owners are provided with sufficient advanced warning).

The outcomes of the assessment indicate that installation of temporary flood barriers would likely afford a positive economic outcome over the long term (i.e., reduced damage to stock and internal fittings and reduced clean up time and associated loss of revenue). Accordingly, it is recommended that Council initiate discussions with commercial property owners to discuss opportunities to install the flood barriers.

6.4 Industrial Land Swap

It is estimated that the economic loss to businesses located within the South Murwillumbah industrial area was in excess of $26 million as a direct result of the 2017 flood. Due to the significant adverse economic impact that the flood had on industrial properties in South Murwillumbah, Tweed Shire Council, through consultation with the State and Federal Governments developed a plan to relocate eligible high flood risk industrial properties to similarly zoned "flood free" land located within the Industry Central subdivision. The project is referred to as the "Industry Central Land Swap project".

Due to the significant impact that the land swap project may have on flood hydraulics and flood damages across South Murwillumbah, Council requested that the impact of the land swap be evaluated as part of the current study.

As outlined in Section 3.5, a "critical flood zone" map was prepared as part of the current study to help inform the land swap project. The critical flood zone map was used as a starting point to identify properties that would potentially benefit from the land swap project. The specific properties were further refined through consultation with Council. Two land swap options were ultimately compiled for hydraulic and economic assessment as part of the current study. The two options investigated were:

- Land Swap Option 1, which is shown in **Figure 52.1**. It incorporates the 17 highest priority industrial properties.
- Land Swap Option 2, which is shown in **Figure 53.1**. It incorporates the same 17 properties from Option 1 but is expanded to also include the next highest 16 priority properties (i.e., 33 properties total).

Two separate versions of each land swap option were evaluated as part of this study:

- Option 1A and Option 2A: Involved removal of the existing industrial buildings on each property shown in **Figures 52.1** and **53.1**. No changes were completed to the existing topography/fill across these properties.

- Option 1B and Option 2B: Involved removal of the existing industrial buildings on each property shown in **Figures 52.1** and **53.1**. In addition, the terrain across each property was lowered to around 2.5 mAHD to provide additional flood storage and conveyance capacity. The extent of the topographic changes is shown in **Figures 52.2** and **53.2**.

As part of the Option 1A and 2A assessment, it was also assumed that the existing Murwillumbah airfield hangers would be relocated to higher ground on the eastern side of the airfield. As part of the Option 1B and 2B assessment, it was assumed that the hangers would be relocated and the existing fill across the airfield would also be removed. Lot 4 DP 591604 Quarry Road was also lowered to the same elevation as Quarry Road as part of the Option 1B and 2B assessment and the existing Quarry Road levee on the eastern side of the airfield was also removed.

It is understood that Council has already purchased the required land within the Industry Central subdivision (this included a $3 million contribution by the Office of Environment and Heritage from its Climate Change Fund). However, Council still needs to invest in required infrastructure (e.g., roads, services). It should also be noted that the cost associated with removal/relocation of existing buildings will need to be borne by the individual business owners.

The outcomes of the assessment of each land swap options are presented below.

6.4.1 PM3 - Land Swap Option 1

Land Swap Option 1A

Recommendation: Recommended for implementation

Land Swap Option 1A will involve relocation of businesses from the 17 highest priority industrial properties to the Industry Central subdivision. The location of properties identified under this option are shown in **Figure 52.1**.

To assess the hydraulic and economic impact of relocating the identified properties, the TUFLOW model that was used to quantify existing flood behaviour was updated to include the changes associated with removal of buildings within the 17 identified properties. This involved removing the impediment to flow that would be afforded by buildings located within the 17 identified properties. It was assumed that the existing buildings would be replaced by grass. No other changes were completed to the flood model.

The updated model was used to re-simulate each design flood. The results from the simulations were used to prepare flood level difference mapping to confirm what impact the Option 1A land swap is likely to have on existing flood behaviour. However, the flood level difference maps did not show any significant changes in flood levels and extents during the 20% AEP flood (floodwaters are not sufficiently elevated to interact with many of the land swap properties during the 20% AEP flood).

Some changes in flood level are predicted during the 1% AEP flood, which are shown in **Plate 54**. **Plate 54** shows that removal of the 17 properties will reduce the impediment to flow afforded by these buildings during the 1% AEP flood. This will allow floodwaters to more readily pass through the industrial area and across Quarry Road. However, the changes in 1% AEP flood levels are predicted to be relatively minor with flood level reductions being less than 0.02 metres and flood level increases predicted to be less than 0.05 metres.

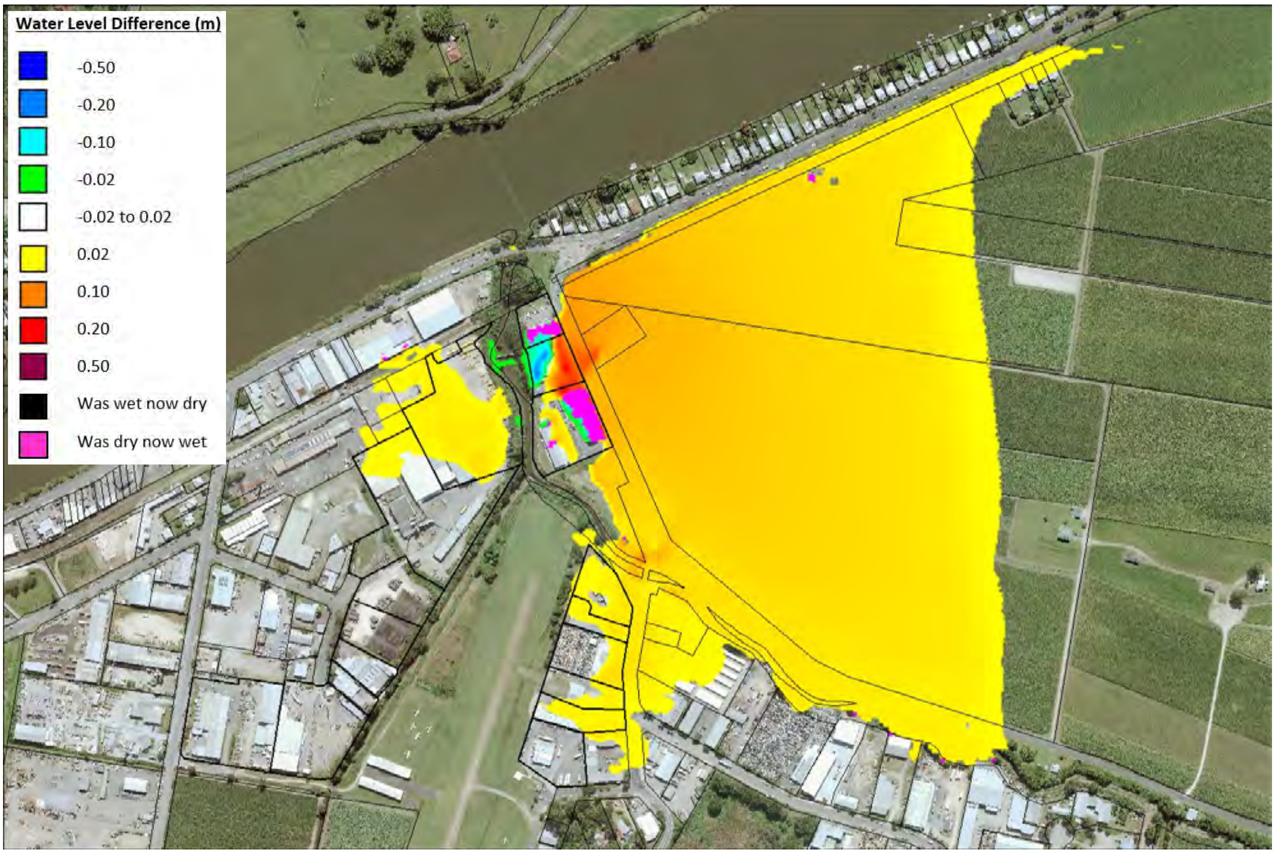


Plate 54 1% AEP Flood Level Difference Map for Land Swap Option 1A

It is noted that flood level increases are predicted to extend across some "remaining" industrial properties located east of Quarry Road and south of Reserve Creek Road. Although the flood level increases are generally minor (i.e., ~0.02 metres) consideration may need to be given to elevating the remaining sections of the Quarry Road levee (or Quarry Road itself) to ensure these remaining properties are not adversely impacted.

Land swap option 1A is predicted to reduce the number of buildings subject to above floor flooding by 1 during the 20% AEP flood and by 18 during the 1% AEP flood.

The cost to implement the land swap is estimated to be about $6.6 million. As discussed, Council has already purchased the required land, so the current implementation cost is likely to be less. However, Council will still need to invest in necessary infrastructure and individual business owners will need to arrange for the removal/relocation of existing buildings.

The potential financial benefit associated with implementation of the land swap option 1A was quantified by preparing revised flood damage calculations assuming that no buildings were included on each of the 17 lots identified in **Figure 52.1** (i.e., the flood damages contributed by these properties was removed from the damage calculations). The outcomes of the damage assessment determined that Option 1A would reduce total flood damage costs

by $6.1 million over the next 50-years. This yielded a preliminary benefit-cost ratio of 0.9. Accordingly, this option is predicted to be roughly cost neutral.
A sensitivity assessment was also completed to assess the economic performance of the land swap option under climate change scenarios. The outcomes of this assessment are shown in **Table 27** for the 1% AEP flood.

Table 27 Predicted reduction in 1% AEP flood damages associated with Land Swap Option 1A for existing and climate change conditions

Reduction in Flood Damage Cost ($ Millions)		
Existing	**Climate Change**	
	10% increases in rainfall and 0.4 m increase in ocean level	**20% increases in rainfall and 0.9 m increase in ocean level**
9.7	11.9	14.0

The information presented in **Table 27** shows that the economic performance of the land swap option 1A will likely improve with climate change. More specifically, the 10% increase in rainfall and 0.4m increase in ocean level scenario is predicted to increase the reduction in flood damages by 22% relative to current climate conditions, while the land swap option 1A would likely see a 44% reduction in flood damages under the 20% increase in rainfall and 0.9m increase in ocean level relative to current climate conditions. Accordingly, the potential reductions in flood damages (and the benefit cost ratio) for with this option is likely to increase significantly under climate change conditions (i.e., the BCR is likely to be well above 1).

This option was generally well supported by the community (59% of the community supported the option and only 12% were opposed).

The option does also have the potential to reduce the burden on SES staff by removing people from the floodplain. Therefore, there is likely to be less of a requirement for SES to arrange rescues and resupply of industrial properties should evacuation not be completed before flooding occurs.

Overall, implementation of land swap Option 1A is predicted to afford a significant reduction in flood damages costs for existing conditions. The economic performance of this option is likely to further improve under climate change conditions. It will also likely reduce the emergency response burden on the SES. Therefore, this option is recommended for implementation.

Land Swap Option 1B

Recommendation: Recommended for implementation subject to further investigations into optimal location and extent of earthworks.

Land Swap Option 1B will involve relocation of businesses from the 17 highest priority industrial properties to the Industry Central subdivision as well as the removal of existing fill to provide additional flood storage and conveyance capacity through the South Murwillumbah industrial area. The location of properties identified under this option are shown in **Figure 52.1** and the extent of potential topographic modifications are shown in **Figure 52.2**.

To assess the hydraulic and economic impact of Option 1B, the TUFLOW model that was used to quantify existing flood behaviour was updated to include the following changes to reflect this option:

- Removal of buildings within the 17 properties shown in **Figure 52.1**. It was assumed that the existing buildings would be replaced by grass.
- The ground surface elevation across 13 of the properties as well as the airfield was lowered to ensure no section of land was located above 2.5 mAHD.
- For the 4 properties located adjacent to Quarry Road, the terrain was lowered to be roughly at the same elevation as Quarry Road as lowering it further was unlikely to afford any additional hydraulic benefits and it may increase the potential for adverse impacts across downstream properties adjoining Tweed Valley Way.
- The existing Quarry Road levee located on the western side of Quarry Road was also removed.

The updated TUFLOW model was then used to re-simulate each design flood. Peak floodwater level difference mapping for the 20% and 1% AEP events with this option in place were developed and are presented in **Plate 55** and **Plate 56**.

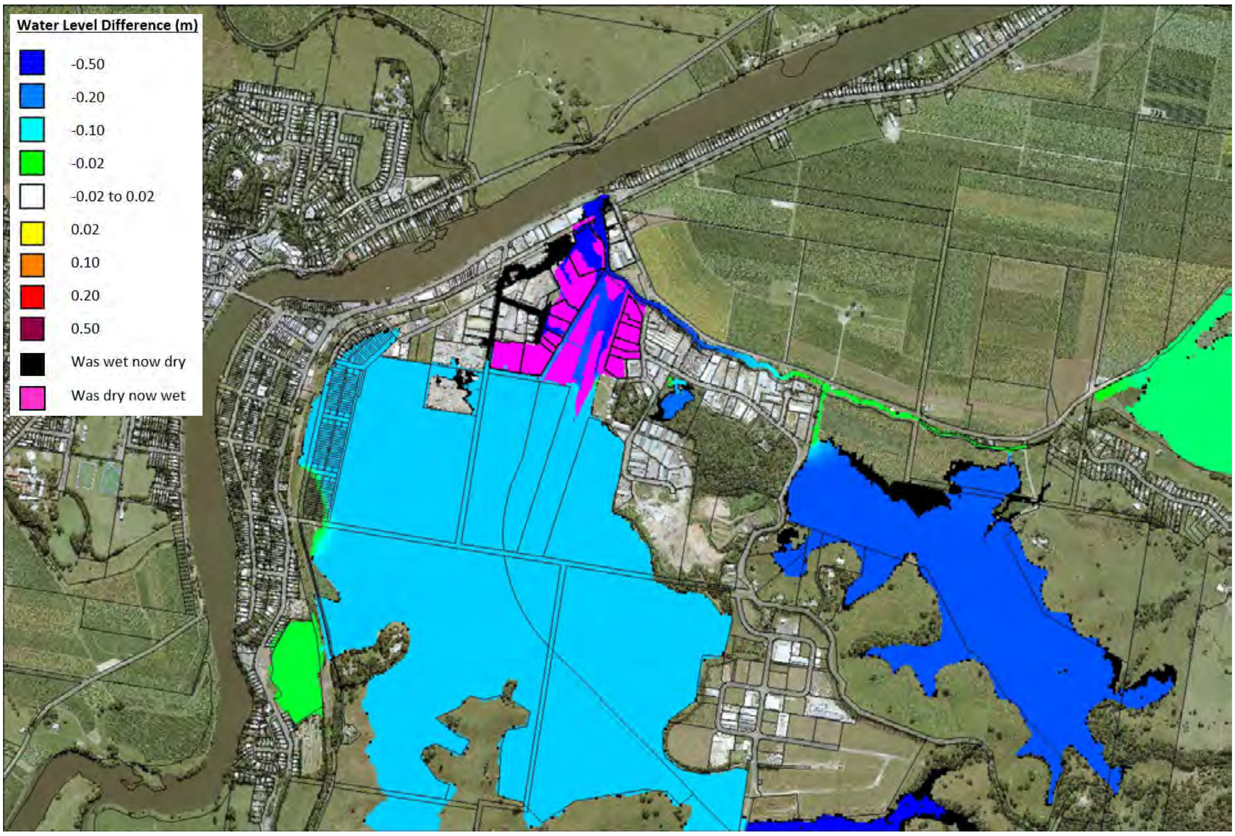


Plate 55 20% AEP Flood Level Difference Map for Land Swap Option 1B

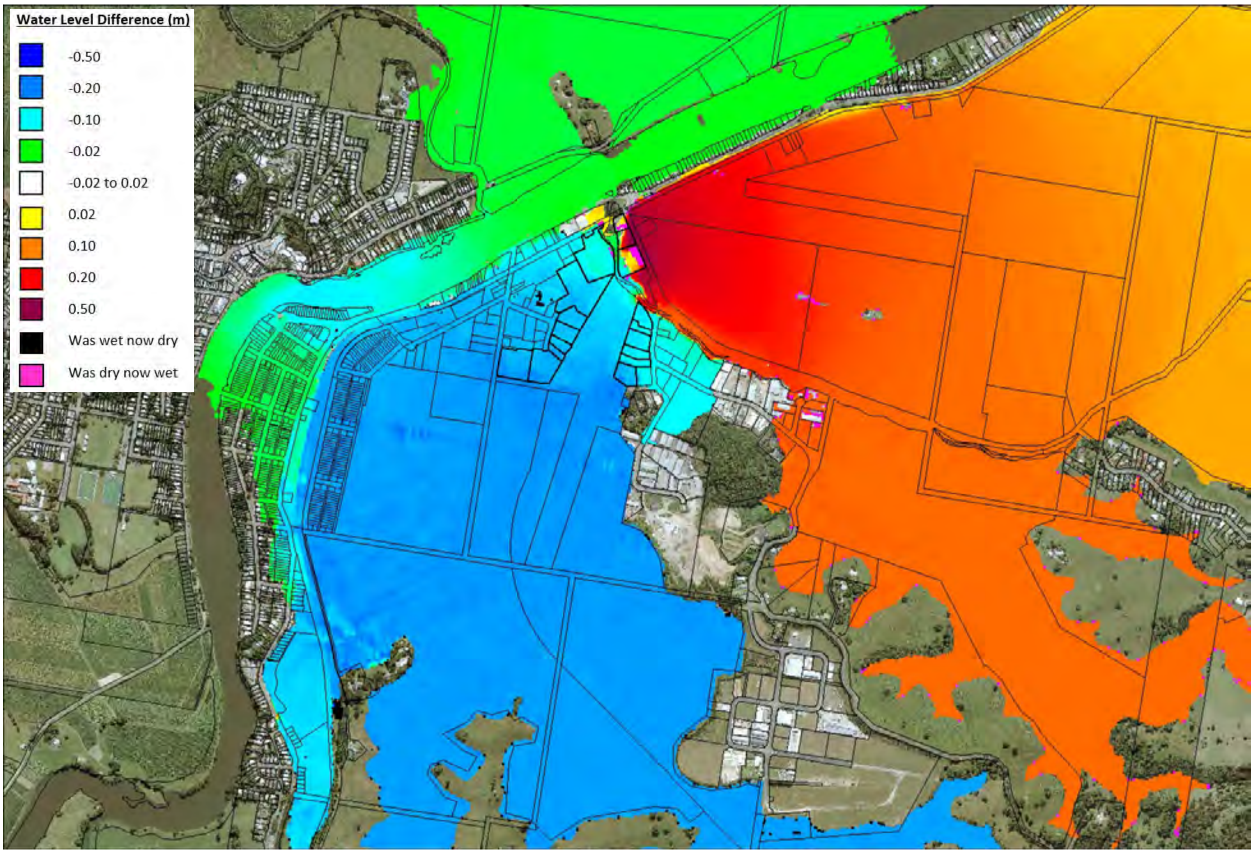


Plate 56 1% AEP Flood Level Difference Map for Land Swap Option 1B

The difference maps show that land swap option 1B is predicted to produce notable changes in flood levels across a large section of the floodplain during both the 20% AEP and 1% AEP flood. **Plate 55** shows that during the 20% AEP flood, flood level reductions of 0.15 metres are predicted across much of the South Murwillumbah basin. The flood level reductions are also predicted to extend across exiting residential properties in Railway Street as well as the Greenhills Caravan Park. Negligible increases in flood levels are predicted during the 20% AEP flood.

Plate 56 shows that flood level reductions of around 0.17 metres are predicted across the South Murwillumbah Basin during the 1% AEP flood. This is predicted to afford benefits to the remaining properties in the South Murwillumbah industrial area. The flood level reductions are also predicted to extend across parts of the commercial and residential areas of South Murwillumbah. Accordingly, the hydraulic benefits of this option across South Murwillumbah are significant. However, **Plate 56** shows that flood levels are predicted to increase across areas north-east of Quarry Road (the increases are typically less than 0.1 metres). The flood level increases are generally contained to the east of Tweed Valley Way which predominately comprises sugar cane fields. However, some residential properties at Condong are predicted to be exposed to flood level increases of between 0.02 and 0.05 metres.

Land swap option 1B will reduce the number of buildings subject to above floor flooding by 1 during the 20% AEP flood and by 18 during the 1% AEP flood.

The cost to implement Option 1B is estimated to be about $8.4 million. Council has already purchased the required land, so the current implementation cost is likely to be less. However, Council will still need to invest in necessary infrastructure as well as for the required earthworks and individual business owners will need to arrange for the removal/relocation of existing buildings.

The potential financial benefit associated with implementation of the land swap option 1B was quantified by preparing revised flood damage calculations. The outcomes of the damage assessment determined that Option 1B would likely reduce total flood damage costs by $7.1 million over the next 50-years. This yielded a preliminary benefit-cost ratio of 0.6. Accordingly, the additional earthworks associated with this option are predicted to improve the flood damage reductions. However, the benefit cost ratio of this option is lower than Option 1A. This is primarily associated with the increased costs associated with the earthworks for this option. It is likely that the economics of this option could be improved by refining the extent of earthworks, which will likely reduce the implementation costs and reduce the potential for increases in downstream water levels.

As discussed, this option was generally well supported by the community (59% of the community supported the option and only 12% were opposed).

Much of the South Murwillumbah industrial area is located within a “class 3” acid sulphate soil (ASS) area (i.e., acid sulphate soils are likely to be found >1 m below ground surface). Although much of the fill that would be removed under this option is likely to be imported, the potential for ASS will need to be confirmed before undertaking any earthworks as treatment of ASS would add to the overall cost of this option and the potential to incorporate any earthworks.

Like Option 1A, Option 1B does have the potential to reduce the burden on SES staff by removing people from the floodplain. Therefore, there is likely to be less of a requirement for SES to arrange rescues and resupply of industrial properties should evacuation not be completed before flooding occurs.

Overall, implementation of land swap Option 1B is predicted to afford some significant reduction in flood damages costs and reductions in existing flood levels. However, further refinement of the extent of earthworks is recommended to optimise the balance between reductions in flood levels across South Murwillumbah while ensuring downstream properties are not adversely impacted. If this can be arranged, this option or a variation of this option can be supported for implementation.

6.4.2 PM4 - Land Swap Option 2

Land Swap Option 2A

Recommendation: Recommended for implementation if land swap option 1 properties do not participate in project

Land Swap Option 2A will involve relocation of businesses from the 33 highest priority industrial properties to the Industry Central subdivision. The location of properties identified under this option are shown in **Figure 53.1**.

The TUFLOW model was updated to include the changes associated with Option 2A. This involved removing the impediment to flow that would be afforded by buildings located within the 33 identified properties. No other changes were completed to the model.

The updated model was used to re-simulate each design flood. However, like Land Swap Option 1A, the results from the hydraulic modelling did not show any significant changes in existing flood levels during the 20% AEP flood. Some changes in flood level are predicted during the 1% AEP flood, which are shown in **Plate 57**.

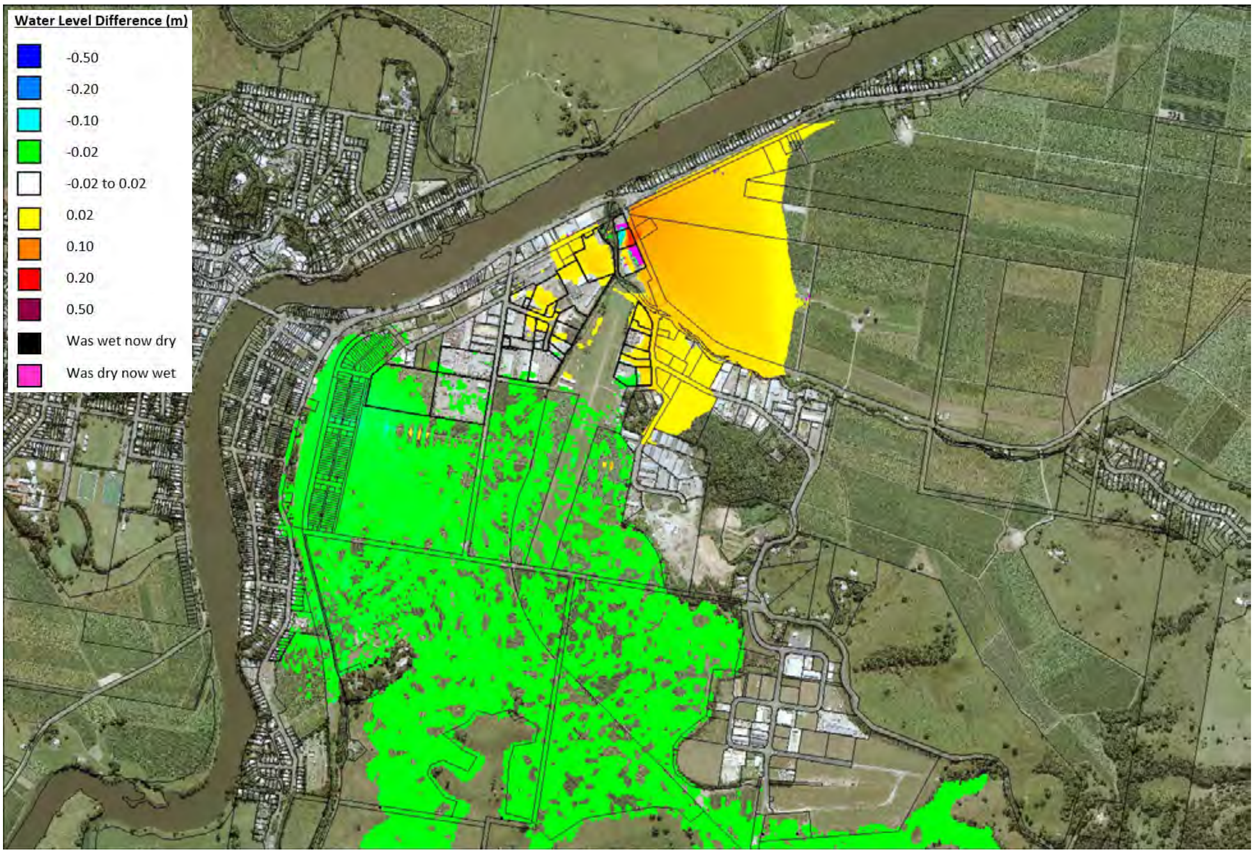


Plate 57 1% AEP Flood Level Difference Map for Land Swap Option 2A

The flood level differences shown in **Plate 57** indicate that land swap option 2A is predicted to produce small reductions in 1% AEP flood levels (i.e., ~0.02 metres) across the South Murwillumbah basin. Like Option 1A, the reduced impediment to flow afforded by the option is predicted to direct more water across Quarry Road resulting in flood level increases across sugar cane fields as well as some remaining industrial properties. The magnitude of the flood level changes under Option 2A is similar to Option 1A indicating that inclusion of the additional 16 properties does not significantly improve the hydraulic performance of the option.

Land swap option 2A is predicted to reduce the number of buildings subject to above floor flooding by 1 during the 20% AEP flood and by 30 during the 1% AEP flood.

The cost to implement the land swap is estimated to be about $13.2 million. As discussed, Council has already purchased land within the Industry Central subdivision, so the current implementation cost is likely to be less. However, Council will still need to invest in required infrastructure and individual business owners will need to arrange for the removal/relocation of existing buildings.

The potential financial benefit associated with implementation of the land swap option 2A was quantified by preparing revised flood damage calculations. The outcomes of the damage assessment determined that Option 2A is predicted to reduce total flood damage costs by $8.6 million over the next 50-years, yielding a benefit cost ratio of 0.7. Accordingly, although Option 2A is predicted to result in a more substantial reduction in flood damage relative to Option 1A, the benefit cost ratio and average return per property is not as substantial (i.e., Option 1A yields an average reduction in damage of $360,000 per property while Option 2A provides an average damage reduction of $260,000 per property). That is, Option 1A appears to provide better value for money.

A sensitivity assessment was also completed for option 2A to assess the impacts that climate change may have on the economic performance of the option. The outcomes of this assessment are shown in **Table 28** for the 1% AEP flood.

Table 28 Predicted reduction in 1% AEP flood damages associated with Land Swap Option 2A for existing and climate change conditions

Reduction in Flood Damage Cost ($ Millions)		
Existing	Climate Change	
	10% increases in rainfall and 0.4 m increase in ocean level	20% increases in rainfall and 0.9 m increase in ocean level
14.4	17.6	20.6

The information presented in **Table 28** shows that the economic performance of the land swap option 2A will improve with climate change. The 10% increase in rainfall and 0.4m increase in ocean level scenario will increase the reduction in flood damage by around 20% relative to current climate conditions, while the land swap would likely see more than a 40% reduction in flood damages under the 20% increase in rainfall and 0.9m increase in ocean level. This is likely to provide a sufficient increase in flood damage reductions to increase the benefit cost ratio above 1 (although the BCR is still likely to be lower than Option 1A).

This option was generally well supported by the community (59% of the community supported the option and 12% were opposed).

Like Land Swap Option 1A and 1B, implementation of Land Swap Option 2A is predicted to afford significant reductions in flood damages costs and will afford localised reductions in existing flood levels. It will also likely reduce the emergency response burden on the SES. However, this option does not perform as well from an economic stand point relative to Option 1A. Accordingly, it is suggested that Option 1A proceed in the first instance. In the event that some of the properties identified in Option 1A choose not to participate in the land swap, inclusion of some of the properties identified in Option 2A could then be explored.

Land Swap Option 2B

Recommendation: May be considered for implementation subject to further investigations into optimal location and extent of earthworks. However, the other land swap options are considered more financially viable at this point.

Land Swap Option 2B will involve relocation of businesses from the 33 highest priority industrial properties to the Industry Central subdivision as well as the removal of existing fill across the same 33 properties to provide additional flood storage and conveyance capacity. The location of properties identified under this option are shown in **Figure 53.1** and the extent of the adopted topographic modifications are shown in **Figure 53.2**.

To assess the hydraulic and economic impact of Option 2B, the TUFLOW model was updated to include the changes associated with the option. This included:

- Removal of buildings from the 33 properties identified in **Figure 53.1**.
- The ground surface elevation across 29 of the properties as well as the airfield was lowered to ensure no section of land was located above 2.5 mAHD.
- For the 4 properties located adjacent to Quarry Road, the terrain was lowered to be roughly at the same elevation of Quarry Road.
- The existing Quarry Road levee was also removed.

The updated TUFLOW model was then used to re-simulate each design flood. Peak floodwater level difference mapping with this option in place were developed and are presented in **Plate 58** and **Plate 59** for the for the 20% and 1% AEP events respectively.

The difference maps show that land swap option 2B is predicted to generate flood level reductions of up to 0.19 metres across the South Murwillumbah basin during the 1% AEP flood (a 0.02m improvement over Option 1B). Flood level reductions during the 20% AEP flood are predicted to be 0.14m across this area (essentially the same as Option 1B). Like Option 1B, the flood level reductions are predicted to extend west to Railway Street and also across the Greenhills Caravan Park (although the reductions here are typically less than 0.15m during the 1% AEP flood and less than 0.05 metres during the 20% AEP flood).

Option 2B is also predicted to generate flood level increases north of Quarry Road during the 1% AEP flood. Most of the flood level increases extend across sugar cane fields, but around 12 residential properties at Condong are predicted to be exposed to flood level increases of 0.02 to 0.05 metres. Further refinement of the earthworks, particularly across the lots that adjoin Quarry Road, may help to reduce the magnitude and extent of these flood level increases.

Land swap option 2B will reduce the number of buildings subject to above floor flooding by 1 during the 20% AEP flood and by 30 during the 1% AEP flood.

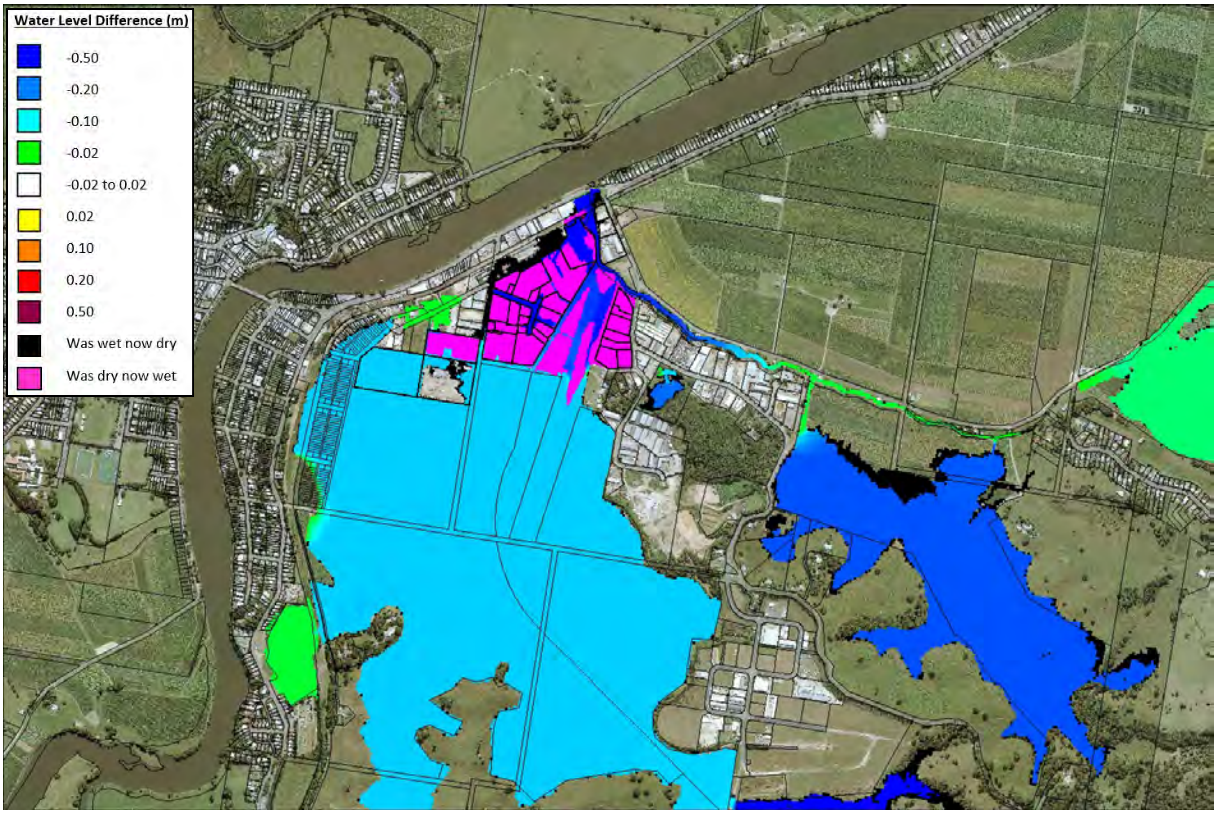


Plate 58 20% AEP Flood Level Difference Map for Land Swap Option 2B

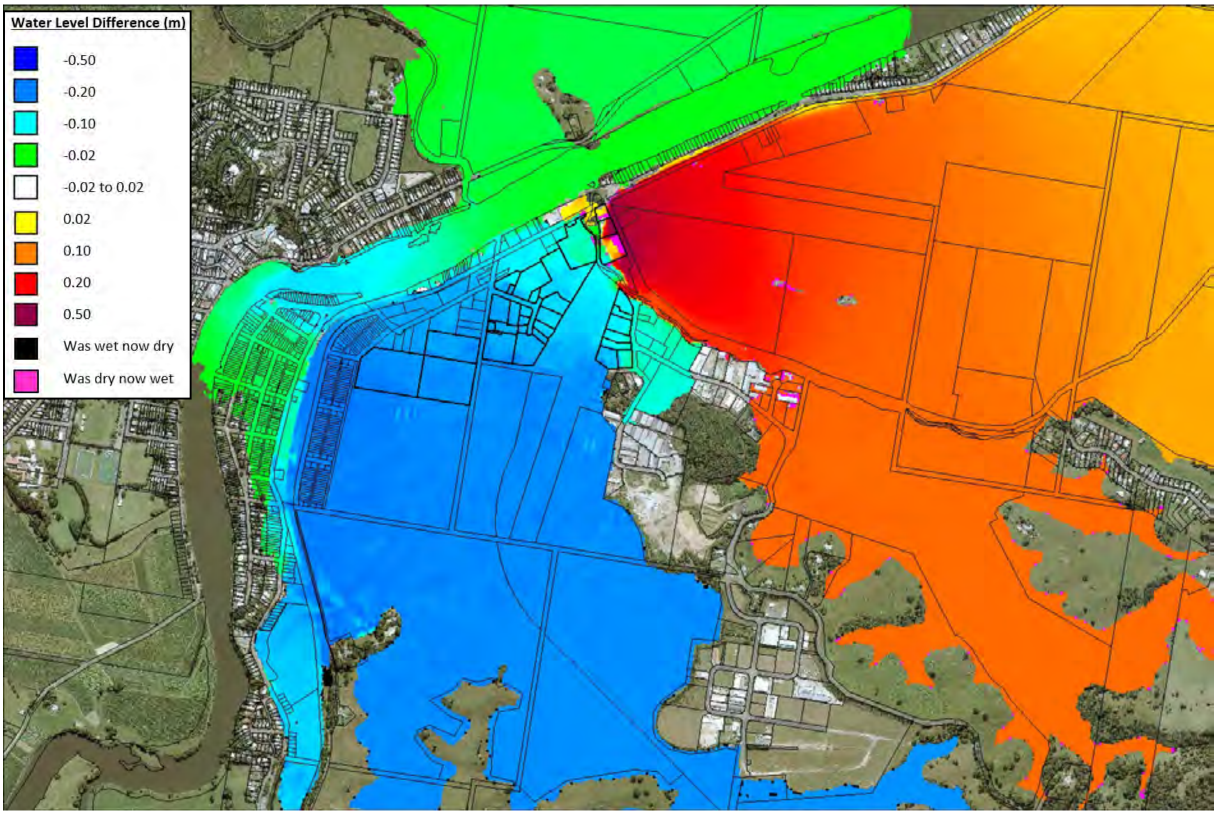


Plate 59 1% AEP Flood Level Difference Map for Land Swap Option 2B

The cost to implement Option 2B is estimated to be about $15.7 million. Council has already purchased the required land, so the current implementation cost is likely to be less. However, Council will still need to arrange funding for new infrastructure at Industry Central and the required earthworks and individual business owners will need to arrange for the removal/relocation of existing buildings.

The potential financial benefit associated with implementation of the land swap option 2B was quantified by preparing revised flood damage calculations. The outcomes of the damage assessment determined that Option 2B would likely reduce total flood damage costs by $9.4 over the next 50-years. This yielded a preliminary benefit-cost ratio of 0.5. Accordingly, the financial benefits of implementing this option are not predicted to outweigh the implementation costs. However, it is likely that the BCR could be improved by reducing the extent of the earthworks and the associated capital costs. This may also afford improved hydraulic outcomes (i.e., reduce the potential for adverse downstream flood impacts).

As for option 1B, there is potential for ASS in the areas where earthworks are proposed. However, the Option 2B earthworks are more substantial so the potential risk of ASS is increased for Option 2B. Verification of the potential for ASS should be confirmed and this should help to inform an optimised earthworks strategy (along with the results of hydraulic modelling) should this option proceed to more detailed design stages.

Overall, implementation of land swap Option 2B is predicted to afford some significant reduction in flood damages costs and reductions in existing flood levels and extents across the South Murwillumbah study area. However, the financial incentives of this option are not as significant as the other land swap options considered as part of this study. Nevertheless, it may be possible to improve the financial viability of this option by refining the earthworks strategy to reduce the capital costs (and, ideally, reduce the potential the potential for flood impacts across downstream properties). If this can be achieved, this option could be considered for implementation. However, it is considered that the other land swap options are more financially sound options and should be pursued in preference to this option.

6.5 PM5 - Consolidation of Residential Lots

Recommendation: Recommended for implementation

There are a number of existing residential buildings located within South Murwillumbah that span more than one residential allotment. An example of this is provided in **Plate 60** and all lots that fit this description are highlighted in **Figure 54**. A total of 65 lots are identified on **Figure 54**, and they currently contain a total of 32 residential buildings.

The current zoning and lot boundaries would permit these existing dwellings to be knocked down and, potentially, two new dwellings to be erected in its place, resulting in a potential increase in population. Based upon the lots identified in **Figure 54**, there is currently potential for 33 new residential dwellings to be introduced across these allotments.

Plate 60 Examples of existing residential buildings that span more than one allotment

As discussed in preceding sections of this report, the residential areas of South Murwillumbah are exposed to a significant flood hazard during the full range of floods. Accordingly, intensification of development across this area cannot be supported.

This option would look to consolidate (i.e., combine) these lots to prevent intensification in development. In general, two residential allotments that contain a single residential building would be consolidated into a single residential lot. This option would not alter existing flood behaviour or reduce the existing risk. However, it will help to ensure that the existing flood risk is not increased in the future and may provide an opportunity to reduce the future flood risk if redevelopment of these lots occurs and more flood resilient buildings take their place.

To provide an understanding of the potential economic benefits/disbenefits associated with pursuing this option, a revised flood damages assessment was prepared. The revised flood damages assessment was completed by assuming that the 32 existing residential buildings contained within the lots shown in **Figure 54** were demolished and replaced by 65 new residential buildings. It was assumed that the floor level of each new building was constructed at the Flood Planning Level (i.e., 1% AEP flood level + 0.5 metres). It was also assumed that the new residential dwellings would be single storey, "high set" buildings.

The outcomes of the flood damage assessment indicate that existing flood damages are predicted to increase by about $1.9 million over the next 50 years if full development of these existing residential lots was to occur. Therefore, if lot consolidation did not proceed and each of these lots were fully development in the future, flood damage costs are expected to increase in addition to introducing more people into a high flood hazard area.

The exact cost that is likely to be incurred consolidating the lots is difficult to precisely define. The costs associated with survey and registration of the lot consolidation is considered to be minor. However, existing land holders may argue that consolidation of the lots reduces the value of the land and they should be compensated. Again, this compensatory cost is difficult to quantify. However, based upon the damage assessment presented above, a payment of up to $59,000 could arguably be made to each of the 32 existing land owners and the benefit cost ratio would be no lower than 1.

This option was generally supported by the community (64% of the community supported the option and only 9% were opposed).

Overall, it is recommended that Council pursue this option. In the first instance, it is suggested that Council initiate discussions with property owners to gain an understanding of the level of interest. If these discussions yield a positive outcome a further detailed economic assessment could be completed to determine the financial implications of the lot consolidation.

7 Response Modification Options

7.1 Introduction

It is typically not economically feasible to treat all flood risk up to and including the PMF through flood modification and property modification measures. This is particularly the case for South Murwillumbah. Therefore, response modification measures are implemented to manage the residual/continuing flood risk by improving the way in which emergency services and the public respond before, during and after floods. Response modification measures are often the simplest and most cost-effective measures that can be implemented and, therefore, form a critical component of the flood risk management strategy for the area.

Response modification options considered as part of the study include:

- RM1 - Community education activities
- RM2 – Preparation of residential flood plans;
- RM3 – Preparation of business flood plans;
- RM4 – Local flood plan updates; and,
- RM5 - Flood warning system upgrades.

Further discussion on response modification options that could be potentially implemented is provided below.

7.2 RM1 - Community Education Activities

Recommendations:

1. Implement the generic education tools recommended as part of the "Murwillumbah CBD Levee & Drainage Study";
2. Conduct a meet the street event to distribute flood information
3. SES to conduct door knocking of select high risk properties
4. Install flood marker near the intersection of Alma Street and Tweed Valley Way.
5. Update Council website to include flood information produced as part of the current study

Actual flood damages can be reduced, and safety increased, where communities are flood-ready:

> *'People who understand the environmental threats they face and have considered how they will manage them when they arise will cope better than people who lack such comprehension… Many people who live and work in flood liable areas have little idea of what flooding could mean to them – especially in the case of large floods of severities well beyond their experience or if a long period has elapsed since flooding last occurred. It falls to the combat agency, with assistance from councils and other agencies, to raise the level of flood consciousness and to ensure that people are made ready for flooding. In other words, flood-ready communities*

must be purposefully created. Once created, their flood-readiness must be purposefully maintained and enhanced' (Keys, 2002).

Based on learnings from recent disasters, the focus of community disaster education has now turned from a concentration on raising awareness and preparedness to building community resilience through learning. Simply disseminating information to the community does not necessarily trigger changed attitudes and behaviours. Flood education programs are most effective when they:

- Are participatory i.e. not consisting only of top-down provision of information but where the community has input to the development, implementation and evaluation of education activities;
- Involve a range of learning styles including experimental learning (e.g. field trips, flood commemorations), information provision (e.g. via pamphlets, DVDs, the media), collaborative group learning (e.g. scenario role plays with community groups) and community discourse (e.g. forums, post-event de-briefs);
- Are aligned with structural and other non-structural methods used in floodplain risk management and with emergency management measures such as operations and planning; and
- Are ongoing programs rather than one-off, unintegrated 'campaigns', with activities varied for the learner.

It is difficult to accurately assess the financial benefits of a community flood education program, but the consensus is that the benefits far outweigh the costs. Nevertheless, sponsors must appreciate that ongoing funding is required to sustain gains that have been made.

A community survey conducted for this floodplain risk management study indicated that 43% of respondents would remain at home and 12% of respondents were unsure of how they would respond during a future flood. Of those choosing to stay at home, they did so because they did not believe their house could be flooded. However, two thirds of those respondents would be flooded above floor level during the PMF and the above floor flooding depth would typically exceed 4 m (refer to Section 3.3). This highlights that further education is necessary to reinforce that bigger floods than those that have been experienced could occur.

A few broader points should be made before considering needs and opportunities for South Murwillumbah.

First, whatever approaches are implemented to increase community flood resilience in the catchment should be congruent with initiatives throughout the Tweed Shire LGA to ensure a consistent and strategic rather than an ad hoc approach to community flood education. A first step could be to audit flood education initiatives recommended and possibly implemented in the LGA over the past 5-10 years. A second step would be to commission robust social research to form a new baseline of current levels of flood awareness and readiness, including any discernible spatial differences across this large and geographically diverse LGA. Then, new initiatives could be pursued, and their effectiveness tested, based on a solid evidence base.

Second, historically the NSW Floodplain Management Program has been reluctant to fund community education initiatives. One reason is that this is seen as the primary responsibility of the NSW SES, with Councils supporting the SES. Another reason is the recognised need for sustained investment to build and maintain community flood awareness and readiness, and in the face of dynamic communities such that people with no prior knowledge or experience of flooding may move into a flood prone area. Historically the Floodplain Management Program has funded capital expenditure but not maintenance expenditure. This means that Council funding to assist the NSW SES may have to be sourced elsewhere.

A review of potential community education opportunities was completed as part of the "Murwillumbah CBD Levee & Drainage Study" (Catchment Simulation Solutions, 2018). In this study, a range of different strategies were considered for community education including:

- installing flood markers;
- providing educational messages discouraging dangerous behaviours;
- making property level flood Information available; and
- developing a flood information portal.

The generic community education tools recommended as part of this previous study are also considered appropriate for South Murwillumbah. However, the following location specific recommendations are made:

- Doorknocking to present and explain household flood plans (discussed in more detail in the following section) to high risk sections of South Murwillumbah would likely be the most engaging approach for disseminating flood information and encouraging participation (with initial follow up the next year and then every two years to confirm how residents/businesses are progressing with plan development, implementation and maintenance). However, this is dependent on the availability of suitable resources within the local SES unit and should be prioritised across the whole region so that the highest risk areas are given highest priority. If doorknocking by SES is not possible, a targeted letter co-badged by Council and SES with a link to the SES FloodSafe website may suffice.
- Given the relatively small geographic area, conducting one or more "meet the street" events may be useful for distributing flood education material and giving the community an opportunity to ask questions and obtain additional education material. Completing this on an annual basis (e.g., anniversary of the 2017 flood) would help to remind and educate at the same times as helping to build a sense of "community" and potential support networks during future floods.
- Using the information produced as part of current study to update the flood information on Council's website.
- Installing a flood marker with major peak flood heights (e.g., 1954 & 2017 floods) at a highly trafficked location such as near the intersection of Alma Street and Tweed Valley Way to serve as a permanent reminder of the severity of past (and potential future) floods. it may also be beneficial to include "design" flood levels on the marker (e.g., 0.2% AEP and PMF) to serve as a reminder that larger floods can and will occur in the future.

7.3 Flood Plans

7.3.1 RM2 - Preparation of Residential Flood Plan

Recommendation: Households should be encouraged to develop a personalised flood emergency response plan using the NSW SES templates.

As discussed, 12% of the community questionnaire respondents did not have a flood plan despite the occurrence of a large contemporary flood (i.e., 2017 flood). Given the relatively limited amount of warning time available for South Murwillumbah, any indecision associated with what actions to take before or during a flood could have a significant impact on the potential for evacuation in the first instance and, ultimately, the potential for survival during large floods. In addition, the more self-sufficient individual property owners are, the less reliance will be placed on the SES and other emergency service providers which will help to ensure these resources are dedicated to the most appropriate locations at the same time as helping to ensuring that SES staff are not exposed to unnecessary risks.

Therefore, there would be benefit in each property that has a significant flood risk in South Murwillumbah to develop their own personalised flood plan. This can be done using resources on the NSW SES website, such as: http://www.seshomeemergencyplan.com.au/index.php

As discussed in Section 7.2, the SES could undertake door knocking of local residential properties to help homeowners translate the available flood information into effective home emergency plans.

For those who do not evacuate, there are things that people can do before, during and after a flood to make themselves and their property safer in the event that evacuation is not completed. For example, they can:

- Always store valuable or dangerous items (fuels and chemicals) in business premises or household garages or sheds at the highest practical level to minimise the risk of them coming in contact with floodwaters
- Always have an emergency response kit available which has as a minimum:
    - Portable radio with spare batteries
    - Mobile phone battery bank and charger
    - Torch with spare batteries
    - First aid kit (with supplies necessary for your household)
    - Candles and waterproof matches
    - Important papers including emergency contact numbers
    - Copy of household flood plan
    - Waterproof bag for valuables
- When severe weather is forecast or during heavy rain, park vehicles outside of the floodplain, move or secure items outdoors which are likely to float and bring pets inside. This should be completed before flooding starts.

7.3.2 RM3 - Preparation of Business Flood Plan

Recommendation: Business premises should be encouraged to develop a flood emergency response plan using the NSW SES templates Plans.

Businesses across flood liable sections of South Murwillumbah would also benefit from flood plans given the significant financial impact that flooding can have on the area. The plans set out protocols to follow by the business before, during and after a flood to help mitigate damages and the potential for risk to life.

As for private home flood plans, the SES as well as Council should be able to provide significant information describing the flood risk at the property scale based on the outputs from this study including the potential frequency and depth of inundation as well which roadways will be cut and the likely duration of any isolation.

The SES has developed a Business FloodSafe Toolkit to assist with the preparation of Business FloodSafe plans. These can be completed either online or as a hardcopy (see http://www.floodsafe.com.au/what-floodsafe-means-for-you/business).

An SES Business Breakfast could also be hosted to promote the development of Business FloodSafe Plans, with sufficient Council and SES staff present to help guide business owners through the process. A follow up audit/breakfast could then be completed at a later date (say, 6 months later) to ensure that the FloodSafe plans have been developed/updated.

Council could also consider regulation to promote the development of a business flood plans when businesses change ownership/use.

7.3.3 RM4 - Local Flood Plan & Flood Intelligence Card Updates

Recommendations:

1) Update Tweed Shire Flood Plan to incorporate new flood intelligence for South Murwillumbah produced as part of the current study.
2) Update North Murwillumbah Flood Intelligence Card to align with new flood modelling results.

The *Tweed Shire Flood Plan* (NSW SES, 2014) covers preparedness measures, the conduct of response operations and the coordination of immediate recovery measures from flooding within the Tweed Shire area.

The local flood plan was last revised relatively recently (i.e., 2014). However, it is suggested that further updates could be made to the local flood plan and/or flood intelligence cards based upon learnings from the 2017 flood as well as the more detailed flood modelling outputs generated as part of this study. Among the flood intelligence available from the current study is:

- Design flood extents, depths, velocities, hazard and warning times;
- Properties subject to above floor flooding;
- Emergency response precinct classifications; and,

- Predicted road inundation locations and details (including road overtopping times and durations of inundation).

The North Murwillumbah Flood Intelligence Card has been reviewed as part of the study. This review has identified several potential updates to the Card based upon the revised modelling completed as part of the current study to more reliable define consequences at various gauge levels (most notably when roads are cut, how many properties are impacted and how much warning time is available.) The suggested updates to the Flood Intelligence Card have been forwarded to SES separate to this report for review. It is recommended that the SES review these comments and update the Flood Intelligence Card, as necessary, and then update the SES online intelligence system with the revised information.

7.4 RM5 - Flood Warning System Upgrades

Recommendations:

1. Establish revised river level triggers for Murwillumbah gauges to determine when evacuation routes will be cut, and when the South Murwillumbah levee will be overtopped (SES).
2. Investigate potential to incorporate SMS messaging into flood warning system (Council & BoM).

A review of the existing Tweed River catchment flood warning system was completed as part of the "*Murwillumbah CBD Levee & Drainage Study*" (Catchment Simulation Solutions, 2018). The study demonstrates that the Tweed River is serviced by a flood warning system that meets most of the requirements of a modern flood warning system. However, the responses to the community questionnaire demonstrated that the community are not entirely satisfied with the current warning system. The outcomes of the community consultation also identified upgrades of the flood warning system as being highly desirable by the community.

As discussed, the preferred emergency response strategy for South Murwillumbah involves early, safe evacuation. South Murwillumbah is considered to have a sufficient amount of warning time during most floods up to and including the 1% AEP flood. However, during more severe floods (e.g., 0.2% AEP flood), the amount of warning time decreases significantly (i.e., reduced from ~30 hours to ~15 hours). Therefore, the efficient distribution of flood warning information will play an important role in the effectiveness of flood evacuation, particularly during particularly large floods.

It is recommended that revised "trigger" levels be established for the Murwillumbah stream gauges based upon the information presented in Section 3.4.2 and **Appendix I** of this report to best identify when evacuation routes (notably Tweed Valley Way and Alma Street) will likely be cut by floodwaters and when the existing levee system will be overtopped.

The "*Murwillumbah CBD Levee & Drainage Study*" (Catchment Simulation Solutions, 2018) also recommended that improved approaches for dissemination of flood warning information be explored. More specifically, the report suggests that opportunities for flood warning information to be sent via SMS messaging be investigated. This is also considered to be a worthwhile pursuit for South Murwillumbah given the reduced amount of evacuation time that is available during large floods.

8 FLOODPLAIN RISK MANAGEMENT PLAN

8.1 Introduction

The Floodplain Risk Management Plan sets out a preferred set of options that can be implemented to better manage the flood risk across South Murwillumbah. It also outlines responsibilities for the implementation of each option along with cost estimates and funding opportunities.

8.2 Recommended Options

The options that are recommended for implementation as part of the South Murwillumbah Floodplain Risk Management Plan are summarised in **Table 32** and are also shown in **Figure 55**. The options have been selected from a range of potential flood modification, property modification and response modifications measures based upon their impact on flood hydraulics, reduction in flood damages, implementation costs, community feedback as well as any potential social and environmental impacts. The outcomes of the detailed options assessment are discussed in more detail in Chapters 5, 6 and 7 of this report.

8.3 Plan Implementation

8.3.1 Prioritisation / Timing

The recommended options have been prioritised according to how easily each option could be implemented and the anticipated benefits afforded by each option. For example, options that are relatively straight forward to implement and have a significant benefit would be assigned a high priority.

A timeframe has also been estimated that reflects the likely time to implement each option. However, the implementation time estimates will most likely need to be refined moving forward based upon available resources (i.e., financial and human resources) as well as the need to undertake additional investigations and/or community consultation.

In general, it is anticipated that the majority of the options could be implemented progressively over a 5-year time frame. However, this will be dependent on the budgetary commitments of Council and availability of funding from other sources. There are also some options, such as voluntary house purchase, that will likely extend well beyond a 10-year time frame due to the significant costs involved.

8.3.2 Costs and Funding

The total capital cost to implement the Plan is expected to be about $7.8 million. The industrial land swap option is the biggest contributor to this total cost estimate (i.e., $6.6 million). This capital cost excludes the cost associated with implementation of Council's proposed voluntary house purchase scheme (this is likely to add $15 million to the implementation cost).

In addition to the capital costs, some options will incur ongoing maintenance costs. As noted in **Table 32**, many of the options will require an investment in time from various agencies including Tweed Shire Council, the State Emergency Service and the Bureau of Meteorology in addition to monetary contributions.

Raising of the South Murwillumbah levee is predicted to afford some significant hydraulic and financial benefits across South Murwillumbah. However, there are several limitations that may limit the feasibility of this option. As a result, it is not recommended for implementation as part of the plan. However, there are sufficient benefits to warrant further investigations to determine if the identified limitations can be overcome. Preliminary cost estimates indicate that the levee raising would cost in the order of $14 million to implement but would afford over $20 million in reduced damage costs.

It should be noted that the costs are estimates only. The cost for each option will need to be refined through further detailed investigations and preparation of detailed design plans which is beyond the scope of the current study.

Funding for implementation of the plan could be potentially obtained from the following sources:

- NSW State Government's Floodplain Management Grants (through OEH)
- NSW State Government's Climate Change Fund (through OEH)
- Tweed Shire Council's capital and operating budgets
- Commonwealth Government's Natural Disaster Resilience Program
- Volunteer labour from community groups
- Volunteer labour from property owners / interested parties

It is expected that most options will be eligible for funding through the NSW State Government's Floodplain Management Grants on a 2:1 basis (State Government:Council). These grants are awarded for the detailed investigation and design and/or feasibility of works identified in a floodplain risk management plan, as well as the implementation and construction of these works. However, funding cannot be guaranteed as projects must complete for a limited amount of funds that are distributed annually to undertake priority projects to assess the risks and reduce the impacts of flooding across all of New South Wales. Furthermore, the NSW Government's Floodplain Management Grants are primarily available to manage risk to residential properties and are generally not awarded to manage the flood risk to commercial and industrial properties (e.g., temporary flood barriers). It should also be noted that ongoing costs will generally be the responsibility of Council.

8.3.3 Review of Plan

It is important that the Floodplain Risk Management Plan is continually reviewed and updated over time to ensure that it evolves with the catchment and takes advantage of any improvements in flood knowledge, such as new flood studies, historic floods or information on climate change.

As noted in **Table 29**, most options are scheduled for implementation within a 5-year time frame. Therefore, as a minimum, it is recommended that the Plan be revisited after 5 years and updated, as necessary.

Table 29 South Murwillumbah Floodplain Risk Management Plan

FM	Flood modification option	PM	Property modification option	RM	Response modification option

Option		Report Section	Implementation Responsibility	Total Cost	BCR	Priority	Timing	Recommendation/Comments
Flood Modification Options								
FM4	Earthworks across Lot 4 DP 591604 Quarry Road	5.2.4	Council	$0.4 million	1.2	High	3 years	Recommended for implementation
FM8	Raising South Murwillumbah Levee to 20%AEP Level + Raising Height of CBD Levee	5.3.2	Council	$50k for additional investigations	~1.6	Medium	5 years	Additional investigations recommended
FM10	Alma Street Modification	5.4.1	Council	$0.4 million	0	Low	>5 years	This option may be considered for implementation as part of any future roadworks/stormwater modifications for the area. If the levee raising option is pursued (FM8), modification of Alma Street will occur as part of this and implementation of this option in isolation will not be necessary
FM15	Modify Condong Creek Channel	5.6.1	Council & Interested Parties	$0.3 million	0.3	Medium	2 years	Council to initiate discussions with interested parties to confirm their willingness to contribute to the implementation of this option.

Option		Report Section	Implementation Responsibility	Total Cost	BCR	Priority	Timing	Recommendation/Comments
Property Modification Options								
PM1	Proposed Voluntary House Purchase Scheme	6.2	Council	$15 million	0.2	Medium	10+ years	Proposed VHP scheme is generally suitable and should continue to be implemented. Council may consider purchasing and/or rezoning identified vacant residential lots. However, this may need to be implemented under a separate scheme
PM2	Temporary Flood Barriers for Commercial Properties	6.3	Business owners	~$60,000 per property	>9	Medium	2 years	Council to initiate discussions with identified commercial property owners. Property owners will likely be responsible for implementation costs
PM3	Land Swap Option 1	6.4.1	Council & business owners	$6.6 million	0.9	High	2 years	Earthworks could also be considered across land swap properties subject to funding availability and designing earthworks to minimise potential for adverse downstream impacts
PM4	Land Swap Option 2	6.4.2	Council & business owners	$13.2 million	0.7	High	2 years	Recommended for implementation if land swap option 1 properties do not participate in project
PM5	Consolidation of Residential Lots	6.5	Council & impacted residents	?	-	Medium	3 years	Implementation costs difficult to define. However, considered economically viable if consolidation costs can be kept under $59,000 per property

Option		Report Section	Implementation Responsibility	Total Cost	BCR	Priority	Timing	Recommendation/Comments
Response Modification Options								
RM1	a) Implement the generic education tools recommended as part of the "Murwillumbah CBD Levee & Drainage Study"	7.2	Council & SES	Council & SES time	-	High	1-2 years	Recommended for implementation and to be repeated frequently (suggested annually)
	b) Conduct a meet the street event to distribute flood information		Council & SES	Council & SES time	-	Medium	1 year	Recommended for implementation and to be repeated frequently. Could be used as an opportunity to promote preparation of residential and business flood plans (RM2 & RM3)
	c) SES to conduct door knocking of select high risk properties		SES	SES time	-	High	1 year	Recommended for implementation and to be repeated frequently. Could be used as an opportunity to promote preparation of residential flood plans (RM2)
	d) Install flood marker near the intersection of Alma Street and Tweed Valley Way		Council	Council time	-	Medium	2 years	Recommended for implementation
	e) Update Council website to include flood information produced as part of the current study		Council	Council time	-	High	<1 year	Recommended for implementation

Option		Report Section	Implementation Responsibility	Total Cost	BCR	Priority	Timing	Recommendation/Comments
RM2	Preparation of Residential Flood Plans	7.3.1	Individual residents	Resident time	-	High	1 year	Council and SES could promote flood plan preparation as part of community education activities and provide additional flood information, as required to interested parties to assist with plan preparation.
RM3	Preparation of Business Flood Plans	7.3.2	Individual businesses	Business owner time	-	High	1 year	
RM4	Local Flood Plan & Flood Intelligence Card Updates	7.3.3	SES	SES Time	-	High	2 years	Recommended for implementation
RM5	Flood Warning System Upgrades	7.4	SES, Council & BoM	SES, Council & BoM time	-	Medium	4 years	Recommendations: 1. Establish revised river level triggers for Murwillumbah gauge based on when evacuation routes will be cut, and when the South Murwillumbah levee will be overtopped (SES). 2. Investigate potential to incorporate SMS messaging into flood warning system (Council & BoM).

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APPENDIX A

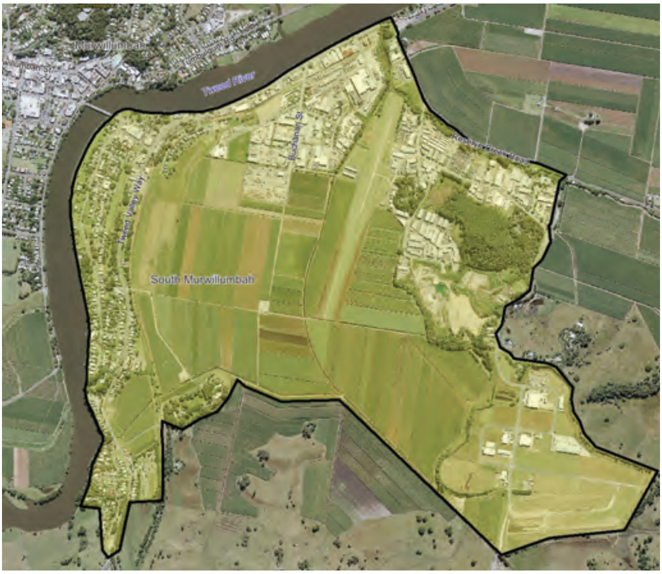
COMMUNITY CONSULTATION

STAGE 1

South Murwillumbah Floodplain Risk Management Study

Flooding is the most costly natural disaster in Australia. The 2017 flood resulted in tens of millions of dollars of damage across the Tweed Shire Council Local Government area and six people lost their lives.

In recognition of the significant impact that flooding can have on the community, Tweed Shire Council has commissioned specialist flood consultants Catchment Simulation Solutions to undertake a floodplain risk management study for South Murwillumbah. The study will build on previous flood investigations and provide Council and emergency services with a detailed understanding of the existing flooding problem across South Murwillumbah.



Above: The study area.

The study also will help identify measures that will best reduce the frequency, extent and depth of flooding and guide future development and re-development in a way that is compatible with the flood risk.

The study, partly funded by the NSW Government, is being completed as part of Council's Floodplain Risk Management Program, which aims to reduce the impact of flooding on the community.

The study area

The study area comprises the residential, commercial and industrial areas of South Murwillumbah.

The study area was inundated in the floods of 1954, 1974, 1989 and most recently in March 2017. Inundation of the study area has the potential to cut roads and cause damage to private and public property. During severe events, there is also a risk to personal safety.

How will the study be completed?

The study will be undertaken using computer flood modelling. The computer models will be used to assess the potential for inundation of South Murwillumbah during a range of different floods and quantify the benefits provided by a range of potential mitigation options and/or upgrades (e.g. levee upgrades).

An example of the type of floodwater velocity map produced by computer flood modelling is shown right.

The consultants would like your input into the study and ask you to complete the enclosed questionnaire and return it to Council in the reply-paid envelope or by email to the contacts below.

Further information

If you would like more information on the study or you have information you think may be valuable, please contact:

David Tetley, Catchment Simulation Solutions
(02) 8355 5501 • dtetley@csse.com.au

Danny Rose, Tweed Shire Council
(02) 6670 2476 • drose@tweed.nsw.gov.au

More information can be found at https://southmurwillumbah.fprms.com.au/

South Murwillumbah Floodplain Risk Management Study questionnaire

TWEED SHIRE COUNCIL

Tweed Shire Council is preparing a detailed floodplain risk management study and plan for South Murwillumbah. The following questionnaire should only take around 10 minutes to complete. Try to answer as many questions as you can and give as much detail as possible (attach additional pages if necessary).

Once complete, please return the questionnaire via email or mail by 30 July 2018. Alternatively, if you have internet access, an online version of the questionnaire can be completed at southmurwillumbah.fprms.com.au

Contact details

Please provide your address to help us identify where floods have been (or haven't been) problematic. It would also be helpful to have a means of contacting you if required. Your contact details will remain confidential at all times.

Name: ....

Address: .... Phone: ....

.... Email: ....

1 What type of property do you live in/own?

- ☐ Residential
- ☐ Commercial
- ☐ Industrial
- ☐ Other (please specify): ....

How long have you lived/worked at this property? .... years

2 Have you experienced previous floods in this area?

- ☐ Yes – what years? .... / .... / .... / ....
- ☐ No (go to question 4)

3 How were you affected by flooding?

Date of flood(s)	Year	Year ....
Type of flood impact	☐ Flooding over main building floor ☐ Flooding of garages/sheds ☐ Lost access due to flooding of roads ☐ Sewage system was not working at our property ☐ Water supply lost ☐ Other	☐ Flooding over main building floor ☐ Flooding of garages/sheds ☐ Lost access due to flooding of roads ☐ Sewage system was not working at our property ☐ Water supply lost ☐ Other
Flood depth/height and location	Depth/height .... Location	Depth/height .... Location ....
How confident are you with the height/depth of the flood?	☐ High (exact) ☐ Medium (within 10cm) ☐ Low (within 50cm)	☐ High (exact) ☐ Medium (within 10cm) ☐ Low (within 50cm)

4 Do you have any photographs or videos of these floods?

- ☐ Yes
- ☐ No

If you answered Yes, can you provide a copy of these photos/videos to assist with the computer flood model calibration?

- ☐ Yes
- ☐ No

5 How do you anticipate you would respond in a future major flood in this area? (Tick one)

- ☐ Evacuate early to an official evacuation centre
- ☐ Remain at my house
- ☐ Don't know/not sure
- ☐ Evacuate elsewhere – please describe: ....
- ☐ Other – please describe: ....

6 If you are likely to evacuate, what factors are most important to you (you can select more than one)?

Please select all factors that would apply:

- ☐ Discomfort/inconvenience/cost of being isolated by floodwater
- ☐ Need for uninterrupted access to medical facilities
- ☐ Safety of our family
- ☐ Not applicable (I intend to remain at my house)
- ☐ Other – please describe:

....

....

7 If you are likely to remain at your house, what factors are most important to you (you can select more than one)?

Please select all factors that would apply:

- ☐ Discomfort/inconvenience/cost of evacuating
- ☐ Need to care for animals
- ☐ My house cannot be flooded and we can cope with isolation
- ☐ Concern for security of my property if I evacuate
- ☐ Not applicable (I intend to evacuate from my house)
- ☐ Other – please describe:

....

8 A list of potential options for managing the flood risk is provided below. If you have any other suggestions, please describe below.

....

....

....

....

....

....

....

9 Council is considering the options listed in the tables below to help manage the risk of flooding. Which of these options do you support/not support?

Flood modification options: Options aimed at modifying the way floodwaters move, thereby reducing the extent, depth and velocity of floodwater.	Strongly against	Against	Neutral	Support	Strongly support	Unsure
Raising existing levees	☐	☐	☐	☐	☐	☐
New levees	☐	☐	☐	☐	☐	☐
Bypass floodways	☐	☐	☐	☐	☐	☐
Modify flow obstructions (e.g. road/rail embankments)	☐	☐	☐	☐	☐	☐
Enlarging/dredging river and/or creek channels	☐	☐	☐	☐	☐	☐
Maintenance and clearing of rivers and creeks	☐	☐	☐	☐	☐	☐
Culvert/bridge upgrades	☐	☐	☐	☐	☐	☐
New/upgraded floodgates	☐	☐	☐	☐	☐	☐

Property modification options: Refers to planning controls and property modifications that reduce the potential for flooding or improve the resilience of buildings to flooding.	Strongly against	Against	Neutral	Support	Strongly support	Unsure
Voluntary house raising	☐	☐	☐	☐	☐	☐
Voluntary flood proofing	☐	☐	☐	☐	☐	☐
Voluntary house purchase	☐	☐	☐	☐	☐	☐
Updated development/planning controls	☐	☐	☐	☐	☐	☐

Response modification options: Are options aimed at improving the way emergency services and the general public responds before, during and after a flood.	Strongly against	Against	Neutral	Support	Strongly support	Unsure
Updated flood warning system	☐	☐	☐	☐	☐	☐
SES local flood plan updates	☐	☐	☐	☐	☐	☐
Community education	☐	☐	☐	☐	☐	☐
Boom gates/signs at roadway overtopping points	☐	☐	☐	☐	☐	☐
Upgrade flood evacuation routes	☐	☐	☐	☐	☐	☐